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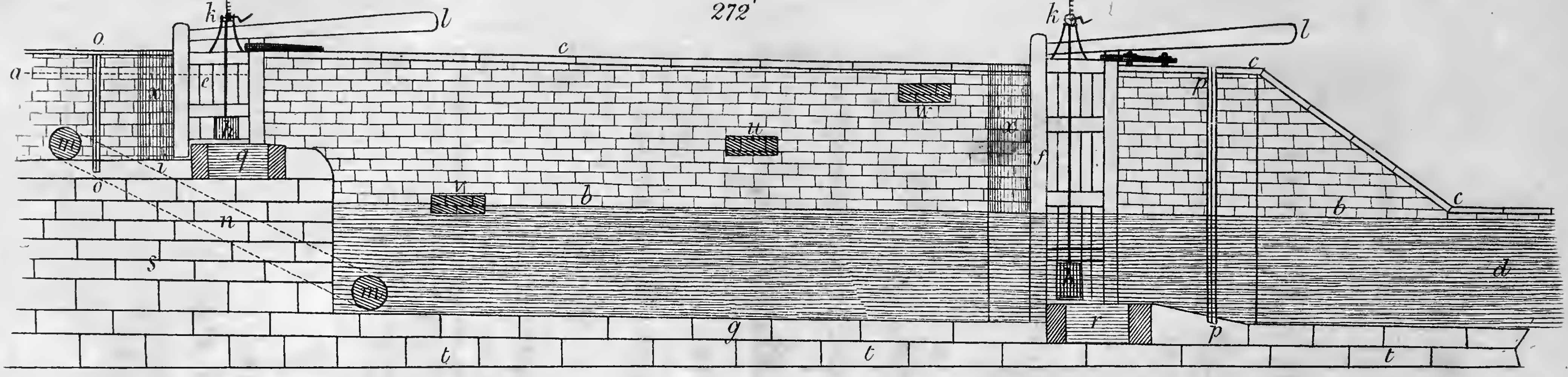

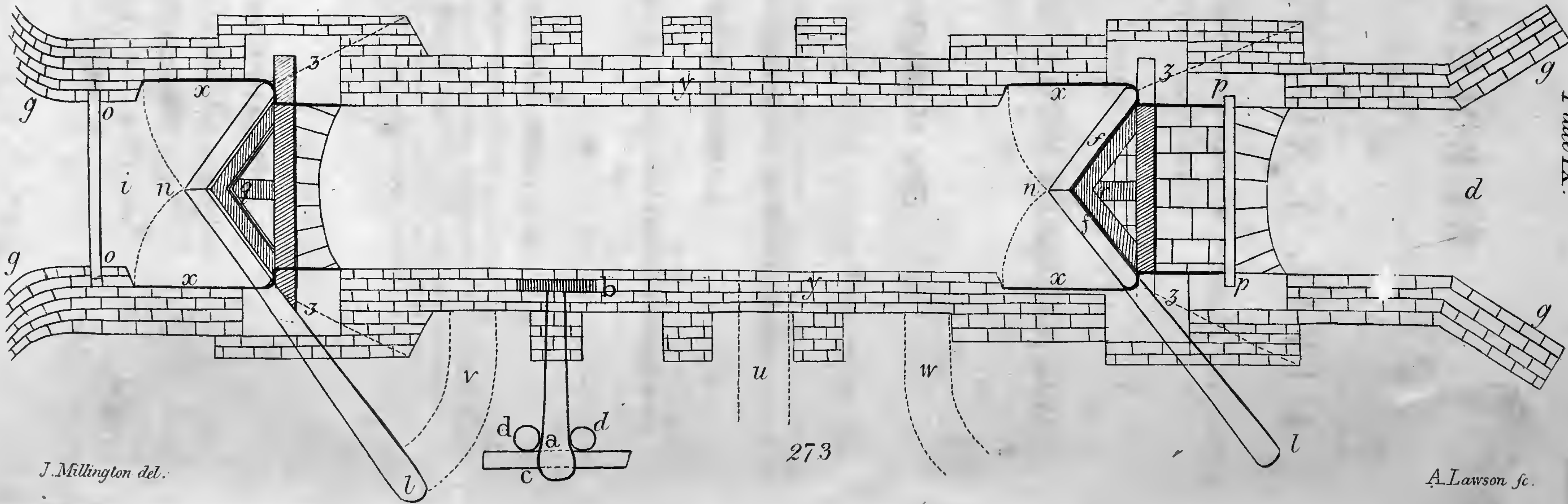

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Plate IX.

J. Millington del. A. Lawson sc.

ELEMENTS

OF

CIVIL ENGINEERING:

BEING AN ATTEMPT TO CONSOLIDATE THE PRINCIPLES OF THE VARIOUS OPERATIONS

OF THE

CIVIL ENGINEER INTO ONE POINT OF VIEW,

FOR THE

Use of Students,

AND THOSE WHO MAY BE ABOUT TO EMBARK IN THE PROFESSION.

ILLUSTRATED BY NINE COPPERPLATES,

CONTAINING 273 FIGURES,

AND INTERSPERSED WITH VARIOUS USEFUL TABLES.

BY JOHN MILLINGTON,

CIVIL ENGINEER;

Formerly Professor of Mechanics in the Royal Institution of Great Britain; and of Civil Engineering and the Applications of Science to the Arts and Manufactures in the London University; and now Professor of Chemistry, Natural Philosophy and Civil Engineering in William and Mary College, Va.

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1839.

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LIBRARY STREET.

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CHAPTER X.

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As the plates are very long, the numbers of the figures upon them are so disposed, that the whole plate need not be unfolded from the book when first beginning to refer to it.

PREFACE AND DEDICATION.

The subject of Civil Engineering is one upon which much has been written by some of the first scientific characters of the world; but their writings are so diffuse, so various, and so detached on account of their investigations having been directed to particular objects, that there is perhaps no branch of science in which the student or young beginner finds so much difficulty in obtaining the knowledge necessary to qualify him for his business, as in Civil Engineering. Among the almost numberless works which the presses of Great Britain and France issue annually, it is surprising that no attempt has yet been made (to the knowledge of the writer) at any thing like a compendium of the science of Engineering. The English nation is even avowedly poor in practical works of this description, for until the formation of the Society of Civil Engineers, of London, and the more recent establishment of the Institute of Civil Engineers, the persons who followed the profession appeared to harbour a jealous suspicion of their modes of operating and proceeding meeting the public eye; and with the exception of Smeaton's account of the building of the Eddystone Light-house, and that of the building of Essex Bridge, in Dublin, there was scarcely a work of any importance to be found in the English language. Even the papers of Smeaton would, for want of being known, probably have been buried in oblivion on the shelves of some public library, had not the late Sir Joseph Banks and others, into whose hands they fell, found them too valuable to be withheld from the public; and therefore caused them to be published after the death of this justly celebrated man, the father of the Civil Engineering profession. He was followed by Brindley, Jessup, Mylne, Walker, Rennie, Alexander, and several others, who were entrusted with all the great and magnificent works that have been executed in Great Britain; but if we look for any detailed or particular account of their operations, our search must be in vain, for nothing of their proceedings has ever been given to the public. The French, on the contrary, have been much more liberal in their publications, but their works are confined either to scientific investigations or to the account of particular objects, diffused through many large and expensive volumes, so that a student in Civil Engineering had no chance of knowing what had been done on the continent of Europe without access to a large public library; and even if he possessed that advantage it was perhaps useless to him, from not understanding the language the works were written in, or more especially from his possessing no key or directory to inform him where he should search for particular information. Thus circumstanced, the young Engineer had no chance of improving himself, except by his own practical means and observation, aided by the information he might obtain from his master, if employed in the office of an Engineer, and yet such was the state of the profession when the writer embarked in it.

The French nation, during the short period of tranquillity which succeeded the accession of Napoleon Bonaparte to the government of that country, were the first who awakened to the necessity of cultivating Civil Engineering as a means of national improvement, by public education; and the two great national schools then established, L'Ecole Polytechnique or College of Practical Arts and Manufactures, and the Corps des Ponts et Chaussées, or Publicly instructed Body of Bridge Builders and Road Makers, contributed in no small degree to the advancement of the profession and the improvement of the country; for the instruction afforded by these great institutions was not confined to the mere objects of their titles but extended to all branches of the Engineer's profession. The first attempt at any thing like instruction in the Engineering profession that was made in England, was on the establishment of the London University; and in 1828 the writer had the honour of being appointed to the chair of Civil Engineering and the Applications of the Principles of Mechanical and Chemical Science to the Arts and Manufactures; and it was in the preparation for the lectures to be given on these subjects, that he first felt the want of a Digest or Text Book, that should condense and bring the whole subject matter of his courses before the student. He searched and searched in vain for such a book, and it was therefore determined that he should endeavour to produce one which was to have been published under the auspices of the Society for the Diffusion of Useful Knowledge, and some progress was made in the undertaking. But being called upon to undertake the Engineering superintendence of one of the Great English Silver Mining Company's concerns in Mexico, he was induced to resign his professorship, and with it, his intended work, and after leaving England thought no more on the subject.

Early in 1836, being then Professor of Natural Philosophy and Chemistry in the venerable establishment of William and Mary College, Va., he was requested by the visitors of that institution to attempt a course of Civil Engineering, as a branch of the collegiate instruction; and although but ill prepared at that time for such an undertaking, being wholly without drawings, models, books of reference, and other means of illustration, he undertook it, using a translation of the elementary course on Civil Engineering by M. J. Sganzin, written many years ago, and intended by its author to be a mere syllabus or collection of memoranda from the course on these subjects, that he formerly delivered at the Polytechnic School in Paris. Those who are acquainted with this book need not be told how meagre and insufficient it is for an Engineer of the present day, independent of which, the language into which it is translated is so full of French words and phraseology, not adopted in this country, as to render it almost unintelligible. Under these circumstances such a book could but be discarded, and in the course of the succeeding session, 1837–8, the writer was under the necessity of preparing a set of notes of his own to lecture from, and these notes, so prepared and somewhat amplified to make them intelligible to a reader, are what are now offered to the public in the following pages.

The writer (for he has in no case assumed the title of author, feeling that he was not fully entitled to that name, when the matter he was inculcating did not originate with himself) in preparing these notes has been careful to select whatever he thought might be most useful to the young Engineer, and on this account he has availed himself of all information that fell within his reach. Not, however, exactly in the shape of compilation or extracts from other books, because unfortunately he did not possess them, and he has therefore, in many instances, been compelled to resort to his memory when he would have preferred giving extracts. There are subjects on which few Engineers have the means or opportunity of making experiments, such as those on the strength and resistance of materials; and in such cases he has borrowed freely from Professor Robison, Dr. Young, Tredgold, and such writers as are deemed most worthy of confidence. But when such extracts have been made he has, in every case, cited the authority; but, with the exception of those extracts, the whole has been written in such manner as to blend the result of his own experience and observation with what is generally taught and understood upon the subjects; and much matter will be found which, he believes, has not before appeared in print.

The course he has adopted, is first to explain the nature of the Engineer's profession, and the views that ought to guide him in the formation of his plans. 2ndly. The means of rendering those plans palpable by means of drawings, the method of making and copying which, and the necessary instruments, are briefly described, and as the value of all building work depends in great measure upon its quantity, so the means of ascertaining those quantities by measurement are next considered.

Possessing this preliminary knowledge, the young Engineer is next supposed to be introduced into an uncultivated country, which he has to improve by carrying his plans into execution; and the first object will be to measure, and make maps of such country, upon which he may lay down the roads, canals, and other improvements that are contemplated. So much of land surveying and levelling and their necessary instruments, are therefore described in the fourth and fifth chapters as will enable him to accomplish this work.

The sixth chapter treats of such operations on the soil as are necessary for the formation of roads, canals, and the foundations of buildings; and this is followed in the seventh chapter by the leading principles of road making.

The selection of materials to work with, comes next under consideration; and the eighth chapter therefore describes the various kinds of building stones, and the methods of quarrying, or getting them out of the earth, which is followed by an account of the making of bricks, burning and preparing lime and hydraulic cements, and forming them into mortar. Secondly, the varieties of timber, and means of seasoning, and converting it to useful purposes, and of measuring and valuing it, either when rough or converted, are considered. Lastly, the metals claim attention, and an account is given of the production of iron from its ore, and its conversion into the pig and malleable state. This is followed by such a notice of the smithing and iron foundry business as the Engineer should be generally acquainted with, particularly the making of patterns to cast from. A few observations on steel, brass, copper, lead, and the other metals in general use, are added, and close this part of the subject.

The Engineer being thus put in possession of a catalogue of the materials he has to work with, must next consider their respective values and importance under the heads of strength and durability, which subjects occupy the ninth chapter.

Construction, or the conversion of these materials (now supposed to be fully understood) next follows, and is treated of in the tenth chapter, under the several heads of building with stone and bricks, and carpentry or building in wood. The principles of building both in stone and bricks, are here described, together with the methods of measuring and valuing the work when executed. Carpentry follows, and after an account of the principles on which this art depends, those principles are applied to the formation of various kinds of framing, such as roofs, partitions, timber bridges, and the centring or frame work necessary for the formation of large arches of stone or bricks, and some of the most approved centres that have been used are described.

The eleventh chapter is devoted to the methods of procuring firm and stable foundations, both on dry land and in the water, for walls and heavy erections; and this, of course, includes the building of piers for bridges, and the usual methods of building in water both by coffer-dams and caissoons, the driving of piles, the fixing of centring, and the construction of large arches, and building of bridges; which subjects are exemplified by a short account of some of the finest stone and cast iron bridges that have been executed, and a notice of the more recently introduced bridges of suspension.

As the foregoing matter comprises most of the information that it is necessary the young Engineer should possess, all that remains is to point out how the principles endeavoured to be established are to be applied to useful purposes; and this opens an almost endless field on account of the many ramifications of the Engineer's profession. Any attempt to describe the whole, or even the greater part of them in such manner as might prove useful, would require a work of vast extent and high price, and might not, after all, prove generally useful or acceptable; because no individual scarcely ever attempts to make himself practically acquainted with the whole of them. On this account the twelfth chapter is confined to a description of those operations which the Civil Engineer is most commonly called upon to design, superintend, and execute; and these are the formation of roads and railroads, the improvement of river navigation, and the construction of navigable canals. In this place, therefore, the form, construction, and methods of fixing rails, and of building locks and weirs, are alone set forth; because the necessary appendages of walls, bridges, foundations, warehouses, carpentry, and earth-work, have been fully discussed and described in preceding chapters. It is therefore presumed that the directions given throughout the work, when combined with some practice, which is indispensable to form a good Engineer, will enable any one to digest and arrange plans; to draw them upon paper; to estimate their probable cost; to set them out upon the ground; and to direct and superintend their construction: and if they should be found to answer that purpose, or even to assist in its accomplishment, the object of the writer will be fully attained.

The work was written and compiled at detached periods, as the matter was required for the lectures of the writer; and having been printed in Philadelphia, many miles from his residence, the presswork has not received that vigilant attention to its correction that he was desirous of bestowing upon it; and he therefore fears many errors will be discovered; but he trusts none that will affect the sense. With these, and all its other imperfections, he sends it forth, relying on the indulgence of the public to excuse the omissions and inaccuracies that ever attend a first attempt to produce and condense into a single volume, so large a body of practical information, and he

DEDICATES

it to the patronage of the rising generation of Civil Engineers, from a conviction, that although the book does not profess to contain anything like the whole of the knowledge that an Engineer ought to possess, yet it contains nothing but what every young Engineer should be acquainted with; and he therefore trusts it may prove useful to them.

If the health and leisure of the writer should permit, he proposes, at some future time, to publish another volume, unconnected with the present one, which shall contain the result of his own experience, embodied with the most material observations of the best writers on the construction of mill-work and machinery, and particularly of the steam-engine; on the construction of water-works for supplying towns with water; and on mining operations, in all of which he has been extensively and practically engaged.

William and Mary College,
Williamsburg, Va., March, 1839.

ELEMENTS

OF

CIVIL ENGINEERING.

CHAPTER I.

INTRODUCTION.—OF THE OBJECTS OF THE ENGINEER'S PROFESSION.—THE EDUCATION AND QUALIFICATIONS OF AN ENGINEER.

THE word *engine* is used in mechanics to express a compound machine, constituted of one or more mechanical powers, such as levers, pullies, screws, and the like, so put together and arranged as to produce an effect which could not be brought about without them; and a person capable of devising or contriving, and constructing such a machine, or, in some cases, of using it to the greatest advantage when constructed, is called an Engineer. Machines, or engines, are constructed by workmen, in their several departments, according to the materials made use of, such as carpenters, joiners, millwrights, blacksmiths, founders, turners, and the like; but men constantly occupied in the daily labour of such avocations cannot be expected to have the necessary time for studying the philosophical principles of the operations they are constantly performing; and hence, although such men will by constant habit and practice become able, expert, and frequently rapid workmen, and will improve their own tools and processes of operation, yet we seldom find them aiming at any thing new or original. They constantly require long explanations, or drawings, or models of the things they have to construct, placed before them; and occasionally the object itself must be within their inspection, in order to enable them to copy it, or contrive what is required. It is only in a very few instances that we meet with bright flights of genius and invention of new machines arising from workmen who are constantly tied down to their daily occupations. This arises from several causes: the first and most important of which is the constant and unremitting attention they are compelled to give to their business in order to gain a comfortable subsistence; secondly, their almost constant confinement to their workshops, where the same kind of occupation is daily going on; so that they have little or no opportunity of seeing a variety of operations, or of knowing what is doing without their walls, and what already exists, or has yet to be invented and discovered; and lastly, the small opportunities they have for improving their minds, or learning the scientific principles that apply, even perhaps to the very business in which they are constantly occupied: for few men feel an inclination to read or study in the evening after a day of hard labour.*

* This difficulty, in the way of acquiring knowledge among the working classes of society, was in a great measure obviated in London by the establishment of the London Mechanics' Institution, of which the author had the honour of being one of the founders and first vice-presidents. Its beneficial influence was soon felt, and many similar societies soon arose out of it, in different parts of the kingdom, as well as in foreign countries. Working men seldom purchase books, and do not in general like to sit down to reading when the labour of the day is over; but they are always ready to attend a lecture for an hour in the evening, and to listen to good and useful instruction, provided it is given to them in a plain, simple, and intelligible form. The truth of this position is amply proved by the progress of the London Mechanics' Institution, which had not been long opened before it was joined by 1200 of the working artizans of London, who came to it voluntarily and without persuasion. The numbers being large, the expense was small. Each member paid an admission fee of 62½ cents, and an annual contribution of $1 50. The sons and apprentices of members were admitted at the rate of 62½ cents per annum, their parents or guardians entering into bond for their good and orderly conduct. Small as this sum may appear, it enabled the society to purchase and alter a large house into a lecture room, capable of holding between seven and eight hundred persons, and to fit up a library and chemical laboratory, which were well stocked with books and apparatus. In this place a plain and simple lecture, connected with science or the useful arts, was delivered every evening at eight o'clock, and the books of the library were circulated among the members. All political and religious subjects were excluded from discussion; and the author, from his own experience, can assert, that during the several years that he was connected with the institution, a better conducted, orderly, and more inquiring audience, never assembled in any public place. Hundreds, who would have spent their evenings and money in taverns and public houses, were thus quietly enticed away and gradually instructed in the rudiments of science and morality, without any trouble to themselves, and their minds and habits ameliorated at the same time. The lectures were in general gratuitously delivered by the friends and patrons of the society.

With the Engineer the case is quite different, since he is not expected to be a workman, although it will be more to his advantage, and that of his employer, and of his workmen also, if he is one, although he may not practise his art; because it is his duty to invent and devise machinery, to select materials, and to direct and superintend his workmen; and no one can do this so fully and effectually, or can be so good a judge of the performance of a piece of work, or the difficulties attending its execution and the time necessary for overcoming them, as one who could work and make the thing himself, in case of the necessity of his doing so. Indeed the Civil Engineer is often thrown into situations in pursuing his profession, where, from thinness of population and the consequent deficiency of mechanical establishments, he can get nothing made for him; and when so situated, that man will always feel his superiority and independence if he can take up an axe or saw, or even a pocket-knife, and fashion out something like what he wants, either to answer his purpose, or to enable a country blacksmith or carpenter to make him a better article, which they can generally do if they have a model to work from, though it might be impossible to make them understand a drawing or oral description.

It is not exactly known when the name Engineer was first made use of, but in its more ancient signification it had constant reference to military affairs, and was so used in this country and in Europe until very near the close of the last century, when we find the term Civil Engineer first adopted to distinguish it from the other class of engineers, now constantly styled Military Engineers.

The operations to be performed by these two classes of Engineers are to a certain extent similar, consequently the course of education to be pursued by them will in most respects be the same. But, inasmuch as the occupations of the Civil Engineer are more general and extended than those of the Military Engineer, so it is necessary that his knowledge should also be more general and extended, as will be seen by taking a cursory view of the duties that these two classes of men are usually called upon to perform, and the manner of executing them.

Military engineering is found of such vast use and importance to every army, that no civilized and well organized nation is now without its corps of engineers, who exist as a body, separate and detached from the general army; and a portion is always selected out from this body to accompany every army that goes into the field. The officers commanding in the engineer corps are required to be qualified for their duties by an appropriate education in Colleges, usually established by the governments under which they are to serve, and which are placed within their immediate surveillance; and here they are instructed in mathematics, drawing, fortification, chemistry, the arts and arrangements of war, both defensive and offensive, and in such mechanical arts as they may be called upon to perform, in addition to the usual duties of a military life; and no man is deemed eligible to serve as an engineer officer until he has passed his examination and received his certificate of competency from such a college. The men, or privates, that are placed under these officers, are in like manner instructed by them as far as necessary, and the majority of them are artizans of some description, as well as soldiers. They consist of carpenters, blacksmiths, masons, earth workmen, timbermen, and other mechanics; and as a corps of engineers never moves without its portable smith's forges, saws, axes, shovels, pick-axes, and various other tools, it will be seen at once that it constitutes the mathematical and mechanical branch of the army, and will be capable of performing many operations of the highest importance to the success of an expedition, which ordinary officers and men could not perform, being deficient not only in the skill, but in the necessary means of carrying them into execution.

If an expedition is ordered against an unknown place, the Engineers must precede. It is their duty to investigate the road or mode of approach, to find out the best one, to render it available for the passage not only of the soldiers, but of heavy artillery, baggage and provisions; and if no such road exists, to form it. A temporary bridge may be necessary for the passage of a river —it is their duty to construct it; and, if occasion requires, to throw up redoubts or batteries, and place guns upon them for the protection of the army as it advances. Having reached the place of attack, they have to reconnoitre, and, if possible, to find out the weakest place for attack; and as they can seldom approach the immediate vicinity of their object of research, they must have recourse to trigonometrical operations in order to determine the distance and bearings of what they have to examine. The digging out of entrenchments for the protection of the army; the formation and throwing up of batteries; the computation of the proper quantity of powder to carry the balls or shells to the distances they have computed; the placing the guns upon such batteries; and many other duties of a similar nature, all having dependence on mathematical knowledge and mechanical skill, devolve upon the Military Engineer. Having thus assisted in getting his party to the proposed point, his next care must be to provide for its retreat in the event of its being overpowered; and to prepare such roads, bridges, batteries, and other works, as may be necessary for this purpose; and not only to prepare, but to destroy them as soon as they have answered their intended purpose, in order that they may become unavailable to a pursuing enemy. The operations of a Military Engineer are consequently of a temporary nature, but they require a concentration of talent and of energy to enable him to avail of every facility that may present itself. Their work, from the haste in which it is accomplished, and the scanty means often afforded of carrying it into execution, is not calculated to endure; nor should it be so, for that which is constructed to-day may all have to be taken down and levelled on the morrow; but still it must be strong enough to answer its intended purpose: and when it is considered that all these operations have to be carried on in the face of an enemy, and under constant exposure to danger, it must be confessed the service is an arduous one, and one that requires no ordinary talent for its fulfilment. The skill and exertions of the Military Engineer are not only required in time of war, but in that of peace also; for in the latter period, the care and repairs of all forts and establishments for the security of a country against invasion, and the construction of such new ones as may be thought necessary, devolve upon him. And of late years the wholesome expedient of employing a part of the engineer corps in making minute topographical surveys of the countries to which they belong, has been resorted to. This at once puts us in possession of better, more accurate, and at the same time more detailed maps of the country than could otherwise be produced, and affords interesting employment and pay to a most valuable profession, which would otherwise be useless and inactive; at the same time that it affords practice, and renders the parties more skilful in the surveys and operations they may be called upon to perform in the pursuit of their immediate duties.

With the Civil Engineer the case is quite different; he may be called upon to make surveys, to construct roads, to build bridges, and to perform many duties similar to those of the military engineer; but they are done in a very different manner. There is no danger in his surveys, or opposition to his plans. He has time to consider and to mature all he undertakes. He has facilities afforded him for obtaining his materials; he has money at his command, and can select the best of workmen. He is not working in the midst of enemies, but every one is trying to assist him. His works are not of a temporary nature, designed to be pulled down and destroyed as soon as they are finished, but they are durable. He works not for the occasion of the moment, but his aim should be to work for posterity; and, if possible, to make his constructions everlasting. To do this, every aid of science must be put in requisition. He must become acquainted with the materials he has to work with, and not only with their mechanical properties of cohesion and solidity, by which they resist fracture, but their chemical properties, which render them more or less liable to decomposition and decay. He must understand the mechanical powers that will enable him to raise vast masses to great heights, that he may be able to put his construction together. He must understand the laws by which such bodies will press and operate upon each other, which can only be ascertained by mathematics; and upon this also, he must rely for determining the best means of putting the parts together and fixing them. His observations are, likewise, not confined to the making of roads and excavations and embankments; but he will occasionally have to combat the power of the elements in every shape. The merciless wave, the expansive power of steam, the raging tempest, and the sweeping torrent are his foes, and he must have them all under his control; for it may become his duty to place constructions that shall, in turn, resist them all. In fact, the versatility of his occupations is such, that it seldom happens that any one man can attend to them all; and thus it happens that the profession becomes divided into a number of branches, and each man takes up that portion which is most congenial to his own views and ability; and by this division of labour and talent, greater perfection is insured to the public. Thus one man may confine his attention to under-ground operations in the working of metallic mines, or mines of coal; and by so doing he becomes more intimately acquainted with the geological construction of the crust of the earth, and the means of raising large quantities of water from great depths, than him who confines his operations to the surface alone. Another may choose to turn his attention to the construction of powerful steam engines, and the formation of machinery for manufacturing purposes. A third may confine himself to earth-work, or the formation of roads and canals, and the improvement of natural rivers; while a fourth may prefer the building art, and the erection of bridges, harbours, lighthouses, or manufactories. All these, however, are but parts of the general business of an Engineer, and to be perfect in his profession he should possess a general knowledge of the whole of them, notwithstanding he may only practise a part. By judiciously selecting a part, and pursuing it with steadfast zeal, he cannot fail of arriving at perfection in that department; and the public readily find out those men that excel most in particular departments, and never fail to give them due encouragement.

From the above short statement of the nature of the occupations of the Civil Engineer, it may appear that they coincide in many particulars with that of the architect, and this to a certain extent is true; and until lately there was a difficulty in drawing the line of demarcation or separation between the two professions. Formerly the Civil Engineer was unknown, and, therefore, all devolved on the Architect, as may be seen by referring to the works of Marcus Pollio Vitruvius, a very distinguished Roman writer on architecture, whose date and birth-place are not exactly known, further than that he was inspector of military engines under the Emperor Augustus. His manuscript work was discovered in the fifteenth century, and has ever since been held in high estimation.* He declares himself to be a practising architect, and he distributes his work into ten books, in which are described, not only every thing that relates to buildings, public and private, their site, materials, forms, ornaments and conveniences, but all that was then known and practised in civil and military engineering; giving detailed accounts of pumps, water engines, mechanical machines, and all the implements of war. Besides the instruction to be derived from this work, it has afforded much important matter to the antiquary relative to the state of arts and sciences, as well as the details of private life, among the Romans. From the post he held, and the description he gives of the nature of warfare and warlike engines, we obtain evidence that at this period the professions of Civil and Military Engineer were conjoined in one person.

As the progress of civilization in society advances, we find the divisions of talent and labour increase, and accordingly the Architect and Engineer now rank as distinct professions. The Architect takes upon himself the construction of all public and private edifices, such as churches, palaces, theatres, public halls or institutions, and private dwellings, and does not concern himself with making the roads that are to lead to them, the canals and navigations that are to convey his materials, or the machinery that may be necessary to convert them, or raise them to their places. All this is done for him by the Engineer, who, in addition to these duties, appropriates to himself the designing and formation of such things as are necessary to the inhabitants, who are to take possession of what the Architect finishes. The Engineer has to construct mills for grinding corn, and machinery for manufacturing those things which are necessary to the comforts or luxury of the public. He supplies their towns with

*A good translation of his works into English, accompanied by many plates, was produced by Mr. Newton of London, 1791; and a magnificent edition of that part which relates to civil architecture has since been published in London by W. Wilkins, Jr., A. M., F. R. S., &c.

water. He constructs the apparatus for lighting them with gas. He supplies them with the means of extinguishing fires; and, in fact, renders himself useful in numberless ways.

Notwithstanding this division, there are some points in which the two professions have common objects. Thus the constructions of the one and the other require the protection of a roof, and the formation of floors and partitions; and whenever these are large, they cannot be made with any certainty of stability and duration without a knowledge of scientific carpentry. The construction of bridges is another object which is claimed by both professions, and it does not appear to have been distinctly determined to which they belong, for they have been executed in an equally satisfactory manner by both. Of late years the practice in England has been to entrust the construction of large bridges to Engineers alone; and this is, perhaps, the safest principle, if the Engineer is well grounded in the scientific principles of his profession; because a well educated Engineer should be acquainted with every thing that relates to architecture, although it is not equally necessary that the Architect should be versed in all that relates to the engineering profession. Some persons are inclined to treat architecture only as a branch of the polite arts, and imagine that all that is necessary to constitute an Architect is, that he need only be a good and tasteful draughtsman, capable of producing an elegant design that shall gratify the eye, embellish the place of its erection, and be replete with every accommodation for the purposes for which it is intended. This is, however, a mistaken notion, for no Architect is worthy to be called by that name, however splendid the designs he may produce, unless he is able to carry the whole into execution in the most minute details. The very derivation of the word, αρχος τεκτων, implies this power; and without it, and mental conception of the means of execution, he might produce designs that might appear perfect and admirable, but which could not possibly be carried into effect, in consequence of their not being founded on the sound principles of construction. On the contrary, being in possession of such principles, he proceeds boldly with his work, and may, in some instances, produce that which, to the untaught, may appear frightfully deficient in stability, but which he knows will be strong and durable. That accomplished and scientific Architect, Sir Christopher Wren, gave an instance of this in a design that he made for a spire for one of the churches in London. It was a tall polygonal pyramid of stone, rising to a great height, and supported below upon flying buttresses, with large open spaces between them, so as to give it almost the appearance of being detached from the building below, and having such an air of instability that, notwithstanding the elegance of its form, the corporation would not permit its erection, from a fear that the slightest gale of wind would bring it down. Wren being satisfied of its stability, became the more anxious to carry it into execution, and at length got permission to execute it; and it was built accordingly, and has stood the test of upwards of a hundred years, without the least symptom of failure or decay; and is considered by all competent judges, as one of the most splendid efforts of architectural genius, and greatest ornaments of London. There is one distinctive difference between the two professions—an Architect must, of necessity, be a man of taste in design, while the Engineer must be a practical mechanic; for without these qualifications, they would neither of them be able to pursue their respective professions. But taste and elegance, although desirable qualifications, are not so much looked for in the Engineer, as strength, stability, and perfection of workmanship. The two professions can, therefore, and do very frequently go hand in hand, particularly in the construction of large bridges, where the Architect may be called upon to design, and the Engineer to execute at least the pile-driving, pumping, and primitive operations, if not to complete the whole structure.

From this account it will appear that a very considerable acquirement of knowledge is necessary, in common to the Architect and the Engineer, before they can become perfect in their several callings; and parts of this knowledge require considerable assiduity and application for its attainment. They should be profoundly skilled in the knowledge of the properties of the materials to be employed, and the best methods of connecting them together; and to attain this, some knowledge of chemistry is necessary. They must know so much of mathematics as relates to gravitation, the composition and resolution of forces, and the properties of the lever and inclined plane, before they can ascertain the stability of their works, and the pressure that one mass may exert against another; and this leads to the theory of the pressure and equilibrium of arches and formation of piers for bridges. A knowledge of mensuration is essential for measuring and estimating the various work performed by artificers, and this implies a previous acquaintance with arithmetic and geometry, which is useful in many other respects, for circles, ellipses, parabolas, hyperbolas, and many other curves, which occur in the formation of arches and mouldings; and polygons are necessary in a variety of instances. They should not be unacquainted with plain trigonometry, for this is necessary in obtaining heights and distances, as well as in surveying land and setting out roads and canals. They must understand drawing, both in simple projection and perspective, to enable them to lay down designs, and make them plain and perspicuous to their workmen. They should understand so much of the law, as will enable them to decide upon the rights and the division of property, to inform themselves of the restrictions under which they have to work, and to make binding contracts or agreements with their workmen and suppliers of materials. They have, in great measure, a new language to learn, for all businesses have technical names and phrases, by means of which, alone, they can convey clear ideas to executive workmen; and they should be clear in judgment, ready in invention, and strict and diligent in their duties; for they are always considered responsible for the mistakes, negligence, and ignorance of those they may employ. An Architect, or Engineer, is an intermediate agent between the employer and the mechanic; they should, therefore, study the honour and interest of the former, while they defend the rights of the latter, by seeing that just and equitable prices are allowed for all that is done, and that no overcharges or impositions are allowed to be made. That no bad or inferior materials are permitted to be used; that contractors act up to the letter of their contracts, and perform all that they have undertaken to do; that workmen are only paid for the actual hours of their employment; and, in fact, that perfect justice is reciprocally rendered by the employers and the employed.

As Engineers and Architects, of established reputation, have generally a number of large works proceeding at the same time, it is quite impossible that they can personally attend to all the particulars above enumerated, and many others that occur. It is, therefore, customary, in all large works, to appoint a Clerk of the works, or resident engineer, whose duty is to give no directions of his own, but to act strictly under the orders and directions of the principal; and to watch that all his arrangements are punctually complied with. He must live constantly on the spot where the work is proceeding; must call the roll of workmen, and note down such as are not punctual in their attendance; must measure their work as it proceeds; and keep a correct account, by weight or measure, as the case may require, of all materials that are delivered for the use of the works, as well as of the quantities consumed in its progress; and all these he must report to his principal, at stated periods. He has care and custody of the plans and drawings, and sets out the work, or gives such directions as from time to time may be necessary, during the absence of his employer; but in cases of doubt or difficulty, should wait his arrival and advice, unless they are of such extreme exigency as not to permit of delay. The post of clerk of the works, is the one that young men usually occupy on their first entry into the profession; but they ought not even to enter upon this, without some time previously spent in the office of an Engineer, or Architect, that they may acquire some knowledge of drawing, of the computations of measurement, the mode of keeping workmen's time and accounts, and many other minutiæ which cannot be so well acquired in any other way. If they have not this advantage it is hoped that the following sheets will, in some measure, supply its place, by diligently studying and working the rules and examples given. No school is, however, so good for learning the practice of architectural or engineering business, as the office of clerk of the works, if entered upon with sufficient qualifications and properly made use of for that purpose. In this post, a man is constantly surrounded by work and workmen; he acquires their technical language without study; he sees operations of every kind going on at the same time, and becomes acquainted with the tools and the methods of using them; he has the inspection and examination of various materials, and becomes acquainted with their respective advantages, disadvantages, and their prices, without leaving home. He learns to judge what quantity of work a man is capable of effecting in a given time, and acquires a fund of information that will prove of vast use to him in after life; for no one need expect to become a good and efficient Engineer by study in his closet alone, however intense. He must be practically a workman, or must become intimately acquainted with the processes of working, by watching those who are proficients, and this is, therefore, a mode of instruction which every young man ought to avail himself of, if he intends to excel; for in after life, when he becomes settled in his profession, he will find that he seldom has leisure or inclination to acquire this kind of instruction.

The term Civil Engineer, that has been adopted by those whose profession it is to execute the internal improvements of the country, in contradistinction to Military Engineers, is of late origin, and does not appear to have been known in England until about 1760. In 1771 a Society was first established in London, under the title of the Society of Civil Engineers, and its origin is thus given in the preface to the quarto edition of the reports and works of Mr. John Smeaton, one of the most eminent Engineers that England has produced, and whose valuable papers were printed and published by that Society after Mr. Smeaton's death, because he had been one of the most distinguished ornaments of the society while living. The account states that the Society of Civil Engineers took its rise about the period above mentioned, when a new era in all the arts and sciences, learned and polite, commenced in England. Every thing that could contribute to the comfort, the beauty and prosperity of the country, moved forward in improvement so rapidly, and so obviously, as to mark that period with particular distinction. The learned societies extended their views, labours, and objects of research. The professors of the polite arts associated together for the first time under the sanction and protection of the throne. Military and naval establishments were made or enlarged, the manufactures were extended on a new plan by the enterprise, the capital, and, above all, the science of men of deep knowledge and persevering industry; and it was then first perceived that it would be better for establishments to be set down on new situations, best suited for raw materials and the labour of patient and retiring industry, than to be plagued with the miserable little politics of corporate towns, and the wages of their extravagant workmen.

This produced a new demand not thought of till then in the country—*internal navigation.* To make communications from factory to factory, and from warehouses to harbours, as well as to carry raw materials to and from such establishments, became absolutely necessary: hence arose those wonderful works, not of pompous and useless magnificence, but of real utility, which had the effect of rendering Great Britain pre-eminent as a manufacturing country, in a period of time much shorter than its fondest advocates could have supposed; and an imitation of this policy, which began in New England, and is rapidly making its way southwards, already begins to shed its genial influence over the whole of the United States, and must, before any great lapse of time, make this country independent of all others for its internal resources and supplies.

Such a state of things in England gave birth to a new profession. Artificers and artists were wanting who possessed sufficient skill and science to carry these improvements into execution, and who could combine with them all the advances of modern research; and hence arose the *Civil Engineer,* to whom alone was confided the trust of carrying all these valuable improvements into effect. If the zeal and energy of England in 1760 could produce such changes, what may we not expect from America? Her magnitude, and the distance between her principal towns, demands a cheap and speedy communication between them for the conveyance of merchandise and travellers; and this has already been effected by her steamboats and rail-roads to a distance and with a rapidity far exceeding any thing that has been done in the mother country. Improvements are daily making in her arts and manufactures, and thus is the profession of the Engineer called into action, and must become more and more in demand as the riches and resources of the country become developed; for who will entrust the execution of his improvements or the expenditure of his money to the ignorant country carpenter or blacksmith, when he finds that a set of intelligent and well instructed Engineers are distributed throughout the country? men who, from their attainments, will be able to judge correctly of the value of all suggestions, and who, from their respectable standing in life, will refuse to expend money and time upon them, should they be found futile and useless, or who will feel proud to execute them and to give them their best attentions and exertions, should they be found worthy of such fostering care.

The profession of the Civil Engineer has, like all other pursuits, flourished with the progression of society and intelligence. When first established in England, Civil Engineers were a self-created set of men, whose profession owed its origin, not to power or to influence, but to the best of all protection—the necessity for its existence, and the encouragement of a great and powerful nation that needed their assistance. Still few could follow it, because few possessed the means of making the necessary acquirements for its successful prosecution. No schools existed for teaching them; no books were printed upon the subject, but such as were in foreign languages, and therefore inaccessible to many, and so large and voluminous as to put them out of the reach of the majority of those who could read and make use of them. The importance of this profession is now so fully ascertained, that the teaching it on scientific principles has been introduced into several of the most respectable colleges of the United States, and it is made one of the regular branches of study. Still, however, a difficulty exists in the mode of instruction, from a want of the knowledge of what is necessary to be insisted on, and from a want of text books; for there is perhaps no mechanic art in which so little has appeared in print in the English language as on the subject of engineering; and the author believes that the present is the first attempt that has ever been made to lay a short and succinct, but connected account, of all the objects of the Engineer's profession before the public. He is aware that the work is much too short to do justice to the subjects, or to be generally useful to the practical man. Still he trusts it will be found replete with information on subjects which every one connected with the building art ought to possess; and should it meet such favour from the public as to call for a second edition in his lifetime, he pledges himself to correct the errors that must inevitably creep into a first attempt, and to make such amendments, alterations and additions, as may render it more useful and worthy of favour.

CHAPTER II.

PRELIMINARY OPERATIONS OF THE ENGINEER, AND AN ACCOUNT OF THE INSTRUMENTS AND IMPLEMENTS NECESSARY FOR THEIR PERFORMANCE.

SECTION I.—*Of the Primary Arrangement of Plans.*

1. It is the business of the Civil Engineer to arrange plans for the performance and execution of the works he may have to carry into effect, and the object of this treatise is to put him into possession of the best means of accomplishing this end, as far as the extent of the instructions here given can extend. No one, however, must expect to be able to form and digest good plans by reading or study alone. Experience and practice are necessary to produce facility and perfection in this most essential part of the profession; and time, patience, and experience must be relied upon as the only means of attaining it.

2. The formation of a first plan for the execution of any work, whether it be a road, canal, mill, bridge, or any other construction, is an operation of the mind alone; and the first steps towards its commencement is as perfect an acquaintance as can be obtained of the locality where the work is to be executed. This must be obtained by visiting and examining the place, and by making the necessary inquiries of those who, from living in the vicinity, may be supposed to be most able to give the necessary information, which will vary with the nature of the proposed construction. Thus, for example, if a mill or a bridge has to be built, the particulars of the stream upon which it is to be erected, such as its width, depth in different places, and the velocity with which the water flows in a given time, must be ascertained by the Engineer himself. He must likewise make himself acquainted with the nature of the soil, not only at the bottom, but the two sides of the river. This frequently requires that pits should be dug, so as to ascertain what exists below the vegetable mould; for upon this circumstance will depend the nature of the foundation he will have to adopt, whether it must be deep or shallow, wide or narrow, or whether it will require the assistance of driving piles.

If one place on the river should thus turn out bad and ineligible, he will have to examine others, until he finds one that is more efficient; unless, indeed, as is frequently the case from pre-existing roads or the limits of private property, he is confined to one spot, and then, however bad it may be, it becomes his business and duty to make it good and secure by the exercise of his skill and contrivance. These and other points he can satisfy himself upon by personal examination; but there are others, almost equally essential to the perfection of his plan, and upon which he can only obtain information by inquiry—such as the healthiness of the place, whether it is subject to drought in dry seasons, or to inundations from freshets or floods at other times; and if the latter, to what height the water rises, in order that he may elevate his constructions above it; the facility that exists of obtaining stone, bricks, lime, sand, clay, iron work, timber, and other materials, as well as workmen to convert and use them; the price of such materials and of wages, and many other points which will affect the expedition and expense of the work to be constructed. If, on the other hand, it is a road or a canal he is about to construct, it will be necessary, not only that he should make most of the above examinations and enquiries, but, likewise, that he should walk or ride over the ground several times, deviating to the right and the left, for the purpose of selecting that which, to the eye, appears to be the best line, before the labour and expense of an actual survey is commenced. If several routes are found that seem to offer equal advantages, it may be desirable to survey more than one; and then that which is the shortest and most level will, of course, be preferred for general purposes. In making this cursory examination, strict attention must be paid to the position and number of water courses passed over, as well as of ravines or bottoms of valleys which, though dry at the time, may be expected to contain runs of water in wet seasons. If a road is contemplated, all these will require either bridges to be built, if they are considerable, or drains under the road to carry off the water, or shallow fords to be left on its surface; and as these, with the exception of the latter, increase the expense very considerably, if one route should be found more free from them than another, even though it be not quite so direct, it would, in general, be preferred. If a canal has to be constructed, such water courses require even closer inspection and notice. They may become highly useful as feeders to supply water to the canal, or may be important for carrying away surplus water. In some places, on the contrary, they may prove highly detrimental, by increasing the height and expense of embankments, or compelling the construction of aqueducts for carrying the canal over them.

In these examinations, the information to be obtained from local residents is always important. They frequently save much time and labour of investigation, by pointing out near cuts or lines that, by passing through woods, or being concealed between hills, might pass unnoticed by a strange examiner; or would, perhaps, not be discovered until much time might have been spent in maturing a less eligible route. The Engineer, in making these examinations, should never be without his memorandum book, and should note down every thing as it occurs upon the spot, and not trust to memory, or making remarks at a future period, as the number of nearly similar objects that engage his attention in succession is, in that case, very apt to produce confusion and mistakes. If he is going over the investigation of a line for the first time, he will save much future trouble by ascertaining and putting down the names of the proprietors of the land he passes through, as well as the nature and quality of that land, and its degree of cultivation. And if he is proceeding over a line for the purpose of marking out and locating the work upon the ground, for any public undertaking, he ought to be provided with the agreement or act of legislature, by which it is authorized, in order that he may know the precise extent of his own, or his employers' power, and the exact line he has to run, and may thus guard against trespassing upon any land, which had been previeusly protected, or was not intended to be infringed upon.

3. Winter, and even sharp frosty weather, is generally considered as the best season of the year for making these first investigations, provided the ground is not obscured by being thickly covered with snow. The reason of this is, that in woody countries the leaves are off, and it is possible to see farther, and to measure with greater facility, than in the full foliage of summer. Small rivers, water courses, morasses, and other wet places, which might offer impediments to pursuing a straight course, if frozen, will be passable without difficulty; and all crops of corn and other produce are off the ground, and therefore not subject to injury. In addition to this, the general building operations of the Engineer are necessarily suspended at this season of the year, and he therefore has more time to devote to these primary investigations. It is, moreover, more healthy and pleasant to the Engineer to be moving about in the active exercise that these examinations require, than to be compelled to perform such duty in the sultry days of summer. In general, therefore, the Engineer stakes or lays out roads, canals, and other extended constructions, in the early spring of the year, in order that the workmen may commence operations upon them as soon as the frost will permit the ground to be moved; and the employer has then the advantage of

having his work executed in the lengthening days of spring and longer ones of summer.

4. The Engineer having thus made himself fully acquainted with the ground he has to work upon, and the nature of the materials with which he can be supplied, has next to form and digest his plans. This will require the utmost exertion of his mental faculties, in order that he may turn everything he is in possession of to the greatest advantage for the perfection of what he has to produce. He will here find ample scope for the exercise of his inventive faculties and genius; but while young in his profession, should not be too vainly confident in his own resources, but must be satisfied with imitating, or rather correctly copying, what others of more experience have done before him.

5. The young Engineer should never be without his memorandum book and pen or pencil. Whenever he meets with a machine or piece of construction that has obtained a good character for performing well, he ought (even if he does not take a sketch of the whole of it) to note down the form and disposition of the several parts, the materials it is composed of, their dimensions, mode of connexion and operation upon each other; the power employed, the mode of obtaining it, the result which it produces, and the expenditure of time and money necessary to that result, whether it be in wages, fuel, or wear and tear. If parts of the machine are hidden from the eye, he will in general be able to obtain such information from the workmen about it as will enable him to describe it; and this should in all cases be done, unless indeed it is a contrivance that the proprietor has purposely concealed for his own advantage, as being his own property; and in that case common delicacy and courtesy would prevent any one from making enquiry about it. Even if a machine is palpably bad, and has been discarded from its insufficiency, it will be well in many cases to note down its particulars; because, while the first will furnish much valuable information to copy from, the latter (which would never have been constructed, had not hopes been entertained of its being good and effective) will in many cases prevent the young and inexperienced Engineer from falling into similar errors. By persevering in this practice of taking memoranda of whatever comes under the notice of the young Engineer, and keeping them carefully in books, the subjects of which can be afterwards arranged and indexed, he will find that in a few years he will be in possession of a stock of practical knowledge that will be invaluable to him in after life. In making out his future plans, whenever his own invention or resources fail him, he may go to these memoranda, which will frequently help him out. Or he may adopt the more laudable plan of ar-

ranging his own views as to the means of carrying an object into effect, and may then compare his own plan when mature, with the information he has so gleaned; and this will in all probability convince him that his own ideas are good and worthy to be acted upon, or may show him what alterations he ought to make to render his plan more perfect.

6. Having arranged the plan of what he proposes to do in his own mind, he must in the next place render it palpable to others, so that its merits and defects may be canvassed and investigated, and the whole be rendered plain and intelligible to the public, or at all events to his employer, and to the workmen who are to have charge of the execution and fulfilment of the design; and this is generally done in two ways: 1st. By such drawings as will show the arrangement, form, proportion and disposition of the parts to each other; and 2ndly. By a written description referring to such drawings, and which is called the specification, or particulars of the work to be executed. If a drawing is made, and even coloured with the greatest care and accuracy, it will be impossible by its means alone, to convey all the information necessary to the workman, and hence all these unavoidable deficiencies must be made up by the specification. A drawing, for example, may show what parts of a construction are to be made of timber, what of iron, and what of brickwork, but it cannot show whether that timber is to be pine, oak, poplar, or of other wood. Cast iron and wrought iron could not be clearly distinguished from each other in a drawing; and although brickwork might be shown, yet the particular bond or mode of laying the bricks could not be designated without endless trouble. All this, therefore, is left to be described in the specification. So also of windows, roofing, and many other things. Should any one take the trouble of putting each square of glass in a window, or marking the exact size of the shingles or slates with which a building is covered, into a drawing, the labour would be thrown away; for they might be too minute to be measured accurately, or the workman might not choose to take the trouble of counting them. Such things are on this account much better left out of the drawing, which makes it more simple and intelligible, and are introduced into the specification by saying that each window is to have a common sash with twelve panes of glass, of 10 by 12 inches, or as the case may require; and that the roof of the building is to be covered with slates of a certain size, or with good cyprus shingles, seventy-two to the square yard, each shingle being fixed with two nails, &c., when of course nothing ambiguous or uncertain remains.

In the next place we will consider the kind of drawing made use of by the Engineer.

Section II.—*Of Drawing, and Drawing Instruments.*

7. It is quite essential to the profession of an Engineer that he should be a tolerable good draughtsman; because, in general, better and more perfect ideas of the arrangement and disposition of a construction are given by a drawing than in any other way, except, indeed, by a model, which is sometimes necessary for complicated things. But as the Engineer is not supposed to be a practical workman, and such a one must be employed to construct the model, so a drawing is necessary in the first instance for the guidance of such workman. In some few instances a piece of work may be so simple as to admit of a clear description in words, and in that case the specification is all that is necessary. But it more frequently happens that a drawing alone is necessary, and that the specification may be dispensed with, although they generally accompany each other.

8. A correct drawing of what has to be constructed may, therefore, be considered as indispensable in all the operations of the Engineer; and if he is unable to make his own drawings, he will have to employ others to supply the deficiency at great expense; for a good draughtsman always receives higher pay than those employed in other junior departments of the profession. This should act as an inducement to students to apply steadily to this art, which requires nothing more than care, attention, and assiduity for its acquirement. Moreover, the Engineer will find that few second persons can convey his ideas, and put them down on paper, in such direct accordance with his own views and wishes, as he can do himself. And on this account it is strongly recommended to all students, in this profession, to devote as much time as they can spare to this desirable accomplishment.

9. The drawing requisite for an Engineer to pursue, is of a character quite different from that pursued by artists, or those who follow the profession of producing pictures as works of art, or for ornamental purposes. This branch of art requires great skill and practice; a correct eye, and judgment to depict forms and their proportions as they appear, without measuring them; for, in this kind of drawing, the rule and compasses are never used; a knowledge of the rules of perspective; a correct discrimination of colours, so as to imitate upon paper or canvass, what is seen in nature; a freedom of touch, and facility of softening down and diminishing the distinctness of objects, to produce the effect of distance; a complete acquaintance with the effects of

light and shadow, and a knowledge of the picturesque, or that form and disposition of things which, by rules of art, is said to constitute beauty. An artist must also be able to depict correctly the appearance of the sky and clouds which, from their irregularity and indistinctness, is very difficult, and can only be acquired by the study and observation of nature, and making constant efforts to imitate that which is seen. It frequently becomes necessary to introduce trees, or other objects, in the foreground, that do not exist in the real view; a license that is permitted him, because, without such assistance, he might not be able to give the proper effect to the other parts of his picture. It is the combination of all these things, and a want of knowledge when and how to use them, that makes picturesque drawing so difficult of acquirement. If an Engineer possesses this knowledge and the above qualifications, his drawings will be more pleasing to the eye, but they will not be more useful to the mechanic or the workman; for none of the requisites of a picture are necessary in the drawing of an Engineer; but, inasmuch as they add to its beauty, it is by no means uncommon for the Engineer to make his own drawing of that which appertains to his profession, and afterwards to employ an artist to finish and decorate it. Thus, for example, if he has made a design for a bridge, all he has to do is to show the form of the arches, their number and proportion, the manner in which the stones are to be cut, laid, and joined to each other; but he has nothing to do with giving a view or representation of the river that passes under that bridge, the boats that sail or move upon it, and the houses, woods, hills, or other objects that may be upon the two shores; and all these he can get introduced upon his paper by a professional artist after his drawing is completed, if it should be desirable to do so. But it will be self-evident that the drawing will be equally valid and useful to the workmen, who have to build that bridge, without such embellishments. Still, however, cases do sometimes occur where it is desirable, from motives of policy, to finish drawings in this style.

10. The regular drawing of the Engineer, in fact, requires none of the conditions just enumerated, and for the most part consists of straight lines and curves, for the production of which there are appropriate instruments, so that it is purely mechanical. Every object requires to be made out clearly and distinctly, without regard to distance. Perspective is rarely admitted into it, because perspective is the art of representing objects by geometrical rules, upon a plane or flat surface, in the way in which they appear to the eye; and, consequently, all objects must be drawn smaller, if they are distant, notwithstanding that their dimensions

are similar, and would appear so if viewed from equal distances. If a circle is viewed obliquely to its plane, it must be represented in perspective by an oval, therefore the represented form does not agree with the real form. Now, in the drawings of the Engineer, every object must have its real form and proportion, instead of its apparent ones; a circle must always be a circle, and all things that have the same length or height must have those heights assigned to them, because the workman has to apply his rule or compasses to the drawing, and must be able to obtain the magnitude of the real thing to be executed from the small representation of it. Hence it will appear that perspective is inadmissible in the principal drawings of the Engineer, though he frequently makes use of it in an accessory or auxiliary drawing, which is not to be measured from, but is merely to show the general form and disposition of the parts figured upon his other drawings. The kind of drawing necessary to the Engineer is, therefore, so simple, and easy of acquirement, that any person with a steady hand, and possessing the necessary instruments and materials, may make himself master of it without an instructor, and that even to a considerable degree of excellence, by nothing more than the exercise of great care and attention, industry and perseverance in practice, and his own determination to excel. The best practice for the beginner, is to acquire the habit of drawing perfectly straight lines of even thickness throughout, by a pencil, or pen and ink and ruler, and also to produce circles of different diameters with a pair of compasses. Then to endeavour to do the same things by hand, unassisted by the ruler or compasses; also to lay down different angles; to draw the several solid geometrical figures in perspective, giving them the necessary shadows, and then to copy outline figures of machines, houses, the columns of architecture, and other simple figures which are to be found in many books, and then to attempt the same things filled in, and shaded. After this it will be well to attempt drawing from models or instruments themselves, instead of from representations of them.

11. The drawings proper, which every Engineer has to execute, are constantly three in number of the same thing. These are—1st. The ground plan or horizontal appearance of a thing as seen from above; and which, if the object is a country, or estate, or road, or canal, is called the *map* or *plan*.

2nd. *The longitudinal elevation*, which is the external appearance that a thing will put on when finished and viewed with its longest dimension turned towards the eye.

3d. *The transverse elevation*, or external appearance of the end or side, which is at right angles, or otherwise connected with the last. All these go by the general name of plans.

The above is on the presumption that the back and front of the construction, and its two ends, are similar; as in the case of bridges, steam-engines, &c. But if a construction has more than two sides that are dissimilar, then it will be necessary to have a separate elevation for each of them.

12. When an elevation consists of a repetition of the same parts, such as columns, windows, and the like, with similar spaces between them, the drawing of one such object and its space on either side, with a notification of the number of times they are to be repeated, will often suffice, and save the time and labour of a drawing containing all the details; and, in the case of bridges, either of a single arch, or any number of arches, the elevation very frequently exhibits but half the bridge, taken from its abutment upon one shore to the middle of the arch, or centre arch, as the case may be. And as both ends of a bridge are almost constantly alike, it will be evident that such a drawing will convey all the information that is necessary to the workman for the construction, and will save half the time, labour, and expense of an entire drawing, which, after all, could contain nothing more than a repetition of that which appeared in the first half.

13. All these several drawings must be perfect representations in every respect of that which has been, or that which is proposed to be, constructed. They must not be mere pictures, giving an idea of the general form and appearance of the thing, but must exhibit every detail with minute accuracy. On this account mouldings, ornaments, modes of fixing together, and many other minutiæ, are drawn upon a much larger scale than the general plans, and are put upon separate sheets, and referred to in the general plan. Every object that is introduced into these several drawings requires to be laid down with the most scrupulous attention to magnitude and relative proportion; because it is by measuring these drawings that the workman determines the size of the things, or parts of things, to be constructed; and on this account it is very desirable that the same scale of magnitude should be adopted in all the general plans and elevations that are made for the same construction, and the scale to which they are drawn should be introduced, or mentioned, on some convenient part of the paper.

14. The expression *drawing to scale* may require some explanation, but is very simple. It is merely supposing a small quantity of space to be the representative of a larger one, or *vice versâ*, and is generally determined by the magnitude of the paper made use of. Thus the Engineer who is about to make a design

for a bridge, may say that each foot of his real bridge, when built, shall occupy one inch upon the paper of his drawing. Then the inch becomes the representative of a foot, and the drawing would be said to be upon an inch scale. If the bridge is to be thirty feet long in reality, then the length of the drawing must be thirty inches, and each inch being divided into twelve equal parts, each of those parts will become the representative of an inch in reality. On attempting to make his drawing he finds that his sheet of drawing-paper is but two feet five inches long, and consequently will not hold the bridge, unless two sheets are joined together, which always disfigures a drawing, unless very neatly done. This must be submitted to, or the scale must be reduced. Half an inch may, therefore, be made to represent a foot; but with a half inch scale the bridge will only be fifteen inches long, and that will look too small for the paper; but by adopting a three quarter inch scale, the length will be twenty-two and a half inches, and this will fill the paper very well and leave a handsome margin. In this way then the scale may be predetermined, and the paper made commensurate with it, or it may be adapted to the size of the paper, as may be most desirable. For the details of work, as above referred to, a scale of two, or sometimes three inches to the foot is often adopted, while the three inches is often made to represent a mile in a plan of a road; and six inches, or a foot, to a mile, is a good scale for plans of canals. An inch or half an inch to the foot scale, is very frequently used for mill-work and machinery; and maps of countries are often drawn at four miles or more to the inch; but in these cases there is not room for the accuracy required in the operations of the Engineer.

15. In addition to the plan and elevations above referred to, the Engineer has frequent occasion to produce another drawing, or set of drawings, which are sectional, or represent sections of the thing indicated, or the exact appearance the object would assume if it were sawed through, or cut in the direction of certain lines, which must always be represented or referred to in the ordinary plan and elevation. These lines represent a plane or flat surface, that is imagined to pass through the object represented. Sectional drawings are highly useful and important, and rank in a higher order than mere plans and elevations; because any one of ordinary skill can produce a plan and elevation of an object that stands before him, or can copy a sectional drawing; but it is not every one that can produce an original section; for this requires thought, experience, a knowledge of workmanship, or the means of uniting things together, of strength of materials, and of mathematical principles which cannot be expected in the unexperienced. The production of a sectional

drawing even of an object that stands before us, and consequently has not to be contrived and designed, is attended with some difficulty; because a section always represents that which can never be seen by the eye, and consequently can only be imagined. We can never cut a steam engine or any other machine in half for the purpose of ascertaining how it would appear; but if we have a perfect knowledge of the shape, use, operation, and mode of putting every part together, we shall have no difficulty in conceiving in the mind how it would appear if so cut, and of drawing the appearance that all the parts would assume on paper. Nothing, perhaps, offers clearer evidence of the practical ability of an Engineer, than his being able to produce a good and perfect original sectional drawing. Because, to do this, as he has nothing to copy from, and must express and lay down all the parts in good and effective proportions—must select his materials, and show the mode of uniting and putting them together—the whole must spring from his mind and inventive genius, coupled with his knowledge of the strength and efficacy of the several parts to withstand the resistance opposed to them, and to effectually answer the several purposes for which they are intended and introduced; and no man can do this without practice, experience, and a considerable knowledge of the object he has in view.

16. Sectional drawings are used by Engineers and Architects to instruct workmen in the interior and particular construction of machines or other constructions, such as the framing and putting together of roofs, partitions, and the internal parts of bridges; and are so generally useful that they should be much studied and practised by all who wish to excel in their profession.

17. To execute drawings, certain materials and apparatus are necessary, and these will be the next object of description.

The paper upon which the drawing is to be made is the first requisite. For sketches, first thoughts, and rough memoranda, any ordinary writing paper will suffice; but as the finished plans of the Engineer and Architect frequently require to be much larger than this kind of paper is made, a thick and fine paper is manufactured for the express purpose of drawing upon, and is called drawing paper. This kind of paper has various names given to it by the manufacturer, all of which depend upon the size of the sheets; and as this volume may fall into the hands of persons in the country who may have occasion to send to the cities for such paper, a list of the names and sizes of the sheets is annexed, in order that persons may know what to ask for to suit their several purposes.

18. *Size and denomination of Drawing Paper.*

				Feet.	*Inches.*		*Feet.*	*Inches.*
Thick woven drawing foolscap,			each sheet,	1	5	by	1	1
Medium drawing paper,		-	,, -	1	10	by	1	6
Royal	do.	- -	,, -	2	0	by	1	7
Super-royal	do.	- -	,, -	2	3	by	1	7
Imperial	do.	- -	,, -	2	5	by	1	9¼
Elephant	do.	- -	,, -	2	4	by	1	10½
Columbier	do.	- -	,, -	2	10	by	1	11
Atlas	do.	- -	,, -	2	9	by	2	2
Double elephant	do.	- -	,, -	3	4	by	2	2
Wove antique	do.	- -	,, -	4	4	by	2	7

Anything larger than the above can only be obtained by pasting or otherwise joining two or more sheets together.*

19. The larger kinds of drawing paper are very expensive; and as a good drawing occupies much time and is otherwise valuable, every Engineer should provide himself with a tin case, or cases, of sufficient length to contain the sheet when rolled, for the purpose of carrying his drawings about and preserving them; but at home no drawing should be rolled or folded up, as the best of paper will soon give way in the crease, by frequent opening and shutting. A good collection of working drawings may be said to be the stock in trade of the Engineer and Architect, and they will prove of immense use to him in the pursuit of his profession. Every young Engineer ought therefore to strive to make such a collection by his own or other hands, and to preserve them carefully when obtained. A small quantity of drawings may be kept in a portfolio; but when they accumulate, it will be found most convenient to arrange them according to subjects, and to lay them flat in drawers.

20. When large paper is made use of, and indeed in all cases, a drawing-board is essential; that is, a perfectly smooth board, rather larger than the paper used, to strain it upon and keep it

* Flour paste is much superior to gum, glue, or any other composition, for joining sheets of paper together. To make it, use the best wheat flour, and add, by degrees, as much cold rain or soft water as will mix with it to the consistence of thick cream. Stir or beat it well while cold, so as to leave no lumps of flour unbroken. To insure that this has been done effectually, the mixture may be strained through a cullender. Then place the vessel containing it over a slow fire, and heat it gradually till it boils, stirring it the whole time with a stick or wooden spatula. Do not continue the boiling, but as soon as it turns yellow move it from the fire; stir it occasionally as it cools, and use it when cold. A little powdered alum dissolved in the water is said to prevent its becoming mouldy by keeping; and corrosive sublimate, dissolved in the water of which it is made, being poisonous, prevents its being attacked by the cockroach and weevle in hot countries.

perfectly flat and free from creases. The drawing board must have its surface not only quite flat and smooth, but should be free from all holes, knots, and hard grain, and be as nearly of the same hardness in every part as possible, otherwise the points of the compasses will scarcely mark in some places, and in others will sink in, making large holes in the paper and disfiguring the drawing. White pine makes a very good board, but Bay or Honduras mahogany is the best, as being more homogeneous. It must be clamped* at the two ends to prevent its warping.

21. The sheet of paper is fixed upon the drawing-board by applying a little paste to the four corners, or to the sides of the paper, if large; taking care that the paste does not extend more than a quarter of an inch under the paper, as that would prevent the cutting of the drawing off the board when finished. In the absence of paste the paper may be laid down with a few wafers, or touches of sealing wax, which must be scraped or washed off the board after the drawing is removed.

22. If it is intended to tint or colour the drawing, then the drawing paper must be made damp by wetting the back of the sheet with a sponge, or rag, and clean water, before applying it to the drawing-board, upon which it must be stretched, with the damp side downwards, before it gets quite dry. It must then be set by, to dry slowly, and must become quite dry before any drawing is made upon it. The reason of this is, that all paper expands considerably in its dimensions by being wetted. If, therefore, we attempt to lay water-colour tints to any extent upon dry paper, the part so coloured will cockle up, and acquire so uneven a surface, that it will be impossible to dispose the colour evenly upon it; and it will even dry with these inequalities, which cannot afterwards be removed except by the damping process, which may injure the drawing. But when a sheet of paper is so wetted and expanded in the first instance before it is put upon the drawing-board, it is prevented from shrinking to the full extent, but will dry perfectly smooth, and may be worked upon in a very satisfactory manner.

23. The best drawing boards are made so as to confine a sheet of paper, either dry or damp, without paste or any adhesive material. These consist of a frame of mahogany or other hard wood, strongly mortised* together, about two inches wide and full an inch thick. The opening in the middle of the frame must be an inch and a half each way less in size than the sheet of paper intended to be used. The drawing-board is only half an inch thick, and fits the opening of the frame, being rebated* into the same

* For explanation of these and other unexplained terms, look for them by the Index.

on all the four sides. The paper being placed on this board so as to extend an equal distance beyond it on every side, the frame is to be pressed down on to the same, when the edges of the paper will fold into the rebates, and the central pannel of the drawing-board is held in its place in the frame by turnbuckles or other contrivances fixed upon the back of it, and which thus hold the paper quite securely. Whatever be the construction of a drawing-board, it is quite essential that its sides should be quite flat and straight, and those opposite to each other parallel, and that the corners should be right angles.

24. The paper being so fixed and prepared, the drawing may be commenced with a black-lead pencil, which must in every case be used for beginning a drawing, on account of the facility with which its lines may be effaced, if wrong, by a piece of caoutchouc, gum elastic or India rubber. If that is not at hand, the best substitute for it is a small piece of *new* wheat or rye bread, free from crust or grease. This is to be worked or kneaded between the fingers until it becomes perfectly plastic and elastic, and will not fall into crumbs. With this any traces or lines made with a black-lead pencil or black chalk may be very effectually removed.

25. There is a great difference in the goodness of black-lead pencils, and those that are warranted are always high priced. The make of Brookman and Langdon of London are most approved, and they cost sixteen cents each at the manufactory. They assort their lead according to hardness and colour, and stamp their pencils with the letters HH for hardest hard, H for hard, M middling, S soft, SS softest soft, B black, and BB very black. A soft pencil should always be used to lay down the first points or parts of a drawing, because its marks are easily rubbed out. A hard or harder pencil is used after to put in the more finished and detailed parts; but the whole of these need not be inserted in pencil, because when the outline is set out and nearly finished, so as to ascertain if it is perfect and will answer its intended purpose, the whole must be gone over again and be inked in; and in this process all the minute parts that have not been attended to with the pencil may be finished with the ink.

26. Common writing ink must in no case be used for finishing drawings, because that dissolves and spoils the appearance of every line that is tinted or coloured over. China or Indian ink, such as is imported in cakes or sticks from China, is the only ink that is admissible. To use this, small blocks of white earthenware, with several concave recesses, and a long channel, deeper at one end than the other, and which are called *ink stones*, are very convenient. The end of the stick of ink is rubbed back-

wards and forwards in a little clean water, until a sufficient quantity of the ink is dissolved to make the fluid as black as required, which must be ascertained by trial. The long channel being deep at one end, the dissolved ink will lie in that part, and a sufficient quantity of ink should be rubbed down to last for hours, or even days, because it will keep well if protected from dust. The concave circular cavities are for holding clean water, or mixing a quantity of black tint for shading drawings. Of this a quantity should be prepared at once, to insure uniformity of tint or darkness. A camel's hair pencil is kept in the long channel of the ink stone, and with this the ink is taken up to charge a common quill pen, or one of the steel ruling pens to be hereafter described, because the pen of either kind should never be dipped in the ink, which would injure its point.

27. China ink, if good, should be entirely free from grit or dirt, and should make an even, well defined line, when drawn upon paper. That line, when dry, should bear tinting or colouring over without washing up or mixing with the colour applied above it. In the event of making a mistake, and placing lines, blots, or marks upon your drawing that should not be there, never use a knife for scratching out or erasing them; but if they have been made with China ink or good water colours, wet the whole of them thoroughly with clean water, applied with a large and clean camel's hair brush, and let the water remain on until the paper is rendered rather soft and you think the colour is dissolved, which will seldom occupy above a minute; then apply blotting paper perpendicularly, or without lateral motion, and by pressure with the hand and renewed applications, get all the humidity absorbed and taken up; which done, apply India rubber (as to a pencil line) before the paper becomes dry; but instead of rubbing backwards and forwards, rub in one direction only, and the line or marks will be taken out as effectually as if they had never existed, and the surface of the paper will be left so perfect that it may be coloured or written upon, and no trace of the erasure will be visible, except by transmitted light on account of the paper having become thinner.

28. The next implements to be mentioned are rulers for drawing right or straight lines, and of these the draughtsman should possess at least three—one a few inches long, as from four to six inches, for short lines; the next two feet three inches long, and a third about three feet six inches. These should be formed out of strips of hard wood, from one to three inches wide, according to their length, and need in no case exceed a quarter of an inch in thickness. They should be quite flat, so as to come into perfect contact with the paper. Their two edges should be parallel,

one being made square or at right angles to its sides and to the paper upon which it is placed, and the other edge should be chamferred, or formed with a sharp or fiducial edge. This edge is to be used with its chamfer towards the paper, and this edge uppermost for drawing ink lines, and in the reversed position for drawing very fine pencil lines. In drawing a long right line, the ruler ought not to be shifted or moved, after once laid down and adjusted to its place, until the line is drawn; and it is on this account that the above lengths of rulers are assigned, for two feet three inches will extend quite across the longest dimensions of the first four kinds of drawing-paper, mentioned in the list at page 33, and these are the papers most commonly used, while three feet six inches will compass all the varieties of paper, except the last, and that is seldom met with.

29. To try the goodness of a ruler, draw as even and perfect a line as possible with it upon a well strained sheet of paper, and then reverse the paper, by placing the side that is most distant from you, next to you, and draw another line close to the first with the same edge of the ruler, and if the two lines coincide, or are perfectly parallel throughout, the edge is straight and perfect; but if the ruler is concave or convex, its error will be doubled by this process, and will become apparent to the eye.

30. All large drawings should be executed on a high table, and in a standing position, not only as the most healthy, but it gives a greater command over the work, and enables the draughtsman to look down close to the edge of the ruler, which cannot be done while sitting, except in small work.

31. Some lead weights, not exceeding three-quarters of an inch in thickness, and two or three inches square, covered with paper or cloth, to prevent their soiling the paper, will be very serviceable to the draughtsman for placing on the sides or corners of drawings, that have a tendency to curl, from having been previously rolled. In drawing long lines with a ruler, these weights must be placed upon the ruler to keep it in its place; it being impossible to hold a long ruler steadily to its position with one hand, while the other is employed in drawing the line. Some persons employ an assistant to steady the ruler, but the weights are more certain, and are constantly at hand.

32. It is very frequently necessary to draw parallel right lines, or to make them at right angles, or perpendicular to each other. To set out such lines by the rules of geometry occasions a waste of time, as mechanical implements are provided for these purposes. The instruments called *parallel rulers*, consist of two slips or rulers, united together by two brass connecting pieces, which permit them to be separated, or placed in contact with each

other. Sometimes three rulers and four connecting links are used; and occasionally a single ruler is mounted upon two small wheels of exactly the same diameter, and which are connected together by a concealed steel wire that prevents the one turning without the other, or their moving in opposite directions. Such instruments answer very well when they are small, as not more than six inches long; and such an instrument is more convenient than the small simple ruler before referred to. But for cheapness, accuracy, and expedition, the French parallel ruler called Marquois's, from its inventor, is decidedly the best for the Engineer and draughtsman, and no other will be necessary. It consists of a thin flat triangular piece of hard wood, one angle of which should be a right angle, in order that it may be used for drawing perpendiculars, or lines at right angles to each other. To employ this triangle as a parallel ruler, it must be used in contact with the common flat ruler, and its application will be obvious on inspection of *Fig.* 1, *Plate I.*, in which, let *a b* represent a right line previously drawn upon the paper, and to which it is desirable to make other lines parallel—place the wooden triangle, *c d e*, upon the paper in such manner that any one of its three sides may be in contact with, or parallel to, the given line *a b*. The hypotenuse of the triangle will, in general, be the most convenient, because it is the longest side. That done, hold the triangle firmly down in its position with one hand, while with the other the flat ruler, *f g*, is brought into contact with the other side, *d c*, of the triangle. The ruler, *f g*, has now in its turn to be firmly held down, when the triangle may be made to move or slide along the ruler, during which movement, the side, *c e*, will always be parallel to *a b;* consequently, any lines drawn against its edge, *c e*, will be parallel to *a b*.

The long side, *c e*, of the triangle should be chamferred on one side to render it fit for drawing ink lines, or by reversing it, to make a thin edge for pencil drawing.

33. In drawing buildings, and the frame-work of machinery, a great number of lines are generally required perpendicular to a horizontal base line, and consequently parallel to each other; and these are most expeditiously and correctly produced by what is called a T square, the form of which is shown at *Fig.* 2, *Plate I.* The blade, *h i*, is a common thin and flat ruler, which is let into and immovably fixed, at right angles, to the stock *k*, which is made of thicker wood, so that while the blade lies in contact with a sheet of paper, strained upon a drawing-board, the inner edge of the stock may be brought into contact with, and be made to slide against either side of the drawing-board, and thus any number of lines may be drawn against the edges of *h i*, all

parallel to each other, and perpendicular to that side of the drawing-board to which the stock is applied. The stock of this instrument is sometimes made of two parallel and similar pieces of wood; one of which is fixed to the blade, and the other attached by the screw *l*, upon which it turns as a pivot, and may be set to any required angle, as shown by the dotted lines in the figure; and if this dotted half of the stock is applied to the edge of the drawing-board, the blade will no longer be perpendicular to it, but any number of lines may be drawn, all parallel to each other, and with any required angular direction, in respect to the base line.

34. *To prove the correctness of a T, or other square.* Bring the stock of the T square into close contact with one side of the drawing-board, and draw a fine but correct line by one edge of the blade; and then turn the square over so that the other side of the blade may come into contact with the paper and the edge of the blade before used into contact with the line, and then draw another line. If the two lines are parallel to each other, or if the last line covers or coincides with the first, the square must be correct, while, on the contrary, if this is not the case, the lines will make a small angle with each other, and the true square will be an intermediate line bisecting that angle. If the square to be tried is not of the T kind, and has not a thick stock, as in the case of the triangular ruler, *c d e*, in *Fig.* 1., a line must be drawn to serve as a base, and a perpendicular be erected upon the middle of it by the square, which is afterwards to be turned over on to the other right angle formed by the two lines, and if a perfect coincidence between the lines and the right angle of the square still holds goods, the square is true.

35. In addition to the implements for drawing before mentioned, the following instruments are absolutely necessary, viz:—

A steel drawing-pen.

A pair of compasses with shifting points for ink or pencil.

A marking-point or pricker.

A protractor for laying down and measuring angles, and a scale, or several scales of equal parts.

36. The drawing-pen is not intended to be used either for writing or drawing curved or irregular figures, but is solely for drawing right lines with Indian or other ink against the edge of a ruler. This pen consists of two thin plates of hard steel, fixed parallel to each other, at the end of a brass handle, in such manner that their points may spring away from each other to a small distance; but they may be brought into close contact, or be set to any required distance apart, by a small screw that passes

through them both, and can be turned by its milled head. The steel plates are ground upon a hone until they are very thin, and they should not terminate in a sharp point, but be made nearly semicircular, so as to insure their not scratching the paper, whether the pen be held upright or in a sloping position. By means of the adjusting screw the thickness of the line to be drawn is regulated, since it will depend upon the distance the plates or cheeks of the pen are from each other. In using these pens they should always be held perpendicular to the plane of the paper or to a line that joins the top and bottom of the sheet, but sloping as to the right or the left. They should never be dipped into the ink, but are to be fed or supplied when necessary by a camel's hair pencil dipped in dissolved China ink, and the required line must be produced by drawing, and not pushing the pen forward against the ruler. Those pens are the best in which the cheeks are allowed to separate from each other by a hinge, after the adjusting screw is removed; because this admits of the points being wiped clean after using; and cleanliness with sharp edges are essential to the perfection of their operation, consequently after long use the points of a pen of this description will require re-setting upon a hone or oil-stone, like a penknife. As this pen is to be used for drawing right lines only, so

37. The compasses with shifting points are for drawing circles and curves, as well as for measuring and setting off distances. The form of a pair of compasses, or dividers, as they are sometimes called, is too well known to need description. As usually constructed both the points are sharp and made of steel; but by having shifting points, it must be understood that one of the steel points is made capable of being withdrawn and removed, and its place may be supplied by either of two other points; one of which is a steel drawing-pen of the construction last described; and the other is a port crayon or tube for containing a small piece of black-lead pencil. By the latter, circles can be drawn in pencil,—with the drawing-pen they are drawn with ink,—and when the two sharp points are in the compasses they are equipped for scratching circles lightly upon paper, or measuring distances from the scale to the drawing, or *vice versâ.*

38. With the best compasses, a piece called a lengthening-bar is usually sold—this is a mere rod of metal, which can be fixed into the shifting leg of the compasses in the place of the points, any of which can in like manner be fixed to the end of the bar. Its use is to enable the compasses to strike circles of much larger radius than could be effected without it.

39. In drawing large circles, the drawing-pen or pencil ought to be nearly vertical to the paper, to effect which, each of the

drawing-points is equipped with a joint by which it may be placed in the required position. The French instrument makers generally add another shifting point to their compasses, consisting of a very small revolving wheel, the edge of which is divided into points like a star. Its proposed use is to draw dotted lines, being supplied with ink for that purpose. It is, however, very difficult to use, so as to produce a good and uniform line, and is very apt to make blots. The best means of producing a dotted line is first to draw it with pencil, or to make a faint scratch with the sharp point of the compasses, and then to pick in the dots with the fine point of a common quill pen.

40. One pair of compasses with shifting points, will answer all purposes when expedition is not an object; but when this is the case, two pair will be necessary, viz.: one pair with shifting points as above described, and a smaller pair with fixed points, to be used for measuring only. The points of the measuring compasses must be kept very sharp, for the double purpose of measuring off small divisions on the scale with accuracy, and to avoid making large holes in the paper, which greatly disfigure a drawing.

41. Compasses are occasionally made for the express purpose of measuring very minute distances with great accuracy, insomuch that they require to be used with a magnifying glass to inspect their points. They contain a spring in one of their legs which tends to make that leg assume a slightly curved form, which can be made straight by turning a screw in that leg, so as to produce a more gradual and accurate motion of the points, in respect to their distance, than could be brought about by the direct application of the hand. Such compasses are called *hair compasses,* because they are intended to measure distances as small as hairs. For measuring such distances, steel spring dividers are, however, preferable and more certain. They are formed like other compasses, but instead of having a hinged joint, the two legs are united by a steel spring, the operation of which is to keep the legs separated or open, and they are brought together in any required degree by a long and fine screw fixed to one leg and passing through the other, so that a nut upon this screw can be turned, and will place the points at any required distance with the greatest exactitude.

42. The student should acquire the habit of using the compasses with one hand only, not only because it looks better, but will prove much more convenient in practice. Both for measuring distances and drawing circles, the compasses should be held by their top joint, between the thumb and first and second finger of the right hand, and these same fingers will also open and shut

them very conveniently, without suffering the left hand to touch the instrument.

43. *The marking-point*, or *pricker*, is merely a very fine steel point for making a small dot through which lines are afterwards to be drawn, and is also useful in copying drawings, as will hereafter appear. Such a point will generally be found concealed in the brass handle of the drawing-pen, if it is unscrewed about its central part. The points usually inserted by the instrument makers are by far too thick and coarse to be used, as they would produce large and unsightly holes in the paper. It is better therefore to withdraw this point, and to fix the pointed half of a fine sewing-needle in its place by sealing wax; or a convenient pricker can be made by so fixing such a needle in the end of a pencil or other cylindrical bit of wood.

44. The *protractor* is a very useful and almost indispensable instrument, both for measuring angles already drawn, or for laying down such as it may be necessary to form upon the paper, with any required degree of magnitude. It usually occurs in two forms, a semicircle or a long parallelogram; but is occasionally made a complete circle, with a diameter running across it, and is formed of brass, ivory, boxwood, or thin horn, which is convenient on account of its transparency; but metal is generally preferred. It is nothing more than a semicircle divided into 180°, counting from the diameter, upon the middle of which the centre of the circle, from which the semicircle has been described, is marked. The divisions are marked with figures for the facility of counting them; and in large and accurate instruments, each degree is divided into two, three, or four equal parts, for measuring angles, to 30′, 20′, or 15′. When the protractor is laid down upon a parallelogram, it answers the purpose of a small ruler, and its opposite side is usually filled with scales of equal parts to be next described. In this form the lower edge of the ruler is the diameter of the circle, and its centre is marked on the middle of this edge, while the other three edges are occupied with the divisions into degrees and their fractions. When the instrument is an entire circle, the circumference is divided into twice 180°, or two semicircles, each set of divisions beginning, as before, from the diameter. The only advantage of such a construction is greater accuracy; because, by extending the lines that form the angle, opposite angles may be measured; and as these should always be equal to each other, it affords an opportunity of measuring the angle both above and below the diameter, or of measuring the same angle twice over by the two opposite divided semicircles, and thus proves the accuracy of the divisions on the instrument,

as well as insures greater precision in the measurement of the angle.

45. The square protractor may, on the whole, be considered as the most convenient of the single arc instruments, not only because it serves for a ruler, and may contain several useful scales, but the divisions, indicating the degrees of all angles less than 60°, are drawn to a longer radius than they could be upon a circular instrument, unless it is made very large; and consequently the measures of all such angles can be taken with greater accuracy.

46. The protractor is sometimes very elaborately and expensively made, with an index, moveable by rackwork, and a vernier for measuring angles to single minutes. But such instruments are useless for the ordinary purposes of drawing, since the expansion and contraction of paper, with different states of humidity in the atmosphere, alters its dimensions to such an extent as to render every attempt at such extreme nicety nugatory and useless. Such instruments, consequently, are only useful for laying down angles upon metals or substances less liable to change.

47. The uses and application of the protractor, as well as of a scale, called the line of chords, usually engraved upon some part of this instrument, when of the square form, will be better understood and explained when treating of angles in a more advanced part of the work.

48. Scales of equal parts, engraved upon brass, ivory, or boxwood, are highly necessary to all who undertake engineering or architectural drawing. They are merely parallel lines drawn upon the surface of a flat ruler, each line being divided into a certain number of equal parts, which parts are to be the representatives of larger portions of space in the real object, as before explained, see par. 14. The lines usually laid down are an inch, divided into tenths, and the tenth again divided into hundredths, two hundredths, and four hundredths of an inch, by the diagonal process. Also a set of simple lines, in which an inch is divided into six, five, four and a half, four, three and a half, and three equal parts. Such scales are usually distinguished by the numbers, 60, 50, 45, 40, 35, and 30, placed at their ends, which indicate that the entire inch is divided into this number of parts, for one of the small divisions is subdivided into ten parts, thus constituting the above numbers. This decimal mode of division is very convenient for all purposes of land surveying by the chain; but for architectural and engineering purposes, the extreme division must be subdivided into twelve instead of ten parts, because the dimensions are always given in feet and inches. Any one division may, therefore, be taken to represent a foot, and the twelfth part of such division will be an inch.

For the purpose of the Architect and Engineer this scale should be carried to larger dimensions than is usually done on the scales that are sold; for there should also be the following scales, half inch, three-quarters, one inch, one and a quarter inches, one and a half, one and three-quarters, two inches, two and a quarter, two and a half, two and three-quarters, and three inches, to a foot, one of each of these dimensions always being divided into twelve parts for inches, or into twelve parts on one side, and ten on the other, for the convenience of the chain operations of the land surveyor. The scale which the author has found most convenient, is represented by *Fig.* 3, *Plate I.*, which shows its two sides, and for the convenince of such as may not possess the means of obtaining such scales, this figure may be cut out and pasted on a piece of smooth wood, and with care will last a long time.

49. The above drawing instruments are absolutely necessary to the Civil Engineer, and they may always be procured, put up in small portable cases, under the name of, cases of drawing or mathematical instruments. Such case always contains what has been above enumerated, and sometimes other things, particularly an instrument called a sector, which has the appearance of a jointed ruler, with a great number of scales engraved upon it. The sector is for solving a number of problems in proportions, and in trigonometry mechanically by the compasses only, and is a highly ingenious and useful instrument, but to be really serviceable, it requires a greater degree of accuracy in workmanship than is usually bestowed upon it, and is always a high priced instrument, although not always to be depended upon; and as all that it can do may be worked out with greater certainty and precision by figures and formulæ, it is an instrument seldom resorted to by practical men. Drawing instruments are always made four or six inches long. The six inch size are the most convenient for general use, and their price varies with the number and excellence of the instruments, or the metal of which they are composed.

50. The following is a list of the articles which a good and complete case of drawing instruments should contain.

A pair of hair compasses, or plain small dividers, with fixed points.

A pair of compasses with shifting points, viz: their proper steel point, a point carrying a pencil, another carrying a drawing-pen for ink, and a lengthening bar to increase the radius.

A bow pen with an ink point, and another with a pencil point, for drawing very small circles.

A steel drawing-pen, with long brass handle, terminating with a rather blunt and round point, for copying drawings by camp paper, as hereafter described. The handle of this pen should contain a sharp steel point or pricker.

A black-lead pencil, with a very thin brass top, the use of which is to clean between the cheeks of the drawing-pens, if the ink should become thick, and cease to flow freely.

A steel file, for bringing the black-lead pencil to a very fine point. One end of this file terminates in a penknife blade for mending pens and cutting pencils. The other end is a key, or screw-driver, for adjusting the friction in the joints of the compasses; because the joint of the dividers for measuring, should move very freely, while that of the large compasses for drawing circles should be rather stiff.

A small parallel ruler.

A sector and a protractor, either semicircular, or in the form of a ruler, in which last case the scales of equal parts, and a line of chords, are usually engraved on the instrument, (in addition to the radiating lines,) for measuring the degrees of angles. When a semicircular protractor is put into the case, a separate ruler is necessary for containing these scales.

51. With the exception of the divided scales and ruler, all the above described drawing instruments are most conveniently combined in a very small and portable form, in what are called the Engineer's folding pocket compasses; an instrument of such utility, that it ought to be in the pocket of every Engineer. But as this instrument is not yet very common, a short description of it may be useful. Its form is shown in *Fig.* 4, *Plate I.*, of the actual dimensions in which it is generally made. The instrument, when opened for use, has the appearance shown in the figure, and is nothing more than an ordinary pair of compasses with two sharp points, except that there is a joint in each leg at *a* and *b*, upon which joints the points turn inwards, so that they can both be put into the positions shown by dotted lines at *c*, when the compasses are closed or shut up, and then they may be carried in the pocket with as much safety as a pocket penknife. When the compasses are opened out, they are ready for taking measurements upon a drawing or from a scale, or for scratching circles. The two legs, *d d*, of the compasses are hollow tubes, and the joints *a* and *b* slip into those tubes and carry the other necessary points of the compasses. Thus, upon drawing the joint *a* out of its tube, a crayon socket and bit of black-lead pencil will be found in it, and by reversing this, or pushing the sharp compass point up into the tube, and leaving the pencil projecting, the compasses are prepared for drawing circles with pencil. The other joint *b*, in like manner, carries a drawing-pen for ink, so that by reversing this point we have compasses with an ink point.

Either or both the joints may be wholly withdrawn from the compasses, and, if bent, the one becomes a bow pen with a pencil, and the other with an ink point; while, on the contrary, if the two shifting points are made straight, one can be used as a black-lead pencil, and the other as a drawing-pen for ink, while either steel point of the compasses may be used as a pricker: so that this little instrument combines in itself an entire case of instruments, in the smallest possible space, and at about one-third of the cost that the instruments would amount to. As the legs of these compasses are not straight when quite open, and the points may be bent inwards, this instrument so used becomes a pair of calliper compasses, for taking the exact diameter of spherical or cylindrical solids, being a measurement very frequently required by the Engineer. And as a small ivory scale, no larger than the compasses, containing lines of inches and equal parts, and a line of chords, may be made and put up in a case with a pair of these compasses, the Engineer possessing them will find himself equipped with all the instruments necessary for making every drawing on a small scale, where expedition is not an object. But in the office, larger and more expeditious instruments are of course desirable.

52. There are many more instruments used in drawing, but they are not, like the foregoing, absolutely essential to the young Engineer. Some of these will, however, be described, when treating of the purposes for which they are particularly intended. For the present it will be sufficient to observe that a set of plotting scales is merely a set of ivory rulers, both edges of which are thin or *feather edged*, and each edge has one scale of equal parts engraved upon it and divided decimally. Each ruler therefore contains two scales, and, consequently, the usual set of six rulers contains twelve different scales, the principal divisions of which are meant to represent chains, and the smaller ones links, as these scales are only used in maps or surveys of land. Each ruler is usually about a foot long; and as the divisions are upon the extreme edge, they are very useful and expeditious, both for drawing maps or plans of land, or for measuring such as have been previously made without the use of compasses, for the measurements are made by applying the scale directly to the paper.

53. Beam compasses are for drawing circles or arcs of very large radius, which sometimes occur in making drawings, particularly of bridges, and need never be used unless the radius is so long as to make it beyond the stretch or opening of common compasses. The beam compass derives its name from its mode of construction; for this instrument consists of a long and straight beam or bar of wood or metal, usually from one to four feet in

length, with a steel point fixed at one of its ends at right angles to the length of the bar, to serve as a centre, and a sliding socket that moves along the bar, and can be fixed upon it by a milled screw at any required distance from the last mentioned point or centre. This sliding socket carries shifting points similar to those of other compasses, viz: a sharp steel point, a pencil point, and a drawing-pen for ink, so that these compasses may be used with the same facility as other compasses, both for measuring distances and drawing circles; and as the top, or one of the sides of the long bar, is graduated to inches and tenths from the fixed point or centre, any dimensions of radius may be very readily obtained.

54. Should the student be desirous of tinting or colouring his drawings, he will require, in addition to the articles above enumerated, a small box or case of water colours, with a few camel's hair brushes, or pencils, as they are generally called. Such colour boxes, with the colours in square cakes prepared for use, may be purchased in all large towns; and to use them, nothing more is necessary than to rub the end of the cake of colour in a few drops of clean water, previously applied by a brush on the surface of a common dinner plate, when a sufficient quantity of colour for present use will soon be obtained. About six cakes or varieties of colour will be sufficient for the purposes of the Engineer and Surveyor, and the most essential are light red, lake, Prussian blue, yellow ochre, gamboge, and burnt umber. Brick-work is generally coloured with light red, and any additions or alterations to it with lake. Pine timber is usually coloured with gamboge, and oak or hard timber with yellow ochre, or that colour mixed with burnt umber. Wrought iron is coloured with Prussian blue, and cast iron with that colour mixed with Indian ink, which is not mentioned in the above list, on account of having been referred to among the essentials. Brass is marked by either of the above yellows. In Plans, roads are tinted with burnt umber; water with Prussian blue; and all the various tints of green, both light and dark, for grass land, trees, hedges, and fields, may be obtained by making mixtures of Prussian blue with gamboge or yellow ochre, or with both. In fact, practice and experience will show the young artist that by combining or mixing the above six colours with Indian ink, in proportions that can only be ascertained by practice, he will be able to produce almost every tint he can require, for the white paper is always left to produce a light or white appearance.

55. In locations where colour boxes cannot be procured with cakes of colour, the unprepared colours can generally be obtained in a state of powder at the drug stores; but, if used in this state, it is necessary to mix them with very weak gum water, or a solu-

tion of gum arabic, instead of with simple water, or they will all rub off the paper as soon as they become dry. If the paper has from any cause become a little greasy, though not to such an extent as may be visible, the colours will not lie or spread upon that part of the paper, unless a little of the gall of the ox is mixed with the water. Ox gall may be obtained at any slaughter-house, and if thinly spread upon the bottoms of dinner plates, it may be dried in the sun and will keep good as long as it is kept dry. When wanted, it is soluble in water, in which a little pot-ash or salt of tartar has been mixed. Infusion or solution of Spanish liquorice, and of tobacco, also make very good general brown tints, and are often resorted to even by artists in cities who have the command of every colour.

56. In order to varnish a drawing to preserve it from injury, it must first be pasted down upon a smooth board, pasteboard, or piece of cloth tightly strained upon a frame. The whole face of the drawing must then be covered over thinly and evenly with strong gum water. Its strength should be such, that when dry it may produce a uniform gloss, or slightly shining effect over the whole drawing or print without cracking. The use of this gum water is to destroy the absorbent quality of the paper, and prevent the varnish from sinking into it; because, if it does so, it will discolour the paper and give it the appearance of having been greased with oil, and these stains cannot be removed, if once produced. When the coat of gum water is quite dry, one or two coats of white spirit varnish, or best copal varnish, may be laid over the gum, and the surface when dry will shine as if glass had been put over the picture; and should it become soiled, it may be washed with water at any future time, without fear of injuring it. Both the gum water and varnish should be laid on with a large soft brush; and wide flat brushes are made and sold for this express purpose, under the name of varnishing brushes. Varnishing ought not to be attempted in cold damp weather, as the success of the operation depends in great measure upon the rapidity with which the varnish dries. It dries best in the sun-shine in open air, and if that cannot be obtained, the varnished piece ought to be set at a good distance from a fire in a warm room, until it is quite dry.

57. Having so far explained the use of the instruments or implements to be used in drawing, our next attempt will be to give the student some insight into the manner of copying drawings, for this is an occupation that generally falls to the lot of the assistants in the Engineer's office, and it is of great importance that facility, accuracy, and expedition, should be acquired in this branch of business.

Drawings are copied by various processes thus,—the copy is made of the same size as the original:

1st. By eye inspection and measurement.

2ndly. By pricking through, and drawing from one point to another; and

3dly. By the aid of tracing, or tracing-paper, and camp-paper.

Drawings are copied of greater or less dimensions than the original.

4thly. By eye inspection, and proportional measurement, which is most easily effected by an instrument called the *proportional compasses*, hereafter described. (93.)

5thly. By proportional squares; and

6thly. By an instrument for the purpose, called a *Pantagraph.*

The first and fourth processes of copying drawings are of the highest character, as requiring more skill and attention than any of the others, and are those in which the young draughtsman ought particularly to practise himself; because when he has acquired facility in this kind of drawing, he will experience no difficulty in any of the others.

58. In the first kind of drawing, it is understood that the draughtsman having prepared his paper on a drawing-board, sets the original before him, and by looking at it, and taking certain measurements from it, that he is to produce a fac-simile not only as to appearance, but to measurement and every other particular.

Suppose the drawing to be copied is a building, it will first be necessary to draw a horizontal line near to, and parallel with, the bottom of the paper, to represent the base of the building or place where it touches the ground. Then the distances of the upright corners of the house from each other, and from the sides of the paper must be measured on the original with compasses, and those distances be transferred to the horizontal line. Upon each of these points, perpendiculars to the base must be raised, and this may be done by the triangular square or T square. (30 and 31.) The positions of the two sides of each window and door are obtained and laid down in the same manner, and long pencil lines drawn to indicate their relative positions in respect to the horizon, without any regard to their height. Next the heights of all the windows must be measured and transferred in like manner, and lines ruled through all these points parallel to the first horizontal line. This may be done by the square or T square, applying its stock to the side of the drawing-board, and the top horizontal line of the building is so obtained. Next come the sloping lines of the roof, which are not parallel to either side of the drawing-board, and consequently cannot be obtained in the same way. To get the direction of these lines, the angles they make with each other, or with other lines previously obtained, must be measured by the protractor, and are transferred by laying down similar angles on the copy by its means; or they may be transferred at once by using the T square with a shifting stock. (31.) This slight view of this kind of drawing will convince any one that some knowledge of geometrical figures will greatly facilitate the progress of the learner—and such knowledge, it is to be presumed, has been previously obtained by those who embark in the Engineering profession. But as mathematical principles are generally taught in schools and colleges with chalk on the black board, and precepts rather than mechanical accuracy are alone aimed at, drawing instruments and that precision of measurement requisite in good mechanical drawing are wholly neglected. Notwithstanding, therefore, the principles of the few examples about to be offered must be obvious to most persons who will take up this volume, yet the practical operation of working or constructing them on paper with care and precision is strongly recommended to all students as a useful exercise. The examples are few, and are only such as are likely to occur in constructing original drawings, or in copying representations of things by the first and fourth methods of copying before referred to, viz: that of simple inspection and measurement. The methods of drawing or constructing curves, and many other geometrical figures, will be given in the course of the work, but it was thought better to describe them where their applications occur, than to enlarge the present chapter with subjects, the use of which would not now be apparent.

59. No demonstrations either of the problems immediately following, or of those that occur in other parts of the work will be given. They would swell its dimensions very unnecessarily, because it does not profess to teach mathematical principles, but only to show some of their applications. Mathematical knowledge must be derived from other sources, and if it is possessed, the addition of the demonstrations will form an agreeable praxis for the student, and may be insisted on or not at pleasure by the Teacher who uses the book.

USEFUL PRACTICAL PROBLEMS IN GEOMETRY.

Problem I.—*Fig.* 5, *Plate I.*

60. *To divide a given line A B, into two equal parts, without the loss of time attendant on making many trials with the compasses to find its central point.*—From the points A and B, (or ends of the given line,) as centres, and with any opening of the compasses, greater than half the length of the line, describe arcs of circles, cutting each other in *c* and *d.* Draw the right line *c d,* and the point *e,* where it cuts A B, will be the middle required.

Problem II.—*Fig.* 5, *Plate I.*

61. *To raise a perpendicular on the centre of a right line.*—This operation is precisely the same as the last, although with a different object. Because the point *e* is the centre of the line A B, and the new line drawn through the two points of intersection *c* and *d,* will not only cut the line into two equal parts, but will be perpendicular to it at its central point *e.*

Problem III.

62. *To raise a perpendicular on any given point of a line A B, such point not being the centre of that line.*—This is another instance of the same operation; for, although the given point is no longer supposed to be in the centre of the given line, yet we must make that point the centre of a short portion of the given line selected for the purpose. Thus, *Fig.* 5, *Plate I.*, suppose A B to be the given line, and that this line is unevenly extended at its two extreme ends, so that the given point *e,* shall no longer be in its centre. The first operation must be to measure and set off two equal distances, *e* A and *e* B, upon the given line, by which the points, A and B, are obtained; and these points are now used as centres for describing the arcs and obtaining the intersections *c* and *d,* when the proceedings are as in the two last problems.

Problem IV.—*Fig.* 6, *Plate I.*

63. *To raise a perpendicular upon the extreme end of a line.*—Let C D be the given line, and D the point upon which the perpendicular is to be raised. Select any point, *f,* at a moderate distance above the line, and from the end D. Then with radius *f* D, describe the arc *g* D *h,* touching the end of the given line at D, and cutting it at *h.* From the intersection at *h,* draw the

line *h g*, passing through the point *f*, and continue it until it intersects the arc at *g*. Then through the points *g* and D, draw the line *i* D, which will be the perpendicular required.

Problem V.—*Fig.* 7.

64. *From a given point, out of a line, to let fall a perpendicular upon that line.*—Let *k* be the given point, out of the line E F. From the point *k*, with any radius greater than its distance from the line E F, describe the arc *l m*, intersecting the line at these points, and from them, with any convenient radius, describe two other arcs below the line which cross each other at *n*. Lastly, draw the line *k o* from the given point, through the intersection at *n*, and it will be the perpendicular required.

Problem VI.—*Fig.* 8.

65. *To draw an angle equal to another that is given.*—Let *r s t* be the given angle, and upon its point, or apex *s*, as a centre, with any convenient radius describe the arc *v w*, cutting both legs or lines of the given angle. That done, draw a line *z y*, in any position, to be the representative of the line *t s*, in the given angle, and fix the point *y*, which is to be the apex of the new angle about to be produced; on this point as a centre, with radius *s v*, describe an arc *a b;* measure the chord or distance *v w*, and transfer that distance from *a* to the arc at *b*, and it will give a point *b*, through which draw the line *x y*, and the new angle will be complete.

Problem VII.

66. *To divide a right line into a required number of equal parts, without the loss of time attendant upon stepping over it, (probably many times,) with the compasses, for that purpose.* —Let G H, *Fig.* 9, be the given line, which is required to be divided into seven equal parts. From G, draw a line G *p*, making an acute angle with the line G H; then from H, draw another line H *q*, making an equal angle with the first, but on the opposite side of the given line; then, with any convenient opening of compasses, set off the required number of equal divisions upon either or both of the lines G *p*, or H *q*, as at 1, 2, 3, 4, 5, &c., commencing from the angular points G or H: join the last of such divisions to the end of the given line as by the line 7 H, and rule lines parallel to this first line, through each of the divisions 6, 5, 4, 3, &c., and the points where these parallel lines intersect the given line G H, will be the equal divisions sought.

Problem VIII.

67. *To measure and transfer any angle by the Protractor.* (42.)—Cause the diameter of the protractor, or the edge that carries the centre of its circle, to coincide exactly with either of the lines forming the angle to be measured. Shift the instrument laterally, until the point, or mark, that indicates the centre of the circle, touches the apex of the angle, when the other line of the angle will be found projecting beyond the graduated edge of the instrument, and the division and number that lies immediately over that line, will be the measure of the angle.

Note.—In practice it frequently happens that one of the lines, or legs of the angle, may not be long enough to project beyond the instrument, which will, therefore, hide it from view. In such case, that line must be carefully lengthened with a pencil and ruler, until it can be seen. This will not disturb the accuracy of the operation, since the lines, which form angles, may be indefinitely long or short, without affecting the measure of the angle, while their relative position remains unchanged.

In order to copy, or transfer, any given angle by means of the protractor, that angle must first be measured, as above described. A line must be drawn to represent one side of the angle, and the position of its apex must be fixed in such line. The centre of the protractor is then placed over the apex, its diameter is made to coincide with the line, and a dot, or mark, must be made against that division, which before marked the measure of the angle. The itstrument is now removed, and a line being drawn from the dot to the point fixed for the apex, will produce the similar angle required.

Problem IX.—*Fig.* 8.

68. *To measure and transfer any angle by a line of chords.*—A line of chords is usually engraved on some of the scales belonging to drawing instruments, (see *Fig.* 3,) and its use may be explained by *Fig.* 8. Instead of drawing the arc *v w* with random radius from centre *s*, we must, when using the line of chords, take the distance from 0 to 60° upon the scale in our compasses, and strike the arc *v w* with that radius. Then measure the chord or distance between *v* and *w*, and transferring that distance from the commencement of the scale, the number of divisions in that space will be the measure of the angle.

To transfer or lay down any given angle, the same process must be resorted to in a different order, viz: Draw the line *z y*, and upon its end *y*, as centre, with radius of 60°, taken from the scale, describe the arc *a b*. Then measure off the required number of degrees for the angle upon the scale, and transfer it to the arc from *a* towards *b*, and thus the point *b* will be obtained, through which and the point *y* draw the line *x y*, and the angle required will be produced.

PROBLEM X.—*Fig.* 10.

69. *To bisect or divide a given angle c d e into two equal angles.*—From the point *d*, with any radius, describe the arc *c e*. From intersections *c* and *e* with the same, or any other radius, describe arcs cutting each other in *f*. Draw a line through *d* and *f*, and it will bisect the angle *c d e*, as required.

PROBLEM XI.—*Fig.* 11.

70. *Through a given point g, to draw a line parallel to a given line h i.*—Assume any point *k* in the given line *h i*, taking care that it is not immediately above or below *g*, but at a convenient lateral distance from it. Then upon points *g* and *k* as centres, with radius *g k* describe the arcs *k l* and *g m;* make these two arcs equal in length, which will fix the point *l*, through which and *g* draw the line *l g*, which will be parallel to *h i*, as required.

71. *When the new parallel is to be at a given distance from the given line n o*, *Fig.* 12.—Assume two or more points, *p q*, in the given line; then with radius *p r* equal to the required distance of the two lines, describe as many arcs upon points *p q*, and as centres, as may be necessary. Make the line *r s* a tangent to all these arcs, and it will be parallel to the given line.

The operation of the common parallel ruler is referable to this principle.

PROBLEM XII.—*Fig.* 13.

72. *Upon a given line t v, to construct an equilateral triangle.*—Upon the points *t* and *v*, being the ends of the given line, and with radius equal to *t v*, describe two arcs, cutting each other in *w*; draw *t w*, and *v w* and *t v w* will be the triangle required.

PROBLEM XIII.—*Fig.* 14.

73. *To find the centre of a given circle, or of one already described.*—Draw any chord *u x* and bisect it with a perpendicular *y z*, running quite across the given circle; bisect this perpendicular as at *a*, and that point will be the centre required.

PROBLEM XIV.—*Fig.* 15.

74. *To draw a circle through any three given points, provided they are not in a right line.*—Join the three given points

b, c and *d* by right lines, and upon the centre of each of such lines erect perpendiculars, (Prob. II.) which will intersect each other in *e*, the centre of the circle; therefore, from *e* as centre, with radius *e b* or *e c*, &c., describe the circle required.

Problem XV.—*Fig.* 16.

75. *To describe the segment of a circle of any required length and height.*—Draw the line *f g* equal or proportionate to the required length of the segment, and bisect it by the perpendicular *k h*. Set off the required height from *i* to *k* in this perpendicular, and join *k f*. Bisect *k f* by the perpendicular *l h*, continued until it intersects *k h*, when the point *h* will be the centre from whence to describe the segment *f k g*, with radius equal to *h f*.

Problem XVI.—*Fig.* 17.

76. *To draw a tangent to a given circle that shall pass through a given point m.*—From the centre *n* draw the radius *n m*, and through the point *m* draw *o p* perpendicular to *n m*, and it will be the tangent required.

Problem XVII.—*Fig.* 18.

77. *To draw a tangent to a circle or segment at any given point q, when the place of the centre is not known.*—Measure off any two equal arcs *q r*, *r s*, upon the circle beginning from the given point *q*, and draw the chord *q t s*. From *q* as centre, describe the arc *t r v* with radius *q v*; make *v r* equal to *t r*, and through *v* and *q* draw the line *r q u*, which is the tangent required.

Problem XVIII.—*Fig.* 19.

78. *To describe a regular octagon in a given square w x y z.*—Draw the diagonals *x y* and *w z*, intersecting at *a*. Upon the four points *w*, *x*, *y* and *z* as centres, with radius *w a*, describe the arcs *b a c*, *d a e*, *f a g*, and *h a i*. Join *i b*, *d g*, *c h* and *e f*, and thus form the required octagon.

Problem XIX.—*Fig.* 20.

79. *In a given circle, to describe any regular polygon.*—Divide the circumference of the circle into as many equal parts as there are sides in the polygon to be produced, as at *k*, *l*, *m*, *n*, *o*, *p*, and unite these points by right lines, when the figure will be complete.

80. *Note.*—This is called a polygon inscribed in a circle. If a circumscribed polygon is required, or one constructed round

the outside of the circle instead of within it, draw radial lines from the centre of the circle through each of the points *k*, *l*, *m*, &c., letting them project beyond the circle; then draw lines from one of these radii to the other, parallel to the sides of the inscribed polygon, and touching the circle like tangents, when a circumscribed polygon will be produced.

The inscribed hexagon requires no division of the circle, because radius may always be taken for one side of the polygon.

For an easy mechanical process of setting out polygons, see *Proportional Compasses*, near the end of the present section.

Problem XX.—*Fig.* 21.

81. *To make a triangle whose sides shall be equal to three given lines q r s, any two of them being greater than the third.*—Draw *t v* equal to the line *q*. Upon *t*, with radius equal to the length of line *s*, describe the arc *u w;* and upon *v*, with radius equal to the line *r*, describe another arc *x u*, intersecting the first arc in *u*. Join *u* and *t* and *u* and *v*, and *t u v* will be the triangle required.

Problem XXI.—*Fig.* 22.

82. *To make a trapezium, a b c d, equal and similar to another given trapezium, e f g h.*—Divide the given trapezium *e f g h* into two triangles by drawing the diagonal *e h;* make *c d* equal to *g h*. Upon *c d* construct a triangle *a c d*, equal and similar to the triangle *e g h*, (by the last problem,) and upon *a d*, which is equal to *e h*, construct the triangle *a b d*, equal and similar to *e f h*, and the figure *a b c d* will then be produced, which is the trapezium required.

Note.—This is a most useful and important problem, as by its means any plan may be copied; because every figure, however irregular, may be divided into triangles, and it is in this way that the irregular forms of fields in land surveying are measured and their quantities computed.

Problem XXII.—*Fig.* 23.

83. *Two right lines being given, to find a third proportional thereto.*—Let AB and CD be the two given lines; make an angle HEI at pleasure; from E make EF equal to AB, and EG equal to CD, and join FG; make EI equal to EF, and draw HI parallel to FG, then EH will be the third proportional required; that is, EF : EG :: EH : EI, or AB : CD :: CD : EI.

Problem XXIII.—*Fig.* 24.

84. *Three lines being given, to find a fourth proportional.*

—Let AB, CD and EF be the three lines given. Draw GH and GI, making any angle HGI; make GH equal to AB, GI equal to CD, and draw HI. Make GK equal to EF; draw KL through K parallel to HI; then GL will be the fourth proportional required; that is, GH : GI :: GK : GL, or AB : CD :: EF : GL.

PROBLEM XXIV.—*Fig.* 25.

85. *To find a mean proportional between two lines given.*—Let AB and CD be the two given lines. Prolong AB by the length of CD; or draw a new line EF equal to AB, and prolong it from F to G by a quantity equal to CD. Bisect this compound line as at H, and from H as centre, with radius HE or HG, describe the semicircle EIG; and lastly, raise a perpendicular on the point F, (where the two lines meet,) cutting the semicircle at I, when the line FI will be the mean proportional sought.

86. When the student has acquired a facility in working the above problems, it is presumed he will find no difficulty in copying drawings by the first process before referred to, (57,) or even in making original drawings, because the above rules will furnish the means of producing all such forms as usually occur in drawings, with the exception of the ellipse and some other curves that occur in the arches of bridges and formation of tunnels, and which will be described in that part of this work which treats upon those subjects.

87. The second process of copying drawings of the same size and appearance as the originals, by pricking through them, is so simple as to need no description; but a few observations upon the mode of executing it may be useful. It requires no skill; and from its facility and the expedition with which copies are made by its means, it is the method most frequently resorted to in the office of the Engineer and Architect.

The sheet of paper intended to receive the copy must be properly stretched upon a drawing-board, (20,) and the print or drawing to be copied has to be laid over it in a proper position, so as to bring that which has to be drawn fairly into the middle of the prepared sheet of paper. That done, lead weights (31,) must be disposed at the corners, sides, and other parts of the copy which contain no part of the figure, for the purpose of retaining it securely in its place. The paper, or paper and drawing-board, should be rather larger than that which has to be copied; not only to prevent injury to the original, but likewise to admit of pencil marks being made in several places on the extreme edges of the original, half of them being upon it, and the other half upon the paper below. These marks are quite essential, and should be made with great care and accuracy. Their use is to indicate whether the original has shifted from its place during the process of copying; a circumstance that must be carefully guarded against, because, should it happen, the work will be spoiled, unless the original is brought back to its first position, which may be accurately done by these marks; and likewise to permit the draughtsman to examine his work in progress, by occasionally lifting up the original. This should never be done, except on suspicion of a mistake or for some cogent reason; and if the marginal marks are not made, all the former labour will be thrown away, as the original can never be correctly reinstated in its former position.

88. The original drawing having been properly placed over the paper, the pricking may commence. This, as before observed, should be done by a fine sewing needle, fixed in a handle, (43). A hole must be pricked through every angle and intersection of lines in the original drawing; but circles, or parts of them, should never be pricked, if their centres are known. Marking the centre is sufficient and better, and afterwards putting in the circles with compasses by actual measurement; but all irregular curves that cannot be drawn with compasses must be pricked at regular small intervals. If the centre of a circle is not marked, three dots made in its circumference will be sufficient for finding the centre by Problem XIV. During the whole operation the needle should be held vertically, to insure that the holes in the paper shall be exactly under the corresponding points in the original. In pricking a drawing, the draughtsman must not run from one part of the original to another; because if he does so, he will get into confusion, and probably leave many essential points unmarked. A regular system of work should therefore be adopted; and the best is to divide the original into horizontal stripes, either by ruling lines across it at every one, two, or three inches apart, according to the intricacy of the drawing, or else to place a flat ruler upon the drawing, exposing a certain quantity above it, and then to begin at the left hand top of such space and proceed regularly to the right hand side, taking care to mark every important part as it occurs in that space. After examining it carefully to see that every point is marked, the ruler may be shifted downwards to expose a new strip, and that must be gone over from left to right in like manner; and so on until the whole drawing is marked, when the original must be taken up and placed before the draughtsman, who now has to find out the marks he has been making on his paper, and their correspondence with each other and with the original. Some difficulty frequently occurs in finding the marks at first, because if they are not very fine and small they will disfigure the drawing; but as soon as a

few lines of connexion are drawn among them, that difficulty will vanish. The first lines of connexion are best drawn by hand, with a very soft lead pencil, and they should be very faintly marked, as errors often occur in the first union of the points; but so soon as the general outline of the figure is got in, the places of the points will become obvious, and the drawing-pen and ruler may be resorted to for putting in every thing in its proper place.

89. It need scarcely be observed that, if more than one copy of the same drawing is required, the pricking may take place through two, or even three sheets of paper, properly fixed down, at the same time, by which much time and labour will be saved. When the original is done with, it should be laid with its face downwards upon a smooth drawing-board, and the burs of the holes made in pricking be rubbed down with the back of the thumb nail. This will close the holes so effectually as to make them almost disappear. The same operation must be performed upon the copied drawings, after the principal lines are got in and the holes are done with.

90. The third process for copying drawings of their real size is by tracing-paper, and this is very frequently resorted to on account of its expedition, when the beauty of the copy is not regarded, and the artist merely wishes to preserve a copy for his own use. Tracing-paper is large and thin paper, rendered transparent by being coated with some oil or varnish, and kept until perfectly dry, so that one sheet will not adhere to another. It is sold in such stores as provide drawing implements, and generally at a much higher price than its production warrants. It may be very well made by providing large and tough thin paper, and anointing it as thinly as possible on both sides with cold drawn linseed oil, applied with a rag, and afterwards hanging up the sheets separately by one corner pinned to a line. The superfluous oil will drip off from the lowest angle, and in a few weeks of fine summer weather the sheets will become sufficiently hard and dry for use, and may be kept flat in a portfolio. Good tracing-paper will receive the marks of pencil, ink, and even colours, without difficulty.

91. To copy a drawing by tracing-paper, nothing is necessary but to fix it in a flat position by a drawing-board or lead weights, placing a sheet of tracing-paper over it. That paper should be so transparent as to permit every line and mark of the smallest kind in the original to be seen through it, consequently all such marks can be traced or gone over with a black-lead pencil or pen and ink; which done, the tracing paper is removed, and will be a fac simile of the drawing copied. Having a tracing, it furnishes the means of producing a finished drawing at any future time,

because the tracing can be strained over a clean sheet of paper, and be pricked through like any other original drawing. Or it may be transferred to the clean sheet without pricking, by what some writers call *camp*, and others *transferring-paper*.

92. Transferring-paper is thin paper, like that used for tracing, but not prepared with oil or varnish; one side of it is rubbed over with a solid lump of black-lead, or of red or black chalk, which must afterwards be sufficiently wiped off again to prevent its soiling the paper on which it is laid. A sheet of paper so prepared is laid with its coloured face downwards upon the paper strained to receive the copy, and the tracing placed above all, when the whole must be kept in their places by weights. The lines of the tracing are next gone over by an ivory point, or the obtuse end of the brass drawing-pen, which is prepared for that purpose, (50,) using sufficient pressure to cause the black-lead or other pigment that has been put upon the transferring-paper to leave marks or corresponding traces upon the paper which is to receive the copy. A perfect drawing cannot be obtained in this way, but a fac simile as to proportion and position will be produced, in a sufficiently accurate manner to enable the draughtsman to finish it up, from the original, with much less labour than would otherwise be required.

93. Camp-paper is only a variety of transfer-paper, prepared with lamp-black ground up with hard soap, and is used in the manner above described: but inasmuch as the lines produced by it are black and appear like those of a copperplate print, and cannot easily be effaced, this paper is never used when the copy has to be worked up and finished by hand so as to produce a perfect drawing.

94. When drawings or prints have to be copied of a different size from the original, whether larger or less, it will be evident that none of the above described processes can be resorted to. The first and most difficult mode of proceeding in this case, is by eye-inspection and proportional measurement. This kind of drawing has its foundation in what are called in geometry, similar and proportional figures; because the enlarged or diminished representation must contain all the same parts as the original, and all these parts must be in the same ratio, or proportion to each other, that they bear in the original. Of course, no assistance can be rendered to this kind of drawing; but each line and part must be laid down in succession, by separate measurements. The easiest way of proceeding is to use two scales of equal parts, (48,) one fitted to the original, and the other to the copy to be made. Thus, if the original is made to a scale of one inch to a foot, and we desire a copy of half size, or double size, we must use scales

accordingly. The length of each line, in the original, must be taken with compasses, and transferred to an inch scale, to determine its value; that done, the same quantity has to be sought in the half inch or two inch scale, as the case may be, for the length of the line that is to represent the first. In like manner, all lines that make angles with each other, must have those angles measured and transferred, by some of the rules herein before given, so that there is nearly as much trouble in copying a drawing to new dimensions, as in making an original one.

95. If a drawing has to be diminished to half, or increased to double the dimensions of the original, the operation is much facilitated by a kind of double pointed compasses, called *Wholes and Halves.* They are formed exactly like common compasses, except that instead of terminating, as they do, in a head or joint, they have opposite legs and points beyond the joint, or, in other words, the joint is intermediate between two pair of compasses, formed by two rods of metal, crossing each other at the joint. One pair of legs is made exactly twice as long as the other, consequently in opening and shutting them, the points of the long legs will move through exactly twice the quantity of space that the short ones do, so that if they are used to diminish a drawing to half its size, all dimensions are taken from the original, by the long pair of legs, and those dimensions are transferred to the copy by the short legs. On the contrary, when using the instrument to enlarge a drawing, the points are used in an exactly opposite manner.

96. The most useful and convenient instrument for copying drawings, with varied dimensions, is the *Proportional Compasses,* the most approved form of which is given at *Fig.* 26 of *Plate I.* They consist of two steel points *a a,* attached to two flat cheeks of brass or silver, *b c.* These cheeks, and the steel points, are both exactly alike in form and dimensions, so that they coincide perfectly when laid over each other. *d d d d* Is a long perforation made through both the metal cheeks, and in which a double sliding piece *e,* of a peculiar construction, slides freely from one end to the other, and can be fixed in any required position by the milled screw *f.* The peculiarity in the construction of the central sliding piece *e* is, that although it slides freely in the long perforation *d d,* which is dovetailed, to prevent separation of the two plates, and can be fixed in any required position by the milled head *f;* still, when so fixed, it does not interfere with the free motion of the two cheeks, *b* and *c,* over each other, when they are moved upon the screw *f,* as a pivot or centre of motion, consequently the two points *a a,* can be used like those of a common pair of compasses. The two points *g g,* are of steel, and

are two other points of these compasses, and it will be evident that if the pivot *f* is brought into such a position that it shall stand exactly half way between the points *a a* and *g g*, equal degrees of motion will take place at both ends of the compasses whenever they are moved. If, again, the pivot is so placed that its distance from *g g* shall be exactly half that from *a a*, then the instrument becomes a pair of Wholes and Halves, like those last described. As, however, the pivot has no fixed place but that which is assigned to it for the time being, it is evident that by duly placing it in respect to distance between the points *a a* and *g g*, every possible proportion, between the opening of the two sets of points may be obtained; and, consequently, dimensions may be taken, and drawings copied by this instrument in every required proportion to each other that the range of the instrument admits of.

97. To insure the proper placing of the central pivot to produce these effects, one side of one of the cheeks is divided into a number of unequal parts, numbered 1, 2, 3, 4, 5, 6, &c., and headed *lines;* and a line is engraved upon the sliding piece *e*, which has to be brought into coincidence with such of the divisions as may be required, keeping in recollection that when the mark is set against No. 1, the joint is in the common centre of the whole instrument, and the legs of both the compasses are of equal length. When set against No. 2, their respective lengths are as 1 to 2, consequently the instrument will be prepared for making a copy of half the size, or double the size of the original. When against No. 3, No. 10, or any other number, the respective lengths of the legs will be as 3 to 1, or as 10 to 1, and so forth; and, consequently, will give lengths at the two ends proportionate to such numbers.

98. The opposite side of the cheek, that is divided for lines, carries another engraved scale of more nearly equal parts, headed *circles*, the lowest division of which is numbered 6, and corresponds with No. 1, on the opposite scale. This scale is for the purpose of producing regular polygons of from six to fifteen sides and angles; and to use this scale, set the mark upon the slider *e*, opposite that number in the scale marked circles, which agrees with the number of equal parts into which any circle has to be divided. Then take the radius of that circle between the points *a a*, and the points *g g* will be at the right distance for stepping round the circumference of the circle, to divide it into the required number of parts.

99. The instrument is complete as above described; but in using it, there is great danger of the points, (especially the longest ones,) getting shifted from their places, in handling and transferring the distances. To remove this inconvenience, all the best

proportional compasses have, in addition to the parts already described, a fixing bar and adjusting screw, shown at *h*, *i*, *k*, *n*, in the figure. By releasing the small screw at *n*, the points *a a* are free to move for taking any dimensions. Having obtained it, the screw *n* is tightened, which renders the points immovable, except by the milled head *h*, connected with a fine adjusting screw *i*, by which the points may be adjusted in distance with the greatest nicety. When the instrument is not in use, the screw *n* is taken out and placed in a hole for the purpose, in the centre of the principal nut *f*, and the adjusting bar is carried with it and fixed parallel to the cheeks, when shut up, so that the instrument then assumes a very compact and portable form.

100. Great care is necessary in the use of this instrument, that none of its four points may be broken; for if this should happen, they cannot be re-sharpened, as in common compasses, without destroying the proportional length of the legs of the instrument, and rendering the divisions upon the cheeks useless. The broken point must be lengthened by a competent workman before the instrument can again become useful.

101. A less laborious, and more common method of altering the relative magnitude of drawings when copying them, is to make use of proportional squares, a process well known to, and much used, by artists of all denominations. It consists in covering the original that has to be copied, with small squares produced by drawing a number of equidistant lines parallel to each other, and to the top or bottom of the picture, and crossing these by similar lines at right angles to the first. The size of these squares must be regulated by the magnitude of the picture to be copied, and the intricacy of the objects it represents. Having prepared the original with such squares, the paper intended for the copy must be prepared in the same way; that is to say, must be crossed by the same number of lines, and be thereby divided into the same number of squares. If the copy is to be of the same size as the original, then the squares upon both must be of the same size. If, on the contrary, the copy is to be diminished to one half, or one quarter, or in any other proportion, the squares upon the copying paper must be one half, or one quarter, or in the required proportion, less than the size of the squares on the original; while, if the copy has to be enlarged, the squares for copying must be made as much larger than those upon the original, as the dimensions of the copy are meant to exceed it. In all cases each line upon the original must have a number placed against it, beginning from left to right at the top, and from top to bottom at the side of the picture, and the corresponding lines upon the copying paper must be

marked with corresponding numbers. Things being thus prepared, the draughtsman sets the original before him, and noticing all lines or marks that occur in the first square, or that formed by the intersection of the lines Nos. 1 and 1, he inserts those same marks in the corresponding square of his copy. The square formed by the vertical lines 1 and 2, and horizontal line 1, is next copied in, and so of all the others in succession, until the entire copy is made.

102. When inserting the lines or marks into the copy, great attention must be paid to placing them in the same relative positions in the copy square that they occupy in the original one. Thus, if a line occurs in the middle of any square in the original, it must be placed in the middle of the corresponding square of the copy. If near the top, bottom, or side of a square, a similar position must be given to it when transferred, and thus will the relative position of every part be preserved. These relative positions may always be guessed at by the eye without measurement, if the squares are sufficiently small; and should that not be the case, the squares must be diminished by drawing intermediate lines through them, either in one or both directions, so as to divide each square into two parallels, or four smaller squares: but those who cannot thus divide by eye may use compasses. Neither is it necessary that the original and copy should be covered with *exact squares* for parallelograms or rectangles, the sides of which are not equal, for even mere parallel lines will in many cases suffice for producing copies. This rule must, however, be attended to, that in whatever manner the original is divided, the copy must be divided in the same manner, and in the same proportion one part with another, and into the same number of parts, otherwise the copy will become a distorted instead of a correct resemblance of the original. Engravers and others who have to copy and reduce a great number of pictures, usually provide themselves with slight wooden frames, divided into squares by threads stretched across them. Such frames not only save the time that would be occupied in dividing the original and drawing squares upon it, but likewise secure it from any injury that might arise to it from the process.

103. The sixth and last method of copying drawings, and at the same time varying their proportional magnitudes, is purely mechanical, and is performed by an instrument constructed for the particular purpose, called *a Pantagraph.* This method is very convenient for copying maps and plans, and all drawings that contain curved or irregular outlines, but is not suited to the production of right lines, though the instrument may be used in connexion with a ruler, for forming them.

104. The pantagraph is usually made of wood or brass, from one to two feet or more in length, and consists of four flat rulers, *Fig. 27, Plate I.*, two of them long and two short. The two longer are jointed at the end A by a metallic double joint, which admits their opening and shutting like a pair of compasses. Under this joint is an ivory castor, to support this end of the instrument. The two short rulers are fixed by pivots at E and H near the middle of the long rulers, and their other ends are joined together by a double joint at G. By the construction of this instrument the four rulers always form a parallelogram. There is a sliding box B on the long arm E, and a similar one on the short arm D. These boxes can be fixed at any required part of the rulers by their milled screws. Each of these boxes is furnished with a cylindric tube, to carry either the tracing-point, crayon or fulcrum.

The fulcrum or support K, is a brass pillar or pivot, rising out of a leaden weight; on this the whole instrument moves when in use. Other rollers or castors are applied under the joints E and H to support the rulers and keep them parallel to the paper. The long and short rulers which carry the sliding boxes, are graduated and marked with the proportions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c., to $\frac{1}{12}$, for reducing or enlarging drawings accordingly. The pencil holder F, tracer C, and fulcrum K, must in all cases be in a right line; so that when they are set to any number, if a string be stretched over them and they do not coincide with it, we may be sure that an error exists in the setting of them, or in the graduation of the instrument.

The long tube or crayon F, which carries a black-lead pencil, is maintained in a vertical position by sliding in an external tube in which it moves easily up and down, and a strong silken thread *s s s* is fastened to the lower part of this crayon, passes up the same tube, is carried through metal eyes placed over the joints E and A, and is finally attached to the tracing-point C. By pulling this string the pencil is lifted up, and prevented marking upon the paper whenever desired. The crayon piece slides so easily in its socket, that the pencil rises and falls to accommodate any unevenness in the surface of the copying paper; and to insure the due marking of the pencil, the top of the crayon piece is formed into a cup for holding cents or other weights, by which the pressure of the pencil upon the paper may be increased at pleasure.

105. *To use the instrument for reducing a map or other drawing in any of the proportions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, &c., as marked on the two bars* B *and* D. *Suppose, for example, $\frac{1}{2}$ is required.*—Place the two sliding boxes at $\frac{1}{2}$ on the bars B and D; slip the tube or socket of B over the brass spindle of the lead weight K;

place the crayon and pencil in the tube or socket of D, and insert the tracing-point in the socket C, and attach the silk thread of the pencil to it, and the instrument will be prepared for use. To use it, open the two long arms or rulers until they make an angle with each other of from 60° to 90°. Fasten the sheet of paper that is to receive the copy to a large flat table, in such position that the pencil-point may stand over the middle of the sheet; and place the original that is to be reduced under the tracing-point C, in such manner that its centre shall also be under the tracing-point; and now, on passing the tracing-point over all the lines in the original, the pencil-point will perform the same evolutions upon the paper, and will produce a perfect copy of the original of half its size.

106. In the same manner a copy, in any other proportion, will be produced by setting both the sliding sockets, B and D, to the numbers indicating the proportions required, on the long and short arms, keeping the fulcrum, pencil, and tracing-point, in the positions before described.

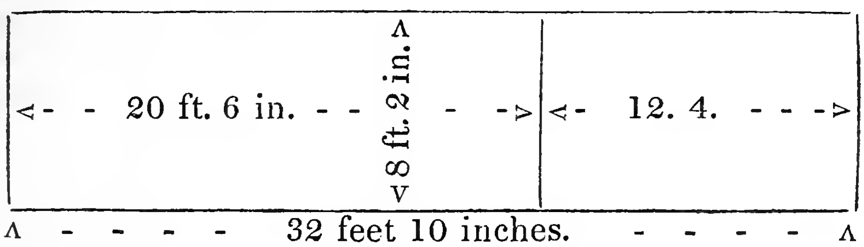
107. If the original should be so large that the instrument will not extend over it at one operation, two or three points must be marked on the original, and the same to correspond upon the copy. The fulcrum and copy may then be removed into such situations as to admit the copying of the remaining part of the original; first observing, that when the tracing-point is applied to the points marked on the original, the pencil may fall on the corresponding points in the copy. In this manner, by repeated shiftings, a pantagraph may be made to copy an original of any extent of dimensions.

108. *To use the instrument for enlarging a drawing in any of the proportions marked on the scales; suppose* $\frac{1}{2}$. The sliding pieces on the arms remain as before, or must both be set to the same proportion required on the long and short arms, when all that is necessary, is to exchange the places of the pencil-point and tracer, viz: to place the tracing-point at D, and the pencil at C, and proceed as before.

109. The pantagraph will also copy drawings of the same size; but in this case every part of the figure will be reversed. To use the instrument for this purpose, the fulcrum must be placed in the central socket D, while the pencil and tracer are placed indifferently in the two sockets, B and C, at the extreme ends of the long rods, taking care when using the instrument in this way to make the distance AB equal to AC, by shifting the slider B accordingly.

110. Drawings are sometimes made from real objects without using the scale and compasses, or paying strict attention to the

proportional magnitude of their parts; but upon which the real dimensions are figured in, so that the drawing can be made over again by scale at a future time. These are called rough eye-draughts, and they are the kind of drawings recommended in the first chapter to be made by the young Engineer, as memoranda for his future guidance; and they will, in many instances, serve for workmen to work from. They consume very little time for accomplishment, compared with other drawings, and the mode of executing them is merely to make as correct a representation of the object before you as you can, without measuring it, and then to take its actual dimensions with care, and insert them in figures upon the drawing, observing that the written line of figures must have the same direction as that in which the dimension is taken. These figures are generally placed near the centre of the dimension taken, and the space between them and the external lines are filled up by dotted or other lines, terminating in arrow-heads, or angular points, which points indicate the exact spot to which the dimensions are taken, or extend, as in the figure underneath, which may be supposed to represent two adjoining rooms



in a plan. The largest of these is 20 feet 6 inches long, by 8 feet 2 inches wide; and the other 12 feet 4 inches long, by the same width. The figures under the diagram show that the entire length of the building is 32 feet 10 inches, being the sum of 20 feet 6, and 12 feet 4. The proportion of these dimensions is not observed in the figure, but it will be evident that with such dimensions given a correct plan to scale can at any time be produced, or the rooms could be set out for building.

111. This kind of drawing, with the difference only of its being accurately laid down to scale, is the one almost constantly resorted to by Engineers, in making their working drawings for the erection of machinery. They save much time, and are often more intelligible to the workman than drawings in greater detail. If, for instance, a bricklayer or mason were employed to construct the necessary building for containing a steam engine, or any other complicated machine, in which a strong wall or basement should be required for supporting the steam cylinder,

all the workman would require would be the height and other dimensions of such wall, and the position of the centre of the cylinder upon it, the position and distance of the main gudgeons of the beam, the central line of the fly-wheel shaft, and diameter of the fly-wheel, the central line of the steam boiler and steam pipes, &c., all which particulars can be more accurately and intelligibly laid down by mere centre lines, with dimensions figured in upon, and between them, than by the most elaborate drawing, which might tend to confuse rather than to instruct, and would occupy much time for its formation.

112. As a first step in the preparation or drawing of plans of buildings, or machines already erected, of rooms, halls, or public buildings, and even for making plans of single fields of regular form, this mode of drawing is constantly resorted to. It being more simple and easy to make a sketch or eye-draught of what is before you, and afterwards to figure in the dimensions upon such sketch, than it is to record or register them in any other way. In making such drawings of fields it will, however, be necessary either to measure one or more angles in the corners, or else to measure a diagonal from one corner to another; because the eye is apt to be deceived, and that may appear to be square, or to have right angles at its corners, which is, in fact, a rhomboid or trapezium, differing so slightly from a rectangular figure as not to be perceived.

113. *Mouldings* are members introduced into constructions, generally, for the purpose of ornament alone, although they may frequently be resorted to with advantage, for increasing strength. They belong equally to the work of the stonemason, the joiner, the plasterer, and the ironfounder, and on this account a description of them does not appear to belong to any class of work with more propriety, than to the present chapter upon drawing; because, under this head, the mode of producing or drawing them, may be given.

114. Mouldings are of great antiquity, having been introduced into buildings in the earliest ages. With the Egyptians they were very large, simple, and few in number; the Grecians increased their quantity, and made them smaller; but in Roman architecture they were not only multiplied in number, but much diminished in magnitude. They are used round columns and upon flat surfaces, and are seldom introduced near the middle of a construction, but are placed at or near the sides or angles, or serve to divide one member from another.

115. The simple mouldings of the ancients are still used in preference to others, and are distinguished by the names of the fillet, the torus, the astragal, the ovalo, the echinus, the scotia,

the cavetto, the cymatium or cyma recta, and the cyma reversa. The modern mouldings added to these are, the quirked bead and the reed. All mouldings are distinguished from each other by the profiles or sections they present when cut across. Thus *Fig.* 28 is a section of a fillet, which is nothing more than a mere rectangular projection, rising above a plane surface, and usually made much wider on its face, than the quantity of its projection. It is frequently called a *band.*

The Torus is a convex moulding, the section of which is a semicircle, or nearly so, projecting from a flat surface. See *Fig.* 29. It is usually the lowest number of the shaft of Grecian columns.

The Astragal, *Fig.* 30, is a semicircular projection placed upon a fillet; the quantity of fillet shown on each side of it being generally equal to the projection above the flat surface, on which it is placed.

The Ovalo, *Fig.* 31, *a*, differs from the two last in only exposing a quarter of a circle. It is generally sunk upon the solid angle of a piece of work, so as to put on the appearance shown at *b*, in the same figure.

The Echinus, *Fig.* 32, resembles the ovalo, but its outline is elliptical instead of circular. It frequently occurs in the capitals of Grecian Doric columns, and is sometimes called the Grecian ovalo.

The Scotia is among the concave mouldings, and is the reverse of the torus, its section presenting a concave semicircle, which is usually bordered by two narrow fillets. See *Fig.* 33.

The Cavetto is another concave moulding, being a quarter of a circle, and the reverse of the ovalo. See *Fig.* 34. It is occasionally made elliptical, or the reverse of the echinus.

The Cymatium or cyma recta, is an undulated moulding, the upper half of which is concave, and the lower half convex. See *Fig.* 35. It is, in fact, an ovalo added below a cavetto, and is formed of two quarter circles, struck from the two dots, one within and the other without the moulding; their positions being formed by dividing the width of the moulding into two equal parts.

The Cyma reversa, *Fig.* 36, so exactly the reverse of the last, being struck from two centres formed as before, but in such manner that the upper half of the moulding is convex and the lower half concave. This moulding is more frequently introduced into modern work than the last, and is generally called an OG, or talon, by workmen.

The modern OG, or cyma reversa, is made to consist of two semicircles instead of two quadrants of circles, united in the same way; the place of the centre being formed by dividing the width of the moulding into four equal parts. It is thought to produce a bolder and more handsome appearance. See *Fig.* 37. The narrow angular indentation marked *, produced by this construction, is called a quirk.

The modern bead is the same as the torus, except that it is accompanied by a quirk on one or both sides, which occasions more than half the circle to become visible, as shown in *Fig.* 38.

The reed is a number of cylindric projections or indentations, placed close and parallel to each other in longitudinal direction, so as to present sections like *Fig.* 39; and which are called convex or concave reedings.

116. The above simple mouldings are sometimes used alone, but are most frequently grouped or compounded according to the taste of the designer, so as to produce the width and boldness or projection required, of which *Fig.* 40, may serve as an example. In this *Fig.* *a* is a fillet, *b* a cavetto, *c* a modern or quirked OG, *d* an astragal, and *e* a quirked bead.

Whenever two lines of mouldings meet at a right angle, they are made to join, by cutting the two surfaces that come together, into angles of 45° each, and such a joint is always called a *mitre;* its appearance is shown at *f*, in *Fig.* 41.

117. Compounded mouldings derive different general names from the positions in which they are placed. Thus the mouldings round the top of a room next the ceiling, or over a row of columns, is called a cornice. These same, or other mouldings, near the bottoms of the walls of a room, or under columns, would constitute a surbase, or a plinth if quite at the bottom; and pannels are surfaces surrounded by mouldings.

CHAPTER III.

ON THE PRINCIPLES OF MENSURATION.

118. Mensuration is that branch of mathematics which shows the mode of computing the magnitude of objects and the quantity of material they contain; and as all kinds of artificers work is paid for according to its measurement, and the total value of any piece of work is compounded of the value of its materials, added to the cost of the work or labour for putting them together, so it is quite necessary that the Engineer, the Architect, the Surveyor, and the builder or constructor, should be acquainted with the modes of taking measurements; as without such knowledge it would be impossible to prepare an estimate or valuation of work antecedent to its execution, or to determine its value when completed.

119. Mensuration is generally divided into three distinct heads, called lineal or running, superficial, and solid measure. The first only contemplates extension in length; the second the quantity of surface to be examined, without any regard to its depth or thickness; and the latter takes in all dimensions, or length, breadth and thickness. For the above reason the technical phrase applied to the second head or superficial measurement is called *squaring dimensions*, while the latter is called *cubing* them. Lineal measurement is so simple and well understood that it requires no explanation; therefore superficial measurement will be considered in the first instance.

120. The computation of either kind of measurement requires a knowledge of arithmetic for its performance; and the operations are conducted in two ways, according to the divisions made use of in the measures adopted. Thus the surface of land is measured by acres, roods and perches, which are estimated by a chain containing 100 equal links; therefore land measure is conducted by common decimal arithmetic. A similar mode of measurement is also adopted in canal and road work. But as the work of carpenters, joiners, and many other artificers, is measured by yards, feet and inches, in which the foot, as the derivative measure, is

divided into twelve equal parts called inches, so the operations upon these dimensions are usually conducted by what is called the duodecimal process. The name of the first being derived from the Latin word *decem*, ten, and the latter from *duodecem*, twelve. All the operations may, however, be conducted by decimal arithmetic, notwithstanding that custom has introduced the duodecimal method into use for some kinds of work, and it must therefore be used.

121. Common arithmetic is so generally known, that it is needless to say anything about it, presuming that its operations are known to all. Duodecimal arithmetic, on the contrary, though generally taught at schools, is frequently forgotten, on account of its never being used or practised except by those who are concerned in building operations, where it is of every-day occurrence. It may therefore be useful to make a few observations upon it.

122. Addition, subtraction and division, are performed by the ordinary rules of compound addition, subtraction and division; all that is necessary being to recollect that instead of carrying tens to the next column or the left, or borrowing tens from it, that the amount carried or borrowed will depend upon the value of the units we are working upon, as in the following example of the addition of two quantities of brickwork.

Add	7 rods	3 qrts.	12 feet and	7 inches
to	12	2	74	9
Answer	20	2	4	4

To understand this, it is necessary to premise that brickwork is always measured or estimated in square rods, quarters of rods, feet and inches. The rod consists of 272 superficial feet, consequently its half will be 136 feet, and its quarter 83 feet. Now, in working the above addition, the sum of 7 and 9 inches amounts to 16 inches, which is 1 foot and 4 inches, therefore the 4 inches are set down, and the one foot is carried to the next column of feet, in which we find 12 feet and 74 feet amount to 86, and one carried makes 87 feet; but as 83 feet make a quarter rod, the 83 must be subtracted from 87, leaving 4 feet to set down, and one quarter of a rod to carry to the next column, which, being added to the 3 and 2 quarters found there, makes 6 quarters. But 6 quarters are equal to one whole rod and two quarters, so that the 2 only are put down, and the one rod is carried to the 7 and 12 rods of the next column, making the whole sum 20 rods, 2 quarters, 4 feet, 4 inches.

123. Suppose it is required to subtract 4 lineal yards, 2 feet

and 3 inches from 50 yards, 1 foot and 2 inches, then the operation will stand thus:

50	1	2
4	2	3
45	1	11

3 inches cannot be taken from 2 inches, therefore the 1 foot must be borrowed from the next column; but as feet and inches cannot be assimilated, that foot must be expanded to its actual value in the computation, and that being lineal measure, will be 12 inches, so that in fact we borrow 12 inches to add to the 2, making 14 inches; from which, subtracting 3, the remaining 11 inches must be set down. Next we have to subtract 2 feet from 1 foot. But the one foot has previously disappeared—having been lent to the inches; therefore, to continue the operation, one yard, equal to 3 feet, must be borrowed from the 50 yards; and now the subtraction becomes converted into 2 feet from 3 feet, and one remains, which is put down. Next we have 4 feet to take from 50 feet. But the 50 feet has been diminished to 49 by having lent one to the inches, so that in fact we have to take 4 feet from 49, and 45 feet remain and are set down.

This is exactly reversing the operation of subtraction, as generally taught; because, instead of considering each group of numbers in the upper line as diminished by borrowing, they are permitted to retain their first value, and the sums borrowed are added to the figures in the lower line without any apparent reason; and the above explanation is introduced merely to show the philosophy or principle of the operation. To prove how necessary it is to pay due regard to the values of the units we are operating upon, the example above given is repeated with the same figures, but on a presumption that they now represent square instead of lineal quantities, which will alter the result, although the mode of working remains the same.

Subtract 4 square yards, 2 square feet, and 3 square inches from 50 square yards, 1 square foot, and 2 square inches.

50	1	2
4	2	3
45	7	143

In this case the 1 foot borrowed from the inches is equal to 144 square inches, which, added to the 2, makes 146, and 3 subtracted from that, leaves 143 square inches. The yard borrowed for the feet is equal to 9 feet, therefore the subtraction is 9—2=7, while the yards remain the same as in the former case.

124. The same observance of values must be preserved in car-

rying on the operations of division; but in general they are more simple than the others, since it frequently happens that this rule is applied to obtain the value of one unit of work out of a great number that have been executed. Thus, from knowing the cost of any number of yards of work, we may deduce the value of one yard; or knowing how many bricks have been used in a given number of rods of work, we may ascertain how many are required for one rod.

125. This rule may evidently be worked in two ways, viz: by reducing all the larger denominations of quantity, either to their smallest denominations, or to a denomination equal to that of the divisor, and proceeding as in common division; or the largest denomination may be divided first and its quotient set down. If there is a remainder, that must be reduced to the denomination next lower in value to which it is added, and the division proceeds as before; and this operation is to be repeated until carried to the smallest denomination we may want.

126. The next and most important rule to the Engineer and builder is multiplication of duodecimals, or, as it is very frequently called, cross multiplication, on account of the nature of the process by which the operation is conducted. By workmen it is generally called squaring dimensions. It applies only to dimensions that are taken in feet, inches, and parts of an inch.

Rule.—Multiply each term in the multiplicand from the right hand by the *feet only* in the multiplier, and write each result under its respective term; observing to carry one unit of the next highest denomination of value for every twelve of the one below it. That done, proceed in like manner to multiply each term of the multiplicand by the inches only of the multiplier, and set the results of each term under the first obtained product; put each term one place to the right hand of those obtained by the first multiplication. The addition of these two lines will be the answer required.

Example.—Multiply 59 feet 6 inches by 3 feet 11 inches.

59	6	
3	11	
178	6	
54	5	6
233	0	6

In the result, the left hand parcel of figures are feet; the next to the right hand, inches; but as none occur in this example, the place of inches is held by a 0. The right hand column is twelfths of an inch, of which 6 occur, equal to half an inch. The practical rule is, that whenever the parts of an inch amount to 6 or more, it is written down an inch; while if such parts amount to less than 6, they are discarded. The above number would consequently be written 233 feet 1 inch. The third column of figures is thus dispensed with; and when this giving and taking principle is applied to a great number of dimensions, the result is found to come near enough to truth for all practical purposes.

127. Whenever the number of inches that occur are aliquot parts of a foot, the process may be shortened by using the rule of practice. Thus, suppose we have

	feet	inches
	6	4 to
multiply by	12	6
	76	0
	3	2
	79	2

The multiplication of the upper line by 12 feet produces exactly 76 feet; and then, as 6 inches is half a foot, there is no necessity to go through the second multiplication, but we may take half the multiplicand, or 3 feet 2 inches, and setting this under the 76, the sum will give the amount sought, or 79 feet 2 inches.

In like manner, suppose we had to

	feet	inches
multiply	33	9
by	10	4
	337	6
	11	3
	348	9

The multiplication of 33 feet 9 inches by 10 feet, gives 337 feet 6 inches; and as 4 inches, the next multiplier, is one-third of a foot, we have only to take the third part of 33 feet 9 inches, or 11 feet 3 inches, and adding this to the product of the first multiplication, will give 348 feet 9 inches, the sum required.

128. To avail of this rule, it is only necessary to commit to memory the following practice table of feet and inches:

1	inch is	$\frac{1}{12}$th	of a foot.
$1\frac{1}{2}$	inches is	$\frac{1}{8}$th	,,
2	,,	$\frac{1}{6}$th	,,
3	,,	$\frac{1}{4}$th	,,
4	,,	$\frac{1}{3}$d	,,
6	,,	$\frac{1}{2}$	,,
8	,,	$\frac{2}{3}$ds	,,
9	,,	$\frac{3}{4}$ths	,,

129. In England, where 12 pence make a shilling, (one of the commonest coins of currency,) every school-boy is required to learn his pence table by heart; and as 12 inches make a foot, as well as 12 pence a shilling, the acquirement of this table affords surprising facility in working duodecimals and casting up all artificers' work. It is therefore strongly recommended that the student should commit the following table to memory. It is the common English pence table, altered by substituting the words feet and inches for shillings and pence.

Table of Inches in Feet.

		Feet.	*Inches.*			*Feet.*	*Inches.*
12	inches make	1		70	,,	5	10
18	,,	1	6	80	,,	6	8
24	,,	2		90	,,	7	6
30	,,	2	6	100	,,	8	4
36	,,	3		110	,,	9	2
40	,,	3	4	120	,,	10	
42	,,	3	6	130	,,	10	10
48	,,	4	0	140	,,	11	8
50	,,	4	2	144	,,	12	0
60	,,	5		150	,,	12	6

130. Those who enter into the employment of an Engineer's, Architect's or Surveyor's office, will have ample means of making themselves perfect in this kind of computation, because the usual arrangement is for the senior clerks (who on account of their experience and knowledge may be trusted with this duty) to go out and take dimensions of work that has been executed; and they bring their books, when filled with dimensions, to the junior clerks in the office, to square and abstract the same, in a manner that will be hereafter described. The junior clerks are frequently kept for months together at this daily occupation; and such is the facility acquired by this constant practice, that in many cases it is not necessary to go through the process of multiplication, for the result becomes evident upon inspection, and may be put down at once without any arithmetical operation. On this point the author speaks from his own experience.

131. For the same reason that some notice has been taken of duodecimal arithmetic, it may be servicable to make a few short observations on fractions; because, as these are not very extensively used in the ordinary occupations of life, the rules for treating them are often forgotten, while their use is absolutely necessary in many investigations of science. No attempt will be made to explain the foundations of these rules, but merely to revive a recollection of their existence.

132. A *unit* expresses one single object of computation in pure mathematics, without any reference to what that object may be. It is simply *one*. But in mixed or palpable mathematics some idea of existence is always attached to it, as a pound, an ounce, a penny, a foot, &c., and sums arise from the multiplication of units.

133. So long as a unit remains whole and entire it is called an *integer*, or *integral*, or *whole number*. It is, however, frequently necessary to examine a less quantity than one whole or entire thing; and in that case we have to consider the unit as broken or divided, and the parts into which it is so broken are called fractions of that unit. Common or vulgar fractions are marked by two figures, one above the other, having a line drawn between them, thus, $\frac{1}{2}$, $\frac{3}{6}$, $\frac{4}{8}$, $\frac{6}{12}$, $\frac{50}{100}$, &c. The lowest figure, or that under the line, indicates into how many *equal* parts the integer has been broken or divided, and thus gives denomination to the fraction, and is therefore called *the denominator;* while the upper figure states the number of the parts or divisions that are to be taken into account, and is therefore called *the numerator.*

134. From the above short account it will be evident that, although a given quantity can only be expressed by one set or form of integral numbers, it may be stated in an almost infinite variety of forms by vulgar fractions, and that all those above stated express the same quantity; for if we divide a thing into 2 parts and take 1 of them, or into 6 parts and take 3 of them, or into 8 and take 4, or into 100 and take 50, &c. &c., we shall in every case have the same quantity, which will be one half of the first quantity. One half is therefore called the lowest denomination of all the above set of fractions; and one of the most common operations that occurs is the alteration of fractions from one form of expression into another, without altering their real value, in order to suit them for the operations of addition, subtraction, &c. From the nature of fractions, if both terms are increased or diminished in an equal degree, the value of the fraction will remain unchanged; multiplication will increase the number of figures and make the expression more complicated, while division will reduce and render it more simple; and the largest number that can be employed to divide both terms, without a remainder, will of course reduce a fraction to its smallest and most simple expression.

135. The first object consequently in treating fractions is,

To find the greatest common measure of two or more numbers.

Rule.—If there are two numbers only, divide the greater by the less. Then divide the divisor by the remainder; and so on, always dividing the last divisor by the last remainder, till nothing remains; and the last divisor of all will be the greatest common measure.

136. When there are more than two numbers, find the greatest common measure of two of them, as before; then do the same for that common measure and another of the numbers; and so on through all the numbers; and the greatest common measure last found, will be the answer.

If it happen that the common measure thus found is 1, then the numbers are said to be incommensurable, or have no common measure.

Example.—To find the greatest common measure of the numbers 1908, 936, and 630.

```
936)1908(2
    1872
    ----
     36)936(26              Hence 36)630(17
        72                           36
        --                           --
        216                          270
        216                          252
        ---                          ---
        ...                           18)36(2
                                         36
                                         --
                                         ..
```

Hence 36 is the greatest common measure of the two first numbers 1908 and 936; and 18 is the common measure of those two numbers and 630.

137. *To reduce a vulgar fraction to its lowest denomination, or simplest expression.*

Rule.—Divide the numerator and denominator of the given fraction by that number which is their greatest common measure, (found by the last rule,) and the two quotients disposed over each other, in the former order of the figures, will be the simple fraction sought.

Example.—What is the lowest denomination of $\frac{936}{1908}$?

The first part of the operation, shown in the last example, would be necessary upon these numbers, if it had not previously informed us that 36 is their greatest common measure. That known, it is only necessary to divide 936 and 1908 by 36; and the two quotients obtained will be 36 and 53, which, formed into a fraction, will be $\frac{36}{53}$; and this is the lowest expression of this fraction, because 53 is not divisible by any number that will divide 36 without a remainder.

Note.—Any number ending with an even number, or a cipher, is divisible, or can be divided by 2.

Any number ending with 5 or 0, is divisible by 5.

If the two right hand figures of any number are divisible by 4, the whole number may be divided by 4.

If the three right hand figures of a number are divisible by 8, the whole number may be divided by 8.

If the sum of the figures constituting any number is divisible by 3 or 9, the whole number is divisible by 3 or 9.

If the right hand number be even, and the sum of all the numbers be divisible by 6, the whole number will be divisible by 6.

138. *To reduce several fractions to a common denominator.*

Rule.—Multiply each numerator of the several fractions into the several denominators, except its own denominator; and multiply the whole of the denominators into each other. The products of the first will be the several new numerators; and the product of the last the common denominator.

Example.—Reduce $\frac{6}{10}$, $\frac{2}{4}$, $\frac{1}{7}$, and $\frac{3}{6}$ to a common denominator.

For the numerators, $6\times4\times7\times6=1008$; $2\times10\times7\times6=840$; $1\times10\times4\times6=240$; and $3\times10\times4\times7=840$.

For the common denominator, $10\times4\times7\times6=1680$.

Hence $\frac{6}{10}=\frac{1008}{1680}$; $\frac{2}{4}=\frac{840}{1680}$; $\frac{1}{7}=\frac{240}{1680}$; and $\frac{3}{6}=\frac{840}{1680}$, will be the reduction of the several fractions required.

139. Fractional notation is not only capable of expressing broken parts of a unit or integral number or quantity, but quantities greater than unity; because the numerator may be, and frequently is, greater than the denominator without at all affecting the nature of the fraction; thus the fractions $\frac{20}{10}$ or $\frac{8}{4}$, are each of them equal to two integers. To distinguish these and other fractions from each other, the following designations have been given to them.

Proper fractions are all such as have their numerators smaller than their denominators; as $\frac{1}{2}$, $\frac{3}{4}$, &c.

Improper fractions are such as have their numerators equal to, or greater, than their denominators; as $\frac{4}{4}$, $\frac{8}{4}$, $\frac{9}{3}$, &c.

Compound fractions are fractions of fractions, which are distinguished by having the word "of," introduced into their expression; as $\frac{1}{2}$ of $\frac{2}{3}$, or $\frac{1}{3}$ of $\frac{8}{17}$, and $\frac{1}{4}$ of $\frac{7}{16}$.

Mixed fractions, or *mixed numbers,* are such as consist of a whole number combined with a fraction; as $8\frac{3}{5}$, $12\frac{2}{3}$, and $17\frac{71}{88}$.

140. *To reduce a mixed number to an improper fraction.*

RULE.—Multiply the integer, or whole number, by the denominator of the fraction, and add the numerator of the fraction to it; when the amount will be the new numerator to be placed over the former denominator.

EXAMPLE.—Required the improper fraction of $183\frac{5}{21}$?

$$183\times21+5=3848;\text{ or }\frac{3848}{21}$$

141. *To reduce an improper fraction to its proper terms.*

RULE.—Divide the numerator by the denominator, and the quotient will be the answer.

EXAMPLE.—Required the proper terms for $\frac{3848}{21}$?

$$3848\div21=183\tfrac{5}{21}.$$

142. *To reduce a compound fraction to a single fraction.*

RULE.—Multiply the whole of the numerators into each other for a new numerator, and the whole of the denominators into each other for a new denominator. Set this down as a single fraction; and, if required, reduce it to its lowest denomination, (by par. 137.)

EXAMPLE.—Reduce $\frac{3}{4}$ of $\frac{5}{6}$ of $\frac{9}{10}$, to a single fraction.

For the new numerator $3\times5\times9=135$
For the new denominator $4\times6\times10=240$ and if this fraction is reduced to its lowest denomination, it will become $\frac{9}{16}$.

143. *To reduce a fraction of one denomination to a fraction of a higher denomination, retaining the same value.*

RULE.—Reduce the given fraction to a compound fraction by comparing it with the denominations through which it has to pass, and then proceed as with compound fractions.

EXAMPLE.—Reduce $\frac{4}{7}$ of a lb., avoirdupois, to the fraction of a hundred weight of 112 lbs.

$$\tfrac{4}{7}\text{ of }\tfrac{1}{112}\text{ lbs.}=\left\{\begin{matrix}4\times1=4\\7\times112=784\end{matrix}\right\}=\tfrac{4}{784}\text{ or reduced }\tfrac{1}{196}\text{ of 1 cwt.}$$

144. *To reduce a fraction from one denomination to another retaining the same value, when the numerator of the new fraction is given.*

RULE.—Multiply the denominator of the fraction by the given numerator, and divide the product by the numerator of the fraction.

EXAMPLE.—Reduce $\frac{3}{4}$ to a fraction of the same value, whose numerator shall be 9.

$4 \times 9 \div 3 = 12$; hence $\frac{9}{12}$ will be the new fraction; for as $3 : 4 :: 9 : 12$.

145. *To reduce a fraction from one denomination to another of the same value, when the denominator of the new fraction is given.*

Rule.—Multiply the numerator of the fraction by the given denominator, and divide by the denominator of the fraction.

Example.—Reduce $\frac{3}{4}$ to a fraction of the same value, whose denominator shall be 24.

$3 \times 24 \div 4 = 18$; hence $\frac{18}{24}$ is the fraction sought; for as $3 : 4 :: 18 : 24$.

146. *To reduce a mixed fraction to a simple fraction.*

Rule.—Multiply, separately, the numerator and denominator by the denominator of the fraction in the mixed quantity; add the numerator of the fraction to where it belongs, and reduce the fraction to its lowest terms by (137.)

Example 1.—Reduce $\frac{23\frac{5}{7}}{38}$ to a simple fraction.

$$\frac{23\frac{5}{7}}{38} = \begin{cases} 23 \times 7 + 5 = 166 \\ 38 \times 7 \quad = 266 \end{cases} \text{ which reduced is } \frac{83}{133}.$$

Example 2.—Reduce $\frac{47}{65\frac{4}{5}}$ to a a simple fraction.

$$\frac{47}{65\frac{4}{5}} = \begin{cases} 47 \times 5 \quad = 235 \\ 65 \times 5 + 4 = 329 \end{cases} \text{ which reduced is } \frac{5}{7}.$$

147. *To reduce a fraction to its proper or nominal value.*

Rule.—Multiply the numerator by the common parts of the integer, and divide by the denominator.

Example.—Reduce $\frac{3}{5}$ of 1 lb. troy to its proper denominations of ounces, pennyweights, and grains.

$\frac{3}{5} = 3 \times 12$ ozs. $= 36$ ozs. $\div 5 = 7\frac{1}{5}$ ozs.; $\frac{1}{5}$ oz. $= 1 \times 20$ dwts. $\div 5 =$ 4 dwts.

So that $\frac{3}{5}$ of 1 lb. troy, is equal to 7 ozs. and 4 dwts.

148. *To reduce the nominal value to the fraction of an integer.*

Rule.—Reduce the nominal value to its lowest term, for the numerator of the fraction; and the number of units in the integer will be the denominator. Reduce the fraction, if necessary, to its lowest terms.

Example.—Reduce 2 roods and 20 poles to the fraction of an acre.

$$\frac{2 \text{ roods} \times 40 \text{ poles} + 20 \text{ poles} = 100}{1 \text{ acre} \times 4 \text{ roods} \times 40 \text{ poles} = 160} \text{ or if reduced } \frac{5}{8}.$$

ADDITION AND SUBTRACTION OF VULGAR FRACTIONS.

149. Before fractions are reduced to a common denominator they are quite dissimilar, as much so as dollars and cents are; and, therefore, cannot be incorporated with one another any more than these can. But when they are reduced to a common denominator, and made parts of the same thing, their sum or difference may then be as properly expressed, by the sum or difference of the numerators, as the sum or difference of any two quantities whatever. The first step, therefore, towards the addition or subtraction of fractions, is to reduce them to a common denominator. This done, for ADDITION, we have the following

RULE—add all the numerators together and place their sum over the common denominator.

Note.—All compound fractions must be reduced to simple ones; fractions of different denominations to those of the same denomination; and mixed numbers must either be reduced to improper fractions, and be so added with the others, or else the fractional parts only added, leaving the integers to be united afterwards.

150. FOR SUBTRACTION.

The fractions being prepared as for addition, subtract the one numerator from the other, and set the remainder over the common denominator, for the difference of the fractions sought.

151. MULTIPLICATION OF VULGAR FRACTIONS.

RULE.—When the given numbers require it, prepare them by any of the foregoing rules; then multiply the numerators into each other, for a new numerator; and the denominators into each other for a new denominator.

Note.—A fraction is best multiplied by an integer, by dividing the denominator by it; but if it will not exactly divide, then multiply the numerator by it.

152. DIVISION OF VULGAR FRACTIONS.

RULE.—Having prepared the fractions as for multiplication, divide the numerator of the one fraction by the numerator of the other, and the denominators in like manner, if they will exactly divide; if not, multiply the numerator of the one by the denominator of the other, reciprocally, to obtain the required fraction.

EXAMPLE of 1st case.—Divide $\frac{14}{27}$ by $\frac{2}{3}$ now $\frac{14\div2=7}{3 \text{ and } 27\div3=9}$ the Ans.

2nd case, $\frac{14}{27}$ by $\frac{2}{3}$ here $\left.\begin{matrix}14\times3=42\\27\times2=54\end{matrix}\right\}$ which reduced to its lowest denomination is, also, $\frac{7}{9}$.

Note.—A fraction is best divided by an integer, by dividing the numerator by it; but if it will not exactly divide, then multiply the denominator by it.

153. RULE OF THREE IN VULGAR FRACTIONS.

State the question as in the rule of three of whole numbers; reduce the fractions that require it as in the other rules: invert the first term in the proposition by changing the places of the numerator and denominator; then multiply the three terms continually together, and the product will be the answer.

EXAMPLE.—If $\frac{3}{4}$ of a yard of paving cost $\frac{5}{8}$ of 4 dollars, what will $\frac{9}{10}$ of a yard come to?

If $\frac{3}{4}$ cost $\frac{5}{8}$ what will $\frac{9}{10}$ cost?

Inverting the first term makes this $\frac{4}{3} : \frac{5}{8} :: \frac{9}{10}$: and multiplying the terms will give

$$\frac{4\times5\times\ 9=180}{3\times8\times10=240} \text{ or } \frac{18}{24} \text{ or } \frac{3}{4}=3 \text{ dolls.}$$

The effect of inverting the first term is that the second and third terms are multiplied together, and divided by the first term, as in the rule of three in whole numbers.

154. DECIMAL FRACTIONS.

Vulgar fractions arise naturally out of the transactions of commerce; but there is so much trouble and loss of time attendant on their necessary reduction and computation, that they are seldom admitted or made use of in the arithmetical operations of science; but another species of fraction is generally adopted, in which the denominator is fixed, being always 1, with as many ciphers placed after it as the numerator has figures. This mode of notation has many advantages, one of the most obvious of which is, that as the denominator is known, there is no occasion to write it down or introduce it below a line, as in vulgar fractions, but the fraction is expressed by merely setting down the numerator after a point or full stop, which separates it from the integral number in the case of a mixed number, or indicates that it is a fraction if it stands alone; though, in some cases, a cipher is introduced to the left of the point to avoid mistakes, and indicate the existence of the fraction more unequivocally. Thus $\frac{4}{10}$ expressed in decimal fractions would be, .4 or 0.4; and $\frac{24}{100}$ or $\frac{74}{1000}$ would be written, .24 or 0.24 and 0.074. So, in like manner, the mixed number $3\frac{25}{100}$ would be written, 3.25.

155. Ciphers placed on the right hand of decimals make no alteration in their value, for .5, or .50, or 0.500 have all the same value, though differently expressed. These numbers would be

read 5 tenths, 50 hundredths, and 500 thousandths, which, after what has been said on fractions, will evidently be equal to one half. A cipher placed on the left of a decimal will, however, alter its value, because decimals increase in their denomination from left to right, or in an order exactly the reverse of whole numbers; consequently, if the above numbers were written .05, .005, &c. the first would indicate 5 hundredths, and the next 5 thousandths; because, as before observed, the denominator that has to be mentally supplied is constantly 1, with as many ciphers after it as there are digits in the numerator; and left hand ciphers reckon as digits.

156. The only disadvantage of decimal fractions is, that quantities very frequently occur that are not an aliquot part of 10, or commensurable by decimal notation; and in such cases the exact quantity cannot be expressed by a decimal fraction, and we must be satisfied with an approximation to it; but that approximation may be brought so close as to become an almost perfect expression. In vulgar fractions we may conceive the integer to be broken into just as many parts as are necessary to obtain a denominator that shall express the exact quantity; but in decimal fractions, where the denominator is fixed, this advantage is lost. All the quantities that can be perfectly represented by decimal fractions are tenths, hundredths, thousandths, &c. of a quantity, or its quarter, half, or three-quarters, which are written 0.1, 0.2, 0.3, &c. for tenths; 0.25 for a quarter; 0.50 for half; and 0.75 for three-quarters; because 25, 50 and 75, are the exact quarter, half, and three-quarters of a hundred. But all other quantities which do not admit of exact division must be expressed approximately by decimals. Thus, if we desire to express the third of a thing, it will be found that it cannot be done exactly, because neither 10 nor any multiple of 10 has an exact third, 10 not being divisible by 3 without a fractional remainder. To express a third we must therefore write 0.3, and multiplying this fraction by 3 to convert it into an integer, we shall have but nine-tenths; so that one-tenth of the whole quantity is lost by this mode of notation. In order to obviate this inconvenience as far as possible, decimals of higher quality must be used. Thus, instead of supposing the integer to be divided into 10 parts, we divide it into 100, we should then have to write 0.33 instead of 0.3; and by taking 33 hundredths instead of 3 tenths, we shall only lose one hundredth of the quantity. Again, if the integer is divided into 1000 parts, then its third would be written 0.333, or three hundred and thirty-three thousandths, and the ultimate loss would be reduced to one thousandth. By using seven figures in the decimal, the loss would be reduced to one millionth, and so on.

This explains what is meant by expressing decimal fractions to a certain number of figures, or, as it is sometimes called, to so many places of figures, because in all numbers not decimally commensurable, approximation to precision can only be obtained by increasing the places of figures; while, on the contrary, such as are exact multiples may be as correctly represented by 1, 2 or 3 figures, as by the greatest multiplication of them. No addition of figures can improve the expression of one half by 0.5, because it is perfect; but a quarter cannot be represented by one decimal, because 10 has no quarter without a fraction, but 0.25 is a correct expression for it, 25 being the exact quarter of 100.

157. The left hand figure of a decimal, or that immediately following the point, is called the 1st place, or place of primes, and always expresses tenths; the next figure to the right is called the 2nd place, or place of seconds or hundredths; the next, the 3d place, expressing thousandths, each figure to the right having a denomination 10 times larger than that to its left, and consequently expressing a quantity 10 times smaller than the one that preceded it.

158. All such decimals as express exact quantities by a certain number of figures and are complete, are called finite, as 0.125, which is an exact eighth. This also is the case with decimals that accord accurately with vulgar fractions, as well as with whole numbers. Thus 0.958 is an exact and complete representation of $\frac{237}{250}$.

159. When decimals can never be made to accord exactly with given numbers, although their places of figures should be infinitely continued, they are called infinite decimals. One-third, or two-thirds of a quantity, are instances of this kind, for they can only be expressed by 0.3333 or 0.6666, which numbers would, if continued, proceed constantly without change, and yet could never produce an exact finite termination.

160. When the same figures thus occur over and over again without change, or when a certain class of various figures occur and are repeated in the same order without end, the decimal is called a repeating or circulating one, of which $\frac{3}{7}$ is an example among many others, for it is expressed by 0.42857142857142, &c , which, as written, is a decimal of 14 places of figures. In order to show that a repeating decimal is not complete, and to save the writing down of a great number of figures, it is customary to place a dot over the repeating figures; thus $0.\dot{3}$ would express the same as if the figure 3 had been repeated any number of times, and is better, because there is no positive limitation to the repetition. Notwithstanding these imperfections of decimals, yet the method of using them is so simple and expeditious, that they are constantly resorted to for all the numerical operations

of science, and vulgar fractions are constantly changed into decimal ones on this account.

161. *To convert a vulgar fraction into a decimal fraction.*

RULE.—Add as many ciphers to the numerator of the fraction as may be necessary for the accuracy or number of places of the decimal fraction to be produced, and divide by the denominator of the fraction.

EXAMPLE 1.—Convert $\frac{3}{4}$ into a decimal fraction.

4)300(.75, the decimal fraction required.
28
20

EXAMPLE 2.—Convert $\frac{1}{99}$ into a decimal.

$1.000000 \div 99 = 0.010\dot{1}0\dot{1}$, answer.

EXAMPLE 3.—Convert $\frac{1}{75}$ into a decimal fraction.

$1.00000 \div 75 = 0.0133\dot{3}$, answer.

The dots over the last two examples show that the decimals are of the repeating and circulating character, and therefore do not give finite results.

162. *To convert a decimal into a vulgar fraction.*

RULE.—Under the figures of the given decimal write its proper decimal denominator, so as to alter it into the form of a vulgar fraction, and reduce it to its lowest terms by (137).

EXAMPLE.—Required, the vulgar fractions that are equivalent to the decimals 0.5, 0.25, 0.625, and 0.5625.

$$\frac{.5}{10} = \frac{1}{2} \qquad \frac{.625}{1000} = \frac{5}{8}$$

$$\frac{.25}{100} = \frac{1}{4} \qquad \frac{.5625}{10000} = \frac{9}{16}$$

163. ADDITION OF DECIMALS.

RULE.—*Treat the fractions as whole numbers, taking care to place the decimal points directly under each other. Observe the same with all the places of figures, placing the primes under the primes, the seconds under the seconds, &c.; carry the tens from right to left, and those that remain after the addition of the fraction must be placed to the left of the point to represent whole numbers.*

EXAMPLE.—Add together the numbers 2.25, 0.64, 0.012, and 1.785.

$$\begin{array}{r} 2.25 \\ 0.64 \\ 0.012 \\ 1.785 \\ \hline 4.687 \end{array}$$ answer.

164. SUBTRACTION OF DECIMALS.

RULE.—*Arrange the numbers under each other, with the points in a direct line, as in addition, and subtract the less from the greater as in common numbers.*

EXAMPLE.—Subtract 1.9185 from 2.73 $\left\{ \begin{array}{r} 2.73 \\ 1.9185 \\ \hline 0.8115 \end{array} \right.$ answer.

165. MULTIPLICATION OF DECIMALS.

RULE.—*Arrange the multiplier under the multiplicand, as in whole numbers, and multiply them together. From the product, reckoning from right to left, point off as many figures for decimals as there are decimals in the multiplicand and multiplier together; but if there are not so many figures in the product, prefix ciphers to make up the deficiency.*

EXAMPLE 1.—Multiply 54.368 by 4.5864.

Answer, 249.3533952.

Here seven figures occur in the decimals of the two factors, consequently the 7 right hand figures of the product are pointed off for its decimals.

EXAMPLE 2.—Multiply 0.003876 by 0.048624.

Answer, 0.000188466624.

Here both the factors are fractions, and together contain only 9 numbers capable of multiplication; but as there are 12 digits in the two decimals, including the ciphers, so 12 decimals must be cut off from the right hand of the product; and to accomplish this, three ciphers are prefixed to the numbers constituting the product.

166. DIVISION OF DECIMALS.

RULE.—*Divide as with whole numbers; and to know how many decimals to point off in the quotient, subtract the number of digits that are in the decimal of the divisor from the number of digits in the decimal of the dividend, including any ciphers that may have been added to complete the division, and the difference will be the number of figures that (counting from the right to the left) must be pointed off in the quotient.*

Those numbers on the left of the decimal point are whole numbers, and the rest are decimals.

Example 1.—Divide 3424.6056 by 43.6.

In this case the dividend contains 4 decimals, and the divisor 1; their difference consequently is 3, which indicates the number of right hand figures to be cut off, viz:

34246056÷436=78.546, answer.

Example 2.—Divide 4195.68 by 100.

419568÷100=41.9568, answer.

In this case there are two decimals in the dividend and none in the divisor, therefore it might appear that only two decimals should be pointed off in the quotient. But in conducting the division it will be found that two ciphers are necessarily added to the decimal of the dividend in order to complete the division. The number 4195.68 is consequently virtually altered into 4195.6800, which does not alter its value, (155,) but it introduces two more digits into the decimal, making the total number 4; and as there are no decimals in the divisor to deduct from this number, it stands good for the number of decimals to be cut off in the quotient as above stated.

Note.—If the division is decimal—that is, if the divisor be 1 with ciphers, as 10, 100, or 100, &c.—then the quotient will be found by merely moving the decimal point in the dividend so many places further to the left as the divisor contains ciphers; prefixing ciphers, should they be necessary.

Examples.—217.3÷100=2.173 | 419÷10=41.9
5.16÷100=0.0516 | 0.21÷1000=0.00021.

There are several other operations to be performed upon fractions, both of the vulgar and decimal kind, but the foregoing have been selected as being those of most common occurrence and most useful to the Engineer, and they are introduced here to save the trouble of reference to other books, in case of the rules being forgotten. Those who are desirous of more extended information on the subject must have recourse to works upon the principles of arithmetic.

167. Before arithmetic can be applied to the practical operations of mensuration, it is necessary that the student should be acquainted with the geometric principles of obtaining the areas of surfaces; and accordingly the following problems will explain the rules that apply to such forms as are most likely to present themselves to the engineer, architect, builder, and land surveyor. To work the whole of them, lineal measure must be resorted to in the first instance, because the length and breadth or other assigned measurements of an object must be taken before it is pos-

sible to obtain either its superficial or solid measure. These primitive measurements may be taken with any convenient standard of measure, such as inches, feet, yards, &c., but in practice it has become usual to apply particular standards of measure to particular kinds of work, as will be explained in the sequel.

PROBLEM XXV.

168. *To find the circumference of a circle when the diameter is known; or the diameter when the circumference is given.*

RULE.—Multiply the diameter by 3.1416, and the product will be the circumference. Or divide the circumference by 3.1416, and the quotient will be the diameter.

Note.—The mixed number 3.1416 has an infinite decimal, consequently the operation is not quite perfect; and in very large circles, where great precision is required and more places of figures are necessary, the following, or such part of it as desired, may be used:

3.14159265358979323846264338327950288419716939937 5, &c.

This number is, however, introduced more as an example of the immense length to which an infinite decimal is sometimes carried, than for its utility. The proportion between the diameter and circumference of the circle has been calculated to 127 places of decimals.

When an approximation only is required, the problem may be solved more rapidly by the rule of three, because diameter is to circumference nearly as - - - 1 to 3.
Or more nearly as - - 7 to 22.
Or still more nearly as - 113 to 355.

This last proportion is very much used on account of its being sufficiently accurate for most practical purposes, and being very easily remembered, for it is a repetition of the first odd numbers 1, 3, and 5, separated into two parcels of three numbers each.

PROBLEM XXVI.—*Fig.* 42, *Plate II.*

169. *To find the length of any arc of a circle, if its chord or radius and angular extent are given.*

RULE FOR THE CHORD.—From 8 times the chord of half the arc subtract the chord of the whole arc, and one-third of the remainder will be the length of the arc nearly.

EXAMPLE.—Required the length of an arc, the chord $a\,b$ of the whole arc being 4.65874, and the chord $a\,c$ of the half arc 2.34947.

$2.34947 \times 8 = 18.79576 - 4.65874 = 14.13702$; $\frac{14.13702}{3} = 4.71234$ answer.

Rule for the radius and angle.—As 180 is to the number of degrees in the arc, so is 3.1416 times the radius, to the length of the arc. Or, as 3 is to the number of degrees in the arc, so is 0.05236 times the radius to its length.

Example.—Required the length of an arc *a b c* of 30 degrees, the radius being 9 feet.

$$3.1416 \times 9 = 28.2744.$$

Whence as 180° : 30 :: 28.2749 : 4.7124, the length of arc.

Problem XXVII.

170. *The span or extent of a building, and the height or pitch of its roof being given, to find the length of the rafters necessary for such roof.*

The general form of roofs is two right angled triangles, having but one common perpendicular between them, as in *Fig.* 44, where *k l* is the extent of the building, *m n* the height of the roof, and *k m* the length of the rafter required, which length, it will be seen, is the length of the hypotenuse of the right angled triangle *k n m.*

Rule.—To obtain it, add the square of the perpendicular *m n* to the square of the base or half span *k n*, and extract the square root of the sum, which will be the hypotenuse required.

Note.—This process must be used for measuring roofs that are inaccessible for want of a ladder or staircase. The extent *k l* can be obtained on the ground and halved; the perpendicular *m n* may be got by counting the courses of brickwork from *n* to *m*, or by holding up a measuring rod on a high pole, or by means of trigonometry.

Problem XXVIII.

171. *To find the area or superficial contents of a square or parallelogram; or any figure bounded by two right lined parallel sides, having right angles at the four corners.*

Rule.—Multiply the length by the breadth, or the dimensions of any one side by the dimensions of another at right angles to it, using the same denomination of measure in both instances, and the product will be the area in square dimensions of the same denomination.

Example.—Find the superficial area of a wall 6 feet 6 inches high and 21 feet long.

Decimally.	*Duodecimally.*
21	21
6.5	6 ft.6 in.
10.5	126
126	10 6
136.5 feet, ans.	136 ft.6 in., ans.

No examples will be given of the problems which follow, as they may all be worked in a similar manner.

Problem XXIX.

172. *To find the area of any rhombus or four-sided figure, in which the opposite sides are parallel right lines, but the angles not right angles, Fig.* 43.

Rule.—Erect a perpendicular *g i* on any part of any side *g h*; measure the distance of two opposite sides upon that perpendicular, and multiply by the length of either side that is perpendicular to *g i*.

Problem XXX.

173. *To find the area of a triangle or gable end of a building.*

Rule.—Multiply the length of one of the sides *o p* in either triangle of *Fig.* 46, as a base, by the length of a perpendicular *q r* falling upon it, from the height *q* of the apex of the triangle, and half the product will be the area; or,

The whole product obtained by multiplying one side into half the perpendicular height of the apex, will give the same result.

Problem XXXI.

174. *To find the area of a regular trapezoid. Fig.* 45.

Rule.—Add the top measure *r s*, to the bottom measure *t v*, and take half the sum for a mean, which multiply by the perpendicular height *u w*, and the product will be the area; or,

Multiply the top and bottom by the height, and take half the product.

This problem applies to the measurement of canal cutting when the work is wholly excavation, the two side slopes make equal angles with the bottom, and the two banks are of equal height.

Problem XXXII.

175. *To find the area of a trapezium, or four-sided right lined figure, in which no two sides need be equal or parallel to each other, as x, y, z, a. Fig.* 47.

Rule.—Draw a diagonal line *x y*, uniting two opposite angles, and converting the figure into two triangles; from the angles *a* and *y*, let fall perpendiculars to cut the diagonal for the purpose of obtaining the height of the two triangles; measure them separately by Prob. XXX., and their sum will be the area sought.

In *Fig.* 48, *x z* is the diagonal, and the side *y x* is at right angles to it, therefore *x y z* is a right angled triangle, and its side *x y* gives its height without any other perpendicular; and, consequently, only one need be drawn from the point *a*, for measuring the triangle *x a z*.

Note.—This is one of the most important problems in mensuration, and applies to a number of cases in building, land surveying, canal cutting, &c.

Problem XXXIII.

176. *To find the area of a circle.*

Rule.—Square the diameter, and multiply the result by the decimal 0.7854; or,

Square the circumference and multiply by 0.07958. The product, in either case, will be the area.

For the area of a semicircle proceed as if it was an entire circle, but only take half the product.

Note.—This rule is used in deducting circular openings in walls, and the semicircular arches over doors and windows, and in a variety of other cases.

Problem XXXIV.

177. *To find the area of a flat annulus or ring, or the space inclosed between two concentric circles, as in Fig.* 49.

Rule.—Find the area of the two circles separately, (by last problem,) subtract the smaller from the larger, and the remainder will be the area sought.

Or multiply the sum of their diameters by their difference, and the product by 0.7854.

This applies to the superficial measurement of the ends or faces of all circular and semicircular arches.

Problem XXXV.

178. *To find the area of a sector of a circle or figure, like c d e, Fig.* 50, *in which d is the centre of the circle.*

Rule.—From the dimensions given, calculate the sector as if it was an entire circle, and then state this proportion:

As 360° is to the number of degrees in the sector, so is the area of the whole circle just found, to the area of the sector.

Problem XXXVI.

179. *To find the area of the segment of a circle, or the space contained within any arc of a circle, and the chord of that arc,* (as at *f*, in *Fig.* 50.)

Rule.—Proceed as in the last problem to find the area of the sector, and from that subtract the area of the triangle *c d e*, formed by the chord and two radii, and the remainder will be the area of the segment sought.

Problem XXXVII.

180. *To find the area of an ellipse.*

Rule.—Multiply the transverse by the conjugate diameter, and the product by 0.7854, as in the circle.

Note.—From this the surface of elliptical arches may be found, following the process given in Problem XXXIV.

OF POLYGONS.

181. Polygons are usually spoken of as many sided figures, although the strict meaning of the word is many angled, and they are divided into two classes, called regular and irregular.

A regular polygon is a figure bounded by several equal right lines, which meet in angular points, which points are disposed in the circumference of a circle.

An irregular polygon is also bounded by several right lines which meet in angular points; but the lines are not equal in length, nor are the angles arranged in a circle.

182. Polygons may have any number of sides and angles without limitation; but, in general, when this figure is spoken of or used, the regular polygon of a few sides is referred to, and the figures are frequently some of the following:

				Multipliers.
The Trgon or Triangle,	having 3 angles	and 3 sides,	-	0.4330127
Tetragon or Square,	having 4 angles	and 4 sides,	-	1.000000
Pentagon,	having 5 angles	and 5 sides,	- -	1.7204774
Hexagon,	,, 6 ,,	and 6 ,,	(See *Fig.* 20, *Pl. I.*)	2.5980762
Heptagon,	,, 7 ,,	and 7 ,,	- -	3.6339126
Octagon,	,, 8 ,,	and 8 ,,	(See *Fig.* 19.)	4.8284272
Nonagon,	,, 9 ,,	and 9 ,,	- -	6.1818240
Decagon,	,, 10 ,,	and 10 ,,	- -	7.6942088
Undecagon,	,, 11 ,,	and 11 ,,	- -	9.3656411
Dodecagon,	,, 12 ,,	and 12 ,,	- -	11.1961524

The column of multipliers is for the purpose of obtaining the areas of the polygons against which they stand. For this purpose, square any one side, and multiply by the number against the kind of polygon under examination, when the product will be the area required.

Polygons are less frequently used than formerly. They were of constant occurrence in regular fortifications. Their use is now confined to the fluting of columns; the construction of panoptic prisons; the towers of Gothic buildings; the spires of churches, and a few other objects.

Problem XXXVIII.

183. *To find the area of a regular polygon of any number of sides.*

Rule.—Multiply the perimeter, or sum of the length of all the sides, by the length of a perpendicular, let fall from the centre of the circle to any side, and half the product will be the area sought.

This depends upon the regular polygon being composed of a series of equal and contiguous triangles, all having the centre of the circle for a common apex. See *g h i*, *Fig.* 51. The sum of all the sides is, therefore, equivalent to the sum of all the bases of the triangles, and the perpendiculars *h k*, is the height of these triangles; consequently this measurement depends upon that of the triangle. Prob. XXX.

Problem XXXIX.

184. *To find the area of an irregular polygon.*

Rule.—Draw or set out such diagonals in the figure as will divide it into trapeziums or triangles, or both, as shown by the lines in *Fig.* 52. Find the area of each separately, and the sum of the whole will be the area of the figure.

Problem XL.

185. *To find the area of a long irregular figure.*

Rule.—Take the breadths in several places, at equal distances from each other; add all these breadths together, and divide the sum by the number of measurements taken, to obtain a mean breadth; then multiply the mean breadth by the length of the figure, and the product will be the area.

Example.—Required the area of the irregular figure *a b c d*, *Fig.* 53, the breadth of which at *a c* is=8.1, at *e*=7.4, at *f*=9.2, at *g*=10.1, and at *b d*=8.6, and the length from *c* to *d*=39.

Here five breadths are taken, the sum of which are 43.4; and this sum, divided by 5, gives 8.68 for a mean breadth, and 8.68 ×39 gives 338.52 for the area of the figure.

This problem is of constant occurrence in land surveying for what is called measuring offsets.

The foregoing problems comprehend most of the cases that usually occur in measuring land or artificers' work, when the superficies only has to be examined; and those that follow relate to solid or cubic measure, which must next be considered.

SOLID MEASURE.

Problem XLI.

186. *To find the solid contents of a cube.*

Rule.—Find the area of one side by Problem XXVIII., and multiply that by the length of any side in the same denomination of measure, when the product will be the solidity required.

Example.—How many cubic inches are contained in a cubic foot?

12 inches$\times$12 inches gives 144 inches for the area of one side, and that product multiplied by 12, the length of one side, gives 1728, the number of cubic inches required.

Problem XLII.

187. *To find the solidity of a parallelopipedon.*

Rule.—Multiply the length, breadth and depth, or altitude, continually together; or, if more convenient, ascertain the area of a transverse section of that which has to be examined, and multiply that by the length for the solid contents.

Example.—What is the solid contents of a piece of timber 12 inches square and 3 feet long?

The sectional area is 1 square foot or 144 square inches by last problem; multiply, therefore, 144 by 36, the number of inches in 3 feet, because the same kind of measure should be used in both cases. The product will be 5184 for the number of cubic inches contained in the piece. To reduce this quantity into cubic feet, divide by 1728, the number of cubic inches in a cubic foot.

Note.—This problem is of most extensive use, and applies in a great variety of cases. Thus, if a wall is 40 feet long, 15 feet high, and 3 bricks, or 27 inches, in thickness, how many cubic feet of brickwork does it contain?

40 feet$\times$15 feet gives 600 feet for the area of the surface, which multiply by 2.25, (because 27 inches are $2\frac{1}{4}$ feet,) and the result will be 1350.00 cubic feet.

Problem XLIII.

188. *To find the solidity of a prism, cylinder, or other solid, having parallel sides.*

Rule.—Multiply the area of the base by the height, and the product will be the solid contents.

Example.—Required the solid contents of an equilateral triangular prism, each side of which is $2\frac{1}{2}$ feet, and whole height is 12 feet. The area of any equilateral triangle may be found by squaring one of its sides, and multiplying that square by 0.433013 (182); and this product multiplied by 12 feet, the height, will give the solid contents.

A consequence of this problem is, that all bodies which have parallel sides, and are therefore of the same size from top to bottom, will have equal solid contents, whatever their forms may be, whenever their bases and altitudes are alike.

Problem XLIV.

189. *To find the solidity of a cone or pyramid.*

Rule.—Multiply the area of the base by the perpendicular height of the cone, and one-third of the product will be the solid contents required.

Note.—If a cone, find the area of base by Problem XXXIII. If a pyramid of any number of sides less than 13, the area may be found by the Table of Multipliers. (Par. 182.)

Problem XLV.

190. *To find the solidity of the frustrum of a cone or pyramid.*

Rule, when the diameters of the two ends and the height of the frustrum of a cone are given—Divide the difference of the cubes of the diameters of the two ends by the difference of the diameters, and this quotient being multiplied by .7854, and again by one-third of the height, will give the solidity.

Rule for the frustrum of a pyramid, the sides of the base and top, and the height being given.—Add to the areas of the two ends of the frustrum the square root of their product, and this sum being multiplied by one-third of the height, will give the solidity.

Problem XLVI.

191. *To find the solidity of an irregular wedge.*

Note.—If it is regular, or has parallel ends, it is a triangular prism, and is found by Problem XLIII. But if the ends are not parallel, then

Rule.—To the length of the edge of the wedge *a b*, *Fig.* 54, add twice the length of the back or base *d e*; multiply this sum by the height *a p*, and then by the breadth *c d*, of the base, and one-sixth of the last product will be the solid contents. Therefore,

If *a p* the height=14, *a b* the edge=21, *d e* the length of base =32, and *c d* the breadth=$4\frac{1}{2}$, the solid contents will be thus found:

$21+64\ (32\times2)=85$; and $85\times14\times4\frac{1}{2}=5355$; and $\frac{5355}{6}=892.5$ cubic inches, the solidity required.

Problem XLVII.

192. *To find the solidity of a prismoid, or tapering pedestal, Fig.* 55.

Rule.—Add into one sum the areas of the two ends, and four times the middle section, parallel to them; and this sum, multiplied by one-sixth of the height, will give the contents.

Note.—The length of the middle section is equal to half the sum of the lengths of the two ends; and its breadth is equal to half the sum of the breadths of the two ends; consequently the middle section so obtained gives a mean sectional area of the prismoid, and may be multiplied by the height, as another means of obtaining the solid contents.

Problem XLVIII.

193. *To find the solidity of a sphere or globe.*

Rule.—Multiply the cube of the diameter by 0.5236, and the product will be the solidity.

Problem XLIX.

194. *To find the solidity of a spherical segment, or plano-convex portion of a sphere.*

Rule.—To three times the square of the radius of the base or flat side, add the square of the versed sine or height; then multiply the sum by the height, and the product so obtained by 0.5236, for the solid contents.

Example.—Required the solid contents of a dome 16 feet in diameter, rising 4 feet from its chord. In this case the radius of the base is 8 feet, therefore,

$8^2\times3+4^2=208$; and $208\times4\times0.5236=435.635$ feet, the solid contents required.

Problem L.

195. *To find the solidity of a spheroid, or solid ellipse.*

Rule.—Multiply the square of the transverse by the square of the conjugate diameter, and the product, multiplied by 0.5236, will give the contents.

Problem LI.

196. *To find the solidity of a parabolic conoid.*

Rule.—Multiply the square of the diameter of the base by the height or length of the axis, and the product by 0.3927.

Note.—Two such solids conjoined base to base, form a parabolic spindle.

Problem LII.

197. *To find the solid contents of a cylindrical ring.*

Rule.—To the diameter of the cylinder of which the ring is formed, add the extent of the inner diameter of the ring. Then multiply the sum by the square of the thickness or diameter of the ring, and the product by 2.4674, (which is one-fourth of the square of 3.1416,) and it will give the solidity.

Example.—Required the solidity of a ring, the thickness of which is 2 inches, and inner diameter 12 inches?

$12+2\times2^2=56$; and $56\times2.4674=138.1744$ inches.

Problem LIII.

198. *To find the superficies or solidity of the regular solids.*

Rule for superficies.—Multiply the square of one linear edge by the number in the table below, opposite the given solid, and headed surfaces, and the product will be the superficies.

Rule for the solidity.—Proceed as before, taking the tabular number, headed solidity, and the product will be the solidity.

199. *Table of surfaces and solidities of the regular bodies when the linear edge is* 1.

No. of sides.	*Names of solids.*	*Surfaces.*	*Solidity.*
4	Tetrahedron	1.73205	0.11785
6	Hexahedron	6.00000	1.00000
8	Octohedron	3.46410	0.47140
12	Dodecahedron	20.64573	7.66312
20	Icosahedron	8.66025	2.18169

200. Examples.—Required the superficies and solidity of a

tetrahedron, the linear edge or side of which is 3 inches. See *Fig.* 56.

$1.73205 \times 3^2 = 15.588$, &c. for its superficies.
$0.11785 \times 3^2 = 3.18195$, for its solidity.

Note.—The hexahedron is the same thing as the cube.

201. Required the superficies and solidity of an octohedron, *Fig.* 57, the linear side of which is 2 inches.

$3.46410 \times 2^2 = 13.85640$, for the superficies.
$0.47140 \times 2^2 = 3.77120$, for the solidity.

202. Required the superficies and solid contents of a dodecahedron, *Fig.* 58, whose linear edges are 2 inches.

$20.64573 \times 2^2 = 82.58292$, for the superficies.
$7.66312 \times 2^2 = 61.30466$, for solidity.

203. Required the superficies and solid contents of an icosahedron, *Fig.* 59, whose linear edges are 2 inches.

$8.66025 \times 2^2 = 34.64100$, for superficies.
$2.18169 \times 2^2 = 17.45352$, for solidity.

204. OF CONVEX AND CONCAVE SUPERFICIAL MEASUREMENT.

This is frequently necessary for determining the quantity of stonemasons, plasterers, or painters' work expended upon curved surfaces, such as domes, niches with arched heads, spheres, or portions of them, and various other figures introduced into buildings, for ornamental purposes.

No rules are given for concave surfaces, because no concave surface can exist, but what we may conceive a convex body that will exactly fit it and fill it up; consequently the convex surface will, in all such cases, be exactly equal to the corresponding concave one, and whenever a concave surface has to be determined, it is done by calculating the convex surface that so corresponds with it.

PROBLEM LIV.

205. *To find the convex surface of a cylinder.*

RULE.—Multiply the circumference by the length of the cylinder, and the product will be the convex surface required.

Note.—The upright surface of any prism may be found in the same manner.

PROBLEM LV.

206. *To find the convex surface of a right cone or pyramid.*

RULE.—Multiply the perimeter, or circumference of the base, by the slant height, or length of the side of the cone; and half the product will be the surface.

Problem LVI.

207. *To find the convex surface of a frustrum of a cone or pyramid.*

Rule.—Multiply the sum of the perimeters of the two ends by the slant height or side of the frustrum, and half the product will be the surface required.

Note.—This problem applies to measuring the surfaces of all columns which taper gradually from their base.

Problem LVII.

208. *To find the convex surface of a sphere or globe.*

Rule.—Multiply the diameter of the sphere by its circumference; or, multiply 3.1416 by the square of the diameter, and the product will be the convex surface required.

Note.—The convex surface of any zone, or segment of a sphere, may be found, in like manner, by multiplying its height or projection by the whole circumference of the sphere.

Problem LVIII.

209. *To find the convex surface of a cylindrical ring.*

Rule.—To the thickness of the ring, or diameter of the cylinder, of which it is composed, add the inner diameter of the ring; multiply this sum by the thickness, and the product by 9.8696, (which is the square of 3.14159,) and it will give the superficies required.

210. It is believed that the above rules will meet every case and form that the Engineer, Architect, Surveyor, or Artificer may have to measure, except in very extraordinary instances; and it may appear that the next step should be to show the practical application of them to their several purposes, with which it was, at first, intended to close the present chapter. But inasmuch as many technical phrases occur in the mensuration of actual work, and these have not yet been explained, and consequently could not be understood, the better and more useful course appears to be, to describe the several varieties of work in the first instance, and to conclude each article as it is completed with the rules that apply to its measurement, making references, whenever necessary, to the foregoing problems, as by this arrangement, it is believed, no difficulties can occur. This mode of proceeding will be accordingly adopted.

CHAPTER IV.

ON LAND SURVEYING.

211. Land surveying, in its detail, is nothing more than a practical application of some of the principles described in the last chapter, but used on so large a scale that the ordinary instruments of measuring, and methods of using them, will not apply without variations and precautions, which it will be the object of the present chapter to describe. It comprehends not only the measurement of land, by which its quantity is ascertained, but the plotting, or drawing of maps or plans, that will represent the precise forms, relative positions, and proportional distances of all the objects that occur upon the ground, all of which should be laid down upon the map with such exactitude that it becomes a perfect representation of what occurs in nature, and should admit of the proportional distances of objects being measured and ascertained by the compasses and scale, as correctly as if they were actually measured on the surface of the earth.

212. Land surveying is usually considered as a distinct profession in the old settled and thickly populated countries; and the regular land surveyor not only measures and ascertains the precise quantity of land, and prepares a map or plan of it, but he is also an appraiser. He sets a value on the several varieties of soil according to its location; he measures and values the timber and standing crops, as well as the buildings, fences, and improvements upon the soil; and should be able to give his employer, not only the quantity and position of his land, but the actual value of every thing that occurs upon an estate.

213. Land surveying does not properly belong to, or form a part of, the duties of the Civil Engineer; but, in many instances, he is unable to lay down his plans without its assistance, especially for the formation of roads or canals. In England, when such works have to be set out in the first instance, it is always customary to employ a land surveyor to make a map or plan of the route, before the Engineer begins his operations, further than by going once or twice over the ground and pointing out the line

proper to be surveyed. The reason for this course of proceeding is—1st. That the land surveyor usually follows no other occupation, and possesses all the necessary instruments; and by constant habit and application to the same pursuit, acquires a facility and expedition, that the Engineer, whose attention is constantly drawn to a great variety of objects, can hardly be expected to possess; and, 2ndly. The constant attention of the land surveyor to the same business, enables him to furnish a plan for a much less sum of money, than if it was prepared by the Engineer, who, on account of the extent and versatility of his knowledge, always receives a higher rate of compensation for his time and services than the mere land measurer. Some of the principal Engineers keep clerks or assistants in their offices, who devote themselves entirely to land surveying and mapping, for the purpose of producing plans for their principal.

214. It frequently happens that good maps, to large scale, may be purchased, or that private local plans of estates may be procured among the land owners upon a line, which afford material assistance, and may save the expense of a primitive survey. The Engineer, in this case, can copy them by tracing-paper, (90,) and afterwards by altering and making the scales to assimilate, may recopy them into one general and connected plan, and the Pantagraph before described, (103,) will be found a most convenient instrument for copying and reducing, or extending plans for such purposes.

215. In whatever manner the primitive map or plan of the country may have been procured, it is the duty of the Engineer to compare and examine it with the real ground, to prove its correctness; and likewise to stake, or otherwise set out his works upon the ground; and to introduce them into such map, as the staking or setting out proceeds, so that the marked map may become a perfect resemblance, as to form and position, of the work that has to be executed.

It frequently happens in new or thinly populated countries, that the advantage and assistance of a land surveyor cannot be procured. Or the Engineer, with a view to correctness, may wish to execute his own survey, and it is hoped that the directions which follow will enable him to do so.

216. Land is always measured lineally, by miles, furlongs, chains, poles, yards, feet, links and inches; and the following table will show the proportions these several lineal measures bear to each other.

Table of American and English Lineal Measures of Land.

in. 7.92=	1 link						
12=	$1\frac{17}{35}$=	1 foot					
36=	$4\frac{6}{11}$=	3=	1 yard				
198=	25=	$16\frac{1}{2}$=	$5\frac{1}{2}$=	1 pole			
792=	100=	66=	22=	4=	1 chain		
7920	1000	660=	220=	40=	10=	1 furl.	
63360	8000	5280	1760	320=	80=	8=	1 mile.

217. The following table exhibits in like manner the proportions that the *Square Measures of Land* bear to each other.

9 feet	1 yard					
$272\frac{1}{4}$	$30\frac{1}{4}$	1 perch				
4356	484	16	1 chain			
10890	1210	40	$2\frac{1}{2}$	1 rood		
43560	4840	160	10	4	1 acre	
27878400	3097600	102400	6400	2560	640	1 mile

218. The words perch, pole and rod, are used synonymously in land measuring, and are all the same lineal measure; but the rood is a square measure, equal to the fourth of an acre. The surface of land is estimated in acres, roods and perches, and occasionally in square yards and feet, when great nicety is required.

219. The instruments absolutely necessary for the ordinary purposes of land measuring are, a chain and arrows, or markers; a few picket or station staves, or sight rods; some small stakes and a mallet; a pair of offset staves; a surveyor's cross, and a pocket compass. And to these must be added, for more accurate and extended surveys, a Circumferenter or Theodolite. Another simple instrument, called a plain table and sights, is also very convenient for small surveys, as by its means the survey and plan

are made at one operation. In all cases a small blank book, called a field book, and pen and ink, are necessary for recording observations; and a measuring tape, which rolls into a leather box by a small brass winch, and is divided into links on one side, and yards and decimals of a yard, or even into feet and inches, on the other, will prove very useful for taking short lengths. Such tapes are made in 2 or 4 pole lengths, and are very portable.

220. The measuring chain is usually made of strong iron wire, with a handle at each end, by which two persons called chain bearers carry it. The one that precedes is called the leader, and the other the follower. Any one can lead a chain, but some skill and attention is necessary in the follower, because he has to direct the leader in his movements, and to give him other instructions. The arrows or markers are always 10 in number, and are composed of pieces of strong iron wire, about 15 inches long, sharpened at the point, and bent into an eye at the opposite end, for the convenience of stringing them upon a cord or leather strap to carry them and prevent their being lost. A piece of scarlet cloth should be attached to the eye of each arrow to render them distinctly visible when stuck in the ground, particularly in the grass, as without this precaution much time is frequently lost in searching for them. In using the chain, a peg or stake is driven into the ground to mark the starting point from which the measurement begins, and the whole of the 10 arrows are given to the leader. The follower stands at the starting stake, and places his end of the chain in contact with it, or rather holds it in his hand over it, while the leader proceeds with the other end of the chain in the desired direction, until it becomes nearly stretched or extended, when the follower gives the word *halt*, and the leader stops. The chain is now lifted from the ground and stretched, when the follower places its end carefully to his mark; and having observed that the chain is in the right direction, and not deflected by bushes or other obstacles, he gives the word *down*, and the leader places the chain upon the ground, keeping it tightly stretched. The follower having observed that all is right, calls out *mark*, when the leader sticks one of his arrows into the ground close to his end of the chain, and the first chain is completed. The bearers then both proceed onwards, and at this time the chain should be slightly strained, so as to take off its bearing against the ground, otherwise it will be liable to get entangled with weeds, or to wear out, or at any rate to become elongated. The follower must look at some mark to guide the proper direction of the measurement, and will accordingly order his leader to the right or left to preserve that line. He must likewise take care to so direct the movements of his leader, that the chain in its

progress may not rub against the arrow that has been left in the ground; for if that gets knocked down or displaced, the operation must commence again. Having proceeded in this manner until the follower arrives at the arrow that was left, he again halts his leader, adjusts the chain, and orders a second mark to be made; and that done, he takes up the first arrow and retains it, and so of others in succession, until the whole 10 arrows of the leader are exhausted and have come into his possession. The chain remaining stretched on the ground, the leader now comes back to the follower to take up the arrows he has picked up, and the follower registers this operation by an entry in his book, or what is more common in the measurement of long lines, by making a knot in a string that he has previously attached to his button-hole for that purpose, each knot standing for 10 chains. In this way errors seldom arise; but some Surveyors, to guard against them, and insure the certainty of not having an entire line to measure over again from mistakes, use the precaution of driving a permanent peg or stake at every 10 or 20 chains, or other stated regular distances.

221. Simple as the common measuring chain may appear to be, it is nevertheless a beautiful contrivance of the celebrated mathematician, Edmund Gunter, who lived in London in the seventeenth century, and is most admirably suited to the purposes for which it is intended. It is 22 yards, or 66 feet, long, and is divided into 100 equal links, so that links are decimal fractions of a chain. The acre contains 4840 square yards, and the chain being 22 yards long, if its length be squared, it produces 484 square yards, or the tenth of an acre; consequently 10 square chains are an acre, and as each chain contains 100 links, so an acre will always be equal to 100,000 square links. In setting down or recording measurements taken with the chain, the number of links are placed as decimals after the number of chains, so that a piece of land containing 16543 square chains and 75 links would be set down as 16543.75, and on taking away the decimal point, the number would be altered to 1654375, which would express the total number of square links contained in the land. But if the measure of a piece of land taken in square links is divided by 100,000, or the number of links in an acre, or, which is the same thing, if the 5 right hand numbers are pointed off as decimals, (which is the same as dividing by 100,000,) the figures will at once express the acres and fractions without further calculation. Thus cutting of the five decimals gives 16.54375, or 16 acres, and the decimal .54375.

222. The acre consists of 4 roods, therefore if this decimal be multiplied by 4, it will become 217500 links; and now, if 5 de-

cimals be again pointed off, it shows that the fraction is worth 2 roods and .17500; and again multiplying this fraction by 40, the number of perches in a rood, we shall obtain 300000, and now pointing off 5 decimals, leaves 3 perches without a fraction, and shows that such a piece of land would contain exactly 16 acres, 2 roods and 3 perches. This example shows at once the process that must be resorted to for converting quantities taken in chains and links into acres, roods and perches, while the remainder, if any, will be square links.

223. In using the chain, it must be borne in mind that the handles at its two ends count into its length; and for the facility of counting the links, small brass indices are attached at certain points among the links. Thus the 10th link from each end has a single point or brass finger attached to it; 20 links from each end has an index with 2 points; 30 links one with 3; 40 links one with 4; and 50 links, or the middle of the chain from each end, is marked by a small round brass plate; so that by looking for these marks the distance from either end is given upon inspection, and a portion only of the next 10 links has to be counted.

Many persons, for the sake of having a light chain to carry, purchase those that are made of thin wire; but they can never be depended upon, because the strength of the wire should be such as to permit the chain to be stretched without any fear of any of the links opening or expanding, an inconvenience to which even the strongest chains are liable. No chain should therefore be used many days in succession without an examination; and this is one use of the offset staves, which are 6 feet 7.2 long, and are divided into 10 equal parts of the same length as links; and the surveyor should have a small hammer for beating or closing up the links and thus adjusting his chain, for upon its accuracy all his operations must depend; and in the more extensive operations of trigonometry the correct measurement of a good base line is of vital importance to the success of the whole operation.

224. Chains are sometimes made only 2 poles long, and are convenient in woody countries. They are called half chains. They should not be used when there is room for a full chain, because they occasion loss of time and lead to errors, being sometimes set down as whole chains.

225. No one without actual experience can conceive the great difficulty that occurs in setting out and measuring right lines of great length in real practice. Indeed, with a common chain, and such apparatus as land surveyors usually employ, it is quite impossible to do it, so as even to approach to mathematical accuracy; therefore every precaution should be taken by the surveyor to make his operations as correct as possible. The principal sources

of error in land measuring proceed from the chain not being carried and stretched in a perfect right line; from the chain being unequally pulled or stretched when laid down; from the surface of the ground upon which it is laid before marking being uneven, which makes the chain measurements shorter than they really should be; from the arrows or markers not being placed exactly at the ends of the chain, or being fixed in an exact perpendicular direction in the ground; and lastly, from the expansion and contraction of the metal itself, which will vary the length of the chain with different temperatures. Most of these circumstances may, however, be much diminished by careful operators.

226. In conducting great trigonometrical operations, in which the success depends in great measure upon the accuracy with which the original base line is measured, no time, labour, or expense is spared in making it as perfect as possible. If chains are used, they are composed of long links, and the chain itself is strained by equal weights, in every case acting over pullies fixed on the tops of pedestals attached to the ground, and made truly level on their tops, so that the chain does not rest upon the ground, and the quantity of its sag or depression is ascertained. At other times cylindrical glass rods have been made use of, supported at such short distances upon levelled stakes as to prevent their sagging, and having their ends rounded, polished, and laid in contact with each other. Glass is selected for this purpose because less liable to bend, or to expand or contract by heat, than almost any other material that could be used. Such precautions are, however, too delicate, costly and tedious, to be attempted in the ordinary measurement of land.

227. The first thing the ordinary land measurer must attend to, before he attempts to use the chain, is the setting out of as good or straight a right line as possible upon the ground; and this is done by means of the station or picket staves, or sight rods, of which every surveyor should possess at least half a dozen. They are nothing more than straight cylindrical or slightly tapering sticks, shod with iron points at their bottoms, for the facility of sticking them upright into the ground. They should be perfectly straight, and at least 6 or 7 feet high; and if painted white, will be more distinctly seen at great distances. A saw-scarf or slit should be cut 3 or 4 inches down each staff, for the purpose of sticking in a piece of white paper to render them visible at great distances, particularly in woody places, or to mark particular rods for particular purposes.

228. To set out a straight line upon the ground, the surveyor must first mark the two ends of the required line by fixing a picket-staff at each point; then standing a short distance behind

either of the staves, he closes one eye, and looks by the side of the staff near to him at that which is distant, and in the meantime gets an assistant to fix up other intermediate staves at as nearly equal distances as can be guessed at without measuring, taking care that they shall be so placed in a direct line as to appear to assimilate and combine with the two first rods set up; or in other words, that the nearest rod shall hide or cover all the intermediate ones when looking from the first towards the last. This adjustment, as to position, is easily affected by making signals with the hands to the assistant, by which he is directed to move his staff to the right or to the left of the line before fixing it in the ground. The picket staves remain in their places until that line is done with, and then they are moved for setting out another, unless the two extreme staves should require to be left standing for other uses.

229. Every line that has to be measured by the chain should be previously set out in this way, whenever its length exceeds two or three chains, and the chain-bearers will then have no difficulty in moving in right lines, since they must keep the chain constantly in contact with the staves, and coincident with the line so set out. In this same way are all diagonals from one corner of a field to another, or from one part of an estate to another, to be set out upon the ground. This operation is technically called *boning* a line, and the examination of its truth is called, seeing if it *bones* well; terms indicating the goodness or perfection of the line, derived from the old Norman French, in common with a great number of other names used in architecture and engineering.

230. The next essential instrument for ordinary land measuring is the *surveying cross*, which is intended only for setting out right angles upon the ground, either for the purposes of surveying, or commencing buildings that are to have square corners. This instrument, as it is usually made by the instrument-makers, is shown in perspective at *Fig.* 60, *Plate II.* It is made wholly of brass, and consists of four upright plates *a b c* and *d*, called sights, which are fixed at right angles upon a cross-shaped piece *e*, on the under side of which is a socket *f* to receive the staff *g*, upon the top of which the cross may be fixed by tightening the screw *h*. The staff *g* should be nearly equal in height to the observer's eye, to prevent stooping; and its lower ex-extremity terminates in a sharp iron point for sticking it in the ground. The sights *d* and *c* are each perforated by a very narrow slit, extending nearly from top to bottom, to the intent that when the eye is applied to look through them for observing an object, it may range upwards and downwards, but cannot be moved laterally. The opposite sights *a* and *b* are perforated by

long square openings, over the middle of which a horse hair or fine wire is extended in a vertical direction; and the instrument must be so adjusted by the maker, that when the eye of an observer is applied to the slit at *m*, and sees the distant object *k* covered or bisected by the wire in *a*, and another observer applying his eye at *n*, and finding the wire of *b*, in like manner covering the object *i*, the two dotted lines of sight *m k* and *n i*, must be correctly at right angles with each other. Hence a right angle may at any time be set out upon the ground by such an instrument; thus suppose the object *k* to be fixed, and that the staff of the instrument is stuck into the ground and turned round until that object is seen from *m*, and is exactly covered by the wire in *a*. The instrument now remaining stationary, the observer applies his eye to *n*, and directs his assistant to fix a picket-rod in a distant position, so that it shall be seen covered by the wire of *b*. It will be evident that the only position in which that rod can be set down, so as to fulfil the conditions, will be at *i*, and that the two sight lines *m k* and *n i*, must be at right angles to each other, crossing at the point where the staff is stuck into the ground, provided the staff has been set upright.

In this instrument the opposite sights must be, at least, five or six inches apart, to prevent the wires coming within the limits of distinct vision when the eye is applied to the slits. The sights are usually made to unfix from the horizontal cross, by thumb-screws, for packing to travel; and the instrument is an expensive one, on account of the necessary perfection of workmanship, and difficulty of so adjusting the sights that they shall give precise right angles, in every direction in which they may be looked through: but, at the same time, it is not a convenient practical instrument, on account of its liability to injury, for the sights are very liable to get bent by blows against trees or fences, or by contact with other instruments in carrying, and it may get out of truth by frequent packing and unpacking. It, therefore, requires frequent examination as to adjustment, and that is done in this, as in all other surveying crosses, by setting out a right angle with the sights in a fixed position, as above described, and then turning the instrument a quarter round, and seeing if it measures that same angle over again with equal precision.

231. A surveying cross, that is very much used by practical surveyors, and is quite as effective, if carefully made, and much less costly, is shown at *Fig.* 61. It consists of a cube of any hard and well seasoned wood, fixed on the top of a pointed staff, as before. Two vertical cuts are made by a tenon saw on the top of the cube, exactly at right angles to each other, and they proceed down to about three-quarters of the depth of the cube, leav-

ing sufficient wood at the bottom to maintain all the parts firmly in their places. These saw cuts are the sights, and they are to be looked through and used exactly like the former instrument. A thin cap of wood may be fixed, by four screws, on to the top of the cube, and then there will be no danger of its breaking or warping. The same instrument might be formed out of a cylindrical piece of wood, and would be more convenient to carry; but it is more difficult to make the cuts correctly at right angles in a cylinder than in a cube. A cylindrical form may, however, be given to the cube after the cuts are made and proved, or the vertical corners may be truncated or bevelled off, as indicated by the dotted lines in the figure. The only inconvenience attending the use of this instrument, is its having so very narrow a field of view in a lateral direction; for nothing can be seen to the right or left of the direction of the cut; but this may, in some measure, be obviated by making two centre-bit holes through the cube, at the bottom of the cuts, to be looked through in the first instance.

232. Both these instruments are troublesome, and sometimes tedious in their practical use, as will appear when their applications are hereafter described. On this account the author contrived a little instrument for his own purposes, and which he has used extensively, with so much satisfaction, that he believes no one will desire to use any other kind of cross, after having witnessed its convenience and expedition. It may be called *the reflecting surveying cross*, and the idea of it arose from his having occasionally used a reflecting snuff-box sextant, set to 90°, for the purpose of taking offsets. The external appearance of this instrument is shown at *Fig.* 62. It consists of a circular box like a large snuff-box, from three to three and a half inches diameter, and about one and a quarter inches deep on the outside. An observing or eye-slit is made in the side at *a*, and directly opposite, on the other side of the box, a round or square hole is made, as large as the width of the box will admit. This is dotted in at *b*, in the figure, because it would not be visible in the position of the box there shown. Another large hole is made in the side of the box at *c*, in a position exactly at right angles to a line that would join the centres of the other openings *a* and *b*. *Fig.* 63 is a plan of the box with the lid removed, to show the relative positions of the holes, which are marked with the same letters *a*, *b*, *c*, and of the reflector *d d*, which is a strip of thin parallel looking-glass, the length of which is equal to the diameter, and its width equal to the depth of the box. The silvering is scraped off the upper half of this strip of looking-glass, in order that direct vision may take place through it; consequently if the eye E, be applied to the slit *a*, it will observe the distant object D,

by direct vision through the hole *b*, and upper unsilvered half of the reflector *d d;* while if another object R is at right angles to the line DE, it will be seen through the hole *c*, will be reflected by the lower silvered half of the mirror into the direction *a*, (because the mirror is inclined 45° to DE,) and will thus appear to coincide with the object D.

The reflector is fixed in its place by four angular blocks of cork or wood, glued into the inside of the box, as shown in *Fig.* 63, and its adjustment as to due angular position may be effected by observing objects previously disposed in proper positions before the glue becomes set and hard. If a slight correction of position should afterwards be found necessary, it may be produced by cutting away a small portion of one of the pieces of cork, and introducing wedges opposite to it, which should be glued in to prevent their falling out. This done, the inside of the box is coloured dead black with lamp-black and thin glue, when the lid of the box may be permanently screwed down to prevent injury to the mirror. The three holes, or openings *a b* and *c*, may also be closed by thin parallel window glass, and then neither dust or any thing else can get into the box to injure it, even if carried open in the pocket.

233. The last of the instruments named, as being necessary to the operations of ordinary land measuring, was a pocket-compass or magnetic needle, for the purpose of ascertaining the north, south, east, and west points of the land, or the cardinal points, as they are frequently called; and such a one may be a separate instrument, or may be very conveniently included in the lid of the reflecting cross, *Fig.* 62. In small surveys the compass is not essential, because the sun is always due south at twelve o'clock; therefore, by holding a stick perpendicularly upon the ground at this hour, its shadow will give a north and south line with sufficient accuracy, and this is an expedient the land surveyor often resorts to, in the absence of his compass.

234. Land surveying, when the estate or object of survey is not very extended, requires no other instruments than those above described, and their application to the purpose is very simple, for the operation is always conducted upon the principles laid down in Prob. XXXII., (175,) and illustrated by *Fig.* 47, *Plate II.* That is to say, a diagonal is to be drawn from any one corner of a four-sided field to the angle most nearly opposite to it, so as to divide the field into two triangles, and then perpendiculars must be raised either upon that diagonal, or upon some side of the triangle for the purpose of obtaining its area. (Prob. XXX., Par. 173.) Thus, suppose *a x y z*, *Fig.* 47, to represent an irregular four-sided field,

which requires to be measured. The first operation will be to set out and bone the diagonal line *x z*, which is done upon the ground by a row of picket-rods; then the line *x z* must be measured by the chain and arrows; and suppose the result to be 18.25 chains—this one measurement gives the bases of both triangles, because *x z* is a common base to the two triangles *z a x* and *z y x*. Having thus got the length of both bases, the next object must be to get the height of the two triangles, or the distances of their two summits, *a* and *y*, from the base *x z*, which is done by measuring the two lines *a b* and *c y*, which must both be perpendicular to *x z*. To set out such perpendiculars for measurement, the surveyor's cross (Par. 230, *Fig.* 60) must be used. That instrument must be set upon the line and be moved backwards and forwards between *x* and *z*, until two picket-rods fixed at the points *x* and *z* may be seen through one pair of sights, and another picket-rod at *a* may be seen through the other pair; and this can only take place when the instrument is fixed over the point *b*, consequently *a b* must be perpendicular to *x z*, and *a b* will therefore be the line to be measured. That done, let it be supposed that it measures 5.50 chains.

The cross must now be removed to another part of the line *x z* that shall be opposite to *y*, that is to the point *c*, in which the two picket-rods at *x* and *z* are visible through one pair of sights, while another rod fixed at *y* shall be visible through the other pair. This will mark the line *c y* as the other perpendicular to be measured; and suppose it to be equal to 6.30 chains, then the triangle *x a z* will be equivalent to 18.25×5.50 or 100.3750, and the triangle *x y z* to 18.25×6.30 or 114.9750, the sum of which is 215 square chains and 35 links. But in measuring triangles only half the product of the base by the altitude must be taken, (173,) therefore the half of 215.35, or 107.675, will be the correct area of the piece of ground.

We thus see that whenever a piece of ground can be reduced into triangles, whatever may be its primitive shape, its superficial quantity can be determined by one long and one short measurement in each triangle, without any notice being taken of the amount of the angles at the corners; and thus a very simple and easy, and at the same time correct, result is produced.

235. The diagonal is of great use and importance in this problem, because it is owing to its interposition that the measurement of the corner angles becomes unnecessary. Thus, for example, a piece of land *a b c d*, *Fig.* 65, may be so nearly square at its corners and parallel in its sides that the unassisted eye might be unable to determine whether it was a regular parallelogram or not, and to decide this question it would be necessary to measure

the two sides *a b* and *c d*, as well as *a c* and *b d*, to ascertain whether they were respectively equal to each other; and if that should be found to be the case, then the contents of the field could be obtained by multiplying a long side *a c* into a shorter one *a b*, or *vice versâ*. Still, however, this field could not be plotted or drawn into a plan from these measurements, because we have no evidence that the angles *a* and *c* are right angles, or what their exact angular extent may be; and since the dotted line *a f* is equal to *a b*, and *c e* is equal to *c d*, these might be the true boundaries of the field, and might yield an equal result to calculation. In order to determine the true shape of the figure, we must therefore measure the two angles at *a* and *c* by a theodolite, or other instrument for the purpose, and thus we have at least five operations to perform, viz: measuring the two angles at *a* and *c*, and the three lines *a b*, *a c* and *c d*, before the true form and proportions of the figure can be determined. But if the diagonal *b c* is introduced, then an equally exact determination of figure takes place upon measuring the diagonal *b c*, and the two perpendiculars *a g* and *d h* fall upon it from the points *a* and *d;* because, while the lines *b c* and *a g* retain a certain determined length in respect to each other, and the distances *c g* or *g b* are given, it is impossible for the point *a* to change its position, or for the angle at *a* to vary. What is said of the triangle *b a c* equally applies to the opposite triangle *b d c*, and this may be considered as the basis of all the operations in ordinary land surveying.

236. If the mere dimensions of land are alone required, no record need be made of the precise positions of the perpendiculars or offsets *a g* or *h d* in the field book, as all that is required to be set down is the respective lengths of the three lines *b c*, *a g* and *d h*. But if a plan of the field has also to be made, then the exact distances *c h*, *h g* and *g b* upon the line *b c* must be noted down, as well as the lengths of the several lines or offsets *a g* and *d h*; because all maps or plans are similar figures, and to produce them, all these lines must be laid down upon the paper, on a scale proportionate to the real lines upon the ground. Thus, if the diagonal line *b c* upon the ground is 60 chains long, then beginning at the point *c*, the first offset *h d* will be to the right or east, and will occur at 14 chains from *c*, as discovered by the cross, and this must be so noted in the book. The surveyor then walks along the line *c b*, measuring it as he proceeds, and looking to the right and left to observe whether any house, tree, angle, or any other object occurs that has to be introduced into the plan. Thus, when he arrives at the 35th chain he will find himself opposite to the angle of a house at *i*, and this must be

again inserted in the book as a right hand offset at 35 chains. Again proceeding onwards, on arriving at *g* he will be opposite the angle *a*, which will be noted down as a left hand offset at the 50th chain, (or 50th chain and any number of links, as the case may be,) after which the measurement is continued to *b*. That done, he returns along the line and measures the left hand offset from *g* to *a*, which is found to be 27 chains, and is noted in the book accordingly. He next takes the right hand offset from the diagonal to *i*, which fixes the position of the house, the dimensions of which must be separately taken in the margin of the book. Lastly, the right hand offset from *h* to *d* is measured, and may be 28 chains, which length is also put down.

237. To produce the plan upon paper, the diagonal *b c* must first be laid down to any scale that will divide it into 60 equal parts or chains, and now the plotting scales (52) come into use. If a scale of 10 chains to an inch should be adopted, then the line *b c* must be 6 inches long, because the real line on the ground is 60 chains. Taking off 14 chains on the scale with the compasses and transferring it from *c* to *h*, will give the point *h*, upon which the perpendicular *h d* must be erected by a pencil line. Taking 35 chains from the scale and transferring it from *c*, the place of the offset *i* will be determined, and must be marked by a pencil line parallel to *h d*; and in like manner the point *g* is determined at 50 chains, and a pencil line *a g* is drawn also parallel to *h d*, or perpendicular to *b c*. The several lengths of the lines *g. a*, *i* and *h d*, are next determined by the scale and marked off, and this fixes the positions of the points *a d* and *i*, consequently drawing lines from *a* to *b* and *c*, and from *d* to *c* and *b*, will complete the plan, all but putting in the house at *i*, which must be done to the same scale, from the dimensions previously taken and noted down.

238. It has been stated that the points *h* and *g*, upon which the offsets or perpendiculars *h d* and *g a* are to be raised, must be discovered by the surveying cross; and this makes a few observations on the method of using that instrument necessary, and they will apply equally to either of its forms shown at *Figs.* 60 and 61. In measuring the piece of land just referred to, the surveyor's first operation would be to set out the diagonal line *c b* by means of picket-staves, and these are left standing until that line is done with. Instead of proceeding to measure it, his next attention must be to discover the first point of offset *h*, (presuming that he is proceeding from *c* towards *b*.) To effect this he walks along the line *c b*, taking the cross with him; and when he believes himself opposite the picket-staff that has been previously set up at the angle *d*, he stops and plants his cross, by sticking

the bottom of its staff into the ground, in the direction of the diagonal line just set out. He now turns one pair of the sights into the direction of this same line, and applying his eye to the instrument, looks towards *b* and *c*, and gets that pair of sights to range exactly with the line. That done, he leaves the instrument so fixed and looks through the other pair of sights for the staff at *d;* but to his disappointment he finds that he was mistaken in his position and has gone too far, for the sights direct him to the point *m* instead of to *d*, and he must not turn the instrument round to catch the point *d*, for, if he did so, the other pair of sights would no longer coincide with the line *c b*. His labour is therefore thrown away, and nothing remains but to take up the instrument and walk back, say to *i*, where he plants and adjusts it as before, and now finds that he has gone back too far, for the cross sights now direct his visual ray to *n* short of *d*. The instrument must therefore be taken up once more, and be re-set and adjusted perhaps three or four times before a perfect coincidence between the points *b* and *c* and one pair of sights is obtained, at the same time that the other pair of sights point directly to *d*; and a repetition of this kind of adjustment must take place at every point upon which it is necessary to use the cross, however numerous they may be. This at once shows that the instrument is not one of very easy application; and in some instances it has been found so trying to the patience of the observer, that he will admit a small error in position, or will incline the staff of the instrument so that it no longer stands over the point in the ground which the bottom of the staff should indicate, and this cannot fail to introduce errors into the measurement that may amount to a link or more at each station.

239. With the Reflecting Cross the case is very different. It has no staff, but is carried in the hand, and requires no fixing or adjustment. The observer has only to walk along the line set out, applying the instrument occasionally to his eye, and looking at the mark *b* by direct vision through the unsilvered part of the looking-glass. As he proceeds he will see the picket-rod at *d* by reflection when he comes opposite to it, and then he stops, and releasing the small mill-wright's plumbet, *Fig.* 64, the string of which is passed through a small eye *d*, *Fig.* 63, purposely fixed in the centre both of the top and bottom of the box, the point of that plumbet will indicate a precise spot upon the ground, which is the summit of the right angle required, and which is immediately marked by setting up a station staff, with a paper in its top slit, to indicate the point. He then walks on, and fixes and marks the other offset points; when, to prevent mistakes, all the

other picket-staves, except the two extreme ones on the points *c* and *b*, had better be taken up.

240. The chain measurement now begins from the point *c*, and the number of chains and links that occur between the starting point and the first, and all succeeding offset points, being carefully noted down, the offsets themselves are next measured and set down; and should they be long, it will be advisable to bone them by picket-staves before the chain is applied.

241. The best field book that can be kept for simple operations like that which has just been described, is to make an eye sketch of the form of the piece of land, and to set down the dimensions as they are taken upon such plan in their proper relative places. For more complicated operations a form of field book should be used which will be hereafter described.

242. The mill-wright's plumbet or plumb-bob above referred to, and represented at *Fig.* 64, is a very useful implement to the Engineer for fixing machinery, and ascertaining any one spot that is directly over or under another. It is made of brass, with a sharp steel point at its lower side for indicating a precise spot. The whole should be turned in a lathe, and the suspending line enters the vertical axis of the instrument, so that the point can have no tendency to turn to one side or the other.

243. The example that has been given of land measuring applies to four-sided fields only; but even if they are more complicated, the same mode of operation would hold good. Thus *Fig.* 52, *Plate II.*, may represent the form of a piece of land bounded by seven right lined sides, and such a piece must be divided into five triangles by the four long diagonal lines shown by dotted lines in the figure. The short lines drawn perpendicularly to these diagonals show the offsets that must be taken to measure the five triangles separately, and the sum of their contents will give the contents of the entire piece of land.

244. When the boundaries of fields are curves instead of right lines, the operation shown by Prob. XL., Par. 185, and *Fig.* 53, must be resorted to. Thus, suppose a piece of land to be in the form shown by *a b d e f* in *Fig.* 66, in which the side *k b m c d* is bounded by a crooked river, and the side *a i k b* by a waving irregular fence. The boundaries of this field cannot be considered as straight lines, as in the preceding example, but the surveyor must consider how it may be divided so that the greater part of the land may be included in a small number of triangles. Accordingly, by setting out the diagonals *a d* and *a g*, the portion included between *a d e* is converted into one large and convenient triangle, and that included between *a g* and *f* is reduced into another. Then by boning a line from *a*, so that it shall

just touch the projection *l*, it will lead to *b*, where a picket-staff must be erected, and another in contact with the river at *c*; and these will produce another large triangle *a b c*, and include all the land except the small irregular portions *i k* and *m*, and these must be obtained by Prob. XL. That is to say, the line *a b* must be measured by the chain and divided into any number of equal parts to be marked by stakes, and from each stake an offset must be measured at right angles to the line, and extending to the boundary. These short offset measurements are more conveniently measured by a pair of offset staves than by the chain. The offset staves are light wooden rods divided into links, and each rod is 10 links, or 6 feet 7.2 inches long. They are made in pairs, because the mode of using them is to place the first rod upon the ground, with one of its ends in contact with the mark to be measured from. The next rod is then placed in contact with its end, and should the length require a third rod or more, that which was first laid down is taken up and moved to the end of the second, and so on. The sum of all the offsets so taken is then divided by their number, which will give the mean breadth of the irregular piece of land; and that mean breadth must then be multiplied into the length *a b* to obtain the superficial contents. The same operation must be performed upon the line *b c* to obtain the measurement of the small irregular portion *m*, between that line and the river.

245. If the irregular boundary is but gently waving or undulating, a small number of offsets will be sufficient, and in that case it will be best to take them as nearly as can be estimated at the least, the greatest, and the mean widths that occur, as shown at *Fig.* 53, where the line *g* is the maximum, *e* the minimum, and *f* the mean width of the figure *a b c d*. If, on the contrary, the boundary is very irregular and uneven, a closer average width will be obtained by increasing the number of offsets in the same space.

246. The process just described, it will be perceived, is that of taking offsets round an inscribed figure; but, in some cases, it may be necessary to adopt the opposite course, and take them within a circumscribed figure, that may be generated for the purpose. Thus if the plan and dimensions of a lake or large pond of water *d e f g*, *Fig.* 67, should be required, it may be obtained by circumscribing it by the right angled triangle *a b c*. A trapezium, or square, or parallelogram would do as well, but these figures could not be set out, because they would require the previous formation of a measured diagonal and offsets, and that diagonal would pass across the water, and therefore could not be measured. The triangle is equally convenient, and has the

advantage of all its lines being on dry land. To set it out, fix three picket-staves at the most projecting parts of the pond, as *d e* and *h*. Then take the surveying cross and move it about until a point *a* is discovered, from which the staves at *d e* will make a right angle with that at *h*, when the two lines *a d e b* and *a h c*, may be set out and indefinitely continued by additional picket-rods. The right angle *b a c* will now be established. Then place picket-rods on the most projecting points *f* and *g*, of the other side of the lake, and select a point *b* or *c*, upon one of the two lines previously set out, at which the two rods *f* and *g* will bone, or appear in a right line. That done, the line *b c* may be set out, and the point *b* in the line *a b*, as well as the point *c* in *a e*, will both become fixed, when the lines *a b* and *a e*, are to be separately measured by the chain, and the area of the whole triangle *b a c* determined, in which there will be no difficulty, since it is equal to half the product of two of its sides into each other. To determine what must be deducted from this quantity on account of the lake being less than the triangle, internal offsets must be made from each side of the triangle to the water, as in the last case, or triangles may be cut off from the corners, provided they are too large to admit of offsets; and, in this manner, the quantity of deduction may be ascertained with considerable accuracy.

247. It sometimes facilitates the operations of land measuring, to change figures or areas of one form, into others of a simpler character, but which shall retain the same dimensions; and on this account the few problems, which follow, may occasionally prove useful.

Problem LIX.

248. *To convert a parallelogram into a square of equal area.*

Rule.—Multiply the length of the parallelogram by its breadth, and the square root of the product will be equal to the length of one side of that square, which is equal to the parallelogram.*

Problem LX.

249. *To reduce a rhombus or rhomboid to an equivalent square.*

Rule.—Multiply the base by the perpendicular height from

* Those who possess tables of logarithms, will find the labour of extracting square roots much abridged by their use, for the operation is performed by dividing the logarithm of the power by its index, when the quotient will be the logarithm of the root; consequently half the number that expresses the logarithm of any number, will be the logarithm of its square root, the natural number corresponding to which must be found in the tables.

one side to that opposite to it, and the square root of the product will give the side of the square required, as in the last case.

Problem LXI.

250. *To reduce a trapezium to a square of equal area.*

Rule.—Multiply its diagonal by half the two perpendiculars or offsets raised upon it, and the product will be thea rea; consequently the square root of that area will be one side of the square required; because the side of the square is a geometrical mean, between the diagonal and the half sum of the perpendiculars.

Problem LXII.

251. *To reduce a trapezium to a triangle of equal area.*

Let *a b c d*, *Fig.* 68, be the given trapezium. Draw the diagonal *a c*, and extend the base line *a d* towards *e;* draw *b e* parallel to the diagonal *a c*, and from the intersection at *e*, draw the line *e c*, which will complete a triangle *e c d*, equal to the trapezium.

Problem LXIII.

252. *To reduce an irregular pentagon to a triangle.*

Let *a b c d e*, *Fig.* 69, be the given figure. Divide it into three triangles by drawing the two diagonals *a c* and *e c*, from the point *c;* and prolong the base *a e* towards *g* and *f*. From the point *b*, draw *b g* parallel to *a c;* and from the point *d*, draw *d f* parallel to *c e*, which will give two fixed points *g* and *f;* from these draw *g c* and *c f*, forming the triangle *g c f*, which will be equal to the given pentagon.

253. The *plane table*, before referred to, is a simple instrument, which produces the map or plan at the same time that the survey is made, and being easily used, the Engineer and Land Surveyor frequently avail themselves of it for simple surveys, notwithstanding it requires more measurements to be taken upon the ground than the method of triangulation, which has been before described. It is merely a rectangular flat board, or rather a pannel drawing-board (23) of at least fifteen by twelve inches, the frame of which not only serves to retain the sheet of paper to be drawn upon in its place, but it is graduated on its upper surface into angular degrees, radiating from the centre of the board. The general appearance of the instrument is shown at *Fig.* 70, *Plate II.*, in which *a b c d* represents the drawing-board with its angularly graduated border, supported upon an ordinary tripod stand of the kind generally used with surveying instruments,

parts of the legs of which are shown at *f f f*, and by these it is elevated to about four feet from the ground. These legs are jointed together at their upper ends, so that by extending one leg more or less than the others, the drawing-table may be made level; or sometimes a ball and socket-joint intervenes between the top of the legs and bottom of the plain table, for producing this adjustment to level. A wooden magnetic compass-box *e*, is made to slide into a dovetail on one side of the table, for taking bearings by its magnetic needle; but the top of this compass must be kept below the upper surface of the table, in order that it may not impede the free motion of a flat brass ruler *m m*, which lies upon the table, and has a vertical sight plate *g g* upon each of its ends, which are pieces with apertures, like those of the surveying cross. *Fig.* 60. This brass ruler and sights is not attached to the table, but is free to move in any direction; and a series of chain or decimal scales are, generally, engraved upon its upper surface. A small brass plate is let into the centre of the table, flush with its surface, and this has a small hole in it, just large enough to admit a small common pin *h;* and another plate with a similar hole for a pin is let in at *i*, close to the edge of the drawing-board, so that a pin may be placed in either of these holes, by passing it through the paper, when the instrument is in use.

254. The plane table may be used either in the middle, or boundary of the estate to be surveyed, and depends upon the principles of similar figures in geometry. Thus suppose *k, l, m, n, o, Fig.* 71, to represent a five-sided field that has to be surveyed, and that a plane table, covered with paper, and represented by the small square *p q r s*, is fixed near the middle of the field. Picket-staves, or other objects must be set up at each angle of the field, and a pin is inserted in the hole, in the middle of the table. The ruler and sights is now to be placed upon the table with its fiducial or chamfered edge in contact with the pin, and while in this position it is to be turned round until the object at *k* is seen through the sights, when a pencil line *p t* is drawn upon the paper. That done, the sight ruler is turned until the object at *l*, is seen as before; it is next turned into the direction *t m*, and so on, (being constantly kept in contact with the pin,) until it has been presented to every object around the field, when a series of lines will be obtained upon the paper, all radiating from the centre *t*, and pointing to the several angles around the field. That done, a plumbet is dropped from the under side of the centre of the table, and a stake fixed where it touches the ground, when the several distances from that stake to the angles *k l m n* and *o*, must be measured by the chain, and these lengths

must then be transferred by the compasses and one of the scales upon the ruler to the paper, making each measurement to proceed from the centre of the table, upon the lines to which they respectively belong, and marking their extreme points. Lines are now ruled from one of these points to the other, when such lines will be parallel to the boundaries of the real field, and the small figure thus produced upon the paper, will be similar and proportionate to the field itself, as indicated by the small similar figure drawn within the table *p q r s*.

255. In the example given in the figure, the lines *t o*, *t k*, and *t l* are all equal, as indicated by their being radii of the arcs drawn round the figure from its centre *t;* but *t m* and *t n* are shorter, and do not reach the arcs.

256. *Fig.* 72, gives an example of the manner of using the *plane table* in the boundary of a field, in which case it must be placed in one of the angles of that boundary as at *v*, (*p q r s* still representing the plane table.) The pin must now be placed in the hole *i*, *Fig.* 70, near the edge of the table, which is used as before; for sights are taken and lines drawn in the direction of every angle of the field, as indicated by the lines in the figure, and each of these lines has to be measured upon the ground and transferred by scale and compasses to the plan, as before.

257. When the plane table is used as last described, the angles of sight cannot be given by the graduated border unless, as is sometimes the case, this border is so fitted as to admit of it being reversed, and another division into angles from the side pin, is engraved upon it. The use of these angles is to obtain the measure of the field, which the plane table divides into a series of triangles, of which the two sides, with their included angle, are given, and from this the contents may be obtained. But as the process is more troublesome than by the simple process of triangulation before described, the plane table is not so much resorted to for obtaining the contents of land, as for producing a plan or delineation of its form and proportions, and if these are correctly drawn to a large scale, the contents may be obtained by scale and construction upon the plan, with tolerable accuracy and expedition. Some persons do not use the pin at all, but make a dot upon the paper, to which the ruler is applied.

258. If more extensive surveys have to be made, the processes that have been described will not accomplish them, but other means, and more expensive instruments, must be resorted to; for now the angles that occur between one visible object and another must be measured with great accuracy by means of a circumferentor, or theodolite, and the observations so made have to be recorded in a field book, by as short a process of entry as possible;

but at the same time such a one as will be intelligible at a future time for making out the map or plan in the office.

259. The *circumferentor* in its usual form is shown at *Fig.* 73, *Plate II.* It consists of a flat bar of brass, about fifteen inches in length, marked *a a*, with sights *b c*, at its opposite ends, and in the middle of the bar is a circular brass box *d* covered with glass, and containing a magnetic compass needle. The ends of the needle play very near to a brass circle, divided into 360 equal parts or degrees, by two semicircles of 180° each, such divisions commencing upon the line that unites the two sights, so that the two numbers, 90°, are at right angles to a line drawn through the sights. Each sight has a very narrow slit to look through, and a large opening with a fine wire or horse's hair strained across it; and these are placed alternately, or with the slit uppermost and large opening below in *b*, and the large opening above, and slit beneath it in *c*, so that the instrument can be looked through with equal advantage in either direction. It is supported at a convenient height, for looking through, upon a single pointed staff, or common tripod stand, either of which must pass into the socket *d*, which has a screw *z*, for fixing the instrument firmly to it, but it can be turned round and adjusted to a level position by a ball and socket-joint *e*, without which the compass-needle would not traverse or move freely round.

260. A well balanced magnetic compass-needle moving freely in a horizontal position upon the sharp point by which it is suspended, has the property of always pointing to the north, with the exception of a certain small angular deviation, called the variation of the compass; and as this quantity of variation is known, or can at any time be ascertained, it may be considered as of no importance, because it can always be allowed for. This allowance must be made, so as to make the magnetic agree with the true meridian; because it is not general or alike in all countries, and it is also subject to a progressive change, but at so slow a rate as not to affect ordinary operations. The circumferentor may, therefore, be turned round until the needle stands parallel to the long bar *a a*, when its two ends will correspond with the north and south points, engraved on the inside of the compass-box, and will point to the cipher and 180°, among the divisions. If now the bar and sights be turned into a new direction, the needle will not move, but will remain pointing in its former north and south line; consequently its new position among the divisions, compared with its former one, will give the measure of the angular quantity that the instrument has been turned.

261. The degree of perfection with which the circumferentor can measure an angle depends, therefore, entirely upon the good-

ness and length of its magnetic needle. If that is short, the divisions on the circle will be proportionately small; and if there is friction on the central pivot, the needle will not move freely, or always settle in the same place, but will follow the motion of the instrument in turning it round, to such a distance, as frequently to make a difference of a degree or two in the result, which is not, consequently, always to be relied upon. To remove these defects the needle should be from four to five inches long; should be strongly magnetized, but made as light as possible. If it is longer, or contains too much steel, it will be too heavy to vibrate freely. The point on which it turns should be very acute and sharp, and be made of well hardened steel, and the cap of the needle should be of agate, rock crystal, or some hard stone. The compass should have a lever or stop, to lift the needle off the point whenever the instrument is conveyed from one place to another; otherwise the shaking of the needle against the point, will soon cause it to become blunt; and whenever the instrument is used to take an observation, and has stood still long enough for the needle to become stationary, the compass-box should be gently tapped with the fingers, before the position of the needle is read off, as the vibratory motion, thus communicated to it, will generally cause it to move through a small arc into its proper place. On account of these imperfections the circumferentor is not much used in England, or where land is very valuable; but it is much used in America, and is a convenient and expeditious instrument, where, on account of woods or other impediments, the sights are short, and great accuracy is not required. In the largest and best instruments the degrees are divided into halves, but it requires an excellent needle, and very careful use and observation, to permit reading off to this degree of precision. An improvement has been made in the construction of this instrument, which will be better understood when the theodolite has been described.

262. The instrument most to be relied upon for accuracy, and which is constantly used in all correct surveys, is the *Theodolite.* It is made wholly of metal in various forms, but that which is most compact and convenient is shown at *Fig.* 74, *Plate II.* The principal difference between the theodolite and the circumferentor is, that this latter instrument, when moved or turned, all turns together, with the exception of the compass-needle, which ought to stand still; but no evidence is given of its having done so, because the division or figure to which its end pointed has been moved away from it, and perfect confidence must therefore be placed on the goodness of the needle. The theodolite, on the contrary, is always composed of two, and, in the best instruments, of three distinct parts, which have separate move-

ments, by the two first of which, the original direction and object, and the new object, together with the angle it makes with the first direction, are maintained and may be re-examined; while the third motion is for the purpose of measuring vertical angles, or angles in a plane that is perpendicular to that in which the first angle was taken. The theodolite, therefore, does not depend upon the compass-needle, but upon its own separate parts for the measurement of angles; and although a compass always forms a component part of the instrument, yet it is only added for giving the bearing of the measurements as they are taken.

263. Theodolites, as formerly made, were only capable of measuring angles in any one plane, and they consisted of a whole or half circle of about 10 inches diameter, divided into the proper number of degrees, viz: 360° for the entire circle, or 180° if they were semicircular. This divided plate was mounted on a tripod stand, so as to stand in a horizontal position, and it had two plain slit and horse-hair sights, just like those of the circumferentor, (254,) rising from its opposite sides so as to guide the sight in the direction of a diameter; such sights being placed opposite to the divisions marked 0° and 180°. Another piece, formed in every respect like a complete circumferentor, if deprived of its stand and ball and socket, was attached by a pivot to the upper side of the brass plate, in such manner that it would move quite round upon it, by being made short enough to pass clear of the external sights. The four sights could by this construction be brought into a right line; and as the holes in them were made to correspond, a right lined sight could be taken through the whole of them at once, or the two exterior sights could be placed in the direction of one object, while the internal pair were directed to another; and thus the angle subtended by the two objects at the centre of the instrument could be ascertained, because the end of the shifting bar that carried the inner sights had an index that pointed to the divisions upon the graduated circle, and the compass in the centre of this piece indicated the bearings of the lines forming such angle. A joint was formed in the stand of the instrument, by which its plate could be thrown from its horizontal into a vertical position whenever it became necessary to measure vertical angles, but no angle could be measured out of the plane in which the instrument was placed.

264. Two great improvements have been made in instruments for measuring angles on the ground. The first arising out of Ramsden's invention of dividing angular instruments by machinery, in consequence of which such accuracy is obtained that much more perfect observations can be made with instruments having circles of only 4 inches diameter, than could formerly be

produced by those of 10 inches, or even a foot. It formerly required a large instrument and perfect observer to measure an angle in surveying to the tenth of a degree, while now an instrument is scarcely ever offered for sale that will not measure angles to minutes or the 60th part of a degree, though their circles may not be more than three inches diameter.

265. The second improvement is in the adoption of a small telescope attached to the instrument for observing, instead of the slit and horse-hair sights formerly used. The horse-hair, from its proximity to the eye, subtends so large an angle as to be capable of covering a tree or any distant object as much as a foot or more in diameter; and this, added to the indistinctness of distant objects, renders it impossible to take a sight with any tolerable precision. But when a telescope, even of small power, is used, it defines distant objects so clearly that a sight may be taken to within half an inch. The hair used for marking the position of the object is placed at the focus of the eye-glass of the telescope within its tube; and being thus magnified and protected from external injury, it may be made much finer than in the other case, so that a single fibre of silkworms' silk, or even a filiment of spiders' web thread, is frequently made use of, and the greatest precision is obtained. In order to obtain the greatest magnifying power with the least length of telescope, the inconvenience of apparent inversion of the object looked at is generally submitted to in the telescopes applied to surveying instruments; but this does not affect the angle or apparent position of the object, and ceases to be an inconvenience when the operator has become accustomed to it. As the theodolite is applied to measuring vertical as well as horizontal angles, two hairs which cross each other at right angles are always applied to the telescope; and to take a sight with precision, the telescope is moved horizontally and vertically until the intersection of the hairs exactly covers the point intended to be measured from, so that if the telescope inverts and is directed to the vane upon a distant church, the appearance on applying the eye to the telescope will be such as is shown at *Fig.* 74, *Plate II.*

266. The divisions of a circle into degrees could not be carried to the extent that has been spoken of unless the circle is very large, or they would become so small as to be invisible, besides being very expensive in their construction on account of their number, and the exactitude necessary in laying them down. On all these accounts circles are never so divided, but a most elegant contrivance called a *Vernier* (from the name of its inventor) is adopted, and by its means, if well executed, the divisions upon instruments may be carried to any degree of minuteness required.

This contrivance has now become so common in all good instruments for accurate measurements, that a perfect acquaintance with its principles, which are very simple, is necessary. Suppose, for example, it is required to divide inches into hundredth parts, as in the common barometer. The scale of inches is engraved in the usual manner, and each inch is divided into 10 equal parts, as in *Fig.* 75, *Plate II.* The vernier is a thin plate of metal *v v*, applied in such manner as that it may slide freely, or free from jerks, against the line of divisions, but with sufficient friction to remain in any place where it may be fixed. The side of the vernier next to the divisions has a fiducial edge, which is made to coincide with them as closely as possible, and upon this an index, or *fleur de lis*, and another set of divisions are engraved, as numbered 1, 2, 3, &c., to 10. The index denotes the point to be counted from, and the divisions are obtained in the following manner. Below the index a space is set off by compasses, equal in length to eleven of the divisions upon the scale of inches, and this space is then divided and marked off into 10 equal spaces, as indicated by the numbers. Of course, therefore, each division upon the vernier must be one-tenth longer than the divisions upon the scale; for if the index is set against any division, No. 10 upon the vernier will stand opposite the eleventh division below the index upon the scale of inches, and thus the vernier scale is capable of subdividing each of the smallest divisions upon the principal scale into 10 equal parts; and as the smallest divisions upon the principal scale are tenths of an inch, the vernier will of course read off to hundredths of an inch. To use this scale, observe where the index points to on the principal scale. If it coincides exactly with any division, then that division shows at once the quantity measured. But if it stands between two divisions, as in the figure, where it is made to point between the fourth and fifth division above 29, then look down the vernier for the first actual coincidence of lines that occurs, and that will be found at No. 4 on the vernier, for 3 is a little above, and 5 a little below its opposite division. Four, or four-tenths of the tenth of an inch, is therefore the quantity indicated by the vernier as it stands in the figure, and this quantity would be read 29 inches and four-tenths of an inch; which, expressed decimally, would be equivalent to 29 inches 44 hundredths. If the index had corresponded exactly with a division, then no coincidence would be found between the divisions on the scale and those on the vernier, except No. 10; and as ten-tenths make a whole, that would indicate that no fraction existed, but that the division to which the index pointed must be taken as a whole number.

267. The vernier is applied in a similar manner to the subdi-

vision of the graduations upon divided circles, with this difference only, that in the barometer the scale is stationary and the vernier is moved to it, but in divided circles the vernier is fixed and the circle moves in contact with it. Reflecting quadrants and sextants are exceptions; because in them the vernier is attached to the index, which is moved, while the divided limb remains stationary. The principle is, however, the same in all cases, and depends upon the divisions on the vernier being greater in a certain known proportion than they are in the scale it is used to divide. Thus *Fig.* 76, *Plate II.*, may serve as an example of the manner in which a vernier *v v* may be applied to subdivide the degrees upon *w w*, which may be supposed to represent a portion of the divided circle of a theodolite, or other instrument intended to measure angles to single minutes of a degree. The vernier in this case is supposed to be stationary by being attached to some fixed part of the instrument, while the circle of which *w w* is a part revolves on its proper centre, keeping its divisions in contact with those of the vernier. In these cases, as the divisions are small in minute instruments, they are read, and the coincidence is observed by a magnifying glass or microscope, which is commonly attached to the instrument for the purpose. The circle is divided into degrees, or 360 equal parts, and for the facility of distinguishing the degrees or reading off, as it is called, every 10th degree is marked with a number, as 0, 10, 20, &c., and the intermediate degrees which extend over three of the concentric circles round the edge of the plate have to be counted. Each degree, it will be observed, is divided by shorter lines extending between the two outer circles into three equal parts; and as the whole degree contains 60 minutes, so of course each of these small divisions are equivalent to the third of a degree, or 20 minutes. All the vernier, therefore, has to do, is to divide each of these small spaces into 20 equal parts of 1 minute each; and to effect this, the divisions on the vernier must extend over 21 divisions upon the circle, and have this extension divided into only 20 equal parts, which are numbered 5, 10, 15, 20, from the index, as will be seen in the figure. The vernier is used as before directed, the index on the vernier pointing to the division on the circle, which is to be taken as the measure of the angle under examination. Thus, in the figure it points above the 8th degree, and looking for the coincident lines they will be found against 10 on the vernier, which indicates 8° 10′, because the index points short off from the first short or 20 minute division. Had it been in the same position, but above that division, then the reading would have been 8° 30′, because the first 20 minute division would then be taken into account.

268. Verniers are not always divided as above described, but are various in their forms; but as the principle remains unchanged, a little consideration will enable any one to judge of the subdivision they produce. Thus the degrees on the circle sometimes are entire, or not divided into thirds or even halves, and the vernier may contain 12 divisions, in which case the whole degree is only divided into 12 parts, and consequently each division on the vernier will be equivalent to, and will divide the degree only to every 5 minutes, 5 times 12 making 60. A very common mode of division on small instruments, is to divide each degree into halves, and to have a long vernier with thirty divisions upon it, and this will give the thirtieth of half a degree or single minutes, as in the first process. A similar length of vernier, with double the number of divisions upon it, will divide to half minutes or thirty seconds. On the best and finest astronomical instruments this process of division is often carried to ten, five, three, and even single seconds, but such nicety is never required for the ordinary purposes of surveying. Even when an instrument reads to single minutes, it requires delicate screw or rack-work motions for its adjustment to objects, because it cannot be moved by the hand with sufficient delicacy.

269. Having thus pointed out the nature of the improvements that have been made on the instruments for measuring angles, no difficulty will occur in comprehending the parts of the improved theodolite, as represented by *Fig.* 77 of *Plate II.*, *a b* is a telescope about twelve inches long. The small tube at the eye end *a*, slides in and out for adjusting the cross hairs, (*Fig.* 47,) to a proper focus, and the object-glass end *b*, slides in a similar manner for adjusting the focus of the telescope to distant objects. The cross hairs are adjusted into their position by small screws at *c*. The telescope is not attached to the instrument, but rests in two forks *d d*, called Y's, from their similarity in shape to that letter, and a spring cap folds over each Y to hold the telescope in its position. The Y's are fixed upon the upper part of a brass semicircle *e e*, which is supported on its proper centre by a double conical axis *f f*, resting and turning on points *g*, in the tops of the angular shaped supports *h h h h*, which are fixed upon the horizontal plate *k k*. The semicircle *e e* is divided into degrees on one of its sides, which are read off by a vernier, attached to a block *l*, immovably fixed upon the horizontal plate, and is for taking vertical angles; the other side is divided, in a manner to be hereafter described, for reducing hypotenusal lines to horizontal ones. This semicircle has teeth on its outer edge, which are acted into by a pinion, concealed within the block *l*, and turned by the wire and milled nut *m*, by which alone the telescope should be

moved in its vertical direction. A magnetic compass is fixed in the centre of the horizontal plate at *n*, and *o*, *o* are two spirit-levels,* also fixed upon it at right angles to each other, by means of which, this plate can be set truly level or parallel to the horizon, without which precaution the circle *e e* and telescope, could not be used for taking vertical angles. As a further precaution to insure accuracy in this operation, as well as for other purposes, another spirit level *w* is fixed by screws to the underside of the telescope, and rendered parallel to its axis, or line of collimation. When the horizontal plate is made quite level, and the 0 or zero point of the semicircle stands against the index of its vernier upon *l*, the level *w*, with its telescope, ought likewise to be quite level, which is a proof that this part of the instrument is in perfect adjustment.

The horizontal plate *k k* is chamfered or bevelled on its external edge, so as to become a portion of a cone, and appears solid and of considerable thickness; but it in fact consists of two parallel plates made to fit so closely together that no space appears between them, and the division of the lower plate into degrees takes place at this juncture; the degrees, with the figures for counting them, being wholly engraved on the lower plate *q q*, and nothing on the upper one except the vernier *s*, for reading the divisions; and a similar vernier is placed on the further side of the top plate exactly opposite to the first, which gives the great advantage of reading off the divisions in two places, and taking a mean of them, in case of error. In the best and most costly instruments, this bevelled edge of the bottom plates, and the divided arcs upon the semicircle, as well as their verniers, are made of silver or platinum, which admits of the figures and divisions being more finely engraved, and more easily read, and when the latter metal is used, never tarnishes. The upper plate *k k* revolves on the lower one *q q*, upon a central long arbor, which should be of the finest workmanship, and descends some distance into the stem *p* of the instrument; and motion is given to this upper plate by another concealed pinion, connected with the milled head *r*, which acts into teeth also concealed, but which are cut upon the lower interior part of the plate *k k*.

Two brass plates, *s* and *v*, called the parallel plates, are connected together by a ball and socket, or conical piece *t*, in such manner that they are at liberty to move out of their parallel positions, but cannot separate beyond certain limits; and four strong

* For an explanation of the construction, use, and importance of spirit-levels, see the next chapter, where the method of adjusting this instrument is also described.

screws, with milled heads $x\,x\,x\,x$, are placed in two diameters, and work through the top plate, while they merely press against the bottom one, so that by tightening these screws, the two plates are fixed at their greatest possible distance apart, and the upper plate may be made exactly parallel to the lower one, or be placed in any small angular position in respect to it; or if the under plate is out of level, the upper one may be made quite level. The three folding wooden staves or legs, which form the stand of the instrument, and raise it to its proper height for observation, are attached to the under side of the lower plate *v*, and the theodolite, or any other instrument, is fixed upon the upper plate by a pivot that enters the socket *p*, and is fixed by a thumb screw.

270. A separate tripod or three legged folding stand is always sold with each theodolite or other surveying instrument; but it seldom happens that the pivot-socket at *p*, by which the instrument is attached to its stand, will fit any other instrument than its own, from which practical difficulty sometimes arises in the operations of the Engineer. It is, therefore, much better to have all his instruments fitted to one stand, or to have two stands which fit all his instruments in common. This is not only convenient but economical, for a well made stand is worth from seven to ten dollars, and the expense of an instrument is so much diminished in its cost. The legs are often made to unscrew in the middle, to render them shorter and more portable on journeys.

271. The several parts of the theodolite having been examined, a few words of explanation may be necessary as to the mode of using it. The legs $y\,y\,y$ of the stand are opened to a sufficient extent to insure the steadiness of the instrument; and they ought to be set on hard ground, or pushed into that which is soft, until the stand is firm and steady. In placing the stand, attention should be paid to getting the under parallel plate *v*, as level as possible, which may always be effected by spreading out one or other of the legs, until the level position is attained by estimation. The bottom plates $k\ q$ of the theodolite are then to be brought into a perfectly level position by means of the levelling screws $x\,x\,x\,x$, which position is determined by the cross spirit-levels upon the top plate $k\,k$, and proved by turning that plate quite round, when the bubbles of the levels should remain motionless. The index of the vernier upon *k* must then be brought to coincide exactly with the 0 or point from which the divisions commence on the bottom plate $q\,q$, and that done, the two plates are clamped or fixed together by a screw opposite to *r*, but which cannot be seen in the figure, so that one plate cannot move without the other. That done, the telescope is directed to the first

object to be observed, by turning the whole instrument round upon the pivot at *p*, while the telescope may be raised or depressed at pleasure by the nut *m*, since in taking a horizontal angle, the elevation of the telescope will not affect it, because however the telescope may be placed it cannot turn to one side or the other, being restrained from doing so by its long axis *f f*, and supporters *h h*. The first object being brought correctly to the intersection of the hairs, the instrument is immovably clamped by a thumb screw that enters the side of *p*. The top plate *k k* is now unclamped and moved by its nut *r*, until the telescope is brought to bear upon the second object to be observed, when the angle subtended between the two objects may be read off at the vernier *s*. Should any doubt exist respecting the correctness of the observation, the telescope may be turned back again to the former object, to ascertain whether the vernier will again stand at 0 when that object is again seen. In the very best theodolites there is a telescope with cross hairs, fixed under the lower plate *q q*, in the direction of its zero point, and which remains constantly fixed upon the first object for the purpose of verification.

It is thus seen that an angle is taken without any reference to the compass *n*, which is used merely for giving the bearing of the lines that form the angle should it be required.

272. When speaking of the circumferentor, (261) it was stated that an improvement had been made in that instrument which would be noticed after the theodolite had been described. That improvement consists in converting it, to a certain extent, into a theodolite, by leaving out the ball and socket *e*, *Fig.* 73, in which case the instrument must be used upon a stand with parallel levelling plates (like that in *Fig.* 77) for the purpose of levelling it. Instead, therefore, of turning round upon the ball and socket, it turns upon the conical pivot of the stand which enters the socket *d*, and may be firmly fixed in any position by the screw of that socket. The compass-box is united to the upright stem *e d*, which passes through the bar *a a*, and this bar is moveable round the compass upon the stem *e d* as a centre, but can be locked or fixed to it at pleasure, by a tightening screw under the instrument, so that one cannot move without the other. The lower outside rim of the compass-box is regularly chamfered, and divided into degrees, and a vernier, or two opposite ones are placed on the bar at *y y* for reading these divisions. A wheel and pinion or tangent screw is, moreover, applied underneath for moving the arm and sights very gradually round the compass, and when so equipped the circumferentor becomes nearly as efficient as the theodolite.

273. As an example of the mode of using it (and which will

apply equally well to a theodolite,) suppose *a b c d e f g*, *Fig.* 78, *Plate II.* to be the boundary of a piece of land to be surveyed, and let the parallel lines NS., *NS*, &c., ruled through every angle of the same, represent so many parallels to the magnetic meridian, or the direction in which the compass-needle will point whenever it may happen to be placed upon the estate. Begin by placing the circumferentor at the angle *a*, level it, and having brought the north and south parts of the compass-box to coincide exactly with the line of the sights, which is done by bringing the 0° on the bottom of the outside of the compass-box to the index of the vernier, lock the compass and bar together: now turn the whole instrument on its socket *d* until the needle stands directly over the north and south line of the compass-box, when the sights will stand in the direction *a* N upon the plan. The instrument must now be locked or fixed in this position by tightening the socket-screw *z*. The compass must then be unlocked from the bar, and the bar with its sights turned into the direction *a b*, (a picket-staff having been previously set up at *b*, as well as at all the other angles) when the angle of deviation will be noted, not only by the vernier *y*, but by the needle also, in the improved instrument, or by the needle only, in the common one. This angle suppose 7° 00′, must now be set down in the field book, but before doing this, if working with the improved instrument, observe that the needle still stands over the north and south line, or that the compass-box has not shifted its place. While this angle is measuring, the chain-bearers proceed from the point *a* to measure the length of the line from *a* to *b*, and there they remain, leaving the last chain upon the ground until the surveyor comes up with his instrument, counts their arrows or markers, and the odd links to the point *b*, which suppose may be 31 chains 10 links, and this he now enters in his book, and sends them to measure the next line from *b* to *c;* while he again adjusts the instrument now placed at *b*, for the purpose of ascertaining what angle the line *b c* makes with the magnetic meridian NS, or in other words, while he measures the angle N *b c*, which is done and entered in his book as before, suppose it to be 55° 15′ E. He then proceeds to *c*, where he obtains the length of the line *b c* from the chain-bearers and enters it, suppose 28.21 chains. They then proceed to measure from *c* to *d*, while he takes his station at *c*, and having adjusted his instrument measures the angle *S c d* and enters it S. 72.40 E. In this manner he proceeds to each corner of the estate until he arrives at *g*, when the next sight carries him to *a*, the point from which he started, and the entries he will have made in his field book will be as follows:

1.	A to B	North	7° 00′	West	31.10	chains.
2.	B to C	North	55° 15′	East	28.21	,,
3.	C to D	South	62° 30′	East	24.41	,,
4.	D to E	South	40° 00′	West	21.00	,,
5.	E to F	South	4° 15′	East	24.00	,,
6.	F to G	North	73° 45′	West	22.40	,,
7.	G to A	South	52° 00′	West	19.18	,,

In the above entries the columns in which nothing but the words north and south occur, is a register of the end of the needle that has been made use of in making the observation, and the column of east and west shows whether the angle is taken on the east or west side of that end of the needle. As a general rule, that end of the needle is selected which makes an acute angle or one of less than 90° with the line observed. The entry in the field book north 7° 00′ west, means that the angle measured is 7° to the westward or left hand side of north, as shown by the needle. By north 55° 15′ to the east, is meant to the east or right hand side of the needle. By south 62° 30′ east, is meant that quantity to the eastward or left hand of the south end of the needle. And by south 40° west is 40 degrees to the westward, or right hand of the needle's south end. In applying the terms right and left hand it must be understood that the face of the observer is turned towards that end of the needle he is using while he himself is supposed to be over the centre of the needle. And following this rule while referring to the plan *Fig.* 78, it will be found that the angles measured in succession and recorded in the above field book are *N a b; N b c; S c d; S d e*; *S e f; N f g;* and *S g a.*

274. The same field book will also afford the means of plotting or laying down a plan of the estate at any future time. To do this, first rule a line *N a S*, *Fig.* 78, upon the paper, to represent the magnetic meridian, and fix the point *a* in that line for the south-west point of the estate. Put the letter W on the left and E on the right hand side of the paper to indicate its east and west sides, to avoid mistakes. Then on the point *a* lay down an angle of 7° to the W. or left of the meridian line by a protractor, and draw the line *a b* of indefinite length. Then measure off from a scale of equal parts, or a plotting scale, the space intended to represent 31.10 chains on the plan, and set off that distance with compasses from *a* along the line *a b*, and this will determine the point *b*. Through *b* draw a second line *N S* parallel to the first, and upon *b* lay off an angle of 55° 15′ to the E. of that second line, and this will give the position of *b c*. Define its length by measuring 28.21 chains by the same scale before used, and this will fix the point *c*, through which draw another parallel line in

order to obtain the angle $S c d$, measure off the length of $c d$ as before, and by proceeding in this way the plan will be completed.

275. The above may serve as a general example of the manner in which large plots of ground may be measured and drawn, but it generally happens that such plots contain separate fields, roads, and other objects in the middle part, which require to be noticed, as well as the mere boundaries; and these require to be filled in, which can only be done by taking separate measurements of each of the fields, and then joining them together. Some defined method must, however, be followed in this work to prevent the plan from becoming distorted, as well as to save labour, and different surveyors adopt different means to accomplish these purposes. The principles on which they depend may be divided into two heads, viz: working by rectangles or perpendiculars with offsets from them, or working by triangulation and offsets. Either may be used at pleasure, and may possess advantages in particular cases, but the method by triangulation is the most safe and satisfactory, and is not attended with more trouble than the other. The principles of these operations will be understood by reference to the plan, *Fig.* 79, *Plate III.*, and the following description.

GENERAL DIRECTIONS FOR LARGE SURVEYS.

276. Walk round the estate before commencing any operation, to become acquainted with its magnitude, general form and bearings, and to ascertain if it contains any elevated positions that command views of large parts of it. In cultivated countries, roads and lanes, or footpaths, will be found, and examine these, as to whether they can be made subservient to the purposes of the survey; because if so, they ought to be used on account of their offering no impediments to the use of the chain or other instruments; while woods, hedges, deep ditches, and other obstacles, frequently occasion delay and inconvenience. To guard against these, the surveyor should be provided with a small hatchet, as it is frequently necessary to cut a chain or sight-way through underwood, as well as to cut and drive marking stakes. He should also be provided with a wallet or strong bag slung over his shoulder for carrying the necessary implements and refreshments. If the surveyor has to plot or draw his own plans from the measurement taken, the author recommends from his own experience the following distribution of time. To spend the first day in the field, taking measurements, and to draw or plot the work so taken early the following morning; that done, to resume the field work till dark, and on the following morning to plot the second day's work, and so on. The reason of this is obvious.

Field measuring is laborious and fatiguing work, and after having spent a long day upon it, the operator is in general in no condition for fine drawing or scale measuring, his hand is unsteady from exertion, and the light of evening is unfavourable to his operations. But after a night of refreshing sleep, he will be well prepared for drawing on the following morning, when the light is good, and he retains a perfect recollection of the positions and particulars of the places he has been over on the previous day, and may even be able to supply small omissions, if such have been made in his field book, and they do not relate to measurements. If errors or omissions occur, he detects them, and has an opportunity of correcting them by revisiting the spot before another day's work is commenced. And as a skilful draughtsman will have no difficulty in plotting as much work in two hours as can be measured upon the ground in ten or twelve, it will be seen that no delay is occasioned by this arrangement. The drawing work may all be finished before an early breakfast, after which the surveyor proceeds to the land, and will generally find himself so fatigued after six or eight hours' work in the field, (for he should carry his dinner with him to avoid delay) that he will have little inclination to do more. If the survey is so large as to occupy many days or even weeks for its accomplishment, it will be best to divide the land into distinct portions which can be finished in a day or two; and this is done by setting out straight lines with picket-staves, and setting up tall poles with white linen or red flags upon them at the angles in order that they may be seen from one station to the other, and be known by their colours. Such flags are marked at N D S A, *Fig.* 79, *Plate III.*, and thus the lot intended to make one complete survey is inclosed by the right lines ND, DB, BA, AS, SN; and if one of these lines, NS, can be laid down in the magnetic meridian, and the bounding lines ND and SA be made at right angles to it, it will afford facility both to the work and the plotting; but this must depend on local circumstances. If the plot represented in the plan is supposed to be finished, and that another has to be laid out for survey to the north of it, then the line ND with its flags will remain stationary, and the flags SA are taken down and carried forwards to mark out a new terminating line for another plot. In each plot, the survey extends to, and ends at these boundary lines, so that the work of one plot will fit on to those which join it, and no plot must be left until every object upon it is measured and noted down. When using a public road for the purpose of surveying, never place the theodolite or other instrument near its centre if it is much frequented, as the arrival of a carriage, or drove of cattle may compel you to take it up after it has been adjusted and an observation began, and as it cannot be re-adjusted into its former exact position it may occasion great inconvenience.

277. If the plot is proposed to be surveyed by perpendicular offsets, it will be best to measure all round it in the first instance, as before described (273). Thus taking the plan, *Fig.* 79, the survey may begin at A, by setting out the right line AB upon the road, as far as it continues straight, and measuring it with a chain. A would then be called the first station, and B the second. Stations are always distinguished in the field book by this mark ⊙, accompanied by a number or letter of the alphabet, and letters are the best, because they cannot be confounded with the numbers that express dimensions or angles. The angle that AB makes with the magnetic meridian at A, must then be measured by planting the theodolite or circumferentor at A, and be entered in the field book. In keeping the field book, it is found most convenient to begin writing at the bottom of the first page, and to proceed upwards to its top, and when full to turn over and recommence at the bottom of the next page, and so on until the survey is finished; but as this would be inconvenient in printing, the following may serve as an example of what would be entered in the field book, in the ordinary way of writing from top to bottom.

Survey of an estate called Brookfield, in the Parish of Stow, in the County of York, &c., taken February 22nd, 1837.

	⊙ A	
On road proceeding north	wards to Stow	at S.E. cor. of Jack. mead.
Road bears	N. 14° 30′ W.	
Width	00.50+1.00	
Offset	5.80	
Hedge and offset	10.30	cross fence
Road wide	00.50+1.00	
	14.40	fence
Jackson's house begins	16.00	
Road wide	2.00+0.50	
House ends	19.00	
Road wide	2.10+0.50	
Offset	22.00	
Fence	22.50	
Road wide	1.00+0.60	
	30.00	road begins and bears S.E.
Cross roads begins	31.40	
	33.07	
	to ⊙ B and ⋈	road ends.

	⊙ B at end of	⋈ road leading west'd to C
Cross road bears	N. 72° 00′ W.	
	00.50 to S.E.	cor. of Thompson's house
Width of cross road	2.00+0.60	to same corner
	2.70	S.W. corner of house
Width of cross road	1.12+0.12	
	8.70	fence
	16.50	
Rivulet	crosses road.	
West side	17.20	of do.
Width of road	1.00+0.25	
	23.00	fence
	27.50	
	to ⊙ C in the	meridian boundary.

	⊙ C in last	road at mer. boundary
Width of road	1.00+0.25	
Bearing	due S. the	west'n. mer. boundary
Offset	6.00	
Rivulet begins	10.00	
Fence	10.50	
Rivulet ends	11.00	
Fence	26.00	
Fence	37.00	
	to ⊙ S in the	south boundary.

	⊙ S in the	west boundary line
Bearing of ⊙ A	S. 90° 00′ E.	
Fence	8.50	
	19.50	
	to ⊙ A	

278. After what has been before said, it is presumed little further explanation need be given of the entries in the field book. They commence by giving the position of the first station, and the angular direction in which the survey proceeds, and the first right line being set out upon a road, the width of that road is given occasionally, not in one direct measure, but in two sums, as 00.50+1.00, because all things in the field book bare relation, in position, to the line set out. Every thing that occurs on the left hand side of that line is placed in the left hand column, the central one is reserved for lengths and bearings, and the right hand one for what occurs on the right hand side; and as the sight line is not in the centre of the road, the 0.50 indicates that the road is 50 links wide to the left of the line, and one chain wide to its right, making a total of 1.50; and if the sight line had not

been upon the road, its measure would have been so expressed. At 5.80 chains an offset occurs, that is to say, a perpendicular to the line has to be measured on the left side, for determining the positions of two cross fences *a* and *b*. This point in the survey is determined by looking at the point *b* through a surveying cross, or by setting the theodolite to 90°, and it must be marked on the road by leaving a picket-staff at *c;* and as this offset is on the left hand side of the road, it is set down in the left hand column. At 10.30 a hedge occurs on the left, which, being perpendicular to the line, is also made an offset, marked by a picket-staff, and set down in the same column, but the cross fence opposite to it, on the other side of the road, is put in the right column. The next fence occurs on the same side at 14.40, and is entered in the same column. At 16 chains on the left a house begins, and at 19.00 it ends, and here the road widens, as indicated by its entry. At 22.00 a left hand offset must be picketed, to be taken as before, to fix the positions of *d* and the rivulet *e*. At 30.00 chains a cross road begins on the right, and bears off to S. E.; and at 31.40 a cross road begins, and at B, the end of the line, it terminates; and the first station being thus far completed, a double line is drawn across the book.

The second station ⊙ B to C; the third from C to S; and the fourth from S to A, bring the surveyor back to the point at which he commenced; and now he has to go over the same ground again for the purpose of measuring the offsets that were passed in the first round, with a view to prevent mistakes or confusion, with no other notice than a memorandum of the place of their existence.

279. In the second circuit of the plot no notice is taken of any thing but the picket-staves that had been left to mark the places of offsets; and the book must at the same time be searched for them, to ascertain that none of them have been removed. The first that occurs is at 5.80 in the book, and at *c* in the plan, *Fig.* 79, and this is measured from *c* to *a*, and turning out to be 12.70 to the fence, is so entered in the field book against the words "Offset No. 1," previously written, (see the next page where this same field book is repeated, with all its additions in the inverted order, or that in which it would be written; consequently the reading of it must commence at the bottom and proceed upwards.) The measurement is, however, continued from *a* to *b*, in order to fix the position of the point *b*, and this making the total length of the offset 21.25, is accordingly entered more to the left in the same line.

The next left hand offset that occurs is at 10.30 in the book, and *f* in the plan, and this is taken in the line of a fence; its length 10.50 is set down with a remark, that two fences meet at this point, and a sketch of their form is given, for this mode of sketching is constantly resorted to in field book entries, and assists very materially in laying down the plan, but cannot be well imitated in printing without cuts or diagrams for the express purpose. The next remark occurs at 16.00 chains, where we find a house begins and continues to 19.00, thus showing that house and premises to be three chains long; and the remark of the left hand side of the road being extended to two and a half chains from the sight line, shows how far that house stands back from the road. The figures 2.12 and 1.25 introduced in parenthesis before the word house, shows the depth of that house in links at its two ends. The third offset is at 22.00 left, and the figures and mark set against it, show that at 18.50 it meets a cross fence, making a salient angle, and at 22.00 it comes into contact with a rivulet, which ends this line. At 22.50 a fence occurs on the left, and another width of the road is given. At 30.00 a road presents itself on the right, and ends at 33.07, which determines its width; and at 31.40 a road appears on the left, the width of which is not determined, and this ends the first station.

In the second station from B to C no offsets are necessary; and only one occurs in the third, because the points already ascertained will be sufficient to determine the positions of all the cross fences.

280. COPY OF PAGE 1 OF THE FIELD BOOK ABOVE REFERRED TO.

	to ⊙ B and ⋈	road ends
	33.07	
Cross road begins	31.40	
	30.00	a road bearing S. E.
Width of	1.00+0.60	road
Fence	22.50	
Riv'let 22.05 ⋈ } offset, fence> 18.50 } No. 3.	22.00	
Width of	2.00+0.50	road
(1.25) house ends	19.00	
Width of	2.50+0.50	road
(2.12) Jack's hou. begins	16.00	
	14.40	fence
Width of	00.50+1.00	road
2 fen. meet> } hedge and 10.50 } off., No. 2.	10.30	cross fence
⋈ f. in m. b. 21.25 } offset, (fence 12.70) } No. 1.	5.80	
Width of	0.50+1.00	road
Bearing of road	N. 14° 30 W.	proceeding north to Stow
	⊙ A	from S. E. cor. Jack.'s m.

PAGE 2 OF FIELD BOOK.

	to ⊙ A	and survey ends
	19.50	
Fence	8.50	
Bearing of	S. 90° 00′ E.	station A
	⊙ S in	west boundary line.
To ⊙ S	in the south	boundary line.
Fence	37.00	
A cross fence	26.00	
Rivulet ends	11.00	
A cross fence	10.50	
Rivulet begins	10.00	
7.00 to rivulet. Offset	6.00	
Width of	1.00+25	road
Direction	due south on	the west'n. mer. boundary.
	⊙ C	in last road at do.
	to ⊙ C in the	meridian boundary
	27.50	
	23.00	fence
Width of	1.00+0.25	road
Rivulet crosses	17.20	the road
East	16.50	side of rivulet
	8.70	fence
Width of	1.12+0.12	road
	2.70	S. W. cor. Thompson's ho.
Width of cross road	2.00+0.60	to same corner
	00.50	S. E. corner of house
Cross road	N. 72° 00′ W.	bears
	⊙B at end of	⋈ road lead'g west'd to C

281. The upper part of the plan BC ND might be treated in the same manner, but it is believed that enough has been said on the method of perpendicular offsets, to render that operation perfectly plain, and the upper remaining plot will, therefore, be surveyed by triangulation; for which purpose begin at B, and set out the right line BD for measurement, when the following field book, read from bottom to top, will, with reference to the plan, explain the operations and measurements that must be made.

PAGE 1 OF FIELD BOOK.

	at station B	N. B. This finishes the first triangle.
	27.50	
Width of	1.00+1.50	road
House ends	27.00	
Width of	0.12+1.50	cross road
Angle of a house	25.00	
Width of	0.25+1.00	road
Cross fence	19.00	
Width of	0.25+1.50	cross road
	12.60	
	10.80	
Rivulet	crosses the	cross road
	10.00	
Cross fence	4.75	
Width of	0.25+1.00	road
	S. 79° 30′ E.	
C to	B bearing in	a ⋈ road; and left the theodolite there.

To	S. W. angle	C
	32.00	
To fence 2.50 To river 8.50 To ⋈ fence 13.00 To B 24.50 } offset	25.00	cross fence
Cross fence } To fence > 1.60. Offset }	16.60	cross fence
	13.75	off. 18.00 to ext'me point N
	S. 37° 90′ W.	
D to	C bearing	

	to ⊙ D	
	35.00	
	24.12	cross fence
>11.00 to ⋈ fence } ⋈ fence and offset	22.00	
Width of	0.74+0.12	bridge
To centre of	a bridge over	rivulet 1 chain wide
	15.00	
To riv't & to fence N. & S. 7.75 } offset, No. 1.	12.00	
House ends	3.00	
Angle of house in line with road }	1.00	
Width of	0.50+1.00	road
	N. 6° 80′ W.	
B to D	bearing	
	⊙ B	

PAGE 2 OF FIELD BOOK.—Survey ends.

	at station D	
	22.66	no offsets or remarks
	S. 90° 00′ E.	
	⊙ N	bearing to D the extreme N. E. point
	to station N	
	29.50	
	13.33	cross fence
	N. due N.	
	⊙ C	bearing to N the extreme N. W. point

282. On examining the above field book it will be found that the operations therein detailed divide the estate into two triangles, B D C and C N D, and in measuring each side of them all the positions of fences, and other objects, become fixed in the outer boundaries, while their internal positions are, in like manner, fixed upon the diagonal CD, or main offsets *Ng* and *B h*, so that no line occurs on the land, the position of which is not fixed by at least two, if not three, points.

283. The student will do well to draw plans from these field books without looking at the plan on the plate, using any scale at pleasure; and likewise to triangulate the lower part of the plan A B C S, and make his own field book from the same, as such practice will facilitate his operations in the field. Such drawings will only require compasses to measure, together with a scale of equal parts to obtain the lengths, and a protractor to lay down the angles.

284. As before mentioned, the regular business of a Civil Engineer is separate from that of the Land Surveyor or Measurer, and he is therefore seldom called upon to survey large tracts of land. But should that become necessary it is hoped that the directions above given, aided by practice and experience, will enable him to perform such duty. It is impossible to give rules, or lay down principles that shall apply to every case; but the great principle to be observed is to obtain right lines of sight as long as possible, and to dispose them, so that one shall fix and determine the position of another, and the more simply this can be done, the less labour there will be in the operation. No disposition of lines does this so effectually as the triangle, consequently no process can be so good as that which reduces the lines to that form; and their careful measurement, and an intelligible

record of them in the field book cannot fail to produce a good plan.

285. When the land to be surveyed is very extensive, so as not to permit the lines to be measured on account of their great length, inequalities upon the surface, interposition of large rivers, bays, mountains, or other impediments, the processes of trigonometry must be resorted to, as is the case in preparing maps of whole countries. In this case it often happens that the exact positions of towns, villages, and other objects, spread over a large extent of country, may be correctly ascertained by the actual measurement of only one single line upon the ground, to serve as a base. Because, if two distant church spires or other well defined objects, can be seen at once from the two ends of such base line, then a good theodolite placed at those ends, will form two triangles, two sides of which are visual, while the measured base forms the third side common to them both, and thus will sufficient data be established, not only to determine the distance the two objects are apart, but the distance of either of them from the ends of the base line, and this with greater precision than if their distances had been mechanically measured. The original base line may now be deserted, and one of the newly ascertained distances used as a second base line, to repeat a similar operation on two other distant objects, and thus may a series of triangles be extended from one part of a territory to another, all founded upon the original base line. This is called a trigonometrical survey, and is the kind of survey that has been long in progress, and is nearly completed in Great Britain, and is now proceeding in the United States, being conducted by detachments of the corps of Military Engineers, as noticed in the introductory chapter. The main triangles having been thus established, the interior parts of them have to be filled up by the ordinary processes of surveying already described.

286. The kind of land surveying the Civil Engineer has most frequently to attend to, though extensive in length, is seldom so in breadth, and is of a very simple nature; for it is generally limited to the examination and measurement of a tract of country through which a road or canal has to pass. A road or canal may be found necessary between one town or city or several of them, but still it can never be laid down upon a map, since its perfection, and even the possibility of its execution depends, in great measure, upon the face formation and materials of the country it has to pass through, and these can never be judged of by a map. All that the map can do is to point out the relative bearing position and distance of the places from each other, and the general form of route to be pursued, and that being settled the Engineer

must inspect the ground in order to find out the best and nearest route, and to ascertain if the project can really be carried into execution. The selected line having been staked or marked upon the ground, has to be levelled by operations that will form the subject of the next chapter, and this process of levelling will show at once whether the line selected is a favourable one or not. If it should prove so, it may be considered as fixed, but if otherwise, it must be deserted, and a new line selected out. Even though the first line may present no formidable impediments, and may appear tolerably good, it is often necessary to examine and level other lines contiguous to the first, in order to ascertain if one that is better can be selected. It will thus appear that the Engineer's line must be selected and marked out before any survey becomes necessary, and as his operations seldom extend to a hundred yards on either side of the line selected for the work, his land surveying operations need seldom exceed that limit. He will have to ascertain the shape and dimensions of those fields and lands he has to cut through, and of those immediately joining to them, but will have no occasion to penetrate farther into the property, and the whole of his measurements may be performed by the chain, cross and circumferentor, or even by a levelling instrument with a large compass attached to it; for a levelling instrument with a large and good compass is the best circumferentor he can have, as will appear in the next chapter, where that instrument is described.

287. As an example of the manner of setting out and surveying for a road or canal, suppose C, *Fig.* 80, *Plate III.*, to represent the plan of a town situated in a hilly or gently undulating country, and that it has become necessary to construct a road or canal between it and a neighbouring village V. The nearest or most direct course for communication would be in the direct line CV, as shown upon a common map in which hills and valleys are not indicated. But upon examining the country it will be found that a hill exists at *a* (as indicated by the shading in the figure, which is so shaded to show the manner in which hills and valleys are represented upon maps when they are drawn) which must be ascended, as more clearly shown in *Fig.* 81, which is a section or profile of the same country, and in which the same letters of reference indicate the same places. That hill must afterwards be descended to get into the valley, after which a second ascent takes place over the hill *c* followed by a descent to *d*, and ascent to *e*, and finally a descent to V, so that although this line might be formed into a road, it would form a very hilly one, without expensive excavation and embankment, and would not be a desirable line; and such a one as would almost preclude

the construction of a canal. Another line should consequently be sought for before an actual survey of the ground was commenced. If, instead of following the right lined direction, the surveyor turns his attention to the valley between the hills, he will be able, very probably, to select a line to *f* that shall be nearly or perfectly level. From thence proceeding to *g* he obtains another similar line, and another from *g* to V. This last line would consequently be the one that he would stake or mark on the ground for levelling and surveying. If a supply of water could be obtained for it, it would be well suited for a canal, and on the contrary, if not too wet, from being in the bottom of a valley, would make a good and level road. But should a rivulet or water-course in the bottom interfere, he would only have to run his line C *f* further out, as to *h*, and to carrry the line of road a little distance up the brow of the hill in the direction of the line *h i* V, when no other inconvenience will arise from the water, except that it will probably be necessary to build a bridge or culvert for passing over it at V or *f*, or perhaps in both places. If this increases the expense considerably, he will examine the other side of the valley to ascertain if they can there be dispensed with.

288. Presuming, however, that the line C *f g d* V has been selected, the process of surveying it will be very simple. The circumferentor is first placed at C and directed to *f*, and the angular bearing of C *f* with the magnetic meridian noted down. This line is now measured by the chain, and every fence that crosses it, noted down to the right and left of it, taking at the same time such offset lines perpendicular to C *f* by the cross or circumferentor as will fix their angular positions in respect to that line, as well as their cross or longitudinal boundaries. That done, the instrument is shifted to *f*, and the bearing of *f g* to the meridian is next taken, and then its cross fences, houses, and other objects as before. The same thing is now repeated at the station *g* looking to V, and nothing more than a repetition of the same operations will be necessary, however extended the line may be.

289. The levelling, or rather determining whether the line selected is really level, or how much it deviates from a level, is always performed before the survey is made, as was before observed; because the value of the line is determined by its approximation to a true level. As, however, the process of levelling has not yet been explained, the method of performing this operation will be detailed in the next chapter, where it will be fully described.

290. There is one other circumstance connected with land

measuring that has not yet been alluded to, but which in practice requires particular attention when the ground is hilly or uneven, but need not be regarded in level countries. This is, that as all plans are drawn on flat paper, and the ground measure must be taken upon the surface of the land, if that land is uneven there will be a want of accordance between the limits laid down on the paper and those obtained by actual measurement. Thus, for example, in *Fig.* 81, *Plate III.*, the right line C *k l* V may represent the flat surface of a sheet of paper upon which the plan is to be drawn. Then for the plan to be correct, it is requisite that every object should appear in its relative proportional place. The town C should be at C on the paper, the valley *b* at *b*, and the valley *d* at *d;* but since the measurements by the chain must be taken from C over *a* to *b*, the curved line C *a b* is evidently longer than the right line C *b*, consequently, when this measurement is transferred by scale to the paper, the point *b* will become shifted to *k*. Again measuring the whole curved line C *a b c d* the point *d* will be found at *l*, and hence on consulting the plan it will appear that we have a greater extension of land than what really exists in nature; and it is this error that requires correction and adjustment, in order that the measurement taken on the land, and that upon the paper, may be in perfect accordance.

291. Land surveyors in different countries, and even in different districts of the same country, do not appear to have come to a decided determination, whether the sloping surface should be considered as the quantity of land to be reported to the land owner, or whether that quantity should be reduced to a horizontal plane. This difference of opinion arises from the sloping surface being in every case larger than the horizontal one, and being capable of growing more grass, corn or other low vegetable products, and consequently affording more animal provision than could be obtained on the horizontal plot. On the other hand, no more trees can grow on the side of a hill than would grow on its horizontal area. And if a pale fence has to be set in a direction ascending a hill, and the pales are to be 6 inches, or any given distance asunder, it will require no more pales to form that fence than if it ran horizontally, the pales still being the same distance apart. The only difference will be that the pales will be further apart where they touch the hill. No question has, however, arisen as to the propriety and even necessity of reducing all sloping lines or surfaces to their actual horizontal extent in drawing plans, because without this precaution, all plans of hilly countries must become distorted, and this reduction should in consequence be always made.

292. To accomplish this reduction, the hill or slope is always

considered as a right angled triangle; the hypotenuse being the slope, while the base is the horizontal distance. On this account the operation is called reducing hypotenusal to horizontal measurements. To solve this problem on the ground it becomes necessary to ascertain the angle that the slope of the hill makes with the horizon, and this is one of the purposes of the vertical graduated circle *e* of the theodolite, *Fig.* 77.

To take this angle, plant the theodolite at the foot of the hill, and adjust it by making its horizontal plate truly level. Then placing a stick in an upright position close to the instrument, cut it off at a height equal to the centre of the axis *f* of the telescope, carry this stick to the top of the hill and direct the horizontal cross line of the telescope into such position that it may appear to touch the top of the stick; or take a levelling staff (described in the next chapter,) and slide the centre line of its vane into such a position that that line may be equal in height to the axis of the telescope when the staff stands on the ground, and carry the vane so adjusted to the top of the hill, instead of the stick, and observe it as directed with the telescope, when the vernier of the semicircle will give the angle of elevation of the hill. It was before mentioned (269) that the vertical semicircle of the best theodolites was divided on one side into degrees for measuring angles, and on the other, into a scale for converting hypotenusal into horizontal lengths. And if the instrument contains such a scale, no further operation will be necessary; because, when the telescope stands at any angle, the number of links and parts of links to be deducted out of each 100 links of hypotenusal length, will be indicated by the engraved figure that stands opposite to a pointer or index on the corresponding side of the vernier block; and on deducting such number of links from the measurement obtained, the remainder will give the true horizontal length to be used. If the instrument has not such a scale, then after taking the angle, the hypotenuse of which has been measured, the base length may be obtained from the table printed at the end of this chapter, or by stating the following proportion, viz:

As radius : 100 links of hypotenuse :: cos of angle of elevation : to base sought.

For example, suppose the angle of the hill to be 29° 30′ then

by logarithms—as radius - - -	10.000000
: 100 links of hypotenuse	2.000000
:: cos of angle 29° 30′	9.939696
	11.939696
—Radius	10.000000
: Base 87 links -	1.939696 log. of 87,

or 13 links short of 100; so that 13 links must be deducted from each 100 links or chain of the hypotenusal length, or in that proportion for a smaller quantity.

293. If the slope of the hill is not regular, but inclines more in one part than another, so that the slope cannot be considered a right hypotenusal line, as is the case with the side of the hill between *a* and *b*, in *Fig.* 81, and which cannot be correctly ascertained until the slope has been examined by levelling; such slope may be divided into one or more reaches or divisions, the angles of which may be taken separately. Thus, in the figure, the slope from the summit *a* to *m* is very gradual; from *m* to *n* is very steep; and from *n* to *b* is nearly a mean between the two. Three angles must, therefore, be taken between the slope and the horizon or level line, viz: one at *m*, one at *n*, and one at *b;* and if a separate computation is made for the length of lines in these three spaces, their sums added together will produce a much nearer approximation to the true horizontal extent, than if only one angle had been taken at *b*, and the curved line *a m n b* had been treated as a right lined hypotenuse.

294. A TABLE

For shortening the hypotenusal line, in plotting hilly ground.

The angle of any hill with the horizon being	Deduct from every chain's length as measured on the sloping surface.	The angle of any hill with the horizon being	Deduct from every chain's length as measured on the sloping surface.
5° 45′	½ link.	27° 45′	11½ links
8° 10′	1 ,,	28° 20′	12 ,,
9° 55′	1½ ,,	28° 55′	12½ ,,
11° 30′	2 ,,	29° 30′	13 ,,
12° 50′	2½ ,,	30° 5′	13½ ,,
14° 4′	3 ,,	30° 40′	14 ,,
15° 10′	3½ ,,	31° 15′	14½ ,,
16° 15′	4 ,,	31° 45′	15 ,,
17° 15′	4½ ,,	32° 20′	15½ ,,
18° 10′	5 ,,	32° 50′	16 ,,
19° 30′	5½ ,,	33° 25′	16½ ,,
19° 55′	6 ,,	33° 55′	17 ,,
20° 45′	6½ ,,	34° 25′	17½ ,,
21° 35′	7 ,,	34° 55′	18 ,,
22° 20′	7½ ,,	35° 25′	18½ ,,
23° 5′	8 ,,	35° 55′	19 ,,
23° 45′	8½ ,,	36° 25′	19½ ,,
24° 50′	9 ,,	36° 55′	20 ,,
25° 10′	9½ ,,	37° 20′	20½ ,,
25° 50′	10 ,,	37° 50′	21 ,,
26° 30′	10½ ,,	38° 15′	21½ ,,
27° 10′	11 ,,	38° 45′	22 ,,

CHAPTER V.

ON LEVELLING AND LEVELLING INSTRUMENTS, &c.

295. The term levelling may appear to convey the idea of rendering a thing level or flat; but, as used by the Engineer and Land Surveyor, it applies only to those processes by which the quantity of deviation from a true level is ascertained, whether the examination takes place for the purpose of determining how much a surface must be raised or depressed, in order to render it perfectly level, or for the ascertainment of the precise quantity of its slope or inclination, in respect to height, instead of angular position in regard to the horizon.

296. When a level line, or level plain are spoken of, the common idea attached to the expression is that of a right line, or a perfectly flat surface, parallel to, or coincident with the horizon of the place where it exists. It infers a plain so constructed, that if a perfectly spherical ball of uniform density, or a small quantity of water should be placed upon any part of its surface, they would remain at perfect rest, or would show no disposition to run from one part of it to another, because bodies acted upon by gravitation alone, can only acquire motion by descending. But as no one part of the plane is lower than another, the body placed upon it could not descend; and therefore would not move at all. And whenever a plane exists which fulfils this condition, we may conceive it to be perfectly level.

297. Man sees all objects around him by rays that proceed in direct right lines from such objects to his eyes, and is incapable of seeing any thing except in these right lines, unless the rays of light that convey the image of the object to him should be bent or refracted by passing through media of varying density, or some other cause; and the height of his eye above the ground is so insignificant when compared with the diameter of the earth, that it may be said, without sensible error, that whenever he looks at a distant object in a horizontal direction, he must look in the direction of a tangent to the earth's surface. Thus suppose the circle E, *Fig.* 82, *Plate III.*, to represent the earth, and that an inhabitant at *a*, is looking around him. He will be able to see

every thing above the tangent line *b a c*, but nothing below it. The line *b a c* is, therefore, his horizon, and if he turns and looks around him in every direction his sight will be limited by a horizontal plane formed by the revolution of the line *b a c* upon *a* as its centre. It may, at first sight, appear that this line or plane is level, but upon examination it will not be found capable of fulfilling the condition above stated, for if we place the ball or quantity of water at *d*, it will not remain stationary there, but will run from *d* to *a;* because all things on the earth's surface are held to it by gravitation, tending towards its centre. All bodies free to move will, therefore, dispose themselves in a direction tending to that centre, and as the line *a* E is shorter than the line *d* E, so the ball will run down the surface from *d* to *a*, and will there only remain stationary, because there it is nearer to the earth's centre than in any other place. In fact, the angular point of *a d e*, projecting beyond the circle, may be conceived to be a high hill or mountain, down which, it is well known, a ball or quantity of water will run, and not become stationary until it reaches the lowest point it can move to, or that nearest to the earth's centre.

298. From this we infer that to construct a canal or other extended reservoir to contain water, its bottom and banks must not be right lined, but must partake of the earth's curvature, and be concentric with it; thus, in *Fig.* 83, if we again conceive E to represent the earth, and we imagine a curved table or platform *e f* to be constructed upon it, with its centre of curvature in the centre of the earth, any number of balls or quantities of water may be placed upon it without fear of their moving; because they will be equidistant from the centre of the earth, in all the positions in which they may be placed. In constructing canals, and building houses or walls, we are in the habit of considering their bottoms and tops as right lined when they are level, and they may be so considered without fear of practical error, for small portions of very large circles may be considered as right lines, and most of our buildings and constructions are of this character. Their dimensions are so small in comparison to the length of the circumference of the earth, that their deviation from the right lined direction cannot be measured or appreciated by any human means, notwithstanding our reason teaches us to know they must be curved. If, however, the length becomes very extended, the difference becomes apparent. Thus, in *Fig.* 82, if the ball *d* is placed one mile from *a*, in the right lined direction *a b*, the line *d e* or distance from the true circumference of the earth will be equal to eight inches. The same reasoning applies to verticals or perpendiculars, which are always raised by plumbets. These,

like all other heavy objects, gravitate towards the earth's centre, and the lines which they indicate will, consequently, converge to that centre, like the dotted lines in *Fig.* 83. It follows, therefore, that the two opposite sides of all buildings radiate instead of being parallel, and that the top of every high building must be larger than its bottom, but still in so small a degree as to be inappreciable, and it is, therefore, never regarded.

299. The obtention of levels is an operation of constant occurrence to the builder and Engineer. The bottoms of foundations require to be made level before a wall or building can be commenced, and as such walls rise in height, the level position of the courses of brick-work or masonry require constant examination. No drain for the conveyance of water can be constructed without first levelling its bottom and giving it the fall or slope necessary for the running of the water. In fixing machinery it is frequently necessary to have certain parts of it truly level, and in the formation of canals, correct levelling is of vital importance to the success of the work; for the water cannot be admitted to try its position during the progress of the work, consequently the level line at which it is intended to stand must be ascertained by other means, and the present chapter will contain an explanation of the manner in which such level lines are ascertained, set out, and examined.

300. The most common implement used in building for setting out and proving levels, is *the Bricklayer's Level*, the form and construction of which is shown at *Fig.* 84, *Plate III.* It depends on the circumstances of a level line being a tangent to the earth's curvature, of a plumb-line disposing itself into the direction of a radius of the earth, of course perpendicular to the middle of that tangent, and that the level direction is a right line. It therefore consists of a board *a e*, from 1 to $1\frac{1}{2}$ inches thick, which should be well seasoned, that it may not crack, warp, or change its form; another board *b* is morticed or otherwise firmly attached at right angles to the middle of the first, in such manner that their surfaces may be flat or flush. A true perpendicular line to the under edge of *a e* (which must be perfectly flat and smooth like a ruler) is now laid off from the centre of the under side of *a e* upon the surface of *b*, and is there strongly marked or scratched; a saw cut is made at the top of *b* in the direction of this line, from which a plumb-line is supported, its weight or *bob* hanging in a hole *d* cut through the bottom board and large enough to give the bob some play or freedom of motion in every direction without contact. The bottom board *a e* should be exactly 2, 3, or 4 yards long from end to end, in

order to give results of deviation from level in yards of length without calculation.

If this instrument is correctly made, it will be evident that on setting its bottom edge *a e* on a wall or other surface that is perfectly level, the string of the plumbet should accord exactly with the line scratched on *b* throughout its whole length, while on the contrary, if not level, the string will be thrown to one or the other sides of that line.

301. To prove the correctness of the implement, place it as above, on a surface that it shows to be perfectly level; and such a one may always be made by driving wedges under one end of a thick plank. After finding that the plumbet hangs in its proper vertical direction, reverse the level by turning the two ends of the bottom plank into the opposite positions they before held, when, if the plumbet retains its same parallel position to the line on *b*, the instrument is perfect. If otherwise, half the error must be corrected by raising one end of the plank, and the other half by altering the position of the line drawn upon *b*. By several reversions of this kind the true position of the perpendicular line will be obtained, and then the instrument may be used with confidence.

302. If on applying such a level to a surface, and that surface is found out of level, and it is necessary to ascertain how much it wants to make it level, as the top of the wall *f f*, let one end *a* of the level rest on the wall, and introduce blocks of wood or wedges under its other end *e* until the plumbet indicates that the instrument stands perfectly level; then measure the distance between the top of the wall and underside of the level at *a* in inches, and that will show how much must be added to the wall at this place to make it level. Suppose that distance to be 3 inches, and that the level is 3 yards or 12 feet long. Then the deficiency of level will be 3 inches in 9 feet, or 1 inch in a yard, or the $\frac{1}{12}$ of an inch in a foot.

303. If it is desired to set out a drain to be built under ground, such drain being 1 foot high throughout, 1 foot under ground at its commencement, and that it shall have a fall or descent of 2 inches in every yard forward, and that the bottom of the level used is 6 feet long, drive a stake even with the surface of the ground where the drain is to begin, and other stakes in the line of its direction 6 feet apart, or so that the bottom of the level will extend from one to the other and can be supported upon any two of them. Then, by driving them down, or cutting off their tops, reduce them by the instrument to a perfect level. Call the first stake A, and the others in succession B, C, D, &c., when precise directions can be given to the workmen for digging

(or as they call it, cutting,) the drain, viz: The excavation must be 2 feet deep at A, 2 feet 4 inches at B, 2 feet 8 at C, and so on, getting 4 inches deeper at each stake, because the stakes are 2 yards apart, and the drain is to fall 2 inches in each yard, or 4 inches in the two yards.

304. This kind of level is made long in order that it may extend over a considerable length of work at once; and no brick or stone wall should be carried up without applying such a level to its top surface at least once in every two or three feet of elevation, in order to ascertain that the courses of work are carried on in a perfectly level manner. The length of this implement precludes its use in many situations, and workmen should therefore be provided with a smaller instrument on the same principle, but in the shape of a right angled triangle. In this the plumbet hangs very near to the perpendicular side, when the triangle is set upright on its base; consequently while the base determines a level line, the other side of the right angle gives a perpendicular one. This kind of level is used by masons for showing when the upper surfaces of single stones are level; by carpenters and joiners in fixing door posts, jambs, window frames, and such things as require to be square and level in some parts and perpendicular in others; and it is frequently used by mill-wrights and others engaged in fixing machinery.

305. The best and most correct instrument for determining a true level is *the spirit-level*, so called from its being usually formed by inclosing a quantity of alcohol, together with a small bubble of air in a glass tube. It depends on the principle of air being much lighter than alcohol or water, and consequently always rising above it; so that if a quantity of either of these fluids is introduced into a glass tube sealed or closed at both ends by the blow-pipe, or what is usually called hermetically sealed, to prevent evaporation, and a small bubble of air is also inclosed, when the tube is held horizontally the bubble will always remain at the top, and not only at the top, but will get into the most elevated position; so that if the tube is sloped in a degree too small to be perceived by the eye, the air bubble will always run towards, and become stationary in that end of the tube that is the most elevated, and consequently can never be stationary in the middle part of the tube except when the tube is perfectly level. The form of the spirit-level, as above described, is shown at *Fig.* 85, *Plate III.*, but to fit it for use as well as to protect it from injury, the glass tube is always mounted in a brass tube equipped with adjusting screws, or more frequently in a piece of mahogany or hard wood, and is covered by a brass plate with a long hole through it, that exposes the top of the tube and bubble

of air, as shown at *Fig.* 86. The bottom of the block of wood being made quite flat and smooth, the level is bedded by glaziers' putty in a cavity on the top of the block. While the putty is soft it admits of either end of the tube being depressed, so that it can be brought into a state of perfect level adjustment with the bottom of the block, and then the brass plate is screwed over it, and when the putty becomes hard it can never alter its position. The adjustment to level is produced by setting the instrument on a surface that admits of adjustment as to height at one end, and making the bubble stand in the middle of the tube. The whole instrument is then reversed, end for end, and if the bubble still retains its central position the level is in adjustment. If not, the end of the tube to which the bubble runs must be pressed down further into the putty, about half as much as will bring the bubble to the centre, and the other half quantity must be produced by elevating the opposite end of the piece it stands upon. The same reversion again takes place to try the adjustment, until the bubble is found to retain its central position under reversion, when its position will be correct.

306. It must not be expected that every tube into which alcohol is introduced, as above described, will make a good level, since it is absolutely necessary to the perfection of the instrument that the upper inside surface of the tube, against which the bubble of air runs, should be a perfect right line, and this is seldom met with in ordinary glass tubes. The very process by which they are made renders it a rarity to procure a tube that is truly cylindrical, or of the same size throughout. They generally taper, or are slightly conical, and are frequently curved in their length, though in too slight a degree to be visible, until they are made into levels, and then, such is the sensibility of the bubble of air, that their imperfections become manifest. The conical form is not detrimental, provided one side of the cone is right lined; because there is no necessity for the bottom of the tube being parallel to the top. But if the tube is curved in its length, the level will be good for nothing. If, for example, the tube curves upwards, or is highest in the middle, the air bubble will stand there, notwithstanding a considerable elevation or depression may be given to its ends; and if it is concave or hollow in the middle, the bubble can never be made to stand in that position, but will constantly run to and settle itself in one or other of the ends. It frequently, however, happens that one side only of a glass level may be good, while all the others are decidedly bad, therefore a tube should not be discarded until it has been turned with every side upwards, and tried in every direction. Careful instrument-makers perform this examination, marking

the sides that must be placed upwards, and discarding the tubes that will not stand the proof. Persons are often surprised at the high prices of levels, but when it is known that out of one hundred tubes filled and prepared perhaps not more than twenty-five will stand proof, and out of this last number probably only two or three will be found superlatively good, the astonishment ceases that a thing intrinsically not worth more than twenty-five cents should sell for five or six dollars, before it is mounted or any expense incurred about it. The fluid with which the tube is filled is generally rectified alcohol, because that never freezes with the most intense cold, while water, when converted into ice, would probably burst the tube. The very finest levels for astronomical instruments are filled with sulphuric ether, which being more fluid than any other material, offers less resistance to the motion of the bubble, and is more sensitive in its action.

307. With a view to remove the uncertainty of the tube of a level being perfectly right lined, the late Mr. George Adams, an eminent philosophical instrument-maker of London, invented and applied a spirit-level, consisting of two flat plates or discs of perfectly flat plate glass, separated by a ring of metal, with all the surfaces so closely ground together, that the alcohol and bubble could be contained between them, when pressed together by a brass ring that surrounded them, without any fear of loss by evaporation; and the author has since improved on this principle by grinding the edge of a large watch glass to fit closely upon the under side of a circular disc of flat glass, so as to make only one joint that requires securing, and in which there is no metal to act upon or discolour the spirit, and no varying expansion by heat or cold in the joint, which may be secured by a cement insoluble in alcohol. In these levels, the air bubble must remain stationary in the middle of the top circular disc when it is properly adjusted; and such an instrument, surrounded by a brass ring with three levelling screws, is a very accurate and convenient portable horizon, to be used on land with the reflecting sextant or quadrant. The upper polished surface of the top flat glass will reflect ample light for this purpose, but great care is necessary in selecting the glass, as both its sides must be perfectly parallel to insure perfection in the instrument.

308. The process most usually resorted to for rendering the top surface of the ordinary tubular spirit-level truly right lined, is to grind that part of the glass tube on a straight iron rod with fine emery. This in some measure destroys the transparency of the glass, but not in a sufficient degree to prevent the bubble being distinctly seen. The best and most expensive instruments are constantly provided with ground levels, and as the tube

must be open at both ends to admit of the grinding, such tubes are not afterwards hermetically sealed, for fear that the heat which must be applied for that purpose might warp or bend the glass by producing unequal expansion and contraction. The fluid is therefore retained in the tube by tying bladder over the ends, the joints being further secured by some peculiar varnish that has been discovered that effectually resists the action of the inclosed alcohol or ether.

309. Any of the above described instruments will suffice for levelling foundations, drains, walls, machinery, or whatever is within the reach of the operator. But the pursuits of the Engineer frequently render it necessary for him to know the relative positions as to level of objects that are distant, even miles asunder; as in constructing canals and laying out roads, or water works for the supply of towns or smaller establishments with water; and whenever this is the case, since no instrument can be made that will extend from one point to the other, the optical principle, that all things are seen in the direction of right lines passing from the object to the eye, must be made use of, as before stated in speaking of land surveying. Hence all we have to do is to determine when that visual ray comes to the eye in a perfectly level direction, and this may be ascertained by affixing sights, such as have been before explained, to any of the instruments just described for determining levels, observing only, that the slits and cross hairs of such sights must now have a horizontal instead of a vertical position; because in measuring horizontal angles, the eye may be allowed any vertical range desired, but must have none in a horizontal direction, while in taking levels, the eye may range quite round the horizon laterally, but must be confined as to vertical position. No sights are, however, so good as a telescope with cross hairs, as already described when speaking of the improved theodolite, and by reference to *Fig.* 77, *Plate II.*, it will be seen that the telescope as there disposed, with a spirit-level beneath it is a levelling instrument, because when the level is set truly parallel to the axis of the telescope, and is made level, such objects only can be visible through the telescope when moved round in a horizontal direction, as are exactly level or equal in height to the telescope itself.

310. As, however, the theodolite is a very expensive and complicated instrument, heavy to carry on account of its several brass circles and adjustments, and troublesome to adjust at each station, simpler and less expensive instruments are made for the express purpose of taking levels, and are called *Levelling Instruments;* and *Fig.* 87, *Plate III.* exhibits their most approved form of construction. The telescope *a b*, is supported in two Y's, *c d*,

rising perpendicularly out of the main bar *e e*, and a spirit-level *i l* inclosed in a brass tube that is cut away at the top to expose the glass tube and bubble, is attached to the under side of the telescope. So far, therefore, this instrument exactly resembles the corresponding parts of the theodolite already described (269,) except that the telescope is made longer, has more magnifying power, and will be more convenient if it shows objects in their natural erect position, instead of inverting them. The spirit-level is likewise larger, and more perfect, as the chief use of the instrument is for taking correct levels. The instrument is often made without a compass; but if it contains one in the middle of the base or bottom bar, as shown in the figure, the instrument becomes a circumferentor of a better kind than that before described, inasmuch as it has a telescope instead of ordinary sights. The Y at *c* is permanently fixed upon the bottom bar, but that at *d* terminates below in a square shank that passes into the socket *f*, and is acted upon by a fixed screw, so that by turning its milled head the Y and end *b* of the telescope can be raised or depressed about half an inch. The instrument terminates below in a hollow tapering socket *h*, filling upon a corresponding pivot that rises out of the centre of the top parallel plate *m*, and the instrument is brought into a level position by the four levelling screws *k k*, *v v*, which pass through the upper plate *m*, while their points press against the under parallel plate *l* to which the folding legs that support the instrument at a proper height for observation are attached. In this figure the heads of the levelling screws are shown above the upper plate, instead of being placed between the two plates, as in the representation of the theodolite, *Fig.* 77, but this is quite immaterial, for their action is the same in both cases; and the intention of making the two figures different is merely to show the two ways in which these screws are applied. *p* Is a tangent screw, by turning which the instrument may be moved through a small horizontal arc for bringing the vertical hair of the telescope into more precise apparent contact with a distant object than could be done by hand.

311. The parts of the levelling instrument being understood, the next thing to be attended to is its adjustment, for upon this the accuracy of its operation depends; and what is said on this subject will equally apply to the telescope and level of the theodolite.

312. The first adjustment to be made, is that of the cross hairs in the telescope, and this is done in the following manner:

The hairs are fixed to a brass ring placed within the tube of the telescope, and kept in its position by four small screws, three of which are seen at *o o n*. The eye tube next *a* is to be drawn out until these hairs are exactly in the focus of its glass, and they are very distinctly seen; after which the eye-tube should not be touched again during the use of the instrument. Direct the telescope to any small and well defined distant object, such as the top of a picket-staff set up for the purpose; and, as this telescope admits of no vertical motion by the hand, give it the necessary elevation or depression by turning the screw *g*. Produce clear and distinct vision in the telescope by turning the nut *p*, which, by a rack and pinion concealed within the tube, projects or withdraws an inner tube carrying the object glass *b;* for all adjustment as to focus of objects examined, must be produced by turning that nut. Having thus brought the horizontal hair in the telescope into perfect apparent contact with the top or point of the object, turn the telescope half round in its Y's, or so that the spirit-level may be above instead of below it, and now observe whether the same apparent contact between the hair and the object is preserved. If it is, the hair is in its right place, but if not, it must be raised or lowered as required by tightening the one and releasing the other of the two opposite small screws *o o*, which force it upwards or downwards. The horizontal hair being so adjusted, the vertical one must be treated in the same manner; for which purpose turn the telescope so that the spirit-level may be first on one and then on the other side of it, which will cause that hair to appear horizontal. When both are well adjusted, the crossing or intersection of the hairs, as shown in *Fig.* 74, *Plate II.*, ought to be exactly in the axis of the telescope; and that they are so, is known by turning the telescope quite round in its Y's, and finding that the intersection does not describe a circle round any small fixed object, but remains permanently fixed upon it in every part of its revolution.

313. The second necessary adjustment, is to get the spirit-level exactly parallel to the axis of the telescope, or to what is called its line of collimation. On inspecting a well made instrument, or its representation in the figure, it will be perceived that the two ends of the spirit-level are fixed to the tube of the telescope by two distinct modes of attachment, for the purpose of making this adjustment. That end of the level next the object end *b* of the telescope, has a rectangular projection of brass which passes in between two cheeks *r*, fixed to the under side of the tube, about half an inch asunder, and the level is held between the points of two opposite screws that pass through these cheeks, so that by tightening one, and releasing that opposite to it, this end of the level may be shifted horizontally and fixed in any required position, but the joint admits of no elevation or depression of the level. The opposite end *s*, on the contrary, admits of elevation

and depression, but of no lateral motion, for the ball *s* is perforated, and a fixed screw, the thread of which works into the telescope tube, passes through it, so that by turning the screw in opposite directions, that end of the level may be raised or depressed. To use these screws for producing the necessary adjustment, turn the telescope in its Y's so that the level may first be on one, and then on the other side of the telescope, level with its centre, having previously brought the bubble to its exact central position by turning the nut *g*, and observe whether the bubble retains its place in all these positions, and if so, the level is right; if not, turn the two screws in *r*, without touching that in *s*, until the bubble will remain in the centre both when the level is put to the right and left hand side of the telescope, and then the screws in *r* are done with and should be permanently tightened. Next open the two spring-caps that hold the telescope down in the Y's, in order that it may be lifted out without disturbing any previous adjustments, and having brought the bubble into its proper position by turning *g*, lift the whole telescope and level out of its place, and invert it by putting the end *b* into the Y *c* and the end *a* into the Y *d*, and observe whether the bubble retains its central position. If so, the level is in its right position; if not, the bubble must be brought to the centre by giving half the necessary motion by the screw at *s*, and the other half by that at *g*. Having got the bubble into its right place, the telescope must be again taken out and reversed into its former position, when most probably a little further motion of the screws at *s* and *g* may be necessary, after which the telescope is to be reversed again, and so on until it is found that the bubble steadily maintains its position in every position, while that of the Y's remains unchanged. If the instrument will not bear this test of its correctness, some radical error of construction, or fault in the level, must exist, which can only be cured by returning it into the hands of its maker, or other competent workman, for correction. All the above are called *the permanent adjustments* of the level, because when once made they never require to be repeated, unless some of the screws are inadvertently turned, or the instrument receives an injury. All the screws that effect permanent adjustment, should have small square heads to be turned by a socket-key, such as is used for winding watches, or should have what are called capstan heads, or small holes drilled in their heads to admit a pin for turning them, in order to render them as difficult to turn as possible without possession of the necessary key or implement.

314. To adjust the instrument for taking an observation, or

for use in the field, which is a temporary adjustment requiring to be repeated at every observation that is made.

Before taking the instrument out for use, it is presumed that all the permanent adjustments, just described, have been previously made. Open and fix the three legs of the stand in such manner that the instrument may stand firmly on the ground, with the lower parallel plate *l* as nearly level as the eye can set it. Release the tangent screw *p* (if the instrument has such a one, which is not always the case,) and turn the instrument round upon its pivot *h*, until the bottom bar *e e* stands directly over any two of the levelling screws, *k k* for example. Then by turning those screws, viz: screwing the one and unscrewing the other in an equal degree, so as always to maintain a moderate pressure against the bottom plate *l*, the upper plate *m* will be moved, and as the instrument goes with it, the bubble of the level will soon be brought into its central position. That being effected, turn the instrument a quarter round, so that its bottom bar *e e* may be brought over the two other levelling screws *v v*, and use them like the two first, until the bubble is brought to the centre in this new position of the instrument. This last adjustment will most probably disturb that before made, therefore turn the instrument another quarter round in the same direction as before, in order to bring it again over the two screws *k k*, but with the ends of the telescope in opposite directions, and now once more turn the screws *k k* if necessary, and the instrument, (if these adjustments have been well made,) will be ready for use; to prove which, turn the instrument completely round on its pivot *p*, and observe if the bubble remains stationary during the whole circuit, if so, it is well adjusted, if not, all the operations just described have to be repeated, again and again, until the bubble is found immoveable. This is a troublesome operation, requiring time and patience, but it must be submitted to, if correct results are desired, and has to be repeated at every distinct station on which the instrument is set up for use.

315. As the levelling instrument is costly, and may not be in the possession of many who may desire to ascertain levels for constructing water courses or other purposes, the following description of two other instruments that will answer the purpose, though in a less perfect manner, may be acceptable, particularly as they may be constructed by ordinary workmen in almost any place.

The first depends on the principle of the surface of water always being level, whatever may be the shape of the vessel that contains it, and the second is dependant on the plumb-line.

The first, or *water level*, may be made by any tinsmith or carpenter, from the following description and representation of the instrument, *Fig.* 89, *Plate III.* Two equal sized square boxes *a* and *b*, about an inch square, and six or eight inches high, are united together by about eighteen inches of half-inch tin pipe *c*, that enters both the boxes close to their bottom, and for the sake of strength, the whole may be fixed to a bottom-board. Water poured into either box will run through the pipe into the other, and the surface of the water in both boxes will stand at the same level, notwithstanding any inclination that may be given to the bottom-board. If, therefore, two sights, *d* and *e*, made of tin, fastened to the tops of two square corks or bits of light wood, less than the boxes, be introduced into them, they will float, and if of equal weight, and the sights, one formed by a hole or horizontal slit, and the other by a frame with a thread across it, are of equal heights from their bottoms, a level line will be obtained on applying the eye to them, without any care as to the precise position of the bottom-board. The boxes and floats are made square to prevent the sights from turning round. Such an instrument may be mounted on a stand, and will answer many purposes for short distances.

316. The plumbet level may be made wholly of wood, and is simple in its use and construction. Cause a wooden, tin, or other metal tube *a*, having a bore of three-quarters of an inch, to be fixed upright in the middle of a triangular wooden foot *b*, *Fig.* 90, which has a levelling screw passing through each of its corners. A cylindrical rod *c* is provided of such size as to fit into and move round in the tube freely, but without shaking, and to the upper part of this rod attach a thin right angled piece of wood *f d e*, having a line and plumbet *g* hung against the perpendicular side *d f*, and two sights on the horizontal top *d e*. The triangle with its sights and plumbet must be fixed to the rod *c*, in such manner that it may balance or have no tendency to throw the rod to one side or the other. This constitutes a very cheap and effective instrument for short distances, and if the rod *c* is of turned metal, and the whole well made, and a small common telescope is attached to the top instead of the sights, it will perform pretty accurate work. It may stand on a table or be mounted on a three-legged stand like other instruments, and is adjusted like the level by first turning the triangular board, *d e f*, into the direction of any two screws, and by their means causing the plumbet to hang in coincidence with the line drawn for it, and also parallel to the face of the triangle. That done, the triangle is turned upon its stem *c*, to a position at right angles to the first it held, when it will be over the third screw, and between the two first. The adjustment is now rendered more perfect by the third screw, and

will not be complete until the triangle can be turned quite round without altering its position in respect to its plumb line, or its parallelism with respect to the face of the triangle, and whenever that is found to be maintained, the instrument is ready for taking an observation.

317. In these, and all other modifications of the levelling instrument, the line of sight is straight, and may be considered a tangent to the earth's surface at the place of observation; consequently supposing the instrument to be placed at *a*, *Fig.* 82, the level line given by the instrument will be that indicated by *a b* or *a c*, called the apparent level, and the manner in which this is converted into a curve, concentric with the earth or a true level, will appear when the method of using the instrument is explained.

318. Whatever may be the construction of the levelling instrument, it is constantly used in conjunction with a measuring-rod, of a peculiar construction, for determining the height of the several objects above or below the level line, and such implement is called a levelling-staff and vane. The vane, or target, as it is called when circular, is the object to be looked at by the telescope or other sights of the levelling instrument, and is made to slide so stiffly upon the rod, (which is divided into inches commencing from the bottom,) that it will remain without shifting in any place at which it may be put. The form of the rod is not material, provided it is straight, and it should be ten or twelve feet long, painted white, with the inches and quarters painted in black upon it. The target is often made of strong tin-plate, painted black and white in quarters, as in *Fig.* 88, so as to mark the central horizontal line distinctly at a distance; and the hole in the centre is to permit the figures and divisions to be seen through it, the division corresponding with the horizontal line being pointed out by a fine wire soldered across the hole. The target frequently has a tin socket, for the rod to slide through, soldered behind it, and a thumb screw to fix it at any required height upon the rod, which, for the convenience of carriage, is made in separate pieces, six feet long, that screw together, end to end. When the required elevation of the target is so great as to be beyond the reach of a man, it becomes necessary to slope the rod, in order to reach and shift it, when it is again held upright, but as this operation has frequently to be repeated many times at each station, it becomes troublesome and tedious, and the form of the best London staves is preferable, as the adjustment is performed at once. The London form of staff and vane is shown at *Fig.* 91, *Plate III.* The rod is about one and a half inches square, and six feet six inches long, made of mahogany, inlaid on its face

with holly, or other white wood, to receive the divisions and figures. The staff consists of two pieces dovetailed into each other throughout their whole length, so that one half of the rod slides upon the other, in consequence of which the rod can be pulled out or extended to twelve feet long, and yet will leave a foot of the two halves jointed together, for maintaining the straight form of the instrument. The divisions begin to count from the bottom of the staff, and are engraved upon its front in the manner shown at *Fig.* 92, viz: a double scale of divisions runs up the middle of the front of the staff. The one side consisting of feet and inches divided into tenths, and the other of feet divided into hundredth parts, without regard to inches; but every tenth division is numbered. This double scale is for the convenience of taking levels directly in inches and tenths, or in feet and hundredths, and the latter is so much more easy and simple, that it is almost universally used, though the contiguous scale of inches is very convenient for converting decimals of a foot into tenths of inches by inspection, without calculation. These divisions terminate at six feet in height from the bottom of the scale. The vane is a thin piece of mahogany, ten inches long and three wide, having projections behind, which form a socket fitting the rod, in order that it may slide up and down upon it, and this sliding is rendered more equable and certain by a flat spring contained in the socket, which produces sufficient friction to cause the vane to remain wherever it may be placed. The form of the vane is shown at *a b*, *Fig.* 91; its front is covered by white wood or paper, but has two strong black lines marked upon it, each half an inch wide, leaving a white line a quarter of an inch wide between them; and in using the instrument the horizontal hair of the levelling telescope must be made to appear to be upon the middle of this white line. There is a hole in the centre of the vane to show the figures on the staff, and the edges of this hole are chamfered to admit as much light as possible to fall on the figures or divisions, and a horizontal wire crosses the hole, at the middle of the white line, to point out the division on the scale that corresponds with the height of this line on the vane. The staff being placed on the ground in a vertical position, is so held by one hand of the assistant, (called, in this case, the staff-holder or rod-man,) while with the other he elevates or depresses the vane, according to the directions or signals he receives from the person at the levelling instrument; because, as the telescope of that instrument admits of no elevation or depression, the vane must be raised or lowered upon the staff, until it is brought into exact apparent coincidence with the horizontal hair of the telescope. When the cross wire of the vane is raised so high as to intersect six feet, there is a stud or stop on the staff that prevents its being pushed higher. If, therefore, a greater height than six feet is required, the vane is put to this height and is not to be touched again, but the staff-holder holds the back portion of the staff *c c*, *Fig.* 91, with one hand, keeping it still upon the ground, and with the other he slides up the front portion *d d*, vane and all, by which it can be raised to twelve feet in height, which is as much as can be taken at any one station; and thus the vane is elevated without sloping the staff, or any loss of time. In order to show the height of the vane when the front half of the staff is raised, the same scale of divisions is continued as before, but is placed on the back of the front piece, and is therefore invisible until the staff is drawn out. The divisions now proceed from the top downwards, and are marked for reading off by the top of the lower half of the staff, the appearance of which, from behind, when raised, is shown at *Fig.* 93, in which *e* is the top of the lower staff, and *f* the under part of the front staff, upon which the two scales of divisions are separated by the dovetailed channel *f f*, in which the projecting slider of the lower staff fits, as shown at *g* in *Fig.* 91, and in which *h* is a clamping screw, for fastening the two half staves together at any elevation that may have been given to the front staff. The appearance of the back of the vane, its socket and spring for producing friction, are shown at *k k*, *Fig.* 93.

319. In order to take levels, or use the instruments above described, the line intended to be levelled must first be selected and set out by picket-staves placed at equal distances asunder. This division in ordinary operations is done by steps or paces; but when great accuracy is required the distances are measured by the chain. Supposing in the first instance that pacing will answer, a picket-staff is set up at the starting point, and the surveyor taking long and equal steps in the direction of the line moves 100 paces, and then sets up another staff. He proceeds in like manner setting up a staff, arrow, or some mark that may be easily distinguished and found again at every 100 paces for some distance. 100 paces is here taken as an example, but the distance between the marked points must depend upon the nature of the country and the object of the survey. If the country is very flat, and it is only necessary to determine the relative altitude of the two extreme points of the survey, much longer distances may be taken between each mark; but if the country is hilly and uneven, it will be impossible to take distances even of 100 paces at once, but we must be satisfied with getting them 50 or even 25 paces asunder, as will hereafter appear. If, likewise, it is necessary to make a correct section or profile of the surface of the country by drawing or plotting it, the stations

must be short, because those points only that are marked or set off as stations will appear, or be given in the field book from which such drawing must be made.

320. Presuming, however, that the country is tolerably level, and that the distances first named of 100 paces each will suffice, we will call the picket-rods or other markers that have been set up No. 1, 2, 3, 4, &c. No. 1 designating the first rod or starting point. The levelling instrument is first set up and adjusted as before described (314) so that its telescope may range all round in a truly horizontal direction at No. 2, turning the telescope towards No. 1, where a staff-bearer is stationed, and holds up the levelling-staff and vane in a vertical position with its front towards the telescope. The observer turns his telescope so as to get the staff in the centre of the field of view, and he now signals the staff-bearer to raise or depress the vane as may be necessary, by making motions with his right hand, such as will indicate that the vane must be lowered if it is already too high, or to raise it should it be too low. The proper manner of moving the vane, which saves much time, and is soon acquired by practice, after receiving the first signal that it is too high or too low, is to keep it in constant gradual motion in the direction in which it has to be moved, during which the observer keeps his eye constantly at the telescope, and as soon as he finds it is at the precise point, or very near to it, he throws his right arm out into a horizontal position, as a signal to the staff-bearer to stop moving. He now applies his eye again to the telescope, to see if the horizontal hair is precisely upon the middle of the white central line of the vane; if not, he signals for the vane to be raised or lowered, or stopped as before, when it is exactly in its right place. If the telescope has sufficient power, he reads the division on the staff that the cross-wire cuts, or if this cannot be done, he signals the staff-bearer that the operation is finished by taking off his hat, or any previously concerted signal, when the staff-bearer comes up to him, bringing his staff, and taking care that the position of the vane upon it is not altered. It is then read off and entered in the book, suppose it to be 3.25 if using the decimal side of the scale, or 3 feet 3 inches if using the inches. This is called *a back observation*, because the observer has been looking backwards towards mark No. 1, from whence the levelling commenced. That done, the observer and instrument remain stationary at No. 2, and the staff-bearer proceeds to No. 3, where he takes his station and holds up his staff with its face towards the telescope, which the observer in the mean time turns round into this new direction. Let it be supposed that the station No. 3 is so much down hill, that the observer on looking

through the telescope finds that it ranges over the top of the staff. He apprizes the staff-holder of this, by holding both his arms up over his head, indicating that both staves must be used. The staff-holder accordingly pushes up the vane until it touches the stop and stands at 6 feet, and then slides up the front rod until the observer apprizes him as before that the vane is brought to its proper elevation, and the observation is concluded. The staff-holder now in turn stands still, and the observer having finished at station No. 2, takes up his instrument and proceeds to No. 3, when he writes down the elevation of the vane in his book, and records this as *a forward observation*, because it is in the direction in which the survey is proceeding; suppose it to be 7.50 or 7 feet 6 inches. Having done this he proceeds to No. 4, where he plants and adjusts his instrument, and turns the telescope back towards No. 3, for another back observation. The staff-holder being apprized by signal that the instrument is adjusted, again holds up the staff at No. 3, *on the precise spot* where the last observation was taken, and having turned the face of the vane towards the telescope, awaits the signals of the observer, and moves his vane accordingly until he is apprized that it is in right position, when he leaves his post and proceeds onwards to the observer to have that position recorded, say 4.33, and that done, he goes to station No. 5, where he again holds up the staff, the telescope is turned to it, the vane adjusted as before, when the observer and instrument move onwards to set down the elevation and take up a new position at No. 6, and there the same operations are repeated. The process of levelling is therefore very simple, and when the observer and staff-holder understand each other's motions the operation may be conducted with great expedition. The only delay that occurs is in the due adjustment of the instrument, which requires great care and attention, without which the whole operation is good for nothing. All the rest may be done at a running pace, and forms a healthful and pleasant exercise in cold weather.

321. The reason for taking the observations, as above described, by back and forward observations, will be apparent after what was said in explanation of a true level line (297) which was illustrated also by *Fig.* 82. If the observations were taken in the forward manner only, they would be subject to the errors then explained, or must be corrected by a troublesome operation at each station, because as distant objects are only seen in right lines, horizontal instead of level lines would be obtained. Thus referring again to *Fig.* 82, suppose the levelling instrument is placed and adjusted at *a*, and that it is necessary to set out a level line towards *e*, that is, such a line as would serve for the

surface of a canal. On looking through the telescope our line of sight will be directed to *b* in a horizontal or apparent level direction, and the bottom of the ball *d* would appear to be level with *a*. But from principle this is known to be untrue; and that we must measure and deduct the distance *e d* from the apparent, in order to obtain the true level, and this is the object of the staff and vane. Suppose the staff to be held up perpendicularly at *e*, and that *d* is its vane, which stands at five feet high. Then the foot of the staff at *e* instead of its vane *d* would give the level point. But the levelling instrument itself stands some height from the ground, say four feet, therefore the point *a* would not be level with *e*, but we must deduct the four feet from the five feet previously obtained, and this would bring the level point to one foot below *d*. But the point *d* exists only in empty space when the vane is removed, and leaving nothing to mark its position, it becomes necessary to compare the position of *e* with *a*, and yet no direct data occur for making that comparison. We have obtained the result of one foot from the figures, but we cannot say that *e* is one foot higher or one foot lower than *a*, because we know it is exactly level. It can, therefore, only be so described in the book, and identified on the ground by driving a marking stake to denote it; and if the level has to be pursued further, the instrument may be placed over this spot, its height taken and a new point identified, an operation that will be found tedious, troublesome and liable to errors if attempted for a continuous line, though it may be resorted to with advantage for proving work when finished or in progress in a manner that will be hereafter described. This operation is called *Simple Levelling*.

322. If, on the contrary, the process of back and forward sights at equal distances, or what is called *compound levelling* is adopted, the process is easy, simple, expeditious and free from errors if carefully conducted. When the method of reducing the observations is explained, it will be found that the height obtained at a back or forward observation is to be deducted from that obtained in an opposite direction, so that these heights are thus compared together without any regard to the height of the instrument, and a result is at once obtained; for the horizontal lines of sight are, by this subtraction, converted into a curvilinear form corresponding with that of the earth. Thus again recurring to *Fig*. 82, suppose the instrument still adjusted at the point *a* just midway between *e* and *f*, and that the levelling is proceeding in a direction from *f* towards *e*. Then turning the instrument towards *f* would give a back observation. The vane staff is held up at *f*, and the distance between *f* and the line *a c* obtained, say five feet; the vane

staff is then moved to *e*, and the telescope turned round for a forward sight, and the height from *e* to *d* measured, which suppose also to be five feet; this subtracted from the last result would leave no remainder, indicating that there is no difference between the level of the two points, or that they are on what is called *a dead level.* If, on the contrary, a hill or projection had existed at *f*, (as indicated in the figure,) the vane staff held upon it would have been reduced in length, say to three feet, and this being deducted from five feet at *e*, would indicate a difference of two feet between the top of the hill and the point *e*, or in other words that the point *e* was two feet nearer to the centre of the earth than the top of *f*. It thus appears, that to obtain the difference of level between two distant points, the height of the instrument need not be regarded or entered in the book; nor indeed is it essential that it should be in the line of the work. But if it is necessary to produce a drawing or profile of the surface of the country passed over, then the more points that are ascertained the more correct that profile will be; therefore it becomes necessary to multiply the stations by taking them at short distances apart.

323. The process of taking levels by this method is so simple that nothing more need be said about it, except what will be developed in explaining the field book, or book in which the several observations are recorded as before mentioned.

The same form of book that is used for land surveying also answers for recording levels. The pages being ruled into three columns, of which the left hand contains an account of the back sights. The central one the stations of the levelling instrument, and the right hand, the forward sights; and these are not written, as in land surveying, from bottom to top of the page, but begin at the top as in common writing, as for example,

324. Account of levels taken from the centre of Mr. ——'s gate, proceeding along the high road in an easterly direction to the ferry on the South river.—28th August, 1837.

Back Sights.	*Instrument stations.*	*Forward Sights.*
At centre M.'s gate 3.25		
110 paces, -	1 ⊙	opposite large oak tree
6.20		7.50 at run across road
110 „ - -	2 ⊙	west end of barn
3.42		3.61 E. corner of ⋈ lane
110 „ - -	3 ⊙	opposite middle of stable
3.48		3.51 two yards short of ⋈ fence
110 „ - -	4 ⊙	opposite field gate on left
3.36		3.90 at a high poplar tree

110 ,, - -		5 ⊙		4 yards beyond ⋈ fence
	4.12		3.31	at angle, and fence ends
110 ,, - -		6 ⊙		a stake driven, as no mark
	4.31		2.31	corner of small house
110 ,, - -		7 ⊙		at door of blacksmith's shop
	4.02		4.00	opposite door of ferry house
55 ,, - -		8 ⊙		corner of ferry house garden
	3.90		7.91	down beach (no mark)
55 ,, - -		9 ⊙		at the mooring post
Total 1600 paces.			8.40	at edge of river

325. The same kind of entry would be continued in the book until the entire line of levelling should be complete, but enough has been given to show the manner in which the book is kept; and very few observations will render the reasons of these entries, as well as the manner of using them, clear and intelligible. Referring to the explanation before given of the process of levelling, the instrument is planted at a certain distance beyond the commencing point, a back sight is taken to that point, and this mark ⊙ is used to denote the station or place of the instrument. Accordingly the first entry in the book is 3.25 in the left hand column, which shows that this number was cut by the vane on the staff placed in the centre of M.'s gate, as viewed by the instrument standing in its first station 1 ⊙, which station is stated to be opposite to a large oak tree, the position of which is identified by the 110 paces written to the left of that station, which shows its distance from the gate.

The next entry is 750, at a brook or run across the road, and this is put in the right hand column, as being a forward sight, but no number is set against it to indicate its distance, because the distances are always presumed to be equal, unless a special entry is made that they are not so. This run across the road is therefore 200 paces from M.'s gate, and the operation as far as it goes is complete, which is the case with every pair of sights, that is 1 back and 1 forward throughout the line; consequently, if we subtract 3.25 feet from 7.50 feet, 4.25 will remain, and this is the difference of level between M.'s gate and the centre of the bottom of the run. But I wish to know whether this difference is so much higher or lower than the gate, to ascertain which I look to the entries to find which position has exposed the greatest quantity of measuring staff or given the highest number, because the more the staff has been exposed the greater must be the distance to the ground. I find the highest of the two numbers is a forward sight, or in the direction

I am going, therefore I have gone down hill from M.'s gate to the run, and I find the ground falls 4.25 or 4 feet 3 inches in 220 paces. If, on the contrary, the high number had been a back sight, then I should have been ascending a hill which will occur in the next pair of sights.

The next entry is 6.20 as a back sight, but no remark is made against this to denote its position, because none is necessary, for by the explanation previously given all the back sight stations after the first, must be on the precise spots from which the previous forward sight was observed. The position, consequently, of 6.20 is identical with 7.50, which has been described. It is the levelling instrument that must move in this case, and accordingly we now find it at 2 ⊙, opposite the west end of a barn, and 110 paces in advance of the sight vane, from which a back sight is taken giving the result 6.20 before referred to. This being entered, its corresponding forward sight is taken at another 110 paces in advance, being the E. corner of a cross lane, and the result is 3.61. This pair of numbers may be subtracted as before, and the remainder, 2.59, is the difference of level; and, as the high number is now among the back sights, I find I am working up hill, and that the land at the cross lane is 2.59 feet higher than that at the run. To ascertain what the height of the cross lane is, in respect to M.'s gate, I may subtract the 2.59 of this last operation from the 4.25 given by the first, and the remainder 1.66 shows me that there is that difference of level between M.'s gate and the cross road, which last is the lowest by that quantity, or 1 foot 8 inches; and as this point is distant 4 reaches of 110 paces each from the gate, that is the general fall of the land in 440 paces, or in so many yards or chains if those measures have been adopted instead of paces.

326. There is, however, no occasion to go through the complicated process of subtraction just referred to, when we desire to compare the level of one spot with that of another, however near or distant, because in the same way that any one pair of sights will give the relative level of the points when they are taken, and the rise or fall of the country between them, so will the sums of any number of pairs subtracted from each other in like manner give the same result with much less trouble. Thus if instead of first finding the fall from M.'s gate to the run, and then the rise from the run to the cross road, we had taken the sum of the two back sights, viz: $3.25+6.20=9.45$, and that of the forward sights $7.50+3.61=11.11$, and subtract these from each other, we should obtain the same result 1.66. In like manner, if we wish to know the difference in level between more distant points, it is only necessary to collect all the back sights into one

column and the forward ones into another, so that they may be separately added and subtracted, when the result will be given; observing always to take the observations in pairs, that is, to have as many back sights in one column as there are forward ones in the other. Thus if I desire to know the difference in level between M.'s gate at the commencement of the survey, and the forward sight of the 7th station opposite the door of the ferry house, which is 1540 paces distant, I must collect all the back observations into one column and the forward ones into another, add up the columns, subtract one sum from the other and the remainder will give the difference thus:

Back sights.	*Forward sights.*
3.25	7.50
6.20	3.61
3.42	3.51
3.48	3.90
3.36	3.31
4.12	2.31
4.21	4.00
28.14	28.14

It happens in this case that the two sums are exactly equal, therefore if subtracted nothing would remain; and this shows that however undulating the country may have been between these two points, that they are exactly level with each other, but proceeding onwards we have

4.02		7.91
3.90		8.40
7.92	against	16.31
		7.92
		8.39

Showing that from the ferry house to the river, there is a fall of 8.39 feet in a distance of 220 paces, or four reaches of 55 paces each, because the fall is here so rapid that it could not be taken like the former part of the survey, in distances of 110 paces each.

327. A field book kept as above described will, therefore, with very little trouble, give the difference of any one single pair of observations; of the extreme ends of a line; of any portion of the same that may be required, or of each distinct portion of an entire line, however extensive it may be; and the operations of levelling, as above described, are constantly resorted to by the Engineer for determining the fall of rivers, for building mills, or other pur-

poses; for ascertaining the slope of hills; judging of the possibility of making navigable canals, or water-works for supplying towns with water, and many other purposes.

328. The reason why the two last reaches in the above described survey were diminished down to 55 paces each, instead of 110, like those that preceded, is, that when the slopes are steep, the instruments of observation cannot command them, unless they should be made of such large dimensions as to height, as would destroy their portable character and render them unfit for practical use. Thus if we suppose *a b c d e*, *Fig.* 94, to represent the side of a hill that has to be levelled, and *c* to be the position of the instrument, fixed and adjusted, for taking the levels, which we will presume is part of a long line that is proceeding onwards in the contrary order of the letters, or from *e* towards *a*, and that *e* is the position in which the vane-staff was placed in the forward sight of the last observation, and where of course it must maintain its position—on applying the eye to the telescope it will be discovered that the line *g f* is the horizontal or apparent level, in which it directs the sight. But that line cuts the hill at *f*, and does not reach the staff *e;* consequently its divisions cannot be read, and as the staff *e* is fixed in position, no alternative exists but to move the levelling instrument higher up the hill or to *d*, so that instead of indicating the line of sight *g f*, it may indicate another parallel to the first, as shown by the dotted line above it, which, it will be perceived, cuts the vane-staff very near its bottom, but still high enough to permit a back sight to be measured and recorded. That done, the telescope is turned round for a forward observation, and if it had stood even in its former position *c*, the slope of the hill is so great that when the vane-staff should be set up at the place *a* measured off and assigned to it, (the distance *a c* being equal to *c e*,) the line of sight *f g* would pass quite over it, even though both staves should be drawn out to their utmost limit as at *a;* but as the instrument has been moved up to *d* the case will be still worse, and the vane-staff will not be visible until moved up to *b*, so that in hilly countries, or where rapid slopes exist, the extent of level that can be determined by each pair of sights becomes very limited, and the working is much more tedious and troublesome than in more level places.

329. The most tedious and troublesome operation in the practice of levelling, and one that requires the most strict attention, is the setting of the instrument truly level by the levelling screws of the parallel plates; and it is provoking after having taken this trouble to find that the instrument has been stationed in a place where it cannot be used, as in the case just described, but that it

has to be moved, and the whole operation repeated, which may happen more than once at a single station. To make sure of avoiding this repetition, the surveyor, therefore, often makes his sights unnecessarily short, and this again is not desirable, because the number of stations is thus augmented. It is with a view to remedy this inconvenience that the adjusting screw *g*, *Fig.* 87, is applied to all the best instruments, the effect of which, as before noticed, is to elevate or depress the Y marked *d*, by which the telescope may be almost instantly adjusted to level in any one direction, although it cannot be turned round. Whenever, therefore, the surveyor is in a hilly or troublesome location, this screw should be resorted to for the purpose of selecting a position for placing his instrument, and by this means he will be able to take the utmost limit of distance at which he can fix his instrument, and proceed to its final adjustment as to level, without fear of having his labour thrown away: and having found the place of the instrument, he measures by paces or the chain, from that to the back sight-staff about to be observed, and sets out that same distance forwards, to obtain the position the vane-staff must be moved to for his next forward observation. In hilly countries, therefore, the line only, without the distances to observe from, can alone be staked out, and the distances so depending on local circumstances must be measured off, after the positions of the instrument are ascertained, instead of beforehand, as in other cases.

330. In performing levelling operations, such as have been last described, it frequently happens from local circumstances that the distances of the back and forward sights cannot be made equal, or at any rate without much additional trouble. Thus in *Fig.* 94 the distances *d e* and *d b* are not equal. It is true they might be made so by shortening *d b*, and setting up the staff at *c* instead of *b*, and this should be done whenever great accuracy is required. But this would create additional trouble by making an additional station necessary in descending the hill, for now the levelling instrument must be set up at *b* to get an observation between *c* and *a*, while if the distance *d b* be maintained, the instrument may be carried below *a* for the next observation; and in short distances there is so little difference between the apparent level, as indicated by the telescope, and the true one, that in all distances not exceeding ten or twelve yards, it may be passed over without notice. Should the distance be greater it will be well to correct it by the table printed at the end of this chapter. Another method is frequently resorted to for producing this correction, which is, that if it happens that one of the sights, whether forward or backward, is unavoidably much shorter than the other in one pair of observations, the sights in the next pair may be

made equally different, but in the contrary order. That is to say, if a very short forward sight succeeds a long back sight at one station of the level, an equally short back sight, and equally long forward sight may be taken at its next position. Thus suppose after traversing a nearly level country *i k*, *Fig.* 95, we arrive at at a hill *l m* which intercepts the view through the telescope of the level placed at *k*, and that *h* is the position in which the last vane-staff has been placed. If the levelling instrument had been placed in the valley at *o*, so as to be half way between *c* and the next vane-staff *l*, several sights might be necessary to carry the operation over the hill. In order, therefore, to save time it is placed at *k*, so high up the hill as to catch the bottom of the staff *l*, and the pair of sights is completed. It is evident, however, that the distance from *i* to *k* is much greater than from *k* to *l*; but the observer knows that from the form of the country he will be able to correct this, and accordingly he next stations his instrument at *m*, so high up that he can see the staff *l* over the hill, and in doing this, he measures off the distance *l m* equal to *l k*, and orders the forward staff to *n*, making the distance *m n* equal to *k i*. By this arrangement the error that is introduced on one side into the observation taken between *i* and *l*, is compensated by an equal error on the other side between *l* and *n*, and the two errors thus neutralize and destroy each other. In difficult positions, therefore, it will be seen that some skill is necessary for selecting a favourable position for the instrument, and this knowledge can only be acquired by experience and the exercise of thought while conducting the operation.

331. The process of compound levelling is so simple that it is presumed no farther explanation will be required of it. Going once over a line, in the manner described, will be sufficient in most cases for determining the possibility of constructing a canal, or selecting the ground for setting out a road. But if the work has to be actually carried into execution, it will be advisable, and, indeed, is necessary in many cases to prove the first work done. The proof of the accuracy of a levelling operation is generally obtained by going over the same ground again in an opposite direction, that is, beginning the second examination where the first ended, and going back to where it began, to ascertain if the results tally in both cases; and in doing this it is not necessary to adhere to the stations before used, with the exception only of those that have to be compared together. When great accuracy is required it will be necessary to measure and set off the distances by the chain instead of trusting to paces, and when the ground is hilly to reduce the sloping measures to their horizontal value. (292.) The distance of the sights ought to be short, and the levelling

instrument to be in good order as to its permanent adjustments, (312,) while its local ones must be very carefully attended to. The staff-holder should be very attentive to keeping the vane-staff quite upright while under observation, and always to place it on the same spot for a forward and back observation. If possible, it is best to read the graduations on the staff by the telescope, instead of trusting the staff-holder to bring them up, as the vane may get altered, while conveying, without his knowledge; and for this reason the telescope should not invert objects. In very accurate work two vane-staves are used, by two staff-holders, at the same time, one being placed at the back and the other at the forward station, in order that the telescope may be turned backwards and forwards to them several times to make sure that no error of position exists; and when a portion of the line has been gone over twice and is proved and known to be correct, long and firm stakes should be driven into the ground at certain known and proved stations, and be entered in the book, to be referred to again in case of doubt, and to prevent the necessity of going over the whole line, should any error or omission be afterwards detected in the work. The staff-holder should never stand behind the vane-staff while under observation, but on one side of it, holding it by an extended arm. And on leaving off work in the evening, for meals, or other cause, always cease after taking a forward sight, with the vane-staff set upon some object that is immovable, and may be recurred to again when the operation has to be proved or resumed. If no such mark exists on the spot, a stake must be firmly driven in it, for concluding upon.

332. The next object of our attention must be to show how a drawing of a section, or profile of the country that has been levelled over, can be produced on paper from the minutes taken in the field book of the observations that have been made; such a drawing being absolutely necessary before the minute particulars of a road or canal can be decided upon, as well as for preparing the specification for the workmen, or the estimates of expense. This drawing, that it may show every thing distinctly, requires to be drawn to a large scale, and that usually adopted by Engineers is either eight or sixteen inches to the mile in length. This is large enough to show all necessary objects distinctly, and has the advantage, if eight inches is adopted, of having each furlong represented by an inch, and each chain by the tenth of an inch, which quantities admit of easy measurement and computation. Sixteen inches is adopted when a larger scale is required, on account of being double the former size, but this is usually denominated the scale of five chains to an inch, instead of sixteen inches to a mile. Such large scales cause the drawings to become very

extended in length, because it is no uncommon thing to give from ten to twenty miles of section in a single drawing; and on the eight inch scale it would require eighty inches, or six feet eight inches of length of drawing to show only ten miles of section. Such drawings are consequently always made on several sheets of paper, pasted together laterally.

333. However large the longitudinal scale may be, a moment's consideration will convince any one, that it will not be large enough for the vertical scale, or that which is to show the elevations and depressions of a country, or the results of the levels taken, even if the largest scale, of five chains to an inch, should be adopted. The use of a section is to direct the Engineer in setting out his work, and the workmen in executing it, and should the construction be one in which water is concerned, as in forming a canal or water course, a foot or even six inches difference in height may make a material difference, and such quantity should, therefore, be shown on the drawing. If, however, a chain or sixty-six feet is to be denoted by the fifth of an inch, as in the scale of sixteen inches to a mile, so small a quantity as the sixty-sixth part of the fifth of an inch would be almost invisible upon paper, or at any rate would not serve a workman to measure from; for the drawing representing a section of a country that only varied a few feet in level would be little better than a line of unequal thickness. In order therefore to render a sectional drawing really useful, a much larger vertical scale is always used than that which belongs to horizontal distances, notwithstanding it has the effect of producing a very distorted representation, (if such it can be called,) of the thing it is meant to show, for it bears no similitude to it in form, although all the dimensions can be measured off and calculated from with certainty and facility. The least space that can be taken with any certainty and utility to represent a vertical foot in the drawing is one-tenth of an inch, or ten feet to an inch, which is a scale of six thousand three hundred and thirty-six inches to a mile, and consequently is most enormously disproportionate to the lineal or horizontal scale; and yet however much larger that scale may be, vertical distances cannot be measured with certainty on a less scale than what has been mentioned, and a larger one is often adopted.

334. The first step towards making a drawing of a section is to draw an accurate right line, with pencil, to represent the horizon; and the length of that line must depend upon the extent of country to be depicted, and the scale adopted for the purpose. Thus suppose it were desired to produce a section of the land recorded in the field book of levels given at page 168. The extent of the line of country to be represented must be ex-

tracted from the book and be cast up if the section is to be brought into a determined size, if not, and it is immaterial how long the plan may be, this will be unnecessary. In the present instance, to introduce the section into *Plate III.*, *Fig.* 96, when there is but 6 inches of length to spare, the extent is limited. On looking to the entries it will be found there are seven stations or reaches, or pairs of observations each 220 paces long and two of 110 each, making a total of 1760 paces. But as the pace (although generally 30 inches) is no regular standard of measure, we may call these yards, and this shows the necessity of taking the distances in chains or yards, as before noticed, when a drawing has to be made from the entries. The 6 inches of line must therefore be divided into 16 equal parts, each of which will represent 110 yards, or half a furlong. If, on the contrary, the space had not been limited, but the scale of 8 inches to a mile had been selected, the line drawn would have been 8 inches long, because the entire length is 1760 yards or an exact mile; or if the larger scale had been taken, this base line would be 16 inches long. To determine its place upon the paper, look down the back and forward entries in the book to see in which column the largest numbers appear; because if they predominate in the forward column, the work is descending, and the line should be near the top of the drawing paper; but if the contrary, the section will be an ascending one, and the line should be made low, while on the contrary, if the numbers fluctuate and are occasionally high and low the line may be about the middle. Such a position will suit the line in the present instance, and accordingly draw the line 0 *p*, *Fig.* 96, with a black-lead pencil, and divide it into 16 equal parts. Number every alternate one of these 1, 2, 3, 4, 5, 6 and 7, which numbers show the correspondence of these several points with the similar numbers of the instrument stations in the central column of the field book. The intermediate points under *a b c d e f* and *g* show the positions of the back sight vane staves up to this point. By referring to the field book it will appear that after the pair of sights from station 7 the distances diminish to half their former length, or to 55 yards or paces; therefore subdivide the two remaining spaces, as at the numbers 8 and 9, which show the instrument stations, while *h* and *i* point out the positions of the two last forward vane staves. The line will now be laid out in exact proportion to the several lineal distances that have been measured upon the ground, and is now ready to receive the lines that are to mark the profile of the country.

335. Before the profile lines can be laid down the vertical scale must be decided upon, and placed at the end of the hori-

zontal line, as at *k l*, making its zero or 0 point at the line, and extending the scale as far as the profile lines will extend above and below it. If the horizontal line should be very long, it will be better to draw several of these vertical scales across it in different convenient places, in order to save the trouble of constantly recurring to the end, to take measurements. Suppose the scale of $\frac{1}{10}$ of an inch to a foot should be adopted, then the vertical line must be divided into tenths of an inch as in the figure. Then calling 0 or the commencement of the line M.'s house or the first back sight, and taking the back sight result 3.25 from the first forward sight 7.50, as before done, 4.25 descending will mark the position of the ground under *a*, or at the foot of the first forward vane-staff. Accordingly take 4.25, or 4 feet 3 inches in the compasses from the vertical scale *k l*, and transfer that distance below the horizontal pencil line under *a*, mark the point *m* so obtained, and ruling a line from 0 to *m* will give a profile of the slope or inclination of the ground in that distance. As the next operation will be a comparison of the position of the staff at *b* with that just obtained, rule a pencil line *n q* through the point *m* parallel to *o p* and extending under *b* to measure from. Then take the pair of observations belonging to station 2 from the book, viz: 6.20—3.61=2.59 working upwards. Therefore take 2.59 from the vertical scale and transfer it upwards from the line *n q* directly under *b*, which will give the point *n*, which mark, and drawing a line from *m* to *n* will complete the section to *b*. Proceed as before, by drawing a pencil parallel line through *r* extending under *c;* and now on comparing the observations belonging to station 3 we have 3.51—3.42=0.09, or only 9 hundredths of a foot in a downward direction, because the forward quantity is the largest, but the quantity obtained being about $1\frac{1}{8}$ inch, is so small as scarcely to admit of being perceptibly laid down by the scale used. Therefore the ground line, from *r* to under *c*, must be drawn very nearly level or parallel to *o p*, and the pencil measuring line *n* may be continued as far as *d*, in order to set down the observations taken at station 4, which are 3.90—3.48=0.42, or about 5 inches also downwards, and which must be transferred to the station under *d*. Through this point draw another horizontal measuring line to *e*, and obtain the result of station 5, viz: 3.36—3.31=0.05, which makes the section line, to be laid down from *d* to *e*, very nearly level, but rather inclining upwards. Station 6 gives 4.12—2.31=1.81 of elevation, which is laid down from *w* to under *f*. Station 7 is 4.31—4.00=0.31 of elevation, which being drawn in from *f* to *g* brings the section to coincide exactly with the primitive horizontal line *o p*, and shows that the point *g* is exactly level with the starting point 0 at M.'s gate, being the same result that was obtained by figures in the example worked on page (171), and affords a proof of the correctness of the sectional drawing. Continuing in the same manner to work station 8 we have 7.91—4.02=3.89, descending. This distance is accordingly set off under *h*, by dropping a perpendicular from the horizontal line *o p* at this point, and measuring the distance upon it to *s*, when the line *g s* is drawn. Through *s* draw another line, parallel to *o p*, extending to the end of the line, for measuring off station 9, which, by the field book, gives 8.40—3.90=4.50, descending, which set off from *t* to *v*, which is the surface of the water in the river, and drawing *s v*, will complete the section. Now draw a permanent horizontal line through *v*, parallel to 0 *p*, until it intersects the perpendicular scale *k l* at *l*, continue that scale down to it, and raise perpendiculars from the horizontal line to the curved surface, produced by the section at each of the points that had been previously marked or set off upon it, and that done, the pencil line 0 *p*, with its marks and divisions and all the parallel measuring lines, may be rubbed out, as may also be all that portion of the vertical scale that is above 0, and then on writing in the distances, between one point and another, on the horizontal line, or what will answer the same purpose, placing a horizontal scale under the figure, and writing any names or references to things or places on the surface, will complete the profile.

336. It will be noticed in the above profile that all the lines that unite one given point with another, are right or straight, in which there may appear to be a want of accordance with nature, as a country is always gently undulating, instead of being composed of right lines and angles, as here represented. This is a fault that must be submitted to in compound levelling, and the only way of remedying it is to make the distances between the sight-vanes as short as possible, by which the right lines are broken into shorter lengths, and a nearer approximation to an undulating line is produced. No points are given in the survey except those on which the vane-staves, or levelling-rods, have been placed, but most surveyors occupy the left hand column of the levelling field book, in which but little is written, by making eye-sketches of the surface of the country, between one station and another; and in drawing the profile, these corrections and additions may be made, provided strict attention is paid to placing the ascertained or fixed points where they really occur. And in speaking of simple levelling, on which a few observations yet remain to be made, another and more correct method of rectifying these variations from truth will be pointed out.

337. A section produced as just described, and as shown in

Fig. 96, is, nevertheless, of great utility. It is by means of such sections that the possibility of constructing a road, a rail-road, or a canal, can alone be judged of, or an approximate idea of its expense be acquired. Thus, for example, suppose it should be desirable to construct a gradually sloping road from M.'s house at 0, to some point, as *s*, on the bank of the river, instead of the up and down hill surface that the profile exhibits, and we desire to look into the possibility and expense of doing so. In the first place the profile shows that the natural surface of the country, from *r* to *w*, is favourable to such a project, but the valley at *m* is in the way. But, by supposing a line drawn from 0 to *r*, it will complete a triangle *o m r*, the area of which may be determined in square yards or feet, while its transverse measure, or the width of the intended road-way may be measured on the ground or determined in the mind, and this will furnish data for calculating the cubical quantity of soil necessary to fill up the valley. As a run of water exists at *m*, a brick culvert must be built to carry it off, and the expense of this must be taken into account. Next an impediment exists at *w*, where the ground begins to rise; but setting out the direction of the desired road upon the section, by the line *w s*, the section of the hill is reduced into an irregular trapezium *w f g s*, the area of which being found is multiplied by its breadth, and thus the entire quantity of earth to be cut away is determined, and comparing that magnitude with the cavity or valley *o m r*, we ascertain at once whether this furnishes enough, or too much soil to fill it up. If too much, as will be the case in the present instance, we can then determine how much the valley must be filled up laterally, to cause it to take all the stuff, or we may determine that it will be better to give the road less slope, by carrying it out to a point higher up the bank than *s*, so as to take no more soil away than what shall exactly compensate or fill up the cavity without surplus. Having thus determined the number of cube yards of soil to be removed, the horizontal scale will show the distance it has to be carried, and this distance must be taken from 7 to *a*, because these are the average distances from which the soil must be taken and replaced. By such data a very near estimate of the expense of the alteration may be made before the work is began.

338. Let us next suppose that a country has been levelled from one river to another, with a view to ascertain the possibility, and form a rough estimate of the expense of constructing a navigable canal, and that the section from such levelling is prepared. The section will at once show the fall or difference of level from one river to the other. If the line turns out to be a continually descending one, and the upper river has abundance of water, no

difficulty will occur to the execution. Being in possession of the total fall, suppose forty-eight feet, the section must be searched, and will generally indicate advantageous places for building the locks, the sum of the depth of which must always be equal to the difference of level between the extremes, so that we may form some estimate of the number of locks and a pretty accurate one of the length and depth of cutting. If, on the contrary, the level presents considerable undulation, the line will not be a good one, because there must either be very considerable embankments to fill up the hollow places, or very deep and expensive excavations through such as are elevated. But when the section shows a gradually rising country, proceeding to a great height in the first instance, and afterwards falling down again to the other stream, a canal will be impracticable, unless a sufficient stream of water should be found in the higher regions to feed or supply both the descending branches; or the position of the canal should be deemed of sufficient importance to warrant the expense of erecting powerful steam-engines or other machines, for pumping up the water necessary to fill the canal and supply the two descending branches, which is actually done upon the summit level of the grand junction canal, between London and Liverpool.

339. Enough has been said on the subject of compound levelling to explain its simplicity and utility, and the chapter will, therefore, conclude with some observations on the use and application of simple levelling, or that in which the sights are taken by direct vision instead of by back and forward observation; for although this process is not applicable to long extended lines, it is, nevertheless, of great utility in many instances, especially in setting out work for execution, and the examination of its truth while in progress. When used in this manner, the object of the instrument is not to observe the difference of level between points, in order to their comparison, but to ascertain points that are actually level in respect to each other, or how much they require to be raised or lowered in order to reduce them to true level. Thus, for example, if a long range of wall has been built, and it is requisite to examine its top range as to level, the usual mode of doing this is by the bricklayer's level, (300,) which, though commonly used in house or small work is, nevertheless, tedious and liable to error, when the length is considerable. Instead of using it, therefore, set up the levelling instrument at a distance in front of the wall, in such a position as will command a considerable range of the work, and elevate the stand of the instrument on a hill or other elevation, (natural or artificial,) to such height as will cause the telescope, when adjusted as for other levelling, to range over the top of the wall. That done, direct the telescope to the beginning of the wall, and place a staff-

holder upon it, with the staff and vane as usual. While looking through the telescope, cause him to elevate or depress the vane, until perfect apparent coincidence is produced between its central line and the horizontal hair of the telescope, after which the vane should not require to be moved or touched again, if the work is truly level; but he walks along the wall, setting down the staff upon it at every ten or fifteen feet, while the observer follows him with the telescope by turning it round upon its vertical axis, and if the wall is level, the wire of the telescope will cut the vane in every one of its positions, at the very same spot as it did in the first instance. But should it not be perfectly level, the vane will require to be raised or lowered by a quantity equal to the deficiency of level, which is thus shown at once by the scale of inches and parts. This operation, although described as being performed upon a wall, it will be self-evident, is equally applicable to any other extended construction that requires to be made truly level, as is the case with the rails of a rail-road, or the bottom of a navigable canal or its top banks, all of which are not only set out for finishing, after the first rough work has been performed, but are examined, as to perfection of level when finished, by this process of single or simple levelling.

340. In the setting out of a canal, rail-road, or other extended construction, simple levelling is constantly resorted to, after the compound operation has been finished, and the profile or section from it has been prepared. The one operation furnishes the grand outline of a plan, and the other comes in aid afterwards to fill up the minutiæ. Thus in describing the section represented by *Fig.* 96, it was objected that the profile lines, that join one given point to another, are all right lines; but should it be necessary to make this section a more accurate one, and to delineate all the little curvatures that exist on the ground between one station and another, recourse must be had to simple levelling to accomplish the object. Thus take any reach of the section, as from *b* to *c*, where the ground is nearly level or appears quite flat. To ascertain if it really is so, or how much it deviates from a flat surface, place the levelling instrument opposite to 3, but at a considerable distance from one side or the other of the line before gone over, suppose, for example, one hundred yards out of the line, then adjust the instrument for a complete horizontal range. Divide the line to be examined into as many parts as it is desired to examine, equal or unequal is immaterial, provided their separate lengths, and the sum of their lengths be ascertained; set up a vane-staff upon one of the previously ascertained points at either end, and cause its vane to be shifted to such height as will make it accord with the horizontal hair of the telescope. Having noted this

height down, cause the staff to be set up on each of the divisions or points to be examined, and the difference in height between this point so ascertained, and the others to which the vane must be shifted in its new positions, will give the elevation and depression of these several positions in respect to the first height obtained. Thus let *b c*, *Fig.* 97, be the portion of line to be examined, the positions of the ends of which have been previously fixed as to elevation by the section, *Fig.* 96. The lateral position in which the levelling instrument is placed is 3, and the dotted lines that radiate from 3 to *b d e f*, &c. show the directions in which the sights or observations are to be taken, by placing the vane-staff in succession on the points *b d e*, &c. It will thus be found, perhaps, that *d* is three inches lower than *b*, while *c* may be ten inches higher, and thus may a waving or irregular line be found out that will exactly represent all the minor inequalities of the country, and which can, of course, be introduced into the section if desired. Each reach of a long line can, of course, be submitted to this method of lateral examination and verification.

341. Again, let it be supposed that the line *b c* is one hundred yards long, and that I desire to set out a fall for a rail-road or other purpose, of three inches or any small quantity in the one hundred yards, from *b* to *c*. This would be next to impossible by the bricklayer's or other forms of level, even though the surface of the ground might have been cleared and prepared for the purpose; but with a good levelling instrument it is easy and certain. Thus take a correct observation of the vane held at *b*, then slide the vane three inches up the staff and carry it to *c*, where, if necessary, a hole must be dug to receive its foot, which should be placed upon the top of a stake driven down until the vane is in accordance with the horizontal hair of the telescope, then digging out a right line from *b* to *c*, it will have the fall required. In this, and all similar applications of lateral levelling, the position of the levelling instrument 3 must be as far removed from the points to be examined, as is consistent with distinct vision, in order to render all the lines of sight 3 *b*, 3 *d*, 3 *e*, 3 *f*, &c., as equal as possible in length, because if they vary much, a compensation must be made for the dip or difference between the real and apparent level, as before spoken of; and for this same reason too large an extent in the direction *b c* should not be attempted, as more certain and correct results will be obtained by making the lines to be examined short, and increasing the number of lateral stations of observation.

342. Simple lateral levelling is not only used to prove and examine work, and set it out to given or required slopes, but also for the purpose of finding lines to be set out. Thus in the

example *Fig.* 96, if it is desired to find a better road to the river than the surface of the land indicates, and yet we do not wish to perform the earth work before referred to, it is probable such a one may be discovered by the use of the level. For the low point *m* is a run of water that must have a fall or natural inclination, consequently the higher we trace that stream upwards, the greater will be the probability of finding land that may nearly agree with the desired line 0 *r* in level, although it may be in a more circuitous route. Such search may be made by fixing the levelling instrument near *r*, with its telescope pointing up stream, while the vane-staff is applied to various parts of the surface; and, in like manner, we may search round the rising ground *w f g s*, if it is in the nature of a detached hillock, to find a way round it that will be more level than going over it.

343. As another instance, let it be supposed that the land represented by the plan *Fig.* 80, has been levelled, and a section made of it. That the crooked distance from C to V through *f g* and *d* is two miles, and that the village V is six feet lower than C, and that this survey has been made with a view to determine whether a navigable cut can be made, or whether it will be better to construct a rail-road between the two places. A navigable canal requires to be perfectly level throughout its whole distance, unless locks are introduced, and then that the reaches between one lock and another should be level. If, therefore, a navigable cut is made of the height of C, its surface will be six feet out of, or above the ground at V, and it will require embankments on both sides during its whole extent. If, on the contrary, the height V is taken, its whole length will be excavation, and the side banks at C will be six feet perpendicular above the surface of the water, and in both cases it will be expensive, on account of the quantity of earth requiring to be moved. But by placing the levelling instrument in proper lateral positions, such as *a*, and beyond *b g d e*, &c., so as to take a succession of ranges, and having the vane-staff held at *h* and in different positions along the line *h c* V, a series of points may be selected and marked with stakes, in such places that the first or nearest to C shall be three feet below C, and all the succeeding points level with it, so that at the end next V the last stake shall be only three feet above V. By this disposition, one half of the canal will be in excavation, and the remaining half in embankment, and the soil that is dug out of one end will serve to form the embankment at the other, without any inconvenient elevation or depression of the water, and with less expense and greater convenience to the work than in either of the former plans.

344. What has been said of a canal applies equally to a rail-

road, as the level points along the brow of the hills will be found and marked out in the same manner. Or, if it is determined to give a certain slope or inclination to the road, it can be done with equal facility, by correctly ascertaining the entire length, and entire fall; then dividing the length into any convenient number of equal parts, and calculating what portion of that fall must be given to each part; and staking out the line upon the ground into a similar number of equal parts. The tops of those stakes must be set level by aid of the instrument, and having numbered them for reference, a specification may be made out for the workman, stating how much the work is to be below the top of each particular stake. Or, what is still simpler and better, after the stakes have been levelled, the necessary portion may be sawed off the top of each of them, so as to reduce their tops to a parallel to the work that has to be executed. A parallel is mentioned instead of the real line, because that line is almost always on, or under the surface of the ground; and if the stakes were so placed, they could not be seen, or be conveniently cut off; but by making them all uniformly a foot, two feet, or any determined height above the work, they offer the advantage of having their tops exposed so that they may be boned, by looking along them to see that they range properly both as to height and to line, they are easily found, and the workmen work with equal facility; for by cutting a stick equal in length to the distance they are to work below the tops of the stakes, and applying it to any stake it informs them whether they are right or not.

345. In using the levelling instrument for simple levels, it must be constantly borne in mind that as the observation is made in one direction only, without any thing to counteract it on the other side, the results will always be apparent instead of real levels. If, however, the radial lines of sight are pretty nearly of the same length, this will be of no importance, because the error that exists in any one observation will exist to an equal extent in all the others; and, therefore, will not effect the truth of the observations. It was on this account that the position of the instrument was directed to be as distant as possible from the objects observed, and that too long a lateral extension should not be attempted from the same station of the instrument. Thus, in *Fig.* 97, the station 3 for observing points on the line *b c* is bad, because the lines of sight 3 *f* and 3 *e*, are much shorter than 3 *b* and 3 *c*, and the longer the line of sight is from the point of observation, the greater will be the difference between the true and apparent levels, as will be evident on inspection of *Fig.* 82. If, therefore, the line 3 *c*, *Fig.* 97, is twice as long as 3 *f*, a compensation will be required to make 3 *c* accord with 3 *f*; for

although the line *b c* may, in fact, be a true level, yet from this cause the two ends will appear a trifle lower than the middle. This is avoided in practice by taking the distance *b c* short, and the point of sight 3 at a distance from it, because that reduces the angular lines to nearly the same length. To have no error the plane of the line *b c* should be circular with the instrument in its centre, for then all the lines of sight would be equal radii. Such lines are, however, seldom met with in practice, but curved lines are very common, and we learn one lesson from the above principle, that whenever a curved line has to be examined as to level by this process, the instrument should never be stationed on the convex side of the curve, but always within its concavity, and as near to the centre of that concavity as can be estimated.

346. It frequently happens that the Engineer or Surveyor is, from local or other circumstances, compelled to take long sights by simple levelling, or looking in one direction, or even to take long and short ones in the same direction, and that the compensation above referred to, has to be applied. As before noticed, when the distances are short, such as about 150 yards from the telescope, the difference between the real and apparent level is so small that it may be wholly disregarded; but when it exceeds twenty chains it begins to amount to more than half an inch, and must, therefore, be taken into account.

347. The method of finding the difference between the true and apparent level at any given distance, is to square that distance and divide the product by the mean diameter of the earth, when the quotient will be the difference required; for the difference of the heights of the apparent levels, at different distances, are as the squares of those distances; consequently in short lengths the differences are very trifling, but increase rapidly as the distance increases. As, however, this rule is troublesome to work at the moment it may be wanted, the following table is calculated from it, and will show, on inspection, what allowance is to be made where the distance between the instrument and object observed are known.

348. A TABLE

Showing the quantity of curvature below the apparent level in inches, for every chain up to 100.

Chains.	*Inches.*	*Chains.*	*Inches.*	*Chains.*	*Inches.*	*Chains.*	*Inches.*
1	0.0012	14	0.24	27	0.91	40	2.00
2	0.005	15	0.28	28	0.98	45	2.38
3	0.0112	16	0.32	29	1.05	50	3.12
4	0.002	17	0.36	30	1.12	55	3.78
5	0.003	18	0.40	31	1.19	60	4.50
6	0.04	19	0.45	32	1.27	65	5.31
7	0.06	20	0.50	33	1.35	70	6.12
8	0.08	21	0.55	34	1.44	75	7.03
9	0.10	22	0.60	35	1.53	80	8.00
10	0.12	23	0.67	36	1.62	85	9.03
11	0.15	24	0.72	37	1.71	90	10.12
12	0.18	25	0.78	38	1.80	95	11.28
13	0.21	26	0.84	39	1.91	100	12.50

CHAPTER VI.

ON EARTH-WORK OR EXCAVATION, EMBANKMENT, PUDDLING, &c.

349. All the preceding chapters of this work have been devoted to an account of the acquirements the young Engineer should make before he attempts to design, execute, or superintend work; and we have now to conduct him into the field, where the principles before taught will be called into action. In stating to him the various kinds of work he will be called upon to execute, earth-work naturally presents itself as first in order. It being that which generally requires attention before any of his other operations can proceed. Among all the various materials employed in building or the construction of machinery, timber is the only one that can be procured without penetrating into the soil; because stone, the materials for making bricks and mortar, slates, and all the metals are the produce of the earth. No building or fixed machine can be erected without first digging and levelling its foundation. No road or rail-road for the conveyance of materials can exist without cutting and preparing the earth for its formation; and in the construction of navigable canals, or docks for shipping, it forms a leading feature of the whole operation.

350. The mere digging or cutting into the earth, is so common and obvious an operation that it may seem to require neither skill nor explanation. This, however, only applies to small and ordinary operations; for when the work is extensive, as in the formation of navigable canals, large reservoirs, tunnels, and the like, many expedients are resorted to that might not occur to the common workmen; they have arisen out of experience, and are only adopted because they economize labour and time, and consequently diminish the expense of executing the work.

351. In populous countries, the mere mode of executing the work is of little or no importance, either to the Engineer or his employer, his only duty being to set out the form of the work according to the plans previously prepared; and to see that it is properly executed. The reason of this is, that in such places

workmen are usually to be found who will contract for the whole business, either at one specified sum of money, or for a certain price per cube yard, whatever the work may happen to measure; and in these cases such workmen hire and pay their labourers, find all the necessary tools and materials, and execute the work in such manner as they believe will render it most profitable to themselves. The Engineer, in this case, has no care or trouble about the execution, nor should he ever interfere in it, unless he perceives something palpably wrong.

352. The usual course of proceeding, when contractors for work can be obtained, is for the Engineer to prepare his map or plan of the country, together with a correct profile or section to scale, of the intended work, and to write out a specification or particular explanatory of his drawings and plans, stating how the work is to be executed, where it is to begin, pointing out where the spare soil is to be deposited; when the work is to commence, what time will be allowed for its completion, how and where it is to be paid for; what penalty is expected to be incurred should the work be slighted, neglected, or not finished within the stated time; whether the contractor is to be kept free from water should springs be cut into in the progress of his operations, or whether (as it is technically called) he is to bear his own water-charges, and any other particulars necessary to be known. These plans and particulars are then deposited in some accessible place, as near as possible to where the work is to be performed, or in a neighbouring town or city. Advertisements are then inserted in newspapers, or otherwise brought before the notice of the public, stating that certain works are required to be done, the plans and particulars of which are deposited for inspection and examination at a certain place, from some specified date to another, and inviting all persons who may be willing to contract for the execution of such work, to inspect the plans, or the ground itself, and to send in sealed tenders to a certain place, on or before a certain day; in which they are to state the price and conditions upon which they will undertake the performance of the work. These tenders are opened by a committee, or some authorized person, and the common course is to let, or give the work to the lowest bidder. Notwithstanding this is the usual practice, it is one that ought not to be universally adopted, because the ability of the contractor to perform the work, and his responsibility, ought always to be enquired into. Many instances occur in which parties, from the hope of gain, will put in tenders, without being acquainted with the nature of the work, and will take contracts for its performance at prices lower than it can possibly be done for, although they perhaps neither

possess the necessary implements, or capital to pay their men, or provide what is necessary for its execution; and, notwithstanding they may give sureties under bond for the due performance of what they undertake, yet when they find it costs more than they are to receive for it, or that their operations are so unsatisfactory to the Engineer that he will not pass their accounts for payment, abscond, leaving their sureties to suffer, or prove that they are not responsible; the Engineer has then to look out for other persons to finish his work, after much delay and vexation, and perhaps can only procure them at very advanced prices. The Engineer from his knowledge and experience, ought to be able to judge of the value of what he means to execute, and should be consulted as to the tenders before any one is accepted; and he ought not to permit any tender to be accepted when he knows the price offered is such a one as will not allow the work to be executed in a good and substantial manner. Cases do sometimes occur, and the author has met with them, in which able and competent contractors having a heavy stock of materials and horses, and powerful gangs of men, whose operations may have met with temporary suspension from unavoidable causes, undertake to do jobs at very low prices through competition, rather than break up their establishments, and dispose of their stock; and in such rare cases, if the contractor is known to be capable and responsible, of course the Engineer is bound to give his employer the advantage arising from the circumstances; but in general he cannot be too careful about the character and responsibility of his contractor. Persons who undertake large contracts for earth-work, as well as their workmen, have obtained the name of *Navigators*, from the circumstance of their work having in general some connexion with the formation of inland canals, docks and rivers or other accessories to navigation.

353. It frequently happens that work may have to be executed in situations where contractors cannot be obtained, and then the Engineer has to provide his own materials, engage his own hands, and direct their operations, and the object of the present chapter is to give such directions as will enable him to do so to the greatest advantage.

354. In all cases, whether contractors are employed or not, the Engineer is expected to set out his own work upon the ground for execution; so that the responsibilty of its form or shape rests upon himself. This setting out is performed by driving stakes at the corners or angles, and straining a line or cord from one stake to the other, to obtain right lines, which are afterwards marked by pegs or small stakes driven close to the line, before it is taken up to set out another length. Or what is much better,

the line may be marked either throughout its whole length, or at regular intervals, by what the workmen call *nicking;* which is merely using a common or straight-edged garden spade, by thrusting it into the ground about three inches deep, while held nearly perpendicular and close to the line while it remains on the ground; and then meeting this cut by another in a more sloping direction about four inches from the first, so as to leave a small angular excavation in shape like the letter V two or three inches deep. Small stakes are often trodden down by cattle, removed through mischief, or hidden by grass, which occasions the trouble of re-setting out a line; while one that is nicked is not easily obliterated, and will remain visible for months after it is made. While nicking or even staking out a line, the cord used for setting it out, should be pegged to the ground after it is well adjusted, at every five or six feet by hooked pegs cut from the forks of neighbouring trees, in shape like *Fig.* 98, *Plate IV.*, in order to prevent its being deranged in position by wind, the spade, or other cause.

355. When a square or right angle has to be set out on the ground, as in digging the foundations for square buildings, or for forming square ponds or reservoirs, it may be done by the surveyor's cross, or by a circumferentor or theodolite, first directed to a picket-staff placed in the direction of one line or side, and then on turning the instrument a quarter round or 90°, the position of a second staff will be obtained, and the summit of the angle will be at that point indicated by a plumbet let fall from the centre of the instrument. The most usual method, however, of setting out right angles on the ground, is by an instrument usually possessed by workmen, or if not, that is easily made, called a *ground square.* It is merely two straight-edged strips of board about five or six feet long, the two ends of which are so united together as to form a right angle, as at *Fig.* 99, *Plate IV.*, and they are held in that position by another similar strip nailed diagonally upon the other two, as shown in the figure. To obtain the right angle in making this implement, or to prove its correctness when made, use the process described at par. 34, substituting strained lines of thin cord for the lines there directed to be drawn upon the paper.

To use such a square for setting out a right angle, strain a line *a b* in the direction of one of the required sides. Fix the point where the right angle is to occur in that line, by driving a stake as at *c*, and fix another line to it. Then apply one side of the square close to, or parallel to the first line, letting the point of the square coincide with the stake; strain the other line close to the other side of the square, and fix its end to a stake *d*, when the square may be removed, and the right angle indicated by the two lines may be staked or nicked on the ground. If a number of other angles differing from right angles have to be set out, similar implements to that described may be made for the purpose; but this will be unnecessary unless they are numerous. In general all angles that differ from right angles, are set out by the theodolite.

356. If large arcs of circles, or curved lines nearly circular, have to be set out, one end of the line must be fixed to a stake to serve as a centre, and a sufficient quantity of line to represent the radius being let out, is held in the hand together with a pointed stake or large spike-nail, and being carried round the centre, the ground is scratched, or points are marked for placing pegs, when the curve may be nicked as before. Problems XIV., XV., and XIX, (pars. 74, 75, and 79,) are often resorted to for this purpose, using cords instead of drawing-lines, and erecting perpendiculars by the ground square.

357. Whenever excavations are made for temporary purposes, and are to be filled in again, as in digging foundations for buildings, or in the construction of drains, the sides of such excavation may be perpendicular; but such form will not answer for permanent operations that are to be exposed to the atmosphere, because, unless the soil is rock, or of a hard and imperishable nature, it will inevitably fall in to a greater or less extent, thus partly filling up the cavity that has been formed. In order, therefore, to make the sides of excavations permanent, especially if they are to hold water, it is necessary to slope or incline them to such an extent as will counteract this effect. No precise rule can be laid down for the quantity of slope to be given, as it varies materially with different soils; thus stiff or strong clay will stand when nearly perpendicular; stony gravel will generally stand at an angle of 45°; but loam that is readily soluble or rather miscible with water, and which contains a large proportion of sand, will hardly stand at any angle, and such soil is very abundant in the eastern parts of the states of New York, Maryland, Delaware, and Virginia.

358. Mathematicians would describe these slopes by saying that they made certain angles with the horizon; but such language is never used by workmen, nor would they, in general, know what it meant; the usual mode of designating slopes being, by a comparison of the sine of the angle with its base, or in other words the perpendicular height to which a slope reaches with a certain extent of horizontal base. Thus, for example, the slope produced by an angle of 45°, as shown at *Fig.* 100, *Plate IV.*, would be called a slope of one to one, because any one distance

measured on the horizontal base *e f*, would be equal to the height of the perpendicular *f g;* if, therefore, *e f* is one yard, *f g* will be one yard also, and hence the expression one to one, which is but an abbreviation of the more extended one, that the slope rises one yard while passing over a horizontal extension of one yard. The next *Fig.* 101, shows a slope that would be called two to one, or two horizontal to one perpendicular, which is the case with an angle of 27° 66′. An angle of $32\frac{1}{2}$° produces a slope of one and a half to one. An angle of 18° produces a slope of three to one; and $13\frac{1}{2}$° one of four to one; but as these angles are never mentioned in practice it is better to abide by the general rule, and, accordingly, in all future notice of slopes we shall designate them according to the usual practical method.

359. The Engineer, after having examined the soil he has to work upon by sinking pits into it, or other means, must determine the slopes he intends giving to his work, as these have to be considered and allowed for in setting out the work upon the ground. Two to one is the slope generally adopted for canal work, because the generality of soils will stand at this inclination; if the soil is stiff clay the slope may be made more steep, or *steer*, as workmen call it; while, on the contrary, if the ground is soft and loamy the slope will require to be more flat.

360. In setting out new canals or roads for execution, the first thing attended to is the central line; that being the one that is always ascertained by the process of levelling before described, and staked out accordingly. This line has now to be more minutely attended to and marked out by an additional number of stakes, if necessary, and which should be at equal distances. That done, the width of the bottom of the canal may be set out by pegs, being small stakes intended to be taken up again, more or less distant from each other, according as the face of the country is even or rugged. If the country is flat and level a pair of pegs at every second chain will be sufficient, but if otherwise they must be placed at every chain or even half chain. These pegs are placed parallel to the first or central line, and at equal distances on each side of it, that distance being half the proposed width of the canal. The depth of canal and extent of slope to be given to its side banks having been previously determined, the slope lines may next be set out by other two lines of permanent stakes, at such distance exterior to, but parallel to the lines of pegs, provided the country is flat or level, but if not, the two exterior lines of slope stakes cannot be proceeded with until another process of levelling has been performed, called cross levelling, and which is generally done at the same time that these stakes are put in. This staking out is simple, but to render it more clear, let us suppose

the canal to be executed is to be six feet deep to the top of its banks, that the bottom is to be twelve feet wide, and that the slopes on each side are to be two horizontal to one perpendicular. The slopes will then extend twice six feet horizontally, or the length on each side, from the pegs, will be twelve feet or four yards beyond the outside of them, making the distance from the central line of stakes to the outside line eighteen feet, for half the width of the canal at its top, or thirty-six feet for its entire width; and, as the water is usually a foot below the banks, its width will be diminished four feet, or made thirty-two feet. Thus let *a b*, *Fig.* 102, *Plate IV.*, represent the level surface of the country in which a canal is to be set out, and let *c* be one of the stakes that has been previously driven to mark the middle of the line. Then measure two equal distances *d c*, *d e*, of six feet each, and mark them on each side of the central line by the pegs *d* and *e*. Next take *e g* and *d f*, each equal to twelve feet, and set these off by the stakes at *f* and *g*, these two points will indicate the extreme edges of the canal, and no other setting out will be necessary, because the workmen are desired to commence their cutting at *f* and *g*, with slopes of two to one, until they reach the depth of six feet, when, of course, they can produce no other figure than *f g h i*, which is the true transverse section of the canal proposed to be formed.

361. In such simple cases as that just described, it will be obvious that the intermediate lines of pegs at *d* and *e* will be useless, as the distances *c f* and *c g*, of eighteen feet each, can be set out at once; and, accordingly, the lines of pegs are never used, but they were supposed in the present case to render the reasons of the operations more obvious, and must occasionally be resorted to in more intricate work.

362. Let us next suppose that the surface of the land upon which the canal is to be set out, is on the side of a hill, or slopes instead of being level, as at *k l* in *Fig.* 103, then the directions above given will not apply, because if we still conceive *c* to be one of the line of central stakes, and attempt to set out the extreme sides or slopes as before, by lines of eighteen feet long on each side of that central stake, one side stake will come at *o* and the other at *p*, and will not accord with the form to be produced; since, owing to the rise of the ground *k l*, the right hand slope will not appear at the surface at *o*, but will become extended to *m*, and the left hand slope instead of being at *p* will be contracted to *n*; consequently the left hand distance *c n* to be set out is much shorter than *c m*. The distance of *m* from the water will also be much greater than before, and the side *n* will not be high

enough to contain the water; consequently the lower side will require to be raised by an embankment *n q r k*, built upon the natural surface *k n*, and formed out of a part of the earth taken out of the excavation, the section of which, in this case, will be represented by the figure *n m s t*. Now the form of this figure, and the quantity of excavation and embankment necessary to form it, cannot be ascertained until we are in possession of the level or horizontal line *s t*, or its parallel *q v*, and this can only be obtained by levelling. The process of simple or direct levelling is the one resorted to, and the result is called *cross levelling*, because it is taking levels across or at right angles to the principal line as set out. It is performed by setting the levelling instrument adjusted over the first central stake, and directing its telescope in the direction of this row of stakes, when several cross levels may be taken without changing its position. The vane-staff is held upon the first central stake, suppose *c* in *Fig.* 102, and its vane moved up or down until brought to its proper coincidence with the horizontal hair of the telescope. The staff is then placed first on the stake *g*, and afterwards on *f*, and, if the vane requires no alteration of elevation, it shows that the three points *e f* and *g*, are on the same level, and that the sectional figure, as set out, is correct.

363. Let us suppose *Fig.* 103 to be the position of things at the next stake in advance. The instrument retains its position without any other alteration than a new adjustment of the object-glass as to focus, on account of the increased distance of the second stake. The vane-staff is held on *c*, and its vane adjusted to height as before. It is then placed on the side bank peg *o*, eighteen feet to the right of *c*, and now its vane will be found too high, and must be lowered by a quantity equal to the distance *o v*, which is noted down. Then being placed on *p* eighteen feet, to the left hand of *c*, its vane will require to be raised a distance equal to *p q*, which is also noted down; and these distances obtained afford sufficient data for drawing or projecting a figure to scale, like that given on the plate; and from the scale, which ought to be at least half an inch to a foot, the positions of the several points are measured off and transferred to the ground. This, it will be perceived, is rather a rough mechanical approximation to the form, than obtaining it by correct mathematical rules which would give it with precision. But the operation would require much more time, and would not be understood by workmen, who, when accustomed to their business, will frequently be able to set out a slope by the head, without paper, lines, or figures, if the difference in level is given to them, and at all events

the process is sufficiently accurate to answer all practical purposes.

364. If the stake *c* is in the regular level line of the canal, the projection as above described will be correct, but if it is above or below that line, then any quantity that it is above must be subtracted from the length *o v* and added to *p q*, and if it is below, the contrary order of proceeding must be observed.

365. It may be imagined that the next central stake in succession, occurs on the summit of protuberant or rising-ground like *w c x*, *Fig.* 104. Then when the vane-staff is held on the outside stakes, the vane will have to be raised in both positions, indicating that an embankment must be formed on both sides of the canal, unless the central stake *c* is so much above the general run of level as to render this unnecessary.

366. The central stake may happen to be so low, that not only the two sides require to be raised wholly by embankment, but this may be necessary even for the bottom of the canal itself; the canal is then said to be wholly in embankment. For while excavation is the digging out and removing of earth, embankment is the placing or piling it up where it did not exist before, so that the filling up a hollow place to render it level, is a species of embankment, although the term is more usually applied to the raising banks or projections of earth in places where they did not before exist.

367. From the foregoing account, it will be apparent that although the central line of stakes by which a road or canal has been set out must be regular, and will have symmetry, this can never be the case with the exterior or side bank stakes, which must always stand in irregular or zig-zag lines unless they are on perfectly level ground, notwithstanding which the work set out by them will be straight and regular when finished and brought to one uniform height. Indeed the face of a country is often so altered by the excavations and embankments of large public works, that its inhabitants scarcely know it, and the Engineer himself would frequently be puzzled in the measurement of the work done, from his inability to distinguish between its former state and the recent alterations, were not certain marks made and left for this purpose. It is on this account that certain conical masses, with grass and stakes on their tops, are generally found standing in the middle of canals, reservoirs and other excavations, particularly in uneven countries, in form like *y* in *Fig.* 104. They are called *bench-marks* by the Engineer, and very frequently *old men* by the workmen. Their use is to mark the position as to the elevation of the soil before it was touched, for they are not built up but consist of some of the former soil left

standing by digging the earth away around them. The grass growing upon them is the grass of the original surface, which, having been untouched, continues to vegetate, and prevents any deception being practised as to the actual former height of the soil when the quantity of excavation is measured after its completion.

368. These little hillocks likewise serve to preserve the positions of the central line of stakes by which the work has been set out, for they are constantly left around those stakes, or round every second or third, as may be necessary; so as to give the Engineer an opportunity of levelling at any future time from the original centre stakes, or measuring distances from them to the side banks, or taking the depth of the cutting. And they are never removed until the work has been measured, and is in such a state of forwardness as to render their longer continuance useless.

369. It sometimes happens that the cutting or excavation for a road or canal is very deep, and wide at the top, as when a hill has to be passed through; and in that case these bench marks cannot be left, for their base would of necessity be so large as to block up all the lower part of the work; in such places they are unnecessary, because whenever the side banks rise considerably above the work, they form the best marks that can be obtained, because a line can be stretched from one side to the other to measure from. If any hollow or protuberance in the natural ground exists, either on a hill or any other place that has to be cut through, it ought to be measured and ascertained by simple levelling or other means, before the work is began, since it may make a considerable addition to, or abstraction from the quantity of earth to be removed, and is frequently a source of dispute with workmen.

370. It has been stated, that when the extreme sides or lines of a canal or other excavation has been set out, nothing more is necessary in order to produce the figure or form required, than to desire the workmen to proceed and carry down the slopes with an inclination of two to one, or any other degree of slope that may have been previously arranged; but it may not be obvious how the necessary correctness of slope is to be obtained and preserved. This is done mechanically by means of an implement called *a bevil plumb rule*, and cannot be effected with any degree of certainty without it.

371. The bevil plumb rule is shown at *Fig.* 105, *Plate IV.*, and consists of three strips of board, *a b* and *c*, framed together in the form of a triangle, the piece *a* being a common plumb rule and plumbet, such as is used by bricklayers, and which

being held upright, the piece *c* is so fixed as to represent the slope required for the bank, and *b* is merely a brace for retaining the other two pieces in their proper angular position, and therefore need not make a right angle with *a*, though it will be better that it should do so, because the implement then becomes useful for other purposes, for it may be used as a ground square, *Fig.* 99, (355,) and by having a large hole for the bob to play in at each end of the plumb rule, the instrument may be reversed by making *b* the bottom rail, and then it becomes a useful level for trying the bottom or other level parts of the cutting. The sloping side *c*, ought to be at least three feet long; and separate instruments of this description will be necessary for each particular slope, if more than one should be adopted in the work. Having such an instrument, there will be no difficulty in giving the necessary slope to the banks. Thus in *Fig.* 102, suppose *g* to be the exterior stake at which the slope is to terminate. The workman begins by opening a hole of about a foot or eighteen inches wide between *e* and *g*, taking care to give sufficient slope to the side *g i;* when sufficiently deep, say a foot or two, the lower point of the bevil plumb rule is introduced into this hole, and its side *c* is brought into contact with the slope *g i*, and then if the plumbet on the rule coincides with the line upon it, the slope is right; if not, it must be altered until this accordance does take place. That done, another similar hole is opened at the next outer stake, a few yards in advance, and is proved and adjusted in like manner, when the intermediate earth may be boldly taken away, until the excavation approaches very closely to the lines so set out, and when that is the case, more care and caution are required to pare away the earth in exact accordance with them, and the bevil rule is frequently applied to ascertain that the work is correct.

372. By the same process the slopes are set out and adjusted on the other side, and throughout the length of canal; and a similar principle is frequently adopted for setting out and working sloping roads, when it is known how much the road is to rise or fall in a given length. For this purpose, an instrument like the bricklayer's level, *Fig.* 84, is used, except that instead of making its bottom edge at right angles to the plumbet, it is made to slope or incline in the necessary degree. It is not, however, worth while to prepare such an implement, unless the slope has to be continued a long distance without any alteration.

373. Excavation is always called cutting, or shifting soil, by workmen, and is measured and paid for by the cube yard worked decimally. The most convenient instrument, not only for setting out road or canal work, but for measuring it when finished, or in

progress, is the rolling pocket tape, which, for this purpose, should be divided into feet and inches on one side, and into yards, divided into hundredths, and numbered at every tenth division, on the other. Such tapes are fitted up in leather cases, with a brass winch to wind them by, and a ring to pass the finger through and hold the tape at its extreme end. The ring counts into the measurement, and in using the tape the Engineer should retain the box in his hand, and give the ring to his assistant to hold against the point to be measured from, by which means he has the figures that give the result of the measurement constantly under his eye. The measuring tape is a most useful implement to the Engineer in many of his operations, and as the tape soon wears out by use, while the leather box and winch are durable, every Engineer should know how to prepare his own tapes for renewal. The best and strongest thread tape, (not cotton,) should be procured, half an inch or five-eighths wide. This should be tightly stretched in long lengths between poles in the open air, in which position it is painted on both sides with white lead ground in oil, such as is used for house-painting, and left until it gets quite dry. It is then brought in and laid upon a long table for division by scale and compasses, and the divisions being marked in pencil, are afterwards finally put in with black oil paint, used with a pen made of a dry reed. The large divisions, such as feet, yards, &c. are usually marked with vermilion ground in oil, in order that they may be more distinctly seen. A tape so prepared will last a long time, and may be washed; while many of those that are sold, have the divisions marked with common writing ink, and are obliterated the first time the tape gets wet.

374. In measuring excavation, it is the hole produced or made in the ground that is the subject of measurement, and not the finished work, or soil taken out. Thus if the excavation is made on level ground, as in the example shown by *Fig.* 102, the whole canal would be in excavation, and the trapezoid *f g h i* would have to be measured by Prob. XXXI. (174); and, according to the dimensions before assigned to the canal, viz: twelve yards wide at top, four yards wide at bottom, and two yards deep, we should have eight yards for a mean width to multiply, by two yards deep, and the product sixteen would be the number of superficial yards in the figure; and that multiplied by the length or extent of the canal while the cutting continues of the same dimensions, will give the number of cubic yards excavated.

375. In the next reach of the canal, the natural slope of the ground has transformed the shape of the cutting from its former figure into the irregular trapezium *n m s t*, *Fig.* 103, which must be

measured by the rule laid down in Prob. XXXII. (175,) while in *Fig.* 104 we have a figure of five sides, formed by the bottom of the canal, its two side banks, and the two sloping surface lines *w c* and *c x;* and where the shortest process will be to measure the entire canal or trapezoid, and deduct the two triangular portions formed by the top horizontal line, the two upper extremes of the sloping sides, and the surface lines *w c* and *c x.* These examples will not only be sufficient to show the manner in which the measurements are conducted, but likewise the importance of retaining bench marks, and any other marks that will indicate where the precise position of the surface was before it was altered. They likewise serve to show another important point, viz: that while every portion of the excavation is measured and paid for, embankment costs nothing unless the soil necessary for its formation has to be dug for that express purpose. The reason of this is sufficiently evident, because whenever a piece of excavation has to be performed, it is the duty of the Engineer to point out and fix a place in which the spare soil, coming out of it, shall be deposited, and it is the duty of the workmen to carry it to that place. If, therefore, the Engineer wants an embankment formed within a reasonable distance from the excavation, he has only to stake out or mark its position, and direct the soil to be deposited there, and the embankment is of course formed. But if the quantity of soil yielded by the excavation is not sufficient to finish it, and an additional quantity has to be dug from another place to complete it, that of course constitutes another excavation, and must be paid for accordingly.

376. Notwithstanding an embankment may in many cases be formed without expense, still it generally happens that some additional labour or care has to be bestowed upon the work, for which a remuneration is always allowed. Thus all removal of soil is paid for according to the distance it is carried, and if that distance should be increased by forming an embankment, instead of throwing the earth at the sides of the work as it proceeds, this would constitute a fair item of charge. Again, many soils used to form embankments, (particularly if they are to stand against water,) require to be laid in regular layers or strata, and to be rammed or pounded, or *punned,* as the workmen call it, in order to break the lumps, and make the work more solid and compact, and this is an additional charge. The punning is performed by wooden rammers, hooped with iron to prevent their splitting, and worked by men, and when adopted, the courses of earth should never exceed nine inches in thickness, otherwise the blows of the rammer will have little or no effect on the under part of the stratum; and, whether the operation of punning is performed or not, it is

impossible for the workmen to wheel and deliver the soil on to an embankment with the same nicety and precision as to form, as can be obtained in excavating soil from the earth. All embankments therefore must be rugged and uneven when first formed, and they require what is called trimming to reduce them to handsome, even and fair surfaces. The trimming consists of filling up hollows and cutting off protuberances, and this accordingly is charged separately, at a price agreed upon and regulated by the superficial measure of the surface of the embankment instead of its solid contents. The same kind of trimming takes place upon the surface of all excavations, but it is never made a separate charge, being included in the price for doing the work and considered as a necessary finish to it.

377. The next object of consideration must be the method of performing the work of excavation, and the tools and implements necessary for its execution. The first thing to be done is the loosening and detaching the soil from its natural position, in order that it may be taken up by a shovel and placed in a wheelbarrow or cart for removal. And this is done by that well known implement the pick-axe, made of iron with two points of steel welded on to it, and bent into the form shown at *Fig.* 106. For ordinary excavation it should be double-ended with an equal quantity of metal in each end, that it may balance well in the hand. Two feet, from point to point, is considered the most convenient length, and the metal should not weigh more than ten or twelve pounds; if heavier, it fatigues the workman without an equivalent advantage in work, and most men prefer this tool chisel-pointed and about an inch wide, instead of being quite sharp. The common fault in pick-axes as usually made, is a want of sufficient depth and strength in *the eye* or socket through which the wooden handle passes, for in this place they usually fail or break. The side-plates that form the eye, ought not only to be thick for strength, but should be at least three and a half or four inches from *d* to *e*, in order to admit of the handle being well fixed, for the operation of this tool is a wrenching one, and unless this construction is attended to, the handles are constantly breaking or getting loose, which proves very troublesome. Pick-axes constantly require sharpening and repairing, if therefore there is no blacksmith in the immediate vicinity of the work, a portable forge on wheels should be provided to accompany it, and such are made in a very convenient form for the cavalry and engineering purposes of the army.

378. The shovel most approved is what is called heart-shaped, as shown at *Fig.* 107, instead of straight edged, though some of both sorts are useful; they are generally used with a long handle,

but occasionally the crook handle, as shown in the figure, is required, and is stronger and cheaper than the usual form. For actual digging upon the surface, particularly in clay or soft ground, a scoop tool, of the form shown at *Fig.* 108, is preferred. It is made like a common garden spade bent into a curved form, and in using it, it is advantageous to have a tub, or puddle of water formed, into which the tool is frequently dipped, to prevent stiff clay or loam from sticking in the hollow of the scoop. An iron plate, called a guard, is rivetted on to a leather strap that buckles under the foot used with the spade, to protect both the foot and shoe, while urging the spade by that means into the ground.

379. The ordinary process of digging consists in loosening the soil upon the surface, and taking it up by single shovel or spades full, which navigators call under-hand working, but they adopt a more expeditious method of proceeding, called under-cutting, by which much labour is saved. The first hole or opening must be made in the ordinary manner, but instead of working on the surface and digging over it one spade deep, and then beginning, and taking another spade's depth, they go to the full depth of the work, provided it is not more than six or seven feet; taking care to form the sides to their intended slopes, but keeping the front or side, on which the excavation is to proceed, nearly perpendicular, or without any slope at all. The bottom of the hole being levelled and tried, the lower part of this front or breast, as they call it, is undermined or dug away by the pickaxe and shovel, to about a foot from the bottom, keeping the bottom as level and as nearly in its proper range as possible. The side slopes are treated in the same manner, or worked into the front about the same depth, the consequence of which is that a large mass of the earth of the front remains without any other support than that which it derives from its cohesion or adhesion to the earth behind it; and large masses, therefore, first crack or separate and fall. If they do not separate as readily as the workmen wish, two or three large wooden wedges, shod with iron, are carried to the surface, and being placed a foot or two behind the front or breast, are struck with heavy wooden mauls, and this never fails to detach large masses of the soil, which, by the concussion of their fall, are broken into pieces sufficiently small to be taken up into the barrows for removal. This, though an expeditious process, is one that is attended with some danger to the workmen; and therefore requires to be conducted with care. For the cracks or fissures that always precede the detachment of a mass of soil, are sometimes unseen or unheeded by the workmen, and masses fall when they are not expected to do so, and crush or maim the

men beneath. On this account a front or breast, of more than about six feet, should not be so worked; but, when the work is deep, the upper breast may be kept four or five yards in advance of the lower one, with a flat surface between, for the soil to fall upon, and deep cutting is almost always so conducted.

380. The common form of wheel-barrows, with boarded sides, will not answer at all for the work of excavation. Such barrows being too heavy in themselves, and very inconvenient for inverting to discharge the soil. The best form, and that constantly used in England for this work, is shown at *Fig.* 109; it is very shallow, not exceeding six inches in depth, its four sides splay open, or make angles of about 45° with the bottom, in consequence of which the soil is very easily discharged from it; but its principal advantage is in the shortness of the axis of the wheel, (which should be of cast iron,) which allows a facility of turning out the contents that cannot be obtained if the axis is long. *Fig.* 110, shows the manner in which the frame of the barrow is constructed, by morticing three cross bars strongly into the two side rails which form the handles, and come so close together at their opposite ends, as just to admit the wheel between them. The box of the barrow is separately made and fixed on to its place, as indicated by dotted lines in the figure, by screw bolts, with nuts underneath; and, as the box soon wears out by use, one frame will last for several successive boxes. The pivots of the wheel run in iron eyes, fixed by screw bolts under the rails, so that they, likewise, can be removed when worn out. A barrow of this kind, shallow as it may appear, will contain quite as much soil, when heaped up, as a man can convey with convenience, when working throughout the day. And the mere frame of the barrow, without its box, is very useful for conveying flat building stones, or short pieces of timber, that will lie on it with convenience.

381. The barrows are never wheeled upon the ground, but three inch yellow pine planks of the usual width are used to form level tracks or inclined planes to run them upon; and for this purpose, when the plank, or one or both of its ends cannot rest upon the ground, they are propped or raised to the required height and inclination by blocks or a kind of stool with long legs, called tressels or horses. Planks of about twenty feet long are preferred when they can be used, not only to obviate a frequent repetition of joints, but because they are more easily fixed and supported. The bearings should not, however, be too distant, because a plank should not spring or vibrate while the loaded barrow is running upon it. If it does so, it should be propped or blocked up in its central part. The slopes or inclined planes,

formed of wheeling planks, should likewise be made as flat as possible, for it fatigues the workman less to run a greater distance on a gentle slope, than a short distance on one that is steep.

382. The usual distribution of hands in shifting earth is to employ two at the immediate excavation, to dig and fill; that is to say, one with a pick-axe to loosen and break down the soil, and the other with a shovel to fill a wheel-barrow that stands upon the end of a wheeling plank close to the work. That done, a third man carries away the loaded barrow, and takes it what is called a stage, being a certain distance along the wheeling planks. He is then met by another man who is wheeling upon the next stage, and a change of barrows here takes place. The second man proceeds onwards with the loaded barrow, and the first man returns to the excavation with the empty one he has just received from the second man. By the time he reaches the excavators, a second barrow, previously left there, is filled, and he therefore drops the empty barrow to be refilled, and returns back with that which is loaded. A stage in wheeling is always considered as twenty yards, when no specific agreement is made with the workmen to the contrary, and the ground is level, but it is subject to variation under particular circumstances. Thus the first man who has to carry the soil out of the work has almost constantly an inclined plane to ascend, in order to deliver it on the surface, while the second man may be working on level ground. The work of the first would therefore be harder than that of the second, if both had to run equal distances. In the commencement of work, it frequently happens that the second or third stage may even be down hill, and this would make a still greater disparity. The first man, therefore, claims a diminution in the length of his run, which is but equitable, and it is on this account frequently diminished to eighteen, fifteen, and twelve yards, according as the slope to be moved up is more or less steep. The level runs that succeed, are each twenty yards, but if they slope downwards they are extended to twenty-two, twenty-four, or twenty-five yards. The reason of being thus particular in the length of stages, is that in England the men are paid a certain price per cube yard for digging, as well as for each distinct stage of conveyance. The average price that the author has paid to master contractors for this work was three halfpence, (or about three cents) per cube yard per man. So that if two men are employed to dig and fill into the barrows, their work would amount to six cents for every cube so moved. Then each wheeler has three cents per cube yard for each stage, so that to dig and deliver soil on the edge of a canal or the end of one stage would cost four and a half cents per cube yard, and

if the soil should be carried two stages, or forty yards, it would cost ten and a half cents per yard. This price was customary for all excavation not exceeding six or eight feet in depth, but when it becomes deeper, the digging and filling, as well as the delivery to the surface, will require a proportionate augmentation of price. The labourers, of course, receive a less sum than above specified, because, out of that, the master or contractor has to provide all barrows, wheeling planks and implements, as well as to derive his profit, and yet small as the sum may appear, the author found that industrious men would generally earn from one dollar to one and a quarter per day.

383. The main object of dividing the shifting of earth into separate stages, is to avoid hindrance or delay to any one employed; because, if the wheeler carried his loaded barrow one hundred or more yards, it would take him so long to go and return, that the digger and filler would be standing still half their time, for want of a barrow to fill, unless a number of barrows and wheelers were stationed near them, and then separate tracks of plank would be necessary, since one barrow cannot pass another on the same plank, and such a multiplicity of tracks would not only be very expensive, but inconvenient, by blocking up the work. Notwithstanding, therefore, that the custom of workmen has established twenty yards as a stage, the Engineer should take the arrangement of the distances into his own hands, and make them dependent on the ease or difficulty of breaking down the soil at the excavation. If that yields so readily that a barrow may be filled before a wheeler can go and return his twenty yards, the stage ought to be shortened, while on the contrary, if the wheelers are required to wait for the charging of the barrows, the stages should be lengthened, and paid for accordingly. In stage wheeling, every man should be at his post either with a full or empty barrow, at the moment when he is wanted, and thus a line of hands, whatever may be its extent, may be kept regularly at work without a moment's intermission or loss of time. It need scarcely be noticed that at the termination of every stage the planks are laid in a double line for a short distance, in order to form turning out places, (as in rail-roads,) in order that the full and empty barrows may pass each other without interference. At the lower termination of the track in the excavation, the planks are also laid double, in form of the letter ≺, so that the full barrow may be on one plank while the empty one is on the other, and they are wheeled, when full, alternately, up one and the other plank, till they reach the common single track. At the upper termination of the track, if a long bank has to be formed, several planks should be disposed in a radiat-

ing form from the single one, in order that the earth may be distributed by carrying it first along one, and then another plank, which saves much after distribution and levelling.

384. When the bank up which soil has to be moved, is necessarily very high and steep, as for example, if it should make an angle with the horizon of 30° or 40°, and is perhaps forty or fifty feet high, an expedient, called a horse run, is resorted to. That is, two tracks of plank are placed upon the slope, and fixed there by stakes driven into the ground, and nailed or spiked to the planks. These tracks should be placed at a distance asunder that rather exceeds the depth of the excavation. Opposite the top of each track a post, with a large iron sheve or pulley fixed to it, is firmly let into the ground. The wheelbarrows used are of the same construction as those before described, but much deeper and larger, and a strong iron staple is fixed in the front of each for receiving the hook of a rope passing from the barrow in the bottom, up the slope, through the two sheves, and terminating in a hook at the second barrow upon the top of the slope, in such manner that the upper barrow cannot be lowered without bringing up the lower one, and *vice versâ*. A straight horizontal horse-track is formed just behind the posts, extending from one to the other of them, and a strong iron ring being lashed to that portion of the rope that is constantly between the two posts, the traces of a horse are hooked into it, and as the animal is driven backwards and forwards, he will elevate one and depress the other of the barrows alternately. The lower barrow being detached from its rope, is placed where it may be loaded with soil, when it is wheeled to the foot of the inclined plane, and the rope being hooked on to it, a signal is given to the driver above to start the horse, when he draws the loaded barrow up the slope, a man following behind at the handles to guide it, and keep the barrow legs above the ground. While the loaded barrow is thus ascending the empty one descends, guided in like manner by the man who had before accompanied it upwards. His weight and that of his barrow compensating nearly for the man and barrow ascending on the other track. The ascending man has to walk in a direction nearly perpendicular to that of the inclined plane, so that he can exert no strength or muscular action to assist the barrow in its ascent; but, on the contrary, a large portion of his weight is added to that of the barrow; but this is compensated by the descending man, who comes with his face forwards, and by hanging on to the arms of his barrow, throws his weight upon it so as nearly to equalize the weight of the ascending barrow.

385. The horse run is a slow and expensive method of raising

soil, and one that should not be resorted to except in cases of necessity; but with all its disadvantages it is cheaper than common barrow work when the excavation becomes deep, because then the plank track must be made so very long for procuring the necessary gradual slope, that it increases the number of sloping or short stages to such an extent as to be very expensive. Barrow and plank wheeling is always expensive, and on this account it should never be made use of where earth requires to be moved more than three or four stages. For greater distances, especially on nearly level ground, it will always be found most advantageous to cart the soil by one horse carts, built for the express purpose. The kind of cart most approved has only three wheels, two being behind and one before, the reason of which is that such carts stand firmly upon uneven ground, and will support themselves without aid from the horse; they are light and easy of draught, and they turn in a smaller space than any other construction of cart. The frame or carriage part, to which the wheels are attached, is independent of the body, and is fastened to it by a pivot-bar, very little beyond the centre of gravity of the body when loaded, so that a very small exertion of strength is sufficient to tilt the body up, and cause it to discharge its load. The trace-chains hook on indifferently before or behind, so that either end of the cart may be made to precede. In the formation of roads, where small protuberances of soil have to be cut off, and probably carried a long distance to fill up hollows for obtaining a uniformly even surface, such carts are almost indispensable.

386. Another mode of raising soil out of deep excavations, without a horse run, is by what is called casting up by stages. A scaffolding is formed with as many boarded platforms, at five feet above each other, as will reach the required height. They are placed one beyond the other like the steps of a stair-case, and a man with a shovel is placed on each. The lowest man, who digs the soil, throws it by his shovel on to the lowest stage, and the man stationed there delivers it, in like manner, on to the stage next above him, and so on in succession, until it reaches the surface. This method is often resorted to.

387. As earth-work proceeds, whether it be excavation or raised embankment, it will be necessary for the Engineer to examine its surface every few days, especially such parts as are said to be finished, or are near completion, by the process of direct levelling, (339,) in order to see that the work is truly level, or has had the proper slope assigned to it, preserved. The work ought also to be measured as often as is expedient, and particularly as soon as finished, lest the marks indicating the original surface should be moved or destroyed.

388. If the excavation or embankment is intended to hold or retain water, another process, called *Puddling*, may be requisite. Some natural soils are of a nature capable of holding water without any artificial assistance, and clay or loam are of this character; others again, as sand or gravel and the *debriss* of stony rocks, absorb all the water that may be deposited above them, or they permit it to percolate or run through them. This likewise is the case with almost all artificial embankments when first made, even though they may have been punned in their courses and every pains taken in their construction; and as it is a matter of great importance, in the construction of navigable canals, that they should retain and hold all the water thrown into them, particularly where water is scarce, or their elevation is such that the escape of it might prove detrimental to the adjoining lands; and as no canal can be formed without raised embankments in some parts of it, so strict attention to the process of puddling, by which alone the escape of water can be prevented, is of the greatest importance.

389. No cheap and common material is found to oppose the filtration and passage of water so effectually as a soft loamy clay when it is well worked or kneaded into a soft paste with water, and is not permitted to get dry again. Even if a little fine gravel, or what is called by the navigators in England *hoggin*, being small sifted gravel, no stone of which is larger than a common pea, is mixed with it, it seems to hold better, but this can only arise from these small stones assisting in the kneading process. The silt or natural deposite of tide rivers is also an excellent material, but stiff or strong and plastic clay does not answer, or rather it takes more time and labour to bring it to the proper consistency than can be afforded, because when worked in the Pug-mill, to be hereafter described, for making bricks, it forms an excellent material for stopping water. Puddling is nothing more than covering the surface of ground, or of embankments, with this prepared clay or loam so as to enable them to hold water effectually, and the only difficulty is in the mode of applying it effectually.

390. The ordinary method resorted to by farmers and others in the country for rendering their ponds water-tight, after they have been formed in soil that will not hold water, is to line them to a thickness of from six inches to a foot, with clay beaten up with water and wheat or rye straw by a hoe, and then to apply it as a plaster as soon as it has become sufficiently dry to prevent its slipping or sliding down. It remains exposed to the air a few days in order that the outer surface may become dry enough to maintain its form, and then the water should be let in upon it, so

as to fill it, and if well executed it will generally prove water-tight. It is, however, by no means a good or effectual process unless there is the certainty of the pond always remaining equally full, and of the water not being disturbed by cattle going into it to drink, or other causes. A perfect adhesion seldom takes place between the natural soil and this lining, consequently if it is disturbed, it will gradually give way and subside to the bottom of the reservoir, thus leaving the old surface of the ground in contact with the water. If the height of water is subject to change, a considerable portion of the top of the lining becomes exposed to the sun, and in drying will crack and open through its whole thickness, thus permitting the water to escape when the pond becomes full again. This may be partly prevented by covering the upper part of the lining with sods or turfs of grass, but as the grass will not grow and thrive under the water, it only affords protection to the upper part.

391. The only means therefore of using a puddle lining effectually, is to inclose it within the bank in such manner that it is supported by earth on both sides, is kept constantly moist, is never exposed to the sun or external air, or indeed to disturbance of any kind, and then it will last and be effective for ever; and such is the process that should constantly be resorted to in puddling the banks of canals. This is done by forming what is technically called a puddle-gutter in the bank, but the manner in which this must be made must depend upon the nature of the soil to be dealt with. Thus suppose in the portion of canal represented by *Fig.* 103, *Plate IV.*, that the soil bounded by the original surface line *k l*, should be clay, or any earth that is capable of retaining water, there will be no necessity for puddling any part of the work, except the newly formed bank *k r q n*, which is wholly above the surface and may require securing. In this case as the natural soil is good, it will only be necessary to form a puddle within the bank, the transverse section of which is shown by the lines *u z q p*, and for this purpose an excavation must be made longitudinally in that bank like a foundation or opening for building a wall, and such an excavation is called a puddle-gutter. It must extend from the top of the bank down to the natural surface, and even penetrate at least a foot or eighteen inches into it, and must be wide enough for a man to work conveniently in it, the usual width being from thirty inches to three feet. All the previously contained soil having been thrown out, the process of puddling begins. This is performed by a man using a scoop-tool, like *Fig.* 108, and wearing a pair of very thick and strong boots made for the purpose, called puddling-boots. They come above the knee and should be imper-

vious to water, like the high boots usually worn by fishermen. The ground is loosened in the bottom by the scoop, but is not thrown out; that done, a pretty copious supply of water is sent into the puddle-gutter by buckets or a temporary pump, and the workmen, by pressing down the scoop-tool, and walking backwards and forwards in the puddle-gutter, reduces all the natural soil that has been disturbed into a state of very soft mud, or slush, as it is called. This is done for the purpose of producing an intimate union and incorporation between the natural soil and the puddling-stuff to be afterwards added. The puddling-stuff is now brought in barrows and cast into the gutter, to be treated in the same manner; a copious supply of water must constantly be given, and the more the puddling-stuff is trod and worked by the feet and scoop, the more perfect the puddle will be. Nothing is found to answer the purpose so effectually as treading with the feet, and the layers of puddling-stuff should never exceed nine inches in thickness, without being trodden and worked. The stuff should be kept so wet that the feet sink in eight or nine inches at every step, and this same operation is continued until the puddle-gutter is filled to the top, or at any rate to a greater height than that at which the water in the canal or reservoir will stand. Dry earth is then placed over the top of the puddling, to protect it from the sun and air, while the body of it is sure to be kept moist by the water that percolates through the inner part of the bank.

392. When the necessity of puddling is ascertained before the work is commenced, the puddle-gutter may be formed by a less expensive method than that just described, because instead of excavating it in the bank after it has been finished, it may be left vacant while the bank is forming, or in other words, the embankment may be formed in two separate parts, as *p n q*, and *k z r u;* and to prevent the gutter falling in and getting filled with the materials of the bank, the puddling process may go on simultaneously with it, so that the whole may be kept nearly at the same level.

393. It frequently happens that the whole of a reservoir, or portion of a canal, may be upon sand, gravel, or some soil that will not contain water in any part; and then, of course, partial puddling would be ineffectual, and the whole surface must be made secure. Under such circumstances it would not even be safe to puddle the bottom and make puddle gutters round the banks, because if the banks themselves were of porous or non-retentive materials, and they stood upon soil of the same character, the water would percolate through them and escape. In such a case, therefore, the puddling must run under the foundations of the banks

and rise almost perpendicularly behind them, so that the work, instead of being excavated or formed with sloping banks in the first instance, must be formed with them on a nearly vertical shape, like *Fig.* 111, *Plate IV.* Such was the case with the large reservoirs of the West Middlesex water-works, formed under the superintendence of the author about thirty years ago, for supplying the western part of the Metropolis of London with water for household purposes. They were formed wholly in open porous gravel, worked, in the first instance, into a shape like the section shown by *a b c d.* A bed of puddling *i e, e i,* was then worked over the whole bottom to a depth of three feet, and gravel was wheeled in to form the angular slopes *e i g,* as soon as the bottom puddle had become sufficiently hard to bear it. Care was taken to leave the nearly vertical puddle gutters, *a g b i* and *g d i c,* three feet wide between the internal slopes as they were formed, and the natural ground behind, and this puddle was incorporated with that in the bottom, and carried up with the banks as they proceeded, so as to make the whole perfectly water tight, in as unpromising a piece of ground as could well have been selected. Such was the scarcity of good puddling soil in this neighbourhood, that many thousand tons of the puddling material were transported upwards of nine miles by barges, on the river Thames, to form this puddle. It may appear extraordinary when it is said this was done for cheapness, particularly as good puddling materials might have been had within a mile of the spot. But a large quantity of soil was wanted, and the land must have been purchased to obtain it, and then would follow the expense of its excavation, and transportation by horse and cart, as land carriages only could have been adopted, and it happened that an extension of the London docks, for shipping, was then making, and that the material excavated was excellent for the purpose of puddling. The excavation at the docks was so extensive that room could not be found to deposit the stuff, and it was loaded into barges for removal. A bargain was made with the barge contractor to carry it the nine miles instead of discharging it at a shorter distance; and thus nothing being paid for the land or its excavation, the water carriage amounted to less money than the digging of it would have cost, even if it could have been obtained on the immediate spot where it was required.

394. The difficulty of obtaining good material for puddling near the place where it is wanted, often proves a great drawback to the construction of navigable canals, and increases their expense very materially. The Engineer, therefore, when he meets with it on a line ought to reserve it, if possible, and not permit it to be deposited in the banks or other places, where it

may be of no use, and from which, perhaps, it cannot be afterwards removed.

395. Before the commencement of earth-work, the ground is very frequently covered with grass, and this is often worth preserving for the purpose of sodding banks and other work; for nothing preserves new work and prevents its cracking or slipping more effectually than grass. The sods may be taken off by a proper tool, so as not to be more than two or three inches thick, and they will then bear rolling with the grass inside, and may thus be preserved a long time if kept from the sun in a moist place. When sods cannot be procured, it is often expedient to sow the ground with hay-seed. The principal matter to be guarded against in new embankments is not permitting large quantities of rain or other water to sink into them; because as new work is always more or less porous and absorbent, it readily admits water to mix with the soil, and this renders many kinds of earth so soft as to make it incapable of bearing the superincumbent pressure. The bottom soil is thus made to sink or settle more rapidly than that above it, and the upper work, by subsiding, is thrown out of form, and large portions of the front or surface work often slide or slip down the slopes, producing ugly and detrimental hollows, called slips, which are frequently difficult to repair. The best preventive of such accidents is to adopt a very shallow slope when working in soils that appear to threaten their occurrence, and to carefully provide drains or gutters on the top of the work, with sufficient fall to carry the water away rapidly, or before it has time to settle into the new work.

CHAPTER VII.

ON THE CONSTRUCTION OF ROADS.

396. A ROAD is a certain portion of land set apart for the sole purpose of communication between one place and another, and consequently, in its formation or construction, every means should be adopted to make that communication as easy and commodious as possible. As a right line is the shortest that can be drawn between one point and another, so, of course, all roads should be made as straight as local circumstances will permit, in order that we may move from one place to another, by travelling over the least possible portion of space; and all curves or deviations from a straight line will of course increase the distance.

397. For the advantage of general conveyance, roads should be kept as level as possible; because, notwithstanding that facility is afforded to the conveyance of a load down a hill or slope, still as burthens have to be moved in both directions, the ascent of that same hill will occasion a counteracting inconvenience. These may appear to balance each other, and, as far as animal labour is concerned, they probably do so. But in a civilized and commercial country, time is an element that must always be admitted into the calculation, and it is found that the same space can be passed over in less time upon a level road than upon an uneven and hilly one, consequently the level road must have the preference.

398. Roads should be as hard as possible, in order that they may not wear into holes or inequalities, because a smooth surface is indispensable to their perfection, consequently if the natural soil over which a road passes is not of a proper quality, it will become necessary to obtain and transport hard materials to place upon it. But the great point to be attended to in the formation and preservation of roads is effective drainage. If water is permitted to remain upon a road, or even in its ruts, hollows, and inequalities, the best materials will fail, and will be incapable of withstanding a heavy traffic; while very indifferent materials may form a tolerably good road, provided proper precautions are

used for keeping them dry. A road should also be kept free from all impediments, such as mounds of earth, trees that may be blown down, large stones, or deep pits; because every road should be kept in such a state that it may be travelled over in the darkest night with as much confidence as in broad day-light. To insure all these objects requires a certain degree of care and watchfulness, and frequently a considerable expenditure of money, and the manner in which these objects may be provided for, will be first considered. Roads are usually divided into three distinct classes, called private roads, public or parish roads, and turnpike roads. Public or parish roads, and turnpike or high-roads, are, in some countries, (of which France is an instance,) national or government roads.

399. Private roads are such as are constructed by private individuals, upon their own estates or farms. In these the soil belongs to the proprietor, and he is alone at the expense of constructing and repairing the roads. He may therefore fix gates and lock them up, or change their direction, or destroy and plough them up whenever he pleases, and the public cannot complain; nor indeed have they any right to use them, except by sufferance. In England, it is necessary to lock up such roads occasionally, and to deny passage through them except by permission, and to keep records of such stoppage; because, if a private road is left open to the public for sixty years, it becomes public property, and the proprietor cannot afterwards close it or even change its direction, especially if it leads to a place of public worship.

400. Public, or parish roads, run through a larger district of country, and generally make communications between one farm and another, or between villages and even large towns, so that these roads are much more extensively used; but, inasmuch as they are seldom in the directions that lead directly through a country, they are not so much used by the general traveller as by those who live in their immediate neighbourhood. Such roads are open to the use of the public generally, without any toll or charge; but as funds are necessary for keeping them in repair, and as they require frequent inspection to see that such repairs are performed, they are entrusted to, and considered as the property of the parish in which they are situated. The parish appoints an officer or surveyor, whose duty it is to frequently examine the roads; to give directions to such labourers as may be necessary for their repair, and to provide and appropriate the necessary materials. The labour, together with the necessary transportation of materials by carts and horses, is provided by the inhabitants of the parish, and in order that it may

be evenly and fairly distributed among them, an assessment is made upon every householder, according to the extent of the property he holds in the parish. And as this assessment is made by the inhabitants themselves, there is seldom any dispute as to its equity. According to the property of the inhabitant, or the extent of his use of the road, (if more than ordinary,) he has to furnish a certain number of labourers, horses, and carts, for a certain number of days in each year; and they are liable to be called out when the surveyor has occasion for their services, and the entire portion of that labour being completed at any time, he is not liable to be again called upon in that year. The labour, horse hire, &c., is also estimated in money, so that if it is not convenient to afford the assistance in kind when required, he may compound for it in money, which enables the surveyor to hire other assistance. These cash payments likewise fall upon such inhabitants as, notwithstanding their possession of property, may not have workmen or teams; and who, consequently, could not contribute at all, unless they were allowed to do so in money. When parishes become large and the above operation might prove intricate and troublesome, the labour finding system is wholly abolished, and a general money rate substituted in its place; so that the surveyor has to hire all his hands and teams, and to purchase or dig his own materials. This is, in general, found to be the most beneficial mode of proceeding; because the surveyor can, in this case, pick out and retain good hands, who become accustomed to their business, and work willingly and cheerfully; and experience fully shows that a few good hands who are accustomed to working on a road will do more good to it in a shorter time than a greater number of unwilling hands not acquainted with the business. By the former plan there must be a succession of strange and uninstructed labourers, who may be said to be unwilling, because country labourers, in general, do not like to be put out of their regular routine of agricultural business, and especially to go to a work that they deem compulsory, and which, in many cases, is to produce a greater benefit to their neighbours than to themselves. Still, however, by the one or other process, parish roads are generally kept in a state of very fair condition.

401. The next and most important class of roads are those which, in Britain, are called the high or turnpike roads. These are the great travelling roads which go from the Metropolis, in as straight lines as can be obtained, through all the principal towns and villages to the extremities of the country; and likewise from one principal town to another. As these roads are for the accommodation of the general public, it would be unjust that the expense of their maintenance and repairs should fall

upon the parishes through which they pass; and, accordingly, these roads are supported solely by tolls, taken from all passengers that use them with cattle or carriages, and they are called turnpike roads because they have gates called turnpike gates, and collecting houses placed upon them at certain distances, and the tolls there collected furnish funds for the preservation and repair of the road. As the maintenance of good turnpike roads is of the greatest importance to the mercantile interests of a country, and those of England are proverbially excellent, and are managed by a system, which, as far as the author's knowledge goes, is very different from that pursued in the United States, and does not appear to be generally understood, he conceives that a short sketch of the system of maintaining these roads in England may be interesting and useful.

402. In the first place, as these roads are of great national importance, they are all established and regulated by acts of the legislature. These acts impose penalties upon all persons obstructing the roads, and limit the maximum amount of tolls to be taken from the public, by which imposition is prevented, and the payment of the tolls is made peremptory; for the collector has the right of retaining a horse or other animal in the event of refusal to pay the toll, until it shall be paid. As foot passengers are not liable to toll, of course no provisions are made respecting them, except that they shall not damage or impede the road in any way. The property and management of these roads is vested in trustees, consisting of a number of the most wealthy, active, and responsible gentry and farmers that live in the vicinity of the road. Their number is not limited, and in the event of death or resignation, new trustees are named by the magistrates of the county when assembled in session; and as their duties are not heavy or troublesome, and the appointment is considered an honorary one, there are always a sufficient number of men to be found to undertake the office of trustee without any pay or remuneration. The only obligation imposed upon them is an oath, that they will faithfully and justly appropriate all funds, over which they may have control by virtue of their office, to the sole purposes of maintaining and improving the road confided to their care, and that they will perform their duties to the best of their ability. They only meet quarterly at some central inn upon the road for transacting business, unless any particular matter should occur that requires extra attendance, to which they are specially convened. Their attendance is not compulsory, though in some cases they establish a small pecuniary fine among themselves for absence, the amount of which goes towards the expenses of refreshment at their meetings. In

order to insure particular serveillance, the length of road confided to any one trust is never very long, and seldom exceeds from ten to twenty miles in any one direct distance; but all the side or cross roads that branch out of the principal road, and are subject to tolls under the same act of parliament, are included in the same trust, and each trust acts under a separate and distinct act of its own. A turnpike road, consequently, of several hundred miles in length, would be divided into a great number of separate trusts, the one beginning where the other terminates; and as the trustees are selected from persons dispersed over the whole extent of the trust road, the certainty of having the whole length under the inspection of interested persons is thus secured, without imposing upon them the trouble of going far from their own homes. Each trust elects a clerk and a treasurer. The clerk is generally a respectable attorney residing in the principal town upon the trust road, and he is the secretary and executive of the trustees, to see all the orders they may issue duly carried into effect, and is in fact the representative of the trustees in the interval of their sessions, but has no power to act otherwise than under the directions of the board, unless such power is specially conferred upon him by them for particular purposes. The act of parliament constituting the trust, usually confers the power of suing and being sued at law, in the name of the trust, upon the clerk for the time being. For the discharge of these duties he receives either a competent annual salary, or a small salary, and is allowed to charge for his time and professional assistance in addition. The board likewise appoint a surveyor who is acquainted with the nature of work and road-making, and whose duty it is to spend his whole time upon the road; to engage, hire and pay workmen; to order all repairs that are necessary for the preservation, maintenance, and repairs of the road, with its ditches, water-courses, under-ground drains, and fences, and to take account of all materials that are delivered. Of these particulars he makes a weekly return, accompanied by his vouchers for wages, and small payments to the clerk, who files the same for the examination of the trustees at their quarterly meetings. As the surveyor may have gangs of workmen employed at the same time in different parts of the trust, and is responsible for the whole line of road under his charge, being at all times in good order, he is not allowed to follow any other business, but is expected to visit every part of the road as often as possible; and as his whole time is thus occupied, he receives a competent annual salary, and in many cases has a horse maintained for him, and he is required to give security for the due and faithful discharge of his office. In some cases where there are many branch roads that are much frequented, and which consequently render the distance to be inspected considerable, one trust is obliged to have two surveyors.

403. All bargains for the supply of large quantities of clean and screened gravel, broken stones, and other materials, bricks, lime, or timber, are made by written contract at the quarterly meetings of the trustees by themselves, and at these times, orders are given upon the treasurer for the payment of such things as have been satisfactorily delivered in the preceding three months. The wants of the trustees are notified to the public by printed notices, and parties willing to supply them agreeably to stated particulars, are required to deliver sealed tenders of the offers they wish to make for such supplies, stating the times of proposed delivery, quality, prices, including hauling or delivery, and other particulars to the clerk, some days before a quarterly meeting, when the parties attend. These offers are opened, written contracts made, and the supplying parties enter into bonds for the due fulfilment of their contracts. The surveyor, therefore, has nothing more to do with these bargains than to see that the materials are delivered according to the terms of the contract, and to report accordingly to the clerk.

The funds required for these arrangements are raised by tolls charged upon all horses, carriages, and droves of sheep, oxen, &c., that use the road. These tolls are limited in their extent, though not always fixed by the acts of parliament that raise the trust; because if the trustees find they can keep the road in good order with a less sum than the maximum tolls will produce, they have the option of lowering the sum, though they have no power of augmenting it without a new act of parliament, which cannot be obtained except on proof that the maximum toll is insufficient to insure comfort and safety to the public. In this way the trustees can at all times make their available income accordant with their necessary expenditure, and they can have no interest in making it larger, because the money raised can in no case be appropriated to any other purpose than the maintenance and repairs of the road in their particular charge.

These tolls are collected at gates which stretch across the road, and have a small house for the collector adjoining them, as in this country. In roads of much traffic, these gates, for the sake of expedition, are never closed during the day, and the collector is constantly at his post, but they are shut and locked at night, though the collector is bound to rise and open them at all hours to any one desirous of passing: and he can shut the gate and refuse passage to any one who objects to paying the toll, which, to prevent imposition, is required by law to be painted and set forth in letters at least one inch high, on a board at the side of the gate. In England these tolls are only payable once in a day of twenty-four hours, except in a few instances of bridges; so that having once paid the toll a passenger can go backwards and forwards as many times as he pleases between twelve o'clock on one night and the same hour on the following one. To prevent a repetition of the demand, the collector is bound to give a printed pass ticket, with the name of the gate and a number, letter of the alphabet, or some private mark upon it, to a person on first paying the toll, and the reproduction of this ticket exempts him from further demand that day. The letter or private mark is changed every day, so that the ticket of one day will not pass for another.

404. The trusts upon all roads, and even upon the same road, are perfectly distinct and separate from each other, and they have no interference; consequently each trust is compelled to raise its own funds, and it does this by having its own toll-gates. Every trust must, therefore, have at least one toll-gate on each of its principal and branch roads; or if the trustees do not think proper to collect the whole sum they are authorized to take, at one spot, they may divide that sum, and receive one part of it at one part of the road and the remainder at another. This accounts for the very large number of toll-gates met with in England, a circumstance that always strikes travellers from strange countries with surprise. Still the principle is good, for if the number of gates is large, the sum taken at each of them is small in comparison to what it must be to raise a similar sum of money with fewer collectors. No person can travel one of these roads for more than ten or twelve miles, in the populous parts of England, without being called upon to pay a toll for the road he is using, and thus the burthen of keeping those roads in repair becomes very much divided among the whole travelling community, and the sum demanded from each is so small that it is not considered a burthen. On the same principle the smallest tolls are collected at the first gates, leading out of large towns and cities, because the greater number of passengers using them, compensates for the smallness of the sum paid. By increasing the number of gates, the number of payers is increased, and although each contributes but a small sum, yet the aggregate collection produces so large an amount, that with the system of surveillance above described, the roads of England can be kept in better condition than those of most other countries.

405. In the United States, as far as the author's experience in travelling has gone, an opposite system appears to be resorted to —that of using few gates—placing them near populous towns and

cities—making the toll high, and extending over a great length of road. If this is generally the case, its operation must be, to lay a heavy tax upon the inhabitants of towns, while those who live at a distance from them, enjoy the free use of the road without paying any thing for it, unless when they are called into town; and thus the distribution of expense does not seem so just and general. It may be urged against the English system, that the frequency of gates occasions great delay and trouble; but, practically, this does not turn out to be the case, it being an ascertained fact that there is more road travelling, and that it is performed with greater punctuality, comfort, and expedition than in any other country. The post-office vehicles, called mail coaches, which carry all letters, are, by law, exempt from all tolls, and as a difference of five minutes in the time of their arrival at any particular turnpike is hardly ever known, the gates are thrown open for them, and they pass without stoppage. The same may be said of all the stage coaches, which being regular and periodical in their passage, they only settle accounts at stated periods. This is also the case with regular inhabitants of the road, who use it daily. The only inconvenience, therefore, must fall upon casual passengers, and the collectors are so expert in giving change and despatching business, that this is never complained of; but should a little delay occur, it is amply made up for by the goodness of the road allowing a degree of expedition which would otherwise be impossible.

406. It must be confessed that these arrangements, good as they are, will necessarily be attended with a very heavy expense, and such a one as could not be borne unless the road had considerable traffic upon it. But a good road increases traffic, by offering increased facilities of travelling, and an increase of travellers produces a proportionate increase of income. Moreover, when once a road is got into good order, it is easily maintained in that order without much expense, by constantly watching it and mending it from day to day, which can only be done by having a person constantly inspecting it, with workmen and materials at his command, which this expenditure provides for. Heavy expenses only occur in roads that, by long neglect, wear into deep holes and inequalities, and require a strong force of men, horses, carts, materials, and work to repair them. Such neglects, are, however, never suffered to occur in English turnpike roads, it having been fully ascertained that two or three men constantly working on a road, will do more to keep it in repair, than a gang of thirty or forty turned in all at once every six months, or perhaps only once in a year, which was the old or former practice of repairing roads.

407. The heaviest expense incident to the English system of turnpike roads, is the maintenance of the toll-collectors, who must be stationed at the many gates, and the apparent liability that may exist of the trustees being defrauded out of a great part of their revenue by their dishonesty, if they do not account for all the money they may receive, or from their being careless and wanting in vigilance in making their collections. This is met and obviated by the trustees never keeping the collection of the tolls in their own hands, but by farming or letting them out by auction for stated periods, to such collectors as will make the highest bidding; such periods being never shorter than one, or longer than three years. By this arrangement the trustees are relieved from all vigilance or anxiety as to the collection of the tolls, and it has the advantage of assuring them of the certainty of receiving an income free from fluctuation during the term of the contract, because the lessees are compelled to give ample security for the punctual quarterly payment of the sum they agree for; so that if the tolls amount to less than the sum contracted for, the loss falls upon the collector, while on the contrary, all he makes above the sum paid, is his profit. There are many men in England who make a regular business of farming turnpike gates, and although they have to engage and watch over their deputy collectors, they generally realize money. It is evident under such circumstances that the trustees must be considerable losers, but their losses are by no means so great as they would be, if they attempted to keep the collection in their own hands; besides which, this plan has the advantage of making them acquainted with the exact sum they will receive, and it therefore enables them to put an exact limit to the extent of the contracts they can make, for labour, gravel, repairs or improvements, as well as to the salaries of their clerk, surveyor, or such officers as they are compelled to employ.

408. As an instance of the vast source of income derived from some of the principal turnpike roads of England, near large cities, the great Western or Bath road out of London, may be adduced; for this, it is believed, is more travelled upon than any other road in the world. The first eight and a quarter miles of this road, between Piccadilly, which is the western extent of London, to Smallberry green near Hounslow, is divided into two trusts, called the Kensington and Hammersmith trusts. The Kensington trust has two turnpike gates upon it, at one of which three cents, and the other six cents are demanded for the passage of a coach drawn by two horses, and a single horseman pays two cents and three cents for his toll, and small as these sums may appear, one of these trusts alone, the Hammersmith, in which

the tolls are rather smaller, used to be let for the enormous annual sum of £10,000, or about $50,000, all of which money was annually expended in the purchase of gravel and other stones, bricks, mortar, and labour for spreading and laying the same upon and keeping in repair the drains, footpaths, and surface of less than four miles of the principal road, and about ten miles of branch or side roads that were but little used; and in payment of the salaries of the clerk and surveyor.

409. Road trustees are, in some cases, allowed to retain a certain limited fund of reserve out at interest on government security, to provide for alterations, amendments, and improvements, where they are likely to occur. And in the event of requiring a sum of money suddenly for such purposes, the tolls are frequently mortgaged, and are considered a full and efficient security for such loans.

410. In France, since the revolution, the great public roads belong to the government, and are placed under the charge of the Corps des Ingénieurs des Ponts et Chaussées, and the expense being provided for by a general tax upon the people, the roads are open, or without toll-gates.

411. The earliest law that appears to have been enacted respecting roads in England, was in the year 1285, when the lords of the soil were enjoined to enlarge those ways where brushwood or ditches were found, in order to prevent robberies. The next law was made by Edward III. in 1346, for laying a toll upon several roads leading out of London, and recited to have become nearly impassable. Little further relating to this subject occurs till the reign of Henry VIII., when the parishes were first entrusted with the care of the roads, and surveyors were ordered to be annually elected to take care of them. From this period the use of carriages and the transport of goods increased so rapidly, that parish aid was found insufficient to keep the great frequented roads in repair, and this led to the introduction of toll-gates or turnpikes, in order that those who used the roads should contribute to their repair.

412. The utility and importance of possessing good roads is acknowledged on all hands, and the best modes of constructing them is, consequently, an object worthy the attention of the Engineers of all countries, and much has been done for their improvement of late years. Still, however, it cannot be said that the improvement has been progressive, for the probability is that the roads of antiquity were much superior in durability, though perhaps not in surface, to any we now possess: that the middle ages wholly neglected their construction; and that our boasted

modern improvements are little more than faint and humble attempts to attain the perfection that formerly existed.

413. Of all people, the Romans took the greatest pains in forming roads; and the labour and expense they were at in rendering them spacious, firm, straight and smooth, are incredible. They usually strengthened the ground by ramming it, and laying it with flints, pebbles, and sand; and sometimes with a lining of masonary, bricks, and rubbish, bound together with mortar. In some places this expensive preparation has been found to have been carried to the great depth of ten or twelve feet under the surface of the ground, making a mass as hard and compact as marble; and which, after having resisted the effects of time for upwards of 1600 years, was found scarcely penetrable by the mattock or hammer, notwithstanding that the flints which composed it were not larger than eggs. The most noble of these Roman works was the Appian way, extending from Rome through Capua to Brundusium, a distance of nearly 350 miles. It was commenced about the year 440 of the city, by Appius Claudius, surnamed Cœcus, and was so wide that several wagons could go abreast upon it, but the central part only was paved with very hard stone, brought from a great distance; and it is described, by modern travellers, as being yet in a good state of preservation, and in places, for miles together, as perfect as when first constructed, particularly in the paved part, which is twelve feet wide.

414. The roads of the Romans were for the most part made for military purposes, and they were probably the first persons who made any regular roads in Great Britain. Such roads were constructed not so much with the object of improving the country, as for facilitating the subjection of the inhabitants, and to secure a communication at all times between their armies occupying different quarters of the island. They therefore stretched across the country from one place to another in very considerable lengths, constantly in straight lines from one station to another, and as they were all paved and placed upon the most elevated parts of the country for watching the movements of the enemy, they afforded a hard, durable, safe, and expeditious means of conveyance, vastly superior to the winding, soft, and swampy paths that had been previously formed by the earlier inhabitants. Many of these roads are still preserved in England, but as they have all been widened and modernized, no traces of their ancient formation exist, except their straight lined direction, and the occasional remains of Roman camps and stations, near which coins and other relics are sometimes dug up, and they are still distinguished by their ancient names of streets,

such as Watling street, Ikenild street, Erminage street, to which, however, the Foss-way, which had a deep ditch on each side of it, is an exception.

415. The ancient roads were in general narrow, because wheel carriages, for the conveyance of goods, appear to be a comparatively modern improvement, and it is not very accurately recorded when, or by whom, they were first introduced. The war chariots of the ancients, it appears, were devoted exclusively to the purposes of war, although it might naturally have been expected that their use would have suggested the advantage of using vehicles of a different form for travelling and general transportation. Still travelling was always performed on horseback, and the transportation of goods conducted in the same way upon the pack saddle, either on mules or horses, and hence the necessity of wide, fine, and level roads did not exist.

416. As civilization reached a higher degree of perfection, and commerce became more extended, the occurrence of articles of trade or comfort in the interior districts of the country, would enforce the adoption of some mode of communication suitable to the advanced state of arts and manufactures, and the mere use of a wheelbarrow would carry conviction to any one that a much heavier quantity of produce could be conveyed, when a part of it was borne upon a wheel resting on the ground, than if the weight of the whole burthen, as well as its motion, rested upon the arms of a man, or the back of an animal. This would lead, by an easy gradation, to the formation of wheel-carriages, but as they are nearly useless except when moving along smooth surfaces, so the introduction of such carriages would naturally lead to an improvement in roads, and accordingly their improvement and perfection generally keeps pace with the civilization and commerce of every country, and justifies the observation of the Abbé Raynal, who says: "Let us travel over all countries of the earth, and whenever we shall find no facility of trading from a city to a town, or from a village to a hamlet, we may pronounce the people to be barbarians; and we shall only be deceived respecting the degree of barbarism."

417. As to the construction of roads, it may be said to be the simplest operation of the Engineer, embracing very few principles beyond those that have been discussed in the present and preceding chapters, with the exception only of the preparation and formation of the top surface, which we shall now proceed to discuss. The settlement of towns, manufactories, mines, or other establishments that engage the attention of mankind, give rise to the necessity of forming roads. And the first principles that should govern their formation, are proximity and facility of

passage. The first is attained by making the road of communication as nearly right lined as possible whenever the country it has to pass over is so level as to admit of it; but the right lined direction should not be persevered in, when it is hilly and uneven, since a more circuitous route over a level tract of country is better than the shorter one that is hilly, whenever the elevations and depressions of the soil are so extensive as to become inconvenient to the passenger. The operation of levelling, as before described, and thereby selecting a good and favourable line, is therefore of the greatest utility and importance in selecting a good line of road.

418. Another and most important subject to be attended to in the selection of a line of road, is its drainage. Many old roads will be found sunk beneath the general surface of the adjacent land, notwithstanding this is the worst principle of construction, and one which no pains should be spared to avoid. As a general rule, every road should be kept above the soil over which it passes if possible; and, whenever this cannot be effected, its surface should be enough of a hill to cause water to run down it; or, if level, it should have side ditches or water-courses, to carry off rains as speedily as possible. Common observation will convince any one that a road formed of almost any ordinary soil, without gravel or any thing to cover and protect it, will be good, provided it is so elevated and drained, that rain water will not remain upon it; while, on the contrary, a sunk road, or one formed like a wide ditch or shallow canal will be soft and bad, and will wear into holes or ruts, even if formed of the very best materials, and the greatest pains should be taken for its preservation. For the same reason, a good road is scarcely ever met with in a thick wood, merely because the foliage shuts off the sun's rays, and by excluding them, and a free circulation of air, prevents that evaporation that would otherwise take place. Perfect drainage must therefore be considered as the great and leading requisite to the existence and maintenance of a good road, and this ought therefore to be the great object of attention to the Engineer in the setting out new roads, and the amendment of those that already exist. It may frequently be difficult of attainment, especially in level countries; but we will endeavour to give such directions as seem most likely to assist in attaining this most essential object.

419. No road should be formed in a hollow or concave form, or even be quite flat upon the surface of its transverse section, but, on the contrary, should be convex or protuberant along its central line. If the centre of a road of twenty feet wide, is made six inches higher than its two sides, this will keep the

middle dry, by throwing the water to the two sides. This rising or convexity in the centre, is called the crown of the road, and as six inches is the twentieth part of ten feet, or the half width of the road, the crown would be said to rise one in twenty, and a proportionate elevation should be given to the transverse section of every road, whether it is narrow or wide. Such a convexity will occasion no danger to carriages running upon it, or any inconvenience. If such a road is above the level of the adjacent land, the water may be discharged from its two sides without inconvenience, or it may be conveyed into ditches sunk on the sides of the road and running parallel to it. In level countries, difficulties may arise in getting the water discharged out of these ditches, and they may require to be made very deep in the progress of their fall; still, it seldom happens, but that a vent or discharge of some kind may be discovered in the progress of a few hundred yards; and, should that prove impossible, ponds or reservoirs may be sunk in the lowest pieces of land that can be found, in which the water may sink into the land, or be dissipated in evaporation. A very small fall or descent will be sufficient for road ditches. They should begin at the surface, or have scarcely any perceptible depth at the upper part of the road, and become gradually deeper and wider as they descend; and all the soil dug from such ditches should be thrown on to the road to elevate it, instead of being thrown on the outside of it, as frequently practised.

420. Whenever it may be necessary to sink deep ditches by the side of a road, they ought always to be separated from it by a foot-path or causeway, raised from nine to twelve inches at least above the road, to prevent accidents to cattle or carriages that might fall into them: the water in this case being conveyed from the road by drains passing through such causeway: and, whenever for the purpose of drainage, it may be necessary to convey water from one side of a road to the other, it should always be carried by a drain or brick culvert running under the road, and in no case be allowed to flow freely over its surface.

421. A perfectly level road is by no means desirable, on account of its property of retaining water; and, as a very slight slope or inclination in the longitudinal direction will be sufficient to produce a discharge of water to the lowest part, while it will hardly be perceptible in its effect upon the draught of carriages, so it ought always to be obtained. By a judicious selection of line, and setting out of a road, sufficient slope may generally be found on the natural ground; but if that is impossible, it must be produced in the earth-work, that is to say, in the slight cutting or excavation that is always necessary for rendering the surface of

the ground smooth and uniform, and fit for the hard materials that have to be laid upon it; and by distributing the soil that should be excavated from one or both sides, for draining ditches. Instead of throwing the soil thus obtained upon that part of the road nearest to where it is produced, it may often have to be conveyed a considerable distance; and, whenever that proves necessary, carting the soil in common or three wheel carts, will be found more expeditious and cheap, than moving it by barrows, notwithstanding that barrows are preferable for short distances. The least slope that a road called level should have, is a yard perpendicular in a mile of length; but, as so slight a slope as this will barely affect the water, two, three, or even four yards in a mile, will be better, and will produce a sensible run or discharge of the water. A greater slope should be avoided if possible; because, when the slope is rapid, the water of hard rains runs with such velocity and force, as to wash away part of the materials that compose the roads or side-banks.

422. The chief business of the excavator in cutting and preparing the surface of a country for a road, consists in what has been before explained in reference to *Fig.* 80, *Plate III.* (337.) That is to say, cutting down protuberances or projections, and filling up hollows, cavities, or valleys with the soil, and the only calculation is, that of obtaining the cubical contents in both cases, whether of superabundance or deficiency, to ascertain the depth of cutting necessary for exactly filling up the cavities without surplus.

423. In forming a road upon an undulating country like that in the figure, the new surface should not, however, be converted into a right line, even though it may be one of such inclination as will afford longitudinal drainage, because experience shows that long runs of water upon roads are detrimental to them, and that the water should be carried off the road at as short intervals as possible; and such means of drainage will be obtained by preserving the former undulations of the country to such extent only as will allow sufficient run or discharge for the water. When the longitudinal slope is sufficiently great, no side ditches will be necessary, but the proper curvature that should be given to the crown will form sufficient channels, and these are called *water-tables* when they do not sink beneath the general surface, like ditches or gutters. *Fig.* 112, *Plate IV.*, shows a profile or transverse section of the form the ground should be worked into for forming a road in level places. Suppose *h h* to be the original level surface of the land, then it must be excavated at *f f*, to produce the necessary rounding of the road, and the soil dug out of these lines is thrown to the centre *i*, in order to raise up

the crown. Should such a road have longitudinal slope, the angular spaces under *f* and *f*, will form the water tables. But should the road be level, then ditches *l l* deeper than the water table will be necessary, and the embankments *k k* raised by the soil from the ditches will form foot-paths, or causeways, and will sufficiently separate the road from the ditch to prevent danger. Whether a raised footpath is formed or not, drains, throats or culverts, as marked under *k*, will be necessary for carrying off the water, which, as before observed, should never be allowed to run a long distance upon the water tables. And if it should be inconvenient to have a receiving ditch on each side of the road, then a mere gutter may be formed at *f*—and a culvert or underground drain should proceed from it, under the road itself, and opening into the ditch as marked at *m m*. These transverse underground drains should be repeated at regular intervals, respecting which no precise directions can be given, because their number and position must depend upon the form of the land, and the facilities that exist for getting rid of the water. Whenever transverse drains are introduced under a slope or hill, they should not be at right angles to the direction of the road, but inclined to it, or sloping downwards; for, although their length will be increased by so placing them, yet a much greater fall or inclination can be given to them, and they are therefore less liable to become choked or stopped up by sand and soil that will subside in them. They should be built of bricks, stone, or other materials not liable to decay, and as the opening of the road for their repairs may be attended with inconvenience, it is better to give them much larger dimensions than may be necessary for the mere passage of the water, so large indeed that a boy may creep into them with a hoe or scraper for removing any obstructions that occur.

424. When a road has to be formed on the side of a hill, the most economical disposition will be to form about one half of it upon solid ground by excavation, and the remaining portion by embankment, unless the hill should be so steep as to prevent this mode of construction, or render it dangerous on account of the embankment sliding down, or giving way, when the more expensive process of forming the whole road by excavation must be resorted to. In general, however, the road platform may be formed by the former process, in the manner shown in *Fig.* 113, *Plate IV.*, where *n p n* represents a profile of a side of a hill, on which the road shown in section by *o p q*, has to be formed. In such case the triangular portion of soil *n o p*, will have to be excavated and removed further down the hill, placing it in the form of *p q n*. About one half of the road *o p*, will then be on solid

ground, and the other half, *p q*, upon embankment. The embanked half should be left higher when first formed than the other, because it will inevitably subside to a considerable extent; and, should any apprehension exist that the whole embankment may slide down, it may be prevented by cutting the hill below the proposed road into the form of stairs or steps, as shown in the figure, before beginning to form the embankment. At all events, whether this is done or not, the natural soil, and any grass or herbage upon it, should be taken off before the embankment is began, for such vegetable matter will take considerable time for its decay, and until it is gone, it forms a kind of drain or open joint, into which the water from above will insinuate itself, and prevent a due incorporation of the old and new soil; and this it is, in general, that occasions slips in new work, the occurrence of which should always be guarded against. When the work has settled, and come to its proper solidity and bearing, they rarely occur.

425. In forming the kind of road just described, *a banquette*, or raised mound of earth, should always be formed at the top of the descending slope, as at *q*, or else a strong line of wooden posts and rails should be fixed there, as a safeguard against passengers and cattle falling over. The latter, if made sufficiently strong, is preferable, because it admits of better drainage, and keeps the road-way more open and exposed to the sun and air. If a banquette is used, it should be pierced with drains at every fifteen or twenty yards, to carry off water. In the draining of such a road a small ditch at *o*, with under-ground drains, *r r*, at regular intervals, is to be preferred; and, if it is adopted, the road-way may rise in the middle, or have a regular crown, like other roads, and will discharge its water on both sides as usual. A road formed in the side of a hill not only receives the rains that fall upon it, but is subject to the greater inconvenience of receiving all the water that may fall on the hill above it, as well as the soil that may wash down; and if this hilly ground is of great extent, the ditch and drains become almost indispensable, for the torrents of water thrown upon it would, unless collected in this manner, soon wash away or destroy the surface. If there should not happen to be any great surface of high land above the road, then the ditch may be dispensed with, but the road must have no crown or convexity, because that would produce a cavity that would hold water, between such crown and the steep bank *n o*. The transverse section of the road must be a sloping right line, falling from *o* to *q*, in a sufficient degree to let all the water that may fall run over the road to discharge itself from the lowest side.

426. As to the width of roads, no rule has ever been adopted,

since they should be made suitable to the kind of traffic expected upon them. As a cart or carriage can pass upon a track eight feet wide, and three feet more allows a foot passenger, or even a horseman to pass, many roads or lanes are found that do not exceed eleven or twelve feet in width; but this is a very bad plan, and one that should constantly be avoided, unless in deep cutting, tunnels, or other positions, in which, from local circumstances, such confined width is rendered necessary. It precludes the possibility of good drainage or repair, and when two carriages meet in opposite directions, is productive of serious inconveniences, even if occasional wider passing places may have been provided. Such narrow roads are only made with a view to economy, but it is economy of a false kind; for, if the wheels of heavily laden carriages are constrained, by the narrow limits of the road, to move constantly in the same track, they cannot fail to wear it out, and fill it with deep ruts and inequalities in a short time; and the ruts and holes, by holding water, soften the adjacent parts, and frequently render the whole impassable; while, on the contrary, if width had been allowed, when one track becomes bad, another is adopted. The vehicles, instead of continuing in one straight forward course, change from one track to another, thus traversing the ruts and inequalities obliquely, which has the effect of tending to flatten or fill them up; and thus a road that is wide, and has considerable traffic upon it, in some measure, repairs itself, of which there is abundant evidence in many country places, where the roads are little attended to. No road should, therefore, ever be made less than twenty-four feet in width for any purpose, and in those that are much frequented, from thirty to sixty feet will not be found too much.

427. We will conclude this account of the setting out and formation of roads, by a few observations that apply generally to them in all positions and situations. Notwithstanding a perfectly straight line forms the nearest communication between one place and another, and can very frequently be obtained in setting out a road, still, if it continues for miles in succession, it is generally admitted to be irksome to the traveller; and, as a gentle undulation or waving of the line produces very little addition to the length, and adds to the beauty of a road, it may be safely admitted, and will in general be approved. When the necessity occurs of a road changing its direction, it should never do so abruptly, but in the form of a long and gentle curve, such a line being more safe and consistent with rapid travelling, than sudden turns, which ought only to be admitted where one road crosses another, and then sufficient space should be left at the intersection to admit of carriages taking such curved direction; and, in

every case a certain distance of the road in advance, should be open to view, to avoid the unexpected meeting of what may be moving in an opposite direction. Guide posts, indicating the place a road leads to, should also be set up at all intersections of roads. They are often disregarded by local inhabitants, as being useless to those who, living in the neighbourhood, know every road, but they are highly useful, and save much time and anxiety to strange travellers. In England the road trustees and parishes are bound, by law, to provide and maintain them as part of the road expenses; and the plan lately adopted for making them is good and convenient. The indices, or pointers, fixed to the top of the post, instead of being made of wood with the place painted upon it, (and which is very apt to be defaced,) is made of cast iron, and consists only of letters about three inches high, attached to the surrounding frame, so that no ground or board is necessary, but the whole is transparent with the exception of the letters, and these being seen against the sky, can be read after it is so dark that no other writing would be visible. The appearance of such a casting is shown at *Fig.* 114. The number indicates the number of miles to the place named, and may be used or not at pleasure.

428. In all great roads, mile stones should be set up to indicate the distances to and from places; and these, of course, are placed at intervals of one mile asunder. Formerly the distances were indicated by posts of wood, painted; but these being subject to rapid decay and obliteration, were replaced by stone posts; which, although durable in themselves, are not so in their inscriptions. They might answer if formed of marble or any good stone for maintaining carving, but in many parts of England they have been formed of the nearest local stone, to avoid the expense of transportation, and the consequence is that many of them are illegible. Of late years, cast iron has been resorted to, particularly in the north-eastern roads of that country, and is found to answer the purpose in a more satisfactory manner than any material previously resorted to. They do not require great strength or weight of metal, and are often fixed upon the face of the old ponderous stone. The form adopted is so convenient that it may be worth copying, and is as follows: The casting consists of two flat sides about fifteen inches wide, and about three and a half high out of the ground, placed at right angles to each other, and united at the top by a triangular piece that slopes so as to make an angle with the horizon of about 60°. The whole is cast in one piece, having the appearance of *Fig.* 115, *Plate IV.*, and the letters stand out, or are in relief. The large figure on the top is the distance from the metropolis, London,

and the two sides present the distance from the nearest post towns in the two directions of the road. Being hollow, they may be attached to a post of stone or wood, or the cast iron may be prolonged sufficiently to be set in the ground. They are painted white, and the letters black, so as to be seen at a distance, and are not only exempt from obliteration, but are cheaper, and, it is believed, better than any previous method of marking the distance upon roads.

429. In many places roads are unavoidably subject to floods, or freshets, so as to become occasionally covered with water. When this is the case, the proper direction of such road should be indicated by posts placed at convenient distances along their sides, with figures, cut or painted upon them at every foot from their bases, so as not only to guide the traveller in his proper track, but to inform him what depth of water he has to pass through.

430. Trees and live hedges are, without doubt, pleasing to the eye, and add much to the beauty of a road, but at the same time, they are highly detrimental to it, particularly if placed at the south or sunny side. Hedges, therefore, should be kept low by cutting, and trees ought not to be permitted, particularly if their branches are long and overhang the road. Many advocate the planting of a road side, on account of the pleasant shade produced, which is desirable during the hot season; but if trees are sufficiently large for this purpose in the summer, they will inevitably produce more than an equivalent mischief in winter or wet seasons, by their retention of water, and dripping upon the road, as well as preventing its becoming dry when the rain has ceased. A good piece of road, overshadowed by trees, is a thing of very rare occurrence.

431. It only remains to speak of the manner of rendering roads hard and durable after they have been set out and formed as before directed, and this can only be accomplished by covering them with hard materials. What these materials will be must in general depend on the locality of the road, and its happening to be in a completely inland country, or one that has the advantage of navigation. There is no doubt but that the hardest flint stones make the best road, and next to them the whin stone, Trap and Basaltic formations, but they are not procurable in all places, and therefore the best materials that can be obtained in the immediate neighbourhood must be resorted to, and in their selection, hardness and tenacity are the great objects to be regarded. When countries are near navigable rivers or canals, it often proves more economical to transport hard materials from a distance, than to use the softer ones with which a country

abounds. No material is more universally distributed over the face of the earth than what is called gravel, and accordingly that is generally used for making roads.

432. Gravel is a general term applied to all stones that have the form of pebbles, whatever their composition may be, therefore it is not admitted as the name or character of any particular stone in mineralogy. The hypothesis usually held respecting pebbles is, that they are fragments of rock broken or separated from the large masses, by decay of parts, or by some great convulsion of nature, and that they have been rounded by having their points and sharp edges worn off by attrition in the sea, from whence they have been deposited, by means of which we have no record, in various parts of the dry land, and frequently at elevations far above the present reach of the sea. These pebbles, therefore, vary much in quality, even in the same parcel of gravel, but they are almost universally hard, because the process they must have undergone to bring them to the form of pebbles would grind the softer materials to a state of powder, producing either sand or common soil; and as flint is the hardest of all common or ordinary stones, so the pebbles of gravel are usually of this material.

433. What may be designated under the general name of gravel, is divided into several classes, by names dependent only on the magnitude of the component parts. Thus large rounded pebbles, which are never quite round, but are flattened on their two opposite sides, and which are found abundantly on many sea shores, of a magnitude varying from that of a man's fist to his head, are called *boulders*, and these are picked up separately and reserved for the purpose of paving streets. What is generally understood by gravel has no stones in it larger than the fist, but it has all gradations of smaller ones down to sand. The sort always used, or at any rate preferred for road making, is termed clean, or screened gravel, that is to say, the mixed gravel passed through a screen or sieve composed of very strong iron wires, or rather thin rods of iron placed at from half to three-quarters of an inch asunder. All that will not pass through such a screen is termed screened gravel, and that which does pass through is, by workmen, termed hoggin, before referred to (389). The first is alone used for road making, and the latter for covering causeways, footpaths and gravel walks; it consists of a mixture of sand and small pebbles, which bind together and produce a hard, smooth, and compact surface.

434. The old system of road making, or rather road covering and repairing, as followed in England, and which is still persevered in in many places, was, after having prepared the ground or

sole of the road by giving it its proper crown or convexity, slope, water tables, and so on, to cart and spread as much screened gravel, without any previous preparation, as would cover the whole road to a depth of from nine to twelve inches, and then to cover this with a thin coat of hoggin, in order to fill up the interstices, and cause the gravel to bind or become compact. This produced a very rough road at first, but by time and use it would become compact and tolerably smooth. In this way it was left until it needed repair, and that repair consisted in first scraping off all soft mud, and then applying another coat of screened gravel without hoggin, so as to cover the old road to a thickness of two or three inches, spreading it by rakes or shovels, to make the surface as even as possible, and to fill up the old ruts and inequalities, and this was repeated every fall or autumn. This practice was continued until Mr. M'Adam, of Scotland, drew the attention of the public to its waste and impropriety, and introduced his improved system of road making, which he began about the year 1810, and which is now almost universally followed. He was led to the consideration of this subject by observing the effect that took place when a heavy carriage, such as a loaded stage-coach, passed over a newly formed road. The wheels being thin and narrow, cut or sunk into the new gravel to a considerable depth, so as to make the draught enormously heavy, and they were permitted thus to sink in, on account of all the gravel pebbles being hard and round, which allowed them to roll about and displace each other, thus completely counteracting any tendency they might have to bind or unite together into a hard mass. Every vehicle that passed in succession produced a new disturbance or displacement of the materials, to such an extent that it might almost be compared to ploughing up the road; nor did the road begin to assume a good and hard aspect, until by the repeated passage of heavy carriages over the materials they were broken and partly reduced to powder. In the same way when a road was repaired by giving it a new coat of coarse gravel, without disturbing the old surface, the wheels constantly made their way through that new coating down to the old surface, displacing the new gravel, unless it was applied in a very thick and expensive manner, and thus the repairs never availed until the new material was partly worn out, as it was supposed, by becoming broken. In the formation of his system he was guided alone by what he saw going on in nature. If the road did not become hard and good until the stones were irregularly broken by the frequent passage of heavy carriages over them in process of time, why impose the duty of breaking the stones upon the carriages, when it could be more speedily, effectually, and regularly done in the first instance, by hard labour? Again observing that when a carriage wheel, or even a horse's foot fell upon a large stone that was imperfectly bedded or fixed in its place, such stone would be moved, or perhaps turned over, by which a disturbance of all the smaller stones around it took place, and they became loosened and disturbed, he became satisfied that no large stones should be used. The leading feature in M'Adam's system of road making, therefore, is that no large stone, or stone of a spherical or rounded form, however small, should be introduced into the formation of a road, but that the operation of breaking them should be resorted to in the first instance, before they were used upon the road; thus not only reducing them to small magnitude but likewise producing sharp points and angular edges upon them, in order that they might lock into each other, and nearly, if not quite, destroy their tendency to roll about or give way to pressure; and this has been attended with the happiest result, for a bed of broken stone of much less thickness than the gravel formerly used, is found to consolidate sooner, and to produce a much more durable and compact surface than could be formerly obtained; besides which, the broken stones preserve the form in which they are placed upon the road, while in the old plan the rounded pebbles had a constant tendency to shift from the middle of the road, which is most used, towards the sides, thus requiring the occasional use of the hoe and rake for several weeks, to draw them to their former places.

435. Another objection to the use of rough or unprepared gravel arises from the various dimensions of its component parts. The small and fine stuff has a tendency to set to the bottom, while the large stones work out to the surface, and occasion inconvenience and irregularity, with great additional wear and tear to wheel carriages, until they are broken down; while in the M'Adam plan, as all the stones are reduced to nearly the same size, this effect cannot take place.

436. Mr. M'Adam also adopted a new system in the repair of former roads, although one of his principles was that a road should never be permitted to get out of repair, which may be effected for a long period, by care and watchfulness. The method of obtaining this desirable end is by having single cart loads or small heaps of ready broken stone disposed at short distances upon convenient places on the waste ground at the sides of finished roads, or wherever they would be out of the way of passengers, and keeping a single labourer to inspect a certain distance of road, who, with a wheelbarrow and shovel could take the few stones necessary to fill up a cavity or rut as soon as it

appeared, from the pile nearest to it, and thus by keeping the whole level, none of those concussions of heavy loads occurred, that are more hurtful to roads than anything else. A road suffers little from a heavy load drawn upon it, provided the surface is smooth and regular; but when ruts or holes occur, the wheel sinks into these with all the increased momentum of the fall, and produces an effect that may be compared to that of a prodigiously heavy hammer falling upon the spot: and thus the hardest materials soon crush and are ground to dust, while no such effect occurs on the road while kept with a smooth and even surface.

437. Still, however, the materials will wear out and give way in time, so as to require renewal, and whenever this has to be done, broken stone alone is to be resorted to; but instead of placing it upon the old smooth surface, as formerly done, and where a very imperfect incorporation took place between the old and hard surface and the loose new materials, he prepares the former road by picking up its top surface with a short and heavy pickaxe to a depth of at least two inches, so as to render it quite rough, or like a newly formed road in appearance, and upon spreading the new stone to a depth of three or four inches upon it, a complete binding and incorporation takes place in a very short time. To this process he therefore applied the new name of *lifting* a road instead of repairing it, though in fact, the lifting only applies to the raising of the old surface to prepare it for proper incorporation with the new material. The road being repaired, has to be watched as before stated, for a few weeks, to fill up any cavities that may occur, since it is impossible, either in making a new road or repairing an old one, to dispose the materials so equably as to insure that one part shall not sink more than another; but when once these inequalities have been adjusted, and the whole surface has become uniformly hard and smooth, it may be left with confidence, as deep holes or ruts occur through negligence alone.

438. It may at first sight appear that the breaking of stones is a tedious and expensive process: so it is in the first instance, but it affords employment to old men and children who might not be otherwise employed, and the expense is amply repaid by the smaller quantity of stone required, and the little repair necessary to the road when once properly made. When first adopted, Mr. M'Adam used an iron ring as a gauge for the size of the stones, and no stone was considered to be broken small enough, unless it would pass through that ring. Now the stones are carted in their rough state to the road side. The labourers sit upon the heap, and selecting a large stone as an anvil, they break the larger ones upon it with a long steel hammer, taking one at a

time, and throwing them, as broken, to one side. The work is paid for by the bushel of broken stone, and this being measured in the presence of the surveyor or his overseer, if he meets with any stones that the breaker cannot take between his teeth, the work is considered imperfectly done, and is not paid for until the heap has been gone over again. This is a sufficiently accurate gauge, and operates as a check upon the inattention of the workmen.

439. After a new road has been formed, or an old one repaired, Mr. M'Adam recommends the use of a very heavy cast iron roller to be drawn by horses over the newly laid stone, to render it more speedily solid and compact than it otherwise would be. But a roller of sufficient weight to do good, is so heavy and expensive that it is not always resorted to. Such a roller ought to be about six feet long by four or five feet in diameter, and full an inch and a half thick of metal, to be effective. And lastly, he insists, (as we have already done,) in the absolute necessity of good and perfect drainage for every road; saying that if the substratum of natural soil is not kept dry and hard, we may in vain look for a perfect road, since the best materials will be pushed or driven down, and will be buried in the natural soil if soft, by every passing load, and in their passage downwards they raise and protrude a quantity of that soil, about equal to their own bulk, on each side, which disturbs and mixes with the broken stones, and renders them unfit for their office, by destroying the foundation they should rest upon. Indeed, so essential it is to the preservation of a good road that it should be kept dry, that the mud or slush remaining on the surface of roads after continued rain, ought never to be permitted to remain and dry there, but should be scraped off and put in heaps at the sides of the road to dry. This scraping should be performed by wooden hoes, about a yard long, as iron ones draw up the stones and produce irregularity. The road stuff, when so collected and dried, forms the best sand for building mortar, and is in general very good for lining furnaces in which great heat is required, and also forms excellent foot-paths.

440. The greatest difficulty a road-maker has to contend with is a bad substratum or natural soil. If that is good and hard, and so situated that it can be drained, a good road may always be formed, especially if good gravel or other sufficiently hard material can be found to cover it. In clay countries, where gravel or stone of any kind is scarce, an artificial material may be formed, (if wood abounds,) by making the clay into balls and burning them until they are nearly vitrified. On the same principle, the slag or refuse from iron and other furnaces, makes an excellent

material. In the neighbourhood of collieries, the stony or slaty part of coal is used, and in the south-west part of England many of the roads are formed wholly of hard or stone-chalk. In fact almost any thing, except sand, will make a tolerable road, if kept dry, properly scraped, cleansed and attended to, and the substratum is hard, dry, and absorbent. Hardness alone is not sufficient, for solid and compact rock is a very bad bottom, unless when covered by so thick a stratum of good material, as will prevent the surface water from sinking down to it, or its irregularities from being perceived. Rocky countries are generally very broken and hilly, and owing to the smooth surfaces presented, and the water being unable to penetrate into them, the materials will not adhere and become fixed, but are very liable to be washed away by the floods of rain, so frequent in such places. A sandy substratum is also difficult to conquer, except by such a thickness of gravel or broken stone as will entirely prevent any concussion or vibration that occurs at the top from being transmitted below. Should it take place, the lower stones will sink gradually into the sand, which will rise and mix with the upper stratum, thus making room for that to descend until the whole may be lost or buried. The most effectual method of counteracting this effect is to dig the sand out to about a foot in depth, and to place large and flat stones upon the bottom, so that they may take an extended bearing upon the sand; to fill in with large broken stones, or old brick rubbish, if it can be procured, and to finish with stones broken to the usual size. The worst bottom, however, that has to be contended with, is a bog-swamp or morass, in which the ground is soft and full of water, so as to be incapable of supporting small stones, and from which no drainage of the road-way can be obtained. It frequently happens on inspecting a situation, even like this, that some outlet may be found for draining off the top water of a morass, though, perhaps, only for a foot or two, and yet this will at times render the surface better, though it will generally sink or become lower when the water is drawn away from it. It is, however, advisable to drain it as far as possible, and that done, there is no better way of forming a road-way than by placing fascines, (as they are called in the language of military engineering,) or bundles of brush-wood tied together, and disposed regularly by the side of each other in the manner of paving, and then placing a second course above these, laid in the cross or opposite direction; the next, or third course, should be parallel to, and in the same direction as the first. The number of layers or courses of these fascines will, of course, depend on the nature of the place, and the quantity of sinking or depression that will take place when they are loaded with gravel.

Should the place be very bad, two or three courses may be laid, and then covered with small poles or young trees, laid across the intended road-way, (in the manner practised in this country in wet and soft places,) when other courses of fascines or faggots should be laid upon them; the only use of the poles being to bind the whole together, and prevent the possibility of one part sinking without another, thus extending the pressure over a considerable quantity of surface. The platform of fascines, being thus formed, should be covered with large and flat stones if they can be procured, and a thin stratum of loam or clay, that is nearly impervious to water, is sometimes laid over them, after which the road is gravelled or covered with stone, in the usual manner. The weight of the road materials will generally cause the fascines to sink in the soft bottom until they disappear, and sometimes even the whole road may sink to such an extent as to become useless; and the only way of recovering it is to repeat the former process until a good and hard road is obtained.

This is a very expensive mode of proceeding, and one which, of course, would never be adopted, except when local circumstances render it absolutely necessary; because, in most instances, it would be better, and probably, cheaper to go a few miles round, than to cross directly over a bog or morass. It is, however, a common mode of construction in Holland, where a great part of the land has been reclaimed from the sea, and is actually under its level; the water being kept out merely by sea-walls and embankments, and a great part of the soil would be constantly under water, was it not for the constant operation of pumping, which is carried on without any great expense beyond the first cost of machinery, which consists of an immense number of wind-mills or pumping-engines, driven by the force of the wind alone. This power, it is true, is an uncertain one, but it is cheap and available, in almost every position, and is found to answer the purpose most effectually. It is often resorted to in England for grinding corn, with good effect, but is not yet much known in the United States, which are so bountifully intersected by fine rivers, affording ample water power, that there is little need of further assistance. Still the power of wind might be rendered available in many places where that of water cannot be obtained, and it is worthy the attention of the agriculturalist and manufacturer. It might be supposed that the fascines and timber placed under a road, upon a morass, would soon decay, and destroy the road; but this does not occur, provided the timber sinks in, and is not exposed to air. Whole trees are frequently dug out of bogs without any appearance of decay, though no records may exist of the time of their disappearance. And the celebrated Peten dike, in Holland, constructed centuries ago by this process, is as stable as ever, and its fascines and rails, when dug up, are in the most perfect state of preservation.

441. Whenever roads are subject to a more than ordinary use and wear, it is found more convenient and economical to pave them, instead of covering them with loose stones. Thus the streets in all cities and large towns are paved, which not only insures better and more regular roads or tracks for carts and carriages, but promotes the cleanliness and health of the place, by the facility that is provided for the escape of rains and other water, and of clearing away the dirt and filth that never fails to accumulate in thickly populated places.

Paving is nothing more than selecting good and hard materials, as nearly equal in size as possible, and disposing them in a regular and close manner upon the surface of a road, previously formed in the same manner as if it was intended to cover it with gravel. The goodness and duration of pavement depends on three circumstances, which require particular attention, viz: the materials employed; the bottom or substratum on which they are placed; and the manner in which the work is performed; and these must be separately considered.

442. The material that has been generally selected for paving the cities and towns of the United States; of the old part of Paris, and most of the provincial towns of France and Britain, and which was, until about twenty-five years ago, wholly employed in London, is the large boulders or rounded pebbles before spoken of, as having a spheroidal or flattened spherical form, and a magnitude of six or eight inches diameter in one direction and about half as much in the other. They generally consist of granite whinstone, or trap rock, supposed to have been reduced to the rounded form by long attrition in the sea, and they are usually collected on the coasts. Notwithstanding the general adoption that has been made of these stones for paving, they possess no advantage beyond their hardness, and their producing a surface that the feet of horses do not slip or slide upon, in consequence of the numerous small projections and irregularities they present. In using them for the purpose of paving, they are placed close by the side of each other, with their longest diameter upwards, or in a vertical direction, and, if one end of the stone happens to be smaller or sharper than the other, that end is placed downwards. The disadvantages of this kind of stone, are, that owing to their thin rounded shape, they are incapable of bearing or supporting each other laterally, except in single points; being in some measure sharp or wedge-shaped, they cannot take a good or flat bed or bearing upon the sole or earth prepared

beneath for receiving them; they are so light that they receive and transmit the pressure or concussion of every load that passes over them to the earth that supports them; and, as their joints can never be brought into any thing like close contact on their upper surface, they present what may be compared to an innumerable quantity of small funnels to catch and retain the rain that falls on them, and very effectually prevent it from running off; the consequence of which, is the formation of much mud and dirt in wet weather, and of dust when it is dry; and as the water thus retained in the cavities has no opportunity of escaping except by evaporation, and principally by percolation, the substratum is kept constantly moist, and rendered less effective than it otherwise would be, in resisting pressure from above. From the small depth of these stones, the frost of winter penetrates, and freezing the moist earth below, causes it to expand, and protrude the stones from their places, and when a thaw returns, the ground having been rendered soft, permits them to sink unequally, and thus to destroy the even surface they before presented. As the stones sink, a portion of the substratum is displaced, and protruded between the joints, so as to afford ample materials for the formation of mud in wet weather, which is washed away by the rain, thus affording room for the collection of a fresh supply, which cannot fail in a greater or less degree to mix with the offal of the streets, to such an extent as occasionally to become offensive. Lastly, the unavoidable inequalities of a boulder paved road, produce a degree of wear and tear in all carriages of rapid movement well known to those who use them; and they are equally unfavourable to the shoes of horses, as well as being far from good for their feet; and the noise they produce is a universal source of complaint among those who live in busy cities.

443. A really good material for paving carriage-roads should be hard and durable; in masses so large and heavy as to afford effective reaction to the concussions of loads that move upon it; should present a surface so smooth as to retain or hold no water, and offer so little resistance to wheels passing over it, that no sudden jolts or concussions would be produced, and would, therefore, admit of even rapid motion with little or no noise, and damage to vehicles, and yet should be sufficiently rough to afford good foot hold to horses. The joints should be so close, as neither to permit much water to pass through them, or of subsoil to rise up, which it will have no tendency to do while kept dry; and, above all, the bottom of the material should be so flat as to permit it to rest and bed in a solid manner upon the sole or ground prepared to receive it; and no material that does not pos-

sess some, or the whole of these qualifications, should be allowed to form the pavement of good or much frequented streets.

444. Many expedients have been resorted to in order to obtain these advantages. At one time, large blocks, or rather hollow boxes of cast iron, with roughened surfaces, and, at another, thick plates of the same metal were tried in London, but were objectionable, not only on account of expense, but from their wearing too smooth for horses to travel upon, and producing a disagreeable noise. In New York, square blocks of timber, with the grain running vertically, were tried, and answered perfectly for giving foot-hold, and destroying noise; but they could not be expected to maintain their level surface long, and from the nature of the material, must be subject to rapid and unequal decay, therefore they have not been encouraged. Nothing has yet been discovered that so completely fulfils all the conditions of a good pavement, as square blocks of the hardest granite, which material is alone used in London, and the modern parts of Paris. Upwards of twenty years experience of the use of this stone, in the most crowded and busy streets, has fully tested its value, not only as to duration, but as to cleanliness, comfort in travelling, freedom from dirt and noise, and length of time that intervenes without necessity of repair; so that although this material is brought by sea from Aberdeen in Scotland, a distance not less than six hundred miles, it proves cheaper in the end than any thing else that has been tried. The nature of the stone prevents its ever becoming smooth or polished by use, and hence it presents as good and firm a foot-hold for horses after years of wear, as when it is first laid down; and being uniform in its texture or hardness, it wears equally. The closeness of the joints permits little or no water to penetrate, and it is never affected by frost, and never gets into partial holes. There is a great variety in granites, as will appear in the next chapter, but the kind selected for paving stones, is very hard and fine grained, contains very little mica, and is very similar in colour, texture, and hardness, to the stone brought from the neighbourhood of Boston, and now so extensively used for making jambs, story posts or pilasters, for supporting the fronts of modern stores in New York, Philadelphia, and some of the principal cities. As excellent granite for the purpose of paving is so abundantly found in the northern states, and is convenient for water conveyance, it is confidently hoped that its efficacy will ere long be tried in some of the principal streets, so that the pebble or boulder pavement that now disgraces them, may be gradually banished, as it has been most effectually in London, into alleys, unfrequented lanes, and provincial towns. The ex-

periment may be tried on a small scale, as it was in London in the first instance, by paving a single principal street, and transferring the stones taken up to any newly formed street of less importance in the suburbs, to prevent their loss; and the author, on his own experience, can assert, that it will give satisfaction and spread rapidly. It was so began in London; whenever a piece of boulder pavement required to be taken up for repair, it was relaid in granite, and the old materials removed; and all new streets were laid with granite in the first instance, so that in the course of a few years, a boulder paved street could hardly be found, and it became necessary to export the boulders by water-carriage to any places that would buy them. A few years ago, the corporation of the city of Bristol in England, came to a resolution to repave nearly the whole of that city at once with granite, which was undertaken by an opulent paving contractor, who bought the whole of the boulders, and having delivered a sufficient quantity of granite to the place before the streets were touched, the whole pavement of the city was changed in a very few weeks, by employing a very strong party of able workmen.

445. In working granite quarries, it is impossible to get all the pieces exactly of the same size, and they are therefore assorted at the place, those that are similar being placed together; for it is essential to the perfection of granite paving, that all the stones used in the same street should be similar in dimensions, (at all events as to height,) in order that they may lay evenly upon the smooth surface prepared for them. If this was not the case, the long stones would require holes to be made in the prepared surface to receive them, and the shorter ones must be blocked up by pushing sand or earth beneath them, as must be done with unequal boulders, and this is one cause of their getting so soon out of level. The blocks used in the best streets of London are twelve inches long and eight inches wide on the top surface, and ten inches deep, or high, from top to bottom. The crossings, for foot-passengers, are of the same material, but, generally, rather larger on the face, and about an inch deeper, so that they may protrude a little above the general surface, for the sake of cleanliness. The smaller blocks are reserved for less important streets; but no stone is used, even in these places, that will not measure nine inches from top to bottom. And in addition to their being measured, they are constantly weighed in scales, and such as are too light, are rejected as being of a less dense and hard quality, if their size is equal to the others.

446. The method of laying pavement is very simple. The road must be prepared for receiving it just as another road would be treated for receiving gravel, except that greater care is neces-

sary in having it all of one uniform hardness; because, if the pavement sinks partially, it is more difficult and expensive to repair the failure than in a gravelled road. The surface is levelled, rounded into a crown, and the side gutters formed in earth exactly as it is meant to appear when paved; because, if the stones are all of equal height, the paved surface, when finished, must be parallel to the prepared surface of earth, which is called the *sole.* To insure an equal hardness in the sole, it is always advisable to go over it with a beetle or paving-rammer, before the stones are placed; this will show if any soft places exist, and if they are found they must be filled in with gravel or hoggin, and be rammed until they become hard and level like the rest. Previously to forming and finishing the sole, a row of curb-stones must be let into it, on each side, for the purpose of forming a border or finish to the paving, for keeping the exterior rows of stones in their places, and to make a boundary to the paved foot-paths that are usually placed on each side of the carriage-way. The curb-stones should be large and strong, and rise several inches above the general surface of the paving, to prevent wheel carriages from getting on to the foot-way; and they should, likewise, sink into the sole below the bottom of the paving stones. The sole being prepared and finished, is to be covered evenly and uniformly, by about two inches of fine hoggin, or coarse sand, for the purpose of receiving and bedding the stones, which are now laid on in regular courses, guided by a line strained across the road. In granite paving, the greatest length of the stone is laid across the road, but in boulder paving, the opposite direction generally prevails. The workman, who places the stones, which are brought to him by an assistant, has no other tool than a hammer about a foot long, one end of which has a broad ordinary face, and the other is shaped like a spoon or scraper. With the scraper he draws a small quantity of sand or hoggin, or displaces it, so as to form a bed that will fit or suit the bottom of the stone now placed upon it, and forced into as close contact as possible with the stones previously laid. That done, he uses the other end of the hammer to drive a quantity of the sand round the stone, and into the interstices between one stone and another, and these operations are repeated until the whole road is paved or covered, when the entire surface is rammed, or beaten down by a number of men who are employed for the purpose, and who use heavy rammers or beetles of wood, with which they beat the surface of the stones until no further sinking or subsidence can be produced. The surface is now covered with fine sand, which is raked or moved about, in order that it may fall into the joints or interstices, when the paving is considered as finished. Large granite paving, including the stones, gravel, labour, and all expenses, costs half a guinea, or about two dollars and a half, the square or superficial yard, in London. There appears to be some difference of opinion as to the form to be given to paved streets, the English and American fashion being to form a channel or water-gutter on each side of the road. The French make but one channel, and place it in the middle of the street. The Spanish adopt the same plan, but they have a deep drain, covered with large stones, running along the centre of the street, between which, the water gets into it. In the French form the streets frequently cannot be crossed for water, while two channels divides the stream into two halves, and is certainly preferable.

447. Paving is not only used in the streets of towns, but is frequently resorted to in roads of great traffic; but in such places, its expense precludes the possibility of extending it over the whole width of the road, and it is, therefore, usually confined to the central part, and made eight or nine feet wide for a single track, or sixteen feet wide to admit of carriages passing each other. The two sides of the road are gravelled in the usual manner, and when so formed, they are generally called summer and winter roads. The gravelled part being used in fine and dry weather, and the paved part, when it becomes bad. In forming these roads, a general curve or convexity should be given to the whole road, in order that the water may run from the two sides; and long curb stones should be placed at the two edges of the paved part, to maintain the outer stones in their proper places. These curbstones must not, however, rise as in other cases, either above the paving, or above the road, but should be exactly level with them. If they are at all elevated they produce a concussion whenever a loaded carriage goes on to, or leaves the pavement, which in one case disturbs the paving stones, and in the other, forms hollows in the inner edges of the gravelled part which hold water, and will, in time, undermine the pavement. The paved centre should have a crown rising higher than the general crown of the road, or have a greater convexity, falling into the general curve, at the two lines of curbstones. On good and hard ground, a summer and winter road is often made without having recourse to paving at all; but the middle part of the road is gravelled for bad weather, while the two sides or wings consist merely of the natural soil.

448. No definite rules can be laid down for the measurement of road work, further than that whenever excavation is required for it, it is treated like other work of the same kind, and estimated in cube yards, except when the cutting or forming is very shallow, and then it is measured and paid for by the superficial

yard. Gravelling is also occasionally done by the superficial yard, but it is a very unsatisfactory method, often leading to disputes. The best and most unequivocal manner of making an agreement for the digging and supply of gravel, is by the cube yard or bushel, and the best mode of measuring it, is to have the bodies of the carts made or marked to a certain size, and seeing that they are filled to that mark; or a strong box with handles, but without a top or bottom, is made of an exact cube yard, or half yard dimensions. It stands on the ground and may be filled, and that done, is lifted up to discharge the contents, and removed to another spot to be filled again.

449. In large cities, and their vicinity, the streets and roads are frequently watered in summer, to cool the air and prevent the dust from rising. This is done by hose pipes from the water-works, when towns possess them, or by carts formed for conveying water, which is distributed through many small holes where the water cannot be otherwise conveyed. Road watering contributes much to the comfort of travellers in hot and dry weather, and if done in moderation is not objectionable. It is, however, often carried to excess, and then after what has been said on the importance of keeping roads dry, it is needless to repeat that it is very objectionable and is always disapproved by those who have the charge of superintending and repairing roads.

450. The paving of footpaths at the sides of streets or roads, has little connexion with the business of the Engineer, but as the object of this work is improvement as well as instruction, and the English method of maintaining turnpike roads has been explained at some length, a contrast of the English and American mode of managing such paths, may not be considered wholly irrelevant. In the cities of America, they are usually paved with bricks, a material by no means objectionable, provided the bricks were of uniform goodness, and laid at the same time; but, if some are good and hard, while others are of a worse description, the pavement which has usually an equal degree of wearing from one end of a street to the other, cannot fail to get into holes and inequalities that hold and retain water. Moreover, the rain from the tops of the houses after being conducted down the pipes, is discharged into shallow gutters on the surface of the path, thus rendering it much more wet than it otherwise would be. The central street, or carriage-way, is taken charge of and repaired by the corporation or ward authorities, and is therefore uniformly of the same workmanship and materials, but the footpaths between the front of a house and the curb stones, which ought to be equally well attended to, are left in charge of the householder, who may happen to be poor or rich, particular about

the appearance of his premises, or negligent, consequently under such arrangement uniformity of pavement cannot be expected. If the middle of the street is kept in good order by the public functionaries, why should this privilege be denied to the side walks? If the whole was under the same control and management from house front to house front, as is the case in England, the paths of a whole street would be laid down or be repaired at once, by the same workmen, with uniformity of level, of material, and of appearance; a circumstance that can never be expected while the control is left in the hands of so many individuals. This, and not permitting any of the roof water to be discharged on the paths, and substituting flag stones, or large flat paving stones, each of which covers at least a yard of surface, constitute the only difference between American and London pavements. The latter city has large and deep sewers or brick drains from four to six feet diameter, running through the centre of every street, at a depth of five or six feet below the pavement, and every house has its drain running into this common sewer, by which all slops, refuse water, and offal, from the houses, are carried away at once without being seen, and the inhabitants are prohibited by penalty from discharging any thing on to the surface of the streets. The rain water from roofs is discharged in the same unseen manner. But towns not possessing such sewers, might convey the rain water from the descending pipes into small drains constructed immediately beneath the pavement, and conducting it as far as the curb stones, from which it would be discharged into the carriage-way channels, without annoying foot passengers. The same thing is frequently done by cast-iron pipes of a peculiar construction, which is shown in section at *Fig.* 116, *Plate IV.* The pipe is of three or four inches diameter, according to the quantity of water to be discharged, and should be of a length equal to the breadth of the pavement, to avoid joints. They only differ from other pipes in having a longitudinal slit or opening of about three-fourths of an inch wide, as shown at *a*, running the whole length of the pipe, for cleaning it out, and in having the side of the pipe in which this opening occurs flat, instead of round. When the pipe is used, this flat side is placed upwards, on a level with the pavement, which abuts close against, as shown in the figure, and by this means the pipe is fixed and prevented turning round. The opening is so narrow that no inconvenience arises from its existence, and it is left for the introduction of a small iron scraper of the form shown at *b* in the same figure, which being thin, may be introduced through the slit, and being then turned a quarter round it nearly fits the cavity of the pipe, and removes any deposit, or obstruction to its discharging end without difficulty.

It seldom happens that a road can be continued for any great distance, without the necessity of constructing culverts for the conveyance of water under it, or bridges for passengers and carriages to pass over rivers or streams, and it may therefore be expected that something should be said on these subjects; but as their formation embraces principles of construction not yet treated of, we must defer any observations on these heads until these principles have been explained.

CHAPTER VIII.

ON BUILDING MATERIALS.

Section I.—*Of Stones and Bricks.*

451. Under the general denomination of building materials are comprehended all the various substances made use of in the formation of buildings, machinery, and constructions of every kind; and the object of the present chapter is, to enumerate some of the principal of these, to point out what they are, how they are procured, and converted into such forms as will render them available; and that done, the succeeding chapter will investigate their value and forms, by an examination of their strength and durability, and the purposes to which each are particularly suitable.

452. Many of these materials are produced by nature in a state fit for immediate use, such as the several varieties of stone and timber; while others require operations of art and manufacture to render them available, of which bricks, lime, the metals, and many other things that might be mentioned, are examples. On this account these materials have been called natural and artificial, but this distinction is unnecessary; and in proceeding to describe them we shall, therefore, follow the order of their unity in preference to any other arrangement. In erecting a building the first thing to be attended to is the foundation and external

walls, which are usually of stone or brickwork. The materials that compose them will, therefore, be the first object of attention. The floors and roof require timber, which will be next considered, and as they often require the assistance of iron or other metal to assist their union and promote strength, the metals will close this division of the subject.

453. Mineralogists and geologists enumerate a great variety of stones, but the Builder and Engineer recognise but three great divisions, which are known as *free-stone*, *slab-stone*, and *rubble-stone*, so denominated merely from their hardness and the nature of their natural fracture. Of each of these there are many varieties.

Free-stone is always granular in its texture, although the grains may vary in magnitude, and are even occasionally crystalline in their form. The name of this stone is derived from the freedom with which it may be worked or wrought into any particular form; for all the varieties of this stone have no disposition to break in one direction more than another, and one of its leading characteristics is, that although durable against weather, yet it is so soft that it may be sawed by the proper stone-cutter's saw, or may be worked into any desired form by the chisel and mallet. This variety of stone is, therefore, constantly resorted to for all ornamental purposes, such as carving the capitals of columns, friezes, and mouldings, as well as for the building of stone walls whenever it is necessary that their surfaces should be smooth and handsome.

454. Marble, in all its varieties, ranks as the first or most valuable of all the free-stones, on account of the large masses in which it is formed, its great durability, its not absorbing water, the ease and certainty with which it may be worked even into the finest ornaments, the compactness of its grain and its hardness, which enable it to receive a high and permanent polish, and its not being sensibly affected by heat and cold, or any fluctuations of season. Marble is a carbonate of lime, and when quite pure, is perfectly white, but it is very rarely found without dark-grey streaks, and is often beautifully coloured with various tints throughout its whole substance, when it is called streaked and variegated marble. The very finest pure white marble comes from the island of Paros, and has long been celebrated both by sculptors and poets under the name of Parian marble, being the stone of which the finest Grecian statues were formed. The next in point of quality is the Carrara marble, equally pure and white, but differing in its grain. These varieties of marble are called statuary marble, being used exclusively for carving statues and the most delicate ornaments, and is so high priced that it is

seldom used by the builder except in the most costly chimney pieces or other ornamental works.

455. Alabaster is a white stone, very much resembling statuary marble in appearance, but it is a sulphate instead of a carbonate of lime, and therefore not a marble, besides which, it is so soft that it may be cut by the common hand-saw, or a knife, is very brittle and not durable in the open air, consequently unfit for the builder, and it is only used for articles of internal ornament.

456. Marbles and many other articles in this class of building materials, have no names except such as are derived from the localities where they are found, and this renders them difficult of description and identification, unless the character and appearance of the stone is known. Thus we have Kilkenny marble, from a place of that name in Ireland, which is exactly the reverse of statuary marble, though equally fine in its grain and good in its quality, but it is of one uniform intense black colour, without any variegation.

Lumachella marble, from Italy, is equally black, but is interspersed with veins, shells, and organic remains, which when cut and polished, give it a very handsome appearance.

Florentine marble, from Florence, is reddish-brown, and presents an appearance of the ruins of old castles and towns, and on this account it is sometimes called ruin marble. Some varieties are named after their appearance. Thus dove-coloured marble speaks for itself. Black and gold marble, (used for table tops,) is from Italy, and consists of a fine black ground, with rich brown and yellow veins and spots running through it, which, at a distance, appear like gold. Breccia marble consists of angular fragments of various coloured marbles united together by a calcareous cement, and is often very beautiful. Sienna marble is of a rich buff colour, variegated by differently coloured streaks. That splendid marble, called Verd Antique, or Ancient Green, was much used by the ancients in their ornamental works, and is an elegant assemblage of various green tints, from almost black to a colour of great brilliancy, and is scarce and high priced, when in large slabs. It is called Egyptian marble in this country. It is not, properly speaking, a marble, or at any rate a carbonate of lime, and is hardly entitled to the name of a free-stone, on account of its being very brittle and refractory. But it yields to the saw, so as to be cut into slabs, and with care may be worked into ornamental forms. Its mineralogical name is precious serpentine, and it contains a large proportion of magnesia, iron, and manganese; and, like most of the preceding stones, is only used for internal decoration.

457. The common marbles that come more immediately into the hands of the builder, are the impure or streaked white, and the dove; and these are very abundant in many of the northern states of America, and are very extensively used in all the best buildings, giving them a stability and beauty not to be met with in any other part of the world, Italy alone excepted, which has always been celebrated for the abundance and beauty of its marbles.

458. Next to marble, in point of utility, firmness of grain, and durability, may be ranked the fine grained white sand-stone, which consists of fine siliceous or flinty sand, held together by a peculiar natural cement, that binds the whole into a solid, uniform, compact mass, but still is so small in quantity that it cannot be perceived between the grains, so that the whole stone appears as if formed of fine sand. On account of the scarcity of marble in England, this stone is alone used for all the best buildings, and as it is found most abundantly in the Portland rocks, on the south coast of the island, it is universally known throughout that country under the name of Portland stone. When clean it is very nearly white, will bear fine carving, and it is very strong and durable, not being at all affected by water, frost, or exposure to air. It will not take a polish like marble; but as this stone is hardly ever polished on the exterior of buildings, the one stone can hardly be distinguished from the other, except on close inspection. St. Paul's Cathedral, the Monument, the Royal Palace, and all the fine buildings of London, are built of this stone. A stone very nearly similar in appearance to it, is found in the northern states, and is called North River, or Hudson's river stone; but, as marble is so plentiful in this country, it does not appear to be much used, and the author has had no opportunity of examining its qualities, to ascertain if it is as good as Portland stone.

459. There are other varieties of free-stone, but they are very soft, particularly when *green,* a term applied by workmen to stone fresh from the quarry; for almost all stones either become hard by age and exposure to the atmosphere, or they *slack,* or become friable, and sometimes even drop to powder; and, of course, this last class is wholly unfit for building purposes. A very useful stone, called by mineralogists *ooilite*, from its similarity in appearance to the roe of a fish, makes an extensive formation nearly through the middle of England, beginning in Somersetshire, and taking a north-east direction for about 150 miles. It has a yellowish-white colour, is wholly calcareous and granular, its grains sometimes being as fine as sand, and, at others, hollow and as large as peas, when it is called pea-stone.

They are united by natural calcareous cement, which is quite visible to the naked eye; but the fine grained stone is alone used for building, and the whole city of Bath is built with it, on which account it has, very generally, obtained the name of Bath-stone. When new, it is so soft that it is cut into any required form by a common carpenter's hand-saw, and is also worked by the chisel; notwithstanding which, and its being absorbent, it is not affected by weather, and hardens and preserves its form remarkably well. It is on this account considered valuable, for it may be worked very cheaply, and produces a handsome appearance. It is believed that it does not exist in this country.

460. Another soft stone is used in the ferruginous districts of England, called ferruginous sand-stone. It consists of coarse or sharp silicious sand cemented together by oxide of iron. It has a dark reddish-brown colour, is soft at first, but becomes very hard by exposure to air. It is common in Bedfordshire and the internal counties, and stone bridges, having arches of considerable span, are built with it, and stand well.

461. Soap-stone is another variety of soft stone which exists abundantly in Pennylvania, and may be readily cut to any form: when good, it withstands very violent degrees of heat, and is therefore valuable for building furnaces and fire-places, but it is too soft to be used for other building purposes.

462. One of the hardest, best, and most durable stones for building is *granite,* and its varieties, which is placed last in this list, from a feeling of doubt as to whether it should rank among the free or refractory stones. It is so hard as to bid defiance to the saw, and almost to the chisel, but still it can be worked to any desired form, and to a fair, but not smooth face, and has no tendency to split into laminæ, and for these reasons it may be considered as a free or workable stone. True granite is a compound of quartz, felspar, and mica, not chemically united with each other, but so closely aggregated, that when the grain is fine, it is difficult to distinguish one from the other; but, if coarse, as at Haddam in Connecticut, the three materials appear almost distinct. In this stone the quartz may be said to be imperishable. The felspar is durable, but still gradually decomposes by exposure, and the mica, which is always soft, and of no importance as to the value of the stone, soon gives way and disappears. The kind of stone now so much in demand for supporting store fronts, and of which several buildings have been constructed in the northern cities, though called granite, is not a granite, inasmuch as it is without mica, and often contains little or no quartz, both of which are essential to the formation of the real granite. All the specimens the author has examined, are what mineralo-

gists call *sienite,* a stone consisting of felspar and hornblende, This stone is commonly called Boston granite, but he is informed it comes from quarries at Quincey, to the south of that city, and is very convenient for sea-carriage. It is got out and sold at from forty-five to sixty cents the cubic foot, increasing in value in proportion to its magnitude. It is harder and more difficult to work than real granite, and, in the writer's opinion, it is one of the best stones he has ever met with for building, where strength, neatness, and he believes durability are required. Neatness is here spoken of, because the stone is too hard to be worked into richly carved and florid ornaments; and, as to its duration, little doubt can be entertained, but this point cannot be decidedly known until it has stood the test of exposure to wind and water for at least a century. Its dark colour may be objected to by some; but the northern district produces a great variety of colours, from very dark to almost white, which is the character of the granite from Hollowel in Maine, but the white stones do not appear so compact and good as those of darker hue. The Quincey granite it is believed would make excellent street pavement, and even the small chips might be used with advantage for M'Adam roads.

463. Slab stone, is stone of a decidedly lamellar construction, and appears to have been formed by the successive deposition of layers of hard material, one upon the other. The character of this stone is, that it splits into thin and parallel plates of greater or less thickness, with considerable ease; and in general possesses great tenacity or strength, in the direction of its laminæ, and most varieties admit of being cut transversely by the saw. So far it resembles a free stone, but still it cannot be cut into any desired form, the capital of a column for instance, for it is refractory and brittle except in the direction of its natural joints, and at these it would separate under the vibrations produced by the mallet and chisel, if attempted to be worked, or if worked by great care and patience, the parts would separate at these joints, by exposure to time and weather. For the same reason, if this stone should be used in building, with its natural joints set vertically, the outsides would scale off, and the stone would decay and fall to pieces unless it happened to be supported in the inside of solid work. It must therefore be always used with its joints in a horizontal or nearly horizontal position, if it is subjected to any load or weight, and then it will prove very durable. On this account, such stone is always used for the foundations of high and heavy walls, where it is advantageous on account of its being flat and smooth, and its large dimensions covering a great portion of the ground. It is also very good for

paving the side or foot-paths of streets, or the bottoms of cellars or warehouses, for making the floors or platforms of balconies or verandahs projecting from buildings, for capping or coping walls, or making the treads of stairs, for covering roofs, and many similar purposes. All the varieties of slate rank under this variety of stone, and some of them are very large, strong, and handsome, running to lengths of twenty feet or more, by three feet wide, and from two to six inches thick, so that they are admirably calculated for floors of balconies, which are very common in the fronts of European houses. The Yorkshire paving with which the footways in England are alone paved, is of the same character, but is silicious grit stone, containing alumine, and forming a very hard and tough stone that splits into laminæ of from two to six inches in thickness, and is very difficult to cut or work; it has the property of never wearing to a smooth or polished surface, which is a great advantage in foot pavements. It is found above the surface of the coal seams or veins in the northern part of England, and is transported, squared, and laid down in the streets for twenty-eight cents the superficial foot. Some stones of this description, which were considered a curiosity from their magnitude, were laid down a few years since near St. Pancrass church. They hold the enormous quantity of nine and twelve yards superficial in each stone, without a joint, having a width of three yards, by a length of three and four yards; but when so large, they must be much thicker than ordinary, and are more expensive.

464. The mica slate of this country is the nearest approximation to the same kind of stone, unless, as is most probable, the same variety of stone may be found in the coal regions now so extensively worked.

465. Shingles are unknown in Europe, or at least never made use of for covering buildings; sheet metal, and slates or tiles, being the only materials used. Slating is the most common covering for the best buildings, on account of its durability, its lightness, its appearance, and its effectually resisting the action both of fire and of water from without; and these slates are the natural slate-stone split into laminæ, varying from an eighth to half an inch in thickness, according to the size of the slate made use of, and from which they derive their names.

466. A very variable compound stone called *gneiss*, which is a variety of granite, generally containing hornblende, in addition to the usual materials, assumes the lamellar formation, and may be divided into plates fit for paving or placing under foundations, but is not so regular and even as the varieties before noticed.

467. Rubble or rough-stone, comprehends all such stones as,

from their hardnesss, cannot be sawed, and from their brittleness or irregularity of grain, combined with hardness, resist the chisel and all attempts to reduce them to regular forms, except by grinding and the lapidary's art, which is too slow and expensive to be applied to building purposes. Flint stones, the trap rock formations, compact limestone, buhr-stone, of which French mill-stones are made, and porphyry, which is a variegated mixture of felspar and quartz, are of this description, notwithstanding the latter can be worked with great labour and expense, for the ancients formed columns and other ornaments of it, to which they gave a high polish. At present, such stones are only used for constructing rough or rubble work under foundations, or for filling in walls of more than ordinary thickness, and backing or strengthening them in places that are concealed from view.

468. Large blocks of stone are only to be procured in rocky places, and the openings or excavations made for obtaining them are called quarries. When once a quarry has been opened and is found capable of yielding a large quantity of stone, the qualities of which have been tested by long use and experience, it becomes a very valuable property, of which the Quincey works, near Boston, the marble works at East Chester, the granite quarries at Aberdeen, and those of slate in Wales and Westmoreland afford ample proof. From the weight of the material produced, a quarry is unworthy of prosecution unless it has the advantage of water conveyance, and of a rail-road for transporting the material to the water's edge, and even with every advantage it requires considerable forethought and skill to work it with continued advantage. The Engineer may be so placed that he cannot have the advantage of the public quarries, and may be obliged to raise his own stone, in doing which the following observations may be useful. A quarry is seldom a deep excavation like a mine, but consists of working a way into the side of a hill. One of the first things to attend to, therefore, is not to begin the work too low, so as to get the quarry into a hole, from whence it may be very troublesome, dangerous, and expensive to raise large masses of stone, but a road leading into it should be formed and maintained with as gentle a slope as possible, in order that horses may draw the stones up as produced. It is better in the first instance, to so arrange as to deliver the first stones obtained, down hill, instead of having to raise them. But it must be kept in mind, that the elevated stone, and particularly such as outcrops and is visible; and has been exposed to the air, perhaps for centuries, is never so good and sound as that which is hidden or has been protected; and pressure also seems to improve the formation of stone, for that which is deeply situated in

the quarry is generally more hard, compact, durable, and better in every respect than that found near the surface, which is tender and friable. On this account it may be necessary to work downwards, but this should be done gradually and with caution. The first operation should be to remove the incumbent soil (which is called *uncallowing*) to such an extent as will expose the extent of the masses of stone fairly to view. They are called masses, because although the whole rock may seem to be but one mass of stone, yet on closer inspection it will be found, in almost every case subdivided by natural joints and fissures, too small, perhaps, even for the introduction of a common nail, but in which the stone has little or no natural adhesion; and consequently, at such places one block will readily part from another, without fear of breaking either of them, if the operation is conducted with due skill and care. The horizontal, or nearly horizontal joints or fissures, will be seen without difficulty from the front, and it seldom happens that they are more than from one to four feet asunder, or one below the other. Vertical fissures do not always exist, but if they do, they will be just as obvious as the others. Having found these, the top of the stone must be searched (first moving all that is above it) for the fissure in a nearly vertical position that corresponds with the front, and should this be found, the entire block of stone that can be obtained in one piece will be seen. The two end blocks that are contiguous to it must now be examined in the same way, in order to determine which of the three blocks shall be sacrificed: for the greatest difficulty is to get out the first block, on account of its being tightly wedged or jammed in by the end ones. One or other must, therefore, be broken, either by a short and heavy miner's pick-axe, or by blasting with gunpowder, or by gads and the hammer; the gad being a thick wedge of hard steel that is held in its proper position, about four or six inches from the fissure, by the two hands of one workman, while it is powerfully struck upon with a sledge-hammer by another, until a sufficient quantity of stone is cut away, to permit the stone that is required, to be shifted or moved in a sufficient degree by small wedges driven behind it, under it and on the undisturbed side of it, to cause it to become detached from its natural bed, when it will be ready for removal: and this, it might be supposed, would be effected by the application of strong iron crow-bars or levers to it in the first instance, so as to raise it sufficiently to get hard wooden rollers under it, by which it might be transferred to a platform, inclined plane, or truck* prepared to receive it, and such accordingly is

* A truck is a more than ordinary strong four-wheel carriage, to run on rail or common roads. It has a strong platform but no sides, and is used for conveying very heavy single stones or masses of cast iron.

the method adopted for the removal of all large stones that come up with broken or irregular sides and edges, and which will, therefore, require to be *scabbled* or rough dressed by a stone-mason, before they can be delivered or used. But as the value of all large and fine stone is much enhanced by its magnitude, by having no cracks or flaws in it, and by having its faces as flat as possible, and its angles sharp or unbroken, so that the mason in working it need not cut much to waste, the introduction of wedges or levers of sufficient strength to raise its weight, could not fail to destroy its figure by breaking away the edges, and it is, therefore, found more advantageous to lift it from above, than to raise it from below, or at any rate, to have both forces in operation at the same time, so as to cause the lifting action to diminish the weight. This is effected by a very ingenious device well known to every mason under the name of a *Lewis*. If a stone is not lifted in the quarry by a lewis, it is sure to be so treated by the mason in setting it in its place when worked and finished, since this is almost the only way in which a heavy stone could be raised, lowered, and moved about with precision in any direction, without fear of injury to its sharp edges and angles.

469. The lewis consists of three pieces of strong iron, formed and held together by a shakle and screw bolt, as shown at *Fig.* 177, *Plate IV.*, which is a front view of the instrument when put together. In the opposite direction the sides are parallel to each other, or the pieces are of the same thickness throughout, which may be from one and a half to three inches, or more, according to the weight of the stone to be lifted. In front view, the two pieces *c d*, *c d*, are made angular, or to spread out so as to be at least twice as thick at the bottom *d d* as they are at *c*. These thicknesses may be one inch and two inches, and the pieces are both alike. The middle piece is parallel, or of the same size from top to bottom, and may be two inches thick; then, according to the above dimensions, when the three pieces are put together, as in the figure, the distance across from *c* to *c* would be four inches, and from *d* to *d* six inches; but on taking out the screw-pin, the central piece *e* may be withdrawn, and the two outside pieces brought close together, when the distance from *d* to *d* will be reduced to four inches; so that if a dovetailed cavity is sunk in the middle of the upper side of a large block of stone, four inches wide at the top and spreading to six inches at the bottom, and deep enough to take in the whole lewis, which may be from four to eight inches long, the two pieces *c d* may be separately introduced into that hole; and then, on putting the middle piece between them, with the bolt and shakle attached as

in the figure, the instrument will occupy the whole cavity, and no force can withdraw it from the stone without tearing away the upper part of the dovetail. The lewis, therefore, becomes a strong handle, by which a stone may be lifted up perpendicularly by a force applied above it. That force is produced by a pair of blocks and fall, or system of pullies, the end of the rope to which the power is applied being connected with the cylinder of a portable winding machine called a crab, being a series of cast iron cog-wheels and pinions, arranged in a proper frame for gaining mechanical power, and much used in quarries, and the construction of heavy masonry. The upper block requires to be attached to a crane or support of some kind, for sustaining the load, and the expedient resorted to in quarries is the same as that constantly adopted in ships for raising heavy goods. It is merely a boom or strong beam of timber, fixed as nearly perpendicular as possible, with its upper end and block over the stone, and its lower extremity so secured as to be incapable of slipping. The crab is placed near the foot of the pole, in order to make the draught of the rope as nearly coincident as possible with the direction of the pole, the top of which is sustained in the required position, or may be moved a short distance from it by three strong ropes called *guy ropes* or guides, meeting in opposite directions and terminating below in blocks and falls, firmly attached to the ground, trees, or neighbouring rocks, so that by tightening one and slacking the other at the same time, the position of the top of the pole may be shifted for taking up a stone in one place, and lowering it down in another, or on to a truck for conveyance. If the stone is very heavy it will be safer to use two poles united together at their tops like the letter A. By giving them considerable inclination while the stone is taking up from its bed, and then making them stand more erect by hauling in the guy ropes, a stone may be lowered on to a truck between the two poles.

470. When the natural vertical fissures before spoken of do not occur in blocks of stone, or whenever it may be desirable to raise smaller blocks than they would produce, fissures or cracks must be produced artificially, and this is usually done by drilling a line of holes into the stone at regular short intervals, in the straight lined direction in which the separation is required; a row of conical steel points, rather larger than the holes, are then set one into each hole, and a number of men strike with hammers simultaneously upon them, which, if done equably, never fails to produce a separation of the piece of stone in the direction required. If the stone is found to cleave easily, dry wooden pegs, previously cut, larger than the holes and driven in

the same way, will answer the purpose, and is most frequently resorted to for obtaining blocks both of granite and marble in this country. Should the wooden pegs fail, a bank or wall of clay must be built around them capable of holding water, and on filling this, so that the water can sink into the pegs, they will swell with such force as never fails to separate the mass, provided hard and perfectly dry wood has been used.

471. The drilling of hard stone cannot be effected by ordinary revolving drills. The drill made use of is a steel cold chisel, eighteen inches or two feet long, its breadth being equal to the diameter of the hole to be produced, and its edge being double bevelled, and not too acute or sharp. It is held by a workman over the place where the hole is to be made, and struck with a hammer in the other hand, or by a separate man when the stone is very hard, and the hole large. Between each blow of the hammer the chisel (called a drill) is turned partly round, and is kept revolving or moving backwards and forwards, so that two cuts or blows never come in the same direction, but make a series of indentations like a star *, and the powdered stone falling to the bottom, is taken out by a kind of screw formed spoon like a screw auger. In this manner holes are made more speedily than might be expected, and they are usually paid for by the inch, according to their size and depth.

472. The process of blasting rocks by gunpowder requires the same holes to be drilled, but for this purpose they must be deeper and larger than for splitting rocks. From half an inch to three-quarters diameter, and six or eight inches deep will, generally, be sufficient for the splitting holes, while eighteen inches to two feet is a common depth for those used in blasting, and they should not be less than an inch in diameter. The gunpowder, for convenience of introducing it, is sewed in a linen or flannel bag, or cartridge, having a train that is confined in a straw or small reed; or, if the hole is wet, the cartridge is made of tin, with a fine tin tube to contain the train. Having introduced the powder, dry sand is put upon it, and rammed down, when the remainder of the hole is filled with sand a little moistened. This is called, tamping a hole. Some wild-fire, or powder kneaded with water, or slow match, made of paper, or old linen, soaked in saturated solution of nitre, is made to communicate with the train, and this must be so arranged as to give the person firing it, time to retreat before the powder explodes, as fragments of the stone are frequently dispersed with such violence as to be very dangerous. The most hazardous thing in *shooting a hole*, as miners call this operation, is when, by improper fixing of the match, the whole charge explodes the instant the fire touches it, or where it hangs

fire, or is so long before it explodes that the workman imagines the match has been extinguished; and, perhaps, goes to inspect it at the very time when it explodes. From both these causes very serious accidents have occurred, and no one ought to approach a hole after the match has been lighted, until such a period has transpired as must render an explosion impossible. Dr. Hare, of Philadelphia, has been engaged on some experiments on the means of producing ignition of the gunpowder by voltaic electricity, conducted through long wires, without the intervention of a slow match, so that the ignition shall take place instantly, or not at all; and such a process, respecting the efficacy of which there can be no doubt, will confer a great obligation on such as are engaged in this business.

473. As marble and granite have always to be transported, unless used upon the spot where they are produced, it may be useful to remark, that fourteen cubic feet are considered as equal to a ton weight, on which account a considerable loss frequently accrues to the purchaser; for the cubic quantities are taken by weight, to determine the freight, instead of by measurement; and as the above proportion is not a true one, the cubic feet rarely measure to what is marked upon the stone, or what they are sold for, particularly when it is hard, good, and compact. But lighter and more porous stone will, on the contrary, yield more than fourteen feet to the ton.

474. Next in order to natural stone comes brick, which is an artificial or manufactured kind of stone, most extensively used in vast building operations. The brick offers some advantage over stone, arising chiefly from the expedition and ease with which the work may be conducted. No stone can be obtained from the quarry of a shape fit for use in close jointed work, without the tedious process of sawing or cutting it to a fair face; and as stones are large and heavy, there is great loss of time in transporting them, and raising them to their positions in the wall. Stone cannot always be procured, owing to local circumstances, but there are few positions in which brick-earth cannot be obtained within a few miles; and bricks are very portable, are square and ready formed, and if good, and used with good mortar, will produce a better and more durable wall than could be produced by small blocks of hard stone. The stability of a stone wall, with straight joints, depends more on the weight and magnitude of the stones than on the adhesion of the mortar. For as the harder stones are not absorbent, the mortar will not adhere to their surfaces and produce union; while, from bricks being of an opposite character, the brick and mortar, after a short time, become one, and their adhesion is so strong that it is difficult to separate them.

475. Bricks have, accordingly, been used by all nations from the earliest antiquity. The bricks of Babylon, many of which bear inscriptions, are known at the present day, and many of the admired relics of the ancients, still extant in ruins, exhibit the perfection to which the art of brickmaking had arrived in these early days. Some of the structures of Egypt and Persia, the walls of Athens, the Pantheon and Temple of Peace, at Rome, and many other buildings are constructed of brick. What is surprising, however, is that many of these bricks, which have stood the test of about 2000 years, do not appear to have been burnt or submitted to the action of fire, to produce their hardness and durability, which can alone be attributed to the extreme dryness and heat of the climate in which they were exposed; for these bricks, on being soaked in water, crumble to pieces, and disclose straws, reeds, and other vegetable matter, from the existence of which it is inferred they have never been submitted to any greater heat than that of the sun. At a later period all the bricks of the ancients were burnt, and it is these that chiefly remain at the present day.

476. A brick is nothing more than a mass of argillaceous earth or clay, properly tempered with water and softened, so that it can be pressed into a mould to give it form, when it is dried in the sun, and afterwards submitted to such a heat as shall bake or burn it into a hard substance. This method of forming bricks puts a limit to their magnitude; for, as the material of the brick is a bad conductor of heat, so, if they were made very large, the heat applied externally would never reach the inside so as to bake it properly, without vitrifying and destroying the outside; hence bricks must be confined to such magnitudes as will admit of their being well and equably burnt throughout. In England, the size of bricks is determined by law, and no man can make bricks larger or smaller than the prescribed dimensions. This law is, by many, considered a hardship, but it was established for a twofold purpose, first, because all bricks made there are subject to an excise duty or tax of about a dollar a thousand, which tax could not be equalized, unless a size was fixed for the brick; and secondly, it enables a person building, to know the exact quantity of work he can erect for a certain sum of money, and prevents brickmakers taking advantage by sending out small bricks, or making them so large that their insides may not be hard and well burnt, a circumstance that would produce unsound work, deficient in durability.

477. This law, as far as regards the determination of the size of the brick, the writer is now convinced is good. No regulation appears to exist in the United States, beyond the custom of

the place and the caprice of the maker. One man makes a large and full brick, and gets a good price for it, because fewer bricks will do a given quantity of work. Another sells cheaper, but he manufactures a smaller article; and it frequently happens that when a builder cannot get his whole supply from one maker, he is compelled to go to another, when probably his size will not work in with the first, unless a previous bargain has been made as to dimensions. The writer having occasion to use a large quantity of bricks, and having consumed the first quantity delivered, had occasion to order many thousands more from a stranger, for which a written contract was made, and on their delivery he found each new brick an inch and a half shorter than those previously used. On remonstrating, he was told that no dimensions had been specified in the contract; that those delivered were of the usual size, in that part of the country, and no redress could be had; notwithstanding it took nearly one-fourth more bricks to do the same quantity of work, as would have been necessary had they been of the proper, or usual standard size, which in London is eight and three-quarter inches long, four and three-eighths wide, and three and three-quarter inches thick; the intention of these dimensions being, that each brick laid end to end, or every two bricks side to side, with the necessary quantity of mortar between them, shall make exactly nine inches of work; or that four bricks laid one on another, will make a foot perpendicular, or twelve courses to the yard. In Philadelphia, the general run of bricks is eight and a half inches long, and fourteen courses with mortar to the yard perpendicular, thus consuming more bricks and mortar than the English gauge, for the same quantity of work. The young Engineer must, therefore, not only attend to the quality, but to the size of bricks, whenever he makes contracts for their purchase.

478. Although clay has been named as the proper material for making bricks, yet every clay will not answer equally well. Pure clay is quite white, and in burning does not change its colour, as may be noticed in tobacco pipes, which are made from it. The brown colour of common clay is usually derived from oxide of iron, and this causes the brick to assume a red colour when burnt; but as red bricks are not approved or used for outside work in London, where more bricks are made and consumed than in any other part of the world, the brickmakers have contrived means of changing their colour in burning to a pale buff, very much resembling the colour of Bath-stone, and which gives buildings a much handsomer appearance, and closer resemblance to stone, than would be expected. The mode of colouring is kept as secret as possible, among the manufacturers, but it is partly pro-

duced by mixing powdered chalk with the clay, and is, probably, greatly dependant upon the firing of the kiln and the fuel used, since many bricks that exhibit a beautiful and perfect buff hue on their outsides, are red and dark within, if broken.

479. A stiff, tenacious, plastic clay is unfit for making bricks, as they generally split and fall to pieces in burning. Brickmakers call such clay *strong earth,* and they prefer what they term a *mild earth;* that is, one of less tenacity, and having more the character of loam. When the loamy soil is not found naturally, it is imitated by adding sand in considerable quantity to earth that is too strong. The London brickmakers, in addition to sand, constantly add a considerable quantity of *breeze* to their clay, and they assert that it is this material that gives the peculiar character of colour, hardness, and durability to London bricks. This is somewhat corroborated by the country bricks, made without breeze, being red and of a very different character.

480. To explain the term breeze, which seems to perform so important a part, it becomes necessary to say that throughout the immense metropolis London, no fuel is used in any of the houses but bituminous or blazing coal, very similar to that known in this country as the coal from Richmond in Virginia. Every house has what is called a dust-hole, in some external part of the premises, into which the ashes and refuse of these fires are put, and the same place is also a depository for any other offal of the house, which must not be thrown into the streets. The parish authorities contract with persons having horses and carts to clear these dust-holes about once a week or oftener, without any expense or trouble to the housekeeper, and the stuff collected is all carried to certain fixed depositories on the outskirts of the town. Here hundreds of men, women, and children, are daily employed in assorting and looking over the mountains of discarded treasure thus brought in, and now become the property of the contractor; apparently worthless in the eyes of the public, but not so in fact, for most of the men who have undertaken this business, in conjunction with that of scavenger or street-cleaner, have in almost every instance amassed immense fortunes. The heaps of soil are carefully raked over, and every atom of them passed through several gradations of sifting, with sieves of various fineness. Rags, old iron, metal, bones, and such things as are usually thrown away, mixed with the refuse fuel, form the aggregate of the mass, and all these things are separated and placed in separate heaps. Here the paper-maker gets supplied with much common rag for packing-paper. The old iron is returned to the forge to be manufactured into scrap iron. The hartshorn and ivory black manufacturer gets supplied with bone,

much new and unconsumed coal and cinders are obtained, and this furnishes the only fuel with which all the bricks of London are burnt, while the small and almost incombustible matter, consisting of very small cinders, and new coal, fire-dust, decayed animal matter, and whatever else may be mixed in the mass is *breeze*. This breeze is mixed with the clay, is in a great measure combustible when exposed to the high heat required to burn bricks, and it is said to assist the brick in getting red hot throughout its substance, and otherwise to improve it very materially.

481. A great deal of care and trouble is necessary in preparing the earth for making good bricks, in order to reduce it to one uniform texture, and to deprive it as much as possible of all stones that might destroy the form of the brick, by breaking in the fire, or becoming vitrified. The bricks of Philadelphia are in general so good, that we will describe the process used there for making them, and point out where it differs from that pursued near London. The clay in both places is invariably dug in the autumn, and during the winter before frost sets in. The ground is divided out into square allotments called spits, four feet wide and sixteen feet long, which surface when dug a foot deep, furnishes the right quantity of earth for one thousand bricks, and of course each foot in depth is equivalent to the same quantity. This earth is shifted by barrows to an adjoining piece of ground previously levelled to receive it, and sunk a little under the general surface to prevent water running off. On this it is worked, if in a fit state to make bricks, if not, sand is added in sufficient quantity, according to the judgment of the workman, to make it sufficiently short or mild, and at this period the London brickmaker adds his breeze, which, answering the purpose of sand, it is added in less quantity. It is then cut, slashed, and worked with the spade, adding water to it to soften it; and the quantity of two spits being added together in one heap, sufficient earth to make two thousand bricks is exposed to the frost in each heap, and the more severe the frost is, the better incorporation will take place. Nothing more can be done with it until spring, when the warm weather thaws the heaps, and if the frosting has been effectual no lumps will remain, but the whole will be converted into a uniformly soft and yielding mass. If too wet, the heaps are opened and spread to dry, or if too dry, more water is added, before the last working with the tool called tempering, in order to render the whole mass uniformly smooth; it is then pressed and patted down, and covered with boards, cloths, or bushes, to prevent the injurious effects of the sun and air, and is now ready for the moulder. The moulder works at a table or bench in the open air, covered by a shed roof only, to protect

him from sun and rain, and the clay is brought to him in a barrow from the tempered heap, and is placed by the boy who brings it on the left hand end of his table; another boy supplies him with dry silicious sand previously dug or provided, and placed on the right hand end of the table, and a third boy stands in front to remove the bricks as fast as they are formed. The mould is formed of mahogany or other hard wood, bound with iron for strength, and cased with iron plate on its top and bottom, or is sometimes lined with thin iron throughout; moulds have been formed wholly of iron, but they are too heavy for expeditious work, and cold to handle in early spring. The mould is four sides of a box without either top or bottom, as the moulding table forms the bottom, and must be very smooth, on which account, and to prevent wear, it may be covered with sheet-iron. The moulder first covers his table thinly with sand, and cutting off a sufficient quantity of the prepared clay with his two hands, finger-end to finger-end, to form about a brick and a quarter, he kneads it on the table, by pressing on it with the palms of the hands, first drawing it towards him and then pushing it from him, and patting the ends to bring it to a form similar to the mould into which it is to be introduced, (the mould having been previously sanded,) and presses it down with force, so as to fill up all the corners. The superfluous earth is now cut off by running a steel tool like a large thick knife, called a plane, along the top of the mould, when the top of the brick is sanded, and a thin board, called a turning board, as wide as the mould, and three inches longer than it is, is laid over it, and the whole being inverted, the mould may be raised carefully by the two hands, and the soft brick will be left on the turning-board, in which state it is taken away. Should any clay remain about the mould, it is now cleaned out and sanded, to prepare it for the next brick. It should here be observed, that the mould must be full half an inch or more longer, and a quarter inch wider and higher, than the brick intended to be produced, as all clay will sink thus much in drying, and sometimes more.

482. In order to receive the bricks when moulded, a high and open piece of ground is provided called the floor, and this is formed into what are called *hacks*. The hacks are perfectly level projections of earth about two feet wide, and rising six or eight inches above the surface of the floor, and are fifty yards or more in length, for receiving the bricks to be dried, and they should run in a north and south direction, in order that both sides of the pile may receive its due proportion of sun-shine, and they must be about four feet apart to allow wheeling with a barrow between them. The boy that receives the bricks from the

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moulder, holds them by the ends of the turning-board and places them on a barrow constructed for the purpose, with a high raised stage of frame-work, that is level when the barrow is running, and holds twenty bricks. It must run upon planks to prevent concussion to the yet tender brick. He carries them to a hack and lays them regularly upon it, leaving the turning boards under them until the row is nearly filled, and this allows time for the bricks to dry and become a little hard on the surface, which they will do in half an hour in fine weather. Another who is in attendance at the hacks, takes them up and moves them to the next adjoining hack, previously covered with sand raked smooth, and in doing so places them on their edges by inclining the turning-board with one hand, and applying the other to the brick, while he slides away the boards to be returned in the empty barrow to the moulder. The soft bricks are thus disposed in an angular manner like a worm-fence, but in no case more than two inches asunder in the widest part, and not touching anywhere. The row or hack being finished, the bricks are sanded on their tops, and if the hack is long, the bricks at the end first put down, will be dry enough to permit a second tier to be laid upon them, and so on until eight tiers or layers are so disposed, which is the greatest number that can be placed without danger of crushing or spoiling the shape of the lower bricks, and this number should not be attempted unless the hacks are long, and the weather fine and dry. The object of placing the bricks in this open manner, is to permit the air to blow through and dry them as effectually as possible, but they must not dry too rapidly, as that will cause them to crack. Should the sun be too powerful, the hack will require shelter, which is obtained by constructing a number of light frames of a kind of basket work of twigs and straw interwoven. They are six feet long, as high as the hacks, and made as light as possible. These straw hurdles are so useful, no brick-maker should be without them; they afford shelter against both sun, rain, and frost, (which are the greatest enemies of the brick-maker in this stage of the business,) or they are set up in angular positions to catch and direct the wind into the hacks, if the bricks dry too slowly. Should violent rains come on which might destroy all the work, the top of the hacks must be thatched, by placing long wheat or rye straw transversely across their tops, keeping it from blowing away by planks laid lengthwise on them. The hacks are raised above the natural soil, for the purpose of keeping the lower tier of bricks out of the wet, should rain occur.

483. In about a week the bricks will be sufficiently dry for turning, which is done by moving them from the hack on which

they were first dried, to the adjacent one left empty to receive them. They are now disposed as before upon their edges, but are put parallel to each other, about one inch apart, and the side that was before downwards is turned upwards. In the second tier or course, each brick is placed over the opening between the two below, and so of all courses that succeed until the eight tiers are again completed. In this manner they still expose considerable surface to the air, and as the bricks have now become tolerably dry, and do not require sun, the last drying hacks are sometimes covered for their whole extent with a slight thatched roof, to protect them from rain; or if the kiln is not ready, they are sometimes moved into a building for safety. The hacks sometimes require turning three or four times before the bricks are sufficiently dry for the kiln, and the drying usually takes from three to five weeks, depending on the state of the weather.

Bricks are always made by piece work near London, where a skilful moulder, having all things in good order around him, will mould and hack from five to seven thousand in a day of fourteen hours work, or about five hundred bricks per hour; but to accomplish this he will require six hands to wait on him, all of which are children. They supply him with the tempered clay and sand, and water to dip his tools into, remove the bricks as fast as they are moulded, and return the turning boards.

484. When small quanties of brick are required in a country where they cannot be obtained, or for particular jobs, the clay may be tempered and mixed by placing it on a hard bottom, and working it by a shovel or spade with water, and trampling it in the manner already described for puddling (391,) instead of waiting for a frost to break it down. In this case more water must be added than is fit for tempering brick earth, but it can be got rid of afterwards by draining it away, or exposing the earth to dry; when the moulding and drying must be conducted as above described, but on a smaller scale.

485. In the vicinity of London, where the demand for bricks is enormously great, the large brickmakers adopt a different method to that above described for tempering and preparing their clay, but there is no variation in the manner of moulding and drying upon the hacks. The clay is dug in autumn and frosted as usual; but instead of being piled in ridges or small heaps, the whole is wheeled into one immense pile, as frosting the interior is of less importance when machinery is used. At the breaking up of the frost the clay is carried in navigators' barrows to a mill called a pug-mill, where it is worked by horse power, and incorporated with the necessary quantity of sand, chalk, or other material, and water, which is often pumped up

and delivered into the mill, by the same power, in such quantity as will reduce the whole earth to so thin a state that it is just capable of running from an opening made in the bottom of the mill for its discharge. It is received upon a wire sieve or strainer, that stops all stones or foreign ingredients, if their size would prove prejudicial to the bricks about to be made. Two capacious ponds or reservoirs, about three or four feet deep, are formed for receiving this diluted earth, and they are so placed in respect to the mill, that its produce can be discharged into either at pleasure, by means of wooden shoots or spouts. The pugged stuff is conducted into one reservoir until it is quite filled, when it is turned into the other; and while the second is filling, the earthy matter subsides in the first, leaving nothing but clear water at the surface, and this is carefully drawn off by withdrawing pegs, that are placed very close, one below the other, from holes in a thick plank let into the upper part of the reservoir. In this way the water is drained off and runs to waste, leaving a finely divided and most equable mud in the reservoir, which becomes of such consistence by draining, that it can be taken up by shovels, put into barrows, and be taken away. The discharge of the mill is then again turned into the first reservoir, which fills, while a similar draining and removal of the contents of the second is taking place. In this manner the clay is more minutely divided and broken up, or tempered, than could possibly be done by the former process of hand labour, and in its soft state, when first moved, is in excellent condition for receiving finely sifted breeze, or any thing else that may be necessary for improving the quality or colour of the brick. After this, all that is necessary for rendering the earth fit for the moulder, is a few days exposure to the air, to make it sufficiently dry for his use; and then the process proceeds exactly as before described, unless indeed a patent moulding machine should be employed, instead of a hand moulder, for forming the bricks, and then the compost is delivered to the machine, of which there are several varieties, said to produce more compact bricks than hand moulding, because greater pressure is exerted to compress the clay into the mould than can be exerted by a man working the whole day through.

486. The form of the *pug-mill*, and its connexion with a pump for supplying it with water, is shown at *Fig.* 118, *Plate IV*. It consists of a very strong kind of conical tub a, formed of oak staves of two inches in thickness, and bound together by strong iron hoops, like a barrel. Its dimensions must depend on the quantity of work to be performed, but it is usually four feet diameter at the bottom, and three feet six at the top, having

a height of about six feet. It has no bottom, that being supplied by the level ground into which it is sunk a little, and the earth may be banked up round it to render it more steady. It should stand on a platform of clay or earth impervious to water, prepared for it. This barrel or external case is to hold the clay, and expose it to the action of the revolving rakes or agitators, seen in *Fig.* 119, (which is a sectional and internal view of a similar mill on a larger scale,) in which *b* is a vertical square iron shaft, the bottom of which ends in a pivot that works in the cast-iron box or step *c*, driven into the ground, or what is better, attached to a horizontal beam of wood let into the ground; this shaft carries several horizontal arms of wood or iron *d d*, and others in a cross or right angled direction as at *e e*, all of which are equipped with a number of iron teeth like those of a harrow, and about the same length and size. These teeth all incline or point forwards, or in the direction the shaft is moving in, in order that they may have a tendency to raise or lift up the clay, which by its weight falls through them towards the bottom of the tub; and thus by the two actions, the lumps are broken and mixed with the water, and the clay is more effectually and speedily broken, and reduced to a uniform mass, than it could be by hand labour. An inclining flat blade or scraper, the length of which is very nearly equal to the radius of the bottom of the tub, is fixed at *f*, for the purpose of scraping the bottom, and keeping it free from adhesion of the clay, which might otherwise block up the orifice through which the pugged clay is to be discharged. *Fig.* 118 shows the arrangement for fixing and giving motion to the mill. A long beam of timber *g* is supported upon two posts firmly let into the ground, and properly braced, to make the whole frame stiff and strong. The upper end of the upright raking shaft *b* is confined in the cast-iron box or bearing *h*, so that it can revolve freely. A wooden arm *i* is keyed on to the upright shaft, close above the tub, and to the yoke at the opposite end of this the horse is attached, and walks round the tub in a track that should not exceed sixteen feet in diameter, or the motion will be too slow. If the mill is large, and the clay stiff, it may be necessary to have a double arm *i*, and to employ two horses on opposite sides, but this will not be required if the mill has a good supply of water. The water is often pumped into the mill by a hand-pump fixed in a reservoir that is kept full, or may be supplied by the horse's motion, if a crank *k* is fixed on the top of the vertical shaft, and connected by a rod *m* to the bent lever *l*, which works the pump *p*, the water of which is conveyed by the shoot or trough *n n* into the mill. This trough should have a hole in its bottom to be stopped with clay, in order that if the pump delivers too much water, a part of it may be stopped and made to run to waste. Planks are laid from the heap of clay to the top of the frame-work *g*, and *q* is a hopper by which the barrows of clay are discharged into the mill, in which it is retained until sufficiently worked; and this is regulated by the sliding door *r*, by the opening or partial closing of which, the pugged clay may be drawn off as slowly or rapidly as required. The contents are discharged into a short drain *s*, passing under the horse-track, and this delivers it into a box or hopper containing a wire-sieve for stopping stones, or any thing too large to be mixed with the brick soil. This sieve is placed at the end of the moveable shoot that conveys the stuff into one or other of the two reservoirs at pleasure, as before mentioned.

487. All that now remains to be done, is the burning of the bricks, which is an operation of great nicety, because, if not burnt enough they will be soft and worthless, and, if over done, they vitrify, loose their shape, and often run together so as to be inseparable and useless. Accordingly, various methods have been adopted for producing the due degree of firing as it is called. In general, bricks are burnt, both in this country and in England, in a kind of building constructed for the purpose, and called a brick-kiln; but in London, the burning constantly takes place in the open air, the bricks being made up into immense quadrangular piles, consisting of from two to five hundred thousand bricks in each. The built kiln is thought by many to produce the best bricks, or at all events, a larger proportion of good bricks out of any given quantity, and must certainly consume less fuel, but as they are never adopted in the immense brick manufactories of London, where no pains or expense for conducting the concerns in the best and most advantageous manner is spared, this is evidence that there must be some objections to them, for if they possessed real advantages, there can be no doubt but they would be adopted.

488. A brick-kiln, as usually constructed, is formed of bricks built into a square form like a house, with very thick side walls, and a wide door-way at each end, for taking in and carrying out the bricks; but these doors are built up with soft bricks laid in clay, while the kiln is burning, and a temporary roofing of any light material is generally placed over the kiln to protect the raw bricks from rain while setting, and so made that it may be removed after the kiln is fired. The English kilns are generally thirteen feet long, ten feet wide, and twelve feet high, which size contains and burns 20,000 bricks at once. Wood is the usual fuel used in these kilns, and they are frequently built with partitions, for containing the fuel and for supporting the bricks,

in the form of arches, as will be presently described. A brick-kiln has no flue or chimney, as its chief purpose is to direct the heat of the fire through the body of bricks piled above it. To effect this they must be placed in a particular form with great care, and this operation is called setting the kiln, and is performed by one or two men who understand the business, and to whom the raw bricks are delivered in barrows. The form of the setting is pretty nearly the same in the country kilns, or London clamps, except that in the latter the arches are much smaller, because wood is only used for kindling and not for burning.

The bottom of the kiln is laid in regular rows, of two or three bricks wide, with an interval of two bricks between each, and these rows are so many walls extending lengthwise of the kiln, and running quite through it; they are built at least six or eight courses high, so as to give the kiln the appearance shown in *Fig.* 120, which is an end view of it. And this is permanent work, or work that remains in the kilns that have fire-places built in their floors, or has to be formed every time the kiln is set, when it has a flat bottom. The intervals between the walls are laid first with shavings, or light and dry brushwood, or any thing that will kindle easily, then with larger brushwood cut into short lengths, that it may pack in a compact manner; and, lastly, with logs of split hickory, or strong burning wood. This done, the over-spanning or formation of the arches is commenced; for this purpose every course of bricks is made to extend an inch and a half beyond the course immediately below it, for five courses in height, taking care to *skintle* well behind, that is, to back up, or fill up with bricks against the over-spanners. An equal number of courses, on the opposite side of the arch, is then set as before, and thus the arch is formed, which is called rounding, and is a nice and important operation, for if the arch fails or falls in, the fire may be extinguished, or many of the bricks above the arch may be broken. The intermediate spaces between the arches are now filled up, so as to bring the whole surface to a level, and then the setting of the kiln proceeds with regularity until it obtains its full height. In setting the kiln, not only in its body, but in the arches also, the ends of the bricks touch each other, but narrow spaces must be left between the sides of every brick for the fire to play through, and this is done by placing the bricks on their edges, and following what is called the rule of three upon three, by brickmakers, reversing the direction of each course as shown at *Fig*. 121. The kiln being filled, the top course is laid with flat bricks, so disposed, that one brick covers part of three others, which process is called platting.

489. The kilns of Philadelphia are constructed and managed

in a manner very nearly according with the above description of the country kilns of England, but they are larger, having an average width of twenty-eight feet in the clear, and are higher; but the bricks are not laid more than thirty-five or thirty-six courses. There are seven arches or firing holes in the end, each two feet high by sixteen inches wide, and the distance between each arch is three bricks. Such a kiln holds 140,000 bricks, and consumes from forty to fifty cords of wood for burning them.

490. The kiln being built, or finished, the firing succeeds, and this is the most delicate operation, and one that requires practice. The fuel is kindled under the arches, but requires close watching and attendance, for being in a large body, it would burn violently and produce so sudden a heat as would crack and spoil the lowest bricks. To check the burning, the arch holes or mouths are closed with dry bricks, or even smeared with wet clay, in order to prevent the entrance of air, and rapid combustion that would ensue. The fire must be made to smother rather than burn, in order that by its gentle heat it may evaporate away the humidity that remains in the bricks, and produce drying rather than burning. The slow fire requires to be kept up about three days and three nights, by occasionally opening the vents, to supply air and additional fuel, and closing or partially closing them, until the fire gets up, as the workmen call it, that is to say, until it has found its way through all the chinks and openings between the bricks, and begins to heat those at the top of the kiln. To ascertain the progress of the fire, the top of the kiln must be watched, and as soon as the smoke changes colour from a light to a dark hue, the drying is complete, and the fire may be urged. The first, or white smoke, called water-smoke, is, in fact, little else but the steam of the water while evaporating, and when that is gone, the real smoke of the fuel succeeds, and now the vents may be opened to admit full draught, and a strong fire kept up for from forty-eight to sixty hours; but the heat must not be white or so strong as to melt or vitrify the bricks, and whenever it appears to be increasing too rapidly, the vents must be partially closed. By this time the kiln, if it contains thirty-five courses, will be found to have sunk about nine inches; but the stronger the clay the more it will shrink, and it is by this sinking that the workman knows when the kiln is sufficiently burnt. The experience of burning a few kilns will show how much the clay of that particular place yields to the firing. When it is thus ascertained that the kiln is done, the vent-holes, and all other chinks through which air can enter, are carefully stopped with bricks and clay, and in this state it remains until the bricks are cold

enough to be taken down, when they are distributed for use.

491. From the nature of the above process it will be evident that bricks of very different qualities will be found in the same kiln; for as the fire is all applied below, the lower bricks in its immediate vicinity will be burnt to great hardness, or, perhaps, vitrified; those in the middle will be well burnt; and those at the top, which are not only most distant from the fire, but exposed to the open air, will be merely baked, and not burnt at all; consequently, if they can be used, they must be reserved for inside work, that is not exposed to weather, or they will soon fail and crumble to pieces.

492. In the London method of open clamp burning, without any kiln, the piling and disposition of the bricks is the same as above described, except that the bottom arches are much smaller, as they are only intended to contain brushwood to produce the first kindling, and not for the future supply of fuel. No fuel is used except the breeze cinders and small coal before described, and this is distributed by means of a sieve, with wires about half an inch apart, over every course as it is laid near the bottom, and over every alternate course, or every third course higher up in the kiln. The first layers of this fuel are from an inch to an inch and a half in thickness; but they diminish as they ascend, because the action of the heat is to ascend, consequently there is not the same necessity for fuel in the upper, as in the lower part of the kiln. The brushwood in the bottom ignites the lower stratum of fuel, and from the nature of its distribution, the vertical as well as horizontal joints will be filled with it, and thus the fire gradually spreads itself upwards, and the whole clamp is nothing but a mass of bricks and burning fuel. The heat is therefore much more generally distributed throughout the whole mass, and in order to confine it, the entire outside of the clamp is thickly plastered with wet clay and sand, the bottom holes being opened or shut as occasion may require for regulating the draught of air.

493. Notwithstanding the heat is much more equably distributed throughout this form of kiln, yet the outside bricks all around receive very little advantage from the fire, and are never burnt; but being on the outside they are easily removed, and are reserved for the outside casing of the next clamp that may be built; and being then turned with their unbaked sides inwards, some of them become available. On taking down the clamp, the bricks are assorted, in London, into three separate parcels or varieties, according to their perfection and goodness. Those that are burnt very hard but have not lost their figure or shape,

are called *malms*, or malm-facings, or malm-paviors, and are used for facing good work; or for paving, for which their hardness makes them peculiarly suitable. The main body of the clamp produces well burnt and regularly formed bricks called *stocks*, with which the generality of houses are built; and such as are imperfectly burnt, and are soft, are called *place* bricks. These last are used for inside partitions, backing walls that are to be plastered upon, and other work that is neither exposed to the eye or the weather. These several varieties of brick have each a separate price, the best being worth almost twice as much as the worst. If the fire has not been carefully attended to, and has been permitted to get too violent, a few of the lower bricks will become distorted by partial fusion, and may fuse and adhere together, when they are called clinkers, and are useless for building purposes, but form an excellent road material. In this country the names of bricks are different, but derived from the same source, being called hard burnt or arch bricks, body bricks, and soft or salmon bricks; though this last name is generally altered by workmen into sammy. The goodness of a brick is derived from its regular shape and appearance, its tenacity and hardness, its sound, and by its not absorbing water, or being affected by frost. The tenacity and hardness are judged of by striking one brick against another, or letting them fall upon stone pavement. Good bricks should have a sound approaching to that of a metal when so treated, and they ought to ring, and bear a very hard blow with the edge of the trowel, before they divide. If they readily break with a blow, or crumble to dust by a fall, such bricks are of the soft or sammy kind, and are unfit for introduction into a heavy wall, particularly on the outside of it, as they will be sure to be attacked by frost, and crumble to pieces. The absorbency of bricks is judged of by weighing them in the dry state, and then soaking them in water for an hour, and weighing them again. Those bricks that take up the greatest quantity of water, are the least fit for use, when they are to be exposed to its action. The average weight of a sound and dry London stock brick, is four pounds fifteen ounces avoirdupois.

494. Independent of the above, two other kinds of brick are made, called *cutters or rubbers*, and *fire-bricks*. Cutters or rubbers are very common in London, but not so generally used in this country. They are made of the best and most select materials, passed through a much finer sieve or strainer than the other bricks, and the whole manufacture is conducted with peculiar care, on which account they are expensive. They derive their name from their being so perfectly homogeneous, and free from stones or hard parts, that they may be cut with a saw, or

chopped to any form, and then rubbed on a rubbing-stone until they obtain a perfectly flat surface. They are only used for ornamental puposes, such as constructing gauged or rubbed arches over doors or windows, niche heads, and the like.

495. Fire-bricks are used for lining the insides of furnaces of all kinds, in which the heat may be so great as to fuse and vitrify bricks of ordinary materials. They are also used for that part of the setting of steam-engine boilers that is most exposed to the fire, and for lining the insides of fire-places intended for burning anthracite coal. Until the last few years, these bricks were imported from England, where two varieties of them are made, called Stourbridge and Windsor fire-bricks, both excellent, but of very different qualities, and they both derive their value from the peculiar local earth of which they are formed. The Stourbridge brick is always larger than other bricks, of a pale yellow or red colour, and when well burnt so hard that it will give fire with steel, and has no absorbent power. When broken, it may be seen that this brick consists chiefly of the same brick previously burnt, and reduced to coarse powder, and then made over again with an additional quantity of the same fire-clay. The Windsor brick, on the contrary, is made below the usual size, and is so soft and tender, that it can scarcely be handled without breaking, and when broken its whole substance is discovered to be nothing but sand, cemented and held together by a very minute quantity of argillaceous earth. This brick is of a deep, but bright red colour throughout, and is so soft that it may be cut to any required form by a common saw or knife, notwithstanding which, it withstands a higher heat than the former kind, and becomes very hard and durable after it has been exposed to such heat. On this account it is constantly used for forming the arch over wind or reverberating furnaces for melting iron. A similar brick is made at Cheam in Surrey, and as they are all stamped with PP, they are known under the name of PP or nonsuch bricks. Each of the above kinds fetch fifty dollars a thousand in London. Within the last few years, the Stourbridge brick has been most precisely imitated in this country, as to size, colour, texture, and quality; the writer has tried these bricks against those of England, and finds them fully equal in goodness and power of resisting heat. They sell in Baltimore for something less than the English brick, which makes them much cheaper than those that are imported. He has never seen any attempt to imitate the nonsuch brick, but has no doubt they might be made as well as the others. The hard brick should be used in all furnaces subject to blows or concussions, as when large logs of wood are thrown in, or the fire has to be raked with large

iron pokers; but for domes, or places not likely to be disturbed, and where the heat is very great, the soft bricks will be found preferable. Large blocks, called *lumps*, are made of the Stourbridge material, and are very useful in the construction of many furnaces. Fire-bricks are often made wedge-formed for building arches, and in segments of circles, for building round furnaces or flues.

496. Common brick earth is frequently formed into what are called drain bricks; they are made large enough to admit of having a semi-circular cavity of about three inches diameter sunk into one of their sides, so that two of them inverted, one over the other, form a three inch tube, with a square outside.

497. Tiles are a kind of thin brick, made exclusively for covering buildings, and they are so little known or used in the United States, that it appears hardly necessary to mention them, except that our account of bricks would be incomplete without a notice of them. In London, almost every ordinary house is covered with tiles, as they, with slates, form the only roof covering, except in some few instances where copper or sheet lead are used for flat roofs. Slating is only adopted in the more elegant and expensive buildings, as forming a much lighter covering, and one more elegant in its appearance than tiles. Indeed the only objection to tiles is their weight, in consequence of which they require stronger timbering in the roof. But still they possess advantages over both the other materials. Metal is objectionable on account of its ready transmission of heat and cold to the building below, the noise that rain occasions when falling upon it, and the liability to expansion and contraction, which causes it to crack and admit water. Slates on the other hand from being very thin and light, are frequently affected, and even lifted by high winds; are so brittle that they are easily broken by passing over them, and they transmit heat and cold very readily, while tiles are too heavy to be affected, are bad conductors of heat, are strong, and may be said to be imperishable; for the older tiles are, the better they are considered, because they lose their absorbency by age, and while they are cheaper than the other coverings, they are perfectly weather-tight, resist fire, and seldom need repair.

498. Tile-making is quite a distinct business from brick-making, and they are never carried on by the same persons. Tiles require a stronger clay than could be used for bricks, a smaller proportion of sand, and no breeze. The clay is sometimes worked by the pug-mill, but generally by hand labour, as a much smaller quantity of it is required than for bricks; but tiles are moulded in very nearly the same manner, are dried in

the open air, and then burnt in very large and high conical brick buildings called tile-kilns, in which they are treated in a manner very similar to pottery-ware.

490. Tiles are confined to three varieties or shapes, called, plain tiles, pan-tiles, and ridge-tiles, and each variety is always made of the same size, so that whether bought at one establishment or another, they fit and work together. The plain or flat tile is the kind most approved and used, as affording a neat looking and perfectly water-tight roof, and with this tile most of the houses in England are covered. Plain tiles are ten and a half inches long, six and a quarter wide, and five-eighths of an inch thick, and each tile weighs two pounds five ounces. There are two small holes made near the end of each tile to receive wooden pegs, by which the tile hangs on to strong laths nailed from one rafter to another, and these tiles are often laid dry, or without mortar, overlapping each other just like shingles. If *bedded*, or laid in a very small quantity of mortar, plain tiling not only resists rain, but the drifting of snow likewise; and as tiles are very bad conductors of heat, so a bedded plain tile roof protects the building over which it is placed from the vicissitudes of atmospheric temperature in a remarkable degree.

500. Ridge-tiles are a plain tile of larger dimensions, bent at the time of making, into a curved form, for the purpose of being placed over the ridges, or angular edges, where the two sides of tiling meet, to make a finish and exclude water. They are always set in mortar, and in addition, are held down by a peculiar thin nail with a large head, made for the purpose, and driven between each tile into the timber ridge piece, so that the head of one nail confines two tiles, and prevents their being blown off, or otherwise displaced, even after the mortar decays.

501. Pan-tiles are a tile so curved that by one edge of the tile being bent down, and the other turned up, while a hollow is left between them, one tile fits under and over the adjoining one; and thus a water tight roof is produced by only one single layer of tiling, in a manner that will be understood by referring to *Fig.* 122, *Plate IV.*, which shows the disposition of a few tiles laid on a roof. Each tile has a projection formed on the under side of its top part, by which they are hung upon laths or slats of wood, nailed at proper distances to receive them, and to permit the lower end of the highest tile to overlap the upper end of that immediately beneath it, as will be seen in the section of this tiling, shown by *Fig.* 123. Pan-tiles are thirteen and a half inches long; cover nine inches of width; and, consequently, are about twelve inches wide before they are curved, and half an inch thick, and each tile weighs about four pounds eleven ounces.

They are much used for shed or temporary roofs, as from the ease with which they are laid on, a large space may be covered in a very short time, and they are the cheapest and lightest kind of tile covering. They keep out rain very effectually, but expose openings through which air and drifting snow can pass; but they are much esteemed on this account for covering founderies, blacksmiths' shops, and chemical establishments, where much smoke or bad fumes are produced, as they pass off readily between the tiles, and the rooms covered with them are kept well ventilated, and supplied with fresh air; but if pan-tiles are laid in mortar and pointed, they make a perfectly good and sound roof, and many dwellings are covered by them so laid, although their general use is confined to stables, manufactories, farming buildings, and houses of small dimensions.

502. The tile-makers also prepare excellent hard paving tiles, of twelve and ten inches square; the first, inch and a half thick, and weighing twelve and a quarter pounds each, and the latter, one inch thick, and weighing eight and a half pounds each. When bedded in sand and mortar they make an excellent paving for manufactories, kitchens, dairys, and other buildings, and are very level, durable, and cleanly.

Section II.—*Of Lime, Mortar, and Cements.*

503. The stones and bricks, spoken of in the last section, would be of little avail in the building art, was it not for some material by which they could be united together, so as to convert the small separate pieces of material into one united mass; and this is effected by the intervention of mortar or cement. The general character of mortar and its use are well known; and cement, among builders, is a name given to such kind of mortar as is capable of setting, or becoming hard, under water, a property that common mortar does not possess.

504. Common mortar is composed of quicklime and sand duly prepared, and mixed with water until it becomes a paste of proper consistence, to be applied by that well known instrument the trowel. It is applied by making a sufficiently thick layer, or bed of it, and then placing the stone upon it with artificial pressure, if its weight is not sufficient to produce the necessary setting or compression; when the quantity of superfluous mortar that squeezes or oozes out of the joint, is removed by the trowel for future use, and the outside of the joint being passed over and made smooth by the point of that instrument, the stone is left for the mortar to set or get hard. There is a great variety in the nature of quicklime, as well of the materials of which it is form-

ed, and some art in preparing and using it, therefore some observations on these heads will be necessary.

505. Limestone is one of the most abundant products of the earth, existing in all countries to a greater or less extent, and often in mountain masses. Lime is, however, never pure or unmixed, unless in rare mineral specimens, but is always mixed with carbonic acid gas, sulphuric acid, or some of the strong mineral acids. The carbonate of lime is alone fit for the purpose of making mortar, and this, as before observed, assumes a great variety of forms, possessing little or no external similarity. Thus, all the marbles are carbonate of lime. Carbonate of lime is sometimes beautifully crystallized in detached crystals, or is found in masses evidently crystalline. Some of the mountain limestones possess this character, while others are earthy and even lamellar. The hard masses of dark grey limestone, used for rubble work in building, are often of this character. Chalk, which forms high cliffs, and even mountains, in the southern parts of England, is entirely carbonate of lime, and nearly all the lime that is consumed in London is nothing more than burnt chalk. Lime also exists in animal formations, for the shells of oysters and other fish, consist almost exclusively of carbonate of lime, which is also the case with many of the madrepores and corallines, of animal formation, found in the sea.

506. All the carbonates of lime effervesce when touched, or brought into contact with the strong chemical acids, such as the sulphuric and muriatic, or hydrochloric acids, and are soluble in them, if in excess, and this is one of the tests by which lime is known. They are all very nearly, if not quite, insoluble in pure water, and they part with their carbonic acid on being exposed to a red heat. This, therefore, is the reason why limestones are burnt or heated. The heat dissipates or drives off the carbonic acid, and a large portion of the water that was previously combined with the limestone, and after this process, whatever may have been its previous colour, it is rendered quite white, or of a light brown colour, and is now called *quick*, or *caustic lime*. The term, caustic, is applied to it from its property of apparently burning things, for it has so very strong a disposition to unite again with carbonic acid and humidity, that it will even destroy the flesh to get at these ingredients; and if water is added, to a certain extent, to quicklime it will disappear, and become solidified in the stone, which bursts to pieces, and afterwards falls into a very fine powder; great heat being given out while the combination is taking place. The lime is then said to be *slaked*.

507. Lime in its caustic state is slightly soluble in water, converting it into what is called lime-water; and if carbonic acid is

thrown into this water, it will combine with the lime, and by rendering it insoluble again, will cause it to appear; in doing which it first makes the water turbid or milky in appearance, and the lime is soon precipitated to the bottom in its former state of carbonate of lime. This seems to point out the use and operation of mortar. If raw or crude limestone in its natural state should be powdered and mixed with water, it has no greater disposition to form a paste or adhesive mass, than sand would have; and when it becomes dry by the evaporation of the water, the limestone will again be found in the state of powder, without any union or tendency to form a solid or compact mass. But if that same limestone is burnt, so as to become deprived of its carbonic acid and natural humidity, on being mixed with water, a combination will take place, a part of the lime will be dissolved in it, and a paste will be formed which gradually imbibes carbonic acid from the surrounding air, by which it is rendered insoluble, and the water now gives back the lime it had previously dissolved, which probably shoots into a kind of crystallized or rather interlaced formation, by which not only one particle of lime is held to another, but adhesion is produced to the stone, brick, or other substance, with which the lime may be in contact.

508. The lime in setting or hardening, becomes re-converted into a kind of stone, and it is a singular fact, that the hardness of this artificial stone, bears a relation to the hardness of the original stone before it was burnt, thus giving a decided character of superiority to one kind of limestone over another, for the purpose of burning lime for mortar. London and Philadelphia offer a striking contrast in this respect. Nearly all the lime consumed in London, is produced from burning chalk, and is therefore called *chalk-lime*. Chalk is of two kinds, stone chalk, and soft chalk; stone chalk is hard and compact, contains hard and gritty particles, and will rather scratch than mark upon a board, if used for the purpose of marking or writing. Soft chalk, on the contrary, is equable and smooth in its texture, and marks or writes freely; but it exists only in small quantities compared with the other, and is wholly unfit for making building lime, although it makes the best for agricultural purposes. Of course the lime-burner selects the hardest chalk he can obtain, and the mortar made from it is tenacious and durable; but still after it has been used in buildings even for a year or two, no difficulty will arise in driving a nail into the joint between two bricks, and the mortar is easily raked out of the joints for pointing. But if the same trial is made upon the lime of Philadelphia burnt from marble, or the dark-blue limestone, which are alone

used, the nail would inevitably be bent, and would be unable to penetrate the joint, even though it might not be more than six months old, the mortar being quite as hard as the brick. The excellence of the lime and bricks in this city, permits much thinner walls to be erected with confidence than could be done in London, where the mortar is of inferior quality, and where *stone-lime* is only used in buildings intended for great duration, on account of the additional expense of its transportation from distant places, rendering its price higher than the lime generally used.

509. Limestone and chalk are burnt near London, and indeed wherever coal is abundant, by coal in preference to wood fuel; the coal being broken into very small pieces or almost to powder. As coal works cannot be conducted without producing a large quantity of this dust coal, it is reserved, and furnished to the lime-burners at a lower price than coal in large lumps. And many of the London coal dealers screen their coal, so as to supply private families with large coal, at a little advance of price, which enables them to sell the small coal at an equivalent reduction.

510. A lime-kiln as usually constructed, is placed, if possible, in the side of a natural hill to avoid the expense of brick-work or masonry in its construction; and as the lime is generally of chalk, it is easily formed by an excavation into a cliff or hill of that material. Indeed lime-kilns should always be built in the immediate vicinity of the stone to be burnt, to save its transportation, and if they cannot be formed in the natural soil, they must be wholly built. The kiln itself is an inverted cone excavated out of the soil, or formed in the brick-work or masonry, and must be lined with fire-bricks, or the hardest bricks that can be procured. Its form, as shown at *Fig.* 124, the cone *a a* is usually from twelve to fifteen feet in diameter at its top or largest end, and diminishes down to about three feet in diameter at *b*, which is the draught-hole or ash-pit; and this opens by an arch-way to the front of the kiln, and should be high enough, near the front, for a man to stand upright to work in it. The cone should be from twelve to fifteen feet deep from its top to the base. Two strong iron bars, called bearing-bars, seen in section at *c c*, are fixed in the brick-work to bear or support the fire-bars that lie upon them, at about an inch asunder. These fire-bars are of wrought iron, about an inch and a half square, and more than two feet longer than the opening they have to cover, so that their ends *d*, project into the arch. The bars being properly arranged, a large fire of brushwood is made upon them, and coals are thrown upon it by baskets, from the circular platform *e e*, formed round

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the top of the kiln. When the fire is properly ignited, a layer of chalk or limestone, broken into pieces, is in like manner thrown upon it, until the layer is about nine inches thick. Sometime afterwards a layer of coal is deposited in the same manner, and if the mass appears to burn well, the whole kiln may be filled with alternate layers of broken stone and coals, in a proportion that must be determined by trial upon the stone that is burning, as some kinds take more fuel than others, but chalk will burn if the layers are in the proportion of ten to one. This is determined by the baskets from which the materials are thrown into the kiln; they hold a bushel, and ten bushels of chalk require about one bushel of coal. When once the kiln is set properly to work, the fire requires no re-kindling, but its operation may be continued for months together, by merely supplying fresh materials to the top of the kiln in the same proportion as the lime is drawn away from the bottom. The kiln is usually drawn every twenty-four hours, by taking out, or pushing to one side, one or two of the fire-bars *d*, when a quantity of the bottom or fully burnt lime falls down into the ash-hole *b*. If the lime does not fall fast enough, it is agitated by a bar of iron with its end turned up about a foot. This is introduced up the hole between the bars, and the lime is easily got down. It is then drawn to the front of the arch by an iron hoe, and when cold, is ready for measuring and carting away. The workman judges from his experience how much lime he may draw at once, and if pieces fall that are not sufficiently burnt, they are returned to the top of the kiln again; but this seldom happens, because an experienced kiln man will cease drawing before such pieces appear. The drawing having closed, the fire-bars are re-instated in their proper places, and the kiln is not touched again until the following day.

It might be supposed that rain falling on a kiln of this description, would be detrimental to the burning of the lime, and that a roof would be necessary for its protection. The heat is however so great, that any rain water is evaporated without sinking into the kiln; and in dry weather the top of it is sometimes watered, as the presence of moist vapour in the upper part of the kiln is thought to assist in the escape of the carbonic acid gas. Some of the best modern lime-kilns have been built in the form of two truncated cones applied base to base, so as to contract the upper opening, and reflect the heat downwards, which no doubt must produce an economy of fuel, and this form ought to be constantly adopted in all kilns where the lime has to be burnt by wood; because this fuel will not admit of mixture with the body of the limestone, and must be applied wholly from below.

The upper part of the kiln is therefore deficient in heat, and any form that will augment or economise it, is advantageous. In lime-kilns for using wood, a fire-brick arch forming a dome or kind of oven, is built over the fire-place, and pierced with holes large enough to let the heat rise up, but not to permit the lime to fall through them, and the largest pieces of limestone are put into the bottom of the kiln, to insure large interstices for the flame to play through. The lime is withdrawn when burnt, by an arched door in the side, made independent of the firing oven, and this door must be bricked up while the lime is burning.

511. As the fuel for burning lime, and the trouble and labour attending the operation, render it much more expensive than the raw materials that nature affords; and as burnt lime, however hard it may become, is more liable to decay by time than bricks or natural stones, and lime undergoes considerable shrinking as it dries, so mortar is never made of lime alone, but of lime and sand; and the goodness and durability of the mortar depends much on the quality of the sand used. Pure siliceous or flinty sand is imperishable by time, and is, therefore, the most suitable for the purpose; and as this consists of grounded grains like pebbles, or of such as are sharp and angular, and experience seems to prove that the lime crystallizes around, or takes better hold of that which is sharp, so sand of that description is always preferred. The great point to be attended to in selecting sand for mortar, is to get it as purely siliceous and free from materials that will wash away or decay, as possible. Good pure sand may be judged of by inspection, and by rubbing a quantity of it in a damp state between the hands; if it soils them by leaving dirt, clay, or any thing but sand upon the hands, it must contain clay or some soluble foreign matter. The best proof of its purity is to put a handful or two of the sand into a wash-hand basin, and having poured clear water upon it, to stir it about. If the sand is quite pure, it will scarcely soil the water in falling to the bottom; but if it contains much clay, vegetable matter, or other material, it will produce such a muddiness and discoloration of the water as will render the sand invisible, and as it produces more or less of this effect, it may be pronounced more or less pure. Mr. Smeaton, who in the course of a long and meritorious attention to his profession as an Engineer, found that when mortar, though otherwise of the best quality, was mixed with a small proportion of unburnt clay, it never acquired that hardness which it would have attained without it; and, consequently, sand of this description should be avoided.

512. The best sand as to form, size, and purity for making mortar is sea sand, such as is found on sea beaches; but there is

one great objection to its use, which is the salt it contains, and from which it is very difficult to disengage it; and unless the sand is perfectly free from salt it crystallizes in dry weather, and deliquesces when it is damp, so as to spoil the appearance of any work done with it, and to keep the mortar in so damp a state as to prevent its setting well. Sea sand should, therefore, never be used until it has been thoroughly soaked and washed in several successive changes of fresh water, which is too troublesome to be adopted in works on a large scale. Fresh water river sand, or pit sand, that is, pure sand dug out of inland pits, are the kinds generally resorted to; and a preference is generally given to pit sand, on account of its being more pure and sharp than that obtained from rivers, the grains of which are, generally, rounded by attrition. Among the London builders sifted road sand is preferred to any other kind. This sand is procured from the mud, scraped after wet weather, from the much frequented high roads, and as these roads are all made and repaired with the hardest flint stones alone, the finest particles of this sand, even the dust, must be siliceous with very little admixture of any thing else.

513. Much difference of opinion exists as to the quantity of sand to be mixed with lime for making the best mortar. Workmen like a large proportion of lime, because the mortar is more plastic, tenacious, and easy to work when that predominates; while, on the contrary, when the sand is in excess, the mortar will not hang together, and is said by the workmen to be too *short*. The facility of the workmen must not, however, be allowed to interfere with the stability of the work to be executed; and experience fully proves that brickwork, in which a superabundance of lime has been used, though it may be strong for the few first years, is never so durable as when it exists in less quantity.

Dr. Higgins, of England, whose name stands highly distinguished as one of the originators of the atomic theory in chemistry, was the first person who undertook a correct investigation of the mechanical and chemical action of mortar* on the true principles of science, and after many experiments and trials he gives the following as a result for the best mortar, viz: newly slaked stone quicklime, one bushel; fine siliceous sand, three bushels; and coarse sand of the same description, four bushels; making a proportion of seven parts of sand to one of lime. But he confesses this to be a very short mortar, and one with which it is difficult to work; "but," he adds, "that if a quarter of a bushel of bone ashes, or calcined bones in powder, is added to the above quantity, it will give it

* Higgins on Calcareous Cements, 8vo., London.

sufficient tenacity, and will render it much less likely to crack in drying." In order to define what is meant by fine and coarse sand, which he says must be free from clay, salt, gypsum, or any thing less hard than quartz, he directs that the sand shall be sifted under the water of a running stream, in a sieve of wire-cloth, No. 16, that is, in which each hole or mesh is the sixteenth of an inch square. The sand that passes is collected, and sifted again through another sieve, in which the wires are thirty to the inch; all that will not pass through these sieves must be rejected, and the produce of the two sieves will give the fine and coarse sand above referred to.

514. This mortar, the writer has no doubt, may be very good, but it would be very unpleasant and annoying to the workman. His opinion is that nature cannot be too closely copied in the formation of a mortar; and Portland stone may be considered as a natural mortar; for, as before observed, when examined even with a magnifier, it will be found to be nothing but fine sand agglutinated together by a lime or calcareous cement, in too small a quantity to be perceived. It is, by geologists, ranked among the oolitic formations, but on examining the obvious oolite or Bath stone, in which the grains are much larger, the cementing material is distinctly visible, and the stone is much weaker. It may be imitated by wetting clear siliceous sand with strong lime water, that is so pellucid that no lime appears in it, yet after exposure for some time to the atmosphere, the grains will adhere, which shows how small a quantity of lime is necessary for the cementing process; but still a sufficient quantity must be allowed to produce facility and stability in the work. In the construction of a large quantity of brickwork, executed at the West Middlesex water-works, the only mortar used consisted of six measures of sand, (without the precaution of sifting and separating it as above,) to one measure of excellent lime, obtained from Merstham in Surry, about twenty miles from the works, that being the nearest good stone lime that can be obtained at London, and that work stood and looked remarkably well. It was the same materials, and the same proportion that had been previously used in the buildings of the London and West India docks.

515. Chalk lime, and the weaker limes, will not bear any thing like this quantity of sand, and the general proportions of the London builders is one and a half hundred weight, or thirty-seven bushels of lime to two and a half loads, or fifty-five bushels of sand. The measures in both cases being struck or not heaped. The writer is, however, persuaded that this proportion of lime is too great. There is scarcely any mortar in which the lime has been well calcined, and the composition well beaten

and mixed together, that will not take two parts of sand to one of lime; and it is worthy of remark that the more the mortar is beaten or *chafed*, the less proportion of lime will suffice.

516. In the vicinity of the sea, where oysters, clams, and other shell-fish abound, while limestone may be scarce, the only lime used is that procured from the burning of shells. This is a very excellent lime, and is much used in the eastern parts of Virginia. It is of course called shell-lime.

517. All quick-lime, from whatever substance it may be produced, requires to be *slaked* before it can be made into mortar. The slaking is nothing more than pouring water in proper quantities upon the lime, previously spread upon the ground in a parcel of eight or ten inches thick. The water should be carefully distributed over the whole surface of the heap, not in such quantity as to make the lime wet, or to run away from it, but merely to make it damp. If it was made wet, it would spoil the sifting or screening, which is the next process it has to undergo; and, as the sand has to be screened, as well as the lime, they are generally mixed together in their proper measured proportions before the screening begins. The sand being placed first on the ground, and hollowed into a kind of basin in which the lime is put, and the proper quantity of water having been poured upon the lime, some of the sand is drawn over it by a hoe, and the parcel is left a short time. The lime absorbs the water, which of course disappears, great heat is evolved, and the lumps of lime shortly swell and burst into a most impalpable powder. The heap is opened and moved about with a hoe, to ascertain if the slaking is complete, or whether any solid lumps remain, requiring more water; if not, the mass is moved about to produce incorporation of the sand and lime, and if the process has been properly conducted, the whole will be found in a very nearly dry state, as the lime will absorb most of the water out of the sand, and any superfluous quantity will be driven off in steam, owing to the great heat of the mixture. The sifting or screening now begins, and produces a most perfect mixture of the sand and lime, as they pass through the sieve together. The most convenient screen for this purpose, is one about six feet high and a yard wide, having projecting sides like a box, and covered by strong wire work, the wires of which are from a quarter to three-eighths of an inch apart. This screen is propped up, so as to stand at an angle of 45°, and the lime and sand are thrown against it by a shovel; what passes through it is fit for mortar, while all that falls in front will be either stones that were contained in the sand or unslaked lime, or pieces of the latter, which, for want of sufficient calcination, remain in the state of limestone,

and therefore are incapable of slaking. Such refractory material is called *lime-core*.

All the fine stuff that passes through the screen may now be made into mortar by merely adding as much water to it as will convert it into the proper consistency for use. The quality of mortar does not appear to be at all affected by the quantity of water added to it, provided it is not in such excess as to cause a separation, or subsidence of the sand from the lime. Indeed all mortar should be used in a rather wet and thin state, particularly for brick-work, because as bricks are absorbent in a greater or less degree, if the mortar is too dry, the bricks when laid upon it will take away a part of its water, and render it so dry and hard that it will be incapable of yielding to the weight of the brick, or even to any pressure exerted upon it, and the work will therefore not be so even and sound, as if the mortar had been in a thinner and more yielding state. Perfect contact, amounting almost to incorporation is necessary between the mortar and the brick or stone, and to produce it, it is advisable to dip each brick into water, as it is laid, or to throw buckets of water upon the pile of bricks as they are used, particularly when the season is very hot and dry; and it is always better to slide the bricks on to their mortar bed, than to put them down by direct pressure, whenever it is desirable to produce very sound work.

518. It is generally admitted that the best and strongest mortar is produced from fresh or recently burnt lime, and for strong work, the sooner the mortar is used after it is burnt, the better. The reason of this may be, that when lime is fresh from the kiln, it is as completely deprived of its carbonic acid and humidity as possible, and is therefore in a more soluble state, and better suited for combining with water; and as mortar after it is made becomes re-converted into carbonate of lime, if exposed to the air, so the sooner it is used the better, because then its changes take place in the wall, instead of upon the ground. A quantity of quick-lime thrown down and exposed to the air will slake itself in a few days without any suffusion of water, because it will imbibe sufficient humidity from the air to produce this effect, and will fall to powder as effectually as if the slaking had been artificially produced; and lime thus spontaneously slaked may be made into mortar, but it will not possess the strength, tenacity, or durability of lime slaked by the quick artificial method.

519. All mortar, made from the ordinary kinds of lime, requires to be kept tolerably dry in order to insure its setting properly in the work in which it has been used; consequently it

will not answer for use under water, or in wet positions. In these, a peculiar mortar called *Cement*, must be used; that is, a mortar composed of such materials as are capable of setting, or becoming hard very suddenly, so that if water is let in upon the building immediately after its completion, it will suffer no injury; and some of the best and most perfect cements will even set under water. The setting of a cement appears to be dependent entirely upon the materials of which it is composed, rather than on its mode of preparation, for that is merely burning it like ordinary lime; and no satisfactory explanation has ever yet been offered of how the hardening takes place, or why one kind of earth should produce a lime so perfectly different and superior to another. It was formerly believed that the effect was due to a certain mixture of metal with the limestone, and that it owed its character to the presence of iron, or manganese, or the oxides of these metals in the stone before it was burnt. Indeed, the French chemist Guyton de Morveau, in his early researches into this subject, came to the conclusion that all calcareous stones that produce cement, or as it is very commonly called *hydraulic lime*, must contain manganese, and he gives a process by which such lime may be produced artificially, which is by mixing ninety pounds of common hard limestone with four pounds of pure dry clay and six pounds of black oxide of manganese, all in powder, and calcining the whole together, when, nothing but water will be necessary to produce a good hydraulic cement. That the oxides of some of the metals do improve mortar, is well known to every workman; for it is a common practice, in England, for bricklayers to get the scoria from smiths' forges, (which is a protoxide of iron,) and after pounding it, to mix a little of it with common mortar, which not only makes it set quick, but become very hard. Mortar for pointing the joints of old brick work, is constantly made with this addition of oxide of iron.

520. The material generally used in England as a cement for water-works, bridge building, lining tanks to make them water tight, and other similar purposes, is called Parker's cement, or Roman cement. Mr. Parker obtained a patent for the material and mode of preparing it, within the last half century, and he called it Roman cement, from a supposed resemblance that it had to a mortar or cement used by the Romans, and which is only known by its great hardness and apparently imperishable nature in the ruins of their former buildings. Parker's cement was found so excellent, that it soon became an article of general consumption, not only in England, but in countries to which it was exported; and it is now known pretty generally over the world under the above names, or Wyatt's cement. Since the expira-

tion of the patent it has been manufactured by many persons; but was always sold under its former names on account of their celebrity. This cement was at first manufactured from a natural boulder or pebble, found only near the Isle of Thanet, on the east coast of the county of Kent, and supposed to belong to that particular locality; but having since got into great request, it has been searched for, and is now ascertained to be one of the accompaniments of the immense formation called the London clay basin, which extends to the sea-side in a north-easterly direction, and surrounds London in an almost circular form. The boulders were at first found on the surface only, having been washed out by the waters of the sea and the river Thames; but they are now discovered to be disseminated throughout this formation, which extends to several hundred feet beneath the surface of the soil, and they have also been found in other localities. The boulders are precisely similar in form and external appearance to those used for paving streets, and they vary in size from two to fourteen or fifteen inches in diameter; but, as they are not sufficiently hard for paving purposes, they were neglected until Mr. Parker discovered their valuable property of making hydraulic cement. On breaking them, they present a curious appearance, which is sometimes very beautiful; the body of the stone being a compact light brown argillaceous limestone that is dull or without polish, traversed by various veins of bright and highly crystallized white carbonate of lime, which cross each other in nearly right angled directions, so as to divide the stone into a number of septæ or cavities, and give it an appearance similar to that shown by *Fig.* 125, *Plate IV.*, which represents a section of one of these boulders. On account of their peculiar formation they are now called septarii by mineralogists, and in some of the older writers this stone is distinguished by the name of Ludus Helmontii. They have been found abundantly at Boulogne sur Mer in France, across the channel, and nearly opposite their first discovered location in England. See Journal des Mines, Vol. XII. These stones are broken and calcined in a dome or reverberating furnace, (510,) to convert them into quicklime. On leaving the kiln or furnace, they are as hard, or nearly so, as when they went into it, therefore this lime requires to be reduced, or brought into a state of powder, by grinding it in a mill formed of a pair of heavy stones called runners or edge stones. From this mill it is taken up as speedily as possible, and packed into close casks about the size of flour barrels. The casks are placed under a stamping apparatus while they are filling, by which the powdered cement is driven down with such force as to render it nearly as compact as solid stone; an expedient that is resorted to to prevent the cement being injured by exposure to air, which soon spoils it. The casks are then closely headed, and the material may be kept or transported without fear of detriment, provided the casks are kept in a dry place. In using this cement, a small quantity is taken out, and mixed with from four to five times its bulk or measure of very clean, sharp, and rather coarse sand, (such as passes the wire sieve, No. 30, (513,) is the best,) and sufficient water added to make it work, and the cement is ready for use. If the cement is fresh and good, no more ought to be mixed than can be consumed in half an hour; because in that time it ought to set, and become hard, and, consequently, unfit for working; and when once it is set hard, there is no method of reviving or softening it again. In many cases, where pure cement and sand would be too expensive for use, it may be mixed or incorporated with good fresh stonelime mortar, and even in the proportion of four or six to one, it will improve the quality of the mortar very sensibly.

521. The celebrity of Parker's cement, and the scarcity, as to locality, of the stone from which it is made, caused this cement to be very carefully analyzed and examined by many eminent Chemists and Engineers; but still nothing could be discovered, further, than that the stones consisted principally of argillaceous limestone, that is, lime and argil, or clay, combined by nature, in the proportion of about two-thirds of the former to one-third of the latter, mixed with a small quantity of oxide of iron; and that the traversing veins were pure carbonate of lime; so that when an entire stone was reduced to powder, the quantity of clay or argil, was very nearly equal to that of the lime. This at once disproved the hypothesis of Guyton de Morveau, that all hydraulic cement must contain a considerable portion of manganese. The composition of the Kentish boulder-stone, appeared simple and easy to imitate by art; and, accordingly, in 1818, M. Vicat of the Corps des Ponts et Chaussées, announced in a work he then published on the subject of limes and mortar, that he had succeeded in discovering a process by which all kinds of limestone whatever, might be cheaply converted into cement, or hydraulic lime. His operation was truly synthetical, being derived, in the first place, from an analysis of the natural stone, by which he discovered the nature and proportions of its several component parts; and then, getting materials as nearly like them as possible, putting them together, and producing their union by aid of fire.

522. The process consists in slaking the lime, and mixing it with pure or brown clay, and sufficient water to convert the whole into an adhesive mass, of which balls are formed; and

being dried in the sun, they are baked in a kiln, and produce lime of qualities entirely different from that at first used; which qualities are variable with different proportions of the materials. The clay is added in the proportion of from five to twenty per cent. to the lime for common purposes; but if forty per cent. is used, the mixture is said to become solid in a very short time after it is immersed in water.

523. It has been before observed, that whenever raw clay enters into the composition of mortar, it is injurious to it; and M. Vicat remarks, that if the clay is baked alone, powdered, and added to the lime in any of the above proportions, it will merely act as sand, without altering the character of the mortar; and that no benefit will result from the admixture of clay unless it is baked in combination with the lime, from whence he infers, that the fire acting at the same time upon the two substances, produces some change in their internal arrangements, by which the character of the compound is affected, but what the real nature of this change may be, has never been satisfactorily accounted for. M. Vicat believes that a real chemical change and combination takes place between the lime and the clay. This subject has been prosecuted with great energy and industry by several of the most distinguished Engineers and Chemists of France, and they all agree in the fact, that clay and lime burnt together, will produce hydraulic cement. M. Berthier states, that one part of common clay and two parts of chalk burnt together, makes a good hydraulic lime, and that all natural limestones that contain clay as a part of their composition, make much better mortar-lime than such as are pure. Many natural limestones are found that produce hydraulic cement. Thus the locks of the Great Canal in the state of New York, and the Union Canal of Pennsylvania, were both built with local limestone. And the Aberthaw lime of Lancashire, in England, is justly celebrated by Mr. Smeaton for its excellent hydraulic qualities. But the component nature of cement was not understood in his time; and if these limestones were analyzed, there is little doubt but that their valuable properties would be found to be dependent upon a certain quantity of clay, entering into the composition of the limestone. Limestone that contains but six per cent. of clay, is found to be perceptibly hydraulic; when it contains fifteen to twenty per cent. it is very good, and with from twenty-five to thirty per cent. the mortar sets almost instantly. This has been proved by Bruyere and Treussart, who assert that the free access of air during the calcination of argillaceous cements, is of great consequence to the tenacity of the mortar, and the quickness with which it hardens; and, therefore, that the common form of lime kilns is

not the best for burning these materials; and, perhaps, as good a method as any for exposing them to heat is the reverberating furnace, described in the section on iron foundery, except that as the heat required is not so great as is necessary for melting iron, the width of the arch and floor may be considerably extended, and the well made much more shallow.

524. Independent of the hydraulic cements above described, there are two natural substances which have been used to a great extent for mixing with mortar, in order to cause it to set under water, which are called *Puzzolana*, and *Dutch Tarrass*, or *terras*. Puzzolana is evidently of volcanic origin, and is found in the vicinity of volcanoes. Its external appearance is that of a ferruginous clay that has been exposed to a high heat, having a great variety of colour, dependent probably on the heat it has undergone, and the proportions of the materials that enter into its composition, which by analysis are found to be clay, flint, lime, and iron. Mount Vesuvius has produced it in large quantities, and it is extensively found between Naples and Rome, this locality being the principal one from which it is imported to different parts of the world for use. From its natural position it became known to the Romans, who, according to Vitruvius, used it very extensively, not only in their public buildings, but in erecting quays and other buildings in the water, in the bay of Baiæ, and as it was obtained principally from the town of Puteoli, and was never used until ground to powder, it obtained the name of pulvis puteolanus; but as the best kind is now obtained from Puzzoles near Naples, the moderns have given it the name of Puzzolana. This substance when ground, sifted, and mixed with water, is capable of producing an hydraulic cement without sand; but on account of the expense of its transportation, it is always used with it, and frequently with lime also as a means of improving mortar and rendering it fit for water building. From the vicinity of Rome to the place where this material abounds, and is found in the highest perfection, it is very probable that it formed a principal ingredient for the union of the stones and bricks used in the ancient Roman edifices, the strength and durability of which has so much excited the surprise of all the modern visiters and investigators.

525. Tarras, or as it is very frequently called, Dutch tarras, by way of designating that of the best quality, was originally brought from Andernach near the Rhine, and possesses properties similar to those of Puzzolana, in forming a compost with lime that hardens under water. It is believed to be a decomposed basalt of volcanic production, and in mass is so hard, that millstones may be made of it, and it is frequently used as a build-

ing stone. When reduced to powder and mixed with lime, it forms the mortar or cement used by the Dutch, in their extensive sluices and other hydraulic works; and in that country such works are carried on to a greater extent than in any other nation. It is even probable that the Dutch were acquainted with the method of preparing artificial cements antecedent to the investigations of the French on this subject, for the privileged cement of Holland prepared at Amsterdam, and analyzed by Bergman, was of this factitious kind; but half its composition was silex or flint, and a very small proportion of it lime; the remainder being made up of clay and oxide of iron, in nearly equal quantities.

526. These two materials are little known or used in the United States or England, since Parker's cement has become common, and the method of making artificial cements from native materials has been discovered and practised. Independent of which, there are many natural stones in this, and indeed in all countries, which, if tried and known, would yield good hydraulic cement. The young Engineer would therefore do well when he finds any stone or clay that he is unacquainted with, to test its quality for himself by actual experiment, which is very easily done, with no other preparation than a strong common fire, urged, if necessary, by bellows; or a smith's forge, should greater heat be required. If the earth be clay alone, it will, when previously dried, be converted by such heat into a hard insoluble mass in the nature of brick. Should the clay be pure, it will become white and hard, like common tobacco pipes; if less pure, it will turn red or brown; and should it become soft and friable, will be unfit for making bricks; while, on the contrary, if it is not only hard, but withstands every heat that can be put upon it without fusion or vitrification, it will be fit for fire-bricks. If the mass should be burnt into a lime or cement, it will slake on adding water to it; in which case a quantity of it may be powdered, and made into a paste or mortar, which should be placed in the bottom of a bowl of water; and if, after standing a short time, it sets into a hard insoluble mass, it will be a water cement, while, on the contrary, should it continue soft, it can only be regarded as common mortar.

527. A very clear idea of the manner in which these hydraulic cements set and become hard, may be derived from noticing what takes place with *Plaster of Paris*, which is a lime made by burning as before described; but the stone burnt is sulphate, and not carbonate of lime. Plaster stone, as the raw material is usually called, retains its solid form after burning, and will not slake or fall to powder on the addition of water. The burnt stone, therefore, requires to be ground to powder in a mill, and

in that state is called Plaster of Paris. On mixing water with this powder, heat is produced, though in a less degree than with quick lime; and a paste or mortar may be formed without sand or any other ingredient, that will adhere to bricks or stone; but it must be very speedily used, for in less than a quarter of an hour the paste will become hard and compact, even under the presence of a superabundance of water, and in a short time afterwards will assume a stony hardness. It might therefore be supposed, that this material would supercede the necessity of searching for any other cement, but it is found inapplicable to the common purposes of cement: first, because in setting, it swells or augments in its dimensions to such an extent as would disturb the regular form of stones or bricks set in it, if used in large quantities; and secondly, it is perishable, or decomposes by the continued action of air and water, in which particular it is quite opposite to limes made from good limestone, for they increase in strength and hardness by time, even in wet or damp situations. It is therefore much more difficult to pull down an old, than a recent wall, if it has been built with good mortar. Plaster of Paris is however a very useful building material for many internal and ornamental purposes, where it is not exposed to weather. It is the mortar or cement constantly used by marble workers for uniting the parts of marble in chimney pieces and other ornaments. It enters into the composition of plastering for ceilings and walls; and from its property of setting hard even when mixed with such an excess of water as will render it fluid enough to run into hollow moulds, it is extensively used for casting plaster figures, enriched cornices for rooms, ornaments for ceilings, and many similar purposes.

528. Another kind of mortar is much spoken of by the French Engineers, under the names of *Concrete and Beton*, and it has also been called *grub-stone mortar*. It is very little resorted to in England, and is not worthy of being treated under a separate head, because it is nothing more than any of the hydraulic cements rendered more hard, solid, and capable of filling up hollow spaces, by being mixed with small fragments or chips of any hard stone, or even with gravel pebbles. It is rather an application of mortar or cement, than one possessing distinct and separate characters from others, and in this respect it may class with *grout* or liquid mortar, therefore an account of the use and application of both these materials will be reserved for the chapter on masonry and brick-work, when their use and applications will be pointed out.

529. It has been before observed, that the more mixing, beating, or *chafing* mortar receives, the better it is, not only to work,

but for the solidity of the work done with it; and when so treated, every lime will bear a larger proportion of sand without detriment. But as the proper beating of mortar is hard work, there is often great difficulty in getting the labourers to attend properly to this business. In all large concerns where a considerable quantity of mortar is required, it is therefore better to employ a mill worked by a horse, to produce the due incorporation of the materials, than to trust to hand labour; and the kind of mill generally used, is in form and construction exactly like the pug-mill before described, (400,) *Fig.* 118, *Plate IV.*, with the exception only of the rakes or cutters which require to be of a different form, because there are no lumps, or any thing solid to be divided or broken in mortar, all that is wanted being a perfect mixture and incorporation of the materials. This may be brought about by a number of oblique scrapers or revolving shovels, like *f* in *Fig.* 119, or by alternating these with rakes, such as are shown in the figure, but in which the teeth are smaller, closer together, and upright, instead of oblique. When a mortar mill is used, the lime is slaked and mixed with the sand and some water, as if it was about to be made in the ordinary way, but it is left sufficiently dry to admit of its being conveyed in barrows without loss, and the remaining quantity of water to render it thin enough for use is added in the mill.

530. Another form of mortar mill is shown at *Fig.* 126. It consists of a large and strong wooden wheel or cylinder *h*, which is maintained in its vertical position by an axle running through the wheel, and which is a continuation of the timber arm *i*, the end of which, nearest to *i*, passes through a morticed hole in the upright revolving post *k*, so that the cylinder *h* is constrained to move in a circle round this post, which circle is formed of brickwork with sloping sides, in the form shown in section at *l l*, and motion is given to this cylinder by attaching a horse at *m*. The two sides of the cylinder are closely boarded to prevent any mortar getting into the inside of it, and its breadth should be very nearly equal to that of the bottom of the circular channel *l l*, into which the lime, sand, and water are introduced in due proportions. As the cylinder revolves it presses the materials before it, and raises them up in the two cavities *l l*, from whence they fall behind it, and the mortice joint at *i*, permits the cylinder to rise and fall for passing over the materials if they are unequally distributed. The horse is placed within the channel *l l*, for the purpose of keeping the outside of it constantly clear and open for the workmen to come and fetch mortar from all sides of the circle, or for introducing fresh materials. Cement may be mixed in a mill of this kind, provided a great quantity of it is wanted

in a short time, otherwise it is always better to mix it by two or three shovels full at a time, as rapidly as it is consumed. Most of the cements work short under the trowel, or are wanting in the tenacity that belongs to well made mortar, and they are consequently more difficult to apply.

531. Of late years, an oil cement has been introduced in England, under the name of *mastic*, which is particularly well suited to forming external mouldings and ornaments, or for plastering exterior walls to protect them from humidity, but it is not suited for the joints of walls unless a great additional quantity of oil should be used, which would render it too expensive. It is a French invention, and has given great satisfaction wherever it has been used, but works in so short and brittle a manner that it requires experience in the workman who applies and uses it. It is composed of very clean and sharp sand, mixed with about a twentieth part, by measure, of slaked stone-lime in powder, and a sufficient quantity of red-lead and litharge, to insure its drying. These ingredients are carefully incorporated together, and at the time of using them are mixed with as much linseed oil as will barely convert the dry powder into a paste. The oil should not be in greater quantity than about three or four quarts to a hundred pounds weight of the dry powder, and the wall or other surface to which it is to be applied must be perfectly dry. Mastic will adhere to brick, stone, slates, lathing, glass, and even wood, if properly applied, but it is necessary to lay a coat of the same oil upon the surface a day or two before the mastic is applied, in order to insure its adhesion.

The methods of using mortar and cement will be described in the chapter allotted to masonry and brick-work.

Section III.—*Of Timber.*

532. One of the most useful and important of the materials for building is timber, but as the means of using and converting it constitute the art of carpentry, to which a separate chapter is appropriated, and such observations as are necessary in regard to its strength and mode of application, will be found in the tenth chapter, so nothing more is required in the present section than to give an account of the varieties of timber generally made use of, and the forms into which it is cut to render it available for building purposes, and to show the manner in which it is measured, or its quantity ascertained while in the rough or unwrought state.

Timber is the production of nature, being the stems or trunks of trees, and it requires no other preparation for the builder's purpose, than seasoning it, and cutting it into the necessary forms. The seasoning of timber is an object that requires particular attention, because the goodness and durability of the timber is materially influenced by it. By seasoning is meant the gradual dissipation of the natural juices of the plant, by which it becomes dry and fit for working. These natural juices are the sap, or food, or nutriment of the plant, imbibed by the roots from the earth, carried up the stem or body, and distributed through the branches to the leaves, by a series of most minute tubes or vessels, by which the distribution is rendered very general. This sap is frequently sweet to the taste, and contains much saccharine matter, is generally fermentable, and is found by experience to be much more detrimental to the duration of the wood than pure water. The sap is thought by many to circulate, that is, to rise into the tree at one season and descend from it in another; but the probability is that it moves in one direction only. It is known to rise in the spring, when its elevation and presence are necessary in the upper part of the tree, for the production of young shoots and leaves; and it continues to flow as long as the leaves are augmenting in size, or fruit is forming. But when once these have attained their full size and maturity, there is not the same occasion for nutriment, and the supply becomes less abundant, or in all probability stops entirely when nature no longer requires it. At all events, whether the sap rises and falls again, or whether it flows abundantly at one season of the year, and not at all at another, there are periods in which every tree is much more full of sap than at others; and as it is desirable to have all timber for construction as free from sap as possible, this at once points out that one season is more favourable than another for cutting or *felling* timber, and the most favourable of all is winter, up to the period when the appearance of buds or young leaves first bursting forth indicate that the sap must be rising for their developement and growth. So soon as the leaves appear, and during the summer, no trees ought to be cut down for timber, for then they are more full of sap than at any other time. When the leaves have attained their full size and vigour, about the month of July, timber may also be cut, because then the leaves carry off the sap as fast as it is brought up, but afterwards when they do not require so much nutriment, or even begin to decay, the draught upon the trunk diminishes, and it is again found full of sap. Hence the only seasons at which trees should be cut down for timber, are the winter, and close of summer, and experience gives a preference to the former period.

533. The trunk or body of a tree is composed of three parts. The pith in the centre, the wood which surrounds it, and the

bark which forms the case or external covering. When a young tree or a shoot first grows, the pith is of large dimensions, and is surrounded by a narrow cylinder or casing of wood, and that is covered by a thin bark. The secretions of the tree are performed principally by the bark, or between the bark and the wood, and there it is that the portion of sap or vegetable nutriment destined to form wood is deposited. The process goes on during the summer, but is suspended in the winter season. But when the spring returns, a new portion of wood making sap, is brought up and deposited between the bark and the last year's wood, forming a new layer or hollow cylinder of wood, which, while it extends the bark, and causes it to crack and become uneven by renewal, compresses the former formation of wood, and renders it more close and compact. This process is renewed every year, in consequence of which, the body and branches of trees when cut transversely through, exhibit a series of rings, by which the years of its growth may be counted. These rings are only concentric in close forests, where the wood is little exposed to the sun's heat and light; but in open or single trees that enjoy these advantages to the full extent, the wood is always more thick and better developed on the south side of the tree. The pith never enlarges, and though very large in proportion to the quantity of wood in the first year's growth, probably becomes nearly useless afterwards, and being compressed by the growth of the surrounding wood, nearly disappears, and as the tree approaches maturity, bears no sensible proportion to the quantity of the wood surrounding it, so that the tree may then be said to consist of two parts only, viz: the wood and the bark. The wood from the nature of its formation, varies materially in different parts, for as the central rings are the oldest and most condensed, so, likewise, they are the hardest, most compact, and durable, and this part of the tree, or of the timber cut from it, is distinguished by the name of *heart*. For the same reason, as a tree begins to grow from the ground, the lowest extremity of it next the root is older, and more compact than the wood produced in the upper part, and is the most valuable part of the timber for use. This at once shows the impropriety of cutting timber in the manner practised in the woody part of this country, so as to leave stumps of from two feet to thirty inches high standing in the ground. The argument is, that timber is so plentiful, that the waste of this quantity is not important, or worth putting into competition with the inconvenience the woodman would suffer from having to stoop to make a low cut. But the great evil is, that two or three feet of the best timber in the whole tree is thus thrown away; and a part that is least likely to rot and decay, is left upon the land. For the same reasons that the central part of a tree furnishes the best timber, so the external part is the worst, for its last layers or rings can only be a few years old, and they (especially the last one) have their sap vessels large, and full of the circulating juices of the tree, in the operation of dispensing which, they co-operate with the bark; and hence this external wood is denoted by the name of *sap*, when speaking of timber, and this part of the wood is not only soft, but liable to very speedy decay, on account of its spongy and absorbent nature, and the great quantity of natural sap, saccharine matter, and gum with which it is always charged. The external bark contains nothing that is valuable for the purposes of building, and therefore need not be regarded.

534. From the above account it will be seen that two principal objects present themselves to the consideration of the producer of timber, one of which is, to diminish as far as possible, the production of this soft and worthless external sap-wood; or if produced, to harden and ameliorate it; and the other is to discharge and get rid of the natural juices of the tree, so as to render it dry, hard, and not liable to internal decay, and make it fit for the purposes to which it is to be appropriated. The first of these has been attempted to be attained by what is called *girdling* and *barking* the tree, while growing; and the latter is called seasoning, and cannot be commenced until the tree is cut down.

535. Girdling is making a deep incision entirely round the tree, near to its root, by means of an axe, so as to sever the sap vessels, and destroy any communication through them, between the root and upper part of the tree; and to do this effectually, the incision should not only pass through the external bark, but extend some depth into the sap-wood; and barking is the stripping off and removal of the bark from the external surface of the trunk of the tree while yet growing.

536. Both these expedients are of great antiquity, for Vitruvius and other old writers say, that the density and strength of wood is much improved by causing the tree to die standing, in consequence of resorting to either of these processes; and Duhamel and Buffon tried many experiments to ascertain the truth of this assertion, and which of the two methods might be most beneficial to the timber. The result was unequivocal; for a decided superiority was given to the timber in both cases, but the advantage as to the quantity of real sound timber obtained was greatly in favour of the barking operation. It was found that when a tree was girded to a sufficient depth, its death very soon followed, and of course no further natural change ensued. The

timber was therefore obtained in very nearly the same state as to its external rings, as it was in when the girdling took place, except that they became partially dried and seasoned. By barking, on the contrary, the death was not so sudden, and the sap-wood almost disappeared. Buffon states that some oak trees thus treated, showed no symptoms of disorder until about four months after the bark had been removed, and then their leaves became yellow and fell. Some of these trees were left standing until the following summer, and in the spring their leaves shot forth as vigorously as if the tree had not been injured, but they languished, did not come to maturity, and soon fell. This last effort of vegetation must have been carried on through the sap-wood, and therefore it might reasonably be expected that some physical change should take place in it, and on cutting down the trees, the sap-wood was found to have almost disappeared, or rather it was so changed in its nature, that it could not be distinguished from the wood of the heart. It had become dry, hard and compact, and was to all appearances as good, though not quite so heavy, bulk for bulk, as the wood in the centre; and in the experiments tried with it, it was evidently improved in strength and tenacity. The weight of equal masses of oak timber that had been barked, was greater than those felled in the ordinary manner, and the strength of the one was to the strength of the other as 81 to 74.

537. These experiments, and others that have been tried, show a marked advantage from barking trees at the period of full growth and vigour, when they are intended for timber, and letting them stand at least one year after the operation. In this way, the sound wood is not only improved in quantity, but in quality also, and at the same time it undergoes a partial seasoning, under circumstances very favourable to that process. It is often resorted to in England, and other parts of Europe, especially with oak trees, not so much perhaps with a view to the improvement of the timber, as on account of the demand for oak bark by the tanners, and the timber is often unintentionally improved in this way.

538. The seasoning of timber requires great care and attention, and is better effected by time than by any artificial method. It consists of getting rid of the natural juices of the wood, but if they are dissipated too rapidly, the timber will crack, and become so full of flaws, or shakes, as they are called, that it may be greatly diminished in value, or may be rendered useless; on the contrary, if the natural moisture is permitted to remain in it, it will undergo partial decomposition, or decay, particularly on its outside, if the bark is permitted to remain upon it. The bark should therefore be speedily removed, and if the timber is want-

ed in a square form it will also be necessary to hew it roughly into that shape, by which a great proportion of the sap-wood will be removed, thus affording better egress for the humidity from the heart of the tree. On this account squared timber always seasons more favourably, and with less injury than that which is round.

539. Timber is generally brought from the countries that produce it by water carriage, but instead of loading it into dry vessels it is made into rafts, or placed in craft that are not particularly water tight, provided it has not to be carried over the seas. This mode of conveyance is not adopted for economy alone, but to produce seasoning, since nothing contributes more effectually to this purpose, than soaking timber for some time in fresh water. The water dissolves and incorporates with the natural fluids of the wood, which are thus removed, and the water takes their place; and as the water is not viscid, and so corruptible as they are, it is more easily evaporated, and does not prove so injurious to the timber. Timber that is imported into foreign countries, must, however, be carried in close vessels, because if it imbibed sea water, its salt is deliquescent, and such timber would require a great length of time to dry, or it might never become perfectly dry, and therefore unfit for all the purposes of sound and dry work. Timber brought by sea is usually discharged into fresh water rivers, where it is formed into rafts, and kept a considerable time before it is sawed or converted to use.

540. In places that do not offer the advantages of water steeping, and where squared timber has to remain upon the ground, it may be piled one log upon another; but the logs ought never to be in contact with each other, or with the ground, unless it is intended for immediate use, as this is apt to produce decay or dry rot, particularly in recent timber. A small opening between one log and another, and between the ground and those at the bottom, should always be left so, to insure a free circulation of air; and this is easily effected by putting sticks or short timber between them. No protection against rain will be necessary, for that does good; but the logs should be screened from the effects of hot sun by putting them in shady places, or covering them with boards.

541. When logs have remained a sufficient time in the water, they should be drawn on to dry land a day or two before they are sawed, in order to dry them, and make them more fit for work. This however produces no advantage to the timber, and as it gives additional trouble, it is seldom attended to, and the logs are most commonly drawn directly from the water to the saw-mill, or saw-pit, where they are cut to any required dimen-

sions. It is then that the timber receives its last and final drying, for when cut into planks or scantling, the quantity of surface is so much increased, that evaporation now goes on very rapidly; so rapidly indeed that it requires checking, by placing the cut timber in places where it is not exposed to the action of wind or sun. The boards or pieces should be placed with intervals between them, for the reasons before assigned, and the triangular mode of piling, with the end of one board or piece resting on the others, is very convenient, as it forms spaces for the air to pass through, and affords security, as the top pieces only can be moved, and the pieces are very easily counted.

542. Different soils, climates, and exposures, occasion very sensible differences even in timber of the same kind. Thus the timber of hot and humid countries is of very rapid and luxuriant growth, and is seldom hard and good, while that of colder regions has an opposite character. In general, those trees that are of the slowest growth, and take the longest time to come to maturity, yield the strongest and most durable timber. But this is not a general rule, for some hard woods of slow growth, belong to warm climates, and the torrid zone produces a few of the hardest woods known. Knots in timber are occasioned by the pushing forth of branches from the trunk or main limbs of a tree, and they always produce contortions of grain with increased hardness, in their immediate vicinity, notwithstanding which, they greatly impair the lateral strength of a piece of timber. The production of knots depends very much upon the place where a tree is grown; for all vegetables require air and light, and should they be deprived of it, will seek it out most mysteriously. In close forests when the trees shade one another, the timber is constantly tall and straight, because trees so placed naturally shoot upwards in search of air and light, and as such positions are unfavourable to the production and growth of side branches, they seldom occur either in great numbers, or of much magnitude; consequently, the timber of such trees will be long, straight grained, and free from knots, or at any rate from large ones; and when timber or planks are thus clear from blemish or imperfection, they are, in the language of carpentry, said to be *clean*. The best white American pine timber, affords a good example of this variety. It grows to great length and width, and is so perfectly clean, or free from knots, inequalities of grain, or other imperfections, that it is almost exclusively used in England for ornamented doors, mouldings, and internal fittings of the best houses.

543. As to the kind of timber selected for building purposes, that must depend upon the facilities of the country for obtain-

ing it. In this respect England and America present a striking contrast. The British isles being of small extent, and England in particular being highly cultivated for agricultural purposes, cannot be considered a timber growing country, it being found more profitable to use the land for raising live stock, and grain, than timber. The few forests that remain in it are considered as part of the royal domain, and are reserved only for the cultivation of oak for ship building, and that generally of the crooked kind, for knees and other parts of vessels requiring curved timber. The pine is almost unknown, except in pleasure shrubberies and plantations, but the elm, the straight oak, and the beech are very common. Notwithstanding the paucity of pine in this country, that is its standard timber, and almost the only one that is used in houses, and all ordinary constructions. This timber is all imported from Riga, Memel, Dantzic, and other ports in the Baltic and north of Europe, for strong and external purposes, and from America for internal and ornamental work, and all goes under the common names of white and yellow *deal*. Oak is used for purposes where greater strength and duration are required, and this is only known to builders under two varieties, called English oak, and wainscot, the latter being an imported wood, of a handsome grain or texture. English pine and poplar, are small and soft, and held in no estimation; but the beech and elm grow very large, and the former is a very close grained and hard wood, of superior quality, and is very durable under water, and useful in the construction of tools and machinery. Mahoghany is an imported wood that is extensively used for furniture, doors, handrails of stairs, and other fittings, in the most elegant and expensive buildings.

544. America, on the contrary, was but a few years ago an almost universal forest, and will continue to yield a most plentiful supply of timber, in every variety, not only for her own wants, but for exportation to foreign countries, for years to come. The oak and pine exist here of many species, though but few of them are used for the general purposes of construction. A very fine and compact oak that is exceedingly hard and durable is found in Virginia, and is called there post oak, probably from the circumstance of its being a straight grained timber that never reaches a very large diameter. But the white barked oak, or white oak, grows generally very large, and is chiefly resorted to for large framing, and heavy machinery, for which it is a most excellent material. The pine also exists in many varieties, but is distinguished, as in England, into two sorts, the white and yellow. White pine is the kind chiefly exported to Europe. It derives its name from the colour of its wood, which is a very

light yellow inclining to white. The wood is very soft and clean; it is very absorbent of humidity, and therefore liable to great expansion and contraction in wet and dry weather; but, notwithstanding this, it is durable, particularly for inside work, and being nearly free from turpentine, or resinous matter, it works well with the plane, and is an excellent wood for holding by glue, although a very bad one for retaining nails. This material is the white deal of England, and grows chiefly in the northern states of America.

545. The yellow pine, on the contrary, is very full of turpentime, insomuch, that it will frequently ooze from the surface of the wood when cut, even though it may have been long seasoned, and the excess of this material gives the wood a reddish yellow colour, from which its name is derived. It is much more strong and durable than white pine, as the turpentine it holds is a great preservation of the wood, and renders it very slightly absorbent of water. It is much used for building and strong framing, attains large size, and is a most useful and valuable timber, though not well suited to small and neat work.

546. Hemlock is another variety of fir, agreeing very nearly with the Memel and Bruwick timber imported into England. It occurs in large logs, but is much more knotty and coarse in its grain and appearance than the other pines. It is very strong and durable, and may be used with advantage in roofs, girders or any places in which whole, or unsawed, or large timber is required, but does not answer so well to cut into boards or small scantling, on account of its knots and inequalities, which render it difficult to plane, and render it uncertain as to its strength.

547. In addition to the above timbers, which are used in common, both in England and America, the latter country has its locust, red and white cedar, cyprus, live oak, and several other useful varieties. The cedars and cypress are much esteemed for their durability, and resistance of decay from humidity, and are therefore much used for foundation work, posts to be inserted in the ground for fences, and likewise for the shingles with which almost every house and building in this country is covered; the cypress grown in the swamps being preferred for this latter purpose. The live oak is a very peculiar tree, hitherto found only in the south-eastern states of this country, and then only upon and within a few miles of the sea coast. Like all other trees growing near the sea, it never attains high growth, but is occasionally of considerable diameter. It affords a very fine grained and compact wood, which is harder and more durable than any other kind of oak, and is interesting to the Engineer and mill-wright, because it is found particularly well suited

for the formation of the wooden teeth or cogs of mill wheels. Formerly a very hard wood called *hornbeam*, was used exclusively in England, for this purpose; but of late years, considerable quantities of live oak have been exported, and it is much esteemed by all who have given it a trial. It is also an excellent material for ship building, and for all purposes where a compact, hard, and durable wood is desirable. Dog wood is a very valuable material for many purposes, particularly for turning, and on this account is much used for the formation of all turned or round patterns, for casting iron or brass from, as will be explained in the next section.

548. Timber, or lumber as it is generally called in this country, obtains different denominations, from the manner in which it is cut or prepared for use. Thus, when a tree is cut down, the top and lop, consisting of all the branches are cut off, as well as the small top end, and these parts in England where wood is scarce, are again cut up into two varieties, called *billet* and *faggot* wood. The billet wood consists of the larger branches divided into four feet lengths, and is synonymous with the small or unsplit cord wood of this country, and is used for the purpose of fuel; and faggots are the small branches and twigs, cut to two feet lengths, and tied into small bundles for kindling fires. The quantity of top to be cut away from a tree, is regulated by the circumference; for nothing is called, or considered timber, that has a less girth or circumference than 24 inches. The body of the tree thus left naked, is called *a stick of round timber*. If four of its sides are hewn or chopped to such an extent only as not to render it square, but with an octagonal section, consisting of four flat and four curved sides, it becomes *a baulk* or log of rough hewn timber; but if the hewing has proceeded to such an extent as to have made it quite or nearly square, then it is called *a die square stick* or piece of timber; and all timber ought to be reduced to this form by hewing or sawing before it is sawed or divided into smaller pieces. These several denominations are not affected by the length of the pieces.

549. Timber is divided into smaller pieces by sawing; an operation that was formerly carried on by hand labour only, but which is now better and more cheaply and expeditiously performed by the saw mill; so that hand-sawing is only resorted to when the convenience of the mill cannot be obtained. If a stick of round timber is sawed, the pieces taken from its two opposite sides will be flat on one of their sides, and will partake of the rotundity of the tree on the other, and such pieces are called *slabs*. They are not of much value, on account of their round side, rough edges, and their being external, and consequently sappy wood,

but are used for covering drains, making temporary fences, and they are occasionally, though improperly, put for planking under the foundations of brick and stone walls.

When timber is cut or divided, it has different names applied to it, depending upon the size and form of the pieces so produced. Thus, when a stick of timber is sawed longitudinally, so as to produce a number of plates of timber, the sides of which are parallel to each other, such plates are called *planks* or *boards*, which names are applied according to their thickness. Every piece that is two inches thick, but does not exceed four or five inches, is called *a plank;* and planks are distinguished by their thickness, length, and species of timber. Thus we have 2 inch pine plank twenty feet long; and the various kinds of plank are thus designated, by always naming the thickness, length, and kind of wood; and the thickness always varies by half inches, so that 2 inch, $2\frac{1}{2}$ inch, 3 inch, $3\frac{1}{2}$ inch, 4 inch, $4\frac{1}{2}$ inch, and 5 inch plank constitute all the varieties. In England pine planks of 3 inches thick are called *deals*, consequently, whenever deals are mentioned in quoting prices in British newspapers, or price lists, this dimension is always understood; the length of the planks being generally added, and the place they come from, by which their quality is in some measure known. Thus 20 feet Christiana deals, would indicate 3 inch planks, each 20 feet long, from Christiana in Norway, and as that place always sends a superior kind of plank into the market, they fetch a higher price than deals from other countries. In describing pine planks or boards, it is also necessary to state whether they are white or yellow, and clean.

550. Any parallel plate of timber less than two inches in thickness, is called *a board*, consequently there are quarter inch, half inch, three-quarter inch, inch, &c. boards, until the thickness reaches two inches, when the board would be called a plank. If no thickness is specified for a board, one inch is always understood; so that if a carpenter was desired to board up a partition, or other piece of work, he would of course use boards one inch thick. Flooring boards are, however, always considered to be one inch and a half, or one and a quarter thick, and would accordingly be so used, unless directions were given to the contrary. Boards are frequently sawed out of whole sticks of timber, but the best are those that are produced by sawing planks, because boards ought to be well seasoned before they are used, and nothing seasons timber more effectually than keeping it in a state of plank for a considerable time, before it is subdivided into thin boards. It is likewise a common practice in this country to produce planks or boards at once out of round timber, when of course the edges

of the thin pieces will be rough and ragged, partaking of the original rotundity of the tree. Such planks or boards are called rough edged, and in measuring them, the purchaser has the right of deducting as much from the quantity as will convert them into *square edged stuff*, because all planks and boards should be sold with straight and square edges, which can only be produced in the first instance by converting the round log of timber into the die square form, before the sawing process commences. When a piece of timber or a plank is sawed into boards, particularly when they are thin, each board is called *a leaf*, from the resemblance to a book, so that if five cuts are made in a three inch plank, it will convert it into six half inch leaves or boards. Sometimes the cuts are not all parallel to each other, but the board produced is made one inch wide on one edge, and only half an inch at the other, as when boarding is wanted for covering the sides of frame buildings, and it is then called *feather edge* or *weather boarding*. The best floors are laid with *battens*, which is the name of narrow boards being from 3 to 6 inches wide, cut out of the heart or best of the timber, and they are consequently free from sap. The best battens are likewise clean or free from knots, and are, therefore, the best and most expensive kind of boarding.

551. When timber is cut in two longitudinal directions at right angles to each other, so as to leave the corners square, the pieces are called *scantling*, or quartering, which last term was probably derived from the entire stick of timber being cut into four quarters, by being first slit down the middle, and each half being again divided. Scantling is, however, any thing that is above two inches square, and less than a whole stick of timber; and it is always designated by the dimensions of its sides. If one dimension only is given, then all sides of the piece are alike. Thus 2 inch, 3 inch, or 4 inch scantling imply a long piece of timber, each side of which measures two, three or four inches, consequently it is square. But if the two sides differ, their two dimensions must be given, as 4 by $2\frac{1}{2}$ inches, or 3×6 inches, &c.; this imports that its two opposite sides each measure the same, so that it will have two sides 4 inches wide, and the other two $2\frac{1}{2}$ inches. Four by two and a half inches is the most usual size of scantling used in brick buildings, because it is the same size as the end of a brick, and therefore works in very conveniently with brickwork. For this reason scantling of this size is commonly called regular quartering, and is the kind of material almost constantly used for the common rafters of roofs, and for lath and plaster partitions between one room and another in a house. Such partitions are frequently called quarter partitions by workmen, on account of their being formed of quartering.

552. In addition to the above forms into which timber is cut, some of the most valuable and expensive woods are divided into very thin leaves, varying from the tenth to the twenty-fourth of an inch in thickness, when they are called *veneers*, and are used for ornamenting furniture, and doors, by glueing them upon the surface of the thing to be ornamented, when it is said to be veneered, and this term is frequently used in opposition to solid work, which means work made of the same kind of wood throughout, and it is, therefore, more substantial and durable.

553. Timber when cut into any of the forms above described has the general name of rough or unconverted timber, and in this state it is always sold by measure to the carpenter, builder, or consumer; and in pursuance of the observation made at the close of Chapter III. (210,) this subject will be concluded by practical directions for measuring the several forms of timber, an operation that should always be performed on receipt of it upon the work, or before any part of it is used or converted.

554. The practice for round timber, that is whole trees, before they are squared or hewn, is to take one quarter of their mean circumference. The circumference in timber measuring is called the *girt* of the tree, and consequently a fourth of it will be its *quarter girt*, a term quite familiar to those who are in the habit of measuring timber, and it is usually obtained by straining a string, strap of leather, or cord round the tree, and afterwards doubling it in four equal parts; the length of one of which is then measured in inches by a common inch ruler. A better way is to take the girt with a measuring tape (373) in inches, and divide the quantity by four, because if the string is large a loss of its length will occur at each fold.

Any part of a tree that is less than two feet round, or six inches in the quarter girt, is not deemed timber, and consequently must not be measured as such. If a tree tapers regularly from end to end, its girt may either be taken in the middle, or half the sum of the girts at the two ends may be used to obtain the quarter girt; but when the tree does not taper regularly, or if it contains branches or arms, it must be divided into two or more parts, the dimensions of each of which must be taken separately. In some cases, where from the irregular form of a tree a difficulty may arise as to the proper girt, the position is settled between the buyer and the seller, previously to taking the dimension. When trees are measured with the bark upon them, an allowance is made for it. In oak and elm the deduction is at the rate of an inch in the foot, from the quarter girt; ash, beech, and such trees as have thinner bark, have from half to a quarter of this allowance, according to the state of the bark. This deduction is, however, a matter of agreement between the buyer and seller, and if nothing has been said about it, the purchaser has a right to make it at the rate above mentioned.

Having ascertained or agreed upon the quarter girt of any piece of timber, it has to be squared or multiplied by itself, when the product is multiplied by the length of the stick in feet, and the result divided by 12, and again by 12, or at once by 144 to obtain the solidity in cubic feet, provided the quarter girt is taken in inches, but if the tree is so large as to permit its girt to be taken in feet, this division is unnecessary.

Example.—What quantity of timber does a tree contain, the quarter girt of which is $14\frac{1}{4}$ inches, and its length 34 feet?

$$14.25 \times 14.25 = 203.06 \times 34 \text{ ft.} = 6904.04 \div 12 = 575.33 \div 12 = 47.94 \text{ ft.}$$

If the above had been an oak or elm tree with the bark upon it, but still measuring to the same girt, its quarter girt would have been called $13\frac{1}{4}$ after making the deduction for bark.

555. In order to avoid the long computations that become necessary in measuring large quantities of timber, timber measurers are in the constant habit of using Gunter's sliding rule, which may be bought at any instrument-maker's, and is the common two feet carpenter's rule with a slider applied to one of its sides. This part of the rule contains four logarithmic lines of numbers, marked at one end by the letters A B C D. The two middle lines, B and C, are upon the slider, and the other two upon the ruler, but in close contact with the slide, and as the figures or numbers on the slide are placed between the two divided lines, they serve for both of them. The three lines A B C, are called double lines, because the figures from 1 to 10 are contained twice in the length of the slide, and the lowest outer line D contains only one set of divisions and numbers from 4 to 40, and is called the *girt line,* on account of its great utility in computing the contents of trees and timber of all forms.

The other blade of the ruler under the slider is usually filled up with tables that are useful in computing quantities of timber and its value, so as to render the instrument exceedingly useful for all the purposes for which it is intended as comprehended under its name, which is *the sliding rule for measuring timber.*

The use of the double lines A and B is for working proportions and finding the areas of plane surfaces; and the use of the girt line D, and the other double line C, is for measuring solids. The only difficulty the learner will find in using this rule, is the correct reading of the divisions; but the method of notation is very simple when once understood. To avoid filling the scale with figures, every tenth division only has a figure set against it, and the intermediate divisions have to be counted. The numbers begin at the left hand, and proceed towards the right; and when 1 at the beginning is accounted one, then 1 in the middle will be 10, and the 1 at the end 100. But if the first 1 is called 10, the central 1 will be 100, and that at the extreme end 1000, and so on; and of course all the small or intermediate divisions must be proportionally varied in reading them off. So soon as the mind has become accustomed to this instrument, the speed and accuracy with which problems may be solved never fails to surprise. With a well divided rule, in skilful hands, a solution to about the 200th part of the whole may be relied upon, and will be obtained in as short a time as would be necessary to set down the figures without working the operation; for in using the slide rule no quantities need be set down, and the result is obtained by inspection, the moment the slider is moved into its proper position. Thus, if it was required to work the foregoing example by this ruler, all that is necessary is to find that division upon the line C that marks 34 or the length of the tree, and to bring that mark opposite 12 on D. Then look for the quarter girt $14\frac{1}{4}$ on D, and this will stand against 48 on C, agreeing very nearly with the result 47.94 before obtained by figures. The slide rule, if not quite as exact as figures, has one decided advantage over them, which is, that from the nature and construction of the instrument, an error cannot occur if the first points are set right; while with figures worked in haste, in the open air, where timber is constantly measured, the chances of error will be very frequent.

556. The method above described of measuring round timber by the square of its quarter girt, is so general among all timber measurers, that it would be in vain to attempt any alteration or innovation upon the process, notwithstanding it is not a correct one; for it gives a result of very nearly one-fourth less than the true quantity in the tree, or very nearly what the tree will hold after it is trimmed and squared. This has been used as an argument by some for continuing this mode of measurement; because as it has become a standard rule of practice, the vender is satisfied with it, and the purchaser gets his squared log fit for use without the loss that would be attendant upon cutting the slabs to waste. The round external pieces, being seldom convertible to useful purposes, ought not to be paid for at the same rate as the hard square wood in the centre, and this is another reason why they should not be fully included in the measurement; but in general they will more than pay the cost of sawing off slabs, or of hewing, when the chips are valuable as fuel.

557. The only true rule for finding the contents of tapering

round timber is that which has been given for finding the solid contents of the frustrum of a cone (Prob. XLV. 190); but it is too tedious for despatch in business, and is considered too nice for the ordinary kinds of timber. As a proof, however, that the rule in general use does not give a correct result, we have only to consider the three following cases extracted from Dr. Hutton's excellent treatise on Mensuration, (8vo. 1802,) in which it will be seen that several distinct measurements may be obtained from the same tree, all correct according to the rule, and yet all different; while, if the rule was a correct one, the result must be the same, by whatever process it may be obtained.

Example 1.—To cut a piece of round timber in such a way that the two parts measured separately by the ordinary method shall produce a greater solidity than when cut in any other part, and greater than if not cut at all. This object will be obtained by cutting the tree through, exactly in the middle of its length. Thus suppose a tree to girt 14 feet at its large, and 2 feet at its small end. Its average girt will then be 8 feet, and if it is 32 feet long, the whole tree, by the common process, will measure to 128 feet; but when cut through in the middle, the thick end will measure 121 feet, and the small end 25 feet, whose sum is 146 feet, being 18 feet more than the entire tree contained.

Example 2.—To cut a tree so that the greater end may measure to the greatest possible quantity.

Make the cut at that place where the girt is one-third of the greater girt. Thus, taking the same tree as in the last example 32 feet long, and with 14 feet for its greater girt, a line of 4 feet 8 inches being one-third of the large girt, must be measured off and applied round the smaller end of the tree until it fits or becomes the girt; this will take place at about 7 feet from the small end, and here the cross cut must be made. The large end or butt will now measure $135\frac{1}{2}$ feet, while the whole tree only measured to 128 feet. This is a rule that the venders of timber are well acquainted with, and often practice, but it is only applicable when the greatest girt exceeds three times the least. For when the least girt is exactly equal to one-third of the greater, the tree has the most advantageous dimensions for measurement, and nothing can be cut away without diminishing the quantity.

Example 3.—To cut a tree so that the part next the greater end may measure very nearly the same as the whole tree would measure to.

Call the sum of the girts at the two ends of the whole tree s, and their difference d, then multiply d by the sum of d and $4\,s$, and from the root of the product take the difference between d and $2\,s$; then as $2\,d$ is to the remainder, so is the whole length to the length to be cut off from the small end. Thus using the same tree as in the foregoing examples, we shall have $s=16$, $d=12$, and length = 32 feet, and on working the rule it will be found that 13.6 feet have to be cut off the small end, leaving the butt 18.4 feet long. The girt where the cut must take place will be found 7.099 feet, and the girt at the large end being 14 feet, the mean will be very nearly 10.5, one-fourth part of which, 2.625, will be the quarter girt. Now $2.625^2 \times 18.4 = 126.88$ feet, being very nearly the same that the whole tree measured to in the first example, notwithstanding that one-third part has been cut off its length.

558. The above mentioned anomalies are interesting to, and ought to be constantly in the mind of the young engineer or builder when purchasing timber, because the small end of a tree never measures to much, and may often be useful as a stake or post, or even for fire wood, and it is, therefore, better to have it delivered than to have it cut off, especially as a larger quantity of timber may have to be paid for, after it is separated, than before, and the only reason for discarding small ends should be bad roads, or difficulty of conveyance, which may make the additional carriage more expensive than the value of the piece of timber would compensate for.

559. Although the preceding is the only rule that timber measurers will consent to adopt, yet Dr. Hutton mentions another which comes much nearer to the truth. That is to multiply the square of one-third of the mean girt by twice the length of the tree, when the product will give the true content very nearly.

560. Another process that has been attempted to be introduced in some parts of England, for accurate work, is to divide the mean girt by five and square the quotient, which in like manner has to be multiplied by twice the length, and this also comes very near the truth.

561. It is frequently necessary to measure timber while it is yet standing, and for this purpose a set of divisions is frequently engraved on one side of the vertical semicircle *e e*, Fig. 77, Pl. II. of the best *theodolites*, which, if the instrument is set truly level, and at a convenient distance from a tree, so that the telescope can be moved towards its upper part, will give the height of such tree in 100th parts of the horizontal distance of the tree at the time of observation. But as all persons who may wish to measure timber may not possess a *theodolite*, and all these instruments do not contain this set of divisions, other expedients must be resorted to; and that which is most used, is to place an upright pole in the ground on a level with the root of the tree, and then to select a station at which the top of the pole (which is of course

placed between the tree and the eye) shall appear to coincide with that part of the tree to which the measurement is required. Then measure the distance of the pole from the tree, and likewise its distance from the place where you stood to make the observation, likewise measure the height of the pole and of your eye, and having deducted the height of the eye from the height of the pole, multiply the remainder by your distance from the tree, and divide the product by your distance from the pole. Add the height of the eye to the quotient, and the sum will be the true height of the tree.

562. Another and less troublesome method is to provide a piece of thin board 10 or 12 inches square, the four sides of which must be perfectly straight, equal and at right angles to each other. To one corner of this board fix a plumb line of such length that its weight may hang about an inch beneath the lower corner of the board when it is held in a plane perpendicular to the horizon. From the upper angle to which the plumbet is attached, draw a strongly marked diagonal line to the opposite low corner, or what is still better make a saw cut in this direction, or fix a tin pipe about a quarter inch in diameter over such line to guide the sight. To use the instrument so prepared, select a station upon level ground from which you can see the part of the tree you desire to measure to, through the tube or saw cut while the plumbet hangs in contact with the vertical side of the board, and then on measuring your horizontal distance from the tree, and adding the height of the eye from the ground thereto, you will obtain the perpendicular height of the tree.

563. To find the girt of a regularly tapering tree while it is standing. First find the height as above directed, and take the girt at the bottom. Then, with a short ladder, or at as great a height as can be reached, take another girt above the bottom. Multiply the difference between the first and second girts by the height of the tree, and divide the product by the distance between the girts, and on deducting the quotient from the first girt, the girt at the height required will be obtained.

564. When large timber is squared on its sides, or is cut into rectangular pieces by the saw, no difficulty can exist as to its mode of measurement, but it must be observed, that the method of computing its value depends on the form and thickness of the pieces, for all boards are computed by superficial, and all large timber by solid or cubical measure. The distinction commences at two inches of thickness, therefore every piece of timber that measures two inches or upwards on one or both of its sides is subject to cubical measure, and of course planks of every description are included in this denomination.

565. Boards and planks are always kept assorted, both as to length and thickness, and in measuring them it is proper to preserve this assortment, and to measure all pieces that have the same length and thickness together. It saves much time, because one dimension as to length and one as to thickness serves for any number of pieces, and the surface measure is, therefore, the only one that has to be taken.

Boards of the same length are usually measured across by a string, the length of which is determined after the operation is finished; but the measuring tape divided into inches is much more certain and convenient, as it gives the measure at once. The mode of conducting the measurement is to strain the string or tape across the width of the board, drawing it forwards with the right hand, while it is pinched or held to the edge of the board between the finger and thumb of the left hand. The part so held is then transferred to the right hand side of a second board, and the finger and thumb of the left hand are then made to slide over the tape until its width is determined, and so on for any number of boards. The width of each individual board is not noticed or set down, as it is only the sum of the whole quantity that is required. Fifty or a hundred feet of string or tape, are, therefore, frequently run over a lot of boards before any notice is taken of the amount; and when the operation is ended, the sum thus obtained of all the separate widths, is multiplied by the common length, and that gives the superficial measure of the whole quantity. As before noticed, all boards and planks should be straight and square at both their edges, and if they are not so, or if they are crooked, or contain such splits or imperfections as might render them useless, the purchaser only measures such part as will cut to a straight and fair board; and the same rule applies to their ends, which are frequently rough, split, and irregular, in which cases as much must be deducted from the length as, when cut off, will make them square and perfect.

566. When the value of *boards* is spoken of, it always refers to such as are one inch thick, this being what is technically called *board measure*. Two half inch boards are worth more than a single inch board of the same length and breadth, by the cost or value of the sawing only; and for the same reason, a two inch plank is not quite as valuable as two inch boards, because the expense of sawing has not been incurred upon it. Feather edge boards, or weather boarding that is one inch thick at one edge, and half an inch at the other, is always valued as three-quarter boards, and all boards are estimated and sold by the hundred or thousand, which of course means 100 or 1000 superficial feet.

Mahogany and the valuable woods, although sold in the log, are always estimated by superficial, or broad measure; so that a cubic foot of mahogany would be sold and charged as twelve feet, because it would cut into twelve slices, each of which would be equal to one superficial foot. And the still more expensive woods that are used by turners, and for ornamental purposes, such as box-wood, ebony, lignum-vitæ, cocoa, &c., are always sold by weight instead of measure.

567. All the ordinary varieties of timber in pieces exceeding two inches square are measured and estimated by cubic measure; the method of taking which is so simple and so generally understood, that it hardly appears necessary to describe it. The superficial dimensions of the transverse section of the piece must be first obtained by multiplying the dimension of one side by that of the other at right angles to it, or what is generally called multiplying the side into the edge, and the product so obtained is again multiplied by the length of the piece. If all these dimensions are taken in inches, then the product will be the total number of cubic inches in the whole piece, and this sum must be divided by 1728, (the number of cubic inches in a cube foot,) to reduce it to cube feet; but if the area has been taken in inches, and the length in feet, which is usually the case, then the product must be divided by 12, and the quotient again by 12, or at once by 144 to procure the necessary reduction.

All planks and scantlings of every size are measured in this manner, and reduced to cubic feet, adding the price of sawing to the cost of the timber, to determine the value. Sawed timber either in boards, planks, or scantling, is worth more than the mere value of such timber and sawing; because, when a whole stick of timber is bought, the purchaser cannot judge of its soundness throughout, and he takes it on his own risk, as to how it will *open*, as it is technically called. But sawing up a piece of timber exposes all its defects and blemishes, if any exist, and the buyer of boards or scantling having the right of choice will of course select that only which is free from sap defect and blemish, and therefore in justice ought to pay a higher price, unless he takes a fair proportion of good and bad together. In England the price of timber is almost constantly quoted by the load instead of the cube foot, but this does not affect the calculation, since a load is in London and many other places 50 cubic feet, but in Bedfordshire and some of the inland counties, 40 feet is called a load. The term is therefore vague and uncertain, and on this account is not insisted on. In reading English works on building or architecture, the price of timber is almost constantly given by the load, and if it should be necessary to reduce this to cubic feet, the price per load may, without much chance of error, be divided by 50, because that is by far the most general number of cubic feet considered as a load; and of course reversing the operation, or multiplying the price per foot, will give the price per load.

568. Sawing is always computed as to its value, and paid for by the superficial measure of the surface sawed through, and is usually charged by the *hundred*, meaning the number of hundred superficial feet that are laid open or exposed by the cuts. Wherever water power can be obtained, the sawing is much more cheaply and expeditiously performed by the saw mill; but where this advantage is not attainable it must be done by the hand labour of sawyers, who always work in pairs. The upper man who stands on the piece of timber to be cut, is the superior workman, because he sets out the lines to be cut, guides the saw during the operation, and measures the work when finished; while the under man is only required to exert strength for pulling down the saw. For common timber the saw made use of is called a whip saw, and is a mere blade of steel with coarse teeth on one of its edges, and a cross handle at each end for the workmen to lay hold of. The blade of this saw must be of considerable thickness to give it sufficient stiffness and strength for its work; and as all saws require their teeth to *be set*, that is each tooth to be forced, in a small degree, out of the plane of the saw, or each alternate tooth to be bent, the first towards the one, and the next towards the other side of the blade, in order that the teeth may cut a wider opening than is necessary for the passage of the blade, to prevent its being pinched by the cut already made, which would introduce much detrimental friction, so this kind of saw wastes a considerable quantity of timber in cutting thin boards, and is not applicable to valuable wood; for the cut made is generally near one-eighth of an inch wide, consequently, in eight or nine cuts, an entire inch board would be wasted by being converted into saw dust. The more valuable woods are therefore cut by a frame saw, which is a much thinner blade, with finer teeth, tightly stretched or strained in a light wooden frame, by which it is prevented from bending, and the cut made by it rarely exceeds the sixteenth or twentieth of an inch in width, so that it produces comparatively little waste. Veneers and very thin leaves are generally cut by circular saws. The saw in this case is a thin circular plate of steel with fine teeth formed on its edge, and it is made to revolve on a central shaft, or axle, with great velocity, by appropriate machinery. Rough timber is usually cut transversely to its length by a long stiff saw, having a handle at each end, to which two men apply their strength, and the implement is called a cross-cut-saw. In all machine sawing

the saws move in such directions as are necessary to promote the cutting action of their teeth, but never change their places, consequently the timber to be cut has to be moved forwards to the saw as the cut proceeds, and this constitutes one of the nicest points in a good sawing mill that is intended to work on various timbers, because the velocity with which the wood moves forwards must be proportioned to its hardness, and the knots and inequalities that occur in it, or the saws, will be broken. If the same size and quality of timber is constantly used, no such adjustment is necessary, because one uniform velocity may always be made to suit similar work. In hand-sawing, on the contrary, the timber is stationary, and the saw moves forward with a speed depending on the exertions of the workmen and the hardness of the timber they are dividing.

569. As all timber is sold by the cube foot, this price of course regulates the price of all scantling; consequently if we calculate how much of any sized scantling will make a cube foot, and add the price of sawing, we shall at once determine the value of such scantling. This calculation is simple and easy, but it occurs so frequently, and for such a variety of sizes, that the following table, in which the quantities are shewn on inspection, will be very useful.

570. A TABLE *shewing what length of timber of any scantling from 2 inches to 12 inches square, will make a cube foot of timber.*

In.		In.		Ft.	In.
2	by	2	requires	36	0
2	,,	2½	in length	28	9
2	,,	3		24	0
2	,,	3½		20	7
2	,,	4		18	0
2	,,	4½		16	0
2	,,	5		14	5
2	,,	5½		13	1
2	,,	6		12	0
2	,,	6½		11	1
2	,,	7		10	3
2	,,	7½		9	7
2	,,	8		9	0
2	,,	8½		8	6
2	,,	9		8	0
2	,,	9½		7	7
2	,,	10		7	3
2	,,	10½		6	10
2	,,	11		6	6
2	,,	11½		6	4
2	,,	12		6	0
3	,,	3		16	0
3	,,	3½		13	8
3	,,	4		12	0
3	,,	4½		10	8
3	,,	5		9	7
3	,,	5½		9	0
3	,,	6		8	0
3	,,	6½		7	4
3	,,	7		6	10
3	,,	7½		6	4
3	,,	8		6	0
3	,,	8½		5	8
3	,,	9		5	4
3	,,	9½		5	0
3	,,	10		4	10
3	,,	10½		4	6
3	,,	11		4	4
3	,,	11½		4	2
3	,,	12		4	0
4	,,	4		9	0
4	,,	4½		8	0
4	,,	5		7	2

In.		In.		Ft.	In.
4	by	5½	requires	6	6
4	,,	6	in length	6	0
4	,,	6½		5	6
4	,,	7		5	1
4	,,	7½		4	9
4	,,	8		4	6
4	,,	8½		4	3
4	,,	9		4	0
4	,,	9½		3	9
4	,,	10		3	7
4	,,	10½		3	5
4	,,	11		3	3
4	,,	11½		3	2
4	,,	12		3	0
5	,,	5		5	9
5	,,	5½		5	3
5	,,	6		4	10
5	,,	6½		4	5
5	,,	7		4	1
5	,,	7½		3	10
5	,,	8		3	7
5	,,	8½		3	5
5	,,	9		3	2
5	,,	9½		3	0
5	,,	10		2	10
5	,,	10½		2	9
5	,,	11		2	8
5	,,	11½		2	6
5	,,	12		2	4
6	,,	6		4	0
6	,,	6½		3	8
6	,,	7		3	5
6	,,	7½		3	2
6	,,	8		3	0
6	,,	8½		2	10
6	,,	9		2	8
6	,,	9½		2	6
6	,,	10		2	5
6	,,	10½		2	3
6	,,	11		2	2
6	,,	11½		2	1
6	,,	12		2	0

In.		In.		Ft.	In.
7	by	7	requires	2	11
7	,,	7½	in length	2	9
7	,,	8		2	6
7	,,	8½		2	5
7	,,	9		2	3
7	,,	9½		2	2
7	,,	10		2	1
7	,,	10½		1	11
7	,,	11		1	10
7	,,	11½		1	9
7	,,	12		1	8
8	,,	8		2	3
8	,,	8½		2	1
8	,,	9		2	0
8	,,	9½		1	10
8	,,	10		1	9
8	,,	10½		1	8
8	,,	11		1	7
8	,,	11½		1	7
8	,,	12		1	6
9	,,	9		1	9
9	,,	9½		1	8
9	,,	10		1	7
9	,,	10½		1	6
9	,,	11		1	5
9	,,	11½		1	4
9	,,	12		1	4
10	,,	10		1	5
10	,,	10½		1	4
10	,,	11		1	4
10	,,	11½		1	3
10	,,	12		1	2
11	,,	11		1	2
11	,,	11½		1	2
11	,,	12		1	1
12	,,	12		1	0

571. A TABLE *for expeditiously measuring round timber.* (See p. 554.)

Quarter girt.	*Area.*	*Quarter girt.*	*Area.*	*Quarter girt.*	*Area.*
Inches.	Feet.	Inches.	Feet.	Inches.	Feet.
6	0.250	12	1.000	18	2.250
6¼	.272	12¼	1.042	18½	2.376
6½	.294	12½	1.085	19	2.506
6¾	.317	12¾	1.129	19½	2.640
7	0.340	13	1.174	20	2.717
7¼	.364	13¼	1.219	20½	2.917
7½	.390	13½	1.265	21	3.062
7¾	.417	13¾	1.313	21½	3.209
8	0.444	14	1.361	22	3.362
8¼	.472	14¼	1.410	22½	3.516
8½	.501	14½	1.460	23	3.673
8¾	.531	14¾	1.511	23½	3.835
9	0.562	15	1.562	24	4.0 0
9¼	.594	15¼	1.615	24½	4.168
9½	.626	15½	1.668	25	4.340
9¾	.659	15¾	1.722	25½	4.516
10	0.694	16	1.777	26	4.692
10¼	.730	16¼	1.833	26½	4.876
10½	.766	16½	1.890	27	5.062
10½	.803	16¾	1.948	27½	5.252
11	0.840	17	2.006	28	5.444
11¼	.878	17¼	2.066	28½	5.640
11½	.918	17½	2.126	29	5.840
11¾	.950	17¾	2.187	29½	5.944
				30	6.250

EXAMPLE OF THE USE OF THE ABOVE TABLE.

Having taken the quarter girt of any piece of timber by measurement, find the corresponding quarter girt in the table, and the number in the column headed "area" that stands opposite being taken out, is to be multiplied by the length of the tree in feet, and the product will be the contents in cubic feet and decimals of a foot. Thus suppose a piece of timber 16 feet 9 inches long, (or 16.75 feet,) and its quarter girt to be 20 inches; its corresponding area is 2.717, therefore 2.717×16.75=45.50975 feet the contents.

SECTION IV.—*Of Iron and other Metals.*

572. Iron and the metals have never been considered as regular building materials, but are treated only as auxiliaries to the

principal substances that have been already described; because the builder generally uses them merely as means of connecting other things together, or adding to their strength in the form of nails, screws, bolts, straps, or connecting bars, with the exception of the sheet or flattened forms of tin, lead, and copper, which have been long used for the occasional covering of roofs, or for forming gutters and pipes for the conveyance of rain water from the upper parts of buildings, or for the pipes by which water is supplied, or is conveyed from one place to another. The use of the metals in ordinary buildings is therefore limited. But in the constructions of the Engineer, the case is very different. The many places in which iron is now manufactured renders it cheap, and easily procured; while the facilities that have taken place in its mode of manufacture, and of working it, resulting from its constant employment, have produced an almost entire revolution in the works of the Engineer and Millwright, insomuch that they now look upon iron almost as their staple commodity, and it is constantly introduced into situations, and applied to uses which half a century ago would have been deemed preposterous, if not impossible.

573. The under-ground pipes that supply our cities with water were formerly bored out of whole trees, or were formed of stone or baked earthenware; the former material was subject to such rapid decay as to occasion constant repairs and expense, and the latter, being very brittle, was liable to frequent fracture, and great difficulty existed in making and maintaining the joints water tight, so that no great head or pressure of water could be put upon them; but now such pipes are superseded by those of cast iron, which seldom need repair, if well laid down in the first instance, and they are so durable and strong that no difficulty now occurs in sending water to the tops of the highest buildings, or drawing it from the bottom of the deepest mines without fear of failure or accident. The cog wheels of our mills and machines, which a few years ago were made wholly of wood, liable to rapid wear and decay, are now constantly made of cast iron or other metal, and work with the perfection and precision of clock work. The chief members of our steam engines are now made wholly of iron; and it is substituted for wood or stone in roofs, in floors, in bridges and in rail roads, so that some information on the nature of iron and the other useful metals, and on the means of working and appropriating them, becomes quite essential and necessary to the Engineer.

574. Iron is one of the most abundant mineral products of nature, but is very rarely met with in the proper metallic state in which it is used. All iron when exposed to humid air becomes

rusty, or, in the language of chemistry, attracts oxygen from the atmosphere, and is converted (at least upon its surface,) into oxide of iron, and in process of time will become oxydized throughout its whole substance; for the rust of iron is a regular oxide, and iron has so strong an affinity for oxygen that it is a matter of difficulty to prevent this oxydation going on, notwithstanding our desire to avoid it. This at once shows why native metallic iron should be scarce, and why most of the ores of that metal that are met with should be oxides. The oxides of iron seldom present a metallic appearance, and vary in colour from bright red to reddish-yellow, or bright yellow, and are occasionally nearly black; and this metal is so generally disseminated over the surface of the globe that these oxides frequently give a tint of colour to the whole soil, rendering it brown, yellow or red. In these cases the iron exists in such small quantities as to render its obtention for useful purposes impossible. What are called iron mines are immense collections of the ore of iron forming in masses that are usually stratified in a nearly horizontal direction, and which are frequently from six to twelve or fifteen feet in thickness, and of great extent. These mines or formations of iron ore are very common, and exist to a greater or less extent in all countries, particularly such as are mountainous; but the ore is useless without the proximity of a plentiful supply of fuel to reduce it, and of limestone, which is necessary for a flux to promote the flowing of the metal when produced from its original matrix. On this account many valuable deposits of iron ore are discovered, but cannot be worked, for iron is now sold at so cheap a rate as not to admit the expense of transporting any of the necessary constituents for its formation to a distance, and those mines only work to great advantage in which the iron ore, limestone, and wood or coal are found on the same location, which is by no means an uncommon case.

575. The art of extracting and raising the ore and coal; building the furnaces for the reduction and purification of iron; and the machinery that is used afterwards for converting it into bars and other useful forms, as well as the water-wheels or steam-engines by which they are set in motion, are parts of the Civil Engineer's business, and the planning and erection of such works are a branch of his duty; but as they belong more particularly to that division of the profession that embraces mining and metallurgy, they will be passed over for the present; all that is intended by the present section, being to put the Engineer in possession of such information as will enable him to judge of the qualities of iron and the other metals, and to use them with advantage, after they are produced, and have reached the public market.

576. Iron has a strong affinity for most, if not all the natural combustibles, and in a hot state will combine readily with them; and it also combines or mixes with most of the other metals, forming alloys that alter the character of the metal very essentially. In proof of this, heat a bar of iron in a smith's forge to a nearly white, or what blacksmith's call a welding heat, and on rubbing it with a stick of brimstone or sulphur, the iron and sulphur will simultaneously melt and fall down in drops, which become hard on cooling, but on examination will be found to be neither iron or sulphur, but a combination of the two, called by chemists sulphuret of iron, which is hard and brittle, without metallic lustre, and in fact possessing none of those properties that render iron valuable. It might be supposed that on heating this compound again, the sulphur would be evaporated and driven off; but this will not be the case. The combination is too strong to be dissolved by such means, and the iron is spoiled for all ordinary purposes. Iron combined naturally with sulphur, is a very common mineral production, found constantly in iron and other mines, and known generally by the names of *iron* or *martial pyrites*, *mundic*, and *marcasite*, and it is one of the most bright and beautiful minerals, being crystalline with metallic lustre, and a colour between brass and gold, so that it has frequently been supposed by the ignorant to be this latter metal. This mineral, when it occurs, must be carefully picked out of the iron ore, before it is worked, as a small quantity of it will deteriorate a large quantity of iron.

577. Carbon, or the pure material of coal, unites with iron in the same manner as sulphur, though to a less extent, and is less detrimental to it; and as the reduction of iron ore consists in filling a very tall furnace, built for the purpose, with alternate layers of iron ore, limestone, and fuel, which soon gets into a state of ignition by the fire previously made, and which is urged by the most powerful bellows or other blowing machinery, so as the iron becomes reduced by being deprived of its oxygen, and trickles down through the ignited fuel, it comes into constant contact with carbon, while both are at a very high temperature, and a union consequently takes place. In this manner, however, all iron is reduced in the first instance, and being obtained in a fluid or molten state, the bottom of the furnace is tapped, or a hole opened into it at stated periods, to permit the fluid iron to flow out; and when cold, it first assumes the character of metallic iron; but it is unfit for general use, being white and almost crystalline in its fracture when broken, exceedingly brittle, and so hard that no file or other tool will touch it. In this state it is thick or viscid while hot, and does not flow or run easily, and is

therefore unfit for the purposes of the iron founder; but large and heavy castings that require to be hard, and have no turning, drilling, or other operations of workmanship to be performed upon them, are often formed of this iron, which, on its first production, is called *crude or forge iron.*

578. From what has been already stated, it will be evident that the fuel used for the reduction of the iron will have considerable influence upon it. Most kinds of coal contain sulphur, which would be so prejudicial to the iron as to prohibit the use of that material for the purpose of smelting the ore. Wood, on the contrary, contains nothing that can injure iron; but, in its ordinary state, its humidity prevents rapid combustion, and it will not yield sufficient heat until it has been converted into charcoal; and then it is the very best fuel that can be used, but is expensive on account of the labour of preparing it, and its very rapid combustion. It is believed that Swedish iron, which has for many years preserved a higher character for strength, toughness, and ductility than the metal of any other country, owes its perfection to its being manufactured by the charcoal of pine wood; and those varieties of iron denominated *charcoal iron,* from a similar process of production, are more sought after for good work and command higher prices than other iron. Next to the charcoal of wood, mineral charcoal, or the cinders of bituminous coal, called *coke,* is the best fuel for reducing iron ore, or melting iron, and this fuel is alone used in Britain, where wood is scarce. It has also been introduced into several iron works in this country. Coke is pit coal broken into small pieces, ignited with free access of air, and permitted to burn until it ceases to give out flame or smoke, and the whole mass becomes red hot. It is then shut up so that the air cannot reach it, when further combustion becomes suspended, and in this state, after being permitted to cool, it is ready for use. The making of coke is carried on in a small way, by ovens built for the purpose, and which usually contain thirty-six bushels of coal. A door serves the common purpose of introducing the coal and admitting air, and a chimney is built to carry off smoke and promote a circulation of air through the oven while the coal is burning, and as soon as the burning has been carried to a sufficient extent, the door and chimney are both closed, and luted with moist clay, so that no more air can enter, and in this state the oven is left some hours for cooling, when the coke is drawn out by a large wide iron shovel called a peel, which is supported by a chain from a small swinging crane or gibbet. Water is thrown on the coke after it is discharged, to prevent its rekindling, and it is likewise said to harden and improve it. After the coke is withdrawn, the oven will retain

sufficient heat to re-kindle the next charge of coals, which is immediately introduced, and each charge of 36 bushels generally requires 24 hours for its coking, so that the oven may be charged daily and kept at constant work. Coke swells so much in its formation, that 36 bushels of coal will produce from 45 to 48 bushels of coke; and when it is good and well burnt it becomes very hard, has a shining and almost metallic lustre, and is very sonorous.

Notwithstanding that coke is better and more economically made in a close oven than in any other way, yet such ovens are too tedious and expensive for large iron works at which the coke is constantly made on the open ground. The coal is piled up in long heaps, and after being ignited and suffered to burn a sufficient time, earth is dug and thrown upon them until the air is thought to be quite excluded, and the heaps are then watered through the earth, and are not opened until the coke becomes quite cold.

579. From the above slight sketch of the manner of producing iron, it will appear that it is constantly obtained in a melted or fluid state in the first instance; and yet it is obvious that it is met with in two distinct forms called *bar* or *malleable*, and *cast iron*, the characters of which are as yet as distinct as two separate metals. Malleable iron is only manufactured into long square or rectangular pieces called *bars*, or long cylinders called *rods*, or flat plates called *sheet iron*, and if good, it should be characterized by its toughness, ductility and capability of bending; its strength; its power of receiving and retaining a highly reflective polish; its fibrous texture; the facility with which it rusts or combines with oxygen, by its capability of welding when highly heated, so that two pieces may be united by hammering, and made as strong as if they had never been separate, (which is one of its most valuable properties,) and by its resistance to fusion by heat; for malleable iron may be rendered soft and ductile by high heat, and may be wholly converted into oxide, and will burn, but will not admit of fusion. Cast iron, on the contrary, has no ductility and but little toughness, will only admit of bending in a slight degree without breaking; is very inferior in strength to malleable iron; may be made smooth and polished, but will never have a highly reflective surface; has a granular instead of a fibrous texture; rusts or combines slowly with oxygen; cannot be united by welding: and it fuses and becomes liquid when exposed to a high heat. The iron in both cases is the same, and these extraordinary differences of character appear to depend entirely on the quantities of carbon and oxygen that have combined with the metal at the time of its reduction. Iron in its malleable state is

believed to be pure or free from alloy, and the more pure it is, the more perfect the metal will be; but cast iron is alloyed or mixed with carbon and oxygen, and the different proportions of these elements that are present, will sensibly affect the quality of the metal. Cast iron is not, therefore, strictly speaking iron, but a carburet of iron combined with some oxygen.

580. The obvious process, therefore, of procuring malleable iron, is to refine or purify the imperfect carburet of iron that is obtained from the ore by the first process of reduction as above described, by taking from it the carbon it had imbibed; and this is done by melting the crude or forge iron a second time in a reverberating furnace, or one so constructed that the iron shall be exposed to a free current of air, and shall be subject to all the heat of the fuel, without being in contact with it. So soon as the iron is fused, it is kept constantly stirred and moved about by iron rods, so as to constantly expose new surfaces to the heat and air, which process is called *puddling*, and by which any carbonaceous matter the iron contained is burnt and consumed, and other portions of iron combine with the oxygen of the air; in consequence of which changes, the iron shortly looses its fluidity and becomes ropy and tenacious like dough, and the workman, judging from his experience when this change has been sufficiently wrought, removes the mass of iron from the furnace, and places it on a large anvil where it receives a few blows from a very heavy forge hammer worked by machinery, and which forms it into the shape of a square bar of from two to three feet in length. The blows of this hammer not only form the bar, but they render the mass more dense and compact, and drive off all the oxide of iron that was formed during the puddling process. This flies off in all directions under the hammer, forming scintillating sparks of great brilliancy and beauty. The short bar while yet in a glowing heat is speedily carried to the forming rollers (of which Fig. 127, Pl. IV., is a representation), and if a square bar is desired, it is presented into the square opening *d*, and is carried forward by the revolution of the two cast iron rollers *b* and *c*. If a smaller bar is required, the hot piece is returned back again through the next opening *e*, and afterwards through *f*, and so on, until it is reduced to the required size. If a round rod of iron is required, then the piece is in like manner presented to and passed through the round openings *g h*, &c., and thus the hot bar which was originally only 30 inches in length, is extended to 10 or 12 feet, or even more, and is afterwards cut by shears to the required length of the bar. All bars of iron are now formed by passing them between rollers of this kind, and of course iron mills must possess a number of such rollers suited

to the sizes and forms of the iron to be produced; because, by altering the indentations in the rollers, bar iron of any form may be produced, and it is in this way that rail-road iron of particular forms is made, or iron mouldings for hand rails and other purposes. The largest indentations are placed near the ends of the rollers, and the smaller ones near their centres, in order to preserve the strength of the rollers. For the production of sheet and hoop iron, the rollers are quite smooth, and without any indentations; but their general construction is the same in all cases. They are supported by two very strong cast iron side frames *a a*, united to a cross piece that is buried in the ground and so fixed as to insure the stability of the whole machine. The rollers and their necks or gudgeons are turned in a lathe to insure their being perfectly cylindrical, and their necks turn in brass bearings to diminish friction. The two strong screws *i i* act upon the tops of the brasses of the upper roller, and are for the purpose of forcing the two rollers into contact with each other; but in rolling sheet or hoop iron these screws are relaxed, to permit the rollers to separate to a distance equal to the thickness of the article to be produced. The two rollers are connected together by the two strong cast iron cog wheels *k k*, to insure their simultaneous motion, and the power of the water-wheel or steam-engine that produces their motion is connected to the lower roller only.

581. Before the introduction of rollers into iron mills, bar iron was shaped and produced by the blows of the forge hammer alone, which occupied considerable time, and did not produce bars of the same uniformity as those now manufactured; but there is no doubt of the hammering process being the best for the production of good iron. The effect of repeated blows is to condense the iron and render it more compact and strong, and at the same time to effectually drive off all oxide, or carburet of iron that may hang about the piece, and which are not so effectually removed by the equable and steady operation of mere pressure. The rollers, however, produce bars with a velocity that is astonishing to those unaccustomed to the operation, and give them a smooth and uniform appearance far superior to what the hammer produces, and it is therefore the interest of the manufacturer to use rollers, notwithstanding the inferiority of the article, and the public, in general, are better pleased to get a handsome looking article for a low price, than to pay more for that which is really better, but less pleasing to the eye. To compensate for the imperfect operation of the rollers, every bar passed through them should be reduced to a small size, and be then cut and doubled; a welding heat should then be applied to the two bars, when they

are again to be passed between the rollers to be consolidated into a single bar, and are reduced to the required size. When two or more bars are heated, placed together and welded into a single bar by the rollers or hammer, the process is called *faggotting*, and the strength of the iron becomes much improved. Some manufactures give an assurance that all their bars receive this treatment, which of course enhances the price of the iron, but it is very seldom resorted to in rods or round bars, and consequently they are considered less trustworthy than those of a square or rectangular shape.

582. When malleable or wrought iron, as it is generally called, is pure and good, it ought to bear bending even in the cold state without breaking; and the fracture when broken should exhibit a decidedly fibrous character, without much lustre; but if the iron is bad or brittle, it will not bear bending without breaking, and the fracture will be brilliant with a granular texture. Iron will not draw into a long continuous wire unless it is good and pure, and the two varieties may, therefore, be very well exhibited and illustrated by breaking a piece of large iron wire, and a similarly sized cut nail, such as are now generally used. The wire must be bent backwards and forwards many times before it will give way, while the nail will break by being slightly bent. Notwithstanding the qualities of good iron should be always alike, yet it is so seldom met with, that three distinctive names have been adopted for it, viz: *tough iron*, and *cold short* and *hot short iron*. The tough variety (of which good Swedish iron is an example), is tough and strong both in the hot and cold state. Cold short iron is approved by the smiths because it is easily welded and works freely while red hot, but is short or brittle when cold. Hot short, on the contrary, will not bear hammering while red hot, but is tough and tractable while cold, and is therefore useful for forming a number of small articles that do not need the aid of fire.

583. The value of bar iron in the market is generally known by the marks or names that are stamped on each bar, indicating the manufactory at which it has been produced, and the character of which soon becomes known to the trade. But a stranger who is unacquainted with these marks or signs cannot select iron with any certainty, without breaking the bars and examining the fracture, in addition to which some of the bars should be heated at their ends and struck with a hammer to avoid obtaining hot short iron, which is nearly useless in large works, unless it has to be used merely for bars to support weights or strains.

584. Scrap iron is a variety that is much approved for purposes where good iron is required. It derives its name from being

formed of all the waste scraps and bits of iron that are cut from bars or produced in working them, as well as from all old iron that is saved. It is sold to the iron mills under the denomination of *bushel iron*, and is there put up into bundles of about half a hundred each, and tied and retained in form by hoop iron. These bundles being placed in a proper furnace receive a welding heat, when they are brought under the forge hammer to weld or beat them into a mass and expel the rust or oxide, after which they pass through the rollers (like other iron) to be converted into bars. The iron being originally in small pieces, packed in all directions, the grain or fibre in this iron is more unequally dispersed and interlaced than in any other kind, and it produces a very superior bar when the scraps have been of good quality and are thoroughly incorporated.

585. As the conversion of wrought iron to useful purposes is never carried on by the Engineer in person, it may seem unnecessary to enter into any details of the manner in which this metal is worked; but as he can do very little without recurring to iron work, and will constantly have to give orders concerning its execution, it is quite necessary that he should know the kind of workmen to be employed, the operations which it is their business to attend to, and such of the technical phrases as will enable him to make his directions clear and intelligible to them, and these are therefore briefly given, as follows:

586. Wrought iron work is performed by two distinct sets of workmen, called *blacksmiths* and *whitesmiths*. The blacksmith is the first to commence the business, and he works exclusively at a fire urged by bellows, and called *a smith's forge*; he receives the iron, and after giving it its due heat in the forge fire, fashions it into the required shape by blows of the hammer upon an anvil, and certain tools to be used in conjunction with it. If the work is so small and light that the smith can blow his own bellows, and hold his iron in the left hand while he strikes upon it with a *hand hammer* in his right, he is said to work single handed, and the work produced is called single handed work; but in general the blacksmith has an assistant called his *striker*, who blows the bellows, and afterwards strikes upon the hot iron, as soon as it is brought upon the anvil, with a heavy sledge hammer, used by both hands, and made to swing or revolve over his head in order to produce the most powerful blows. The blacksmith all this while turns the hot iron into its proper position for receiving the blow, uses his hand hammer to assist, as well as to keep time or regulate the succession of blows, and occasionally to point out to his assistant where he wishes a particular blow to be given, and this is continued until the iron becomes so cold that the hammers

have little effect upon it, when it is returned to the fire to be heated again. Each separate heating is called *taking a heat*, and thus smiths will often say they can do a particular job at a single heat, or at two or three heats. When the work is very large, the wind from two pair of bellows is frequently carried into the same fire, and in this case one striker will not be sufficient, but two or three are employed, and strike in regular succession, when a correct division of time is quite necessary, or they might injure each other, as well as the tools they work with. The smith's anvil has a beak for turning round or curved work upon, and it has a square hole at the opposite end for putting iron over to be punched, and for holding the shanks of what are called bottom tools, or tools that fit on to the anvil; for if a piece of iron has to be rounded or made in the form of a moulding, it is done between top and bottom tools. These tools are of steel, and carry a concave mould, of the form the iron has to take, made in two halves. The bottom tool is inserted in the hole in the anvil, the heated iron laid upon it, and the top tool held by a long handle, is placed over it and struck by the sledge-hammer until the necessary form is given to the iron. Large bars are cut by a chisel-edged pair of tools, one of which is a bottom tool, and the top tool being placed directly over it, the bar placed between them is soon cut. Holes are very expeditiously made by punches, which are slightly tapering top tools of various sizes, and with blunt ends; the hot iron being laid over the hole in the anvil, the punch is held over that hole by its handle, and a few blows of the sledge will produce the required hole. Maundrells are generally cylindrical tools to be introduced into holes after they have been punched, in order to render them truly cylindrical and of certain size, which is quite necessary when the holes have been formed for converting into screws. Maundrells are, however, also made square and of various shapes.

587. One of the most frequent operations of the blacksmith is the welding or joining pieces of iron together, which is technically called shutting them together, or taking a shut upon them. The facility with which this is done adds much to the value of wrought iron, and is taken extensive advantage of in many of the works of the Engineer; for whenever the length of large bolts for fixing a piece of machinery cannot be exactly determined, each bolt is finished at its two ends, but sent home in two pieces which have to be shut or welded together, when the machinery is so far fixed that the necessary length may be ascertained. The heads of bolts are put on by forming a collar of square iron, which is fitted to the end of the bolt, and is there welded by a single heat, but small bolts may be headed by a kind of rivetting

process, for which purpose the piece of iron is driven into a square or cylindrical hole in a block of iron called a *swage*. The hole should be rather too small to admit the hot iron which is driven into the swage hole, by a hammer, and is thus made truly square or cylindrical, and if properly adjusted as to size, will form a head by the action of the hammer. The iron contracts as it cools and can be easily taken out of the swage, although it may have been driven into it with great force while hot. The swage is the fellow tool to the maundrell, one being to give a determinate size to the bolt, and the other to the hole the bolt is to pass into when screwed or otherwise finished; and as all large machinery is put together with screw bolts and nuts, the due fitting of these tools saves much labour afterwards.

588. Another ordinary operation of the blacksmith is doubling and faggotting iron, as before described (581,) but on a smaller scale. Whenever a bar of more than ordinary strength is required, it is much safer to weld or faggot several bars together than to trust to a single one of the same size, more especially as large iron is seldom as good and as well wrought throughout its whole substance as small bars; for all good iron is rendered better and more tough by long hammering in a hot state, and the hammer, unless very heavy, does not produce an effect that is felt throughout the thickness of a large bar, as it does in a small one. Instead, therefore, of using a single bar of iron three inches square, it will be better to faggot or weld together nine inch bars to form one of the required size; and in like manner a two inch bar may be formed of four inch bars laid together. All nuts for screw bolts that are subject to great strain should be formed in this manner, by taking iron of the proper width, but of only half or one-third of the thickness required, and doubling or tripling it with a welding heat, so as to unite the several thicknesses. The only thing to be guarded against in shutting and faggotting iron is imperfect junction of the parts, owing to a want of sufficient heat, or to the presence of oxide upon the surfaces that are to come together, which will sometimes prevent their union, and produce what is called a *cold shut* or *false shut*. Such a defect may exist without being visible on the outside, and is the cause of many shafts, axles, and other parts of machinery breaking; but it is a defect that rarely occurs in the workmanship of a good and experienced smith, and is always guarded against by bringing new and clean surfaces into contact, and by sprinkling them with dry sand after they have become considerably heated; the sand fuses and vitrifies with the heat, and thus protects the surface of the iron from oxidation by forming a thin coating of glass

over it, which is dispelled or driven from the joint by the first few blows of the hammer.

589. *Jumping* is an operation that is always performed on the ends of iron bars that are about to be welded together. It is merely making them red hot, and driving them in a longitudinal direction against the side of the anvil, or against a block of cast iron fixed on the floor, in order to render the ends thicker than the rest of the bar; because in welding, the two ends have to be beaten together to produce union, consequently the joined part of the bar would be less in diameter than any other part, if the reduction had not been prevented by previously making the parts to be joined so much larger that the necessary hammering reduces them to the former dimensions. The joint is then finished between a pair of top and bottom tools, and if well made, ought not to be perceptible. The great point to be attended to in obtaining perfect union is a correct heat, which can only be learnt by experience. As a general rule it may be said the heat cannot be too great, provided the iron does not burn. This burning is in fact conversion into oxide, for if iron is heated above a certain extent, it becomes very suddenly oxidized, and the then almost fluid iron burns with most beautiful corruscations, and is destroyed in its qualities. This excess of heat must therefore be carefully avoided, and yet the smith must come as near to it as he can with safety.

590. The fuel of the smith's forge is of great importance, for the best iron may be spoiled and rendered incapable of working by a bad fire, composed of coals containing sulphur, arsenic, lead, or other minerals that will combine with the iron at a high heat, and destroy its valuable properties. A small quantity of metallic lead thrown into a smith's fire will generally make the best of iron hot short, or in the smith's language, *rotten in the fire*, so that it will neither weld, or bear hammering without breaking into pieces. Wood charcoal is the safest fuel to use in respect to the iron, because it contains nothing that can injure it; but it is troublesome in its management to those unaccustomed to it, and throws off so many sparks as to make it disagreeable to work with it, independent of its burning away very rapidly, and requiring the fire to be constantly supplied. Some varieties of pit coal make an excellent forge fire, of which the Tanfield-moor coal of Northumberland, in England, is an example. It is a small and bad coal for household purposes, but so excellent on the forge that it is eagerly sought after, even by the blacksmiths of London and other distant places.

591. All work produced by the blacksmith is said to be forged, and he delivers it in the black or unpolished state in which it

leaves the fire; this accounts for the name of this class of workmen. From the blacksmith it passes to the whitesmith, who has nothing to do with the fire, but he files, polishes, and finishes the pieces for use; and the perfection of blacksmiths' work is to forge so neatly as to bring the pieces very nearly to their intended shapes and dimensions, so as to leave the whitesmith little more to do than to file away or otherwise remove the black external surface. In many instances one man goes through both operations, but in manufactories, where much is achieved by division of labour, it is found most advantageous to keep these branches distinct.

592. The whitesmith works before a vice, which is a strong screw press for holding his work firmly and steadily, while under his hands, and his tools are cold chisels, saws, files, machinery for drilling holes in metal, rimers, apparatus for cutting or making screws, and a turning lathe. Cold chisels are made wholly of steel, and are urged or driven by a hand hammer. They are used like the saw, for cutting away portions of iron with greater expedition than a file, and they derive their name from their being used to cut iron and other metals in the cold state, instead of being heated at the forge. Coarse and heavy files succeed for bringing the iron under operation, very nearly to its intended size and form, and they are followed by finer files and burnishers which remove less metal, and produce the necessary smooth surface. Any necessary holes that have not been punched by the blacksmith, or which may have been too small for his implements, he drills by steel drills, which are fixed for use in a strong cranked piece of iron called a brace, one end of which carries the drill, and the other is pressed upon by a lever and weight, for forcing the drill into its work, which is held in the vice, while the brace and drill are made to revolve by the hand, or occasionally by the power of machinery. Rimers are long tools of hard steel made slightly tapering, and with angular sides, and are used for enlarging round holes that have been drilled or punched, and for giving a bright surface to them. They are placed in the same position as a drill in the brace, and are used with it in the manner of a drill. Screws are formed by tools constructed for the purpose, and for large work they are taps, dies, and a stock or frame, and for small work taps and a screw plate. The tap in both cases is a short circular rod of the best steel, with a square head for turning it by the application of a spanner or screw wrench, which are the names applied to those tools by which Engineers and Millwrights turn all square headed nuts or screws requiring considerable power. The tap is made slightly conical or tapering towards its point, and a good and perfect screw or thread is cut upon its surface, when

the point and some distance above it, is filed away until this part of the tap becomes square, and only carries the screw threads at its four angles. The tap is then hardened and tempered in a manner that will be explained where steel is described, and is ready for use. Being slightly conical, its point is introduced into the hole, or nut, in which a hollow or female screw is required, and by turning it around by the spanner while the nut is firmly held in the vice, the sharp angles will cut away the metal within the hole, and produce a concave thread exactly accordant with that formed upon the tap, which may be forced into the hole to a greater or less extent, as the concave screw is required to be larger or less in diameter. The *dies* are two small blocks of steel fitted so as to slide close together, or to a small distance asunder, in an iron frame, with two long levers or handles called the stock. The steel blocks are brought together by a screw passing through one side of the stock, and their two sides that face each other are filed out to form a nearly circular hole, in the inside of which a screw is cut by the tap before described, so that the impression of one half of the screw is in one block, and the other in that which is opposed to it, and indentations are filed across the screw threads to produce sharp and cutting edges. The bolt to be cut having been previously forged into a cylindrical form, is fixed vertically in the vice, and the part on which the screw is to be cut having been introduced between the dies, they are compressed upon it by their forcing screw, and made to pinch it tightly, when the stock is turned round by its long handles, and a screw thread is soon produced upon the bolt. As the cutting proceeds, the moveable die is pressed forwards by its screw, until the screw is finished, or is cut as deep as required. Each size of screw requires a tap and pair of dies proper to itself, but they all fit the same stock, so that these tools are always made in sets, and are one of the most expensive implements the whitesmith has to use. Small screws are not sufficiently deep in their threads to require moveable dies, and they are consequently cut by a screw plate, which is a thin plate of hardened steel containing a number of holes, each differing in diameter, and in each of which a screw has previously been cut, so that any cylinder that will pass tightly into any of the holes, will be cut or converted into a screw by the turning of the plate. The taps are alike for both implements. As an immense number of screw bolts and nuts occur in the construction of machinery, the formation of them is generally done by piece work instead of time. The blacksmith forges bolts and nuts when they are all of the same length and thickness, at an agreed price per dozen or hundred, and the whitesmith screws them in the same manner, subject to the usual agreement that every bolt shall have a stipulated quantity of thread upon it, shall be cut home, that is shall be worked between the dies until the projecting edges of the thread upon the bolt are sharp and smooth, instead of being rough and ragged as they will be at first; and that every nut shall be free upon its bolt, that is, may be screwed on and off without the exertion of any violence. A washer or flat iron ring, should accompany every bolt; and is put under the nut, not only for ornament, but it assists in tightening or screwing it up. The operation of cutting screws on bolts, and in nuts, is constantly called *tapping*, when performed by the above described tools, and it is so simple, requiring strength more than skill, that the whitesmith usually transfers it to a labourer. The best and most highly finished screws that are used for the adjustment, instead of the putting together of machines, are usually produced by chaseing tools in the turning lathe, and such screws are said to be chased. Large taps, such as before mentioned, should always have their screws cut or chased in the lathe.

593. The last tool to be noticed is the turning lathe, which is of first rate importance to the Engineer and mechanic; for without its assistance, the perfection that machinery has reached could never have been attained, for it affords the only means the mechanic possesses of rendering materials perfectly round or flat. In this machine the thing to be operated upon, is made to revolve steadily on an axis, usually in a horizontal position, and the cutting tool is supported on what is called a rest, in such manner that it may remain perfectly steady, or may be made to approach or recede from the axis of motion, or can be moved in the direction of its length. Every part of the thing to be wrought in a lathe will therefore have a correct circular motion round its central axis, and the tool will only cut away or remove such parts as project beyond a circle, the radius of which is determined by the position of the tool. When such parts have been removed the work will be truly circular, and by continuing to press the tool inwards towards the axis of the work, its diameter will be diminished in any required degree. Spheres, cylinders, cones, spheroids, and every other solid figure that has the circle for its base or root, may, therefore, be formed with the greatest exactitude by this useful implement; and if the lathe is so strong as to resist vibration or tremulous motion, and is equipped with what is called a screw-rest, or one in which the cutting tool is held in a firm press, and is moved only by the action of fine threaded screws, it will work with mathematical precision. By such means Mr. Barton of London, succeeded in diminishing a steel wheel of two inches in diameter, by the twenty-two thousandths of an inch, using a diamond as the cutting tool. By such tools the pistons of steam-

engines, which require to be truly cylindrical, and many other parts of machinery that require great precision in their dimensions can alone be produced. The lathe is not confined to wrought iron work, but applies equally to cast iron, brass, wood, and in fact every thing that can be cut into regular forms by its operation, which is called *turning*, and it varies in its dimensions from lathes capable of carrying pieces of several tons in weight, down to the small implement upon which the watchmaker forms his finest wheels and pivots. The method of communicating motion to the work, must of course vary according to its weight and magnitude; thus the maker of large steam-engines and machines drives his lathes by the power of steam or water-wheels, while smaller concerns are satisfied with the power of a horse or man. The generality of lathes for common purposes, are turned by one foot of the workman acting upon a treadle; and the watchmaker moves his work with a single horse hair strained by a light cane bow that is worked by the left hand, while his right holds the cutting tool. The moving velocity of all lathes should be variable, if they are intended for various materials, because cast iron requires a very slow motion; iron and steel one rather more rapid; brass a great velocity, and wood one that is more moderate. Lathes are not only used for the ordinary purposes of turning, but likewise for drilling holes, boring cylinders, chasing screws, and many other useful purposes. The diameter of work while proceeding in the lathe, is measured by compasses with curved legs, called *calliper compasses*, and if the calliper compasses have straight legs in one piece, with the curved ones projecting beyond the joint or pivot, like wholes and halves, (95,) but of the same radius as the curved points, then such compasses become *in and out callipers*. Each pair of points will be at the same distance at every opening, therefore by such an instrument a hollow cylinder may be formed that will exactly fit a convex one, without the trouble of trying them together.

594. Soldering is a process constantly resorted to by workers in metal, for the purpose of permanently uniting similar or dissimilar metals, so that they can only be separated again by fracture or exposure to as great a heat as was at first used to produce their union. It depends on the principle of different metals requiring different temperatures for their fusion, and on compound metals or alloys fusing more readily than simple ones. A solder must, therefore, in every case, be more fusible than the metal to which it is applied, and yet by using the solder with a flux that promotes the fusion of both, such an incorporation takes place as unites both firmly together. Solders are divided into two kinds, called soft and hard; and soft solder includes every composition

that can be applied and will take effect below a red or visible heat; while for hard soldering the metals to be attached, as well as the solder, must be red hot before the union can be effected. Every joint, therefore, that has to resist great heat, must be hard soldered, and soft solder can only be applied to such things as will never be heated above 550°. Tin and lead occasionally mixed with small quantities of silver or copper, constitute the materials of soft solder, while hard solder is very fine yellow brass, containing an excess of zinc, reduced to a fine granular state for application, when it is called spelter. The fluxes used with soft solder, are powdered rosin for tin, copper and iron; tallow for lead, and muriate of ammonia, dissolved in water, for brass. For hard soldering brass and cast iron, muriate of ammonia is frequently used; but the salt called borax, (biborate of soda), is the ingredient most frequently resorted to, and is the only one that answers perfectly for hard soldering iron, steel and copper. As hard soldering is constantly effected by brass, it is more frequently called *brazing* than soldering, which last term is constantly applied to all soft soldering operations. The soldering that the whitesmith has to perform, is almost constantly brazing, to effect which the parts of the iron to be joined are made to fit each other, and if necessary, are tied and bound together by small soft iron wire, called binding wire. The powdered spelter and borax are applied upon the intended joint, and the work is held by a pair of tongs over a charcoal fire in a small forge for the purpose. The heat is raised by the bellows, and the work watched, that the process may not go too far, and as a red heat comes on, the spelter and borax will fuze and run into the joint, which must be instantly moved from the fire, and when cold, the binding wires are taken off, and the inequalities of the joint made smooth by the file.

595. The several processes and operations to which wrought iron is submitted to produce its different forms, are all included in what has been above described, with the exception of mere details, which belong alone to the workman, and cannot be interesting to the Engineer. Indeed the processes that have been enumerated, would not have been extended to such a length if it was not necessary that the Engineer should be acquainted at least with their existence; and as they will all have to be referred to again in future parts of this work, it was thought better to describe the whole of them at once in this place, than to detach what must have been said upon them. Wrought iron work, whether black or bright, is always charged and estimated by weight.

We shall now proceed to point out the nature and treatment

596. *Of Cast Iron,*

Which, on account of its hardness, strength, durability, and small tendency to oxydation, its resistance of heat and cold, and the facility with which it may be put into any form, at a small expense, renders it by far the most valuable and important material that the Engineer has control over.

A general account has already been given of the first production or reduction, as it is called, of iron from its ore, (577,) and of the kind of metal produced, which, owing to its being very hard, viscid, and incapable of flowing freely, is unfit for making castings in iron. The first running of the iron as there stated is called *crude* or *forge iron*, because it has not been refined, but is in a proper state for the forge, or mill, where it is converted into bar iron, for which it is well suited, as containing very little carbon. Now, iron for casting, or foundry iron as it is called, becomes good and soft in proportion as it receives a higher charge of carbon, consequently, a completely opposite process must be used to obtain this iron and bar iron; the one having to be charged with carbon, while the other has to be deprived of it. Accordingly instead of remelting the forge iron in a furnace where it is exposed to air and heat only, without contact with the fuel, as is done to make bar iron; it must be remelted for making foundry iron in close mixture with the fuel, and with as little exposure to air as possible; and it accordingly undergoes this melting in which it absorbs an additional quantity of carbon, after which it is tapped and cast into foundry pigs. The name of pig iron is very generally applied in all countries to those straight bars of about four feet in length in which iron for casting is sold. The iron, when it first runs from the furnace, is received into a round bottomed trough or gutter made in sand, from one side of which a number of similar troughs are formed at right angles to the first, and three or four inches apart, the whole being truly level, and open to common communication, so that when the first or principal gutter fills with fluid iron, all the others will fill also, and the quantity of iron when so cast and taken up, resembles an immense comb with coarse teeth. These teeth are knocked off close to their junction with the transverse piece, and then become pigs of iron; while the cross piece, which is always larger and more irregular than the others, is called the sow. Pig and sow iron are always sold together; but the sow often contains impurities on the furnace, and is not so much esteemed as the pigs.

597. It was stated, as a general principle, that the first reduction of iron ore produces crude or forge iron, but there are excep-

tions arising from the quality of the ore, the nature of the fuel, and the management of the furnace, by which foundry pigs of good quality are produced in the first instance, and thus the loss of time and fuel attendant upon a second melting is avoided.

598. The making of iron castings constitutes a distinct branch of business, and is carried on by the iron founder in a manufactory called an *iron foundry;* and the utility of cast iron is now so universally established that few large towns are without such an establishment. It is a business seldom personally attended to by the Civil Engineer; therefore no specific directions need be given for carrying it on. But every Engineer should be acquainted with the operations carried on in the foundry, and with the manner of making moulds; because he will constantly have to correspond with foundries, and to send orders to them, and if he does not possess this knowledge, he will frequently incur great expense in preparing patterns for castings that may be useless, or he may require articles to be made that cannot be executed; but the explanations that follow, it is presumed, will prevent his running into these, or other difficulties.

599. In order to save the expense of transporting, and remelting large quantities of iron, very heavy castings are most frequently made at the iron works, where the iron is produced. Such is the case with the castings for large iron bridges, or the plates for rail-roads. But these large concerns will not be troubled with small orders, and they consequently devolve upon the iron founder, who is very seldom an iron maker, but has to buy his pig iron at the common public market, where it varies in price according to the demand and quantity manufactured. The founder therefore works entirely with new pig iron or with old metal, such as old or broken cast iron articles, which he buys for less than half the price of new metal, and melts over again, generally in conjunction with new metal.

600. Pig iron is known in the market under three denominations, called No. 1, 2 and 3. No. 1, also called soft grey cast iron, is the best quality. No. 2, a medium kind, and No. 3 is hard and white, and very little better than forge iron. The founder judges of it chiefly by the appearance of its fracture, by its sound, and by seeing if it indents or gives way, or breaks before the blows of a hammer. Pigs are usually tried by placing one upon the ground, and then throwing those that have to be examined transversely across it, and the ease or facility with which they break will afford a very fair criterion of the strength or toughness of the iron. The sound of the blow must at the same time be attended to, for the finest soft iron scarcely yields any sound, except that of the blow; it falls dead upon the block like a bar of lead,

and its fracture will be coarsely granular, with no great lustre, but much resembling coarse grained black-lead. A No. 3 pig, on the contrary, being very brittle, breaks with a slight blow, and rebounds from the block with a ringing metallic sound, and its fracture will be of silvery whiteness, with strong metallic lustre, and little or no granular appearance, while No. 2 should be a medium between the two, and without much lustre. The shape of the pig must be regarded among the other qualities in selecting iron, for if the top surface is clean and smooth, and the under side carries a good impression of all the little inequalities of the sand in which it has been cast, this is proof that the iron is *free* as it is called, i. e. will flow well into the mould when it is cast; but if its impressions are obtuse, or it has not filled out all the pig mould, and carries much dross or scoria on its back, it denotes sluggish iron, or such as is viscid, and will not flow freely. These varieties of iron bear prices proportioned to their goodness, and No. 1 is frequently twice the value of No. 3. They have their advantages in particular kinds of work; thus, if a piece of cast iron has to be turned, or filed, and has many holes to be drilled into it, and these perhaps tapped for screws, it should be cast from the purest No. 1 iron. If the piece when cast, has but little work to be done to it, but is to be used as it leaves the mould, and great strength is required, No. 2 iron should be selected; and if the piece has to give or receive repeated hard blows, and has no work to be performed upon it, as in a cast iron head or anvil, or the ram of a pile driving engine, or the shoes of a stamping mill, then No. 3 iron will be the best on account of its hardness. The Engineer knowing these qualities, will order his castings to be made from that metal which he knows will answer his purpose best, while the founder constantly uses the iron ordered for the sake of his reputation, and charges according to its quality, and the difficulty of executing the work.

601. The several varieties of pig iron above enumerated, appear to derive their character from the quantity of carbon with which they have combined at the time of their formation; thus, No. 1 iron contains the largest quantity, so large indeed that an artificial carburet of iron resembling black-lead, is frequently seen to float on the surface of the pigs, while the metal is running into them from the furnace, and as they cool this substance runs into minute and highly resplendent crystals, which are found in cavities on the surface and in the interstices in the inside of the pig, and is denominated by the iron makers *kish.* The experienced iron founder desires no better proof of the softness and goodness of No. 1 iron than finding that it breaks with a *kishey* fracture. No. 2 iron of course contains less carbon, and No. 3 is scarcely removed in this respect from crude or forge iron.

602. The iron founder uses two distinct kinds of furnace for melting his iron, called a *cupola* and an *air furnace;* but small foundries seldom have more than one, or at most two cupolas. The cupola will only melt from 1 to 10 cwt. of metal at once, and during the whole of its operation requires to be urged by a very large and powerful pair of bellows, or other blowing machine; while the wind or air furnace should never be used to fuse less than one ton of iron, and is made large enough to melt from five to seven tons at once, and requires no artificial blowing, but works by a natural current of air induced by a very tall chimney: and as the fuel of the cupola is coke or charcoal, and it requires the power of two men, or their equivalent in machinery, to work the bellows, and the air furnace works with well selected but raw pit coal, free from sulphur, so of course its operation is much more economical, and it gives the large founder who has sufficient work to keep it in constant action, a decided advantage on the score of profit.

603. The weight of every large casting that has to be made, is calculated before the metal is melted to make it, and from 15 to 20 per cent. more metal is put into the furnace than will be necessary for it; because if a large casting should be spoiled for want of sufficient metal to fill up the mould, the loss of fuel and labour would be very considerable; and a sufficient number of small moulds are constantly in readiness to consume the extra quantity that may be left. The method of making this calculation is given hereafter (631 and 632).

604. There are four denominations of castings among iron founders, depending upon the manner in which the mould is made. They are open sand; flask or box castings; in green sand; dry sand; and loam castings: and as different degrees of trouble and risk attend them, they generally increase in price in the order above mentioned, exclusive of the value of the iron used in their formation. The moulds for all of them, with the exception of the last, are made with sand, but it is sand of peculiar properties, and is difficult to procure in some places, for it should be perfectly homogeneous, and its grains as equal sized as possible, and it must contain sufficient loamy or clayey matter to cause it to maintain any particular form that is given to it when slightly moistened, and it must not coke or burn into a kind of brick from the heat of the melted iron, nor be so close and compact as to prevent the escape of steam and rarified air which are rapidly generated when the hot iron is poured into the mould. Good moulding sand is, therefore, a great desideratum with the iron founder, and is on this account often transported many miles.

605. Open sand casting is only applicable to flat plates or bars

in which it is not detrimental to have one side rough and uneven. They are made by spreading a sufficient quantity of moulding sand, sufficiently moistened to give it tenacity, upon the floor of the foundry, which spreading is always effected by passing it through a fine wire sieve, and then making its surface (if a flat plate has to be cast) perfectly hard and level, which is done by a light flat faced iron rammer with a long handle, and repeated applications of a small level like that shewn at Fig. 84, Pl. III., tried upon the surface in all directions. When the surface is thus rendered hard and level, it is made smooth and almost polished by being rubbed over with a small trowel, similar in shape to the floating trowel of a plasterer. That done, the walls that are to confine the iron, and give a particular form to the plate, whether it be square, circular, or of any other shape, are built; and for this purpose smooth strips of wood of the same thickness that the plate is to have, and having the same contour on their edges with itself, or the same mouldings or ornaments, are laid down upon the flat surface in positions exactly accordant with the intended edges of the plate, and some of the external sand is gathered by the hand and pressed closely against these strips, and rammed close to them by a hand rammer, after which all superfluous sand is cut away by passing a trowel over the tops of the strips in a horizontal direction, when the strips are taken up, and a perfect concave representation of the plate to be cast will be left in the sand. If a name, letters, or ornaments in relief are required on the face of the plate, they may now be stamped or indented on the smooth surface of the sand, and the mould will be ready for receiving the metal.

606. The moulders and the furnace men, are a distinct set of workmen in a foundry, and while the former are employed in making their moulds, the latter are engaged in melting the metal, and as soon as it is in a fit state for running, the furnace man gives notice to the moulders that he is about to *tap*, that is to say, to knock open by means of an iron crow bar and a sledge hammer, a hole made purposely in the bottom of the furnace, but which during the melting of the iron had been stopped by clay and sand, which becomes exceedingly hard from the heat of the inclosed melted iron. When this hole is open the whole charge of iron that has been melted runs out; therefore, previously to opening it, the moulders place a large iron bowl lined with loam, and called a shank, before the tap hole to receive the iron. The shank has a long single iron handle in front, and a forked or double handle behind, so that it can be carried either by two or by three men, according to its weight, and in this the melted metal is carried to the moulds which are filled, and as the moulders should

use the precaution of keeping a number of small moulds in preparation, so if this is done, the shank is carried from one to the other, and not an ounce of the melted metal need be wasted. This is a necessary precaution to insure profit to a foundry, the chief expense of which is the fuel necessary to melt the iron, and if unused metal remains in the shank, it must be discharged upon the floor to be melted over again, with a certain loss that iron sustains at every fusion by a portion of it being converted into useless oxide.

607. But to return to the open sand plate, this only requires the melted metal to be poured into the mould for its completion. If the mould is not quite filled with metal, the plate may be thinner than was intended, but it never can be thicker, because the walls were regulated in height by the strips made use of for their formation, and which were equal in thickness to the intended plate; consequently, if too much metal is poured into the mould, it will flow over the walls and run to waste; and if the sand bottom has been correctly levelled, we may be sure that the two sides of the plate will be parallel, because the upper unconfined surface of the fluid iron will be truly level. The instant the iron sets or becomes hard, a covering of three or four inches in thickness of dry sand should be thrown by a shovel over every open sand casting to prevent exposure to the air and sudden cooling which would warp or bend the plate, or perhaps cause it to crack. It is a matter of importance in all recent castings to prevent partial cooling, and the irregular contraction that would follow it. All metals expand by heat and contract on cooling; and iron in its melted state is in its greatest state of expansion, but contraction follows rapidly, and as the metal in contact with the mould chills and sets very speedily, so contraction takes place on that side, while the upper part of the metal may be yet fluid and highly expanded. Covering the top of the casting with sand, puts it therefore in the same state as the bottom, and as sand is a very bad conductor of heat, a more equal and gradual cooling is produced, and an equable contraction follows.

608. Open sand casting is not confined to mere parallel plates, but is applicable to every solid figure that will admit its upper surface, (which must be flat,) to lie in a horizontal position. Thus the fire bars of steam-engine boilers and other furnaces require neither beauty or perfection of workmanship, and these are, therefore, very commonly cast in open sand. But to produce these what is called *a pattern* is necessary. The pattern is a fac simile of the thing to be produced, but is made of wood instead of iron, and its use is to make the impression in the sand, which the melted iron is intended to occupy after the pattern has been withdrawn. The pattern is therefore imbedded in the sand, which is

closely rammed around it, taking care to keep the top of the pattern perfectly level. When moulded, the pattern is gently and carefully withdrawn in a vertical direction from the sand, and may be used to make another mould or impression, because one pattern will produce any number of castings, all of which must be perfectly similar. Even a three or four sided solid pyramid may be cast by the open sand process, provided its point be placed downwards and its base upwards, of even if one of its sides is upwards and placed horizontally.

609. The disadvantage of open sand castings, is their liability to warp or change their flat form if they are large and extended, and great care is not taken to insure slow and equable cooling; and that their upper side will always be full of air bubbles, blisters, and portions of dross or oxide, that will float on the metal and render it rough and unsightly, but the under side that was next the sand, will be as perfect as castings produced in any other way. Such castings can therefore only be used for flooring plates, backs of fire places, or in positions where one side only is exposed to view, or for plates that are used within walls or in hidden positions, where strength without beauty is required. The advantages of this sort of casting are, the ease and expedition with which it is made, which renders its price lower than other work, and that in many cases no pattern is necessary, except a thin board cut to the contour of the plate to be produced if it is irregular, and which is called a *template*, or about a foot of a circle with a wooden radius, if a circular plate is wanted, which is called a *sweep*. Square or rectangular plates require no preparation, as straight edges are kept in every foundry.

610. When every side of a casting requires to be fair and smooth, the top of the mould must be covered with sand as well as the other parts, and this can only be effected by making the mould in a box that divides into two or more parts, according to the intricacy of the body to be formed, and such boxes make a part of the implements of every foundry, and are called *flasks*. All flask castings require a model or pattern, and if the box is filled with the ordinary damp sand of the foundry, without drying or other preparation, such sand is called green or fresh sand, and the casting produced is called a box or flask casting, or sometimes a flask casting in green sand. The boxes or flasks are frequently made of plank, especially for temporary purposes, but as wood is very liable to be burnt by the heat of melted iron, or at any rate to crack and warp, old established foundries have their flasks of cast iron, when they are very durable with proper care. Flasks are made of various sizes and forms suitable to the moulds they have to contain, and one advantage attending cast iron flasks is

that by having a few side and end plates of various lengths, put together with screw bolts and nuts at the angles, one pair of sides or ends may be substituted for another, provided the bolt holes are made to correspond, and thus a pair of flasks may be altered from one form to another to suit any work that has to be done. Fig. 130, Pl. IV., represents a pair of long narrow flasks suitable for casting straight iron pipes. They consist each of four plates, forming two boxes *f* and *g*, of exactly the same dimensions, and are without tops or bottoms; but to prevent the long sides from bulging when the box is filled with rammed sand, a sufficient number of cross braces *h h* must be fixed across the top of the upper box *f*, and the lower side of the box *g*; the two sides that come into contact being left quite open and unincumbered. The lower edge of the upper box, and the upper edge of the lower one, must be even and smooth, to insure their making a good joint, or fitting without the possibility of moving when placed together, and their exact position is preserved by iron steadying pins fixed in the projections *m m*, called *lugs*, and passing into holes in similar projections *l l* on the upper edge of the lower box. Similar projections and pins are placed on the other side of the boxes, so that the upper box may be lifted from the lower one by its handles *i i*, and can be replaced again with the certainty of being in precisely the same position. To make a casting, a pattern is necessary, and if a pipe with flanches or flat circular plates at its ends for making a screw bolt joint is to be produced, the form of the pattern will be such as is shewn at Fig. 132. The two flanches *x x*, have the size, form, and appearance that the real flanches are to have when cast, but the body of the pipe *v u*, is a solid piece of wood, turned in the lathe, and the whole must be very smooth and well polished, for the good and smooth appearance of the casting always depends upon the perfection and finishing of the pattern. To mould this pattern, the top box *f* is removed, and the bottom one *g* is placed in a nearly level position, on the floor of the foundry (which is always formed of moulding sand) which makes a close bottom for it. The lower box is then filled with moulding sand, which is rammed into it by small rammers of iron, until it attains such a height that the pattern placed in the box may be supported on the two edges *x x* of the flanches, at such a height that the central line *w v w* of the pattern will be even with the top of the box, or in other words, until one half of the pattern is sunk into the box, and the other half is wholly above its top edge. The lower box is then filled up level with its top, with moist sand, carefully rammed around the pattern, so as to insure the obtaining a perfect impression of its lower half in the sand of the lower box, when the top of the sand is made as hard, level, and smooth as possible by the moulder's well polished trowel. That done, a small quantity of perfectly dry sand, or fine Flanders' brick dust, is sprinkled over the sand, and is called parting sand, its object being to prevent the sand about to be placed in the upper box from adhering to that already deposited. The top box is now placed upon the bottom one, as shewn in the figure, when it is in like manner filled with well rammed moulding sand, for obtaining the impression of the upper half of the pattern. Before filling the top box, two slightly tapering turned sticks are placed vertically upon the top of the pattern, and are rammed about with sand as well as the pattern, and when the upper box is quite filled, the moulding will be completed. A funnel shaped cavity is sunk by the fingers in the top of the sand round one of the taper sticks, and they are then withdrawn from the sand, by twisting them round and drawing them upwards at the same time, when of course two corresponding holes reaching to the pattern will be left. The one that has been made funnel-shaped is called the *gate*, and is intended for the channel by which the melted iron is to be poured into the mould, and the other is called the *vent*, because it is for the escape of the air contained in the mould when the iron is introduced, as well as the steam and gas that is generated as soon as the hot iron reaches the damp sand; and it answers another important purpose, that of informing the moulder *when the iron is up*, or in other words when the mould is full, and he may cease pouring; because the fluid iron will not rise up the vent in attaining its level until the mould is quite full. Having finished the moulding as described, one of the most delicate and troublesome operations of the moulder follows; that is, separating the two boxes for the removal of the pattern without breaking down any of the sand in which the impression has been formed. To effect this, a workman goes to each top handle, *i i*, and they raise the top box vertically and as steadily and carefully as possible, when the pattern remains fixed in the bottom box, and in general a correct and perfect impression of the upper half will be found in the top box, which is now inverted or placed on one of its sides upon the floor for the purpose of its examination and repair, if necessary. It very frequently happens that portions of the top sand will hang about or adhere to the pattern, and if so, they require to be carefully taken up, and restored to their proper places in the top box, where they are made to adhere by the pressure of a small trowel, and in this way the top impression is made as smooth and perfect as possible. The pattern has now to be removed from the bottom box, which is in general an easy operation. A little water from a wet rag or sponge is applied all round the pattern, to render the sand more compact, and one or two nails are driven into the top of the pattern to make handles for lifting it; or it is gently struck with a hammer to loosen it in the sand, when there will be little difficulty in raising it gently and carefully from its bed, without much breaking or damage to the sand; but if any happens, it is always repaired and rendered smooth; and then the top box is restored to its former place upon the bottom one, and a perfect concave representation of the pattern will of course exist ready to receive the metal.

611. If metal should now be poured into this mould, it would evidently produce a solid mass shaped like the pattern, but no pipe; because the bore or hollow cavity has not been provided for. It is impossible in most cases to produce a clean or well shaped and defined hole in castings by the pattern alone; because if a hole is made in a pattern, the plug of sand that will be rammed into it in moulding, will constantly break off and remain in the pattern, unless the hole is very tapering or conical. The founder, therefore, whenever he desires to produce holes in his castings, either for the passage of screw bolts, the bores of pipes, or any other purpose, has recourse to what are called *cores*, and a knowledge of the management and application of cores is of more importance to the Civil Engineer than almost any other part of the foundry business.

612. One way in which an Engineer transacts business with a distant foundry, is for him to make very complete and detailed drawings, indicating every hole, cavity and other particular that he wishes to appear in the desired casting, and to order the iron founder to make patterns in accordance with such drawings. Pattern-makers who perfectly understand the nature of this business, therefore usually form part of the establishment of every large foundry. This method, although often resorted to, is by no means the best. Making such drawings as are necessary, occasions loss of time and great trouble to the Engineer. Loss of time frequently occurs again at the foundry from their pattern-makers being previously occupied on other business, and patterns so made are generally charged at very high prices, and what is worse than all, the drawing is frequently misunderstood, and a casting sent home that does not agree with what is wanted. The most usual and convenient proceeding is, therefore, for the Engineer, who requires many castings, to have a workman in his employ that is capable of making patterns. He works in that case from oral description, without a troublesome drawing; the pattern is made under the eye or directions of the Engineer, he tries its dimensions, or even puts it into the place the iron is to occupy, it is made at the time it is wanted, and when sent to the foundry it is soon cast, and there is a perfect confidence that the metal when re-

ceived will answer the purpose for which it is intended. Still, if the Engineer or pattern-maker does not know how to make the necessary preparations for hollows, holes, and cavities, he will probably receive a solid casting, when he expects a hollow one, or may have the trouble and expense of drilling holes which might have been produced without charge by the founder; and cast iron is so hard and refractory a material to work in, that every precaution should be used to insure having as little work as possible to do upon a piece of cast work after it leaves the foundry.

613. Patterns in most respects are perfect representations of the thing to be cast, but the holes that are required are just the reverse, for instead of making a hole in the pattern where a hole is desired in the casting, holes in patterns are almost constantly marked by convex projections of the size and shape of the hole, and such projections are called *prints.* The print is for the purpose of making the impression of a hole in the sand, which hole is to contain or retain a core that the founder always provides; and as the core must fit the print hole, so the size of the print at once informs the founder what sized core he must make use of, and the hole will be the same. These cores are made of sand loam or other materials according to their magnitude, and the purposes they are applied to. The moulding of the pipe above described, offers a good example.

Recurring to the pattern for the pipe represented by Fig. 132, it will be seen that its two ends are terminated by cylindrical projections *w w* which protrude beyond the flanches, and any one accustomed to pipes will know that these projections do not belong to a pipe, and should not be there; nor will they appear when the piece is cast, for these projections are merely the prints that determine the size of the bore, and provide for the support of the core, which is to produce it. If this pipe is three inches diameter on its outside, and the thickness of the cast pipe is to be half an inch, then the prints *w w* must each be two inches in diameter, which will of course leave half an inch all round for the thickness of the metal of the pipe. If prints of only one inch in diameter had been left, then an inch core only could be introduced, and the pipe would have been an inch thick of metal. The diameter of the print therefore determines the size of the core to be used, and consequently the size of the bore or hole, while the extreme distance between the two ends of the prints determines the length of the core. In moulding this pattern, therefore, the two prints *w w*, will make their impressions in the sand, as well as the rest of the pattern, and the hollow spaces they leave are for the reception and retention of a core that the founder has to prepare, and which when placed in its proper place in the mould, will occupy the position *w w*, and of the two exterior dotted lines in the figure which show the outlines of the core. In the formation of cores several things have to be attended to. The core must be of such materials as will resist the heat and pressure of the iron, and yet it must not bake into so hard a substance as to prevent its removal from the hole when the casting is finished. Long cores, (particularly when used horizontally,) must be very stiff, strong, and incapable of bending, for iron in a fluid state has a buoyant power of more than half that of quicksilver, and will float or bear up any thing lighter than itself; and as the iron first runs into the bottom of the mould, it will bear up the core, and break or bend it, if weak enough to give way, and in this effort will also force up the upper box, and spoil the casting if that box is not loaded with a sufficient quantity of pig iron, or is not hooked to the bottom box. All long cores are, therefore, made upon iron bars if small, or upon tubes or pipes of wrought or cast iron pierced with small holes, if the bore of the pipe to be made is large enough to admit the latter. Such bars are called core bars, and the tubes core barrels. Fig. 131, Pl. IV., is to illustrate the formation of a long core, and *o p o* is the iron core barrel in which some of the holes are seen near *p*. These holes are for the discharge of air, steam, and gas, from the inside of the pipe when the hot metal is poured in. These barrels are either 7 or 10 feet long, because iron pipes are usually cast in 6 or 9 feet lengths, and the core must be longer than the pipe. Each core barrel has wrought iron pivots fixed to its two ends, as at *q* and *r*, so that the barrel can be turned in a proper cast iron support by a winch at *q*. Being thus arranged, a tightly twisted band of wet hay is wound round the iron barrel from one end to the other, in an even manner, part of which is seen at *s*, and this being secured, the hay is covered over with well beaten wet loam mixed with plasterer's hair, to give it greater tenacity, and thus a cylindrical coating of loam like *t t*, is made over the hay bands. The loam is well known to founders, and is a sandy weak clay, or one that has not enough of clay in its composition to burn to a hard stone. The core is made truly cylindrical by turning it by its winch against the straight edge of a board, called a striking board, placed parallel to the barrel, and at such a distance from its axis that the board will scrape off all superfluous loam, or show the hollow places to which more loam must be added until the core is made truly straight and cylindrical from one end to the other. The core thus prepared, is carried into another appendage to the foundry called the *stove*, but which is in fact a brick room with an arched covering, and closed by iron folding doors, and good fires are kept within this chamber so as to make it constantly hot, that it may answer the purpose of an oven for drying cores or other moulds that are placed within it. The cores are arranged in racks one above another, and there left till they become quite dry and hard, when they are dressed and made smooth by rubbing, or by a coarse file if necessary, and they are blackened by a mixture of finely ground coal dust and water and being again dried are ready for use. To use the core, it is only necessary to cut away so much of one or both its ends *o o* by a knife, as will permit the loomed ends of it to fall into the two cavities made in the sand by the prints *w w*, and likewise to cut away so much of the sand in both boxes beyond the core prints, as will give room for the ends *o o* of the barrel, and the pivots *q r* to lie in the sand, or even project beyond the ends of the flask; for the core barrel and all its appurtenances remain in the mould until after the iron has been poured into it. The use of the several parts will now be apparent. The core barrel produces the necessary stiffness, and provides for the escape of vapours, and if the loom was placed immediately upon it, the heat of the iron would bake it into so hard a consistence, that neither the barrel or loom could be extracted without difficulty. But the heat is so great, that before the iron cools all the hay is burnt away and consumed, so that the barrel is easily withdrawn, and only leaves a thin tube of baked loom within the pipe, which is taken out by long chisels or scrapers for the purpose. Short cores, such as are introduced for making bolt holes and the like, are formed of damp moulding sand rammed into moulds prepared for the purpose, and called *core boxes*, the sand when formed is taken out, put on iron plates and placed in the stove, where a large collection of dry cores of various shapes and sizes should be kept, and when dry the sand will have sufficient tenacity to permit of its being handled and placed in the print marks made for its reception, without fear of breaking or injury. As a general principle, therefore, it must be recollected that whenever holes are required in a casting, their places must be indicated in the pattern by prints and not by holes. Those unacquainted with the practice of moulding will sometimes be at a loss how to place the prints in the most advantageous positions for the moulder, and whenever such difficulty occurs, the best way is to put on the prints exactly where the holes are wanted, because this shows the moulder where they ought to be, and if they are not placed in a manner convenient to himself, he will alter them; for prints are only stuck on with brads, and should not be glued. Indeed glue should be avoided in every part of a pattern if possible, for however neatly it may have been managed, the moist heat of moulding sand is sure to dissolve it more or less, which causes the sand to adhere to the pattern and produce imperfect or rough castings. Nailing with brad, or dovetailing are, therefore, constantly resorted to in making patterns. If the hollow to be produced in a casting varies from the usual regular forms of cylinders, squares or rectangles, it is customary for the pattern-maker to furnish the founder with a core box, for forming such cores.

614. Notwithstanding that green or damp sand is almost constantly made use of for the common run of work in foundries, it requires great nicety and is not the best material. The sand requires to be moistened to a certain extent to enable it to maintain the form that has been given to it by the pattern; but if it is made too wet, it is exceedingly dangerous to the workmen, for steam is generated so suddenly and in such quantities the moment the iron is poured into the mould, that it is blown up, and the fluid metal dispersed in all directions. The moulder therefore has to be very cautious in damping his sand, to prevent such accidents. But even when the mould is safe, the melted iron coming into contact with damp sand, and the cold produced by the sudden evaporation, never fails to produce a bad effect upon the iron, if it is intended to be worked by turning or filing, for it renders the outside very hard and refractory, which is an advantage if the casting has to be used in the state in which it leaves the sand. All castings that have to be cut or worked upon, should therefore be of the third variety before enumerated, (604,) or be made in *dry sand.*

615. The process for green and dry sand castings, is in every respect alike, except that for dry sand, as soon as the mould is finished, the flask is carried into the stove, and there opened and kept for a day or two, or until the sand has become perfectly dry and hard. It is then carried into the foundry, and being properly disposed for receiving the metal, a charcoal fire is made round, and over it, so as to get the sand in a very hot state before the metal is poured into it, and thus the metal runs into a hot and dry mould, instead of a damp and cold one; and as the flask is not opened until quite cold, the metal receives no chill, and will be superior in quality for working upon. Dry sand is worth more than green sand casting, because the founder has the same trouble and expense in both, with the additional loss of time and expense of fuel for drying the mould in dry sand work.

616. The fourth and last kind of casting, is the most difficult and costly, and is called *loam-work.* It is only resorted to for producing large cylinders for steam-engines, air vessels for forcing-pumps, boiling pans for sugar refiners, soap-makers, and other manufacturing purposes, and generally for any thing that is so large that a pattern would be inconvenient, or that flasks could not be made sufficiently large to contain and mould it, without having them of enormous weight, and unmanageable dimensions.

Loam work is carried on from drawings without any pattern, and is so different from sand work, that those foundries that undertake it, have distinct sets of men called sand and loam moulders; for loam moulding is indeed modelling in clay or loam. It constantly requires a very powerful crane in foundries where it is undertaken, and a dry location, or one free from springs, to the depth of at least 10 or 12 feet, because the casting always takes place in an underground pit, which must be deep enough to hold the thing to be cast without any part of it rising above the surface of the floor, or its lower part being exposed to natural humidity. A description of the manner in which a large steam-engine cylinder is moulded and cast, will suffice to explain how loam casting in general is conducted. The moulding takes place on the floor of the foundry, and is carried on upon a circular foundation plate of cast iron, made for the purpose, and which must be at least one foot more in diameter than the proposed cylinder when finished. This plate is so placed, in a horizontal position, that the jib of the crane can sweep over its centre, and it has three short arms projecting from its circumference, to which chains are attached and carried up to the crane, for elevating the plate in a perfectly horizontal position whenever required. The chains having been adjusted as to length, are taken down and put away. The *sweep* is now erected, which is a strong bar of iron longer than the cylinder to be formed, its bottom is formed into a shoulder, with a cylindrical pivot which works in a corresponding hole in the centre of the foundation plate, and its top has a similar pivot working in a bearing, in a cross piece of timber, so that the bar thus fixed in a vertical position, can revolve freely, but without shaking, and is set truly perpendicular by a plumb rule. The upper end of the vertical bar carries one or two arms one above the other, but both parallel, and at right angles to the bar, and these arms have many bolt holes, with screw bolts passing into them, by which striking boards may be fixed to them in any required position. The first striking board to be used for a cylinder has a perfectly straight inner edge, which is placed towards the iron spindle, parallel to it, and at a distance from it equal to the intended radius of the inside of the cylinder. This board is screwed to the arms and extends down to within an eighth of an inch of the foundation plate, and being so disposed its inner edge will of course describe a cylinder when turned round upon the vertical iron bar as an axis. The building of the cylinder mould now begins, and this is done with very soft or sammy bricks (493) laid four inches thick in wet loam, instead of mortar, upon the foundation place, taking care that the outside of every brick shall be at least an inch within the inside edge of the striking board, as it is moved round. A hollow cylinder of brickwork will in this way be produced, which must be a few inches more in height than the intended cylinder. The wall being finished, is next to be plastered with the same wet beaten loam and hair used for covering core barrels, and which, when it becomes about an inch thick all round, will touch the striking board and be scraped off by it, until a fair and smooth loam cylinder is produced, and which is the core of the intended iron cylinder. It now stands till it is dry, and this operation is expedited in damp weather by putting ignited charcoal into the brick cylinder. The striking board is then shortened or taken up about two or three inches, for striking or forming a horizontal plate or layer of loam upon the foundation plate, to protect it from heat, and to form the underside of the bottom flanch of the cylinder. This work being dry, the cracks or fissures that have occurred in it are mended or plastered up with damp loam, and the whole is painted over with a thick coat of coal and charcoal powder and water, and the print holes for the bolt holes of the bottom flanch are set out by a thin template of wood and cut out by a chisel. The thickness of metal for the proposed cylinder having been determined, say $1\frac{1}{2}$ inches, and the flanches at 2 inches, the striking board must now be raised 2 inches higher, and be placed $1\frac{1}{2}$ inches further from the centre, when another coat of loam prepared without hair is put on, and struck round by the board, and this coat we will call the representative coat, because it holds the place that the iron is to have, and represents its form. If any bands or mouldings are to surround the cylinder, they must be made on this coat, and are produced by cutting the profile of them in the inner edge of the striking board. The bottom flanch must also be struck and formed. This coat of loam being dried, must in like manner be black-washed, the blacking answering the purpose of parting sand, and preventing one coat of loam adhering to another. The striking board is now done with, and may be taken down. Two semicircular plates of iron, each with three projecting arms as before, and with their insides made circular to suit the curvature of the lower flanch, are now placed opposite to each other on the foundation plate, to serve as foundations for the external case of the mould, which is built in two semi-cylindrical halves upon them. The lower part of the representative coat and flanch are first covered with wet loam and hair which is backed or supported by soft brickwork as before, but which in this case will require to be twice as thick, and these walls are made with straight joints over the ends of the semicircular plates that they may be taken asunder when dry. This outer wall, or jacket, as it is generally called, having been carried to the full intended height of the cylinder, the upper flanch must be struck upon its top, by a short striking board fixed for the purpose, and lastly, a circular cake of loam is struck on another iron plate to cover the top of the flanch. The several pieces being well dried are now to be separated by the crane; the two halves of the jacket or external casing are moved laterally away, and the representative coat is carefully broken and cleared away as useless. The pit is dug, and made level in its bottom, the first foundation plate with the core upon it is taken up by the crane and chains, and lowered into the pit; the two jacket pieces are next lowered in the same manner, and put in their proper places; the cores for the bolt holes of the lower flanch having been arranged in their proper positions, and now the sand dug out of the pit is returned again by shovels, and carefully rammed round the outside of the mould, which is generally further secured from separation by an iron chain being wound round it; lastly, the loam cake or covering is placed over the mould, having a gate and vent holes made in it, when the whole is buried in sand by filling and ramming the pit to its former level with the foundry floor, when the mould will be ready to receive the melted iron.

617. Heavy loam castings, such as have been described, cannot be made from a cupola, but require a large charge of metal and a wind furnace; and the quantity of metal is too great to be carried in shanks or ladles, therefore a gutter is generally made in sand from the gate of the mould to the tap hole of the furnace, and when the tapping takes place the metal flows immediately into the mould. In getting the casting out of the pit, the sand has again to be dug out and thrown to the surface, the jackets are broken to pieces, and the fragments brought up in baskets to lighten the load, and chains must be fixed round the remainder for hauling it up from the pit by the crane. Such is the process that must be gone through with slight variations in all loam castings.

618. It is sometimes desirable to produce castings of more than ordinary density and compactness, as in forming the rollers before described (580,) for making bar iron and sheet metals. This is done by placing the mould in the bottom of a deep pit, and having a gate and vent of several feet in perpendicular height, while the metal is to be poured to the full surface of the gate; and as fluids press in all directions according to their perpendicular height, so of course a great pressure and condensation is produced on the casting at the bottom of the pit. The gate, in this case, should not be perpendicular, or the heavy iron in falling so great a height might break or injure the mould, and would carry down air with it which would make the casting show air bubbles. A large gate and vent having a small connexion with the casting

that they may be easily broken off, is always an advantage, because all metals shrink much in cooling, and this shrinking takes place to the greatest extent in that part of the metal that remains longest fluid. This is the case with the gate, therefore the contraction takes place in that and does not deface the casting, but if the gate does not contain metal enough to supply the deficiency, the shrinking will extend to the casting itself, and may spoil it.

619. Castings of any kind appear rough, when they leave the mould, and require to pass through the hands of a workman called the trimmer. His business is to cut off the gates, vent pieces, and all superfluities, by the cold chisel and hammer; to take out and remove all cores or remains of cores from holes or pipes; to scrape and file the outsides and remove any sand that may adhere to the castings, and to finish and improve their surfaces by rubbing them with charcoal and coke. He likewise performs another duty that would be better let alone, as it often gives the Engineer great trouble and vexation; that is hiding all blemishes and defects in castings by running lead or cement into holes or bad places, so as to render them invisible, in order to make castings pass for perfect, which would frequently be returned upon the hands of the founder, had the defects been apparent on the delivery.

620. From the foregoing description it will be seen that one of the most difficult and delicate operations the moulder has to perform, is the raising a top flask from a bottom one after moulding a solid pattern, without breaking down much of the sand. This difficulty arises chiefly from his having no means of access to the pattern for the purpose of loosening it; for whenever a pattern is gently struck by a hammer, it becomes detached from the sand, and may, in most cases, be raised with ease. On this account solid patterns or patterns in single pieces, are never made when they can be avoided; but every pattern should consist of two halves, put together with steady pins, for preserving the position of the parts, and is so placed in the flask that the joining may be horizontal; consequently on separating the two boxes, one half of the pattern remains in the lower, and the other in the upper box, and the difficulty of taking them out of the sand is much diminished, at the same time that advantages in the facility and perfection of moulding are presented.

621. In order to increase the facility of withdrawing patterns from the sand, it is essential that their surfaces should be smooth and regular, on which account patterns that are very frequently used are varnished and polished. It is also quite necessary that every pattern should have *draught* as it is called, that is, the lower part that is to sink into the sand must be smaller, though

in a small degree, than the upper part; so that whenever the pattern is raised in the slightest degree, it may become detached from, and independent of the sand. If a pattern is larger below than above, it will be impossible to withdraw it without tearing up the sand and breaking the mould; while if it diminishes in the slightest degree no such effect can occur.

622. Another very important point for the Engineer to attend to in making his patterns, is the contraction of the metal in cooling, which constantly causes the finished casting to be less than the pattern from which it is made. Different kinds of iron contract in different degrees, and the white or No. 3 pigs most of all, so that the exact quantity of allowance is best learnt by dealing with a foundry and observing the diminution that really occurs. The average allowance that is made is one-eighth of an inch to each foot of extension for medium or No. 2 iron, but this is rather too much for No. 1, and not enough for No. 3. From this cause, if we want a pipe or a column to be exactly 9 feet long, the pattern must be made 9 feet $1\frac{1}{8}$ inches long, or nine-eighths of an inch has to be allowed, and this same principle applies to the thickness as well as the length of all castings, and must be particularly attended to in cogged mill wheels. The cavities for the wooden cogs of an iron mortice wheel, are all produced by cores, for which purpose a core box is indispensable, that all the holes may be alike; and the prints for such cores are always set in pairs opposed to each other on the inside and outside of the rim of the wheel pattern.

623. In the formation of all patterns, especial care must be taken not to introduce more metal than is necessary for due strength and good appearance, because a superabundance of metal greatly enhances the weight and cost of the work, and what is of more importance, there is not the same proportional security as to strength in very large castings as will be obtained from an equal area of smaller ones. This is brought about by the natural contraction of the metal in cooling, and the impossibility of producing any change in the shape of a piece of cast metal the moment it becomes hard or sets. In moderately sized castings the setting takes place throughout the whole mass at once, and all its parts solidify at the same instant, or nearly so, therefore a uniformity of contraction occurs. But in very large castings, it frequently happens that their outsides, which are in contact with the mould, will cool and set all around, and thus inclose a considerable portion of yet fluid metal in the centre that will not set for some minutes afterwards. When it does so set and cool, it must contract, and in doing so would draw the outside inwards, and diminish the whole size of the casting; but the out-

side is set and cannot change its figure, therefore the inside is compelled to contract alone, and in doing so frequently runs into crystalline forms, and leaves cavities that are called air bubbles, but which are in fact perfectly empty spaces, similar to the torricillian vacuum of the barometer. Such conformations are constantly found when very large and heavy solid shafts break, and the iron is said to have a honey-combed grain. This is avoided by making shafts and columns hollow or tubular, and experience proves that the same quantity of metal in a hollow shaft or column will produce much greater strength than if it were solid.

624. These considerations, however, belong more particularly to the next chapter, where they will be explained and investigated, and where it will be shown that the same materials are capable of producing very different degrees of strength, depending upon the manner in which they are placed and used. Thus it is known to every one, that if an inch pine board of 12 inches wide, and 10 feet long, is placed with its broad side upwards to be used as a shelf, it will support very little weight without first bending and then breaking; but if this same board is placed with its thin edge upwards, and any means is resorted to for preserving it in a right lined direction, a most enormous weight in comparison to the first it could bear, may be hung to it without fear of its fracture. This principle is constantly resorted to in using cast iron; for a thin plate of cast iron, like a board, can bear but little, and from the brittle nature of the material, will break upon a slight bending; but if two such plates are used conjunctively, and one is placed flatwise like *y y*, *Fig.* 133, *Plate IV.*, and the other, *z*, is put under it with its thin edge upwards, then the position given to *z* will prevent *y y* from bending downwards, and consequently it cannot break until such a force is applied above it as will break *z*, because until that is done *y y* cannot bend sufficiently to break. In practice two bars are seldom used in this manner, but the two are conjoined or cast in one piece, as shewn in the figure, which is a transverse section of a cast iron beam fit for a breast-summer for carrying a wall or a girder for supporting a floor. The figure likewise shews the draught that should be given to the pattern to make it deliver from the sand. Such a beam would be cast in the direction in which it is drawn in the plate, therefore every part is made narrower below than above. The two edges of the horizontal plate *y y* incline, so that the bottom side is not as wide as the top, and the strengthening plate *z*, which in foundry work is called a *feather*, is wedge-shaped, or thinner at the bottom than the top; and as the last contraction of cast iron in cooling always occurs where there is the greatest quantity of metal, and this is generally where two plates or surfaces intersect, so when surfaces

are joined at right angles, there is more chance of their cracking and even separating there, than any where else, so to avoid such accident, it is prudent, and very customary, to introduce a fillet or ovalo (115) into all retiring right angles, to give additional strength; and accordingly such a one is shewn at *a a* in this beam; and the same precaution is also necessary in the similar angle made by the junction of a pipe with its flanch as shewn in *Fig.* 132.

625. *Fig.* 128, *Plate IV.*, is a front view of a pattern for a cast iron wheel of great strength, and *Fig.* 129 is a transverse section of the same, and these figures are introduced to show how the principles above explained are applicable to the formation of wheels, and a vast variety of articles now made of cast iron; in the planning of which the Engineer must always endeavour to obtain the greatest possible strength out of the smallest possible quantity of material, not only as before observed, for saving expense in the original cost of construction, but likewise in the transportation of the materials, and for the equally important purpose of preventing unnecessary weight upon the moving bearings of machines, and of diminishing inertia and friction, by which greater freedom of motion is induced, and the appearance of the construction improved: for light and delicate machinery is always more pleasing to the eye than that which is clumsy from being overloaded with material.

626. Suppose it is desirable to construct a strong cast iron wheel that shall present a face or surface of 4 inches wide to the ground or surface on which it is to run. Instead of making the felly or circumference a ring of 4 inches square in metal, or even 4 inches wide by 2 inches thick, and putting strong cylindrical spokes like those of a carriage wheel to support it, the whole, with the exception of the boss or nave, may be made of metal not exceeding three-quarters of an inch in thickness, with greater certainty and more strength by adopting the construction shewn in the figures. The nave or boss *b* must of course be a solid block of metal, as it requires length of bearing for the axle-tree, and has to support all the other parts of the wheel, but it may be tapered on both sides like two truncated cones, as seen in the sectional figure, and this will give it good draught from the sand; *a a* are the prints for the cylindrical core that is to form the hole through the centre of the wheel. The six arms *c c*, and the internal ring *f f* may be made of $\frac{3}{4}$ inch board, having a width proportioned to the load to be carried. The external ring *e e* is fixed on the edge of the thin internal ring *f f*, and must of course be 4 inches wide, but need not exceed $\frac{3}{4}$ inch thick, but it will be better to make it a little thicker in the middle of the inside, not

only to produce draught, but to increase strength. To give strength and stiffness to the arms, feathers *d d* are applied on both sides of them instead of on one side only, and these feathers should be thinnest on their outer surfaces. A transverse section of each arm will therefore present the form of a cross as seen at *i, Fig.* 129, and thus not only the arms, but the circumference will be strengthened by flat pieces at right angles to each other, and sufficient strength for any required purpose may in this way be obtained.

627. If the opposite mode of construction had been adopted, and a heavy periphery had been connected to a solid boss or nave, by spokes of much smaller dimensions, such a wheel might be cast, but the chances are greatly against its being raised out of its mould in an entire state; and if that should happen, there is the greatest probability of its breaking by a very slight shock or concussion in after use, owing to unequal contraction, and the metal not being in a state of what may be called tranquil equilibrium throughout its substance. The spokes being so much smaller than the other parts, will set and cool, and arrive at their maximum of contraction while the other parts are hot or even fluid, and this inequality of contraction will, in all probability, cause a separation of the spokes, or some of them, from the nave or from the circumference, or if it does not take place on the first cooling it will occur afterwards, if the wheel should be struck with a hammer, or receive any shock or vibration that will permit the unnatural tension to overcome the cohesion of the weakest part. These accidents to castings and their spontaneous fracture are very common, and the blame frequently attaches to the founder, who is accused of having used bad iron; whereas the real cause will generally be apparent to any one acquainted with the nature of cast iron, and may be traced to an injudicious form of the casting; and such accidents can only be guarded against by such a skilful disposition of the quantities of metal that no one part shall have an advantage over another. If one part of a casting is made thick, others that join it must be thick in proportion, and no attempt made to unite very large and very small pieces except by rivets or screws, for they must be made separately.

628. It is on this account, as much as for the convenience of transportation, that the large fly wheels of steam engines, and cog wheels for mill work are made in separate pieces, consisting of the central boss, arms and segments, which are afterwards united by screw bolts and nuts; and it is found that wheels, shafts, and other heavy pieces, are more strong, and trustworthy, when so put together, than such as are cast in single pieces. Another advantage also attends the union of separate pieces, which is that

owing to unequal cooling and contraction, (however much guarded against,) it is nearly impossible to obtain a large flat casting without some little warping or winding, which cannot be cured in a single piece. But when large wheels are put together there is an opportunity of curing this defect, if it exists, in the making of each joint, in consequence of which, built wheels, as they are called, can generally be made to run and work with more truth and accuracy than such as are cast in single pieces.

629. Cast iron work for engineering or mechanical purposes is always sold by weight, except in the instances of straight water or gas pipes, and rail-road plates, and these being of uniform size, take, on an average, the same quantity of iron and labour, and can therefore be charged by the running yard, which for these articles is a more satisfactory method, as it enables the Engineer at once to name the cost of any given quantity of such materials. But if a pipe or plate of more than ordinary weight, or of peculiar construction is required, it is not included in measure, but is weighed.

630. Pattern making, from its nicety, and requiring the best of workmen and materials, is always expensive, and a single pattern frequently costs more than the casting made from it. The expense of patterns always falls on the employer, whether he makes them or has them made at the foundry; and they are his property, and should be preserved, or sent back with the castings. Of course, therefore, in making estimates, the expense of the patterns must be added to the cost of the metal. But many large foundries are in the habit of keeping patterns of their own, for all such things as are in common request, and of which great numbers are required, and in this case the founder adds a small per centage for the use of his patterns upon the charge he makes for the iron, and where this is done, it is a great saving in point of expense as well as time to the Engineer. Messrs. Galloway, Bowman & Co. of the Caledonian foundry, at Manchester, in England, publish a list of the patterns they thus keep, and which amounts to upwards of five hundred bevil and spur wheels of all sizes and strengths which are specified, together with the number and pitch of their cogs, besides about one thousand varieties of shafts, gudgeons, coupling boxes, pullies, pipes, frames for presses, and other articles, so that the Engineer can find almost every article he stands in need of, for the ordinary construction of mills, presses, rail-ways, gas and water-works, spinning machinery and power looms, without having occasion to construct patterns of his own.

631. The only method of estimating the expense of cast iron work is by measuring and calculating the solid contents of castings,

or else reducing them to board measure, (566,) and computing the weight in either case from the known weight of iron. The average specific gravity of cast iron is 7.207,* and as striking out the decimal point from the number expressing the specific gravity of any given substance, at once gives the number of avoirdupois ounces that a cubic foot of that substance weighs, so a cubic foot of cast iron will weigh 7207 ounces, or 450 pounds and 7 ounces. But as bolt holes and small cavities in castings are never deducted, so foundries usually disregard the 7 ounces, and call a cubic foot of cast iron 450 pounds, the twelfth part of which, or a superficial foot of iron one inch thick, will weigh $37\frac{1}{2}$ pounds, or 600 ounces, and a single cubic inch 4.163 ounces. Solid castings are, therefore, cubed and compared with the weight of the cubic foot or inch, while hollow castings, such as hollow cylinders or pipes, are measured superficially, and estimated as if they were one inch thick. If they are more or less than an inch, then the product obtained by one inch is increased or diminished accordingly. Thus if the cylinder is two inches thick, the product is doubled. If one and a half inches thick, only half its amount is added, or the same quantity subtracted if the iron is but half an inch thick, and so for other thicknesses.

632. The weight of solid castings may be determined with sufficient accuracy for many purposes by weighing the wooden pattern and multiplying that weight by 14.4 if the pattern is made of white pine wood; or by 10.8 if made of hard mahogany; because cast iron is heavier than these varieties of wood in very nearly these proportions. This is an expedient that iron founders constantly resort to for determining the quantity of iron to be *put up* or melted, in order to insure having iron enough in the furnace for the intended purpose (603); and Engineers may resort to it when they wish to become acquainted with the approximate weight of any casting for which the pattern has been prepared. Patterns are sometimes called models, but pattern is by far the most common name by which they are designated.

Steel.

633. Steel cannot be considered as constituting a building material, and therefore in strict propriety ought not to be included in the present chapter. It is however of so much importance in the building art, as constituting the only material of all cutting tools, and is so frequently used in machinery, that some information as to its properties cannot fail to be interesting to the Engineer.

* Dr. Thomas Young's Lectures on Nat. Phil., Vol. II. p. 503.

634. Steel is an artificial or factitious metal, being produced by causing bar or malleable iron to unite with a quantity of carbon, but at the same time, a less quantity than that which it held before it was converted into bar iron. Cast iron generally contains about 5 per cent. of carbon, while steel seldoms holds more than from $1\frac{1}{4}$ to $1\frac{3}{4}$ per cent. The formation of steel is therefore partially bringing iron back again to its primitive state, and yet the variation produced by this small difference in the quantity of carbon, produces a great difference in the two metals; for cast iron is always more or less brittle and cannot be forged or welded, while steel yields readily to the hammer, and may be forged and worked with nearly the same facility as bar iron. It nevertheless requires more care in the heating, for steel is fusible, though in a less degree than cast iron, and by over heating, it looses all its valuable properties, and in the language of the workmen becomes *burnt.*

635. Steel is made by selecting the best and most pure bars of iron, and inclosing them in a tight box with powdered charcoal, in which state they are kept in a furnace exposed to a very violent heat for about a week, and on being withdrawn, the box with its contents is allowed to cool very slowly, before it is opened. During this process the iron bars combine with the necessary quantity of carbon, and become converted into steel. The process is called *cementation.* The steel made in this way exhibits many blisters like air bubbles on its surface, and hollow cavities of a similar kind occur in the middle of the bar, on which account steel in this state is called *blistered steel.* Steel is very commonly sold and used in this state, but it requires considerable forging, that is hammering in the red hot state, to get rid of the hollows and blisters, and to render it equally close and compact throughout its whole substance. This forging is very frequently performed at the place where the steel is made, by means of heavy hammers driven by machinery, and called *tilt hammers,* and when the blisters and cavities have thus been got rid of and the bar is rendered uniform throughout, it is sold under the name of *sheer steel.*

636. Blistered steel instead of being forged, is occasionally broken into short pieces, which are put into large crucibles having close covers, and containing powdered charcoal, and in this state is fused by heat, and cast into ingots about 30 inches long, in which state they pass the grooved rollers like bar iron, (580,) and are converted into bars which are called *cast steel,* and this is considered the best and purest kind, and is more used than any other for cutting tools.

637. In selecting steel for use, regard must always be had to

its qualities, which seem to depend on the quantity of carbon it contains, and the care with which it has been manufactured; hence there is a great difference in the quality of steel, and that manufactured by some makers has a decided preference over others. For making springs, the steel should contain but a small quantity of carbon. Articles of cutlery require a larger quantity, and files and all tools for cutting the hard metals, require the largest dose, and should therefore always be made from cast steel.

638. Notwithstanding steel is but a variety of iron, still it differs from that metal in several important points. It is of a lighter colour, and always appears granulated instead of fibrous. It is susceptible of a much higher polish, and is less liable to rust. It has a greater specific gravity, and is capable not only of being rendered much harder, but much more elastic than iron. When touched by a strong acid it turns nearly black. It is less powerfully attracted by the magnet, but retains permanent magnetism which cannot be communicated to iron. It is fusible, although capable of welding, but its most valuable and distinguishing property is the facility with which it may be hardened or softened to almost any required extent by different degrees of heat, the application of which is called *tempering*.

639. Steel in its first state is flexible and nearly as soft as bar iron, but if a piece of it is heated to a low red or cherry heat, and is then suddenly cooled by plunging it into cold water, it becomes intensely hard and brittle, and will not bear the slightest bending without fracture. All files and tools for cutting hard metals must therefore be hardened in this way; but it renders them subject to the inconvenience of very readily chipping or breaking on their edges, from the extreme brittleness of the metal. If, however, the hardest steel is heated to redness, all its hardness disappears again, and by thus heating it and permitting it to cool very slowly, it becomes almost as soft as iron. If the steel is polished or made bright by grinding while in its hard state, it will assume a succession of brilliant prismatic colours upon its surface when heat, much below redness, is applied to it for the purpose of softening it. These colours are constantly in the same order of succession, and bear relation to the hardness of the metal; and if the steel is cooled by plunging it into cold water at the moment any colour makes its appearance, the hardness that is peculiar to such colour becomes permanently fixed in the steel, and this operation, which requires care and dexterity, as well as experience on the part of the workman, is called *tempering*. Steel in its hardest state, has a peculiar white appearance, by which its hardness can be judged of by an experienced eye without trial, provided the surface is free from oxydation. On applying heat to such hard steel, the

first colour that makes its appearance is pale yellow, which becomes darker or more inclining to a tawny brown, if the heat is continued. The medium yellow is by workmen called straw colour, and it is on the appearance of this colour, that the steel must be cooled, to obtain the most favourable temper, for all tools for cutting brass, iron, and copper. If, instead of being cooled, the heat is continued upon the steel, the brownish-yellow changes to that beautiful blue colour so common upon steel implements. The blue temper is also called the spring temper of steel, because when blue, it is much less hard than while straw coloured, and it now possesses its highest degree of elasticity. Steel at the straw coloured temper, is so devoid of elasticity, that it will not bear the slightest bending without breaking, but at the blue temper it may be bent to a great extent without fracture, and on being released from the bending force, will revert to its former figure. All steel springs should therefore have the blue or spring temper, the nature of which is well exemplified in the main spring of a watch. The various tools for cutting wood should also have this temper, which will render them hard enough for their intended purpose, while they will not be so liable to be broken as when they are harder. Should the heat be continued upon the steel beyond the appearance of the blue, it will assume a reddish or violet tint, and the steel is then too soft for the generality of tools, and is flexible, but possesses but little elasticity or tendency to revert to its former figure, but will retain any shape into which it may be bent, and if heated to redness and slowly cooled, it will be black like iron, and is in its softest state. Of course, steel is constantly worked and formed in this state, and is not hardened and tempered until the article is finished, all but receiving its last polish. Drills and other tools of hard steel, that are subject to rapid motion, frequently become so heated by friction during their use, that they soften themselves and become inefficacious, in which case there is no alternative for restoring them, except by the above described process of hardening, and afterwards tempering them; for every piece of steel must be made hard before it can be reduced to a lower temper. On this account chisels and many working tools are sold hard, in order that the workmen who are to use them, may let them down, or temper them to their own wishes; and this can be very conveniently done by placing them on a sufficiently large bar of iron previously made red hot, and having a bucket of cold water at hand to plunge them into the moment the desired colour has appeared. Saw blades, swords and other articles of steel, that expose considerable surface, are very difficult to temper equally, and the heat is best applied to them by placing them in a bath of boiling oil, or of melted tin, or lead, so that every part shall be simultaneously exposed to the same elevation of temperature.

640. Steel has the same faculty of welding as iron, and it will not only unite with itself, but with iron in this way, so that tools and other articles are very seldom made wholly of steel, but a thin piece is welded on to iron when a cutting edge is required. The manufacturer takes this additional trouble to save the expense of steel, which usually costs from three to four times as much as iron; and it is equally advantageous to the consumer, for hardened steel is always more or less brittle, and articles made wholly of steel, would be very apt to break; but as the quantity of iron usually predominates, its tough and flexible property if good, adds a strength to the steel which could not otherwise be obtained.

641. The same object is obtained in another way, by the process called *case hardening*. Articles to be finished in this manner are made wholly of the best iron, and are filed up, finished, and rough polished. They are then inclosed in a close iron box, in which they are imbedded in charcoal, a part of which should be produced by burnt leather or bones. In this state the whole is exposed to a full red heat in a furnace, for a few hours, when the whole external surface of the iron will be converted into steel, penetrating no deeper than the thickness of common paper, but which thin casing will bear hardening, tempering, and polishing, thus giving the article all the external characters and advantages of steel, while the unchanged iron within gives strength, or rather tenacity.

642. *Brass*

Is not a building material, but is much used by the practical Engineer, who should therefore be acquainted with its properties.

Brass is an alloy or artificial metal, and is distinguished by four principal varieties, called *fine yellow brass, gun metal, bell metal*, and *pot metal* or *cock metal*. The first is a compound of copper and zinc, in the proportion of five parts of the first to three of the latter, which produce the beautiful yellow metal of which philosophical instruments, and articles of household ornament are formed. It is but little used by the Engineer, and then only for the ornamental parts of steam-engines, or for small wheelwork. It is ductile, tough, and very tractable in the hands of the workman, and bears a fine polish.

643. *Gun metal* is of a reddish-yellow colour, and is a compound of nine parts of copper, and one part of block tin, to which sometimes a little zinc is added. It is distinguished by its peculiar

toughness, and derives its name from all brass cannon being formed of it; its toughness preventing them from bursting. It is much used by the Engineer for the bearings in which the iron gudgeons or pivots of all machinery turn, and also for the formation of steam and water valves, and the cylinders or working barrels of pumps. It is less easy to work than yellow brass, but is stronger and more durable.

644. *Bell metal,* so called from its being the composition with which bells are cast, is made of six parts of copper, and two of tin. Its colour is much paler than either of the foregoing, inclining to a reddish-white, or very pale yellow, and it is so hard and brittle, that it will not bear the slightest bending without breaking, and can scarcely be touched by the file or other tools. It can therefore only be altered in form by chipping with the cold chisel or grinding. It is used by the Engineer for the bearings of gudgeons, when extreme hardness is required, and in other places where steel would be objectionable from its liability to oxydation, a property which this metal possesses in a very slight degree.

645. *Pot or cock metal* is the cheapest and worst kind of brass, and is composed of copper and lead usually in the proportion of 2 to 1, or sometimes in equal quantities. Of this metal all water and steam-cocks are made, as well as the various pieces of brass-work made use of by plumbers. The metal has a handsome tawny yellow colour, and takes a good polish, but is soft, and at the same time very brittle, and possesses very little toughness or strength, but it files and works readily, and when not subject to blows or concussions is very durable.

646. *Copper, Lead and Zinc*

Are principally used in the rolled or sheet state, for covering roofs, forming gutters for water, or pipes for its conveyance. Sheet-lead is sometimes cast upon a flat bed of sand prepared for the purpose, when it is called cast lead; but of late years it has generally been prepared by passing it between smooth cast iron rollers, as is always the case with sheet copper, and then it is called *milled lead.* Milled lead is preferable to cast lead, because it can be made thinner and more uniform in thickness, and is not subject to the small air holes or bubbles that cannot be avoided in casting sheets of lead. Lead pipes of diameters less than two inches, are usually cast without a longitudinal joint, but larger pipes require to be turned up out of sheet metal and soldered. Formerly lead pipes could only be cast in short lengths, of about 30 inches each, which were *burnt* together to form a long pipe. Such burning consists in placing the two ends that are to be connected together, in a brass mould made for the purpose, introducing a polished iron core, and then running melted lead upon the joint until by the continued application of its heat, the two contiguous ends of the pipe are fused, and join to the new metal introduced. Now, lead and copper pipes are generally drawn in the same manner as wire, so that they are produced of a uniform size, and in lengths of 12 to 16 feet. An iron triblet or polished rod is introduced into the pipe while it is drawing, to preserve the magnitude of the bore, and this is withdrawn when the pipe is finished. All copper pipes are turned up from sheet metal, and the joint ought to be brazed and not soft soldered. Zinc is applicable to many of the purposes for which copper has been used, but being of a more brittle nature is more liable to crack than either of the above metals. From the soft and pliable nature of lead, the Engineer makes frequent use of it in filling up the joints between iron pipes, and it is likewise used in a state of fusion for connecting iron to stone.

647. Lead, copper, and zinc are always sold by weight, but in the sheet state are designated by the weight of metal in a square foot. Thus four pound lead, which is the thinnest sheet lead that is made, contains 4 pounds of metal in the square foot, and is $\frac{1}{16}$ of an inch in thickness. Six pound lead is $\frac{1}{10}$ of an inch thick. Eight pound lead is $\frac{1}{8}$ thick, and ten pound lead $\frac{1}{6}$ of an inch. Quarter inch lead, which is as thick as it is generally used, is very nearly 15 pounds to the square foot. Sheet copper being a more tough and costly metal, is rolled much thinner, and is designated by the number of ounces in a square foot; six ounce copper is very thin, but from 8 to 10 ounces forms a good covering, and 12 to 16 ounces is very stout.

648. In covering large roofs or other surfaces with any of the sheet metals, the joints should never be soldered together, but certain risings are made at the edges of the plates, and one plate is made to fold or lap over the projection of another in the manner of *pantiles*, (501,) but in a much more close and perfect manner. Such joints are called *laps*, and if well executed will effectually prevent the passage of rain water. If the joints were soldered so as to render the whole one connected plate, the expansion that occurs in hot weather would cause the metal to cockle up, loose its original flat surface, and perhaps form hollows that might retain water above the level of the laps, and cause the roof to leak. The contraction in cold seasons has an opposite effect, and causes one part of the covering to tear or break away from another, thus producing cracks that destroy the continuity of the covering. Laps should therefore be always so constructed as to allow of expansion and contraction, and as these laps are never very distant from each other, the quantity of allowance

need be but very small. The plan for covering roofs with sheet metal, for which Professor Bonnycastle of the University of Virginia has obtained a patent, is very simple, excellent, and effective, and provides amply for the effects of change of seasons.

649. Sheet metals, particularly in forming gutters, are frequently nailed to the smooth boarding that is placed under them, for their support, and in order to prevent the nail hole suffering water to pass, the nail and hole are covered by a small patch of solder. This is called *dotting*. The use of nails in this manner requires some judgment and foresight, as to the effect that may be produced by expansion and contraction, because this very frequently draws the nails when they are improperly placed, and produces worse evils than those they were intended to prevent.

650. *Tin Plates*

Soldered together are very extensively used in the northern cities of the United States, for making gutters, rain pipes, vallies of roofs, and even for covering buildings, but their cheapness is their only recommendation. Tin plates are merely very thin sheets of iron, coated on both sides with melted tin, so as to protect the iron from rusting. But as the covering is not always perfect, and the iron must be exposed at the edges of each plate, if cut, it very soon becomes rusty, and is of short duration, unless protected by frequent painting. It is a very convenient material for temporary purposes, but one that cannot be recommended where duration is desired.

All the other metals are useless to the Builder or Engineer on account of their costliness or want of strength and durability, and therefore need not be noticed.

651. The following tables of the average weight of square, flat, and round, or bolt iron, will be very useful to the Engineer in making his estimates of work to be executed, and in determining the weight or value of what is already done. The weights are given for pieces each ten feet long, which is better than giving the weight of single feet. A single foot in many sizes would require long fractions, and would after all be subject to error when expanded into large quantities from the smallness of the unit. Ten feet is less liable to this objection, and the weight of a single foot, or indeed of any quantity however small may be obtained from the tables, by taking the tenth part of the weights there given, or by dividing any weight by a quantity that has the same relative proportion to ten feet, as the quantity required to be known.

652. *Table of the average weight of bars of flat Iron, each 10 feet long.*

Inches.	cwt.	qrs.	lbs.	Inches.	cwt.	qrs.	lbs	Inches.	cwt.	qrs.	lbs.
6 × ¾	1	1	15	3¾ × ¾	0	3	12	2¼ × ⅝	0	1	23
⅝	1	0	13	⅝	0	2	24	½	0	1	10
½	0	3	19	½	0	2	8	⅜	0	1	1
5½ × ¾	1	1	1	⅜	0	1	20	2⅛ × ¾	0	2	2
⅝	1	0	6	3½ × ¾	0	3	5	⅝	0	1	18
½	0	3	10	⅝	0	2	18	9/16	0	1	14
5 × ¾	1	0	13	½	0	2	4	½	0	1	9
⅝	0	3	23	⅜	0	1	16	⅜	0	1	0
½	0	3	2	3¼ × ¾	0	2	27	2 × ¾	0	1	24
4¾ × ¾	1	0	10	⅝	0	2	14	⅝	0	1	15
⅝	0	3	19	½	0	1	27	9/16	0	1	11
½	0	2	25	⅜	0	1	14	½	0	1	6
⅜	0	2	5	3 × ¾	0	2	22	⅜	0	0	26
4½ × ¾	1	0	4	⅝	0	2	8	1⅞ × ¾	0	1	20
⅝	0	3	13	½	0	1	23	⅝	0	1	12
½	0	2	21	⅜	0	1	10	9/16	0	1	9
⅜	0	2	11	2¾ × ¾	0	2	14	½	0	1	5
4¼ × ¾	0	3	25	⅝	0	2	2	⅜	0	0	24
⅝	0	3	7	½	0	1	20	1¾ × ¾	0	1	17
½	0	2	17	⅜	0	1	7	⅝	0	1	10
⅜	0	2	0	2½ × ¾	0	2	8	9/16	0	1	5
4 × ¾	0	3	19	⅝	0	1	25	½	0	1	2
⅝	0	3	1	½	0	1	15	⅜	0	0	23
½	0	2	12	⅜	0	1	4	1½ × ¾	0	1	11
⅜	0	1	24	2¼ × ¾	0	2	5	⅝	0	1	3
								9/16	0	1	0
								½	0	0	22

653. *Table of the average weight of ten feet in length of square bars of Iron.*

Inches square.	cwt.	qrs.	lbs.	Inches square.	cwt.	qrs.	lbs.
3	2	3	0	1⅝	0	3	2
2⅞	2	2	3	1½	0	2	21
2¾	2	1	8	1⅜	0	2	11
2⅝	2	0	11	1¼	0	1	25
2½	1	3	18	1⅛	0	1	15
2⅜	1	2	24	1	0	1	6
2¼	1	2	5	⅞	0	0	26
2⅛	1	1	14	¾	0	0	19
2	1	0	25	⅝	0	0	13
1⅞	1	0	8	½	0	0	8
1¾	0	3	21				

All square iron less than half inch on a side is called *nail rod*, and such iron is sold in bundles of about 5 feet long, each bundle containing about a hundred weight of such rods.

654. *A Table of the average weight of ten feet of bolt or round Iron.*

Inches diameter.	cwt. qrs. lbs.	Inches diameter.	cwt. qrs. lbs.
3	2 : 0 : 18	$1\frac{5}{8}$	0 : 2 : 16
$2\frac{7}{8}$	1 : 3 : 22	$1\frac{1}{2}$	0 : 2 : 3
$2\frac{3}{4}$	1 : 3 : 6	$1\frac{3}{8}$	0 : 1 : 24
$2\frac{5}{8}$	1 : 2 : 17	$1\frac{1}{4}$	0 : 1 : 14
$2\frac{1}{2}$	1 : 1 : 23	$1\frac{1}{8}$	0 : 1 : 5
$2\frac{3}{8}$	1 : 1 : 11	1	0 : 0 : 27
$2\frac{1}{4}$	1 : 0 : 24	$\frac{7}{8}$	0 : 0 : 20
$2\frac{1}{8}$	1 : 0 : 9	$\frac{3}{4}$	0 : 0 : 14.7
2	0 : 3 : 24	$\frac{5}{8}$	0 : 0 : 10.2
$1\frac{7}{8}$	0 : 3 : 9	$\frac{1}{2}$	0 : 0 : 6.54
$1\frac{3}{4}$	0 : 2 : 26	$\frac{3}{8}$	0 : 0 : 3.68

655. All cylindrical pieces of metal, whether iron, steel, brass, copper, &c., less than $\frac{3}{8}$ths of an inch in diameter, are called wires; and wires are measured and described by passing them into a tool called a *wire gauge*. It consists of a thin flat plate of hardened steel, having a number of indentations made along its edges, all diminishing in size from the largest, and numbered in regular succession, so that whichever indentation a wire fits into, the number corresponding to it is the number of that wire. The wire gauge is an expensive tool, because it requires to be made with great care, since the gauges of different places and even of different countries, should be all exactly alike; consequently, naming the number of any wire to a distant correspondent, informs him the size of that wire if he possesses a similar gauge. The thickness of plate or sheet metals, is also designated and described by the numbers of this same gauge. The indentation No. 1, should be $\frac{3}{10}$ths of an inch wide, or would measure a wire of that diameter, or plate of that thickness. No. 6 is $\frac{2}{20}$ths wide, No. 13 $\frac{1}{10}$th, No. 19 $\frac{1}{20}$th, No. 24 the $\frac{1}{30}$th of an inch, and so on.

656. As iron chains are frequently used by Engineers for various purposes, the following table of their weights is given.

A Table showing the weight of one yard of close or short linked crane chain made from the best wrought iron.

Diameter of the round iron of which the links are formed taken in inches.	$\frac{1}{4}$ inch,	$3\frac{1}{4}$ lbs.	Diameter of iron.	$\frac{15}{16}$ inch,	27 lbs.
	$\frac{3}{8}$	$4\frac{1}{2}$		1	32
	$\frac{7}{16}$	$6\frac{1}{2}$		$1\frac{1}{16}$	37
	$\frac{1}{2}$	8		$1\frac{1}{8}$	41
	$\frac{9}{16}$	10		$1\frac{1}{4}$	50
	$\frac{5}{8}$	12		$1\frac{3}{8}$	62
	$\frac{3}{4}$	16			
	$\frac{7}{8}$	23			

CHAPTER IX.

ON THE DURABILITY AND STRENGTH OF MATERIALS.

SECTION I.—*Of the Durability of Materials.*

657. Having in the former chapter given as full an account as our limits would admit, of the various materials that are used for the purposes of building and constructing machinery, the next object of enquiry must be into their durability and strength, and how these qualities may be affected by their position in the work; for until some knowledge is obtained of these points the Engineer would not know how to select or use his materials to the greatest advantage.

658. The durability of materials can only be known by trial and experience, from which general deductions may be made. Thus it becomes known that a pine post, fixed in the ground, will soon rot and decay, while one of good swamp cedar will be of considerable duration; and of course the first material should never be selected for use, if the second, or one equally good, can be obtained. Again, experience teaches us, that some kinds of stone and brick are almost imperishable, whether they are placed under ground or exposed to the vicissitudes of the atmosphere; while others will moulder away and crumble to dust, or will break off

in splinters if exposed to frost. Of course, therefore, the latter classes should not be used, except for internal work, or such as is protected from weather.

659. It is impossible to lay down rules that shall be applicable to all cases, as it must be that knowledge which the Engineer or builder can only acquire from experience, that must guide him in the selection and disposition of his materials. The following observations and remarks on these heads may, however, prove useful.

660. The principal agents of nature in carrying on the work of destruction, are *heat*, *water* or *humidity*, *frost*, *wind*, and *electricity;* of course the action of all these should be guarded against as far as possible.

661. Heat has a twofold operation; first, in producing actual conflagration or the consumption of constructions by fire; and secondly, in expanding the dimensions of all things; thereby altering their figure or shape, and making them perfectly dry, by the evaporation of the natural juices or other humidity they may contain; thus causing them to be more absorbent than they otherwise would be. This latter effect does not require the presence of artificial fire, but is daily going on, under the sun's influence; and as cold contracts all things, so the natural change of temperature that occurs daily, or at any rate annually, is constantly altering the dimensions of things.

662. The first effect of fire, makes it necessary for the Engineer and Builder to be very careful in the direction and construction of all flues or chimneys of fire places, and to guard against their coming into contact with any timber used in the roof or other parts of the building; and of course no timber or combustible matter of any kind should be let into, or be supported by a chimney, or be placed so near to it as to be endangered by the heat. In London the ravages of fire are to a certain extent guarded against by legislative interference; for an act of parliament, called the *building act*, was passed in 1774, which not only regulates the thickness and strength of walls, but contains many wholesome precautionary regulations against fire; and an act having similar objects, though less extensive in its range, was passed in Boston, Mass., in 1818. These acts prohibit the erection of wooden frame buildings in the respective cities, except in a few particular cases comprehended in very narrow limits, and require that all future erections shall be in brick, stone, or other uninflammable material; that all roofs shall be covered with slates, tiles, or metal, and nothing inflammable be used upon them, and that brick partitions shall be formed between every house, and shall extend above their respective roofs, so that no one roof may have communication with another. The London act goes still further, because it ordains

that all flues or fire places shall be made in the party or partition walls; and that no hole or open communication shall be left or made through such walls, nor shall any timbers be inserted into them, unless the ends of such timber are covered with a quantity of brickwork sufficient in thickness to prevent the transmission of heat; consequently nothing but girders are so used, and all joists and rafters run from back to front, or parallel to the walls of partition. The consequence of which is, that if one house takes fire, there is little or no opportunity afforded for its communication with those that adjoin it. In the modern houses of Philadelphia, where it is believed no such regulations exist, partition walls of brick are also used; but if several houses are on the same estate, or built by the same person, it is no uncommon thing to find the floor joists running through the party walls, and extending from one house to another; and to see roofs covered with shingles of wood, passing in a uniform line over several houses, and over the partition walls, so as to establish a free communication for fire between one house and another. To prevent the passage of fire between the bricks of a chimney, in case of its taking fire, the joints of such brickwork ought always to be laid close and full of mortar, and the inside of the flue should be *pargetted,* which is the technical name applied to plastering within a chimney. This effectually stops up all crevices or openings through which sparks or flame could pass, and renders the inside of the flue more smooth and even for the passage of the smoke.

663. The expansion and contraction of materials by heat and cold, is a natural effect that cannot be guarded against, except when circumstances admit of the materials that are most subject to it being covered by brick, stone, wood, or other bad conductors of heat, or such as transmit it slowly or imperfectly; in which case they will be much less affected. Those substances that conduct heat most rapidly, are also those that are most subject to expansion and contraction; consequently, this effect does not prevail to any sensible or detrimental extent in stones, bricks, mortar and the earths; but it is quite perceptible, and requires to be guarded against in the metals, particularly when used in a long continuous length, as in the construction of iron bridges, or laying iron pipes for conveying water long distances; for notwithstanding the effect may be too small to be seen in a single pipe of 9 feet long, yet, if the line of pipes extend 500 yards, and it takes place simultaneously in all of them, the sum of all the actions is frequently such as to open a joint, or even tear a perfect pipe asunder. Several instances have come under the eye of the writer, in which strong bars of wrought iron, not exceeding 6 feet in length, have been let into stone walls at their oppo-

site ends, and then run in with lead to produce perfect stability and firmness, and yet one or both the joints so made have become loose, and torn out, and the stone near the lead shivered away, as if it had been struck by a hammer. Metals alone are, however, subject to this inconvenience.

664. Another species of expansion and contraction frequently occurs in bodies that are not metallic, arising from their hygrometrical properties when damp and dry; and this belongs more especially to some varieties of wood. Wood is not subject to any material alteration in the length of its fibres from this cause, but it operates very perceptibly in the opposite direction. Wood and most vegetable substances, always shrink to a certain extent by drying, and swell or expand to their former dimensions, or nearly so, when wet or humid. This property gives tightness to casks, vats, or tubs for holding water, and it causes the boards used in floors, doors or joinery work, to expand and become tight and close in damp weather, or to shrink when dry. This effect in vegetable matter diminishes with age, and its prevention is one of the uses of seasoning timber, and keeping it a long time before it is used.

665. Water, or rather humidity, is the great and general cause of decay in materials. It acts as a solvent, if the substance contains any thing that is soluble; and in this way, or by the motion of water, parts of the material are abstracted and carried away. It also acts chemically in producing fermentation, decomposition, or decay, commonly called *rotting;* and it encourages and promotes the production of certain *fungi* or paricidical plants which destroy the texture and hasten decay. Notwithstanding this character has been given to water, it belongs more properly to water and air conjoined; for neither of them act powerfully, or rapidly, when separate. Thus a piece of sound timber, or a bar of iron, if exposed to the free action of air that is perfectly dry, will endure for ages without symptoms of decay; of which the present roof of Westminster Hall, London, the largest room in Europe, is a fine example. It is wholly of black chestnut, unpainted or protected, and is in perfect repair, although erected in 1397, by Richard II. Being a gothic structure, it is unincumbered with a ceiling, and open to full view as well as to the action of the air within the building. Timber and iron will also endure an immense time, if constantly and wholly covered by water; for on taking down the old London bridge in 1830, when the present new bridge was completed and opened, most of the piles of the old bridge erected between 1176 and 1200, were found as sound as new timber, and much harder. But if timber or iron are occasionally wet and dry, the first will decay in a few years,

and the latter will speedily contract rust, which gradually eats into it, until its whole substance is destroyed. The more rapidly a substance can become dry after it has been wetted, the less likely it will be to be affected by decay; hence, whenever humidity is retained, it never fails to operate prejudiciously. Wooden, and even iron posts, always fail first near their bottoms, because the natural humidity of the ground, or even the moisture that may fall upon a horizontal floor or platform, assists in the operation. If a column of timber is faced or ornamented with a plinth or moundings nailed upon its outside, and water can get into the joints between them, decay will take place there, although the upper part, that is fully exposed to the air, may be quite sound. This decay is produced by the effect of capillary attraction, retaining the water or humidity that is introduced and absorbed, thus permitting it much longer time for its operation than if it dried away, which it would have done, if open; for the same reason the sills of wooden buildings, the feet of rafters, and tenons fitting into mortice holes, always decay sooner than the parts that are exposed to the full action of open air.

666. The sun's heat by drying and expanding timber, causes it to become much more absorbent of water than it otherwise would be, and if the water so absorbed, is not permitted to escape freely, it never fails to produce decay. The great object to be attained by painting external wood with oil colours, is, therefore, preservation more than ornament, for if the paint is good, it ought, when dry, to form a coat or casing that is impervious to water, or even humidity, and when that is the case its preservative powers are well known. For this reason paint should never be applied to work that is in a humid state, not only because it will not adhere with certainty, but because it incloses and shuts in the moisture.

667. The detrimental effects of humidity not only apply to wood work, but extend to bricks, stones, and all things that are absorbent, especially if they are at all soluble at the same time; but the worst consequences ensue from the exercise of frost upon bodies that contain moisture; for water in freezing crystallizes, and occupies more bulk than in the fluid state; and the force with which the expansion takes place, is so great, as to be capable of bursting the strongest water pipes, lifting portions of walls, and disturbing the state and condition of the heaviest bodies. If, therefore, brickwork, masonry, earthwork, or even timber that is absorbent, happens to be attacked by frost while full of humidity, it is frequently so burst or shaken by its effects, that if it does not fail immediately, it becomes so loosened and detached as to give way afterwards to the smallest force, or at any rate its

surface becomes more disposed to rapid decay. Many varieties of brick and stone, that is, such as absorb moisture readily, and are tardy in parting with it again, ought therefore never to be selected for outside or foundation work.

668. The same reasoning explains why external brickwork and masonry, as well as plastering, should not be done in frosty weather; for if the water necessarily introduced into the mortar should freeze before the mortar sets, it will afterwards fall to powder, and never make a strong or adhesive joint.

669. Nothing resists the effects of spontaneous decay more effectually than charcoal, and it is on this account that the bottoms of wooden posts are frequently burnt before inserting them in the ground. The error generally committed is in not burning the surface of the wood to a sufficient depth; because when advantage is to be taken of the preservative quality of charcoal, it ought to have a considerable thickness.

670. The salt of mercury, called corrosive sublimate, (*bichloride of mercury*,) has a wonderful power in resisting decay, as well as in preventing the occurrence of dry rot, one of the greatest enemies the builder in wood has to contend with. On this account this salt is now extensively used in ship building, and it is believed that its adoption will be attended with very beneficial consequences. Corrosive sublimate is a strong poison, and therefore requires great care and circumspection in its use. One pound of the salt is dissolved in five gallons of water, or in that proportion; and this lye or pickle being made in a brick or other close tank, the timber intended to be preserved is soaked in it until it becomes fully saturated, when it is taken out, dried in the air, and may be used.

671. The dry rot is a disease that attacks converted timber, but which seldom makes its appearance unless that timber is put in a damp situation, or is deprived of free access of air. It is therefore of common occurrence in the ends of joists or girders, that are let into walls, or in wainscotting applied against a damp wall, and is very common in ships which consist of strong ribs boarded on both sides, so as to confine air and humidity between them. Although humidity seems necessary to the production of dry rot, yet its effects and appearances are quite different from those of rotting by water. In general, it causes the surface of the wood to swell up in an appearance like blisters, with cracks between one blister and another, but without any appearance of humidity; and the wood not only looses all strength, but will crumble to a brown dust or powder on the smallest touch. The colour of the wood is always much darkened by dry rot, and it acquires a smell similar to that of mushrooms. Dry rot has the

singular property of spreading very rapidly after once making its appearance, thus communicating the contagion to neighbouring timber that otherwise would not be affected. It is also capable of propagation, since if a piece of wood infected with dry rot, is carried to a distant place, and put in contact with wood that is damp, it will frequently produce the disease. Of course, therefore, whenever dry rot is discovered, no time should be lost in cutting away and removing the infected parts, taking care at the same time to expose those left to as free a circulation of air, or other drying process, as possible. It was formerly supposed that dry rot was produced by using timber too soon after it was cut, and which therefore contained the natural juices of the tree which dissipate by seasoning; and there is no doubt but this description of timber, if it does not produce, encourages the disease, which is now clearly proved to be produced by a parasitic plant of the fungus or mushroom tribe (*boletus lachramans*) that grows upon the wood, and exhausts it of all its substance and strength. This plant requires a certain degree of moisture for its production and maintenance, which accounts for its only occurring in damp situations. It has not the shape or appearance of the common fungi, but sends forth long and extended branches of considerable tenacity, very much resembling some of the fine branched sea-weeds when spread upon a board or paper; and these ramifications, which are of a brown colour, adhere strongly to the wood, but never rise or branch beyond its surface, and frequently assume a beautiful appearance, though the strength of the wood is rapidly destroyed wherever these rapacious branches attach themselves. Dryness, whether produced by heat or evaporation, assisted by a free circulation of air, destroys the plant, or even prevents its appearance, and these are therefore amongst the best remedies that can be applied for the prevention or cure of this enemy to timber work. Any thing likewise that destroys the vegetative power of the wood, will also remove the liability to this disorder, and accordingly steeping wood in hot tar, or in strong brine of salt and water, or of those salts called *vitriols*, have been resorted to; but recent experiments that have been made in the British navy yard at Deptford, near London, prove decisively that nothing yet tried is so efficacious as the solution of corrosive sublimate before referred to, since timber prepared with that material, and placed in damp vaults, in contact with the most vigorous dry rot, and under the most favourable circumstances for contracting it, was not affected in the slightest degree.

672. The effects of wind can only be guarded against by strength, and the adoption of such forms as will not present flat sides for the wind to act upon. On this account the round or

cylindrical shaft of a column, will have a much better chance of standing against a high wind than a square shaft or chimney exposing the same surface; because in whatever direction the wind comes against a cylinder, it is always met by a round surface which divides it, and presents an oblique action. Had the shaft been square, and the wind blowing perpendicular to any one of its sides, its power would be much greater, although it would be still further diminished when blowing against one of its angles. On this account the spires of churches are never made in the form of square pyramids, but are polygonal, and would be stronger, though less handsome, if round. But light-houses for navigation, where strength is more important than beauty, are made circular and tapering towards the top. The effects of wind ought always to be guarded against in every erection, with the same care as weight or any other force; for if this is not attended to, the whole may be unexpectedly destroyed. One of the chief objects of bracing in carpenter's work, to be hereafter spoken of, is to resist the action of wind.

673. Electricity has a double action, sometimes showing itself in the powerful and tremendous form of lightning; and constantly operating to produce the decomposition and decay of things by the slow and unperceived influence of galvanic action. Lightning can only be guarded against by the erection of proper conducting rods of iron or copper, which should extend above the highest part of the building and pass downwards, without any break or intermission to the ground, which they should enter and pass into, to a depth of several feet below the lowest part of the foundation of the building, or at any rate should penetrate the earth until they meet with constant humidity in all seasons; because moist earth is a good conductor of electricity, and readily permits its escape. Conductors, or lightning rods, should be of such magnitude as will insure their carrying off the whole quantity of electricity without melting; and as may insure their not wasting rapidly by rust or oxidation. No rod of iron less than $\frac{3}{4}$ of an inch in diameter, should be used, but an inch will be better. Both the upper and lower ends should terminate in sharp points, because electricity is known to enter and to leave points with less violence than any other shape; and as the upper point, from its constant exposure to all weathers, soon decays, and is sometimes melted by a stroke of lightning, it is best to protect it by forming it of some good conducting substance that is nearly imperishable, and *charcoal, solid plumbago* or *black-lead*, and the *metal platinum*, are best suited to this purpose, the last being the best; and as the quantity of platinum is not necessarily large, the expense is not great. As lightning rods cannot be procured of sufficient length in one piece, the

separate rods ought to be welded together if of iron, or one length may be screwed into another, which method is usually adopted with copper rods: and when they are made of iron, (that metal being usually selected on account of its cheapness,) the lower termination, and about three or four feet above the ground should be made of copper, to prevent the decay and dangerous consequences that might attend the lower end being rusted away and deficient. Perfect continuity of the metallic rod is of the highest importance; for lightning never does damage, except when it strikes an imperfect conductor, or has to jump or pass from one conducting substance to another. If a building is unprotected by a metal rod, and happens to be struck by a flash, it is generally found that the lightning first strikes and melts any lead, copper, iron, or other metal that is in the roof, even to the nails; from thence it finds its way to bell wires, the silvering of looking-glass, fire grates, locks, bolts, hinges, or other articles of metal that may be distributed about the place, and if these are separated by dry timber, brick or stone work, through which the lightning must force its way, it never fails to break them asunder or shatter them to pieces, because it is in the effort to get from one conductor to another that it exerts its violence.

674. It has long been known, that where wrought iron railing or other work was fixed to stone-work, by letting the iron into the stone, and filling up the vacuity with melted lead, the iron would decay much more rapidly in the open air near the lead than in any other part. Likewise that ships fastened together by iron bolts could not be sheathed with copper, on account of the rapid decay of such bolts; consequently, all vessels intended to be coppered, are fastened with copper bolts. No one suspected this to be an electrical effect, until the late researches into galvanism laid open the fact, that whenever two metals possessing different susceptibilities of oxidation, were placed in contact with each other, and with water or any saline solution at the same time, the most oxidable metal would soon be dissolved and disappear. Ships are sheathed with copper to protect the wood from an aquatic insect that bores into and destroys it, but which cannot penetrate the metal. The copper is however acted upon by the friction and salt of the sea water, which corrodes and partially destroys it, so that it soon wants repair, if not renewal.

Sir Humphrey Davy most ingeniously applied this electrical principle to the preservation of ship coppering, by soldering a small plate of zinc to each sheet of copper; and as zinc is the most readily oxidized, he expected that the salt sea water would act upon the zinc in preference to the copper, which would thereby be preserved at the expense of a small quantity of the much less expensive zinc. The trial of the experiment on a large scale, fully corroborated the truth of his views; for the copper was kept quite clean and free from oxidation as long as the zinc lasted; notwithstanding which this beautiful exemplification of the inductions of science to the useful purposes of life failed from a cause Davy had never contemplated. When copper is used in the ordinary way without protection, its surface becomes green from the oxide and muriate of copper, and other salts that form upon it, and these salts being acrid and poisonous, prevent shell fish and other marine animals, from attaching themselves to the copper, or even approaching it. But when the copper was kept clean and free from oxide by the zinc preservers, there was no longer any thing poisonous about it, and it was found that oysters, limpets, barnacles, and other crustaceous marine animals attached themselves to the copper at the bottom of the vessels in such quantity, as to effect the rapidity of their sailing; and they adhered so closely, that they could not be knocked off without injury to the copper. Any one acquainted with the nature of sailing vessels, knows that a great part of their perfection consists in having a perfectly clean, smooth and uninterrupted surface next the water, and on this account alone the mode of preserving copper on Sir H. Davy's principle, has of necessity been abandoned.

675. Iron is painted with oil paint, to preserve it from the effects of weather, and the base or body of such paint is usually white lead, or carbonate of protoxide of lead reduced to powder and ground with linseed oil. Recent experiments that have been made, seem to prove that even the oxide of one metal is not a proper protecting cover for another, on account of a galvanic decomposition, similar to that above referred to, being brought about; and that the earths, such as the ochres and boles, sulphate of baryta, and animal charcoal or ivory black, are much better calculated for insuring duration. Asphaltum, which is a black and very insoluble bituminous substance, also makes a good and permanent covering for iron in the nature of a japan or varnish, as it dries with a fine gloss.

676. As the great enemy to the durability of materials is humidity, and their being permitted to be occasionally wet and dry, so of course every thing that tends to prevent this effect taking place will promote durability. For this reason all wood and iron or other metal work, especially such as is exposed to the constant action of the atmosphere, should be thickly painted with oil colour, or should be covered with pitch, tar, or something that is capable of resisting atmospheric action. All roofs and walls should be made as smooth as possible, and all projections and cavities that may catch and retain water, should be avoided.

677. Although pointing a wall, which is scraping out the old mortar from its joints, after it begins to decay, and filling the cavities afterwards with new mortar that will become hard, adds but little to the strength of a wall, yet it adds much to its duration. For old and decayed mortar is porous and so absorbent, that it retains humidity a long time, and the exposed upper edges of bricks and stones catch and retain water, which soaks into the wall, and the use of pointing is to fill up all these cavities, and produce a uniformly smooth surface, upon which water will run down. For the same reason all large timbers exposed to the open air, should have their upper sides worked into a *saddle back form,* that is, should be angular upwards like a roof, to such an extent as will prevent water lodging upon them, as it would do if the upper side was a horizontal plane.

SECTION II.—*Of the absolute strength of materials.*

678. By absolute strength, we are to understand, the resistance which any body whatever is capable of offering against change of form, as in stretching, or against actual fracture or breaking when it is subjected to the action of a direct and known force, operating in a right lined direction.

679. This subject naturally divides itself into three heads for consideration, viz: 1st. The weight or load which any body is capable of sustaining without crushing or breaking to pieces; 2ndly, the weight or load which a material is capable of supporting when that load is appended to, or suspended by it: 3dly, the force of torsion or twisting, or the force that will be necessary to twist or break a bar, fixed at one end, while the force is applied to the other as a tangent to a circle supposed to be produced perpendicular to the axis of the bar, and having that axis as a centre.

These are cases that occur constantly in the Engineer's practice, and may be illustrated by the following examples.

680. 1st. Suppose a stone pillar or column has to be erected: the building of it of course, commences from the bottom, and the stones that are to form the base or foundation, must be first put in their places. Layers or courses of stone are placed one above the other in succession upon this base, and each additional course of stones is an additional load which the base has to bear. Now we may consider these courses of stone to be piled one upon the other, until at last the weight becomes so enormous, that the stones in the base are unable to support it, and of course they will crush or crumble to pieces; the basement being thus destroyed, the whole fabric no longer retaining its perpendicular position must

fall. It is, therefore, quite necessary that the Engineer or Builder should possess some rule by which he may apportion the strength of his basement to the load that he intends placing upon it, for this principle not only applies to the column that has been chosen as an example, but more particularly to the piers of bridges in which the upper part of the load increases in a much more rapid ratio than in a column, and it applies even to every column, pier, wall, and house that may be built, in all which cases the weight of the material employed must be added to the load it is intended to support.

681. 2nd. Every weight that is lifted from the ground by a rope or chain affords an example of the second head, and this is an operation that is constantly going on; for all heavy stones, or pieces of machinery that have to be placed in elevated positions, are so raised by pullies and ropes (technically called blocks and a fall), and if the Engineer had not some data to work upon, no confidence could be placed in any rope or chain, since it might break, and destroy the piece before it had reached its destination, besides endangering the lives of those employed below in the act of raising it. When the load has to be moved a great distance, the weight of the rope itself forms an element in the calculation, and must be added to the load that has to be sustained and lifted; and in mining operations, when the perpendicular shaft or pit is deep, this weight is of material consequence. Thus in the celebrated silver mine of Valenciana, at Guanaxuato, in Mexico, the principal shaft is 640 varas deep, (33 English inches to the vara,) and this is worked by flat ropes 4 inches wide, every vara of which weighs rather more than 5 pounds; consequently when this rope is extended or let down the shaft, the upper end of it, together with the cylinder to which it is attached, has to bear its own weight of about 3200 pounds, or rather better than a ton and a half, independent of any load that may be attached to its lower end, and which is usually about one ton more; so that the weight of the rope in this case exceeds that of the load it has to support. The force of extension not only applies to raising loads, but to supporting them in a quiescent state, as in roofs and suspension bridges, where the whole weight of the platform or roadway, and all loads that pass over it, is hung up to, and supported by chains or rods of iron properly arranged for the purpose. Galleries, and even rooms, are sometimes supported in this way from the roofs of buildings which inclose them. The power of adhesion of nails, glue and cement, are likewise generally considered under this head.

682. 3d. The third head is of constant occurrence in all millwork in which cog wheels are introduced. A rotary motion is produced in the first instance by the action of a steam-engine, a

water-wheel, or some power; and this has to be communicated to the place of operation either immediately, or by the intervention of wheels, which in either case must be supported by long bars with pivots or gudgeons on their ends, and which are called shafts or journals. If the power of the first mover is not sufficiently great to impel the machinery at the opposite end of the shaft, then the shaft will be incapable of revolving, and will be set fast; consequently, the whole power of such first mover will be expended in an effort to twist and break off the shaft, because it cannot move. Or if it does move, and the machine is strong enough in all its parts to perform well, since the motion and power are always communicated through the shaft, that shaft while moving will always be subject to a force equal to the power of the machine to twist and break it off, and must consequently have strength sufficient to resist this action.

683. The only knowledge to be acquired on these several points is derived from experience alone, and can derive little or no benefit from science; because the strength that is called into action in all these cases, depends alone on the cohesion or tenacity and rigidity of the material employed. All, therefore, that science can do to aid the practical Engineer, is to select proper materials; to try the amount of their cohesive force or strength by the most approved methods; and to record the results of the experiments faithfully and impartially, accompanied by such an account of the material as may prove its identity, stating at the same time the temperature and other circumstances under which the experiment was tried. If for instance a bar of iron or a rope of hemp of a certain size, were found capable of sustaining a certain weight before they broke under the experiment, it is but fair to infer that another similar bar of iron or rope, would bear an equal weight or strain at any future time or place; and by loading it with a weight considerably under that which produced fracture, we should have a confidence in its stability, which may fairly be said to be in the proportion of the weight placed upon it, with that which was known to produce its fracture.

684. All therefore that can be done to assist the student in this part of the subject, is to place before him the results of such experiments as have been accurately tried and recorded, and which may therefore be relied upon, accompanied by such observations as apply to the organic construction of the materials used; and being in possession of them, it will be for him to make experiments upon the materials he has to work with, in order to determine whether they are more or less worthy of confidence than those taken as examples.

685. In naming the forces brought into action, it is necessary to

state that passive or quiescent and not concussive forces are always understood. By passive force, is meant that the weight is either gradually accumulated, or very gently transferred to that which has to bear it, like the gradual building of a wall or a column, and is not discharged suddenly upon its bearing, so as to add moving impulse to its weight, because then its power would be much increased. A flint pebble may have a board placed over it, and that board may be gradually loaded with a ton of iron or other material, and yet the pebble will not break; but if that same load fell suddenly, and all at once upon it, or even if the pebble received a smart blow from a hammer not weighing more than two pounds, it would be shivered to pieces. Indeed the effect of a concussive force is so different from a quiescent one, and is attended with so many varying circumstances, that it is almost impossible to calculate the effect of the first with any thing like practical certainty. The same reasoning teaches us that rooms that are built for dancing, or for any manufacturing purpose, which is attended with sudden shocks, concussions, or vibrations, require to be made much stronger than what would be necessary for supporting the same weight applied in a passive manner.

686. As the absolute strength of materials depends upon their cohesion and tenacity, so of course that strength will be governed in great measure by the quantity of material that is exposed to action, or will be as the area of the surface acted upon. Thus, if a cubic inch of stone is capable of resisting or supporting a certain load or weight, two cubic inches should be capable of supporting twice as much; consequently, the strength is as the surface, or what is the same thing in most cases, as the square of the diameter. If, therefore, a block of one inch square, can support a certain load, one of two inches square should support four times as much, one of three inches square nine times as much, &c., and this applies not only to the force of compression, but of extension likewise, so that a small difference in diameter produces a great difference in supporting strength.

687. We shall first examine some of

The effects produced by Pressure,

a subject to which less attention has been paid by men of science, as well as of those of practice, than any of the other modifications of force applied to materials. This has probably arisen from the enormous pressure that most strong substances are capable of sustaining before they crush or give way; a pressure so great as to induce many practical workmen to suppose, (though very improperly,) that their strength is infinite. Galileo was the first person who investigated this subject with any thing like rigorous exactitude, and he was followed by several men of eminence. But however plausible their investigations appeared to be, they were more theoretical than practical, as turned out in the sequel. For no sound practical results can be derived from a theory that is not founded upon careful and well directed experiments, which at that time had not been made. M. Buffon, the celebrated naturalist, was among the first who tried such experiments upon various kinds of timber, and they are recorded in the annals of the Academy of Sciences at Paris, for the years 1740–41, and were on a scale sufficiently large to have afforded just conclusions, had he not omitted to ascertain the direct and absolute strength of the timber he employed. It may, however, be inferred from his experiments, that the strength of the ligneous fibre is nearly in proportion to the specific gravity of the wood. Muschenbroeck, whose accuracy entitled him to confidence, made a number of experiments on wood and iron, which, by being tried on various specimens of the same materials, afforded a mean result considerably higher than other previous authorities. The Royal Society of London likewise instituted some experiments on this subject among its earliest labours, and experiments were also tried and are recorded by Marriotte, Varignon, Perronet, Ramus, and many other Engineers and Philosophers of France, and they were afterwards taken up again by *l'Ecole Polytechnique*, under the direction of M. Prony. But the investigations of Emmerson in his Mechanics, and the more recent experiments of Messrs. Telford, Rennie, Brown, and others, and the subsequent investigations of Drs. Thomas Young, Professor Robison, Messrs. Tredgold, Barlow, and Peter Nicholson, are deemed most accurate, and are therefore mostly relied upon, and generally quoted as authorities. Dr. Young has been most happy in his mode of investigating and illustrating this subject, as detailed in his Lectures on Natural Philosophy, 2 vols. 4to., 1807; and this work and the treatise on the Strength of Materials, written by Dr. John Robison, late Professor of Natural Philosophy in the University of Edinburgh, for the Encyclopedia Brittanica, and republished after his death in 1805, with his other scientific papers, under the title of a System of Mechanical Philosophy, revised and edited by the able hand of Dr. Brewster, may be said to contain the whole of what had been done, or was known of this interesting subject in all its different bearings to their several dates. Since the publication of these books, additional experiments have been made, and new investigations taken by the late Mr. Thomas Tredgold, who has embodied all that is practically interesting and useful in respect to iron, in his valuable treatise on the strength of Cast Iron and other metals, with numerous tables and practical examples; and Mr. Peter Barlow has published a separate work, on the same principle, respecting the strength and management of timber. Two works that are so replete with valuable information, that no Engineer should be without them, and the student of this profession is therefore referred to them for details which are beyond the scope of the present work to introduce.

688. The experiments of Mr. George Rennie, Junr., above referred to, were communicated to the Royal Society of London, and are published in their Philosophical Transactions for 1818, Part I., and afterwards copied in the Philosophical Magazine, Vol. LIII. p. 173. These experiments were made with an accurate lever or steelyard machine constructed for the express purpose, and in which every care and precaution was used to prevent friction and insure accuracy. The iron lever was ten feet long, and the pieces to be subjected to pressure, were placed five inches from the fulcrum or centre of motion. The pressure required to crush specimens of metal, was however so great, that Mr. Rennie was compelled to limit his experiments to very small pieces, which were reduced by the file to a perfect cubic form. They were placed between flat plates of hardened steel, above and below which were pieces of thick sole leather, by which means an equable pressure was communicated to every part of the surface. The beam was balanced so that its own weight could not interfere with the accuracy of the experiments, and the pressure was brought into action by the most gentle means, so as to make the effect gradual, and to avoid any thing like a blow or concussion, and the following are some of the most useful results.

689. A cube of good grey cast iron, each side of which was $\frac{1}{8}$th of an inch, taken from the middle of a block, the specific gravity of which was 7.033, on the average of three experiments, required to crush it (*Avoirdupois lbs.*) 1439.66

Another specimen of cast iron with specific gravity of 6.977 was tried in rectangular blocks of $\frac{1}{8}$ by $\frac{1}{4}$ inch, and the average of three experiments was their crushing with *lbs.* 2116.

The following experiments show that the power of resisting a perpendicular pressure, is not in proportion to the horizontal surface, but is compounded of that and the attitude of the *prism.* Pieces $\frac{1}{8}$th inch square of the same cast iron, were cut to different lengths, as stated below, when the resistance diminished with their increased height, but not in any regular ratio.

A prism of $\frac{1}{8}$ inch by $\frac{1}{2}$ inch, yielded to			*lbs.* 2005.
$\frac{1}{8}$	by $\frac{5}{8}$	do.	1407.
$\frac{1}{8}$	by $\frac{6}{8}$	do.	1743.
$\frac{1}{8}$	by $\frac{7}{8}$	do.	1594.
$\frac{1}{8}$	by $\frac{9}{8}$	do.	1439.

In four experiments with $\frac{1}{4}$ inch cubes taken from the middle of a block, having specific gravity 7.033, the average weight supported was 9773.5

In four experiments on iron cast *horizontally* into bars, the specific gravity of which were 7.113, and reduced to $\frac{1}{4}$ inch cubes, the average resistance was 10114.

In five experiments made with $\frac{1}{4}$ inch cubes taken out of the lower ends of similar bars cast *vertically* instead of horizontally, but having specific gravity of only 7.074, the average resistance was 11136.75

Thus proving what has been before insisted on (618) that the strength of iron is improved by the heavy weight of the mass in fusion above it, although the specific gravity in this case does not show increased density.

The above are only a very few of the many experiments that were tried on cast iron and other metals, for the details of which the reader is referred to Mr. Rennie's paper,* but the following experiments on other metals were also made, and may be useful.

A quarter inch cube of cast copper crumbled with *lbs.* 7318

Do. of fine yellow brass, would not crumble but was reduced one-tenth of its thickness by 3213*lbs.*, and to $\frac{1}{2}$ its former thickness by 10304

Do. of wrought copper did not crumble—was reduced $\frac{1}{16}$th of its thickness by 3427

and to $\frac{1}{8}$th of its first thickness by 6440

Do. of cast tin, was reduced $\frac{1}{16}$th by 552*lbs.* and to $\frac{1}{3}$d by 966

Do. of cast lead, was reduced to $\frac{1}{2}$ its thickness by 483

690. The following are among experiments that were also tried on miscellaneous substances. In these the pressure was communicated by a pyramid of steel, the base of which rested on the substance, leather being interposed between them, and the lever pressed on the apex of the pyramid.

A cubic inch of seasoned elm wood failed with		*lbs.* 1284
Do.	of American pine	1606
Do.	of White Norway deal	1928
Do.	of English oak (mean of two trials)	3860

* Philosophical Transactions of Royal Society for 1818, Part I., or the Philosophical Magazine, Vol. LIII.

An inch cube of chalk crusted with		*lbs.* 500
An inch and half cube of pale burnt or soft brick		1265
Do.	of well burnt brick	1817
Do.	of hard paving bricks (3 trials)	2254
Do.	of same highly burnt	3243
Do.	of Stourbridge fire brick	3864
Do.	of red or ferruginous sandstone (460)	7070
Do.	the like from another quarry	10264
Do.	of Portland stone (458)	10284
Do.	of Yorkshire paving stone (463) with the strata	12856
Do.	of same, against the strata	12856
Do.	of white statuary marble	13632
Do.	of granite from Cornwall, England, (462)	14302
Do.	of variegated red marble, Devonshire, (462)	16712
Do.	of compact limestone (467)	17354
Do.	of compact black marble	20742
Do.	of compact Italian veined marble	21783
Do.	of blue Aberdeen granite, such as is used for paving streets in London, (444)	24556

691. It might be supposed that density, as expressed by specific gravity, would influence the duration of stones, or rather their resistance to fracture; but this does not appear to be the case on trial, for statuary marble has a specific gravity of about 2.760, while Aberdeen granite has only 2.625; and yet the granite offers a resistance considerably greater than the marble. Neither is hardness a characteristic of strength, for all the marbles may be scratched by a knife, and will divide by the saw, and yet many of them approach very nearly in their power of resistance to the Aberdeen granite, which is very refractory.

692. The results of the above mentioned late experiments, vary materially from those that had been formerly tried. Thus M. Gauthey, a French Engineer, tried many experiments upon freestones of uniform texture, selecting the hardest and softest that were generally used for building, and the following are a few of his results.*

Hard Stone.

8 by 8 lines	crushed with	736 oz.	which is equiv. to	11.5 oz.	on each square line.
8 by 12	,,	2625	,,	27.3	,,
8 by 16	,,	4496	,,	35.1	,,

* From Vol. IV. of Rozier's Journal de Physique: the dimensions are French lines or twelfths of the French inch, and consequently larger than American measure.

Soft Stone.

9 by 16 lines crushed with	560 oz.	which is equiv. to	3.9 oz.	on each square line.
9 by 18	”	848	”	5.3	”
18 by 18	”	2928	”	9.	”
18 by 24	”	5296	”	12.2	”

Little can be deduced from these experiments, because they are devoid of ratio; and there is even a want of accordance in the results; but they show one important fact that will presently be noticed, viz: that the strength increases much faster than the area of the section, for in the first experiment each square line of surface could only support 11.5 oz.; in the second, where the area is not doubled, each line could support 27.3 oz.; and in the third experiment, where the section is just double that of the first, each line could bear 35.1 oz. before it crushed.

693. The modern experiments on timber are considerably below those of former writers. Thus Rondelet states* that from 5000 to 6000 *lbs.* avoirdupois is necessary to crush a cubic inch of oak; and from 6000 to 7000 *lbs.* to produce the same effect on a cubic inch of fir (or pine), and that the former piece was compressed to $\frac{1}{3}$d and the latter to $\frac{1}{2}$ its former dimensions in the experiments. The later experiments having been tried with great care and precision are, however, most to be depended upon.

694. The late Mr. Thomas Tredgold, who is considered as one of high authority among modern Engineers, has also made many experiments on this subject, and he states† that the power of cast iron to resist compression, was formerly much overrated. Mr. Wilson estimated the power necessary to crush a cubic inch of cast iron, at 1000 tons, or 2,240,000 *lbs.*; and in describing an experiment by Mr. W. Reynolds of the Ketly Iron Works in Shropshire, it is stated that a quarter inch cube of the toughest cast iron, such as cannon is made from, required 448000 *lbs.* to crush it,‡ but this is incorrectly stated, since the experiments were made for Mr. Telford, and his report upon them is, that quarter inch cubes of grey soft metal yielded to 80 *cwt.*, and of gun metal to 200 *cwt.* The first being equivalent to 143360 *lbs.*, and the second to 350,400 *lbs.* on the square inch.

695. Mr. Tredgold in a paper inserted in the Philosophical Magazine, (Vol. XLVII., p. 22, for January, 1817,) asserts that the force necessary to crush a solid cylinder of any homogeneous material, should be expressed by

$$8 f p r^2$$

* L'art de Bâtir par Rondelet Tom IV. p. 67.

† Practical Essay on the strength of cast iron and other metals, by Thomas Tredgold, London, 1824.

‡ Nicholson's Journal, Vol. XXXV., for 1813, p. 4.

in which f is the direct cohesive force of a square inch of the material obtained by experiment, r the radius, and p=3.14159, &c., and from this formula he deduces that cylinders one inch in diameter of cast iron, should crush with 314160 *lbs.*, because the direct cohesion of that metal was 5000 *lbs.* to the square inch.

An inch cylinder of lead has direct cohesion of 3000 *lbs.*, and would therefore crush with *lbs.* 18849

Fine marble, cohesion of	1000 *lbs.*	should crush with	6283
Fine sandy freestone	205	„	1288
Good brick	280	„	1759

but he observes, these deductions have not been compared with actual experiment.

696. In a table of data appended to his excellent treatise on cast iron, he gives the following calculated results of what a square inch of each of the following substances should sustain without permanent alteration or fraction; and these materials are alphabetically arranged.

Ash wood	*lbs.* 3540	Iron, malleable	*lbs.* 17800
Beech wood	2360	Larch	2065
Brass, cast	6700	Lead	1500
Brick failed with	562	Mahogany (Honduras)	3800
Cast iron do.	93000	Marble (white) failed with	6060
Chalk do.	500	Oak (good English)	3960
Elm wood	3240	Pine (yellow American)	3900
Fir, (yellow pine,)	4290	Porphyry, red, failed	35568
Do. white	3630	Stone (Portland) do.	3729
Granite, Aberdeen do.	10910	Tin, cast	2880
Gun metal (8 cop. 1 tin)	10000	Zinc, cast	5700

697. Being thus in possession of the powers of different substances to resist pressure from above, it would seem that the Engineer has nothing more to do than to compute the weight of what has to be supported, by the table of specific gravities at the end of the present chapter, or other convenient means, and then to form a base of such material as he may select, the magnitude of which may be determined by the last of the foregoing tables; because if a superficial inch of white marble, for example, can sustain 6060 *lbs.*, it may be inferred that a superficial foot composed of 144 inches, laid contiguous to each other, would support 144 times as much, or 872640 *lbs.* If, therefore, we had a building, or the arch of a bridge to support, and it should be found by calculation that its materials weighed 2617920 *lbs.*, that same weight might be divided by 6060, the resistive power of an inch, or by 872640, the resistance of a superficial foot, when the quotient would give the number of square inches or square feet of marble that must be used to support this load. In the example just given, three piers of

one foot square each, would be required to carry the load, because each square foot would carry 872640 *lbs.*, which number, multiplied by three, would amount to the same as the weight of the load.

698. It is found however, in practice, that the power to resist compression increases more rapidly than the surfaces, as before mentioned, and proved by the experiments of M. Gauthey (692), where we find that while a piece of stone of 8 lines long, by 8 lines broad, and consequently exposing a surface of 64 square lines, could only withstand a pressure of 11.5 oz. upon each square line, that by increasing the surface to 8 by 12, or 96 square lines, each line could bear 27.3 oz., and when increased to 8 by 16, or 128 square lines, each line could bear nearly 35.1 oz. before it broke, being three times the pressure that the same quantity of matter could withstand in the first experiment.

699. To account for this change, we must look to the conformation of solid substances. Solid matter is stated by all writers on the subject, to be composed of minute particles of matter held together by the attraction of cohesion, and those ultimate particles are believed to be possessed of the power of impenetrability, or to be infinitely hard. If, therefore, we conceive a mass of matter to be composed of a series of perpendicular columns of such particles placed directly over each other in lines that are in contact laterally, it would be impossible that a body so constituted, could give way to any force, acting in the direction of such lines, however great it might be; because as the particles are themselves impenetrable, they cannot sink into each other, and as the lines are close and parallel, they cannot for the same reason slide laterally out of their places. It is, however, impossible to find any natural body thus regularly constituted. All things have certain formations that are crystalline, or composed of grains of some form or another, and these fit into the interstices formed by the adjoining grains, as may be seen by inspecting a piece of sandstone with a magnifying glass. Such an aggregation of particles may, therefore, be compared to a parcel of small shot, and if its upper surface is not level and flat, and a weight with a level bottom is placed upon them, those shot that are the highest, or most protuberant, will be pressed down, and can only descend by pushing the shot under them in lateral directions, and sinking in between them. But let us further suppose that the shot are confined by an iron hoop, or the sides of a vessel capable of resisting this lateral spreading; then the lower shots will be unable to give way to the same extent, to make room for those that are above them, and the shot, now prevented from sliding away, will press against each other; consequently, the upper stratum will be enabled to support

a much greater weight than before without disturbance (which may be called breaking) of the mass below.

700. This is a case very similar to what takes place in experimenting upon small or large masses of matter to produce their fracture by compression. This fracture can only take place when the power applied is so great as to be capable of overcoming the cohesion of the particles of which the mass is composed. They then give way and spread laterally, which is called *crushing;* and when a cube of any material of a quarter of an inch square is subjected to pressure, having no external support to assist it, it will evidently give way much more readily than if it was surrounded by eight other cubes of the same material placed in close contact with it, and in one piece with itself, all being held together by the same power of cohesion, and forming a square surface of three quarters of an inch, instead of one quarter. Thus let *a*, Fig. 135, Plate V., represent the solitary cube to be experimented upon, which would readily yield to lateral expansion, while it had nothing to support it: but when it is surrounded by the eight similar cubes *b c d e f g h* and *i*, it is evident that it cannot spread laterally without displacing *e c f* and *h*, consequently, the force necessary to overcome them, must be added to that exerted on *a;* and as they are supposed to be of the same material, each of them would require a force equal to that which was before exerted upon *a* alone, and this would be the case if four cubes only, *e c f h*, were placed round *a*. But *e c f h* cannot give way without at the same time disturbing *b d g* and *i;* therefore the power of resistance is still further augmented. If again we imagine the nine cubes just spoken of, to be again surrounded by sixteen others, as shewn in the figure, then the resistance to compression will be much increased, for now *a* cannot give way without displacing two cubes on each of its sides, while those two cubes are held in their places by four others, two being contiguous to each of their sides; hence it will appear that the power to resist fracture by compression, should be enormously increased by extent of surface, but what that increase may be, as regards practical applications, has never been satisfactorily proved. What it should be on mathematical principles has been determined; but this gives a result far greater than is found to hold good in practice, owing to the impossibility of subjecting every particle, or even every small space to an equal degree of pressure; and it is likewise a very difficult and intricate problem, because the central particle is supported on every side, and has the greatest strength, while the exterior rows have no support on one side, and the angular particles are deficient in support on two sides. The strength must consequently be an increasing series from the ex-

tremities to the centre. Muschenbrock, Euler, and some other high authorities have made the strength of columns on the foregoing principles to be as the biquadrates of their diameters, and this was received as a principle by the academicians of St. Petersburgh. Others again maintain that the strength increases as the area of the section, and such was the opinion of that accurate philosopher M. Coulomb; but Professor Robison makes it twice as much. If, however, this force be supposed to be simply equal to the direct cohesion, it may be inferred that the strength of a square bar in resisting compression, is twice as great as its cohesive strength, allowing that the fracture takes place in the surface of least resistance. It seldom however happens that the strength with which a body resists compression is in so great a proportion as this, to its cohesive strength, and where the substance is in any degree composed of fibres, they must naturally produce great irregularities by their bending; but experience denies both these assumptions, and while it shows that the first is enormously too large, it proves equally that the other is too low, though not in the same degree. After all, therefore, it must be confessed, that the relation between the dimensions and strength of pillars has not yet been established on sound mechanical principles, nor is it probable that general principles applying equally to all substances, can ever be established, since much depends upon the internal structure of the body, and experiment seems alone to offer the means of coming at the truth.

701. The illustration that has been given with the shot, applies to all granular bodies, such as sandstones, and the several varieties of free stone. But if we suppose a body to be of a fibrous texture, having all its fibres in the direction of the pressure, and adhering to each other by some kind of cement, such a body would fail only by the bending of the fibres, by which they would break the cement, and become detached from each other. Something like this may be supposed in wooden pillars. In such cases, too, it would appear that the resistance must be as the number of equally resisting fibres, and as their mutual support jointly, and therefore as some function of the area of the section. The same thing must happen if the fibres are naturally crooked and undulating, as they occur in many woods and other substances, provided we suppose some similarity in their form. Similarity of some kind must always be supposed, otherwise we need never aim at general inferences.

702. In all cases, therefore, we can hardly refuse admitting that the strength in opposition to compression is proportional to a function of the area of the section.

703. As the whole length of a cylinder or prism, is equally

pressed, it does not appear that the strength of a pillar is at all affected by its height, unless it looses its right lined vertical position by bending, when a transverse strain will be produced which increases with the height of the pillar. But this does not fall within our present subject, and will be hereafter treated upon.

704. The rule that is generally followed by practical men for determining the necessary strength and dimensions of a pillar or vertical support, is to take such of the experiments as have been before detailed, as may suit the case, and to multiply the result given, until it reaches the sought for power, and then to take only one-fourth or one-fifth of that quantity to work upon. Thus if a single square inch of brick is capable of supporting 562 *lbs.*, two inches should support twice that weight, or 1124 *lbs.*, and ten inches should support 5620 *lbs.*, and so on; but instead of trusting ten inches of brick to bear the 5620 *lbs.*, only one-fourth or one-fifth of that load should be placed upon it; or if the whole load must be carried, the surface of brickwork should be extended to four or five times ten inches. This has always been deemed a safe rule, because it is merely making the strength to increase as the area, and then only using about a quarter of the strength given by the trial. The reason for making so large a deduction is two fold; first to guard against imperfect workmanship, and secondly against natural decay.

705. By imperfect workmanship is meant the almost impossibility, in practice, of getting heavy beams or pieces of stone to bear equally upon every part of the surface that is prepared to support them, arising from the difficulty in moving and placing heavy bodies, or from the support settling or sinking to a greater distance than was contemplated, in consequence of receiving the new load, or its settling unequally in different parts. Thus a pier of brickwork containing 180 square inches of surface, might be built to support a burthen of many thousand pounds, which it would be fully competent to bear, provided the weight was equally distributed over the whole surface. But in placing it, it might happen that the whole would rest upon three or four square inches, which, being incompetent to the load, would fail, and transfer it to another small part equally incompetent to bear it, and thus the whole might fail.

706. Provision against natural decay hardly wants elucidation. A pier or column of new work, composed of good and sound materials, might be fully equal to the support of the load placed upon it; but when those materials, through lapse of time, begin to decay, they may fail and produce serious consequences. Every construction ought therefore to be made strong enough in the first instance,

to permit a certain extent of decay taking place, without derangement of the whole fabric.

707. Dr. Thomas Young, who has bestowed much pains on the subject of the strength of materials, shows that even if the whole surface of the support could be brought into simultaneous action, it ought not to be trusted to on the principle of every particle throughout that surface having equal strength; because all particles as they recede from the centre towards the circumference, become weaker and weaker for want of mutual support, as already explained (700). The consequence of this external weakness is that the outside particles break off, and thus transfer the load more directly to those in the centre, which are the strongest. Dr. Young observes, that in a rectangular pillar so loaded, the parts slide away laterally, and if the texture of the substance is uniform and not fibrous, the surfaces of fracture will make nearly a right angle with each other, supposing the resistance arising from the lateral adhesion in the direction of any surface or section to be simply proportional to that section; but if this force, like that of friction, is increased by a pressure which tends to bring the parts into closer contact, the angle left after fracture must be more acute. This last is the effect that most generally occurs in practice; because if a load is equally disposed over the top of a column, that load must tend to increase the contact of all the particles beneath it. Thus if A, Fig. 136, represents the top of a prismatic or cylindric column, and B a heavy stone or load placed upon it, the tendency to break, under the first supposition, will be in the lines *c d*, *c e* radiating from the centre *c*, and *d c e* will be nearly a right angle; but if B produces a tendency to compression of the particles in A, then the direction of fracture will be in the dotted lines *c f*, *c g*, and the angle *f c g* will be more acute than in the former case.

708. With a view to diminish the tendency to compression in A, and thereby to render the angle of fracture more obtuse, Dr. Young suggests that there may be an advantage in avoiding perfect contact between the top of the column and the under side of its load, by making the former very slightly convex, and highest in the centre, so that the centre, which is the strongest part, shall bear the whole load. This convexity may be carried to the extent of making the top hemispherical, as in Fig. 137; because a circle is as strong as its circumscribing square, supposing the adhesion proportional to the surface, the relative force of all its chords being equal.* This is one method of preventing the external parts

* Dr. Young's Lectures on Nat. Phil., Vol. I., pp. 145 and 767. See also a long demonstration of this effect in the same work, Vol. II., p. 46.

from breaking and falling off. But if the whole surface is level and brought into action, the lateral expansion may be counteracted by hooping it with iron; for a hooped shaft of wood or any fibrous material will support more when so hooped than without such assistance. May not the mouldings that surmounted the columns of antiquity have been originally nothing more than hoops or bandages placed there for strength and security, and which, as time and improvement advanced, became the graceful capitals as we now see them?

709. Whenever a body that possesses any elasticity is subjected to pressure, it will be found that it begins to condense or decrease in dimensions before the actual fracture takes place, or before the cohesion of its particles is overcome; and if the load be removed at this instant, the organic arrangement not having been disturbed, its strength will be unimpaired. With a view to express this effect and others that took place in the progress of experiments, as well as to obtain a means of comparing the resistance of any one substance with another, Dr. Young introduced some new terms which have since been so commonly adopted by all writers, that an explanation of them becomes necessary in this place.

710. He states that where a weight is suspended below a fixed point, the suspending substance being stretched, retains its form by its cohesion and rigidity, or stiffness: and when the weight is supported by a block or pillar below it, the block is compressed, and resists fracture, primarily by a repulsive force, and secondly, also, by its rigidity.

711. *Detrusion* is produced where a transverse force is applied close to a fixed point, with sufficient power to move the particles that are opposed to its action; they being held together by cohesion assisted by their rigidity; and the force thus generated is called *repulsion*.

712. Where three or more forces are applied simultaneously to different parts of a substance, they produce *flexure* or bending, in which case some of its parts will be subjected to a compressing, and others to an extending force. In *torsion* or twisting the central particles remain in their natural state, while those that are in opposite parts of the circumference are detruded or displaced in opposite directions. Forces applied in any of these ways may produce a permanent alteration or change of figure of the body, which will not affect its strength, and is well known to all workmen, who call it *settling*, or *taking a set*. Thus a brick wall settles, or becomes lower than when first built, by the semi-plastic mortar giving way to the weight of the bricks, mortar, or other load placed above it. A long straight stick of timber laid across the opening of a building, will sag or sink in the middle, giving a downward convexity

to the piece; but this only goes on until the compressing force becomes exactly balanced by the resisting or repellant force, and then no further change occurs; the new form becomes a permanent one, and the thing is said to have taken *its set*, or has arrived at its full settling. The limit of all these effects is fracture, which is the consequence of the application of any force capable of overcoming the strength of the substance; and the power that all bodies possess of resisting any impulse is called their *resiliance.*

713. If the rigidity of a body was infinite, and all lateral motions of its particles were prevented, the direct cohesion alone would be the measure of the force required to produce extension; in this respect, indeed, the actual rigidity of some substances may be considered as infinite, wherever the extension or compression is moderate, and no permanent alteration of form is produced; and within these limits, such substances may be called perfectly elastic. If the cohesion and repulsion were infinite, and the rigidity limited, the only effect of force would be to produce alteration of form; and such bodies would be perfectly inelastic, but they would be harder or softer according to the degree of rigidity.

714. It is found by experiment that the measure of the extension and compression of uniform elastic bodies, is simply proportional to the force which occasions it; at least when the forces are comparatively small.* Thus, if a weight of 100 *lbs.* lengthened a rod of steel one hundredth of an inch, a weight of 200 *lbs.* would lengthen it very nearly two hundredths, and a weight of 300*lbs.* three hundredths of an inch. The same weights, acting in a contrary direction, would also shorten it one, two, and three hundredths respectively. The former part of this law was discovered by Dr. Hooke, and the effects appear to be perfectly analogous to those that are known to take place in all elastic fluids.

715. According to this analogy, we may express the elasticity of any substance, by the weight of a certain column of the same substance, which Dr. Young denominated its *modulus of elasticity*, and of which the weight is such, that any addition to it would increase in the same proportion, as the weight added would shorten, by its pressure, a portion of the substance of equal diameter. Thus, if a rod of any kind, 100 inches long, were compressed one inch by a weight of 1000 *lbs.* the weight of the modulus of its elasticity would be 100,000 *lbs.* or more accurately 99,000, which is to 100,000 in the same proportion as 99 to 100. In the same manner we must suppose that the subtraction of any weight from that of the modulus, will also diminish it in the same ratio that the equivalent force would extend any portion of the substance. The

* Young's Lectures on Nat. Phil., Vol. I. p. 136.

height of the modulus is constantly the same for the same substance, while its specific gravity remains unaltered, whatever its breadth and thickness may be: for atmospheric air, it is about 5 miles high, and for steel is nearly 1000. This supposition is sufficiently confirmed by experiments to be considered, at least, as a good approximation. It follows that the weight of the modulus of any substance must always exceed the utmost cohesive strength of that substance, and that the compression produced by such a weight must reduce its dimensions to one half; and it is found that a force capable of compressing a piece of elastic gum to half its length, will usually extend it to many times that length, and then break or tear it; and also that a force capable of extending it to twice its length, will only compress it to two-thirds.

716. The modulus of elasticity, therefore, admits of being expressed in two forms, according to our wish to use it as a general or specific term. If it is general, then it can only be expressed in height; but if it is specific, then it may be expressed either in height or in weight, or by both conjoined. Thus in stating that the modulus of elasticity for the air of the atmosphere is about 5 miles high, we are to understand that a stratum of air, 5 miles thick from the surface of the earth, will press upon the air at the earth's surface with a certain force equal to about half the pressure of the whole atmosphere. But this pressure will be equally exerted according to surface, upon every square foot or square mile of the earth as upon its whole surface, therefore this is a general expression. If, on the contrary, we desire to express the modulus of elasticity of air upon a single square inch of the earth's surface, we can in like manner say it is 5 miles high: but as the surface is defined and limited to one inch, the dimensions of the pressing prism of air is likewise defined, and can be nothing but an inch square prism of air, 5 miles high. The dimensions being given, its weight can be ascertained, and as the whole pressure of the atmosphere is usually rated at 15 *lbs.* upon each square inch, so the half of that pressure will be $7\frac{1}{2}$ *lbs.*; consequently we may say the modulus of elasticity of air is 5 miles high, or is $7\frac{1}{2}$ *lbs.* on the square inch, which will be the same thing.

Let the same principles be applied to lead, the height of the modulus of elasticity of which is stated to be 146,000 feet, while the weight of its modulus upon the base of a square inch is 720,000 *lbs.* This is saying, in other words, that a weight of 720,000 *lbs.*, either in the form of a perpendicular column, or produced by a lever, or applied in any other way upon the side of an inch cube of lead, would squeeze or reduce it in thickness to a certain extent, to one half of its former dimensions for example: But a stratum of lead 146,000 feet thick, would produce the same proportionate reduction upon another stratum of lead, however extended its surface, placed under it, provided the two surfaces were equal. Then in order to compare the elasticity of lead with that of cast iron, we must find a height or weight that will produce the same effect upon cast iron that 146,000 feet or 720,000 *lbs.* produced upon lead. The height of the modulus of elasticity for cast iron is 5,750,000 feet, and for the base of an inch square, is 18,400,000 *lbs.*, (as given by Tredgold,) and the quantities that belong to lead being compared with those that belong to cast iron will express the proportionate elasticities of these two substances, or the proportionate resistance they will offer to the action of any load placed upon them.

717. The moduli of elasticity can, therefore, be put in a tabular form for ready use, and by which the respective advantages of the several materials are exposed to view at once, as in the following short example, in which the numbers are extracted from Tredgold.

	Height of Modulus of Elasticity.	*Weight of Modulus for base of 1 square inch.*	*Modulus of Resiliance.*
Ash wood,	4,970,000 feet	1,640,000 pounds	7.6
Beech wood,	4,600,000 „	1,345,000 „	4.14
Brass cast,	2,460,000 „	8,930,000 „	5.0
Cast iron,	5,750,000 „	18,400,000 „	12.7
Elm wood,	5,680,000 „	1,340,000 „	7.87
Fir or Yellow Pine,	8,330,000 „	2,016,000 „	16.4
Do. white „	8,970,000 „	1,830,000 „	7.2
Gun metal brass,	2,790,000 „	9,873,000 „	10.4
Iron, malleable,	7,550,000 „	24,920,000 „	12.7
Mahogany,	6,570,000 „	1,596,000 „	8.0
Marble,	2,150,000 „	2,520,000 „	1.3
Mercury,	750,000 „	4,417,000 „	——
Oak,	4,730,000 „	1,700,000 „	9.2
Slate,	13,240,000 „	15,800,000 „	8.4
Steel,	8,530,000 „	29,000,000 „	——
Stone, (Portland,)	1,672,000 „	1,530,000 „	0.5
Tin, (cast,)	1,453,000 „	4,608,000 „	1.8
Zinc, (cast,)	4,480,000 „	16,680,000 „	2.4

718. Mr. Tredgold observes,* that a set of general numbers of comparison to exhibit the power of bodies to resist blows or impulses, and which might be termed their modulus of resiliance, would be extremely convenient on many occasions; and as such numbers may be easily obtained by a simple process that he describes, and he has calculated many of them, the right hand

* Essay on Strength of Cast Iron, p. 250.

column of the foregoing table contains such numbers as given by himself.

Of the Force of Tension.

719. The effects of tension, or the power that substances have of supporting weights attached to them, must next be examined. This subject has been much more extensively written upon than that which is just concluded, and is at the same time of a more simple character and more easy to experiment upon. After the observations already made, it may, therefore, be investigated in few words.

720. Tension, which is produced by a body being fastened at one end, while a force is applied to its opposite extremity to tear it from its attachment, or break it asunder, is opposed solely by the attraction of cohesion of the body under experiment, with very little modification of its action by any particular circumstances. If we conceive a long cylindrical or prismatic body, such as a rod of metal or wood, or a rope to be fastened at one end, and to hang down perpendicularly, while the power it has to resist is fixed to the other, every part of it will be equally strained or stretched if we conceive such a body to be without weight, but as this is an impossible case, all parts of such body will be equally streched by the load, but unequally strained by the amount of its own weight, which must be added to the power employed, and this last quantity will be a continually increasing series from the bottom, where it is nothing, to the top, where it is the full weight of the body operated upon. On a large scale this weight must never be neglected; but as experiments on the cohesion of bodies are usually tried on short pieces, the weight of which hardly bears an appreciable proportion to their strength, this element in the calculation may be safely overlooked, and is accordingly discarded in the observations about to be made.

721. Since all parts of a body thus become equally strained, it follows that the strains in any transverse section of such body must be equal to each other; consequently, if the body is perfectly homogeneous or composed of particles all alike in substance and arrangement, no one part of the bar can be weaker than another; and if the force applied is not sufficiently great to disturb the internal organization, such body will not be weakened by the experiment, which may be repeated an infinite number of times, or what is equivalent, may be continued permanently without danger of failure. But if the arrangement of particles has

been disturbed beyond the sphere of their elasticity, the body will be permanently weakened, or may even break.

722. This disturbance of organic formation may be judged of by the effects that take place: for most things subjected to the influence either of compressing or extending influences, will give way to a certain extent, by contracting in the first instance, and stretching in the second. But when the power producing either of these actions is removed, the body will revert to its former, or very nearly former dimensions, provided its texture remains uninjured. This applies more particularly to granular bodies, because all such as are fibrous, and particularly with crooked fibres, will admit of very considerable permanent elongation without effecting their strength; because it may arise from drawing the crooked fibres straight. This is observable in all new ropes which untwist and elongate very sensibly when first used. Straight grained woods, such as pine or fir, will not admit of much stretching without fracture, and they break abruptly when over strained; while oak and birch, which have very undulating fibres, stretch sensibly, and do not break suddenly, but give warning of the event by shewing visible derangement of texture, accompanied by a creeking noise, which carpenters call *complaining*. Notwithstanding the immense variety which nature exhibits in the structure and cohesion of bodies, there are certain general facts of which we may avail ourselves with advantage.

723. It may be asserted as a general proposition that the strength of any substance under the influence of an extending force, is proportional to the area of the section of that substance, such section being taken perpendicularly to the line of the extending force. This must be the case where the texture is perfectly uniform, as in glass, and the ductile metals. The same must be admitted with respect to bodies of a granulated texture, where the granulation is regular and uniform; and likewise of fibrous bodies, if we suppose their fibres equally strong, equally dense, and similarly disposed through the whole section. It follows, therefore, that all cylindrical or prismatic rods are equally strong in every part, and will break alike in any part; and that bodies that have unequal sections will always break in the slenderest part; also that the length of the cylinder or prism, has no effect on the strength; and the vulgar notion that it is easier to break a very long rope than a short one, is a great mistake.

724. From the above we learn, that the absolute strength of bodies that have similar sections, are proportional to the squares of their diameters or homologous sides of the section.

725. The weight of a body itself may be employed to strain and break it. It is evident that a rope may be so long as to break by

its own weight. When the rope is hanging perpendicularly, although it is equally strong in every part, it will break towards its upper end, because the strain on any part, is the weight of all that is below it; and its relative strength, or the power it will have of withstanding any strain laid on it, is inversely as the quantity below that part.

726. On this principle a set of comparative numbers might be found that would express the absolute cohesion of bodies, or the quantity in length and weight of the same substance that would produce separation, supposing the areas to be constantly the same, and such numbers might be called the *moduli of cohesion.* The writer is not aware that this has been done to any extent, but the few following results calculated by Professor Leslie, show the possibility and utility of such a table. The following are for prisms an inch square.*

Teak	12,915 *lbs.*	36,049 feet long.
Oak	11,880	32,900
Sycamore	9,630	35,800
Beech	12,225	38,940
Ash	14,130	42,080
Elm	9,720	39,050
Memel fir	9,540	40,500
Christiana deal	12,346	55,500
Larch	12,240	42,160

727. When a rope is stretched horizontally as in towing a ship, the strain arising from its weight often bears a very sensible proportion to its whole strength. Thus let *a e b*, Fig. 138, Pl. V., be any portion of such rope, and *a c*, *b c* be tangents to the curve into which its gravity bends it. Complete the parallelogram *a d b c*. It is well known that the curve is a catenaria, and that *d c* must be perpendicular to the horizon, and that *d c* is to *a c*, as the weight of the rope *a c b* is to the strain at *a*.

728. In order that a suspended heavy body may be equally able in every part to carry its own weight, the section in that part must be proportional to the solid contents of all below it. Suppose it a conoidal spindle formed by the revolution of the curve A *a e*, Fig. 139, round the axis C E. We must have $AC^2 : ac^2 =$ AEB solid: *a* E *b* solid. This condition requires the logarithmic curve for A *a e*, of which C *c* is the axis.

729. These are the chief general rules which can be safely deduced from our knowledge of the cohesion of bodies. To make any practical use of them, it is necessary to have some measures of the cohesion of such bodies as are commonly employed in ma-

* Gregory's Mathematics for Practical Men, p. 407.

chines or constructions where they are exposed to this kind of strain, and these can only be obtained by experiments. These experiments must not, however, be implicitly relied on, notwithstanding all the care and precision with which they may have been made; because natural substances are liable to so great a variety of changes, that we can never feel perfect assurance that the material we possess, agrees in every respect with another of similar name, upon which an experiment has been tried. Timber produced by cold countries is slow in growth, and in general much harder and stronger than that of hotter climates. Metals differ by many circumstances that have never been accounted for, as well as from their purity; thus their strength is affected not only by the fuel, but the heat with which they have been melted, the moulds into which they have been cast, and the treatment they afterwards receive, such as forging or hammering, wire-drawing, tempering, annealing, and the like.

730. It might be supposed, that giving repeated blows of a hammer to a piece of metal, or drawing a fine rod of it through holes in a plate of hard steel, so as to diminish its diameter and increase its length to a vast extent, would affect the internal corpuscular arrangement of the metal, and thus injure, if not destroy its cohesion. The first of these processes takes place in forging a piece of metal, and the latter in wire-drawing, or converting it into wire; and yet experience shows that both these processes increase the cohesive power very considerably. Thus gold, silver, and brass, have their cohesive strength tripled, and copper and iron have it more than doubled; and the hardness and density of the metal are at the same time increased. So that after drawing the metal through a few holes, it becomes necessary to heat it red hot, and suffer it to cool slowly, which restores its softness and ductility. This heating and cooling is called *nealing or annealing*, and it prevents the metal from cracking.

731. For the reasons above stated, the student must not consider the following tabulated results of experiments that have been tried as fixed data, but must look upon them rather in the light of general values deduced from the average of many trials. Before he can rely upon the numbers given, he must assure himself that he possesses the same material; that is to say one of equal goodness and strength, and this he can only do by experiment. And fortunately such experiments are cheap and easy, in comparison with those made on the compression of materials; nothing more being necessary than to fix the strips of wood to be tried, firmly at their upper ends, and to apply a long wooden lever with a shifting weight like a steelyard to the lower extremity, the connection between the lever and strip of wood being made by a small

smith's vice attached to the upper side of the lever. If metal has to be tried, the rod of metal may be formed with a hole or eye at each end, and then a strong hook fixed in a beam of wood above, and another hook attached to the lever as in Fig. 140, will be all the apparatus necessary for this purpose. The strips of wood should not exceed $\frac{1}{2}$ inch square, and the pieces of metal $\frac{1}{4}$ inch. By such means he will readily determine whether the metal or other materials he possesses, is inferior or superior in strength to the examples given in the tables, and will thus be able to work with confidence.

732. Brick and stone are from their brittle nature never thrown into a state of tension, or employed for supporting pendant loads; therefore their properties in this respect have not been estimated or examined; but the materials usually resorted to for this purpose, are bars of metal and chains, cylindrical or prismatic pieces of timber, ropes, and leather or raw hide; and the following tables show the power of those substances most commonly met with and used, to support loads, the measure of their cohesion being the number of pounds avoirdupois, which are just sufficient to tear asunder a rod or bundle of one inch square. From this it will be easy to compute the strength corresponding to any other dimensions.

Metals.	*lbs.*	Results obtained by Mr. George Rennie as given by Dr. Gregory, Math. for Pract. Men, p. 408.
Gold, cast, varies between	20,000 – 24,000	
Silver, cast do.	40,000 – 43,000	
Copper, cast, Japan	19,500	
Copper, cast, Barbary	22,000	
Copper, cast, Hungary	31,000	
Copper, cast, Anglesea	34,000	19,072
Copper, cast, Sweden	37,000	
Cast Iron varies between	42,000 – 59,000	19,096
Bar Iron, ordinary	68,000	55,872
Bar Iron, good	75,000	
Bar Iron, best Swedish and Russian	84,000	72,064
Steel bar, soft	120,000	Cast Steel 134,256
Steel bar, tempered straw colour	150,000	
Tin, cast, Malacca	3,100	
Tin, cast, Banca	3,600	
Tin, cast, block	3,800	4,736 (block and English block)
Tin, cast, English block	5,200	
Tin, cast, Do. grain	6,500	
Lead cast	860	1,824
Regulus of Antimony	1,000	
Zinc	2,600	
Bismuth	2,900	

The above table is extracted from Professor Robison's Mechanical Philosophy, Vol. I., p. 398, and no authority for the experiments is quoted. The results vary considerably from those stated to have been deduced from Mr. Rennie's experiments, as given by Dr. Gregory, and his numbers as far as they go, are, therefore, placed on the right hand side of Dr. Robison's, that the difference may be apparent at the first glance. Unfortunately for the cause of certainty on this subject, neither of these sets of numbers appear to accord with those of Mr. Rennie, as given in his paper before referred to, for which reason the following extract from Mr. Rennie's paper is given.

733. The experiments were tried with the same iron lever apparatus that has before been referred to (688); and Mr. Rennie observes, "that the lever was used as in the former case, but the metals were held by nippers made of wrought iron, with their ends adapted to receive the bars, which, by being tapered at both extremities, and increasing in diameter from the actual section, and the jaws of the nippers being confined by a hoop, confined both. The bars which were 6 inches long, and ¼ inch square, were thus fairly and firmly grasped." The following are a few of the experiments that were tried 30th of April, 1817.

¼ inch bar of	Cast Iron, cast horizontally,	broke with	1166 *lbs. av.*
„	Cast Iron, cast vertically	„	1218
„	Cast Steel, previously tilted	„	8391
„	Blister Steel reduced by the hammer		8322
„	Shear Steel do.	do.	7977
„	Swedish Iron do.	do.	4504
„	English Iron do.	do.	3492
„	Hard Gun Metal (mean of 2 trials)		2273
„	Wrought Copper, reduced by hammer		2112
„	Cast Copper	„	1192
„	Fine Yellow Brass	„	1123
„	Cast Tin	„	296
„	Cast Lead	„	114

734. As all these experiments were made on ¼ inch square bars, sixteen of which laid in close contact with each other, would constitute a square inch, it may be inferred that multiplying any of the numbers above given, would produce the amount of strain that would break a bar an inch square; but it is found in practice, that a number of small bars thus laid together, will bear a greater proportion of load than a single bar equal to the sum of all their areas. This anomaly is believed to proceed from the greater perfection with which small bars may be wrought and prepared than large ones, as all metals are improved in their strength by hammering or wire-drawing; so the effect of hammering sixteen small bars separately, will add more to their strength, than hammering on a large bar equal to the sum of their areas. Metals can only be improved in their strength by hammering or wire-drawing, in

consequence of these operations forcing their constituent particles into a closer state of aggregation; and this can easily be done in small bars, because from their want of reaction, they yield to every blow of the hammer, and its effect is transmitted through their whole substance; while the reaction of a large and heavy bar opposes this effect, and the condensation is more confined to the surface. A number of small bars acting simultaneously, are, therefore, found to produce more strength than one large bar equal in size to their sum. It likewise explains why a faggotted bar (588) of iron should be stronger than one that has not undergone the operation.

735. This property of small bars induced Mr. Telford to propose supporting the justly celebrated and stupendous iron suspension bridge of Menia in Wales, by iron wires instead of bars of iron; and this would in all probability have been carried into effect, had it not been for the practical difficulty of preventing oxidation of the wires. The thousands of wires that must have been used for this purpose, would of course have exposed an enormous surface to the action of the air, compared with the surface of the same area of iron in solid bars. It was proposed to twist the wires together like ropes, and to protect them on the outside with painted canvass, while all the internal cavities were filled with paint, tar, or some substance that should protect the iron. Still as the wire ropes could not be expected to be stationary, but would be constantly subject to the action of wind, and the vibrations produced by the traffic passing over the bridge, it was feared that this might break away the cementing material, and leave interstices that would catch and retain water by capillary attraction, and that the wires in the insides of the ropes, rendered invisible by those that encompassed them, might rust away unperceived and endanger the whole fabric. A scheme, therefore, that was perfectly good in theory, was of necessity given up from the practical difficulties that attended its execution, and iron bars were used as the suspending rods, in place of the wire ropes as first proposed.

736. The experiments of Mr. George Rennie are more to be confided in than perhaps any that preceded them, for they were performed under peculiar circumstances, which give them value. They were not like some others, prompted by the desire of gratifying scientific curiosity, but were intended to establish actually useful results. Mr. John Rennie, the justly celebrated Engineer of England, was employed to construct the Southwark Bridge over the river Thames in London, which was proposed to be made of only three cast iron arches; the central one to have a span or opening of 240 feet, and the two side arches of 220 feet each.

The central arch was therefore larger than any arch that had been constructed in the world, and the undertaking was so stupendous that it excited great public interest, as well as doubts in the minds of scientific men, as to its practicability. It was feared that the expansion and contraction of so large a mass of iron, from changes of temperature, would endanger it; and moreover, that the weight of the materials would be so enormous, that its own parts would crush each other, or destroy the stone piers upon which it was to stand. Before hazarding so great an undertaking, it therefore became necessary to call every aid of mathematics and experiment into play. The venerable Dr. Hutton, who had devoted great attention to the mathematical principles of arches, was, among others, constantly consulted, and experiments on the compression and extensibility of iron and stone being necessary, they were tried by Mr. Rennie, and those who assisted him with their advice and investigations, in the most perfect and careful manner, with apparatus made for the express purpose, without limitation as to expense, and may, therefore, be considered as more rigidly accurate than any others that preceded them. They are no doubt the investigations of the elder Rennie, and his able assistants; although Mr. Rennie thought proper to give the credit of them to his eldest son, Mr. George Rennie, who was professionally associated with his father, and probably might have been the sole conductor of the experiments. These circumstances are, however, only mentioned to show the means that Mr. George Rennie possessed for experimenting, and the reliance that therefore may be placed in whatever he asserts in his valuable communication to the Royal Society before referred to.

737. Mr. Muschenbrock made many experiments on the tenacity of the metals in which much confidence has always been placed; and he states the remarkable fact, that almost all the mixtures of metals are more tenacious than the metals themselves. This change of tenacity depends on the proportions of the ingredients; and the proportion that produces the most tenacious mixture, is different in different metals. The following results are selected from his experiments, the proportions here given being those which produce the greatest strength.

Two parts of gold with one of silver	*lbs.* 28,000
Five parts of gold with one of copper	50,000
Five parts of silver with one of copper	48,500
Four parts of silver with one of tin	41,000
Six parts of copper with one of tin	41,000
Five parts of Japan copper with one of Banca tin	57,000
Six parts of Chili copper with one of Malacca tin	60,000
Six parts of Swedish copper with one of Malacca tin	64,000

Brass, consisting of copper and zinc in unknown quantity	51,000
Three parts of block tin with one of lead	10,200
Eight parts of block tin with one of zinc	10,000
Four parts Malacca tin with one of regulus of antimony	12,000
Eight parts of lead with one of zinc	4,500
Four parts of tin with one of lead and one of zinc	13,000

738. These numbers are of considerable use in the arts. By them it will appear that mixtures of copper and tin produce alloys of great strength, and accordingly this compound is called *gun metal*, from its being constantly resorted to in the formation of brass ordnance. The greatest strength of copper alone never exceeds 37,000, and tin alone 6000; yet by mixing these two metals, the tenacity of the compound is almost doubled, at the same time that it is harder, and yet more easily wrought. It is, however, more fusible, which is a great inconvenience. A very small addition of zinc almost doubles the tenacity of tin, and increases the tenacity of lead five times; and a small addition of lead doubles the tenacity of tin. The last are mixtures of the cheaper metals, and a knowledge of these changes will enable Engineers to augment the strength of steam or water pipes, and to produce pipes of such metal and of such thickness and strength as shall be in proportion to the pressure to which they may be exposed.

Of Woods.

739. In addition to what has been already stated about timber in the section allotted to that subject (532), it may be remarked, that a certain age is necessary to the full vigour and strength of timber, which age cannot be defined, since it depends not only upon the species, but upon the soil and climate in which the tree grows. Maturity of growth appears to be essential to the goodness of timber, for a young tree or sapling never possesses the strength or durability of a full grown tree; and if it is over aged, decay always begins in the heart or centre. When timber is in its proper state of maturity, the heart or centre is always preferred; but among the experimenters who are most relied upon, a difference of opinion exists as to the value of the heart. Thus, Muschenbrock's experiments tend to prove that the heart is the weakest part of the tree, while Buffon asserts a directly contrary result, but without experiments in proof of it. This discrepancy can only be accounted for by supposing that these able experimenters used wood of very different ages. In young shoots, as well as in young trees, the central pith is always large, light and porous, and the rings of wood that surround it partake of its properties. But when the tree or branch has arrived at full maturity, the pith

almost disappears, and the surrounding wood becomes the hardest and most sound. Whether the small tube of pith that remains, may be the means of collecting and retaining water and humidity that may not be drawn off by the healthy secretions of the tree, we will not pretend to say; but certain it is, that in old age the decay of a tree begins at the pith, and proceeds gradually outwards to a certain extent, and thus it is that we find old trees hollow, and that many sticks of timber, apparently sound on their external surfaces, will contain bad or decayed parts in their interior, which cannot be discovered till the stick is opened by sawing. (567.)

740. The wood next the bark called the *white* or *blea*, is weaker than the rest, and it gradually increases in strength as we recede from the centre to the blea. In respect to altitude, the wood is stronger in the middle of the trunk than at the springing of the branches, or at the root; and the wood of the branches is weaker than that of the trunk. All branches proceed from near the centre of the tree, or at any rate from that ring from which they have sprouted. The springing of every branch, therefore, produces what is called a *knot*, and knots weaken timber considerably, by the contortion of the fibres which they produce; and hence the advantage of selecting clean timber, i. e. timber free from knots, for good and strong work. When trees grow close together, as in forests, the absence of light, and free circulation of air, is unfavourable to the production of branches; hence, as before noticed, (542,) forest trees are less subject to knots, and generally produce longer and straighter timber, than trees that grow singly; and the white wood or blea may be in a great measure got rid of by barking the tree some months before it is cut down. (534.) Still the wood of single trees is generally harder and more compact than that of such as have not had the full advantage of sun and air. Those woods in which the annual rings are closest together, are the most hard and durable; and notwithstanding seasoning greatly improves all timber for general use, still all woods are more tenacious and capable of bending in the green than in the dry state.

741. The only author who has put it in our power to judge of the propriety of his experiments on wood, is Muschenbrock. He has described his method of trial minutely, and it seems unexceptionable. The woods were all formed into slips fit for his apparatus, and part of the slip was cut away to a parallelopiped of $\frac{1}{5}$th of an inch square, and therefore $\frac{1}{25}$th of a square inch in section. From this the absolute strength of square inches were deduced, and were as follows: the numbers being the average of a great number of trials on each species.

Locust tree	*lbs.* 20,100	Elder	*lbs.* 10,000
Beech and Oak	17,300	Fir	8,330
Alder	13,900	Walnut	8,130
Elm	13,200	Pitch pine	7,650
Willow	12,500	Cyprus	6,000
Ash	12,000	Poplar	5,500
Plum	11,000	Cedar	4,880

The numbers set against elm and ash are the result of more than fifty experiments tried upon slips taken from different parts of the tree, and all the experiments were tried with so much care that there can be no reason for want of confidence in the results. Still they are considerably higher than those given by some other writers. Thus M. Pitot on the authority of his own experiments and those of M. Parent, says that 8640 *lbs.* is the utmost strength of a square inch of sound oak, being very nearly half what the above table states. Still, however, the numbers in the table are the utmost strains the slips could bear, or such as produced separation, and no one employing timber would think of loading it to any thing like this extent. It may be said in general, that two-thirds of the weights given would sensibly impair the strength after a considerable time, and that one-half is the utmost that can remain suspended by them without risk forever; and it is this last allotment, or even less than it, that the Engineer should reckon upon in his constructions.

742. According to Mr. Emerson, the load which may be safely suspended to an inch square, is as follows:

Iron	*lbs.* 76,400	Walnut, Plum	*lbs.* 5,360
Brass	35,600	Red Fir, Holly, Cedar, Plane	5,000
Hempen rope	19,600	Cherry, Hazle	4,760
Ivory	15,700	Alder, Beech, Willow	4,290
Oak, Box, Yew and Plum tree	7,850	Lead	430
Elm, Ash, Birch	6,070	Freestone	914

He gives as a practical rule, that a cylinder whose diameter is d inches, loaded to one-fourth of its absolute weight, will carry as follows.

Iron	135	*Cwt.*
Good rope	22	
Oak	14	
Fir	9	

743. The rank which the different woods hold in Mr. Emerson's list, is very different from that in Muschenbrock's. But it is difficult to obtain precision in experiments of this kind, especially when so few have been tried and recorded. Such experiments seldom carry sufficient interest to induce individuals to attempt them, and the proper apparatus for repeating them is too heavy and costly to be within the reach of most people. Such matters

ought, therefore, to be taken up and prosecuted at the navy yards, or other public establishments of different nations; because there a knowledge of the strength of materials is of first rate importance, and until such public experiments are established and published, it is in vain to hope for certain and precise results, which can only be extracted from the compared results of numberless experiments conducted and recorded with the utmost care and precision.

744. Bars of metal or wood, such as have been referred to, should always be used when bodies are required to be steadily and durably supported; but when flexibility is necessary, as in raising loads, by drawing the suspending medium over a pulley, or winding it round a capstan or cylinder, chains of metal, or ropes and straps must be resorted to; and what has already been said upon rods of metal, will of course apply to chains composed of such metal. The action is nevertheless not precisely the same as when a direct force draws upon a rod of metal, but is of a more complicated nature, partaking of an extending and lateral or detrusive force thrown into action at the same time. The strength of metal chains was not much attended to until an attempt was made about 30 years ago, to introduce them into sea service for cables, in lieu of the hempen ones that had been previously used. At first they met with most decided opposition, and many objections were urged against them, among the principal of which was the brittle nature of iron, making it liable to break suddenly when subjected to a great strain; the trifling elasticity iron possessed, and the great weight of the material. It was urged that a hemp cable would expand considerably when tightly stretched, and thus was in less danger of breaking from sudden jerks or concussions. Experience has, however, gradually cleared away every objection, and few vessels are now without their iron cables. If their weight is superior to a hemp cable of equal strength, their bulk is incomparably less; and from their flexibility, they are much more easily managed, coiled away, and occupy little room. Their weight, formerly complained of, is now deemed one of their greatest advantages; for when a ship is riding at anchor, the chain cable from its weight, partly sinks to the bottom, and partly forms a curve leading to the vessel; so that if the vessel is urged by wind or current away from her anchor, the chain is taken up and becomes nearly straight, and by its constant tendency to sink again, is found to give much more play to the vessel than a rope cable could do; for a hemp cable, from its buoyancy, would become nearly straight, with very little tendency to sink, and consequently could give no play beyond the mere expansive power of its materials. If the chain cable is not wanted, it may be stowed in the hold, or

be used as shifting ballast, while a hemp cable would soon rot, if not exposed to air. Captain Samuel Brown of the British Navy, was a staunch advocate for the introduction of iron cables, and became an extensive manufacturer of them; and being a man of skill and science, tried many experiments upon their strength to prove their competency, when among other points that thus became settled, it was proved that a chain cable formed of $1\frac{1}{4}$ inch iron, was superior in strength to the largest hemp cable that is made, which is nearly 8 inches in diameter, or 24 inches in circumference.

745. Chain cables are made out of round or bolt iron, which has been stated to be the least trustworthy of any bar iron (581), but when this kind of iron got into demand for cable making, it became necessary to hammer it, and pay more attention to its fabrication, in consequence of which the best iron is selected and manufactured with great care, when it is sold under the name of *cable iron*, and when this can be procured, it is the best and most tenacious iron that is made, having nearly double the strength of common bars.

746. If the links or rings of a chain are made circular, the force of tension exerted upon it, will draw or extend them into the oval form; consequently, this shape should be given to all links in the first instance. It might then be supposed that if the force was sufficiently great, it would draw out or extend the links into longer and narrower ovals. But the experience of Captain Brown proved that instead of this effect taking place, the compound force exerted on each link, caused its two sides to collapse before it began to expand, thus making each link to assume nearly the form of the figure ∞, by which the links passing through each other become so tightly and mutually embraced as to destroy the flexibility of the chain. To obviate this inconvenience, Captain Brown introduced a small column or stretching piece of cast iron into each link to maintain the two sides at their proper distance, and this proved so effectual, and added so materially to the strength of the chain, that he obtained a patent for the contrivance, and it is now generally used. Every chain is proved as to its strength before it leaves his manufactory, and the result of some of his experiments on the strength of iron chains, will be found in a place where probably they would not be searched for, viz: in Barlow's Essay on Strength of Timber, pp. 221–237.

747. Small iron chains are now very generally used instead of ropes in cranes for raising iron and stone for building purposes, and in stone quarries and coal mines; and the account of their performance at the Old Park Iron Works in Shropshire, England, as given by the proprietor, Mr. G. Gilpin, and published in the

Transactions of the Society for the Encouragement of Arts, Manufactures and Commerce of London, confirms their decided advantage. He says, "after three years experience of the use of a chain, without any accident or impediment, I have ascertained that its cost compared with a rope, is more than as 43 to 171. That is to say, the new chain cost £43, and at the end of three years' use, was not a quarter worn out; while formerly ten ropes at 8 pence a pound, were completely worn out in the same period, and after deducting the value of the old ropes the cost was £171." When Mr. Gilpin first thought of adopting a chain, he was fearful that its weight (being 110 yards long) would impose a difficulty, by increasing the load to be drawn up the shaft of the mine; but he found a chain of 5 *lbs.* to the yard, or weighing 550 *lbs.*, was amply strong enough for his purpose; and as the rope was necessarily large, to be equally strong with the chain, the two weighed very nearly alike.

748. In computing the strength of iron chains, it will only be safe to consider them the same as a single rod of wrought iron, equal in size to that the links are made from. It is true each link has two sides, which would give the appearance of double strength; but the iron is only single at the place where any one link bears upon another. This bearing is not one that is direct, but partakes of the nature of a lateral force at the point of contact, and an extending one upon the two sides of the link; and the writer is not aware that this complex action has ever been considered and investigated mathematically, nor is he aware of the existence of a table giving the strain that small chains will bear without fracture. The weight of short linked chain fit for cranes or working over pullies, made of the best iron, from the experiments of a friend, has already been stated (656).

749. Ropes consist of many small fibres united together by twisting or spinning, which answers a double purpose. It unites the fibres together, thus causing them all to act at the same time, and it thereby increases the general strength; for if one fibre is weaker than another, or weaker in one part of its length than in another, it derives strength and support from the other fibres that are contiguous to it.

750. On examining the different fibrous materials in common use according to their diameters, silk is decidedly the strongest, and flax, hemp, cotton, and other vegetable matters follow in succession. Silk and flax are too expensive to be used on a large scale, and cotton is too weak; therefore hemp is the material generally resorted to in Europe for making ropes; but different countries adopt such materials as are most convenient to themselves. Accordingly all the ropes that are used in South America and

Mexico are made from the fibres of the aloe. (The agave of the country, and *disticha* of Linnæus.) The rigging and ropes of the native East India shipping are made from the fibrous external coat of the coca nut. A great deal of the rope used in the United States is called grass rope, which is believed to be the fibre of the *yucca*, a kind of *bear's grass* as it is called in this country. In fact, almost any tall vegetable that possesses great strength of fibre, may be manufactured into ropes. The Society for the Encouragement of Arts, &c. in London, have paid particular attention to this subject, and by consulting the different annual volumes of their Transactions, it will be found that fine and strong thread and cloth may be obtained from the stems of the common stinging nettle and the bean, and that a coarse and strong material is yielded by the stalks of the hop plant, the bark of the lime tree, and several other vegetable productions.

751. The value of these several materials depends, however, upon their strength and durability, and the changes that they undergo by being wet and dry, bent or straight, and under other casual circumstances; and after a fair trial and investigation of their several properties, good hemp appears superior to all that have so far been experimented upon. One of its valuable properties is that its strength is not impaired by sudden bending, while if the aloe or grass rope are so treated, as in tying a knot, they loose their strength very considerably, unless previously steeped in water; and even then, are not so strong in the bent as in the straight parts. As hemp is the best known material, and has been more experimented upon than any other, we shall confine ourselves in the few observations to be made on this subject, to ropes of this material.

752. When a number of small fibres are united together by the process of twisting or spinning, the thread so produced, whatever may be the material, is called a *yarn*. Yarns may be made large or small, according to the purpose they are intended for. Thus all the varieties of sewing thread, however fine they may be, consist of at least two yarns spun or twisted together. But for rope making the yarn is much larger, and is generally about $\frac{1}{8}$th of an inch in diameter. In the British navy yards the size of hemp yarn is determined by its strength, for each separate yarn must be capable of supporting one hundred weight, and will therefore be a little more or less in diameter, according to the goodness of the hemp. A rope is composed of a number of these yarns, usually from 16 to 25, twisted together, and this in large ropes is called a *strand*. Large ropes are never made immediately from the yarns, but by twisting two or more of these strands together. In the language of rope makers, three strands united, form a

hawser; but when four are used, the rope is called a *shroud.* A *cable* is the union of three hawsers or three shrouds, and this large process of spinning is called *laying* a rope.

753. By unravelling the end of a rope, the number of its component yarns may be readily discovered and counted, and as each yarn should bear 100 *cwt.,* it may seem that this would offer a ready means of ascertaining the strength of new ropes. But the very formation of a rope renders this impossible. If the fibres ran in right lined directions from end to end of the rope, it would give a near approximation to truth; but the twisting of the fibres together makes the action an oblique, instead of a direct one; and thus, as those fibres near the centre of the rope, take a much straighter direction than those on its outside, all the violence of the strain will fall upon the central lines of fibres, while those on the outside will scarcely feel it at all. Taking the sum of the fibres or yarns, therefore, will give no clue to the strength of a rope as they are usually made; and no rope so made can possess a strength any thing like equal to what the sum of the yarns would produce or support if they could act singly.

754. The late Captain James Huddart, of the British East India company's service, contemplating the imperfections to which large ropes were liable, from unequal or imperfect twisting, and the unequal strain to which the individual yarns were exposed in their common arrangement, invented a most admirable and simple contrivance which he called a regulator, and for which he obtained a patent, by means of which different quantities of yarn was supplied to the different parts of the strand while it was twisting or laying. That yarn that went to form the centre of the strand, never deviated from its right lined direction, while a larger quantity was given out to the outsides which had to pass obliquely, and consequently through more space, and by this means, and using a less hard twist than had formerly been resorted to, he produced the most perfect and uniform ropes, which were so perfect as to the equilibrium of their own parts, that they had no tendency to twist or recoil even when quite new; and on subjecting his ropes to experiment, it was found that instead of losing any of the original individual strength of the fibres, they assisted each other, and produced an aggregate power greater than their primitive one. Since the expiration of his patent, some of the principal rope-makers have adopted his plan of working, the advantages of which soon became known among nautical men.

755. The tarring of ropes can evidently add nothing to the absolute strength of the materials of which they are formed; and yet it is thought to render ropes stronger. If it does so, it can be on no other principle than that the tar cements the fibres together,

and thus causes those parts to act conjointly, which without such assistance might have acted separately. The great use of tar is, however, to exclude moisture and prevent the rope from rotting, which it would do in damp situations; and it likewise prevents sand and grit getting into the inside of a rope, and these are very detrimental to ropes that are kept in constant motion, as they fret and wear away the internal fibres.

756. The rule that has been established by practice for ascertaining the strength of *new* ropes made of the best hemp, without tar, is that they should support one-fourth of the square of their circumference taken in inches, in tons. Thus, if a rope is $2\frac{3}{4}$ inches in diameter, its circumference may be taken at 9 inches, the square of which is 81 inches, and dividing this by 4, the quotient would be $20\frac{1}{4}$ tons, which such a rope should bear upon a fair and even strain; but as all ropes are subject to jerks and concussions, it is better to take a fifth instead of a fourth of the square of the circumference, and this would reduce the above named rope to $16\frac{1}{5}$ tons. Moreover as this rule applies to new ropes, made of the best material, and much inferior hemp is used, or cheaper materials of less strength are almost constantly mixed with it, and a rope is expected to last and wear a considerable time; so it is not prudent to put more than half this load upon a rope that is in constant use, because if strained to its full extent in the first instance, it will soon give way by use.

The rule which Captain Huddart established in his rope manufactory, and upon which he would warrant all ropes made there, was to multiply the square of the circumference of the rope by 900, and this would give the number of pounds avoirdupois which the rope would sustain with safety. If we take the same example as before, of a rope having 9 inches circumference, then $9^2 = 81 \times 900 = 32\frac{1}{2}$ tons, or rather better than a third more than a rope of ordinary formation would bear.

757. M. Du Hamel states that tarred rope is much weaker than that which is untarred, their diameters being equal, and he gives a table of comparative experiments made with three inch rope in proof of this assertion, in which the tarred rope is in every instance greatly inferior in strength to that without tar, but he assigns no reason for this apparent phenomenon, although it is well understood by every rope-maker. They usually demand the same price for tarred rope as for that which is clean, and even sometimes make a favour of charging nothing for the tar and trouble of applying it. But the fact is, the tarring is always performed upon the separate yarns, by drawing them through a kettle of boiling tar, before they are twisted into strands. The hot tar swells the fibre, and a quantity of it adheres to each of them, so that the

diameter of the yarn becomes sensibly increased, and of course a much less number of yarns become necessary to form a rope of the same diameter, than if clean hemp was used. This is quite sufficient to account for the deficient strength of tarred ropes; but if, instead of comparing the ropes by their diameters, they were compared by the number of yarns they contained, then the tarred rope would, it is believed, have the advantage. The inexperienced purchaser when he buys a tarred rope, does not usually consider that in each pound of rope he buys, he gets but about 14 oz. of hemp and 2 oz. of tar, which are both sold for the same price, although hemp is at least sixteen times more costly than tar. M. Du Hamel, however, goes on to state, that it is decided by experience that white cordage in continued service, is one-third more durable than tarred; that it retains its strength much longer while kept in store; and that it resists the ordinary injuries of the weather one-fourth longer. These observations deserve the attention of practical men, being very important. There is, however, a reason why tarred ropes should be used in particular cases, such as the standing rigging of ships, or that which does not require to be run over pullies or to move; such as the main-stays, fore-stays, and shrouds, by which the masts of vessels are held and maintained in their vertical positions. The reason is that all untarred cordage (particularly when new) is highly hygrometric, and expands and contracts in its length to a great extent by being dry and wet. The damp state constantly producing contraction, and the dry one extension. This contraction by wetting exercises so much force, that if a rope is fully stretched in its dryest state, and then wetted, it will break, or tear away the parts to which the ends are attached if they are less strong than the rope. If, therefore, a mast was braced in its proper position by dry white ropes, a shower of rain would probably bend the mast or break the ropes. On the contrary, if the mast was braced as tightly as possible by damp ropes, a few hours sunshine would render it quite loose. Any thing therefore that will destroy the hygrometric properties of the rope by rendering it less, or not at all absorbent of humidity, will be beneficial in such cases; and tar or paint answer this purpose. This subject is worthy the attention of the Engineer, who will, in the course of his practice, frequently have to rig out temporary cranes or lifting apparatus for heavy stones, or masses of iron and timber, which are constantly supported by three or four guy ropes attached to the top of the apparatus, and drawing in opposite directions, the action being thus very similar to that on the mast of a ship. In the inclined planes that have been introduced into rail-roads, for surmounting considerable inequalities of level in the country they pass over, the cars or other loads are drawn up, and let down the inclined plane by what is called an endless or perpetual rope, (as will be described when we arrive at that part of our subject,) and in these this expansion and contraction is a source of great inconvenience and trouble; for as the rope must be kept constantly in a state of extension by passing over rollers at the top and bottom of the inclined plane, so it would inevitably become slack, or break, by contraction, with changes in the weather, unless some means was adopted for varying the distance of the rollers from each other, according to the varying length of the rope; and this necessary motion becomes very considerable when the rope is long, as in the inclined plane of the Columbia rail-road, rising from the river Schuylkill close to Philadelphia, and which being very nearly a mile long, requires a continuous rope of two miles in length, to which the cars are attached whenever necessary.

758. Ropes are always sold and valued by weight, but are described by their circumference in inches. Thus what is called a 3 inch rope would only be about 1 inch in diameter, and when a 24 inch cable is spoken of (being the largest size usually made), a cable less than 8 inches in diameter is understood.

759. Strips of leather and raw hide are occasionally used for overcoming resistances instead of ropes; but of this we have few instances. They may be used with advantage in places that are usually dry, but do not answer well if exposed alternately to the wet and dry states. Strips of cow or horse skin leather, about four or five inches wide, sewed together in such manner as to form two thicknesses, and to break joint, or permit the joining of the two ends of every piece forming the one thickness, to come to the middle of the piece contiguous to it, are very commonly used to draw coals up the shafts of the coal mines of Staffordshire, and other internal parts of England; and they are said to be more economical than ropes, and to last much longer. But the great use that the Engineer makes of leather, is to form bands for driving revolving machinery by means of large pullies or wheels called *riggers*, encompassed by such bands, and pulling them round by the mere friction exerted between the surfaces. Straps or bands employed in this way, are much more economical than toothed or cog-wheels, and are in many cases not only more convenient, but produce a safer and more effectual action, particularly where heavy machinery has to be alternately put in motion and stopped. Thus a rotary motion can be communicated from one side of a mill to another by means of a strap or band, which could not be otherwise done, except by a long revolving shaft. The motion may be carried on in the same, or a reversed direction, by carrying the strap directly round the riggers, or by

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simply crossing the band; while a similarity of direction cannot be given by wheel-work without using three wheels. When motion is given to heavy machinery, or has to be stopped frequently, the inertia common to all matter frequently causes teeth or cogs to break off, because nothing can slide or give way; but if such motion is communicated by band-wheels, the band will slip over its wheels to a sufficient extent both at the beginning and end of the motion, to prevent the occurrence of any damage; and for these and other reasons that might be assigned, leather bands are well worth the attention of the Engineer. For small machinery, such as driving lathes, the governors of steam-engines, and such things as do not require much surface in the band to produce the necessary friction, catgut, or a string formed by twisting the intestines of animals in a wet state, and using them when dry, answers very well. This material in its state of greatest purity and perfection, is used for the strings of violins, harps, and other musical instruments; and if kept dry, is the strongest animal substance that can be formed. The power of a band for driving machinery, is increased by augmenting its width and the diameters of the drums or riggers over which it passes, thus offering more surface for producing friction; and this is sometimes increased by occasionally chalking the surface of the drums, or applying powdered rosin to them.

760. The comparative strength of the materials generally used for forming bands for driving machinery, may be judged of from the following statement of the modulus of cohesion of each substance, or the length in feet of a piece of the same magnitude that would be required to overcome its cohesion, or tear it asunder, as calculated by Mr. B. Bevan, an English Engineer, and published by Dr. O. Gregory.*

Tanned Cow's skin	*feet* 10,250	Tanned Cordavan leather	*feet* 3,720
„ Calf skin	5,050	Untanned Horse skin	8,900
„ Horse skin	7,000	Hempen Twine	75,000
„ Sheep skin	5,600	Catgut, old	23,000

The strength of adhesion produced by nails, screws, and glue.

761. Every carpenter is aware of the mode of applying these materials, and of the advantages derived from them; but until lately this subject has never been experimented upon or examined with any degree of accuracy, and we are now indebted to Mr. Bevan, above mentioned, who is the only person who appears to have paid attention to this subject. He has tried many experi-

* Gregory's Mathematics for Practical Men, p. 411.

ments with great care and attention, the result of which he has communicated to the public through the medium of the Philosophical Magazine, in which work he has several papers, all showing the accuracy with which he has investigated this new subject, and the attention he has paid to it.

762. Mr. Bevan observes, that the theoretical investigation points out an equality of resistance to the entrance and extraction of a nail, supposing its thickness to be invariable; but as the general shape of nails is tapering towards the point, the resistance of entrance necessarily becomes greater than that of extraction. In some instances he found the ratio to be as 6 to 5.

The following table exhibits the relative adhesion of nails of various kinds, when forced into dry Christiana deal at right angles to the grain of the wood.

Description of nails used.	Number of nails to the lb. avoir.	Length of nails in inches.	Inches forced into the wood.	Pounds requisite to extract.
Fine sprigs	4560	0.44	0.40	22
Do.	3200	0.53	0.44	37
Threepenny brads	618	1.25	0.50	58
Cast Iron nails	380	1.00	0.50	72
Sixpenny nails	73	2.50	1.00	187
Do.	—	—	1.50	327
Do.	—	—	2.00	530
Fivepenny nails	139	2.00	1.50	320

763. The percussive force required to drive a common sixpenny nail to the depth of one inch and a half into dry Christiana deal, with a cast iron weight of 6.275 *lbs.*, was four blows or strokes falling freely the space of 12 inches: and the steady pressure to produce the same effect was 400 *lbs.*

764. A sixpenny nail driven into dry elm to the depth of one inch, across the grain, required a force of 327 *lbs.* to extract it: and the same nail driven endways, or longitudinally into the same wood, was extracted with a force of 257 *lbs.* The same nail driven two inches endways into dry Christiana deal, was drawn by a force of 257 *lbs.* To draw out one inch, under like circumstances, took 87 *lbs.* only. The relative adhesion, therefore, in the same wood, when driven transversely and longitudinally, is 100 to 78; or about 4 to 3 in dry elm; and 100 to 46, or 2 to 1 in deal: and in like circumstances the relative adhesion of elm and deal, is as 2 or 3 to 1. In other species of wood, the requisite force to extract nails was different. Thus, to extract a sixpenny nail from a depth of one inch, out of dry oak, required 507 *lbs.*; from dry beech 667 *lbs.*; and from green sycamore 312 *lbs.*

765. From these experiments we may infer that a common sixpenny nail driven two inches into dry oak, would require a steady force of more than half a ton to extract it. Nails that are slightly rusty, hold much more strongly than such as are quite new and clean. Millrights, therefore, frequently steep their new nails in a solution of crude sal ammoniac, to induce this effect, and drive them into the wood in their wet state where great adhesion is required. This is unnecessary in oak, unless it is very dry; because the natural juices of oak will always rust iron that is driven into it. Wrought iron nails hold more firmly than the cut nails now in general use, owing probably to the cut nail being more right lined and smooth on the surface than such as are produced by the hammer; for all nails hold merely by the compression that exists between themselves and the wood. Large nails are called *spikes*, and these are sometimes jagged on their angles to increase the friction and adhesion, and then they approach the nature of screws; for a screw holds faster than a nail, because its thread enters into, and lays hold of the substance of the wood; consequently, a screw cannot be drawn by a direct force, without tearing away part of the wood into which it has been introduced, and thus the adhesion produced by screws, is always much greater than that of nails.

766. Glue is a well known material, and one that is extensively used by the cabinet-maker and joiner for fastening pieces of wood together. It is obtained by digesting the skins, hoofs, and other parts of animals a long time in hot water, straining the liquid to deprive it of impurities and solid matter, and then further evaporating the water until the residuum becomes of a proper consistence for use. Glue when in a thin and gelatinous state while cold, is the *size* that is extensively used by painters and paper-hangers; consequently, this size, which is not procurable out of large towns, may be made at any time by dissolving glue, and diluting the solution with hot water. Glue is sold in thin cakes which are semi-transparent, and very hard while dry. In this state glue will keep any length of time without injury to its qualities. The greatest inconvenience of glue is its solubility in water; consequently, it cannot be used for outside woodwork, or even for inside work that is subject to wet or damp, unless such work is painted in oil, or varnished to protect it, and then it will stand many years. To obtain the greatest strength from glue, it ought to be recently dissolved, and used soon afterwards; for glue that has been heated and cooled, and kept a long time, as in a common carpenter's glue pot, is more brittle, and does not hold so strongly as that which is recently made. Isinglass is the best and purest glue, and this is made from the gelatin of certain fish, instead of from

animal substance. It is as soluble as other glue in water near the boiling point, but has the advantage of being insoluble, or nearly so, in cold water. Hence joints made with this glue will not be affected by the humidity of the atmosphere for want of sufficient heat, and it is on this account always used by the makers of violins and such other musical instruments as are put together by glue alone.

767. To obtain the greatest strength or adhesion in a glued joint, the wood to which it is applied should be slightly absorbent, and the surfaces made to fit together as closely as possible, before the glue is applied. These surfaces should be smooth, but not polished, and they must be perfectly clean, or free from grease or any resinous matter, on which account surfaces of yellow pine will not glue together with any certainty of firmness. The glue must be free from all dirt or grit, which would prevent close contact, and should be so far diluted with water that it will just run freely, and wet, and sink into the surface to which it is applied, and it should be as hot as possible at the time. Both the surfaces should, if possible, be covered with glue; if not, and the joint is straight, the edge of one board may be rubbed upon the other that has received the yet fluid glue, until both surfaces are covered, and the superfluous glue is squeezed out of the joint, when a very considerable pressure should be instantly applied by implements called glueing screws, or by the application of wedges, to press out the glue, and bring the two surfaces into as close contact as possible; and this done, the joint should be set by, under the pressure, and not be touched for several hours, or until the glue is quite cold, and all the water it previously contained has had time to dry away. The time required will therefore depend on the state of the atmosphere at the time, or the temperature of the place in which the work remains. A well made glued joint in dry wood will in this way be found as strong, and in some cases stronger than the wood itself. Glue will produce the adhesion of woods, leather, paper, and all things that are absorbent; but it cannot be applied to unite metals, or wood and metals, glass, porcelain, or hard stones, because these are not absorbent, and the glue cannot attach itself to their surfaces. To unite them, mortar, plaster of paris, putty, white-lead ground in oil, or resinous cements, formed by melted rosin, shell-lac, wax, or such kind of materials must be resorted to.

768. Mr. Bevan, before referred to, is the only person who has published the results of any experiments on the adhesive strength of glue. He glued together by the ends, two cylinders of dry ash wood, of an inch and a half in diameter, and about 8 inches long. After having been glued 24 hours, they required a direct force of

1260 *lbs.* to separate them; and as the area of the circular ends of the cylinders were 1.76 inch, it follows that the force of 715 *lbs.* would be required to separate one square inch. This experiment was made with new glue, dissolved for the purpose, and on repeating it several times with glue that had been frequently heated, and to which additions, both of glue and of water, had been often made, he obtained a result of from 350 to 560 *lbs.* to the square inch. In these experiments the force was applied gradually, and perpendicularly to the centres of the surfaces glued together. The force was generally sustained for two or three minutes before the separation took place. On examining the surfaces after their separation, the coat of glue appeared to be very thin, and did not adhere over the whole surface of the wood; so that the actual adhesion of glue must be something greater than 715 *lbs.* to the square inch.

769. Mr. Bevan also tried the lateral cohesion of a piece of dry and well seasoned Scotch fir, or pine board, and found that it required 562 *lbs.* to the square inch to divide it; consequently, if two pieces of this wood should have been glued together, the wood would have yielded in its substance before the glued joint.

770. From a subsequent experiment made on solid dry glue, its cohesive force was found to be 4000 *lbs.* to the square inch; from which it may be inferred that the application of glue as a cement does not give so large a result as might be expected, and that the method of using it is defective, and susceptible of improvement.

Of the force of Torsion.

771. The only subject remaining to be noticed in the present section, and with which we shall close it, is the resistance that a shaft or axis offers to a force applied to twist it round, and this is called the force, or resistance of torsion. This force is in the nature of a lever, revolving about the axis or central line of the shaft, and is so considered and investigated by Mr. Tredgold. Professor Robison on the contrary, views the shaft as a series of concentric tubes placed one within the other. The demonstrations and examples given by Mr. Tredgold, are so extensive, as to preclude their being admitted wholly in this place, and the student is therefore referred to them,* and ample directions will be found applying to most shapes and materials in practice. Professor Robison's observations are more general and concise, and are, therefore, adopted in our present explanations.†

* Essay on Strength of Cast Iron, Section 9, p. 215.
† Robison's Mechanical Philosophy, Vol. I., p. 488.

772. He observes, we cannot have a very distinct conception of that modification of the cohesion of a body by which it resists this kind of strain; but there can be no doubt, that when all the particles act alike, the resistance must be proportional to their number. Therefore, if we suppose the two parts *a b c d*, *a b f e* (Fig. 141, Pl. V.) of the body *e f c d*, to be of insuperable strength, but cohering more weakly in the common surface *a b*, and that one part *a b c d* is pushed laterally in the direction *a b*, there can be no doubt but it will yield only there, and that the resistance will be proportional to the surface.

773. In like manner, we may conceive a thin cylindrical tube, of which KAH, Fig. 142, is the section, as cohering more weakly in that section than any where else. Suppose it to be grasped in both hands, and the two parts twisted round the axis in opposite directions, as we would twist the two joints of a flute, it is plain that it will first fail in this section, which is the circumference of a circle, and the particles of the two parts that are contiguous to this circumference, will be drawn from each other laterally. The total resistance will be, as the number of equally resisting particles; that is, as the circumference (for the tube being supposed very thin, there can be no sensible difference between the dilatation of the external and internal particles). We can now suppose another tube within this, and a third within the second, and so on till we reach the centre. If the particles of each ring exerted the same force (by suffering the same dilatation in the direction of the circumference), the resistance of each ring of the section would be as its circumference and its breadth, (supposed indefinitely small,) and the whole resistance would be as the surface, and this would represent the resistance of a solid cylinder. But when a cylinder is twisted in this manner by an external force applied to its circumference, the external parts will suffer a greater circular extension than the internal; and it appears that this extension (like the extension of a beam strained transversely), will be proportional to the distance of the particles from the axis. We cannot say that this is demonstrable, but we can assign no proportion that is more probable. This being the case, the forces simultaneously exerted by each particle, will be as its distance from the axis. Therefore, the whole force exerted by each ring, will be as the square of its radius; and the accumulated force actually exerted, will be as the cube of the radius; that is, the accumulated force exerted by the whole cylinder, whose radius is CA, is to the accumulated force exerted *at the same time* by the part whose radius is CE, as CA^3 is to CE^3.

The whole cohesion now exerted, is just two-thirds of what it would be, if all the particles were exerting the same attractive forces which are just now exerted by the particles in the external circumference. This is plain to any person familiar with the fluxionary calculus, and such as are not may easily see it in the following way.

Let the rectangle AC*ca*, Fig. 142, be set upright on the surface of the circle, along the line CA, and revolve round the axis C*c*, it will generate a cylinder whose height is C*c*, or A*a*, having the circle KAH for its base. If the diagonal C*a* be supposed also to revolve, it is plain that the triangle *c*C*a* will generate a cone of the same height, and having for its base the circle described by the revolution of *c a*, and the point C for its apex. The cylindrical surface generated by A*a*, will express the whole cohesion exerted by the circumference AHK, and the cylindrical surface generated by E*e* will represent the cohesion exerted by the circumference ELM, and the solid generated by the triangle CA*a* will represent the cohesion exerted by the whole circle AHK, and the cylinder generated by the rectangle AC *ac*, will represent the cohesion exerted by the same surface, if each particle had suffered the extension A*a*.

Now it is plain, in the first place, that the solid generated by the triangle *e*EC is to that generated by *a*AC as EC^3 is to AC^3. In the next place, the solid generated by *a*AC is two-thirds of the cylinder, because the cone generated by *c*C*a* is one-third of it.

774. We may now suppose the cylinder twisted till the particles in the external circumference lose their cohesion. There can be no doubt that it will now be wrenched asunder, all the inner circles yielding in succession. Thus we obtain one useful piece of information, viz: that a body of homogeneous texture resists *a simple twist* with two-thirds of the force with which it resists an attempt to force one part laterally from the other, or with one-third part of the force that will cut it asunder by a square edged tool. For to drive a square edged tool through a piece of lead, for instance, is the same thing as forcing a piece of the lead as thick as the tool laterally away from the two pieces on each side of the tool. Experiments of this kind do not seem difficult, and they would give very useful information.

775. When two cylinders AHK and BNO, Fig. 142, are wrenched asunder, we must conclude that the external particles of each, are just put beyond their limits of cohesion, are equally extended, and are exerting equal forces. Hence it follows, that in the instant of fracture, the sum total of the forces actually exerted, are as the squares of the diameters. For drawing the diagonal C*e*, it is plain that E*e*=A*a*, expresses the distension of the circumference ELM, and that the solid generated by the triangle CE*e*, expresses the cohesion exerted by the surface of the circle ELM when the particles in the circumference suffer the extension E*e*

equal to A*a*. Now the solids generated by CA*a*, and CE*e*, being respectively two-thirds of the corresponding cylinders, are as the squares of their diameters.

776. Having thus ascertained the real strength of the section, and its relation to its absolute lateral strength, we must next examine its strength relative to the external force employed to break it. This examination is very simple in the case under consideration. The straining force must act by some lever, and the cohesion must oppose it by acting on some other lever. The centre of the section may be the neutral point whose position is not disturbed.

Let F be the force exerted laterally by an exterior particle. Let a be the radius of the cylinder, x the indeterminate distance of any circumference, and $\dot{x}$ the indefinitely small interval between the concentric laminæ or arches; that is, let $\dot{x}$ be the breadth of a ring, and x its radius. The forces being as the extensions, and the extensions as the distances from the axis, the cohesion actually exerted at any part of any ring will be $f\,\frac{x\dot{x}}{a}$. The force exerted by the whole ring (being as the circumference, or as the radius), will be $f\frac{x^2\dot{x}}{a}$. The momentum of cohesion of a ring, being as the force multiplied by its lever, will be $f\frac{x^3\dot{x}}{a}$. The accumulated momentum will be the sum or fluent of $f\frac{x^3\dot{x}}{a}$; that is, when $x=a$ it will be $\frac{1}{4}f\,\frac{a^4}{a},=\frac{1}{4}f\,a^3$.

777. Hence we learn that the strength of an axle or shaft, by which it resists being wrenched asunder, by a force acting at a given distance from the centre line or axis, is as the cube of its diameter.

But farther, $\frac{1}{4}f\,a^3$ is $=f\,a^2\times\frac{1}{4}a$. Now $f\,a^2$ represents the full lateral cohesion of the section. The momentum, therefore, is the same as if the full lateral cohesion was accumulated at a point distant from the axis by $\frac{1}{4}$th of the radius, or $\frac{1}{8}$th of the diameter of the cylinder. Therefore, let F be the number of pounds which measures the lateral cohesion of a circular inch, d the diameter of the cylinder in inches, and l the length of the lever, by which the straining force p is supposed to act, we shall have

$$F\times\tfrac{1}{8}d^3=p\,l,\text{ and }F\,\frac{d^3}{8l}=p.$$

We see in general that the strength of an axle, by which it resists being wrenched asunder by twisting, is as the cube of its diameter.

778. We see also that the internal parts of an axle do not act as powerfully as the external. If a hole be bored out of the middle of an axle, equal to half its entire diameter, the strength is diminished only one-eighth, while the quantity of matter is diminished one-fourth. Therefore hollow axles are stronger than solid ones containing the same quantity of matter. Thus let the diameter be 5, and that of the hollow 4; then the diameter of another solid cylinder, having the same quantity of matter as the tube, will be 3. The strength of the solid cylinder of the diameter 5 may be expressed by 5^3 or 125. Of this, the internal part having the diameter of 4, exerts 64; therefore the strength of the tube is 125—64,=61. But the strength of the solid axle of the same quantity of matter, and diameter 3, is 3^3 or 27, which is not half that of the tube.

779. Engineers, therefore, have of late, since cast iron has been so extensively used, introduced this improvement into their machines, by making all cast iron shafts and axles hollow, when their size will admit of it. They have the additional advantage of being much more stiff and free from vibration; while at the same time much metal is saved, by which they are lighter on their bearings and produce less friction; and what is most important is, that they are less costly, and more certain in their duration; because large solid castings are likely to be defective in their internal parts, for reasons that have been before explained. (618.)

780. Professor Robison states, that when the matter of the axle is of the most simple texture, such as that of metals, he does not conceive that its length has any influence on its fracture; but it is otherwise in fibrous materials like timber, for then the fibres are bent or twisted into spirals like a corkscrew before breaking. The length of the axle in this case has somewhat the influence of a lever, and will be easier wrenched asunder if long, than short; but he has not been able to reduce this influence to calculation. Experience, however, proves that long shafts or axles, whether of iron or of wood, are more easily broken than short ones; and, therefore, as a practical rule, all shafts should be kept as short as possible, or the nature of the place where they are used will admit of. All shafts, whether of wood or metal, will twist to a certain extent in working, from the natural elasticity of their materials; and this twisting may be permitted, and is not detrimental to their action, provided it does not go so far as to disturb the natural arrangements of their particles, or produce jumps and jerks in the work.

781. The quantity of twisting that is thus inevitable, is called *the angle of torsion*, and Mr. Tredgold observes, that if it is under two degrees in a cast iron shaft, it need not be regarded, but it should never exceed this quantity. In wooden shafts it is frequently more considerable. He gives rules and their demonstrations at greath length in his excellent work on the Strength of Iron, for determining the strength of shafts, and from these the three following examples have been selected.

782. RULE I. *To determine the diameter of a solid cylindrical shaft of cast iron to resist torsion, with a given flexure.*

Multiply the power in pounds, by the length of the shaft in feet, and this by the leverage with which the power acts. Divide this product by 55 times the number of degrees in the angle of torsion, which is considered best for the action of the machine; and the fourth root of the quotient will be the diameter of the shaft.

EXAMPLE.

Let it be required to find the diameter for a series of lying shafts 30 feet in length, to transmit a power of 4000 *lbs.*, acting at the circumference of a wheel of 2 feet radius, so that the twist of the shafts on the application of the power, may not exceed one degree?

Here the whole length must be taken as if it were one shaft, and by the rule

$$\frac{\overset{lbs.}{4000}\times\overset{ft.}{30}\times\overset{ft.}{2}}{55\times1}=4364$$

Then by a Table of Powers,* or the ordinary process of working, find the fourth root of 4364, which is 8.13 inches, the diameter required.

783. If the machinery be required to act with much precision, this will be as much flexure as can be allowed; but in ordinary cases, two degrees might be admitted, and then the diameter of the shaft would be rather less than 7 inches. Where there is much wheelwork, the flexure should be less. In accurate work it is not desirable to allow the shaft or axles to exceed a quarter of a degree.

784. RULE II. *To determine the diameter of a hollow cylinder to resist torsion, when the thickness of metal is one-fifth of the diameter, and the flexure is given.*

Multiply the length of shaft, the power, and its leverage into each other, as in the last case; and divide the product by 48 times the angle of flexure in degrees; the fourth root of the quotient will be the diameter required in inches.

* See Barlow's Mathematical Tables—Table III.

EXAMPLE.

Required the diameter of a hollow shaft 10 feet long, that may be sufficient to withstand a force of 800 *lbs.*, acting at the circumference of a wheel of 4 feet radius; the flexure not to exceed one degree, and the thickness of metal to be one-fifth of the diameter?

In this case $\frac{800\times10\times4}{48\times1}=666.6$ the 4th root of which is 5.1 inches nearly, being the diameter required. The hollow through the middle of this shaft, would therefore be 3 inches, thus leaving the metal about one inch thick all round, or $\frac{1}{5}$th of the diameter which experience as well as demonstration points out to be the best proportion for the thickness of metal in hollow shafts.

785. RULE III. *To determine the side of a solid square cast iron shaft to resist torsion, with a given flexure.*

Multiply the length of the shaft, the power, and its leverage into each other as before; and divide the product by 92.5 times the angle of flexure in degrees, and the square root of the quotient will be the *area* of the shaft in inches.

EXAMPLE.

The length of the shaft is 12 feet; it is to be driven by a power of 700 *lbs.* acting on a pinion on the shaft of one foot radius to the pitch line; the flexure not to exceed one degree.

By the rule $\frac{700\times1\times12}{92.5\times1}=90.8$ the square root of which is 9.53, the *area* of the section in inches; and the square root of 9.53 is 3.1 inches nearly, for the breadth of one side of the shaft.

SECTION III. *Of the relative strength of Materials.**

786. By the relative strength of materials is meant, the strength or resistance they are capable of offering when placed in such positions, or under such circumstances, as will not permit their actual or absolute strength, as before explained, to be fully exercised; or the relation of their absolute strength, to that which they may be able to exert under the particular circumstances by which they are constrained to act. The actual or absolute strength of a body cannot be changed or augmented in any way while the body remains the same, but it may be diminished by position and other causes; and in considering the nature of this force, we shall have frequent occasion to refer to what has been already stated; be-

* Chiefly compiled from Professor Robison's Mechanical Philosophy, Dr. Young's Lectures on Natural Philosophy, Hutton's Mathematics and Gregory's Mechanics.

cause the actions of compression, extension, and torsion, are often in operation at the same moment.

787. What is meant to be implied by relative strength, and the difference between it and absolute strength, will, it is believed, be better understood by an example than by description. Thus suppose a beam or piece of wood *a b*, Fig. 143, to be supported under its two ends by brick walls, as is the case in the girder of a floor of any ordinary building. Such a beam, if long and perfectly straight before it is so placed, will inevitably swag or sink downwards in its central part *c* by its own weight. But if we further suppose the floor to be loaded with furniture, persons, or any additional load, which may be represented by a heavy iron ball *d*, the beam will suffer a further bending, or may even be broken in two. The same thing will occur, whether the weight *d* be applied above the floor, or is hung or appended below it as at *e*. If now, we suppose either of these weights to be divided into 5 or any other number of smaller weights, the sum of which shall be equal to the large one, and that they shall be ranged at equal distances from each other, the beam will evidently have the same weight to sustain, and yet it will not swag or yield to the same extent, but will appear to have more strength to resist the distributed load, than the one that is concentrated upon its centre. The strength or resistance in one case, will therefore be relative towards that in the other, and there will be a relation between these strengths and that of the beam when not loaded at all; and as these strengths or powers of resistance are all different, it is clear that they cannot agree with the absolute or actual cohesive strength of the beam which is immutable: neither will they agree with either of the strains before discussed; for a strain of compression would tend to bring the ends *a* and *b*, or the sides *d* and *e* into a state of closer approximation; while a strain of extension would have the directly opposite effect.

788. Supposing the beam to break under the influence of its load; if we examine what takes place, it will be found that the fracture or opening will commence at the bottom or under side of the beam, and will proceed upwards in as nearly a perpendicular direction as the fibres of the wood will permit; but that no chasm or opening will appear at the top of the beam. In some cases, a separation of parts will not even occur; but the top surface, though much bent, may hang together by its fibres. A different action must therefore have taken place at the top and the bottom of the beam, and such really is the case; for some fulcrum or resisting part must exist in the beam, to produce the opening or fracture on the under side. That is brought about by an extending force, but the reaction to produce that extending force, is in the upper

part of the beam, which therefore suffers compression; consequently, all the part of the beam under the point *c* will be extended, and all above it compressed, the two forces being in operation at the same instant. These two forces exist to the greatest extent at the top and bottom of the beam, diminishing gradually towards the centre, where they change into each other; and at this place, therefore, the forces are neutral, or diminish to nothing. This neutral position will extend quite across the beam at right angles to the direction of the applied force, and is called *the axis of fracture.*

789. It matters not whether the force that produces this bending or fracture is applied above or below, or to one side or the other of the beam, since its operation will be alike in all cases, except so far as it is increased or decreased by the weight of the beam itself; therefore such a force is called a *lateral force,* and as its effects are influenced by other circumstances besides the positive strength or cohesion of the material, the resistance to its action is called *the stiffness of materials* to distinguish it from their strength. Strength being the power they possess to resist fracture or breaking; and stiffness the power to resist flexure or bending.

790. We have taken as an example, a beam supported at both its ends; but if one end was built into a solid wall, so as to be firmly supported, while the other projected beyond it, and was unsupported, and a load should be applied to this end, or to any other part of the projection, its stiffness would be called into action, but under different modifications. The object of this section will therefore be to examine a few of the most common cases that occur in practice, and to point out the means of obtaining the greatest quantity of strength with the least quantity of material, an object that the Engineer should always keep in view, because the greater the quantity of material, and the greater will be the cost of the work, which will be considerably enhanced by the time and workmanship necessary to convert and put it together.

791. This subject is of such vast practical importance, that it has been much written and experimented upon, and has occupied the attention of many of the first philosophers and mathematicians, among whom may be mentioned Gallileo, Mariotte, Leibnitz, Euler, Bernoulli, Lagrange, Emerson, Hutton, Girard, Robison and Young; and more might be said on this subject alone, than is intended to fill the whole of the present volume; for under our limited extent, all that can be attempted, is to give the student a general outline of what has been done, and to direct his attention to such points as it is believed will be most useful to him. For particulars he must refer to the works that have appeared

on this and other subjects, and those already noticed with Tredgold's Elementary Principles of Carpentry, will be found replete with useful information.

792. Let us in the first place examine the effects that would occur if a rectangular piece of plank *k l m n*, Fig. 144, should be firmly built into a brick wall as at *k m o p*, in such manner that the end so built in shall be incapable of motion; but that the other end *o l p n* may project into open space without any other support than the cohesion of its own particles, which unite it to the part built into the wall; and moreover, that a weight *w* shall be suspended from the point *n*. It will be evident that the weight of the projecting end of the plank added to that of the weight *w*, will constitute a force that will tend to break and depress it; and if it was equally strong in every part, but very brittle, it ought to break off in the direction of the dotted line *o p*, and descend perpendicularly by the moving surface at *o p*, sliding downwards over the corresponding fixed surface. Such an effect would, however, be prevented in almost every case by the fibrous nature and cohesion of the parts of the plank, which would prevent its breaking so abruptly and sliding downwards; and in almost every case the projecting end *o l p n* would become curved by being bent downwards at its end *l n;* and as the point *p* close to the wall is supported, that point may be conceived to be the centre or fulcrum, upon which the first bending would take place, and the wood near *p* would be in a state of compression, while the whole upper surface *o l* would be subject to a force of extension. Hence, in such a case, the fracture or breaking would always commence at the top of the beam, and would proceed downwards in a direction as nearly perpendicular as the texture of the substance would permit. The strength of such a beam would, therefore, depend mainly on the direct cohesion of its parts near *o*, to resist such separation; but still this case is quite different from those examined under the head of extending forces, in which the weight or power to produce separation was acting with its own unmodified force, in the direction of the axis, or length of the piece; and, consequently, would exert an equal power on every particle in the transverse section where the fracture occurred.

In this case the action is neither equable over the whole section, nor is it directly as the power of the weight or force employed; but is of a more complex nature, because a bent lever is produced, in which the supported point *p* is the fulcrum, the line *p n* is the acting arm, or represents the force with which the weight can act to produce fracture, and the line *p o* will be the resisting arm, or measure of the force that can resist fracture; and in proportion as the line *p n* is longer than the line *p o*, so will the weight *w* have a greater power to break the projecting timber; so that if we conceive this piece to be cut horizontally to half its former depth by the line *r s*, then *r s* will be equal to *p n*, so that the power of the weight remains the same; but *r o* is only the half of *p o*, consequently the weight will leave twice the power to produce fracture; while, if *p o* should be increased in depth, it will bear a larger proportion to *p n*, and will therefore be stronger. Depth, or distance from top to bottom, in beams of this kind, therefore, increases their strength; while the thickness may remain the same.

793. We see likewise in this example that the fracture must occur at the place *o p* near the wall; because all other things remaining the same, if we assume any other point *v* in the bottom of the beam as the fulcrum, then *v n* will be the acting arm, and *v t* the resisting arm of the lever, and they are equal; but *p n* is four times as long as *v n*, while *p o* is equal to *v t*; therefore (independently of the weight of the timber) the weight *w* will have 4 times as much power at *o* as it has at *t*; and consequently the fracture will take place at *o p*. For the same reasons increasing the length of the piece *o l p n*, while its area remains the same, will diminish its strength, because this is increasing the arm *p n*, while *p o* remains unaltered. A piece of timber, or other material, may therefore be so extended as to break by its own weight, or without the assistance of any weight *w* applied to it.

794. In examining cases of fracture by direct extension, the cohesive force of all particles in the cross section is considered equal, and these forces will, in fact, be also equal in the plane of fracture that takes place from a lateral strain, like the beam projecting from a wall just spoken of; yet, in practice, they are not equal, or rather, although they are really equal, they are acted upon by different degrees of force in different parts of the beam, and this produces the same effect as if they were unequal. That this operation is unequal will be rendered manifest by recurrence to the last figure, in which we may conceive the transverse section *p o* to be composed of a line or series of particles infinitely near to each other, and all possessing equal cohesive power. But as the arm of the lever *p n* remains of uniform length, the weight *w* will act with diminished power on every particle as they succeed from *p* towards *o*, and the power of the weight at *o* to separate two particles horizontally, will be only half as great as it will be at *r*, and will diminish while it proceeds upwards from *o*, and will increase downwards to *p*, where it will be greatest of all. Notwithstanding, therefore, that the cohesion may be equal in every part of the beam, that beam will be weaker in effect below *r* than above it, because the force tending to produce rupture in

that part, is greater than it is above. Still the parts near *r*, rendered weaker by this effect, will be strengthened and sustained by the upper parts near *o*, because they have more power to resist separation; and it will therefore appear that if a fracture begins near *o*, by which the sustaining power of those parts are abstracted, the beam must inevitably break off, from the less favourable position of the lower particles to resist the strain.

795. This is a case that requires the aid of the fluxionary calculus for its investigation, but Professor Robison puts it in a very simple form,* by supposing the beam instead of projecting from a wall, to be hanging from the ceiling, in which it is firmly fixed, and then considering how the equal cohesion of every part operates in hindering the lower part from separating from the upper by opening round the joint *p*. The equal cohesion operates just as equal gravity would do, but in the opposite direction. Now we know that the effect of this will be the same as if the whole weight was concentrated in the centre of gravity *r* of the line *o p*, and that this point *r* is in the middle of *o p*. Now the number of fibres being at the length of the line *o p* may be represented by D, and the cohesion of each fibre being $=$F, the cohesion of the whole line will be $F \times D$, or FD.

The acumulated energy, therefore, of the cohesion in the instant of fracture is, $FD \times \frac{1}{2}D$. Now this must be equal or just inferior to the energy of the power employed to produce fracture. Let the length of the beam *p n* be called L, and the weight *w*, W; then $W \times L$ is the corresponding energy of the power. This gives us $FD\frac{1}{2}D = PL$ for the equation of equilibrium, corresponding to the vertical section *o l p n*.

796. Suppose now that the fracture is not permitted at *o p*, but at another section *β δ* more remote from *n*. The body being prismatic all the vertical sections are equal; therefore $FD\frac{1}{2}D$ is the same as before. But the energy of the power is by this means increased, being now$=w \times n\,\delta$, instead of $w \times n\,p$: hence we see that when the prismatic body is not insuperably strong in all its parts, but equally strong throughout, it must break close to the wall, where the strain or energy is greatest. We see too, that a power which is just able to break it at the wall, is unable to break it at a distance from that wall; because although an absolute cohesion FD, which can withstand the power W in the section *o p*, will not be able to withstand it at *β δ*, and will withstand more in any external section, as *t v*.

797. This teaches the distinction between absolute and relative strength. The relative strength of a section has a reference to

* Robison's Mech. Philos., Vol. I. p. 415.

the strain actually exerted on that section, and is properly measured by the power which is just able to balance or overcome it when applied at its proper place. Now since we had $FD\frac{1}{2}D=WL$, we have $W=\frac{FD\frac{1}{2}D}{L}$ for the meausure of the strength of the section *o p* in relation to the power applied at *w*.

798. If the solid is a rectangular beam, whose breadth is B, all the vertical sections will be equal; consequently the length *p r*, or $\frac{1}{2}D$, must be the same in all. Therefore the equation, expressing the equilibrium between the momentum of the external force and the accumulated momenta of cohesion, will be $WL=FDB\times\frac{1}{2}D$.

The product DB, evidently expresses the area of the section of fracture, which we may call S, and we may express the equilibrium thus, $WL=FS\frac{1}{2}D$, and $2L:D=FS:W$.

Now FS is a proper expression of the absolute cohesion of the section of fracture, and W is a proper measure of its strength in relation to a power applied at *n*. We may therefore say that *twice the length of a rectangular beam is to the depth, as the absolute cohesion is to the relative strength.*

799. Since the action of equable cohesion is similar to the action of equal gravity, it follows that whatever is the figure of the section, the relative strength will be the same as if the absolute cohesion of all the fibres were acting at the centre of gravity of the section. Let G be the distance between the centre of gravity of the section and the axis of fracture, and we shall have $WL=FSG$, and $L:G=FS:W$. It will be very useful to recollect this analogy in words: *The length of a prismatic beam of any shape, is to the height of the centre of gravity above the lower side, as the absolute cohesion is to the strength relative to this length.* Because the relative strength of a rectangular beam is $\frac{FBD\frac{1}{2}D}{L}$ or $\frac{EBD^2}{2L}$ it follows that the relative strengths of different beams are proportional to the absolute cohesion of the particles, to the breadth, and to the square of the depth directly, and to the length inversely; also in prisms whose sections are similar, the strengths are as the cubes of the diameters.

800. Such are the more general results of the mechanism of this transverse strain, in the hypothesis that all the particles are exerting equal forces in the instant of fracture. But the hypothesis of equal cohesion being exerted by all the particles in the instant of fracture, is not conformable to nature; for we know that when a force is applied laterally against a beam, one side will become convex and have its particles on the stretch, while the other, becoming concave, will condense them. The particles on one side

will, therefore, be moved further from each other than those on that which is opposite; and it is impossible to say, with precision, to what extent the fibres are acted upon; but the probability is that the extensions are proportional to the distances from the fulcrum or centre of motion. Assuming this to be correct, and admitting the law, that in all moderate extensions, the attractive forces exerted by the dilated particles are proportional to their dilatations, Professor Robison enters upon a further investigation, from which he deduces the analogy that "*As thrice the length of a beam is to its depth, so is the absolute cohesion to the relative strength.*" We are chiefly indebted for this doctrine to the celebrated Galileo; and it was one of the first specimens of the application of mathematics to the science of nature. He, however, proceeded on the supposition that the fulcrum was on the outside of the beam where the fracture ends. But Mr. Barlow has since proved that it is wholly within the section, and he calls this line the neutral axis.

801. In the preceding investigation no notice has been taken of the action of that force which tends to cause the part *o p l n* of the beam to slide down vertically in the direction of the line *o p* in front of the part *k o m p* that is fixed in the wall; because this force is so small in comparison to the others that exist, that no notice need be taken of it in any practical application.

802. Applying these principles to practice and we find that

The strength of a beam, or bar of wood, or metal, &c., in a lateral or transverse direction, to resist a force acting laterally, is proportional to the area or section of the beam in that place drawn into the distance of its centre of gravity from the place where the force acts, or where the fracture will end.

Thus, let A B, Fig. 145, represent a stick of timber or other rectangular beam, supported upon props at its two ends, while it is pressed upon by the weight W placed over its centre, and which may be supposed heavy enough to break it; and let *a b c d* be a cross section taken under such weight. The fracture will, under these circumstances, commence at the bottom of the beam, and will proceed upwards in a direction nearly coincident with that section. The power of a beam so disposed to resist fracture, must be proportionate to the number of fibres or contiguous cohering particles that are contained in the section, and the operation would be similar in effect to a simple longitudinal force (723), if the leverage before described did not operate to produce a change; but the reaction of the props under A and B being equal to the whole weight supported, and severally acting at the long ends of bent levers AW*a*, BW*a*, AW*b*, BW*b*, &c., produced by supposing the beam divided into an infinite number of equal horizontal laminæ, the tendency to fracture from this leverage will be lessened as the shorter arms W*a*, W*b*, &c. are increased, while the longer arms remain the same; therefore the strength being inversely as the stress, will be regularly increased as the distance of any lamina from W is increased, and the sum of all these forces will express the power that is called into action to separate the fibres or particles of the beam. The resistance to this power will, however, depend upon the sectional area; therefore we must also consider the thickness of the beam as shewn in Fig. 146, instead of regarding its height only as in Fig. 145. Now the area *a e* in Fig. 146, contains and denotes the sum of all the fibres to be broken or torn asunder; and as they are supposed to be all equal to one another in absolute strength, that area will denote the aggregate or whole strength of all the fibres in the longitudinal direction. The fulcri or centres of motion of the levers before referred to will all be in the line *e e;* consequently, each fibre in the line *a b* will resist the fracture by a force proportional to the product of its individual strength into its distance *a e* from the centre of motion; consequently, the resistance of all the fibres in *a b* will be expressed by $a\,b \times a\,e$. In like manner the aggregate resistance of another course of fibres, parallel to *a b* as *c c*, will be denoted by $c\,c \times c\,e$; and a third as *d d* by $d\,d \times d\,e$, and all these products will express the total strength or resistance of all the fibres, or of the beam in that part. But it is demonstrable that the sum of all these products is equal to the product of the area *a e e b* into the distance of its centre of gravity from *e e;* hence the proposition is manifest.

803. We learn from the above, that the lateral strength of any beam or bar, is considerably less than its absolute longitudinal strength either against extension or compression; or that it will break with a much smaller force when applied laterally; because in the one case the fibres must be all separated at once, or in an instant; while in the other, they are overcome and separated successively, or one after another in some perceptible portion of time. An experimental proof of this is offered in a common walking stick, which will support an immense load hanging perpendicularly beneath it, or will sustain a great load pressing in the direction of its length, provided the stick can be kept from bending; but if the bended knee is applied to the centre of such a stick, while the two hands draw the ends towards you, it will break with a comparatively small force. Thus originates a principle in carpentry which will be insisted on in the next chapter as being of great importance to the stability of all constructions, which is never to admit a lateral strain in any case where there is the possibility of substituting a longitudinal one for it.

804. We also learn the great advantage that arises from using

timber or metal beams, which oppose considerable depth to the direction of the lateral force, notwithstanding they may be thin in the opposite direction; and as rectangular pieces of timber or iron, such as are generally used in constructing buildings or machinery, may in general be considered as homogeneous, their centres of gravity will be found in the centre of their dimensions; consequently the application becomes very easy. Suppose for example, in placing a girder to support a floor, we select a square stick of timber measuring 12 inches on each side, its transverse sectional area will of course be 144 square inches, and its centre of gravity will be in its centre, or 6 inches from either side. Being used in a floor, its tendency to bend in consequence of any superposed load, will be downwards, and if it breaks, the fracture will terminate at the upper surface, or 6 inches above the centre of gravity; consequently, the area 144 inches, must be multiplied by 6 inches, making 864 as a representative number, by which to compare the lateral strength of this piece with any other. Being square, this piece may be placed with any side upwards, without producing any alteration in the elements of calculation. The result will therefore be the same for every side, or its strength will not be affected by placing the one or other side uppermost.

805. Let us next suppose this girder to be sawed longitudinally through its middle, so as to produce two equal pieces of timber the sides of which are 6 and 12 inches, or exposing an area each of 72 square inches, and placing them as before with the 12 inch sides vertically, let us examine what change will be produced. As the girder is still 12 inches high, the position of the centre of gravity will not be altered, but will still remain 6 inches below the upper surface; consequently, the area 72 must be multiplied by 6, producing 432, which is exactly half the product obtained when the timber had double the breadth. We thus see that while the depth remains the same, the strength varies as the thickness, and that the same strength may be obtained in a building by multiplying small pieces as by using fewer large ones.

806. Again let us examine the effect of using the same last mentioned timbers measuring 6 by 12 inches, with the 6 inch sides vertical instead of the 12 inches. The area 72 inches of course remains unaltered; but the centre of gravity will now be only 3 inches below the upper surface, so that multiplying 72 by 3 we only obtain 216, or half the former strength, notwithstanding the quantity of timber remains undiminished.

If instead of selecting a girder 12 inches square to support the floor, one of 14 by 10 inches had been taken, this would only contain 140 superficial inches in its area, and would therefore be cheaper as containing less timber than the 12 by 12 inch piece, and yet considerably stronger when placed with its largest dimension upright, for now the centre of gravity would be 7 inches beneath the upper surface, and $140\times7=980$, so that 140 superficial inches produces a strength of 980, while 144 inches only produces 864.

807. On this same principle we see why a board can support so much more when it is placed with its edge upwards, than when placed flatwise like a shelf. Suppose the board 10 inches wide and one inch thick, its sectional area will then be 10 superficial inches. When placed with its edge upwards, its centre of gravity will be 5 inches from the upper edge, and $10\times5=50$; but when placed flatwise, its multiplier will be only $\frac{1}{2}$ an inch, and $10\times\frac{1}{2}=5$. It is therefore 10 times stronger against lateral pressure in the first position, to what it is in the second.

808. For the same reason, a triangular beam is twice as strong against lateral pressure when resting on its broad base, as it is when resting on its edge, notwithstanding the area is the same in both cases. For the transverse section of such a beam must be a triangle; and the centre of gravity of a triangle is $\frac{1}{3}$d of its height from the base, or $\frac{2}{3}$ds from the apex. These distances being as 2 to 1, so of course if a triangular beam is placed with its base downwards, the centre of gravity will be twice as far below the top of the beam or place where the fracture will end, as it will be if the base is upwards; consequently, the multiplier will be twice as large in the one case as in the other, and the strengths will be in the same ratio.

From the above principle several useful corollaries are derivable.

809. *Corol. 1st.*—In *square* beams the lateral strengths are as the cubes of the breadth or depth.

810. *Corol. 2nd.*—In general, the lateral strengths of any bars, whose sections are similar figures, are as the cubes of the similar sides of the section.

811. *Corol. 3d.*—In cylindrical beams, the lateral strengths are as the cubes of the diameters.

812. *Corol. 4th.*—In rectangular beams, the lateral strengths are to each other as the breadths and square of the depths, for here the area being as the product of the two sides, and the distance of the centre of gravity being equal to half the perpendicular side, and therefore proportioned to that side; the proposition is that the strength varies as the breadth multiplied by the depth, multiplied again by the depth, or as the breadth into the square of the depth. Hence, as above shown, the same oblong beam, with its narrow side upwards, is as much stronger than with its broad side upwards, as the depth exceeds the breadth.

813. *Corol. 5th.*—If a beam be fixed firmly at one end into a wall so that it may project horizontally, and its fracture be caused by a weight applied at the opposite end, the process will be the same; only that the fracture would commence above and terminate at the lower side; and the proposition, and all the corollaries, would still hold good.

814. *Corol. 6th.*—When a cylinder or prism is made hollow, it is stronger than when solid with an equal quantity of materials and length, in the same proportion as its outer diameter is greater; and if the hollow beam is not meant to revolve, and has the hollow, or pipe, nearest to that side where the fracture must end, it will be still stronger.

In the foregoing proposition (802) no reference is made to the length of the beam, but

815. *In beams of different lengths, resting on two supports, like* Figs. 143, 145, *and* 146, *the strength will vary as the area of the section, into the depth of the centre of gravity, divided by the length into the weight.*

Let L*l* denote the lengths; W*w* the weights; A*a* the areas of the sections; and G*g* the depths of the centres of gravity of two prismatic beams resting horizontally on their two ends.

The *stress*, or tendency to produce fracture *from the weight of* the beam *itself*, will be expressed by $\frac{1}{8}\mathrm{L}\times\mathrm{W}$ and $\frac{1}{8}l\times w$; for the reaction at each support is a force$=\frac{1}{2}\mathrm{W}$ acting upon $\frac{1}{2}\mathrm{L}$ at the centre of gravity; but the centre of gravity of $\frac{1}{2}\mathrm{L}$ is at a distance from the prop$=\frac{1}{2}$ of $\frac{1}{2}\mathrm{L}$, or $\frac{1}{4}\mathrm{L}$; therefore the effect of the force will be equal to $\frac{1}{4}\mathrm{L}\times\frac{1}{2}\mathrm{W}=\frac{1}{8}\mathrm{L}\times\mathrm{W}$.

The tendency *to resist* fracture is denoted by $\mathrm{A}\times\mathrm{G}$ and $a\times g$. Hence the aggregate strength of the timber will be directly as the latter, and inversely as the former. That is

$$\mathrm{S}:s::\frac{\mathrm{A}\times\mathrm{G}}{\frac{1}{8}\mathrm{L}\times\mathrm{W}}:\frac{a\times g}{\frac{1}{8}l\times w}::\frac{\mathrm{A}\times\mathrm{G}}{\mathrm{L}\times\mathrm{W}}:\frac{a\times g}{l\times w}$$

816. *The lateral strength of prismatic beams of the same materials is directly as the areas of their sections, and the distances of their centres of gravity; and inversely as their lengths and weights.*

Let AB and CD, Fig. 144, represent two such beams fixed horizontally by their ends C and A into a wall. Now by the first proposition, (802,) the strength of either beam considered as without, or independent of weight, is as its section drawn into the distance of its centre of gravity from the fixed point; viz. as $s\,c$, where s denotes the transverse section at A or C, and c the distance of its centre of gravity above the lowest point of A or C. But the effort of their weights W, or w, tending to separate the fibres and produce fracture, are by the principles of the lever, as the weight drawn into the distance of the place where it may be supposed to be collected and applied, which is the centre of gravity, situated in the middle of the length of the beam; that is, the effort of the weight upon the beam is as $W \times \frac{1}{2} AB$, or $w \times \frac{1}{2} CD$.

817. *Corol.* 1*st.*—Any extraneous weight or force applied any where to the beam, will exercise a similar power to break it as its own weight; that is, its effect will be as $w \times d$, or as the weight drawn into the length of lever, or distance from A or C, where it is applied.

818. *Corol.* 2*nd.*—When the beam is fixed at both ends the same property will hold good, with this difference only; that in this case, the beam is of the same strength as another of an equal section and only half the length, when fixed only at one end. For if the longer beam should be bisected, or cut in halves, each half would be in the same circumstances with respect to its fixed end, as the shorter beam of equal length.

819. *Corol.* 3*d.*—Square prisms and cylinders have their lateral strength proportional to the cubes of their depths or diameters directly, and to their lengths and weights inversely.

820. *Corol.* 4*th.*—Similar prisms and cylinders have their strengths inversely proportional to their like linear dimensions—the smaller being comparatively larger in that proportion. For their strength increases as the cube of the diameter, or of their length; but their stress, from their weight and length of lever, as the fourth power of the length.

821. From the foregoing deductions it follows, that in similar bodies of the same texture, the force which tends to break them, or make them liable to injury by accidents in the larger bodies, increases in a higher proportion, than the force that tends to preserve them entire, or to secure them against such accidents; their disadvantage, or tendency to break by their own weight, increasing in the same proportion as their length increases; so that although a small beam may be firm and secure, yet a larger but similar one may be so long as to break by its own weight. This is particularly deserving the attention of the Engineer, who may frequently have models of machines to execute before he attempts them on a large scale; or who may have models presented to him for his inspection and approval. He must, in such cases, bear in mind that what may appear very firm and successful in a model, or small machine, may be weak and infirm, or may even fall to pieces by its own weight, when it is executed on large dimensions, even according with the scale or proportion of the model.

822. This same principle places limits of extension to the productions both of nature and art. Thus, if trees grew much larger than we are accustomed to find them, their branches would break

and fall from their own weight: so with floors, roofs, arches, and many other artificial constructions. The larger they become, and the grosser must be the proportions of the materials used to form them, so that they become unpleasing to the eye, and so enormously heavy as to crush and destroy their supporting bearings, by the enormity of their own pressure.

823. *If a weight be placed, or a force act, on any part of a horizontal beam supported at both ends; the stress upon that part will be as the rectangle, or product, of its two distances from the supported ends.*

Let AB, Fig. 147, be the beam so supported, and W a weight suspended from, or placed upon, the point C; then the stress upon the beam AB, at C, by the weight W, is as $AC \times BC$. For by the nature of the lever, the effect of the weight W on the lever AC, is $AC \times W$; and the effect of this force acting at C, on the lever BC, is $AC \times W \times BC = AC \times BC \times W$. And the weight W being given, the effect, or stress, is as $AC \times BC$.

824. *Corol. 1st.*—The greatest stress is when the weight acts in the middle of the beam; for then the rectangle of the two halves $AC \times AC = \frac{1}{2}AB \times \frac{1}{2}AB = \frac{1}{2}AB^2$ is the greatest. And from the middle point the stress is less and less all the way to the extremities, where it is nothing. Hence in practice, where a load has to be supported on the middle of a beam, that middle ought to be stronger than the two extremities, a part of which may be cut away according to a certain rule to be presently explained, (see 837) without abstracting at all from its strength.

825. *Corol. 2nd.*—If instead of the weight being applied to any point in the beam, it is diffused equally all over it, the same effects will occur; but the stress in this case will only amount to half of what it would otherwise be. Hence in all structures, we should avoid as much as possible placing loads or strains in the middle of beams.

826. *Corol. 3d.*—If w be the greatest weight that a beam can sustain at its middle point, and it is required to find the place where it will support any greater weight W, that point will be found by saying as $W : w :: \frac{1}{2}AB \times \frac{1}{2}AB$, or $\frac{1}{4}AB^2 : AC \times BC$ or $AB \times (AB - AC) = AB \times A - AC^2$.

The foregoing observations apply to beams supported at both ends, and we now proceed to the case where the beam is supported at one end only.

827. *In similar prismatic or cylindrical beams supported at one end only, the strength varies inversely, either as the diameter or as the length.*

Let ABEF, *a b e f*, Fig. 148, represent the longitudinal sections of two prismatic beams fixed horizontally into the wall HK, then the power of these beams to resist fracture at the ends EF, *e f*, where they are inserted into the wall, will be measured in the same manner as in the preceding cases, that is, *by the area of the lateral section into the depth of its centre of gravity* (802). In this case, the fracture will begin at the upper points F*f*, and end at the lower points E*e*. The tendency to produce fracture will be the weight of the beams acting at the distance of their centres of gravity, from the supported ends EF, *e f*. Hence

$S : s :: \frac{A \times G}{\frac{1}{2}L \times W} : \frac{a \times g}{\frac{1}{2}l \times a}$, or if any weights W′ w' are placed at the ends of the beams, then (since the effects of these weights to produce fracture will be measured by $W' \times L$, and $w' \times l$) we have

$S : s :: \frac{A \times G}{L . \overline{\frac{1}{2}W + W'}} : \frac{a \times g}{l . \overline{\frac{1}{2}w + w'}}$; and if the weights W, w, of the beams are very small when compared with the added weights W′, w', then $S : s :: \frac{A \times G}{L \times W'} : \frac{a \times g}{l \times w'}$.

Hence in similar beams $S : s :: \frac{1}{D} : \frac{1}{d}$ or $\frac{1}{L} : \frac{1}{l}$.

Let Ww, represent the weights of the parts ABCD, *a b c d* of the beams, (Fig. 148,) then the tendency of those parts to produce fracture at C*c*, will be measured by $\frac{1}{2}AC \times W$, and $\frac{1}{2}ac \times w$; therefore if S*s*, represent the strength of the beams at C and *c*, then $S : s :: \frac{A \times G}{AC \times \overline{\frac{1}{2}W + W'}} : \frac{a \times g}{ac \times \overline{\frac{1}{2}w + w'}}$; or if W$w$, be very small with respect to W′ and w', then $S : s :: \frac{A \times G}{AC \times W'} : \frac{a \times g}{ac \times w'}$.

Hence, if a given weight W′, be supported at the end of a given beam, whose weight is so small as not to be taken into consideration, the strength of that beam to support the weight W′ at any point C, between A and F, will vary as $\frac{A \times G}{AC \times W'}$; or since W′ is constant, as $\frac{A \times G}{AC}$.

828. So far, we have throughout considered the beams under examination as placed in horizontal positions; but in the construction of roofs, and many other cases, beams are made use of in positions that incline to the horizon, and in such cases a variation in the mode of investigation becomes necessary. Thus,

When a beam is placed in an angular position with respect to the horizon, its strength to resist a vertical force, is to its strength when *placed horizontally, as the square of the radius is to the cosine of the angle of elevation.*

Let *a b*, Fig. 149, represent a sloping beam; draw *c f* perpendicular to the horizon *a f g;* then *c d* will be the vertical section of the beam at the point *c;* and *c e* perpendicular to *a b* is the transverse section, being the same as in the horizontal position. Now the strength in both positions, is as the section drawn into the distance of its centre of gravity from the point *c*. But the sections being of the same breadth, are as their depths *c d, c e;* and the distances of the centres of gravities are as the same depths; therefore the strengths are as $cd \times cd$ to $ce \times ce$ or $cd^2 : ce^2$. But by the similar triangles *c d e, a f d* it is $c\,d : c\,e :: a\,d : a\,f$, or as radius to the cosine of the elevation. Therefore the oblique strength is to the transverse strength, as $a\,d^2$ to $a\,f^2$ or the square of radius to the square of the cosine of elevation.

829. Hence, every beam is weakest against lateral pressure when in a horizontal position, and becomes stronger and stronger as it revolves into a vertical position, where it reaches its maximum strength.

830. *When beams stand obliquely, and sustain weights either at their middle points, or in any other similar situations, or equally diffused over their whole lengths, the strains upon them are directly as the weights, and the lengths, and the cosines of elevation.*

For in the inclined plane the weight is to the pressure on the plane as *a c* is to *a f*, or as radius to the cosine of elevation; therefore the pressure is as the weight drawn into the cosine of the elevation: hence, the stress will be as the length of the beam and this force; that is, as the weight × length × cosine of elevation.

831. *Corol.* 1*st.*—When the lengths and weights of beams are the same, the stress is as the cosine of elevation. It is therefore greatest in horizontal beams.

832. *Corol.* 2*nd.*—In all similar positions, and the weights varying as the lengths, or the beams uniform, then the stress varies as the squares of the lengths.

833. *Corol.* 3*d.*—Suppose *a f g* to represent a horizontal beam, and *a d b* (Fig. 149) a sloping one. When the weights on the two beams are equal, the stress upon them will also be equal when *g b* is vertical. For the length into the cosine of elevation is the same in both; or $a\,b \times \cos.\ a = a\,g \times \text{radius}$.

834. *Corol.* 4*th.*—But if the weights on the beams vary as their lengths, then the stress will also vary in the same ratio.

835. *Corol.* 5*th.*—And universally the stress upon any point of an oblique beam, is as the rectangle of the segments of the beam, and the weight and cosine of inclination directly, and the length inversely.

836. *When a beam is intended to sustain any force or pressure acting laterally upon it, its strength ought to be proportioned to the stress upon it. That is to say, the breadth multiplied by the square of the depth, or in similar sections, the cube of the diameter in every place ought to be proportional to the length drawn into the weight or force acting upon it. And the same is true of several different pieces of similar material compared together.*

It is obvious that every piece of timber or metal, as well as every part of the same used in a building or the construction of a machine, ought to have its strength proportioned to the weight, force, or pressure it is intended to sustain. Therefore the strength ought to be universally or in every part, as the stress upon that part. But the strength is as the breadth into the square of the depth, and the stress is as the weight or force into the distance it acts at. Therefore these must be in a constant ratio to each other to produce the desired effect. This general property gives rise to the adoption of different shapes in beams, according to the particular circumstances in which they may be placed. An attention to this property is of less importance in timber work than in the metals; because the former material is comparatively light and cheap, and it would often cost more in labour to cut a stick of timber into its true mathematical form, than the saved timber would amount to. But in using metals, the case is different, for they are both heavy and expensive; consequently, if we neglect the natural laws of diminution, which may be resorted to without impairing the strength, we should not only throw much unnecessary and even detrimental burthen into our construction, but uselessly augment its expense.

Thus, for instance, it has been explained (793) in reference to Fig. 144, that the greatest stress upon the beam *o l p n* is in the line *o p*, and that the weight *w* cannot exert so much force to bend or break the beam, in any point intermediate between *p* and *n*, as it exerts at *p*. This being the case, it is evident that the beam need not be as strong towards its end *n*, as at *o p*, and yet that it will be equally capable of sustaining its load; independent of which, the substance that might be cut away near the end *l n*, would relieve the part *o p* of the useless weight of that portion of material, and the beam would, therefore, be rendered effectually stronger, as a whole, by making it weaker in a part where strength is not required.

837. In like manner, it was lately stated, (824,) that when a load is placed upon the middle of a horizontal beam, that middle requires to be stronger than the ends, and that although a prismatic or parallel stick of timber is generally used for such purposes, having equal areas and equal positive strength throughout,

yet a large quantity of the substance of the ends might be cut away without impairing its strength. We shall next proceed to examine where such cutting away is desirable, and the rules by which it may be executed with certainty and advantage, of which there are many cases.

838. 1*st*. Suppose that the strain arises from a weight to be supported at the extreme end of a beam, the other end of which is firmly fixed in a wall. This admits of at least three cases depending upon the form we may be obliged, from circumstances, to give to the supporting piece. It may be necessary to have both its upper and under surfaces flat or horizontal planes, parallel to each other; or, 2*ndly*, it may be necessary to have the two vertical sides parallel planes; or, 3*dly*, the supporter may be circular in its transverse sections.

839. The FIRST CASE will be met by giving the supporter the form of an isosceles wedge as at ABD, Fig. 150, in which the flat top and bottom are parallel to the horizon; for if we call the area of any section a, the given depth d, and the distance of the centre of gravity from the top g, then $a = \text{BD} \times d$ and $g = \frac{1}{2} d$ $\therefore$ $a \times g = \frac{1}{2} \text{BD} \times d^2$, which varies as BD or BC, which also varies as AC. Hence the strength is as $\frac{\text{AC}}{\text{AC}}$, that is, it is constant. This form only requires half the material that would be necessary for a rectangular support.

840. SECOND CASE.—When the sides of the beam must be vertical parallel planes, the depth must vary so that d^2 shall be every where proportional to l the length. This will be obtained by making the depths of the beam the ordinates of a common parabola, of which the extreme end of the beam is the vertex and its length the axis. The upper or under side of the support may be a plane as $e f g$, in Fig. 150, where the upper side is flat; or both the upper and under surfaces may be curved, provided the distances between them in every part be as the ordinates of a common parabola. In this form one-third of the material is saved, or dispensed with, without any diminution of strength. The double parabola, or plate, equally curved at its top and bottom edges is always resorted to for forming the vibrating beams of steam engines, when they are made of cast iron.

841. THIRD CASE.—When the support is circular, or the sections in all places will form similar figures, whether they be circles, squares, or similar polygons; then we must have d^3, or b^3, proportional to l; or the depths or breadths must be as the ordinates of a cubical parabola. This would also be the strongest form for a steeple or light-house, exposed to high wind or storms.

842. If the weight, or load, instead of being applied to the ex-

treme end of the support is uniformly distributed over every part of it, as in those brackets called in building *Cantilevers*, and which are used to support balconies, galleries, and heavy cornices, if one surface is plane, or right lined, and its two sides are parallel vertical planes, then the other surface, whether top or bottom, will be right lined also, but making an angle with the other surface as *d b e*, Fig. 151. Then *b d* will always be as *d e* and *b e*, *b d* two right lines; consequently *d b e* is a wedge, and half the beam may be cut away without diminution of strength. Cantilevers are often much ornamented by being formed like leaves, &c.; but the ornaments must not cut into the lower line *e b*, or the strength will be impaired.

Beams supported at both ends.

843. When a beam, supported at both ends, is to be of uniform depth, from one end to the other, and is intended to sustain a load in any fixed point near its middle, its horizontal section should be two isosceles triangles, joined base to base, as in Fig. 152, the junction of the bases *c* being the point at which the load is to be deposited (839).

As this form would be inconvenient in practice, on account of the very narrow bearings the beam would have at its ends, upon the supporting walls, it is customary to extend the breadth of the ends, as shown by dotted lines at *f*, instead of letting them terminate in sharp angular points. The plan of the beam would then be such as is shown by the dotted lines drawn from *f*. If the beam is formed of cast iron, then the form dotted in at the end *g* may be given to it. Or the beam may be formed of a flat plate formed in plan like the end *g*, and the double isosceles wedge may be cast on its under side, so as to form a feather (624) to it, causing the whole beam to assume a form like Fig. 153, when viewed from one side.

844. *As a general rule to be attended to in the use of beams in buildings*, their ends ought never to rest immediately upon the bricks or stones that support them, particularly when the load the beam may have to carry is very considerable; because the breadth of a beam is never very great, and if it rests immediately upon the wall, the whole load will be transferred to the single stone, or few bricks that may be directly under the ends of the beam, and they may thereby be crushed. A piece of timber, or a plate of cast iron, called a *template*, should therefore be constantly placed in a transverse direction, or at right angles, to the axis of the beam, upon the wall under each end of the beam, for its ends to rest upon, as shown at *h h*, Figs. 152 and 153. The length and thick-

ness of the template must be regulated by the load it has to bear, and the solidity of the materials under it; and its use is to distribute the load of the beam over a considerable quantity of the wall, instead of permitting it to operate on a confined spot. Wooden templates are generally used for wooden beams, and open sand cast iron plates for cast iron beams. Their edges may be flush with the inside of the wall, but they must not be so wide as to appear on its outside. Templates should be bedded in mortar, and where iron is the material used, if the under bearing of the beam and the top surface of the template do not coincide accurately, the beam should be prevented from rocking or moving by driving small iron wedges between the two, and then running melted lead between them; the iron having been previously heated by a charcoal fire built upon it, and when cold, the lead should be caulked in by a caulking chisel.

845. A beam with plane and parallel vertical sides, that is intended to support a permanent load upon any one point, should be formed of two parabolas, united at *c d*, where the pressure occurs, as in Fig. 154. The top or bottom surface may be right lined, or both may be curved, provided the conditions of proportion, before described, (840,) are preserved. The extended ends, dotted in, in the figure, are to give the beam a proper bearing on the walls.

846. The same effect of strength will be very nearly produced by right lines only, as in Fig. 155, in which two right lined wedges are used, being united at *c*, where the fixed load is placed. In this case, the depth at the ends must be equal to half the greatest depth *c*, where the load is placed.

847. Fig. 156 shows how a very large beam of this description may be formed of cast iron, with the least consumption of metal. It consists of two plates at right angles to each other, but cast in one mass, as shown by Fig. A, (being a section of the beam,) by which stiffness is produced. The vertical plate has the necessary contour to insure strength when the load is placed at *c*, but a considerable quantity of metal is saved by the holes or perforations *e e e*, which are left through it.

848. When the load is not confined to a particular point in a beam, but is equally distributed over it without being subject to change, and the two ends *are firmly fixed* in opposite walls, the middle part of the beam may be weaker than its ends; because in this case such a beam may be assimilated to two opposite wedges, like Fig. 151, meeting at their points, *b*, although in practice some considerable depth is always given to the middle or junction of what otherwise would be sharp, angular edges.

849. When the load is equally distributed, but is not fixed in its position, but is liable to change from one part to another, as in

rail-road plates, or girders for supporting the floors of warehouses, which may sometimes be laden in one part and sometimes in another, and where the ends of the beams cannot be firmly and immovably fixed, the elliptic, or semi-elliptic section is the best, being the form shown by Fig. 157; because when the beam is bounded by two parallel planes, perpendicular to the horizon, $d\,e^2$ will, in all positions, be as the rectangle *a d* into the rectangle of *d b*, and the curve *a e b* will be an ellipsis. If the figure was solid, as shown by the dotted line, so as to cause all its transverse sections to be similar figures, then $d\,e^3$ would bear the same proportion to the two rectangles, and the condition of strength would be still greater.

850. After the foregoing observations, the use of transverse plates or surfaces at right angles to each other, called *feathers* in foundry work, as before described, (624, 626,) will be sufficiently obvious, as well as the principles upon which their superior strength depends. Fig. 133, Pl. IV., is a section of such a plate or beam in which the upper surface is flat and smooth for receiving joists or building a wall upon. But if we desire to give still greater strength to such a beam, its transverse section should present a regular cross, as shown by Fig. 158. This form is constantly adopted for what is called the connecting rod of large steam engines; being the piece that connects one end of the vibrating beam with the crank of the fly wheel, when such rod is made of cast iron, and it also swells or enlarges in the middle of its length where it would be subject to bend by vibration. A similar form is likewise frequently adopted for cast iron pillars or columns for supporting great weights. Fig. 159 is the transverse section of another form of cast iron beam which is very much used for beams, girders, and columns, where great strength is required, particularly if the strain is likely to come from one side, as next B, for instance. This beam consists of the union of three flat plates, which are cast in one piece. It has greater strength in the direction of the width of the two flat plates than of the one, but it may, nevertheless, be trusted in the position shown in the figure for a girder in most instances, and it is convenient, and saves room when so used, because instead of the joists running over the girder and taking nearly double its height, they may be morticed or cut out to fit into the hollows on each side of the beam, as seen at B, which shows, by dotted lines, the end of a timber joist so fitted into one of the longitundinal cavities on the side of the iron beam. The cylindrical or slightly tapering form is, however, decidedly the handsomest for a column or support, and when made of cast iron possesses advantages from being tubular or hollow, which have been before explained (623). This

form is likewise advantageous for the journals or revolving shafts of mills, because more stiffness and strength is obtained out of the same quantity of material than if they were made solid (784).

851. *The lateral strengths of two cylinders of the same material, and of equal length and weight, the one being hollow, while the other is solid, are to each other as the diameters of their sections.*

Let ABG, *a b g*, Fig. 160, represent the sections of two cylinders of equal length and weight; AGB being hollow, and *a g b* solid. By the conditions, the area of the ring D must be equal to the area of the whole circular section *a g b*. But the strengths of cylinders are as their areas multiplied into the distances of their centres of gravity from the points of pressure. G and *g* are the common centres of gravity of both the cylinders, and calling A and *a* the two points of pressure, their relative strength will be as *a g* : AG, or as their radii, and consequently as their diameters.

852. The strongest form, therefore, in which any given quantity of matter can be disposed, is that of a hollow cylinder; and in principle, it would seem as if this disposition could be carried to a great extent by augmenting the diameter of AB, and that of its contained tube. But in this way the annulus might become so thin as to be incapable of supporting even its own weight; and Tredgold has demonstrated that the maximum of strength is obtained in cast iron when the thickness of the annulus or ring amounts to one-fifth of the external diameter of the cylinder. By a property of concentric circles, a chord, *c d*, drawn across the exterior circle will be the diameter of a circle that shall be equal in area to the annulus exterior to it; therefore, in the figure *c d*=*a b*, and by this law it becomes easy to put the same quantity of metal in an annular form as would make a solid cylinder of equal weight.

853. Nature adopts this principle in a great variety of cases. Thus obtaining lightness and strength at the same time. All the principal bones of the animal frame are hollow or tubular. The feathers of birds, the straws of wheat and several other grains—the stalks of reeds and many plants. Indeed, all trees partake of this formation, their first shoots being frequently hollow and filled with pith, and as the tree grows and expands, it becomes a series of tubes superposed on each other, the hollow of each tube being filled up by the previous growth. Still this very construction adds strength to the trunk of a tree as well as its branches, and instructs us how to cut up a stick of timber so as to obtain scantlings of varying strength suited to different purposes. Thus let Fig. 161 represent the cross section of a round tree consisting of concentric annual laminæ of wood. The largest piece of timber that can be cut out of such a tree will be a die square stick as

shown by the lines *a b c d*, and this will also be the strongest piece, provided it is required to resist strains which vary and act towards the centre of the beam; because now the centre of the tree is in the centre of the stick, and it will consist almost wholly of concentric tubes of wood. Such a piece of timber would be better suited than any other (except an entire round tree,) for forming an upright post or pillar to bear a vertical load; because it will have no greater tendency to bend to one side more than to another. A pressure towards the centre of a beam laid horizontally is a thing that never occurs, and such beams are generally laid to support loads pressing downwards. For this purpose the scantling ought to be cut in such way that the laminæ may coincide as nearly as possible with the direction of the pressure, and this will be the case, if we cut out a piece like *e f g h*, in which as many parallel laminæ as possible are preserved in a vertical position. For the same reason the scantling *i g m n* (although equal in area to the last,) would be the worst that could be selected, provided *i g* or *m n* was made its top; for now the laminæ are all nearly horizontal in their width; but if *g n* or *m i* were made the top and bottom, the laminæ would become vertical, as in the last case, and the greatest strength would be obtained.

854. The reason for thus attending to the position of the laminæ in pieces of timber, is that the wood has a natural tendency to split or divide between them. Each laminæ may, therefore, be considered as in the nature of a thin separate board; or a stick of timber may be regarded as so many thin boards laid close together. We have before seen that a board placed with its edge uppermost is capable of supporting a much greater load than when its flat side is uppermost (807). The scantling *e f g h*, Fig. 161, may therefore be considered as composed of a number of thin boards with their edges uppermost, while *i g m n* is made up of boards laid flatwise, and therefore less prepared to resist pressure from above or below.

855. In obtaining the comparative strength of beams by the processes above described, *i. e.* taking their sectional area, and multiplying it into the distance of the centre of gravity from the point of pressure, it may appear that no difference should occur in the result, whether that area was made up of one solid beam of timber or metal, or of a great number of thin boards, plates, or laminæ piled one upon another until the same depth and width was accomplished, since the area and material would be the same in both cases. The result would, however, be different; for one element in the strength of beams is their rigidity or stiffness, occasioned by the natural cohesion of the particles which prevents one set of particles from slipping or sliding over another, so that

no very considerable change of form can occur without fracture taking place. But when thin plates or laminæ are piled one above another to produce depth, the action of cohesion will be much diminished, and the plates will slide over each other without difficulty. The bottom plate instead of cohering to the one next above it, and thus lending its assistance to produce strength and stiffness, may even sink beneath it, and thus withdraw all its support: and in like manner the next, and the next above it, and so on, may follow, though to a diminished extent. Therefore two or more beams placed one above the other in parallel positions, can never exert the same effect in supporting a load, as one solid piece equal to their conjoined area will do, unless some effectual method is resorted to for so uniting the pieces that they cannot possibly slide over each other. This, on a small scale, may be effected by gluing the two pieces together, but the mechanical process that is used for this purpose in large work is called *joggling*, and is usually performed by making the two surfaces of the pieces that are to be joined so smooth and level that they may come into close contact with each other. F and G, Fig. 162, show two pieces of timber to be so joined in order to give them power to sustain a heavy weight W without swagging. The pieces during their preparation are laid on perfectly level temporary bearings, and being fitted together, a set of transverse notches *n n n*, &c., are cut in such manner that they project a sufficient distance (according to the size of the pieces,) into the under side of the upper and top of the lower piece. These notches proceed quite across the beams, and the upper and lower corresponding notches must coincide very accurately with each other. That done the two beams are strongly screwed together by iron screw bolts *b b b*, when *keys* or rectangular blocks of oak, or any hard wood are fitted into the holes *n n n*, and driven forcibly into them. If the work is well executed, one piece of timber cannot now bend without the other, nor can they slide over each other, consequently the same stability and stiffness will be obtained as if the whole was one solid piece of timber.

856. The masts of large ships are of such large diameter that no single piece of timber can be obtained big enough to form them; and as such masts require great strength and stiffness, the pieces of timber which compose them are always joggled together. The shipwright's joggle is, however, more complicated and difficult to execute, and at the same time more wasteful of timber than that just described. It is at the same time more durable, as it has no detached pieces about it, which would become loose by the bending and play of the mast. In this kind of joggling the two sides of the timbers that come into contact are *scarfed*,

or let into each other by certain corresponding elevations and depressions, cut out of the solid wood, as shewn at Fig. 163. The two pieces of timber being thus let into each other, the two sides on which the joints show are planed smooth, and two thinner pieces, equal in breadth to the two that have been so joined, are again joggled by a nearly similar process upon these sides, when the whole are rounded into a cylindrical form, and kept together by iron hoops applied round their outsides. By joggling, any number of timbers may be thus united, so as to possess the stiffness of one piece, and this process is frequently used with advantage in the formation of large timber arches, roofs, and all constructions where single trees cannot be found to yield timber of magnitude sufficient for the intended purpose.

857. Although a die square stick of timber holds the greatest quantity by measurement that can be obtained out of a round tree, yet it is advantageous to obtain pieces of the greatest possible strength for building purposes, and the stick that is exactly square does not fulfil these conditions, because the product of its breadth by the square of its depth is not the greatest possible. This relation of dimensions will, however, be obtained by drawing a diameter across the section of the tree as at *a d*, Fig. 164, and dividing it into three equal portions at *b* and *c*, upon which perpendiculars to the diameter must be raised and prolonged until they cut the circumference. Joining the points where the circumference is cut by the perpendiculars to the ends *a d* of the diameter by right lines, the rectangle *a f d e* will be produced, and this will give the boundary lines of the strongest beam that can be cut out of such tree.

858. It will be perceived that all the foregoing rules point out the comparative, and not the actual strength of the beams they refer to. They teach us how to compare the strength of one beam with that of another, but they do not show us how to compute the actual weight which any given beam can bear. To accomplish this last problem, data derived from experiment must be had recourse to; and hence the use of those investigations and tables of strength that were detailed in the second section of the present chapter relating to the absolute strength of materials. By such tables, the actual or absolute strength of bars, either against compression or extension may be pretty nearly ascertained, and having determined the power of a bar, it may be converted into the area of a beam, or large mass, by multiplication, with sufficient accuracy for most practical purposes, because a large allowance must constantly be made for the strength of materials in use. Then by the rules before given, (798, 9 and 800,) the value of absolute strength can be converted into that of rela-

tive or lateral strength: because the length and other dimensions of any beam we are about to use, are known quantities; and as thrice the length of a beam is to its depth, as its absolute cohesion (obtained as above,) is to its relative strength, the question is readily solved; and all that is then necessary to add is the weight of the beam, in order to ascertain what addition it makes, or what proportion it bears to the load to be sustained, and this weight may be obtained by actual weighing, or by calculation, assisted by the table of specific gravities annexed to the end of the present chapter.

859. Independent of the above mode of proceeding, experiments may be tried on a small scale upon the materials we are about to use, and these will either furnish the necessary data in themselves, or may be used in proof or corroboration of the calculations made as above. Thus, for example, taking a prismatic piece of oak, 1 foot long and 1 inch square, it will weigh $\frac{1}{2}$ a pound; and supporting it at its two ends, it will be found capable of bearing a weight of 600*lbs.*; while a bar of iron, of similar dimensions, will sustain 2,190*lbs.*, and weighs about 3*lbs.*

To determine, from such data, what load a 4 inch square piece of oak, 6 feet long, could sustain at its middle point?

Let S=the strength of the beam required; and *s*=the strength of the trial piece, 1 foot long and 1 inch square, equal 600*lbs.*

W the weight of the larger beam; and *w* that of the smaller= $\frac{1}{2}$*lb.* Let L=6, *l*=1, D=4, *d*=1. Weight required=W′, the given weight (600*lbs.*)=*w*′.

Then the weight of the beams not being taken into account,

$$S : s :: \frac{D^3}{L\times W'} : \frac{d^3}{l\times w'} :: \frac{4^3}{6\times w'} : \frac{1^3}{1\times 600}.$$

But the strength at the moment of fracture=0 in both cases,

i. e. $S=s \therefore \frac{4^3}{6\times W'}=\frac{1^3}{1\times 600}$; whence W′=6400 pounds.

860. If the weight of the beams be taken into account, then

$$S : s :: \frac{D^3}{L\times\frac{1}{2}W+W'} : \frac{d^3}{l\times\frac{1}{2}w+w'} :: \frac{4^3}{6.24^*+W'} : \frac{1^3}{1.\frac{1}{4}+600}.$$

Hence $\frac{64}{6.24+W'}=\frac{1}{600\frac{3}{4}}$; and W′=6378$\frac{2}{3}$ pounds. *Ans.*

The above example is from Professor Olmsted's Introduction to Natural Philosophy, 3d edition, 1838, where several other applications of the same kind will be found under the head of Strength of Materials. In the older writers on this subject, various and

* For $W : w :: L\times D^2 : l\times d^2, \therefore W : \frac{1}{2} :: 6\times 16 : 1 :: 96 : 1, \therefore W=48.$

copious information is given as the absolute strength of materials, although practical facts, respecting lateral pressure, are but scantily detailed. This most important element, in all constructions, therefore had to be worked out by individual calculation and experiment. This deficiency has, however, been most amply supplied by the more recent and highly valuable publications of Tredgold and Barlow. Tredgold, in his Practical Essay on the Strength of Cast Iron and other Metals, before referred to, gives 15 pages of tables by which the strength of cast iron, of all forms and sizes, may be determined by very simple formulæ, as well as their deflection under certain loads; and in his Treatise on Carpentry, a nearly similar tabular arrangement is adopted, not only as applying to timber, but many other materials of the builder, so that the labour of the Engineer and Architect, in making the necessary calculations, is not only much abridged, but his work has the advantage of being founded upon the most solid principles that mathematics can give to a practical act, almost wholly dependant upon its principles. Professor Barlow, of Woolwich, promises a new edition of his work on the Strength of Timber, which, no doubt, will be replete with authentic and valuable information.

861. Table of the Specific Gravities

Of such things as are most frequently used by the Engineer, Architect, or Builder, by means of which the weights of masses of such articles may be calculated. Pure water is the standard of specific gravities, and is called 1. By adding three ciphers it becomes 1,000, and since a cubic foot of water, at 40° Fah., weighs 1000 ounces avoirdupois, or $62\frac{1}{2}$ *lbs.*, so striking out the decimal point from the specific gravity of any substance, causes the entire number to represent the number of ounces contained in a cubic foot of that substance, and from this datum the weight of any mass may be readily found. The numbers are chiefly extracted from Dr. Young's Natural Philosophy, Vol. II. p. 503.

Metals.	
Antimony, regulus of,	6.624
Bismuth, do.	9.823
Brass, best yellow,	8.370
Gun metal, (8 cop., 1 tin,)	8.153
Pot metal,	7.824
Copper, cast,	7.788
rolled,	8.750
Gold, cast,	19.258
hammered,	19.362
Iron, cast,	7.207
malleable in bars,	7.788
Lead, cast,	11.352
rolled,	11.725
Mercury, frozen solid,	15.632
at 32° Fah.,	13.619
at 60° ,,	13.580
at 212° ,,	13.375
Nickel, cast,	7.807
Platina, crude in grains,	15.602
in metallic state,	20.337
hammered or rolled,	22.069
Silver, cast pure,	10.474
hammered,	10.511
Steel, soft,	7.833
hard,	7.840
Tin, cast,	7.291
Zinc, cast, (in usual state,)	6.862

Zinc, pure, in rolled sheets,	7.191
Woods.	
Alder,	0.800
Ash,	0.845
Beech,	0.852
Box wood, (hard Dutch,)	1.328
Cedar, (American,)	0.561
Cherry tree,	0.715
Cork,	0.250
Cypress,	0.644
Ebony,	1.330
Elm,	0.544
Fir, or Pine, (yellow,)	0.557
(white,)	0.469
Lignum vitæ,	1.333
Lime tree,	0.604
Mahogany, Spanish,	0.863
Honduras,	0.560
Maple,	0.750
Oak, (English, heart of,)	1.170
good dry,	0.932
Poplar,	0.833
Walnut,	0.671
Willow,	0.585
Yew,	0.800
Stones, Earths, &c.	
Alabaster,	2.699
Bath building stone,	2.200
Borax,	1.714
Brick, (best, hard burnt,)	2.000
Brick, general average,	1.845
Chalk, British block,	2.684
Do. soft,	2.315
Coal, Cannel and New Castle,	1.269
Inland and British,	1.240
Anthracite, Pennsylvania,	1.300
Flint stones,	2.582
Granite, Aberdeen blue,	2.625
Cornish,	2.662
most compact spec,	2.761
Grindstones,	2.143
Gypsum, common opaque,	2.168
best transparent,	2.274
Limestones, vary from	2.710
to	3.182
Lime, (quick,)	0.843
Marble, common slaty,	2.707
Kilkenny black,	2.695
Brocatella,	2.650
general average,	2.720
Mill stone,	2.484
Portland building stone, from	2.113
to	2.570
Purbeck stone,	2.601
Porphyry, average,	2.750
Serpentine, do.	2.600
Slate, (for roofs,)	2.672
Sand stones, from	2.000
to	2.700
Linseed oil,	0.940
Essential oil of turpentine,	0.870
Rectified alcohol,	0.829

CHAPTER X.

ON CONSTRUCTION, OR THE PROCESSES OF BUILDING.

862. Under this head will be included all such rules and principles of practice as experience has dictated for using the several materials that have been described, so as to produce the greatest stability and duration in the work, with symmetry and beauty of appearance. And as all large constructions are necessarily expensive, so the most economical modes of building will at the same time be pointed out, or the principles by which the greatest

strength can be procured out of the smallest quantity of material, a problem in which the scientific Engineer will have constant exercise for his skill and judgment.

The operations to be carried on with different materials are themselves so different as to demand separate explanations, therefore this chapter will be divided into four sections, treating respectively of stone-work, brick-work, wood-work, or carpentry and joinery; metal-work, and such other matters as could not be included with propriety under any of the above mentioned heads, and in pursuance of the observation that closed the chapter on mensuration, (210,) each section will conclude with the methods of measuring and computing the value of the work it describes. This arrangement has been adopted for the reason then stated, that such mensuration cannot be conducted without using many technicalities peculiar to each variety of work which, not having been described in the early part of the treatise, would have been unintelligible.

Section I.—*Of Stone-work or Masonry.*

863. Building with stone is conducted in several manners, but they are all comprehended under the general name of *masonry*, a term that in England is appropriated solely to stone-work, as the wood *mason* is to the worker in stone. If, therefore, any thing is said to be supported on a mass of masonry, it is generally understood that such mass consists of stone *only*. In France the term is more general, for they have no other mode of expressing a worker in bricks, or bricklayer, than by the compound *maçon de brique*, or *maçon de pierre*, and in this country it is still more general, since we have stone-masons, brick-masons, and marble-masons. The latter being that superior class of artists called *statuaries* in Europe, or those who carve and form statues, busts, capitals for columns, tombs, monuments, or other highly finished ornamental work, but are seldom employed in the mere building or construction of edifices. The worker in stone in England is always considered as a higher grade of artificer than him who works in brick, and therefore called a bricklayer, and on this account he would feel his dignity lowered by having his art confounded with that of the bricklayer, by calling the latter a brick-mason.

864. The ruins of antiquity still remaining, show to what perfection the art of masonry was carried in the early ages; and from the difficulty, accuracy, and skill that is necessary in making perfect constructions in stone-work, those who excelled in it were much encouraged, and received many privileges and immunities not enjoyed by others. Dr. Henry, in his history of Britain,

attributes the origin of Freemasonry to the difficulty of procuring a sufficient number of competent workmen to build the multitude of churches, monasteries, crosses, and other religious edifices which the superstition of the early ages prompted the people to raise. Hence the masons were greatly favoured by the Popes, and many indulgences were granted them in order to augment their numbers. In times like these, it may be supposed that such encouragement from the supreme pastors of the church must have been productive of the most beneficial effects to the fraternity, and hence the increase of the society may be naturally deduced. He even goes further in tracing the origin of this institution, stating that some Italian and Greek refugees, and a number of French, Germans, and Flemings, joined themselves into a fraternity of architects and builders, procuring papal bulls for their encouragement and protection. They styled themselves Freemasons on account of their enjoying the privilege of working in all parts of the country, and they ranged from one nation to another, as they found churches to be built. Their government was regular, and when they engaged to execute any building, they made a camp of huts near it. A surveyor governed in chief, and every tenth man was made a warden, and was the foreman or superintendent of each nine. Freemasons date the origin of their institution much earlier, and believe that it commenced with the building of Solomon's temple. These observations are, however, merely introduced to show the importance of good builders in stone in early periods, and how that which was once a working society or fraternity of great public importance, has dwindled down into a mere social meeting of friends, in which moral precepts, metaphorically derived from the arts of building, are inculcated and taught.

865. The mason conducts all the operations of stone-work after the stone is delivered from the quarry, until it appears in the finished building, and in small jobs is likewise the merchant, or supplier of the stone used in his own work. In large concerns it is customary for the Engineer or architect to make his contract with the proprietor of some stone quarry, and to order blocks of such dimensions and forms as he may require, and these are delivered to the place where they are to be used. The quarryman gets out such blocks as are ordered, and dresses them up to something near their intended shape, so as to reduce the weight, and consequent cost of transportation, as much as possible; and journeymen masons are hired who convert them to their ultimate shape, and finish them by working as close as possible to the place where they are to be used. The Engineer having completed his drawings for the intended erection, ascertains by his scale and

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compasses, what forms of stone will be required, with the magnitude and number of each kind; and he then delivers a corresponding particular or schedule to the quarry, in which the stones are distinguished by numbers, all those stones that are similar in size and shape having the same number. This saves much waste of time, as well as material, in the execution, because instead of having to hunt over a whole field of stone for a piece that would fit a particular place, the blocks of stone are identified at once by corresponding numbers that are painted upon them at the quarry, and each piece that is delivered has its assigned place in the work. Great care should also be bestowed upon the distribution of stone when it is received, in order to make it convenient of access when wanted. The numbering should begin with those stones that are to be used first, or in the foundation, and proceed regularly to the top of the work; and as the quarryman has the whole list, and cannot with certainty know the exact size of the stone he may get up, and must get them out of his way, he cannot, of course, send off the stones according to rotation of numbers, but sends away all stones indiscriminately that accord with the sizes in his list. It may therefore happen that he despatches a parcel of Nos. 1, 30, 50, and so on, at the same time. On receiving them they therefore require sorting, the low numbers should be laid close to the work, No. 2 behind them, and the high numbers in a more distant part. Then as all the Nos. 1 are to be used first, they will be placed in the work and be out of the way before No. 2 need be moved. While if No. 1 had been put beyond No. 30, there would probably be no means of getting a No. 1 into its place, except by raising and moving it over a number of stones in front of it, and stone is too heavy and fragile a material to admit of such treatment. For similar reasons alleys or lanes wide enough for a truck and horses to pass, ought to be left between the rows of stones for the purpose of fetching any of them from their places.

866. No rule can be given for the size of stones to be used in a building, because that must depend alone on local circumstances, such as the nature of the stone and facility of obtaining it, and the appearance the erection is to have. As a general principle, large blocks of stone are preferable to small ones, because the strength of stone erections depends more upon the weight and goodness of the stone, and the close fitting of its joints than upon the adhesion and strength of the mortar. It is therefore advantageous to use large and heavy stones, and as few mortar joints as possible. Still no stone should be so large as to render it inconveniently heavy, or difficulty may occur in working it, moving and raising it into its proper place, and finally in adjusting it into its final position or bed, particularly if it is to occupy an elevated

position. The ancients frequently used much larger masses of stone than are used in modern constructions, and some of these are still existing in the remains of their edifices, which excite surprise as to how they could have been placed, as the task would impose great difficulty upon modern workmen with all their advantages and improvements of machinery.

867. Masonry, or stone-work, is divided into several varieties, depending on the quality of the stone, and the manner in which it is worked or used. To explain this it is, however, necessary to define some of the terms that are made use of in building a wall. The bottom of every wall, or erection, whether of stone or brick, is called its *foundation*, and this should, in all cases, be level and right lined, not only to give the work a better appearance, but to insure equality of pressure, and to avoid any tendency the materials would have to slide out of their positions, if they were laid on an inclined or sloping bottom. The work always proceeds by horizontal layers, or rows of material, which are called *courses*, and these during their formation ought to be constantly examined by the bricklayer's level (300), to insure keeping them truly horizontal. The interval between one course and another, is called a horizontal joint or bed, while those that occur laterally between one stone and another, are called vertical joints. The outside of every wall is called its face, while the inside, or interior, is its back, on which account filling up the inside of a wall is frequently called backing it up. As the materials of which all walls are built, are more tenacious and strong than the mortar or cement used to unite them, particularly in its recent state, so great care should be used in depositing the stones, to so place them in the work as to *break joint*, as it is called, but which means that one vertical joint shall not come over another, in two or more successive courses; because such a disposition of the blocks of stone not only produces a bad appearance in the work, but renders it less strong, and may even permit one block to separate laterally from another. Such a proper disposition of the pieces is called producing *bond*, a term that is derived from one stone bearing upon and holding the adjacent stones by its weight and consequent friction, as well as by the tenacity of the mortar, thereby binding, or holding, the work together. When a wall is spoken of it is always understood that the parts that compose it, are held together, or united, by some mortar or cement placed between the joints, unless a *dry wall* is referred to, and that means any wall built without mortar or other soft or cementing material between the joints, when the work is said to be laid dry.

868. The varieties of masonry, above referred to, are called *rubble stone-work; solid wrought masonry;* and *ashlar-work*. Rub-

ble stone is the coarsest, cheapest, and worst kind of masonry that is executed, for it consists of stones of the greatest irregularity of shape and size, placed one upon the other, without any regard to the closeness of the joints or beauty of appearance; but still the stones are so picked out, as to produce the effect of a general flat surface on the outer face of the wall, and sometimes on both its faces or surfaces. It is divided into three classes, called dry rough stone walling or rubble-work; rough rubble-work in mortar; and rubble stone-work in courses. The two first classes explain themselves, the one being nothing more than rough stones, which ought to be large, flat, and not very thick, piled one upon another in such manner as to produce as flat a face, or vertical surface, as possible; and in executing this work care should be taken to break joint as much as possible, and occasionally to introduce *thorough stones*, or stones that run from face to face of the wall, in order to bind or tye the two external surfaces together, so as to prevent the wall splitting or dividing longitudinally. In executing this work, the outside faces of the wall are always first attended to, and such stones are selected for the purpose as will produce the best and smoothest surfaces, which are regulated in their straight forward direction by a line or cord stretched in the direction in which the wall is to be built, while the vertical position is preserved by the occasional application of a plumb rule. The outside of a course being finished, the inside of the wall is backed by filling in all the interstices between one stone and another with fragments of the same material, driven into their places by a hammer or stone axe, which is the only tool required for this kind of work, with the exception of the line and plumb rule.

869. The second variety, or *rubble stone-work in mortar*, only differs from the first in the stones being laid or bedded in mortar, instead of being piled up without any connecting material. From the irregular shape of the stones, and the large spaces that consequently exist between them, this work consumes an immense quantity of mortar, and thereby becomes expensive. To obviate this, if the wall is not intended to be carried high, or has not a very heavy load to support, it is customary not to use mortar throughout the whole thickness of the wall, but merely to lay its external faces to the depth of 3 or 4 inches in mortar, and leave the middle part of the wall dry; and sometimes a dry rubble wall is merely pointed on its outsides with mortar forced into the joints by a trowel, and even this adds much to the stability and appearance of the work.

870. *Rubble-work in courses*, is the same kind of work executed with greater care and attention, particularly in selecting stones of the same thickness for the external faces, so that the work may

proceed in horizontal layers or courses, which are nearly equal in perpendicular height. This work not only looks much neater, but is stronger and more durable, because as the stones are equal in thickness, they may be presumed to be equal in strength, and no one stone will have a greater tendency to break than another. Rubble stone-work, in all its varieties, is improved in appearance and stability, (especially mortar work,) by being *chinked;* that is, by having small wedges of stone driven by the hammer into all the larger interstices that occur in the joints, thus giving the stones a firmer and more solid bearing upon each other than they would otherwise have.

871. Rubble stone-work is much used in all countries that abound in stone, particularly where it is not of the freestone quality; and of course the slab stones or those that divide naturally into flat laminæ or plates, will produce stronger and better work than boulders or stones that present rounded surfaces to each other; but even these produce much sounder work than would be expected, when the mortar is good; for many of the oldest churches and castles in England are built entirely of such materials, and a large part of the tower of London, its most ancient fort, or citadel, is of rubble-work; and many instances occur of flint stones, which are constantly of rounded forms, being the principal material used. Rough dry stone walling is the only fence or boundary between one field and another, or between estates, in the western parts of England, where rough stone abounds. It was much more used by the ancients than by the moderns, and its durability cannot be better proved than by the remains of it which still exist in many parts of Europe, notwithstanding that the ancients do not appear to have had great faith in its duration, for Vitruvius informs us the name by which it was distinguished among the Romans was, *opus incertum.* It is frequently used in England, on account of its cheapness, for foundations and plinths for heavy buildings; but this is a practice that ought not to be encouraged, unless the stone is very hard, and occurs in tolerably flat masses, because as stones of irregular shape can only bear on each other in points, instead of flat surfaces, there is a probability of such points crumbling away, which of course must produce a sinking and settlement of the work, if the superincumbent load is very great.

872. Rubble stone-work, in all its varieties, is generally executed and valued by measurement, at an agreed price per rod or pole, in which case 18 inches is usually considered the standard thickness of a wall; and of course $16\frac{1}{2}$ feet is the length of a rod; but there seems some doubt, or different local modes of computing, as to its height. There can be no doubt but that a square or superficial rod of work should be as high as it is long, or $16\frac{1}{2}$ feet in each direc-

tion, or rather should contain 272 superficial feet, disregarding the quarter foot that arises out of the multiplication (122). But the writer has not met with any workman in the United States who would admit a rod of rubble stone-work to be $16\frac{1}{2}$ feet high. Some say that $16\frac{1}{2}$ feet long by 8 feet high, is admitted to be a rod of such work; and he has found others who contend that this work is measured like corded wood, and that 4 feet in height makes a rod. The only safe way, therefore, to make a contract for rubble stone-work is to specify the height that shall constitute a rod in the first instance, or what perhaps is still better, to agree how many cubic feet the rod shall contain; or even to have the work done at a price per cubic foot, without reference to rods, and then there will be no occasion to regard the thickness of the wall; while if the work is done by the rod superficial, 18 inches is the established thickness for a *single* wall; consequently should it be 3 feet thick, it will be paid for as two walls, or at double price; and 27 inches thick would be charged at the price of a wall and a half, and so in proportion for other thicknesses.

873. The second variety of stone-work called *solid wrought masonry*, is the best and most expensive that is executed; because it consists wholly of solid blocks of free-stone that are sawed, or otherwise cut, and made to fit close to each other in all their points, vertical as well as horizontal throughout, the whole thickness of the work. This kind of masonry is seldom used to any large extent, on account of its great expense; for it consumes an immense quantity of stone, as well as expensive labour, to reduce all the stones to perfectly flat sides. Solid masonry is therefore seldom executed in this manner, but all the external faces of the wall are formed of stones cut square, and of such magnitude as to run a considerable depth into the wall, and occasionally quite through it from face to face; and when the external surfaces of a course have thus been finished, all the internal vacuities are filled up with the smaller pieces of the stone, either square or irregular, which are laid in mortar with great care to render the inside of the work as solid and regular as possible. Solid stone-work, executed in this manner, is often called *mixed masonry*, but it seems scarcely necessary to make this distinction, because in solid work this kind of rubble-work filling in should bear but a very small proportion to the solid square stones used, or the work will become ashlar-work, the next variety to be described.

874. Solid masonry is made use of in building the stone piers of bridges, for stone columns, the side walls of canal locks, the foundations for large warehouses, and generally in all cases where the greatest strength, particularly resistance to pressure, is required; and it therefore requires particular care and circumspection in the

choice and selection of the stone, which should be of good and durable quality, and free from cracks or fissures, either natural or accidental. Great care should also be taken in forming the horizontal joints or beds, in order that the stones may bear throughout their whole surfaces, and not partially. On this head it becomes necessary to give the young Engineer a caution. There is no difficulty in getting the upper surface of a course of stone-work perfectly smooth and level if due care is taken in its formation; but in placing the next course upon it, workmen do not like the trouble of making the under sides or beds of the courses of stones that are to succeed, perfectly flat, and at right angles to that side of the stone that is to form the external face, but will generally only continue the right-angled direction for an inch or two next the face, and then give the remainder of the bed an angular direction, as shown in Fig. 165, Pl. V., where *a b* is the upper level surface of a course of stone already laid, and *c d* the bed of one of the stones to be placed upon it, which, instead of being flat and level at its bottom in the direction of the dotted line, as it should be, is inclined upwards towards *d*, thus only producing perfect contact for the depth of an inch or two between *c* and *a*, and a considerable angular space between the two stones at *d c e*, which has to be filled up with mortar, or even supported by chips or wedges of stone or iron driven in between *d* and *e* in order to support the stone, and bring its external face *f c* into a right lined direction with that of *a*. This mode of blocking up stones, as it is called, is a common practice, but one which ought never to be tolerated when the work has to sustain a great weight from above. It produces a very neat and close joint on the face of the work, but without much solidity; because all the superincumbent pressure falls on the narrow joint, and upon the wedges and mortar, instead of upon the main body of the stone, consequently the wedges (if of stone) frequently crush to powder, and the sharp edges of the joint at *c a* give way, and produce unequal and detrimental settlements in the work, by which its beauty and regularity are destroyed, and its strength impaired, owing to the breaking of the mortar joints. This mode of angular jointing is admissible in vertical joints, provided the spaces produced are but small, but even then it is better avoided, and ought never to be permitted in horizontal or bed joints. The breaking away of sharp edges (which in masonry and brick-work are always called *quoins*,) is sometimes prevented by bevelling the horizontal, and in some cases the vertical quoins of every stone to an angle of 45°, as shown at *g h i* in Fig. 165, and then the joints are said to be *rusticated*.

Some other particulars relating to the building of stone-work have to be noticed, but as they apply to the next variety of masonry to be described they will be introduced in that place with greater propriety.

875. *Ashlar masonry* is the third and last variety to be described, and this, though not the best and most substantial kind of work, is more frequently used than any other, on account of its cheapness and its producing all the beauty and symmetry of solid stone-work, though destitute of a great part of its solidity and durability. It is, in fact, casing or veneering a common brick or rubble wall with wrought free-stone, so as to give it all the appearance of a building of solid stone.

876. Ashlar stone-work is more or less worthy as it approaches more or less to solid masonry. It consists of building a wall or mass of common brick-work, or rubble stone-work, and facing it with pieces of wrought and squared free-stone, either on all its sides or generally on those sides that are to meet the eye. Thus if a house is to be built in ashlar-work, only the outer surface of the external walls would be cased with stone; because their insides have to be plastered or otherwise covered.

877. No particular thickness is assigned for ashlar-work, consequently this is left to the choice of the builder; but as a general rule no stone facing less than 6 inches thick should be used, and ashlar facings generally run from this thickness to 8 or 9 inches, their length being from two to three feet, and their height 9 or 12 inches. The front face and four sides, *i. e.* the top, bottom and two sides of every stone require to be exactly cut and squared, that they may fit close to each other, but the back may be left rough and uneven, especially if the backing is to be of rubble-stone, but if of brick-work the stone should be cut smooth and flat. Some masons deem it an advantage to have the backs of facing stones angular to the face instead of parallel, in order that the backing may take hold of a part of the top or side of each stone instead of being applied to its back only.

878. To build an ashlar faced wall, the facing stones must first be set accurately in their places bedded in mortar, and adjusted to their positions by the line and plumb rule, which, being done, the backing succeeds, and this is building a wall in bricks or rubble-stone immediately behind the stone facing and in close contact with it, taking care to fill in between the stone facing and the wall with mortar. This wall proceeds horizontally until it reaches the same height as the first course of stone, consequently if the backing is to be of brick-work, the height of the facing stones ought to be such as may agree exactly with a certain number of courses of brick-work, three or four courses, for example. The whole wall being thus brought to one height or

level, the second course of ashlar facing stones must be set upon the former course; and in doing this, a thorough stone or tail stone should be introduced at every interval of three or four feet. Thorough stones have been before stated (868) to be stones that run quite through a wall from face to face, but they are not necessary unless the backing is of rubble work; and when brick-work is adopted, tail stones are used, which are stones usually about 9 inches longer than the thickness of the facing stones, so that they present one of their ends to view in the outer face of the wall, and the other end tails, or runs about 9 inches into the brick-work, to bond with it, and thus prevent the facing stones from separating from the backing or filling-in work. The more effectually to obtain this object, the bed or under side of every tail stone, ought to come into contact with, or be very close to the upper side of the top of the facing stone over which it is placed, so as to admit a very thin mortar joint. In this manner the wall may be carried up to any required height, taking care to introduce bonding tail stones at proper intervals into every course, or every alternate course, according to the thickness of the ashlar facing, and the strength and durability that is intended to be given to the wall.

879. In building wrought stone walls, the mortar joints are always very thin, so that the stones almost come into contact with each other. This could not be brought about if common mortar was used, on account of the coarseness of its component parts. Masons, therefore, use a mortar called *water-putty*, or *fine stuff*. It is the same as other mortar, but the slaked lime is passed through a fine wire cloth seive, and the sand, which should be of the purest silicious kind, undergoes the same treatment, and is used in much smaller proportion, though some masons use no sand at all with their lime. This mortar is applied in a softer or more fluid state than for brick-work, and the layer of it should not exceed the $\frac{1}{8}$th of an inch in thickness when the stone is placed upon it. In Glasgow and some parts of Scotland, wrought stone-work is frequently laid in oil putty, such as is used for glazing window sashes. This is made of finely powdered chalk, mixed to a proper consistency with linseed oil. This produces an unsightly appearance in newly executed stone-work, because the oil is absorbed by the stone, and gives a dark or dirty and irregular appearance to the joints, but it wears off and disappears in a few months, and makes a most excellent joint for strength and durability.

880. Notwithstanding ashlar facing is the kind of stone-work more generally used than any other, it requires no argument to prove it to be a bad mode of construction, and one that is difficult to execute without considerable practice, so as to insure its stand-

ing without flaws or derangement of figure. No wall can be built of any considerable height, without its being subject to some sinking or settlement, owing to the mortar, while yet soft, giving way to the great weight that is accumulated upon it, especially in the lower horizontal joints; and this sinking will always be proportionate to the number of joints that occur. Now, in the stone facing, the mortar joints are not only less frequent, but are much closer or thinner than those in the backing, whether it be of rubble, or of brick-work. The facing will, therefore, be subject to little or no settlement, while the backing will go down considerably; hence a tendency exists to separate the two parts of the wall, and when the settling occurs in the backing, a great part of its weight is transferred to the projecting ends of the tail stones, causing them sometimes to break off, and at others to lift or separate the joints of the face work, and often making it to bulge or project forwards out of the perpendicular right lined direction it ought to preserve. Skill and experience are, therefore, necessary in the performance of this work, in order to maintain the several parts in perfect adjustment with respect to each other. The experienced bricklayer will know how much his work may be expected to settle, and will therefore keep his backing, in every place, so much higher than the face work, that although the upper surface of the wall may appear irregular during its progress, yet that it shall all sink to one common level soon after its completion—he will also take care to leave thick mortar joints over the tops of the tail stones, in order that the work, in sinking, may not fall directly upon them. With every care and precaution a faced wall is never as good as one that is built of equal sized homogeneous materials, so that level joints may run through the whole work in every direction, and that the joints, counted vertically, may be equal in every part of the wall.

881. One thing of great consequence, that requires attention in masonry generally, whether it be rubble-stone, solid, or ashlar-work, is that all stones should be placed in the position of their natural beds, or in other words, shall stand in the work to which they are appropriated, in the same position as that in which they grew, or were produced in the earth. To those unaccustomed to the use and inspection of stones, it may appear impossible to determine which is the upper or lower side of a block after it has been removed from the quarry and dressed up into shape; but the experienced mason seldom feels any difficulty in determining this point, particularly if a stone has been some time exposed to the air and rains; for a more or less decided lamellar construction may, by attention, be discovered in all stones, and it is these lamellar stones that most particularly demand attention as to this mode

of using them. If a stone shows no character of this kind, the experienced quarryman, who understands his business, will always put his mark on that side of the stone that was uppermost in the earth. It is not so necessary in using stones to place the natural top upwards, for, in most instances, it will do quite as well if the natural position is exactly inverted, but no stone ought to be placed at right angles to its natural position, because if it is at all lamellar the plates cannot separate from each other when the burthen is so disposed as to press them into closer contact, but if the plates are in the direction of the pressure, they will not fail to separate from each other in process of time, or after frost, particularly when they are in external positions. This circumstance was either not understood, or not fully attended to, in the building of Blackfriar's Bridge, in London, and the inconvenience is much felt; for stones are found to burst out and shiver away after each winter's frost, thus occasioning constant labour and expense for replacing them with new stone.

882. Little more can be said on the subject of building in stone, because the operation is so simple as to require no explanation, its execution requiring strength of apparatus combined with the greatest nicety of workmanship for its perfection. Still a few observations on the manner of placing the stones, and fixing them in their positions, may be necessary.

The stones being cut to their square shapes and dimensions by the stone-cutter's saw, are afterwards dressed and finished by variously formed steel chisels, urged by a small short handled wooden mallet;—any carving, letters, mouldings, or other ornaments that are to appear on the surface of the stone, are accurately drawn upon the face (previously made quite smooth) with hard black chalk, when they are worked out by these tools, drills of different sizes, rasps and files, and being finished, the flat parts of the stone are rubbed with a flat piece of stone, or if a moulding, by a piece of stone in which a similar or corresponding moulding has been sunk; and these being used with water and a little very fine sand, soon destroy any inequalities that may have been left, and produce a fine regular surface. If the work has to be polished, this rubbing has to be followed by other rubbers of soft wood, and finally of buff leather, upon which polishing powders, such as emery, pumice-stone, chalk, polishing putty, &c. must be applied. In general, however, stone-work is left with what is called a rubbed surface, or sometimes after being rendered flat and smooth without rubbing, it is chisel worked, that is, the whole surface of the stone is passed over with a sort of gouge tool, that cuts it into very shallow grooves or furrows, about $\frac{3}{8}$th of an inch wide, made close and parallel to each other. This is quite a matter of taste, some thinking that the chiselled face looks handsomer than that which is rubbed smooth; but the fact is, the indentations are so shallow, that at three or four yards from the stone, it would be impossible to say whether it was rubbed or chiselled, except when the light shines obliquely across the furrows.

883. The stone being thus finished, must be carefully and delicately handled, so that none of its sharp corners, or angles, may be broken or chipped; and to insure this it must have the Lewis inserted in it, (469,) and be raised by blocks and a fall suspended from a set of shears, until a truck, or hand-barrow, can be got under it, when it is lowered on to it and conveyed to its destination, where it is again lifted by another set of shears placed over the wall, and is thus brought exactly over the place where it is to be set, and bedded in mortar or putty. It is suspended about 4 or 5 inches over the place it is to occupy, so as to allow the mortar to be thinly spread by a trowel, and when all is ready, three or four workmen lay hold of the corners of the stone to keep it in its proper vertical position, while the men at the rope slack out, and lower it very gently on to its bed. A few blows with a heavy wooden maul are then given to the end of the stone, in order to drive it into close lateral contact, or produce a close vertical joint between it and the stone previously laid, and the superfluous mortar, squeezed out of the joint by the pressure, being removed and made smooth by the sharp point of a trowel, the setting of the stone is finished. If the stone is moved from its first position on a truck by horses, it ought to be placed on a bed of straw and old sacking, to prevent injury to it; but the hand-barrow is the most safe and usual mode of conveyance, when the stone is not too heavy. The hand-barrow has no wheel, but is merely two parallel poles nearly three feet asunder, with a flat boarded platform to receive the stones between them. It requires two men to work it, and they walk between the poles, or for greater weights four men are employed, one at each end of each pole; or six men can apply their strength by four walking on the outsides of the poles, and two between them.

884. Mr. Smeaton in his published account of the operations and proceedings during the building of the Eddystone light-house, describes a most excellent form of shears that is simple and admirably suited to the moving and placing of heavy stones on walls, or other buildings. It consists of three pieces of timber disposed in the form shown at Fig. 166, the bottom piece *h* is square, and may be from 12 to 15 feet long, and should be sound and hard. The shears consist of two poles only *i i* which may be round, tapering, and as long as they can be conveniently obtained, say from 18 to 30 feet. Their lower ends are connected with the bottom piece *h* by two very strong iron eyes or links, loose enough to

permit motion, while their upper ends meet, and are connected by the strong iron pin *k* which passes through both of them, and also serves to support the top hook of the blocks and fall *l*, the running rope of which passes downwards from the upper block, and takes a course close to one of the poles and is passed through the snatch block *m*, fixed to the bottom piece *h*, and to this rope the workmen apply their strength immediately, or through the agency of a crab, or windlass, according to the force to be overcome. The central point of the horizontal piece *h* is marked on its top, at the point to which the bottom block would descend, when the piece *h* is set truly level. To use this apparatus the bottom or foundation piece *h* is set truly level upon hard ground, or is supported on piles or timber skids, if the ground is not hard enough to sustain the load; and the poles are retained in their vertical or other required position, by two sets of running blocks and falls, pulling in opposite directions, and at right angles to the direction of the length of the foundation piece *h*, as may be better seen in Fig. 167, which is a perspective view of the same machine as fixed for use. The upper ends of the guy blocks are attached to the tops of the poles, and their lower ends to strong posts fixed in the ground, or to stumps of trees, parts of buildings, or any thing that will afford stability. Then by lowering out the fall *n*, and tightening that at *o*, the shears may be made to incline or bend over, as shown in the figure, until the bottom block *p* hangs directly over a stone *r* that has to be lifted, and thus this stone may be taken off the ground, and raised to any required height, by the principal blocks and fall *p q*. That done, the guy fall *o* is slacked while *n* is tightened, so that the shear poles are first brought into a vertical position, and are afterwards allowed to turn over or incline to the other side, as shown by the dotted lines *q q*, when the sustaining force will be transferred to the guy fall *o*, and *n* will become useless, and in this way a stone may be brought from the ground upon which it was worked, directly over the place *s* in the wall in which it has to be deposited, without disengaging it at all from the block by which it was first lifted, and without hand-barrows, or any trouble whatever. To insure the delivery of the stone into its proper place by this machine, a line must be strained from the centre of the stone to be moved, to a point perpendicularly under the centre of the place in which the stone has to be placed, and the foundation piece *h* of the shears must be moved until its central marked point *t* falls under that line, while the length of the piece is at right angles to it; the foundation piece must then be fixed in this position by driving short stakes round it into the ground, and then the upper end of the shears in moving will describe an arc of a circle *v v*, the plane of which will pass through the centre of the stone, and the centre of the bed or position in which it is to be placed.

885. A machine somewhat similar in principle, but different in construction to that just described, is much used in Philadelphia and the northern cities, for raising heavy stones in building. The bottom piece *h*, Fig. 166, is still square, but not so long as has been described, and has several small but very strong cast iron wheels let into its under side, so as to make the machine easily moveable in a longer bed plate that rests on the ground, and is grooved out to receive the wheels, and prevent their slipping. The upright poles are longer than those described, and are put much closer together and nearly parallel, and they are united throughout their whole height by rounds or steps, so as to form a ladder. The poles do not on this account meet at the top, and their lower ends are permanently morticed into the bottom piece *h*. The machine when fixed in its place, has its wheels wedged up to prevent its moving laterally, and is retained in its nearly upright position by guy ropes, or falls, as before described, but from the proximity of its poles, and the steps that unite them no stone can pass between them, and therefore although it is an equally convenient machine for raising stones from the ground in front of a wall, and placing them upon such wall by altering its inclination, still it is incapable of moving stones through so large a range of space as the former machine. This apparatus does not turn over, but always works with an inclination on the same side of the perpendicular.

886. To make a stone wall look regular and handsome, the stones ought to be as nearly of the same colour, quality, and dimensions as possible, but as stones of the same size cannot often be procured, some arrangement has to be adopted by which symmetry of appearance may be produced; thus if the courses cannot be had of the same height, the highest stones should be used near the base, and they may decrease in magnitude regularly as the work proceeds upwards. The ancients considered the equal courses as forming the handsomest work, and according to Vitruvius this arrangement was called *Isodomum*. No variation in the height of a continuous course can possibly be admitted; but courses of different heights are very frequently made to alternate with each other in succession, and this was called *Pseudisodomum*, and has a good effect. Great care is necessary in placing the vertical joints so that no two shall ever be allowed to come over each other in contiguous courses, and yet they ought to come directly over each other in every alternate course. This will easily be brought about if all the stones are of the same length as in Fig. 168, because then the vertical joints will all fall directly in the middle of the stones above and below them, if stones of half length are used

to commence every alternate course. If, however, the stones so disposed have not sufficient magnitude to reach quite through the wall, and two vertical lines of work should be necessary, this will be a bad disposition of the materials, because a straight vertical joint will exist between the two faces of the wall, without any thing to tie or connect them together, and such a wall will be very apt to split longitudinally. To obviate this, thorough stones, called *diatonos* by Vitruvius, must be introduced frequently, or at all events tail stones, which will nearly traverse the wall, and this will be produced by placing one stone with its length in the direction of the wall, and the next with its length across it, as in Fig. 169. When a stone presents its small end in the face of the wall, as in this example, the end is called its head, and the stone itself is called *a header;* while a stone showing its greatest length is called *a stretcher:* hence this mode of building is often called header and stretcher work.

887. The ancients were very partial to a disposition of joints, such as is never adopted in modern work, although Vitruvius speaks of it as the most handsome in appearance. In this the stones are all square and of uniform size, and the face joints instead of being horizontal and vertical, are inclined in angles of 45° to the horizon, the transverse joints alone being level. This gives an appearance of net-work to the face of the wall, and was on this account called reticulated work by the Romans. Its appearance is shown at Fig. 170, but it has not a single good quality to recommend it, and on this account has fallen into disuse. The *Emplecton* of the Romans was a wall similar to one of modern ashlar facing, except that the wrought facing was carried up on both faces instead of one side of the wall only, while the central part was backed up or filled in by rubble-work only. The walls of the celebrated Pantheon at Rome, are a fine example of this kind of building. The emplecton of the Greeks, on the contrary, was a completely solid stone wall with no rubble-work in it, but all the internal filling in stones were squared and dressed so as to form the best, most solid and durable of all walls.

888. With a view to give greater strength and security to walls that are built of stone, it was customary with the ancients (and that custom has been continued,) to use attachments of metal to tie or connect the several stones together, such pieces being called *cramps, cramperns,* or *cramp-irons.* They are made in different forms, suited to the purposes to which they are to be appropriated, and then obtain different names, such as dowell cramps, dovetail cramps, cauked or cogged cramps, and chains. The dowell cramp is used in ashlar facing to secure the vertical stones from getting out of their positions; and it is often used, with a like

view, in horizontal joints, to prevent stones from sliding or moving from the places in which they are set, so as to injure the appearance of the finished face of the work. The dowell cramp is merely a piece of round or bolt iron, from $\frac{1}{2}$ an inch to 3 inches in diameter, and from 1 inch to 12 inches in length, according to the thickness and size of the stones made use of, the two ends of which are let half the length of the cramp into two holes that are drilled into the contiguous faces of the stones exactly opposite to each other; so that if we conceive Fig. 168 to represent a piece of ashlar faced work instead of solid masonry, *v v* will show the positions of the dowells in the vertical joints, and *x x* those in the horizontal courses. *w w* Are two dowells fixed in the top course to pass into the beds or under sides of the next course of stones to be laid. The holes for receiving these dowells ought to be very little larger than the metal pins that pass into them, so as not to permit them to move, and in light work the dowells are set or fixed in soft or nearly fluid plaster of Paris and water, but in heavy work they are run in with very hot melted lead. When this has to be done a very small channel is carved out between the faces of the stones that are to be contiguous, for introducing the lead, and a small cup or funnel is formed at the end of the channel with damp clay to receive the lead from the ladle. This channel must take a perpendicular direction, or an oblique one to the back of the work, in order that it may be covered and hidden when the work is finished. Stones thus dowelled together cannot break away or quit their positions, unless a part of the stone gives way.

889. In Fig. 171 a dovetailed cramp is shown at *v*. This may be made of cast or wrought iron, and is a flat plate of metal varying in dimensions with the strength required from it, and it derives its name from its two ends spreading out into a form like the tail of the dove or pigeon. A cavity corresponding exactly with the size and shape of the cramp, as at *u*, is sunk, half in one stone and half in the other, so that the cramp may be sunk rather more than its own thickness into the two stones when it is bedded in melted lead within a joint, and of course does not appear externally. The form of a caulked or cogged cramp is shown at *y* in the same figure. This is merely a piece of square bar iron bent down or cogged (generally called *corked* by workmen,) at its two ends to a sufficient length to take good hold of the two stones into which it is inserted, as before described, by sinking a cavity into the two stones large enough to receive it, as indicated by the dotted lines below it in the figure, and then it is run in with lead. The two last described clamps are those that are constantly used for connecting the flat coping stones with which walls are fre-

quently covered, and stone cornices should be cramped in the same manner. Cramps are always employed in works that require great solidity, as in the piers and abutments of bridges, and the voussoirs of large arches, and all external work liable to be injured by weather should be cramped. Iron is used in modern buildings, but the Romans, who were accustomed to employ cramps in the greatest profusion, used brass or bronze, a material much more durable than iron, and not so liable to rust, which is the greatest objection to the use of cramps in external work; because even though they may endure a long time, the oxide of iron discolours the rain-water that falls upon it, and produces very ugly yellow and brown stains, which greatly disfigure the work. In all plaees where this is likely to happen, it is, therefore, much better to use cramps of gun metal, (643 and 737,) and as these can be cast from a pattern, the expense of forming them is small, and we have an assurance of their all being of the same size, which saves trouble to the mason in sinking his holes. Chain cramps are only used for tying large masses of work together, and are applied in addition to the detached cramps before described. The chain may be made of links as usual, or may consist of a single bar of iron united at its ends into a hoop, and with projecting collars or knobs welded on to it at short intervals. The whole is let into a groove or cavity in the upper surface of the course of stones to which it is applied, so that the work is hooped or bound together. Sir Christopher Wren used two cramping chains below the springing of the dome of St. Paul's Cathedral in London, in order to resist and distribute the lateral pressure of so immense a load, for this dome is 145 feet in diameter, and 240 feet high from its springing to the top of the large stone lantern and cross which surmount it. Sometimes when the work requires to be more than ordinarily solid, not only cramps and chains are resorted to, but the stones instead of having flat joints applied to each other, are so shaped that the side of one stone may dovetail or lock into the side of the other. When this construction is adopted, every stone, after the first, has to be lowered perpendicularly into its position, and cannot afterwards be removed by any lateral force that is not strong enough to break and tear to pieces some of the stones of which the course is composed. Mr. Smeaton adopted this mode of joining the stones in the erection of the celebrated Eddystone light-house, built by him between June, 1757, and October, 1759. This light-house stands on a detached and isolated point of hard rock, rising out of the Atlantic Ocean nearly S. S. W. from the important port of Plymouth, in England, and only 14 miles from it. The rock is so small as to be invisible at a short distance, and having 30 fathoms water all round it, vessels used formerly to strike upon it, and were lost before they were aware of any danger. The exposed situation of this rock, and its inclined direction, both above and under water, makes it subject to most heavy and violent seas, so that it was thought impossible to erect a permanent light-house upon it, to warn mariners of their danger. In 1696 the first erection was attempted, and was finished in four years. The building was of stone, eighty feet high from the rock, and was designed and executed by a Mr. Winstanley, a gentleman of great mechanical genius, and after it had undergone considerable alterations and improvements it was thought to be so strong that nothing could affect it. Mr. Winstanley, in his account of this extraordinary building, however, states that he had seen the sea, in times of violent gales, fly, in appearance, a hundred feet above the vane on the top of the building, and on the night of the 26th of November, 1703, it was carried wholly away by a violent storm, while Mr. Winstanley and many of his friends and workmen were in it, being just then on the eve of its completion. Not a trace of it or its remains were ever after heard of, except only some very heavy iron ties that had been fixed into the rock to assist in holding it down. From these it broke away, and it is thought to have been overset in an entire piece, breaking off from its attachments to the rock. Very soon afterwards a second light-house was erected by a Mr. Rudyerd, which was a frustrum of a cone 23 feet 4 inches diameter at the base, rising to a total height of 92 feet, in which it diminished to a diameter of 14 feet 3 inches. This second building was altogether of timber, and has been much extolled for the strength, excellence, and skill of its framing. It must, indeed, have been well contrived, for it endured forty-six years without symptoms of failure, and then was consumed by accidental fire, originating in some want of attention to the candles which were then used in the top lantern for producing the light. This accident happened to it in December, 1755, and in June, 1757, Mr. Smeaton commenced the present building, which is admitted by all competent judges to be a chef d'œuvre of modern engineering, at least in this department of work. Mr. Smeaton kept a journal of his thoughts and proceedings while carrying on this most difficult and perfect piece of workmanship, and it was published after his death in a very large folio volume with many plates. In this work every minute particular concerning the progress of the work, and the difficulties met with, are described with the most minute detail, and in such manner as cannot fail to be interesting and useful to the practical Engineer. This book is high-priced and scarce, but may be found in many public libraries, and a careful perusal of it is strongly recommended to such as may have an opportunity of meeting with it. Eddystone light-house is circular on the plan, cylindrical near its top, and swells at its lower part into a parabolic conoid. Mr. Smeaton observes, that he took the hint of this form from noticing the shape that the trunks of old oak trees assume, and the power they have of withstanding high winds, notwithstanding the great surface their tops expose to its effects. As the proposed building was to cover nearly the whole top of the rock, and a part of that had great inclination, the first thing to be done was to cut this sloping part into horizontal steps, a work that had been partly carried into execution when the former buildings were executed. These steps were to serve as level foundations for courses of stone that were laid upon them, in the form of segments of circles, each succeeding one approaching nearer to a complete circle, until by seven such segmental courses the foundation was brought to a general level, after which the future courses were complete circles. In this manner the building was carried up in perfectly solid masonry to the height of 35 feet 4 inches above the base by 14 courses or layers of stone, of an average diameter of 22 feet at the middle point of this height. These courses were not only laid in the best cement, but were prevented moving from their places by eight strong perpendicular dowells formed of square blocks of the hardest marble, introduced at $\frac{1}{3}$ of the radius from the outside, and a still larger one in the centre; and the stones were not only cramped and pinned or dowelled together, but all the stones of each course were dovetailed into each other in the manner shown at Fig. 172, so that no one stone could separate from another. Each succeeding course was so far twisted round in its horizontal direction that the zigzag radial joints of one course came over the solid stones of the next below it. This solid work was carried up to such a height as was thought would raise it above the force of the waves of ordinary seas. The entrance door was placed upon the top of this solid work, and was approached by a moveable ladder. Four circular apartments succeeded, the two lowest of which were store rooms, the next a kitchen with a fire place, and the uppermost a sleeping chamber, and this was surmounted by the lantern, an octagonal chamber ten feet across, the sides of which were copper, and iron sashes glazed with strong glass for containing the lights. Each apartment is separated from the other by a vaulted roof of stone with a flat top, forming the floor of the room above it. The same process of dovetailing the stones into each other is preserved in all these vaults and floors, in addition to which two endless chains are sunk into the stones that surround the abutments of these vaults to resist their lateral thrust. This short notice cannot pretend to do justice to the account of this curious and interesting building, and is only introduced here to show the care and precaution that should be used in constructing stone buildings, when they are intended to be very durable or to resist great strains.

890. One of the most important uses of stone is for constructing large arches for bridges and other purposes; but a large arch cannot be built without timber centring to support it during its progress, and this in some measure connects this subject with carpentry. For this reason, and because the building of arches involves principles quite different from those that apply to perpendicular walls, nothing is said upon them in this place, but a separate chapter will be devoted to their consideration after the leading principles of carpentry have been explained.

891. Wrought stone-work is not only used by itself, but is frequently mixed in small quantities with brick-work for the double purpose of producing strength, and adding to the beauty of appearance. Thus in the handsomest brick buildings the *sills*, or lowest member of each window, should be of cut stone—steps leading to entrance doors should be of the same material—a *plinth* or *surbase* of from 2 to 3 feet high of wrought stone, is often used next the ground, before brick-work commences. Straight horizontal lines of stone, of 6 or 9 inches wide, and plain or carved, are frequently introduced across the brick front of buildings, between the tops and bottoms of windows, to break the monoscopy of appearance, and these are called *string courses*. Brick semicircular arches are frequently made to rise, or spring from stone *imposts*, or horizontal springing pieces, and key stones of stone are often introduced into the centres of such arches. Stone pilasters and cornices are likewise not uncommon, and every well finished wall ought to be coped or covered with long plates of stone, about 4 inches wider than the wall is thick, so as to project or oversail the wall about 2 inches on each side, to throw rain away from it. In all these cases (except steps) the face of the stone should project from one to two inches beyond the face of the brick-work, to produce a handsome and bold effect. The upper projecting surface of such stones ought not to be level, but should be bevelled downwards to throw off water; and stone so bevelled is said to be *weathered.* The flat underside of these projecting stones should have a shallow longitudinal groove sunk into it, about $\frac{1}{2}$ an inch from its front side, to prevent the water that may hang to its lower edge from getting into the wall. Such groove is called a *throat*, or the stone is said to be *throated*, and all coping stones should be throated along both their edges. Coping for common work is made of slab or lamellar stone, like Yorkshire paving or North River stone, and then it is called *parallel coping*, and it should be set a little out of

level to throw the water to the front or back of the wall, as may be most convenient. The best coping is made out of sawed free-stone, so cut that one edge may be an inch thicker than the other, to *produce weather*, or throw the water off. The parapet, or side walls of bridges, are generally covered with coping that is an inch or two thicker in the middle than on either side, so that the water runs both ways, and such coping is said to be *saddle backed.*

Wrought stone is not only used for building walls, foundations, and such things as have been already noticed, but likewise for forming columns and pilasters with their capitals, pedestals, bullasters for bridges and terraces, cornices, pediments, cantilevers, and many ornamental purposes; but as these belong more particularly to the province of architecture rather than engineering, they must be passed over without notice. Some terms and operations, that apply in common to masonry and brick-work, will be explained in the next section, which treats on this latter subject.

Of the Measurement of Wrought Stone-work.

892. If stone is bought or transported by weight, such weight may be pretty accurately determined by consulting the table of specific gravities (861). Free-stone is, however, generally sold by cubic, and slab, or paving stones by superficial measure, the price varying with the goodness and dimensions of the pieces; for large stones (owing to the difficulty of getting them out of the quarry without shakes or flaws, and of moving them afterwards) are worth considerably more per foot, than the same stone in smaller pieces.

Paving stone, though sold by superficial measure, is brought out of the quarry with rough edges, and has always to be squared by the saw or chisel, and its upper surface frequently requires to be *tooled* or *rubbed* to a flat face, and such operations are always additional charges, computed by superficial measure. Coping stones, string stones, and such kinds of stone-work as contain the same quantity of stone, and labour, in equal lengths, are usually sold by the foot, running measure, at prices depending on the quality and value of the stone, its magnitude, and the degree of labour or finishing that has been bestowed upon them. Throating is paid for by the foot run, and holes sunk for admitting iron railing, or for pins, dowells, or other cramps, at a certain sum for each hole, or each dozen holes, the mason finding his own tools. Masons' tools, such as chisels, drills, mallets, and other small articles, are so frequently lost or mislaid, that it is better for the workman to find such tools for himself; but all large implements, such as saws, tressels, or benches, barrows, shears, blocks and fall, long level, &c. are provided by the master or employer, who also pays smith's charges, or the blacksmith's work for sharpening and repairing such tools as are deranged by fair use.

893. Wrought stone-work is among the most expensive of all the building processes, on account of the weight of the raw material, the cost of its transportation, the workmanship requiring good and experienced hands at high wages, and all their operations being, from the nature of the material, slow in their progress. The harder stones, such as granite and sienite, are frequently cheaper than the softer free-stones, because they can be got out of the quarry, and are dressed there to very nearly their required forms, for much less prices than the masons of cities could do the same quantity and quality of work for. The soft free-stones are delivered from the quarry in large square blocks, to be afterwards cut up, and converted as may be required. They are first paid for as cubic stone at the quarry, according to the measurements usually marked on each block. On their arrival at the mason's yard they are sawed into square blocks, slabs, ashlar blocks, and various scantlings, as may be required, and this sawing, which is a slow operation, is paid for by the superficial measure of the surface exposed by the cuts, and such work is called plain work—any thing is also called plain work that is finished with a flat surface, whether produced by the saw, by chiselling, or other means.

894. The thin edge of a piece of stone is very often worked into the form of a moulding to project over a plain surface for forming cornices, architraves, and other ornamental finishing, and such work is called moulded work. As such mouldings could not be set out or lined for the workman, upon a rough and uneven surface, so the mason is entitled to charge for superficial plain work before the moulding is commenced, and then the moulded work is a separate charge. Mouldings are also paid for by superficial measure, according to what is called their girt. To obtain this, a piece of fine twine or thread is applied to the top or bottom of the moulding, is pressed down into all the cavities, and forced into all narrow chinks or quirks, and strained over protuberant parts until the opposite side of the moulding is reached, when the string on being opened out will give the superficial breadth of the whole moulding, and this being multiplied by its length will express its entire superficies to be charged for. When mouldings return at right angles, and are mitred, or are made to meet at an angle of 45°, the workman is entitled to the extreme, and not the least or even the mean measurement of the moulding.

895. When mouldings are worked upon a stone that is to expose a flat surface with the moulding projecting above it, the flat surface of the stone must evidently be sunk or cut away to a depth equal to the projection of the moulding, and such work is called

sunk plain work, and is charged at a price increasing with the depth of the work, or quantity of stone that has been cut away and the difficulty attending its execution. Likewise when a sunk pannel, surrounded by a moulding, is introduced into a flat surface, that pannel would be sunk work, but the moulding, moulded work, and the entire surface would be first measured and allowed for as plain work.

896. If a stone column, or pillar, has to be formed, superficial plain work is allowed in the first instance upon all the six sides of each block of stone, because the top and bottom of each block must be made fair and flat, that it may fit to the other stones above and below it; and as these joints must be at right angles with the outside of the column, or at any rate with its axis, so these joints cannot be accurately set out unless the four upright sides are made flat and smooth. A skilful mason can, however, set out and square these joints after one of the upright sides of the stone has been rendered flat and smooth, and it is a common practice to do so; but still as custom has established the practice of charging for all four of the sides at plain work price, masons always expect this charge to be allowed to them. All architectural columns taper, or are slightly conical, therefore to set out a column for work, the centre of each block of stone must be found upon the two sides that are to become its top and bottom; and from these centres, circles are struck corresponding to the circular area of that part of the column that such stone is to form, which done, all the solid angles, and other parts of the block exterior to the circles, are chopped away, and the stone is then chiselled down to the cylindrical or nearly cylindrical form, and this is called plain circular work. If a fillet, or other ornament is to appear upon the column, and project from it, this will be circular moulded work, and as the shaft of the column above and below it must be diminished, what is taken off it will be sunk circular work; and should the column be fluted, the sinking of the flutes will be of the same kind. Circular work, in its several varieties, being more difficult to execute than plain work, is paid for at a higher rate. These several varieties of work, at different rates of charge, make the measurement and valuation of highly finished masonry intricate and troublesome; and greatly advance the cost of its execution, because first, the rough stone has to be cubed and paid for; next, the plain work on its surface; next, sunk plain work, moulded work, circular work, &c. &c.; thus requiring the same surfaces to be gone over and over again in different dimensions, and at different prices. The working out is therefore tedious, but the operation is very simple when understood, because it only amounts to common cubing in the first instance, and to squaring

superficial dimensions afterwards. As, however, the Engineer will seldom have to measure and value stone columns and richly ornamented architectural work, a single example of a plain stone wall will be sufficient to illustrate the application of the above mentioned principles to practice.

897. Let it be required to measure, and determine the value of a piece of ashlar stone-work 12 feet long, 4 feet high, and 6 inches thick, in 4 courses, containing 10 upright joints, without any tailing stones, so that the stone-work shall be of the same thickness throughout. First, to determine the quantity of stone, each stone may be separately cubed, or, what in this case is a shorter process, the whole stone may be cubed at once by multiplying its length 12 feet, by its height 4 feet, making 48 feet super., and this again by 6 inches for the thickness, gives 24 feet, cube, of stone. But small ashlar stones, when all of the same sectional area as in the example, are more frequently sold by the running foot; therefore the dimensions and particulars may be entered in the measuring book as follows:—

Ft. In.			$ *cts.*
4)12 0	48 0	Run of 6 inches rough ashlar 12 inches wide, at 48 cents,	23 04
12 0 4 0	48 0	Super. plain face and rubbed, at 45 cents, - - - - -	21 60
8)12 0 6	48 0	Beds, }	
10) 1 0 6	5 0	Upright joints, }	
	53 0	Super. plain beds and joints, at 30 cents, - - - - - - -	15 90
			$60 54

Thus it appears that 48 superficial feet of such work will cost $60 54 at the prices set down, or if that sum is divided by 48 it will show that each foot of such work comes to $1 26.

898. To understand the above mode of entry, it must be kept in mind that in measuring artificer's work of every kind, when a figure is set before a sum, and separated from it by a bracket or parenthesis, as in the case with the 4) and the 12*ft.* 0, at the commencement of the entry, the separated figure shows that the dimension following it is to be repeated or multiplied so many times; and as the question supposes that there are 4 courses of stone each 12 feet long, so 12×4 give the entire length, in running measure, of stone used in the whole work, or 48 feet, which is set down in the second column, and a line is drawn under these two columns of figures to indicate that they are done with.

The first column next contains 12 feet with its multiplier 4 feet placed under it, showing that 12 feet, the total length, is multiplied by 4 feet, the total height, producing 48 feet, the total number of square or superficial feet of plain work existing in the front or face of the wall, and this product is also inserted in the second column, and another line is drawn under these figures for a like purpose.

Then 12 feet, the length, is again set down with 6 inches under it, as its multiplier, because the stone is 6 inches thick, and the product would give the area of smooth surface in one horizontal joint. But as the work consists of 4 distinct courses, the top and bottom surface of each course has to be taken, therefore this quantity is preceded by 8,) showing that the product of 12 feet by 6 inches must be taken 8 times, which produces 48 feet superficial of bed, or horizontal surface, and this product is put in the second column and a line drawn.

Lastly, 1 foot, the height of a course, is multiplied by 6 inches, the thickness of stone, and as 10 vertical joints occur, so 10) is placed before these figures to indicate that the product of 1 foot by 6 inches must be taken 10 times, producing 5 feet in the second column; and as the 48 feet and 5 feet are both dimensions of the same kind, and at similar prices, they are joined by a circumflex and added together, making 53 feet superficial for the total quantity of horizontal and vertical jointing in the whole work.

899. The prices to be set against these several varieties of work, and indeed every kind of builders' work, can only be accurately determined by taking the cost of the raw material before any labour is bestowed upon it, and adding thereto all expenses upon it for transportation and other incidental charges, then making an allowance for the waste that always arises in cutting large pieces into smaller ones, then adding the net cost of workmen's wages for converting it into shape, adding thereto the expense incurred for nails, glue, screws, solder, or other materials used, and lastly, adding a per centum charge upon the whole for the master's profit, which must be large enough to cover the wear, tear, and destruction of tools, shop rent and firing, and interest of the money expended, provided credit is given upon the work. This allowance is usually from 15 to 20, and sometimes 25 per cent. upon the actual cost, which may appear a large profit, and would be so was it all profit. But when it is considered that the master mechanic makes no specific charge to his employer for the rent of the large premises he frequently occupies, for the fires he is obliged to use in different processes, for the tools he has to provide, some of which are costly, and all constantly wearing out, or getting broken in use, that he often takes great risk upon himself, and has to pay his workmen weekly in cash, while he

himself has frequently to wait twelve months or more for his money, the profit will be found far from excessive, and in some cases even too moderate.

900. It will thus be seen that setting prices upon work is not an easy task, and cannot be done at all with anything like precision, without some knowlege and experience of the nature of the work to be valued. To assist the builder and surveyor in their operations, books are published under the title of Builders' Price Books, and they render great aid. Thus in London, and for some distance around it, builders regulate their prices either by Crosby's or Taylor's Price Book, both of which are published annually like almanacs, and contain the prices for which all the various operations connected with building have been performed in the past year, as well as the prices of materials, and many tables and remarks that are highly useful to Builders, Engineers and Architects; and a similar work is now published in Boston, called Gallier's American Builders' Price Book and Estimator, which is replete with useful information, insomuch that such a book should be in the hands of every young Engineer and Architect, for the sake of the minute and particular information that is conveyed respecting the measuring and pricing of every kind of work and material, as well as for becoming acquainted with the technical phraseology that is applied to the various kinds of work or parts of the same work, which details cannot be found elsewhere. Still, however, the prices quoted for work in these books must not be relied upon, or applied to similar work in distant places, for no such book can be general. A price book published in London, Boston, or any other city, may give true and faithful accounts of the prices for which work should be executed at or near to those places, and may therefore be confided in at home. But it often happens that in a less distance than 100 miles the price of materials and rate of wages, owing to local circumstances, may be quite different, consequently different prices must be allowed. London and Boston are both shipping ports and populous cities, abounding with the best workmen of every description, who, by being constantly occupied in the same operations, acquire the greatest readiness and expedition, combined with perfection of workmanship, in their several departments. They have also the advantage of every facility that good tools and machinery can afford them, and buy their raw materials at first hand where competition exists, and therefore at the cheapest rates. A sum, therefore, that would be amply sufficient for an artizan in such cities might prove a starving price to an inland workman having none of these advantages; for although he might do the work as well, he would perhaps take twice as much time for its perform-

ance, and would probably have to pay much higher for his materials. Whenever, therefore, a price book is used out of the place for which it is intended, the prices it quotes both for materials and labour or wages, ought to be compared with the prices and rates of the place where it is used, when it will show how much ought to be added or subtracted from the prices it gives, in order to obtain local prices of the place, and price books thus used will prove very useful, and save a great deal of trouble.

901. The example of measuring the ashlar-wall before given, (897,) is extracted from Gallier's Boston price book, page 22, and is here referred to again, because it appears that there is either a mistake in one of the dimensions, or that the American method of measuring wrought masonry differs from the English. But the writer has not had sufficient experience in measuring such work in this country to decide whether Mr. Gallier's statement is correct according to the custom of the country, or an error that has been overlooked. The dimensions are all right down to the vertical joints, which are expressed by 1 foot, multiplied by 6 inches, and the product repeated or multiplied 10 times, because the question states that there are 10 vertical joints. It will be observed in the preceding sum that the beds are repeated 8 times, although there are but 4 courses of stone, thus showing that the top and bottom of each course of stone is separately measured in plain work, and this, according to the English system, applies equally to vertical joints. If 10 such joints occur, they imply that 20 surfaces or sides of stone have been rendered flat and smooth, and in addition to this if the extreme ends of the wall have been rendered flat and smooth, these ends would also count. Thus by referring to Fig. 168, it will be seen that the wall there represented consists of four courses with 10 vertical joints, as in the example; but these 10 joints require 20 flat surfaces, in addition to which there are 8 flat ends to the courses, consequently, according to the English mode of computation, the co-efficient or multiplying number for the area of one joint would be 28 instead of 10, as stated in the example. If the Amerian custom is to call each vertical joint, one face of plain work only, it produces a considerable advantage to the employer.

Section 2.—*Of Brick-work.*

902. The method of building with bricks is so nearly similar to that with stones that many of the remarks made in the last section will apply with equal propriety to both materials: and as this also applies to some of the observations about to be made on brick-work, so the simple term *wall* will be employed, in future,

to denote erections that may be made indifferently of either material or operations that apply equally to them both, and *brick-wall* or *stone-wall*, when either particular kind of work is referred to. The nature of bricks, and their dimensions and qualities have been already described (477 and 493,) and in using them for building purposes, an even surface or foundation is first prepared, and should be truly level in each direction.* This may be covered with mortar, and the bricks are then placed upon it flatwise, or with their broadest surfaces upwards and downwards, with mortar filled in between their vertical joints; but the general practice in beginning a wall is to lay the first or foundation course dry, or without mortar; that done, another layer of bricks is placed above the first, each layer being called a *course of brick-work.* Any course being finished, mortar is laid over a part of its upper surface to bed the bricks of the next course, and in this manner the work proceeds upwards until finished.

903. All bricks that are laid with their length in the direction of the length of the wall are called *stretchers,* and all those that take an opposite direction, or present their ends towards the faces of the wall are called *headers*, whether they are visible on the outer faces of the wall or are hidden within it.

904. A heading course is one in which all the bricks that compose it are headers; and a stretching course has all its bricks laid as stretchers. All brick-walls ought to commence with a heading course, in order that the lower bricks may be so covered by the superposed wall that they cannot slip out of their places.

905. Brick-walls are generally described by the number of bricks that occur in their thickness, rather than by their dimensions in inches; thus we speak of a single brick-wall, a brick and half wall, two bricks, &c., and if the size of the bricks are determined as they are in England, (476,) this at once gives the thickness of the wall, and then walls are spoken of as nine inch, fourteen inch, eighteen inch, &c. walls. A four inch wall is one that is half a brick thick, or built with whole bricks all laid in the direction of their length. In paving with bricks, or bringing up courses to a proper level, the bricks are often laid with their thin sides upwards, and when so disposed this is called *brick on edge-*work. *Brick on end*-work is only used for paving floors, and in this the bricks are placed with their ends upwards. From the small dimensions of bricks a great part of the strength of brick-work depends on the joints being well and regularly broken, or so

* It may appear that some further observations on the nature of foundations should be made here, but they are of such vast importance to all buildings that a separate section will be devoted to their discussion, after the processes of building have been described.

disposed that no two vertical joints shall occur in the same line over each other in two contiguous courses; or in other words, that good bond should be preserved; and yet to make the work look handsome, all vertical joints in alternate courses must be correctly over each other, so that if a long plumb-line should be fixed in any vertical joint of a piece of work at its top or upper course, that line should also cover or pass over the vertical joints in every alternate course below it.

906. In order to produce this regularity of appearance in the joints, so necessary to the handsome appearance of brick-work, as well as to break the joints and cause the bricks to overlap each other for procuring strength, bricks are always laid in particular forms distinguished by the name of *Bonds*. Of these two varieties are used in England, and are called *Old English Bond* and *Flemish Bond*, and a third variety has been introduced in the United States, where it is extensively used, and may, therefore, for distinction's sake, be called American Bond.

907. Old English bond consists of alternate courses of all headers and all stretchers alternating with each other, except when the wall contains an odd number of half bricks, and then a single row of stretchers becomes necessary in each heading course, and a row of headers in each stretching course to make out the thickness of the wall. Thus, for example, in building a brick and half wall, or a two brick and half wall, such thickness can only be obtained as above, or by cutting whole bricks into halves, which would occupy more time, and produce great waste of material. The first course of a brick and half old English wall would therefore be laid headers and stretchers, disposed as at A in Fig. 173, and the next higher course in succession would be like B, or show its stretchers on the opposite face of the wall. If the wall is $2\frac{1}{2}$ bricks thick as at C, the stretching course can be laid in the middle of the wall, and then the succeeding course may be all stretchers. And when the wall is two bricks thick as at D, it may consist entirely of alternate courses of headers and stretchers. The forms C and D are, however, neither of them proper for building walls, because the joints are not sufficiently broken; for, as each of these courses has to be covered with a course of all stretchers, whose positions are shown by the dotted lines, it will be evident that a straight joint, or one without bond, will run through the whole length and height of each of these walls, and that there is nothing to tie the two faces together, consequently such walls would be liable to split in two in their vertical longitudinal direction when loaded, or carried to a considerable height. To obviate this, every third or fourth header should be laid in the middle of the wall, as at *a a*, when its deficient

length must be made out by pieces of brick called *batts*, or bricks cut to shorter lengths, as at *b b b b*, which will not at all alter the external appearance of the face of the wall, but will add materially to its strength. In reference to the plans A and B, it will be seen that as the length of every brick should be equal to twice its breadth, so if whole bricks are wholly used in laying down A, the stretcher joint *c* will always come in a line with the header joint *d*, and thus produce bad work, or straight contiguous joints; to avoid which a portion of the first stretcher *e* must be cut off so as to reduce its length, until it is equal to the breadth of a brick and half, as in the figure, when each vertical joint *c* will come against the middle of the end of a whole brick, and the joints will be broken throughout the whole work. Pieces of brick less than half a brick in width are often necessary in the face of a wall to shift a joint, so as to produce good bond, and such short pieces are called *closers*, but pronounced closhures. E shows the appearance that old English bond has on the face of the wall. The advantage of this kind of bond is that it contains no hollows or interstices, but is perfectly solid, and is therefore peculiarly well suited to any work in which great strength, rather than beauty of appearance, is desirable. It is therefore constantly resorted to both in masonry and brick-work, for the piers and abutments of bridges, the side walls of canal locks, and all such purposes.

908. Flemish bond has the external appearance shown in Fig. 169, and consists of headers and stretchers alternately in every course, but so disposed that no vertical joints occur over each other in contiguous courses. This bond is generally adopted in house building, because it is thought to look handsomer, and takes fewer bricks, or at any rate permits the builder to use a great deal of the small batts and broken rubbish that constantly occur in building; for no wall, consisting of an odd number of half bricks, can be built solid when this bond is adopted. Fig 174, at F, shows the disposition of the bricks in a single brick wall, and G that of a two brick wall, both of which are solid, and consist of whole bricks; but H shows the disposition in a brick and half wall, in which many cavities *f f* are inevitably left, and these are always filled up with mortar and small fragments of brick, which not unfrequently also happens in the wall G, where instead of introducing the two whole bricks *g g*, one only is often used, and the remainder filled in with rubbish, as at *h*. This is more particularly likely to happen in work contracted for, and in which the contractor has to find all materials, as by this means many whole bricks are saved.

909. The third variety of bond, which we have distinguished

by the name of American bond, is produced by laying four or five courses, one above another, all in stretchers, and then alternating with a single course of headers, followed by the same number as before of stretchers, as shown at I. This, like old English bond, produces solid work, but without the strength of the former, for the stretching courses must have straight vertical longitudinal joints between them, depending only on the single heading course to tie them together, and as it produces no beauty of appearance it cannot be recommended.

910. Mr. Robert Vazie, a Cornish Engineer, some years ago endeavoured to introduce what he called *vertical bond* into wall building, and from the experiments he tried, it appeared to possess a decided advantage of strength in walls subject to lateral pressure, such as in supporting embankments of earth. Vertical bond is produced by working bricks on end into the middle of the wall at two or three feet apart. Some of these are placed on each succeeding course, so as to carry the perpendicular tye from the bottom to the top of the wall; and each vertical brick will of course be covered and hidden by three successive horizontal courses. In using this bond great care is necessary to see that the vertical bricks are not too long; for, should this be the case, they would prevent the due settling of the wall, and produce horizontal cracks and weakness rather than increased strength.

911. Straight walls are built by first setting out the quoins or angles of the building upon the ground, and then straining a line from one point to the other, which will of course be straight. The line is fastened at its two ends to what are called *line-pins*, which are stuck into the soft mortar joints. In order to be able to fix this line in its proper place, two quoins of the building must be carried up three or four courses higher than the intermediate work, and the lower courses must be made truly level by the application of the bricklayer's level (300). That done, the work may proceed upwards with any required rapidity, all that is necessary being to examine that the faces of the wall are truly perpendicular, which is done by the application of the edge of a plumb-rule at every course, and an occasional examination of the level state of the courses, which ought to be made at every 5th or 6th course. The plumb-rule should be at least 3 feet long, and instead of holding it on to the last finished course, as is sometimes done, it ought to be made to bear about 18 inches against the finished wall below, to obtain the surest indication.

912. To insure the stability of a high wall that has nothing to support it, it is quite necessary that it should be perpendicular, or at any rate that its centre of gravity should be completely within the base or foundation upon which it stands; and upon the princi-

ples before explained, (837, et infra,) a wall to be equally strong from bottom to top, ought to be thicker near its base than near its top, and this is always attended to in building high walls. Thus, for example, in a three story house, the external walls may be 2 bricks thick up to the parlour ceiling at *a*, Fig. 175, and there a break, or *set-off*, of 4 inches may be made, so as to reduce the thickness of the next walls to $1\frac{1}{2}$ bricks. In the ceiling of the next room at *b*, another set-off of 4 inches more occurs, reducing the thickness of the last story to a single brick wall; thus lightening the load and diminishing the expense as the building proceeds, without diminishing its actual strength. In addition to this it is always customary to give a wider base to a wall than its thickness, and this called the *footing* of the wall. Thus the 2 brick wall may begin with a 4 brick footing, as shown in the Fig., and this footing diminishes by small breaks, or sets-off, at every second or third course, until it reaches the thickness the wall has to have above ground; for the footings of walls are, in general, under ground, and therefore invisible. This explains what has been before stated, (904,) that every wall should commence with a heading course, as an external line of stretchers might slip out of their places for want of being covered by other bricks.

913. In order to give the greatest possible stability to a wall, it ought to stand over the middle of its footing, as at *d*, Fig. 175, and the offsets ought to be equal on both sides of the wall. This is however impossible in practice, since it would give a building a very bad appearance, if its principal front was crossed by the projections that such offsets would make, and they would moreover be detrimental, by catching and retaining water. The face of the external wall is therefore necessarily made flat like *c*, and the offsets *a* and *b* are confined to the inside, where they are hidden, by becoming the ledges that support the joists of the floors, at which places the offsets should be made; but this throws more of the weight of the wall to the outside than to the inside. In houses for containing steam-engines, warehouses for heavy loads, and manufactories requiring buildings of more than ordinary strength, this may be remedied without producing any disagreeable appearance, by introducing a string course of stone, weathered on its top, wherever an offset may be desirable in the external wall, which may be set back an inch and a half or two inches above such stringing, without producing any disagreeable appearance.

914. It sometimes happens that a wall cannot be set upon the middle of its footing without the loss of a small portion of ground; for the divisions of land and estates run in planes from the surface to the centre of the earth, and no man has a right to build, dig, or perform any act that may infringe on the rights of his neigh-

bour. If, therefore, we desire to build the front *f c* on the utmost limits of any estate, it must be without any projecting footing beyond the dotted line *c*, which is the extreme boundary. The wall, therefore, must be without any foot next the side *c*, or else the whole footing must be moved so far inwards upon the estate, that its extreme edge may be in the boundary line, instead of the perpendicular *f c*, which will thus be thrown back by a distance equal to the projection of the footing.

915. When walls are required of extraordinary strength, as to withstand high winds, or the pressure of embankments of earth made against one side of them, they are made to slope, or *batter*, as it is called, that is, they are made much thicker at the base than at the top; or if they are built vertically they are assisted and strengthened by *buttresses*, or *counter-forts*, placed at short, but sufficient distances from each other, to produce the necessary strength. When walls are built in this form the horizontal position of their foundation is still preserved as to its length, but it ought not to be level in the transverse or opposite direction; because as bricks and stones are generally used in parallel horizontal courses, a transverse level foundation would not produce the greatest strength, and yet would be attended with increased labour in its formation. Thus let *a b c d*, Fig. 176, be a transverse section of such a battered brick wall, built to resist the lateral spreading force of an embankment of earth *e*. If the bottom course *c d* is level, all those above it will be parallel to it, or all the wall will consist of horizontal courses, while its exterior battered face *a c* will be a series of small steps or offsets, unless each course of bricks in succession is cut in the direction of the dotted line *a c*, which requires much additional workmanship, and after all, will never produce the appearance of an even and well finished face to the work; nor can such a wall offer the greatest resistance to the bank of earth *e*, the lateral spread or thrust of which will be in the horizontal direction of the arrow under *e*, and as it is opposed by nothing but flat horizontal joints and courses of brick-work, diminishing rapidly in weight as they proceed upwards, and having no bond among themselves, (unless vertical bond (910) has been introduced,) there will be great probability of the upper part of the wall being pushed or made to slide horizontally out of its proper place, or at any rate cracking and losing a part of its strength and stability. If, on the contrary, we draw a line *e f* from *e*, the centre of gravity or central height of the soil bank to be supported, and carry its lower end *f* to about the middle, or near to the outside of the bottom of the intended battering wall, another line *c g* may be produced at right angles to the first, and this will give the direction in which the courses of brick-work

should incline to produce the greatest effect of strength; instead, therefore, of building the wall as shown in Fig. 176, the bricks should be disposed as in Fig. 177, when the only cutting to be performed will be in the vertical plane *hk*, which being within the wall, its imperfections, if any, will not be seen, while *h i* will present a smooth and finished surface of entire bricks, and all the courses being parallel to the foundation *i k*, will oppose the most effectual resistance that can be obtained against the lateral pressure.

916. Except for supporting the embankments of canals and reservoirs, walls seldom batter to such an extent as in the example just given, but they are often required to batter in a slight degree, such as from $\frac{1}{2}$ an inch to 2 inches in a yard perpendicular, to give greater strength to the works of the Engineer; and in such slight cases, no slope is necessary in the foundation, nor should the facing bricks be cut except when absolutely necessary, because this degree of batter can always be obtained by making the mortar joint wider on the face of the wall than in its inside. In fact the internal bricks may be laid close, or with scarcely any mortar between them in the middle of the wall, and then a joint of ordinary size will suffice for the outsides.

Battering walls are always built by a battering plumb-rule, that is, one in which the sides are cut to the necessary batter, instead of being truly parallel to the central line over which the plumbet hangs. Such a plumb-rule is on the principle of that before described, (371,) and shown by Fig. 105, for setting out and proving the slopes of canal banks.

917. As walls that batter considerably are always expensive on account of the great quantity of materials they consume near their bases, *buttresses* or *counter-forts* are very commonly used with a common straight wall, instead of a long battering wall, and, in many instances, with equal effect. Thus the side walls of canal locks are usually in this form. The ground plan of a wall with buttresses is shown at Fig. 178, Pl. VI., in which *l m* is the straight face of the wall, and *n n n* buttresses formed against its opposite side; and these in lock walls are placed on their land sides, at 4 or 6 feet apart, according to the depth of the lock. To produce more strength in the walls they might batter, and be built in either of the forms shown at Figs. 176 or 177, but as such walls are not only subject to the lateral pressure of the water and earth on their two sides, but to concussions near their tops from loaded boats when the locks are full of water, they are usually carried up perpendicularly to near the ground level, and when that is the case they will work better in level, instead of sloping courses. In the old Gothic buildings of Europe, which are usually very high, buttresses are constantly used, one being placed between every

window, and at their bottoms they frequently extend out a great distance, and are diminished in their extent as they proceed upwards by sloping offsets, as shown at *q*, Fig. 179, and they finish at their tops in slender pyramids *r* called pinnacles, which being frequently enriched, add much to the beauty of Gothic buildings. In many instances instead of terminating in a mere pinnacle, they carry a quarter of a circle of stone arched work, as at *p* in the figure, when this arch, from its apparent want of support, is called a *flying buttress*. It is not however deficient in support, and its real use is to transfer a part of the strength and resistance of the main buttress *q*, to points *s s* where resistance was necessary in the roofs used in these buildings, as will appear in the next section, when treating of the construction of roofs.

918. In the same way that buttresses are used to save materials, and yet produce strength in heavy work, so likewise pannels are frequently introduced into the brick-work of ordinary walls, by which their appearance is much improved, particularly if the necessary wall is high, and is a dead wall, (this being a term that is applied to walls having no doors, windows, or other openings through them.) Thus instead of carrying up the side of a house or other building as one uniform flat surface, its appearance will be much improved if it is built as shown at Fig. 180. That is, commencing below with a plinth of ashlar facing or brick-work, of 2 or 3 feet in height, up to the line *s s*, where the wall should set back or show a break of 2 inches. The wall *t* then goes up for 6 or 8 courses in a perfectly flat manner until the pannels *u u* commence, and the faces of these may be set back two inches more, or even half a brick, if the pannels are large. The work proceeds upwards until the height of the pannels is completed, and then the wall *x* breaks forward again so as to become flush or even with the face of *v v*, leaving a break of equal depth round the four sides of each pannel, and the whole may be surmounted by a cornice *y*. This design is taken from the street front of the Cannon brewhouse at Knightsbridge, near London. The pannels extend laterally much further than in the figure, and the whole has a very bold and handsome appearance. The advantage of this mode of building, independent of its appearance, is that by setting the wall 2 inches back upon the line *s s*, and 4 inches in the pannels, the centre of gravity is thrown further back, so as to be over the middle of the footing; and 4 inches in thickness of brick-work is saved over the whole surface of the pannels, which in a large building is considerable, while the projecting piers *v v* produce strength nearly equal to that which would have been obtained had the wall been of uniform thickness. If it should be desirable to increase the elegance of appearance, white free-stone mouldings in

the form of capitals, may be introduced over every projecting pier, as at *w*, so as to give them the appearance of pilasters.

The same mode of construction may be adopted with equal advantage in house building. Thus Fig. 181, is the end elevation of the engine house of the West Middlesex Water Works, at Hammersmith, near London, erected by the writer in 1810. It contains two 70 horse power steam-engines, with their pumps and apparatus for supplying water from the river Thames to the Metropolis of London, and therefore requires great strength. The construction is the same as that last described, except that the sunk pannels commence at the top of the plinth, and terminate above in semicircular arches, instead of straight lines, the arches springing from a stone string course, constituting *imposts* in this case, because the stringing merely passes over the piers, and is not continued through the pannels.

919. As bricks are right angled at all their edges, of course they are better suited for building straight than curved walls, nor can they be used for any quoins or angles, except right angles, without cutting them. It frequently happens that buildings and walls require other angles, and whenever a wall deviates from its right lined direction to a less extent than 90°, such wall is said to *splay*, and the bricks at the external angle of the splay must be cut to suit it. Thus, suppose two walls are required in the directions *a* and *b* of the ground plan, Fig. 182. Those walls can only be built of common bricks with right angles at their ends, and in order to produce bond in the angle, each wall must *over-sail* or intersect the other, as shown in the figure, the consequence of which is that a triangular portion *c d* of every brick will project beyond the face of the wall, appearing alternately on each side of the perpendicular line which forms the point of the angle; and it is these triangular portions that require to be cut away by the edge of the trowel from each brick as it is laid at the angle, which is called *cutting to splays;* and being attended with extra trouble and workmanship, this cutting is always allowed for in measuring the work, and is charged by lineal measure, or at an agreed price per foot run upon the height to which it extends.

920. In like manner, a similar extra allowance is always made for cutting to *rakes* and *ramps*. A wall is said to ramp when instead of terminating in perpendicular ends it assumes the form of a vertical angle, as in the gable end of every house, or in *lean-to* buildings, or such as are built against the side of another building. Thus, if it was proposed to close up the end of the building, Fig. 179, by a wall, it would proceed vertically at both ends, in the principal building A until it reached the points *s s*, and then it would take angular directions to *t*, in order to fill up the trian-

gular space *s t s*, while in the lean-to building B the wall would terminate in a sloping direction correspondent with the roof *v*. Such walls would be said to ramp at *v* and from *s* to *t*, and to produce such ramps every brick requires to be cut, otherwise the wall would show a series of indentations like *a c*, in Fig. 176. The rake is the quantity of angular deviation from a horizontal line, thus we say that the ramp of a wall rakes 2 to 1, as in canal banks (358), or a ramp may have a rake or slope of 22°, or any other number of degrees. Ramps are sometimes curved instead of right lined, of which the wing wall *w*, in Fig. 181, is an example.

921. When walls are built circular, or curved on the plan, it is evident they cannot be carried up by the line and pins, which can only give right lines. Curved work must therefore be carried on by what are called *moulds*, and these are merely thin boards 3 or 4 feet long, one edge of which is cut into the curved form the wall is intended to have; and they are used in the manner of a ruler, being applied upon the upper surface of every course of work at the commencement, when the bricks or stones are placed in exact coincidence with the curved edge. When the first two or three courses are laid, the mould will only need occasional application, if the wall is to be perpendicular, because the plumb-rule, used in the ordinary way, will be sufficient to carry the work up correctly from the bottom courses, if properly laid. When curved work is of small radius, it will require all whole bricks to be cut into wedge shapes, or must be worked with half bricks; and as it is in every case more slow and troublesome than plain work, it is customary in London to allow one-third more money for its execution than for plain work. The perpendicular offsets that occur round windows, or in forming pannel work, as in Fig. 180 and 181, are called *reveals*, and as they are more troublesome than a plain wall, they are subject to a small extra charge upon their lineal measure, unless an agreement is made to the contrary. The bedding of wall plates, and fixing door and window frames in a wall, is also an extra charge.

922. It sometimes happens that the bricklayer may have to wait for the carpenter or joiner, on account of his not having timbers, or door or window frames ready for fixing at the moment they are required; and in such cases, rather than be delayed, the bricklayer will *rack back* his work, that is, carry it up at the quoins, or such parts as require nothing to be inserted in them, as shown at Fig. 183, and leave it low in other parts, still however working back in steps, so that the deficient work may be added afterwards without any variation of the bond and external appearance of the wall. Racking back is often inevitable, and is not detrimental

unless when carried to too great an extent, which ought to be carefully avoided, especially in brick-work: for in that, the sum of the heights of the horizontal mortar joints form a much larger proportion of the entire height of the building than in masonry. Now as mortar is soft when first used, and the bricks become a heavy load as the wall ascends, the mortar of the lower joints will, of course, be somewhat compressed, and the wall must sink or settle until the mortar becomes hard, when no further change can occur in its height. When racking back is carried up a considerable height, such setting will, of course, take place in it, and if left a few days, the mortar used will have become hard. The work that is afterwards filled into the cavity will also have to settle, consequently its joints must be made rather thicker than those of the old work, or if not, the new work will sink in its horizontal joints below those of the old work, thereby breaking the vertical joints, and spoiling the appearance of the whole, and not unfrequently producing cracks that are detrimental to its strength.

923. As a general rule, therefore, the brick-work or masonry of every large building ought to be carried up as nearly as possible of one uniform height all round, which is easily effected by having workmen stationed on every side who work simultaneously; or, when hands are scarce, the slower process of working the same level course, or nearly so, all round the building should be adopted, and no one part be permitted to rise more than a foot above the others, by which means an equal weight will be thrown upon every portion of the foundation and lower work, and no one part will have a greater tendency to sink or settle than another.

924. In the immense city of London where nearly every thing is built with bricks, and consequently the workmen have the best experience of what is good or bad in its execution, this circumstance of keeping the courses of even height, and distributing the load as evenly as possible over all the substructure, is so closely attended to, that even a common house is never built without running strings of *bond timber* around the whole building, and repeating them at about every 4 or 5 feet in height. Bond timber is merely pitch-pine or oak scantling of $4\frac{1}{4}$ by $2\frac{3}{4}$ inches square, or the same size as the end of a brick, in long lengths, and it is laid upon the walls in a level position, sometimes in the middle of the wall, but more frequently flush with its inner face, and lapped and nailed at all angles, or wherever joints occur in the wood, and being bedded in mortar, and built upon, it becomes a permanent part of the wall, and not only transfers all the load of the upper structure to that below, but prevents unequal settling and the possibility of vertical fissures taking place in the wall. As the whole front of a house is frequently run up so rapidly, that the mortar

in the base has not had time to set and become hard before the top is finished, such walls would be very apt to warp or wind, that is, to loose their perfectly flat vertical surface by some parts bulging outwards and others sinking in, was it not for the bond timber, which effectually prevents this occurrence; for although the bond timber is not strong, yet a very little force or restraint will be sufficient to maintain the flat figure of a wall, if it has been well built, and has been kept truly perpendicular during its erection. The more effectually to secure this object, bond timber is always permitted to run across all doors, windows, or other openings without any intermission, and it is sawed out of these openings when the work has become hard and dry, and has settled to its full extent, so as to make the continuity of the timber no longer a matter of importance. All joists, and beams also, rest upon the bond timber, which thus becomes a template (884), for distributing their weight over a large under surface. In Fig. 175, *a*, *b*, *g g g*, show sections of the bond timbers as introduced into all houses in London.

925. For the same reasons that racking back is detrimental to the appearance and strength of work, so likewise the method of uniting new work to old by means of what is called *toothing* is, if any thing, worse, notwithstanding it is much used. Toothing derives its name from the regular tooth-like appearance of the joint before it is made, as shown at *e*, Fig. 184, and it is frequently seen running up the whole side of a building to which it is contemplated to join another at some future time. If the walls proposed to be added are to be at right angles with the old wall, then the toothing is produced by leaving out a brick in every alternate course, in a vertical line, as shown at *f*. The new wall, in both cases, must be built with bricks so projecting as to fit into these indentations, but such new work will be almost sure to crack in settling, owing to the bricks in the toothing being upheld, or not permitted to descend and settle with the rest of the work. The modern improved method of producing a junction, or tying of new work to old, is by leaving what is called a *chase* in the side of the old work, as shown by the dotted lines at *g*, and the new work when built is formed with tongues, as at *h*, which fit into the chases, thus holding the two walls together, and producing the appearance of a perfectly straight vertical joint between the two buildings, and permitting the new work to sink by sliding downwards against the old work, to admit which, care must be taken at the time of building that the bottom of every tongue shall be at least one, or if the wall is high, two courses above the bottom of the chase into which it fits. The chase is left from ½ a brick to a whole brick behind the face of the wall, not only to insure

strength, but to conceal the mode of joining and produce the appearance of a straight joint. *i* Shows an indent left for a wall to be built at right angles to the first.

926. A low wall can be built for less money than a high one, because in the former, the materials are easily conveyed to it; no scaffolding is necessary for carrying on the work, and there is none of that loss of time and labour, constantly attendant on raising heavy materials to a great height. Whenever the height becomes such that the workman cannot reach his work, (and which should always be beneath his chin,) scaffolding becomes necessary, and this is usually constructed by fixing long poles in upright positions about eight feet apart and six feet in front of the wall to be erected, these are crossed and braced together by horizontal poles, tied on to the upright ones, wherever a stage may be necessary, and shorter poles, called *putlocks*, are placed at four or five feet asunder, one end resting upon the horizontal poles and the other passing into $\frac{1}{2}$ brick holes purposely left for them in the wall, and called putlock holes. The putlocks are finally covered with $1\frac{1}{2}$ inch boards, which form the floors or platforms of the scaffold, and these boards and putlocks require neither nails, tying, or any kind of fixing, as they are sufficiently firm and steady from their own weight, or the loads placed upon them; but all the materials have to be delivered on to these platforms, and this constitutes a considerable item of expense in very high buildings. Heavy stones, pieces of timber, and articles that are too heavy to be carried up a ladder by a single man, are usually raised by shear poles, such as have been already explained, (884,) or by blocks and a fall attached above to a strong projecting pole, fixed for the purpose near the top of the scaffolding. But bricks, mortar, and the more portable articles are carried up by tall ladders, or occasionally, in this country, upon inclined planes, formed by a succession of sloping scaffold boards, rising first in one direction and then in another, and these have been preferred, on the principle, that a man can carry a greater load up a gradual slope than up an almost perpendicular ladder. This is, no doubt, true, but at the same time, to make the inclined plane easy of ascent, its surface must be made so much longer than the ladder, that a man moving with equal speed might ascend the ladder twice, while he would move once up the inclined plane; consequently, if he could only carry half the weight at once up the ladder, he would deliver the same weight of load in the same time, whether he ascended by one means or the other. In England the ladder is constantly used, and the bricks, tiles, mortar, &c. are carried up on the shoulder of a labourer in an implement called a *hod*, which is found very convenient for the purpose. The hod is formed of two strong

boards nailed together at right angles to each other, with a square board to form an end, so that it is a trough of three sides, the top and one end being open. Its inside dimensions are nine inches wide on each board and sixteen inches long, so that it will hold eighteen bricks, or very nearly half a bushel of mortar. A wooden shaft or handle, three feet in length, is attached by a hollow socket of iron, terminating in a fork like a Y, to the centre of the angular bottom, which being rounded and covered with a pad of carpetting, the load is easily carried on the shoulder, and by placing the handle in a slightly inclining direction over the front of the body, a man will with some practice carry a loaded hod with great speed up a ladder without holding it at all; consequently he has both his hands at liberty for his security, or to assist him in climbing. High building ladders ought to be strong enough to bear the weight of three or four loaded men upon them at once, because when buildings proceed rapidly, the ladder is generally filled with labourers following each other in rapid succession.

927. By experiments that have been tried, it has been found that few men, even among those who are in the constant habit of serving bricklayers, can work under a load equal to half their own weight, for a whole day, which in England is made up of ten hours actual work. That is to say, twelve hours are considered a day; but half an hour is allowed for breakfast, one hour for dinner, and half an hour at 4 o'clock for rest or refreshment. Taking the average weight of men at 120*lbs.* it is found that 45*lbs.* is about the average load they can carry constantly, therefore, in the raising of materials for extensive buildings, a great advantage arises from using the weight, instead of the strength of men. This method was adopted in the building of the present Drury Lane Theatre, in London, which is a very lofty and extensive building. Instead of carrying up the smaller materials by ladders as usual, large cast iron single pullies of about four feet in diameter, with deep grooves on their edges, for ropes to run in, were fixed in the scaffolding, at a height somewhat above the greatest intended height of the building. A single rope being passed over each pulley had two large, strong, square boxes, one attached to each of its ends, and the rope was so adjusted as to length, that when one box rested on the ground, the other was elevated to a few inches above the height of that stage of the scaffold on which the materials were to be delivered. The lower box being filled upon the ground with bricks, mortar, water, slates, or any materials required, a man stepped from the scaffold into the upper box, and the load below was so adjusted as to be ten or twelve pounds lighter than himself; consequently he would descend, holding by the rope, with a velocity due to the difference in weight of the two loads, but

had the power of diminishing this velocity by letting the ascending rope slide through one of his hands as he descended, or by holding it tight, could even stop all motion. By this method the labourers could raise loads that were very nearly equivalent to their own full weight, and with scarcely any fatigue; the only exertion of strength being during their ascent of the ladders, which they had to run to and climb up as soon as they were landed on the ground, and the upper loaded box was hauled on to the scaffold to discharge its contents. But they had to ascend empty handed instead of being fully loaded, and could therefore move with much greater speed, and the advantage in economy of labour and expense was enormous. This method of raising materials was probably taken from a process of a similar character that has been used during many years for unloading the coals that are brought in the holds of vessels into London. A very large basket being slung from the end of a rope is lowered into the hold of the ship, the other end of this rope being passed over an elevated sheve or pulley, terminates in four separate ropes about five feet above the deck of the vessel; a man holds on to each of these, and when the basket is filled, the four men jump simultaneously down the hatchway, and by their joint weights overcome the weight of the coals, which are thus raised as high as the deck, and there they are caught and swung to one side by two other men standing in readiness to receive and discharge them, by a wide trough or shoot over the side of the ship into a lighter moored to receive them. The empty basket is then thrown down to be refilled, and the time occupied in its filling allows the four men ample time to ascend again to the deck by a ladder, and prepare themselves for another jump. The distance passed through in unloading coals is very insignificant when compared with that of a high building; and it may, therefore, appear that the lives of the labourers are placed in great jeopardy by using the Drury Lane method of raising materials, and it was accordingly much reprobated when first introduced, from a just notion that no saving of time or expense to the builder ought to be adopted if it exposed the lives of fellow creatures to a more than ordinary risk. The danger is, however, more ideal than real; for sailors, who are in the habit of living among ropes, and are frequently suspended by them, and miners, who are daily accustomed to ascending and descending shafts much deeper than most buildings are high, feel just as much confidence in their personal safety, while suspended to a rope, as other persons unaccustomed to such support would feel upon the boards of a scaffolding, or any other apparently more substantial support. And those who know how careless labourers (who are accustomed to the business) become, in ascending high ladders with heavy loads, will admit that there is quite as little danger attendant upon descending by a good rope. At any rate no accident occurred to bring the method into disrepute while it was extensively and constantly used in the erection of this large theatre, and the labourers, when they became accustomed to it, preferred it to the ordinary mode of using ladders. A notice of it has been introduced here, from a conviction that the Engineer may employ the weight of workmen in raising loads, in many instances, with greater effect and satisfaction to the men, than if he employed their strength alone, as usually done.

928. In the execution of brick-work, since a great proportion of the strength of the work depends upon a proper adhesion of the mortar to the bricks, it ought always to be used in a thin, rather than a nearly solid state, and in dry weather it will be advantageous to wet the bed, or top of the course to be worked upon, by sprinkling water from a large brush upon it, or even dipping the bricks into water. As the mortar is a more perishable material than the bricks, the mortar joints cannot be too thin, provided the bed is entirely covered with it. When it is necessary to give brick walls the greatest possible strength and solidity, and they are sufficiently thick and large to admit of the process, they ought to be *grouted* at every second or third course. Grouting is pouring very thin mortar, or common mortar mixed with as much water as will render it nearly as fluid as cream, upon the top of a course of brick-work, in order that it may run down between the joints and fill every hole and crevice that may have been left in the work. Whenever grouting has to be performed the surrounding edges of that course on which it is to take place must be carried up at least one course higher than the central work, to form a basin or recess for holding the grout, which should be stirred about with the edge of the trowel, or a small hoe, to distribute it evenly over the whole surface of the work.

929. Nearly allied to grout in its nature, is the concrete, beton, or grubb-stone mortar, before spoken of under the head of cements (528). As was then observed, this composition is little known in England, and the writer has never known an instance of its application or recommendation by any practical Engineer. As, however, it is spoken of in high terms of approbation by some of the French Engineers, and is said to combine many advantages for constructions in water and forming foundations, it ought not to pass without notice.

Sganzin states that "grubb-stone mortar is used for building the foundations of hydraulic works; it is poured into the water, either directly, or by means of boxes made for this purpose, in order to prevent the mortar from spreading in passing through the fluid to the bottom. No general rule can be given for the composition of grubb-stone mortar, as the quality of the materials influences the proportions and causes them to vary. The following is a composition of this mortar, which has been employed with success:—

In 40 parts,	Puzzolana from Italy, - -	12
	Coarse gravel, - - - - -	6
	Hydraulic lime, (quick,) - -	10
	Clippings of stone, - - -	12
		40

"To make grubb-stone mortar, the puzzolana is spread and formed into a hollow basin, in which the lime is placed and slaked, according to M. Fleuret, after which the gravel is mixed with the lime and puzzolana; after the mortar is made, the clippings of stone are added without water, that used for slaking being sufficient. The mixture should be well worked with a hoe and shovel, after which it should be left for ten or twelve hours, and then be worked up again and mixed before it is used. When this mortar is required to fill up between two walls, to render the work impermeable to water, the quantity of stone is reduced to one half, and to smaller dimensions; the gravel is also suppressed, and pit sand substituted."

As the writer is unacquainted with the use of this mortar, it is perhaps not correct to hazard an opinion upon it; but it does appear to him to be a wasteful process of employing expensive materials, and one not calculated to produce the necessary solidity. He, therefore, prefers another process, which his experience has proved to answer the purpose of filling in or forming foundations, and that is to use broken stone free from round pebbles, and the harder the better; to place this in shallow layers not exceeding three or four inches thick—to beat down the stones into as compact a state as possible by a stone axe or light wooden hammer, and then to grout over the whole in the usual manner, except that the grout may be formed of cement or hydraulic lime, or of a mixture of common mortar grout with cement added to it, at the moment of stirring it into the work. This produces a very hard mass with a small quantity of expensive cement.

930. As frosty weather is decidedly inimical to brick-work, because mortar that is frozen will never afterwards set hard, but will always be pulverulent, no brick-work should ever be attempted in weather that is so cold as to freeze the mortar. And should frost come on after brick-work is finished, but before the mortar has had sufficient time to set and get hard, the walls should be pro-

tected by thatching, or covering them with straw matting, or some protecting substance.

931. Mortar joints should be finished on the face of all good walls, by passing the point of the trowel over them to render them quite smooth, when they are said to be *flat*, and the work is called *flat jointed*. Formerly a practice existed of striking the joints of the best exterior work, which is nothing more than applying a straight edge or ruler to the middle of the joint, and drawing a flat, but round ended steel tool, so as to draw or rule an indentation of about $\frac{1}{8}$th of an inch wide, and half as deep, along the middle of the mortar joints. This must of course be done before the mortar sets hard, and gives a very neat appearance to the work when closely examined, but as it affords no advantage to brick-work when seen from a distance, and adds to its expense, it is now seldom adopted. Another method of ornamenting brick-work is by what is called *tuck pointing*, but this is generally employed to renovate and beautify old work. The common mortar being raked out, is replaced, or pointed in with pointing mortar, made of common mortar mixed with powdered charcoal or soot, and the scoria from a blacksmith's forge. The joints are filled in *flat* with this composition, which dries of a dark gray, or nearly black colour. A *tuck* or strip of fine stuff, made of finely sifted slaked lime and plaster of Paris, but no sand, mixed as thick as glazier's putty, cut by a long knife or trowel, so as not to exceed a quarter of an inch in width, is now laid carefully along the centre of every joint, and if well done, it gives the work a very handsome appearance. Tuck pointing is however tedious, and requires great accuracy of workmanship to look well, and is therefore expensive.

932. Brick-work to furnaces, such as those for melting or refining metals, the boilers of steam-engines, the coppers of brewers, distillers, and the like, should be built with an internal facing next the fire, of fire bricks (495) at least half a brick, or frequently a whole brick thick, according to the constancy and intensity of the fire to be maintained; but the external walls may be of ordinary bricks. In fire-work, or brick-work exposed to the action of strong fires, the joints cannot be too thin, and no mortar should be used in them, for that would burn to quick lime again and loose all its tenacity. Instead of mortar, loam or fire clay, (if procurable,) tempered with water till rather thin, should be used, as this will burn hard by use: and as strong heat usually expands, vitrifies, and cracks the brick-work of furnaces, their sides ought to be tied or connected together by bars of wrought iron passing through the brick-work, and through cast iron plates on the outsides of the same, held by screws on the ends of the ties, or by iron keys

passing through them. The ties should, of course, pass in directions where they will be as much protected from the heat of the furnace as possible. The flue or *stack* of all furnaces ought to have a separate foundation, and should in no case be set upon the furnace; for all furnaces wear out speedily, and require taking down and rebuilding, therefore the means of doing this without disturbing the stack should always be provided for.

933. As Engineers, in the prosecution of their works, have frequent occasion for temporary buildings, both as dwellings and for workshops and storehouses, these are generally made of timber constructed as rough framed buildings, so put together that they can be taken down and removed from one place to another. But sawed timber is often scarce, and if the buildings are required for smiths' shops, melting metals, cooking, and other purposes where fire is extensively used, wooden buildings are not safe, and are excessively hot in hot countries and seasons. It may not, therefore, be amiss to remark, that more comfortable and safe buildings may be easily constructed in hot countries where clay abounds, without burning it into bricks. The clay may be tempered with water and mixed with straw, to give it tenacity, when it may be moulded into large flat bricks, 24 inches long, 12 wide, and 4 inches thick, which being set on their edges in the sun, and turned, will soon have sufficient strength to be moved and used: and with blocks of such dimensions, the external walls of a single story house or workshop, with its fire-place, door, windows, &c. may be soon built, without any other mortar than the same clay rendered thin by water. The roof is formed by placing straight poles in a sloping direction, and covering them with the same blocks, thatched on the outside with large leaves, slabs, shingles, or any thing that will protect the upper surface from rain; and all unnecessary chinks and holes being stopped and plastered with clay, a very comfortable dwelling as to temperature, either in hot or cold weather, will be produced. These sun-dried blocks of clay are called *Adobis* in Mexico, and a large proportion of the houses, out of the cities, throughout that republic, are built of no other material, and when plastered with lime plaster, they stand a number of years.

934. Another mode of mud building, called *pisé building*, much used in Italy and the south of France for farming purposes, is carried on by driving a double row of parallel upright stakes into the ground in the form of the intended building, the rows being at a distance asunder equal to the thickness of the proposed walls. Thin smooth boards are then set upright against the insides of the rows of stakes, and the space between them is filled up with tempered clay and straw, placed in even horizontal layers, and ram-

med down by wooden rammers. When this work becomes sufficiently dry to stand and maintain its shape, the boards are withdrawn, and placed in higher positions, to be again filled with tempered clay, and so on until the walls reach their full height. Bond timbers (924) may be placed at the bottom and top of each window, and these, by running quite round the building, will add much to its strength and durability. Sir John Sinclair, in his Agricultural Reports, speaks in terms of approbation of these buildings, and recommends their use in England.

Of the Measurement and Valuation of Brick-work.

935. Brick-work is almost constantly measured by the square rod or perch of 16½ feet, by a thickness of 1½ brick, or what is called in England 14 inch work, so that if a wall is thicker or thinner than this standard, it has to be reduced to that thickness, and hence the term so frequently used of so many rods of *reduced brick-work.*

The square of 16½ lineal feet is 272.25 square feet, but by custom the fraction is cancelled, and 272 square feet are considered as one rod of work, consequently 136 square feet will be half a rod, and 68 square feet a quarter rod.

936. Brick-work is measured by a pair of five feet wooden rods, divided on both sides into feet, and half and quarter feet, any dimension less than three inches being taken by the estimation of the eye, while the rod is applied. The operation is usually conducted by three persons, viz: the Engineer or Measurer, who writes in the measuring book, directs what measures are to be taken, and inspects their correctness before he enters them, and two assistants or rodmen, each of whom carries one rod. The rods, when used, are made to coincide with, or be parallel to, either horizontal or vertical joints, and the first rod having been applied to the work in its proper position, is held there by the first man, while the second causes the end of his rod to abutt against its end: the second rod is then in turn held firmly against the work, while the first man moves onwards and places his rod in the same position, and so on, until the whole horizontal range of work is measured, when the entire length is put down as one dimension.

Vertical heights are obtained by the same process, the measurers using ladders, or scaffolding, or climbing up to the openings of windows, should no more convenient mode present itself. The rods ought to be so flexible as to bend readily round arches or circular openings, for getting their dimensions.

937. Who ever has charge of the superintendence of brick-

work ought to measure, and keep a record of all foundations, footings to walls, and other underground work, as soon as it is done; or at any rate before the soil is returned into the trenches of the foundation, because such brick-work then becomes invisible, and if its measurement has not been previously recorded, it will be necessary to dig holes for examining and measuring it afterwards, and this occasions much additional trouble and delay.

938. Whenever the thickness of brick-work changes, a new dimension must be taken, and a new entry made in the book; but any work that is of the same thickness and at the same level, may be included in the same dimension.

939. The dimension book is ruled with three narrow columns on the left side of each page, the remainder being left for writing descriptions and remarks; being the same as the stone measuring book referred to (897), but there is no moneying column on the right hand side.

940. Brick-work is sometimes cubed, (particularly when walls are very thick,) but the usual mode of measurement is to merely measure the square superficies on the face of each wall, and write against it the thickness of the wall in bricks and half bricks. The dimensions, as taken, are written down one under the other, with a line under each when complete, in the second column of the book, and the third or next column is left blank for the insertion of the products or multiplication, or squaring of those dimensions, which is never done at the time of measuring, but is left to be performed in the office at home, and is usually the lot of the junior clerk, or clerks, in that office. The working of the operations is performed on a slate or waste paper, and the result above carried to the third column of the book, while the fourth or wide column, contains the thickness of the wall in bricks (when cubing is not used), an account of the place where the dimensions occurred, and any other necessary observations.

941. When brick-work is cubed, take the long, or horizontal dimension first, and set it down in feet and inches in the second column; next, take the perpendicular height, and set that down in a second line immediately under the first dimension; lastly, take the thickness of the wall in feet and inches, and write it as a third line, directly under the two others, and draw a line across the column, because that dimension is complete. In like manner proceed to take other dimensions, and set them down in the same order and manner, until the top of the building is reached, or the work otherwise finished. Each complete dimension will now consist of three members, a length, a height, and a thickness, and these have now to be worked out. The length multiplied by the

height will give the superficies, and this multiplied by the thickness will give the solid or cubic contents of that portion of the wall, which must now be entered in the third column. When all the quantities have thus been separately cubed and carried to the third column, that column may be cast up, and its sum will be the total number of cubic feet and inches contained in the work. If the work has been agreed to be paid for by the cubic foot, as is often the case, this is all that will be wanted: but if the cubic measure has to be reduced to rod measure, multiply it by 8 and divide the product by 9, when the quotient will be the rods of reduced brick-work, because the standard thickness of $1\frac{1}{2}$ bricks should be $\frac{9}{8}$ths of a foot.

942. When brick-work is measured by the more usual process of taking the thickness of the walls in bricks and half bricks, only two dimensions will appear in the second column of the measuring book, viz: length and height; the third column is left blank as before, and the thickness of the wall is placed before the description of the work, as will appear in the following short example of keeping a bricklayer's measuring book.

A M, in the following heading, means all materials, i. e. the workman finds bricks, mortar, labour, scaffolding, and all tools and materials for executing the work. L and M is, in like manner, used to signify labour and mortar only, and L *only*, when the bricklayer is provided with all materials, and has to furnish labour alone. Brick-work is contracted for under one or other of these conditions. The headings of all measuring books should be full and explicit, because they are often produced in courts, or at arbitrations, as evidence; consequently they should contain no erasures, except such as are made by striking the pen through articles and writing them again; neither should any leaves be torn out. The time when the work was done should be particularly specified on account of the price, for as both materials and labour fluctuate in value with times and seasons, so by specifying the date of the work, prices accordant with that date, can always be obtained.

Measurement of Bricklayer's Work

A M, executed by A B for C D, between January and June, 1832, in building additions to Jefferson Medical College, in Philadelphia, as measured this 27th day of July, 1832, by J. M.

	58 1	6 6	87	9	4 brick footing to west wall.
	58	0 9	43	6	3½ brick footing to do.
	57	6 9	43	1	3 brick footing to do.
	56 11	8 2	632	7	2½ brick wall of basement story.
4)	6 4	6 10	125	8	½ brick DD in recess pannels.
4)	4	10	36	8	2½ bricks DD 4 semicircular arches.
4)	7	6	22	6	run of 9 inch gauged arches over same, 4 inches thick.
2)	29 1	6 6	88	6	4 brick footing to north and south walls.
2)	29	6 9	44	3	3½ brick do. to do.
2)	29	6 9	44	3	3 bricks do. to do.
2)	29 11	6 2	649	0	2½ bricks north and south walls.
	9 8	6 6	80	9	2½ bricks DD gateway in south wall.
	4 3	6 3	14	8	2½ bricks DD window in do.
	5	0	3	9	run of 9 inch gauged arch over same, 4 inches thick.
	12	0	9	0	run of do. over gateway.
	56 16	8 0	906	8	2 bricks—west wall above first set-off.

2)	29 16	6 0	944	0	2 bricks north and south walls above 1st set-off.
6)	10 5	6 0	315	0	2 bricks DD windows.
6)	5	0	56	10	2 bricks DD semicircular arches over same.
6)	6	6	29	3	run of 9 inch gauged arches, 4 inches thick, over same.
	56 11	8 3	637	6	1½ bricks, west wall in third story.
2)	29 11	6 3	663	9	1½ bricks north and south walls in 3d story.
6)	4 2	0 3	54	0	1½ bricks DD openings for ventilators.
6)	5 3	3 6	113	3	1½ bricks DD windows.
6)	3	9	18	0	run of 9 inch camber gauged arches 4 inches thick to windows.
	56	8	396	4	1 brick in pediment finishing west wall and rising 14 feet in centre.
2)	32	0	64	0	run cutting to ramps of do.
	13	0	63	0	1 brick DD semi window in pediment.
	21	0	24	6	run of 14 inch gauged arch over same.
No. 14.					wrought stone sills bedded and fixed to windows, &c. &c.

The above work abstracted in Abstract Book, No. 5, page 60.

943. The building referred to in the above entries, was an addition, consisting of three walls, to a former building, which constituted the fourth side to the new work; consequently, there were two new walls on the north and south sides, and only one on the west. The net external length of the new building, as it appeared above ground, was 56 feet 8 inches, and its breadth 31 feet 9 inches. As the measurement always commences at the bottom of a building, the first dimension to be taken is the lowest footing or foundation of the largest or principal wall, which is 58 feet 6

inches long by 1 foot 6, or six courses high, and four bricks thick, as entered at the commencement of the measuring book. Then the footing diminishes to $3\frac{1}{2}$ bricks, which makes a separate dimension necessary; and this is 58 feet long by 9 inches high. The footing still diminishes to 3 bricks, and is accordingly set down as 57 feet 6 inches, by 9 inches high in 3 bricks. All this work is underground, and unseen, and consequently should be measured before the earth is refilled into the foundation trench. The wall of the basement story next appears above ground, and this is 56 feet 8 inches long, by 11 feet 2, in $2\frac{1}{2}$ bricks up to the first offset or line, where the wall diminishes in thickness. This wall is, therefore, all taken at one dimension, as if it was of even thickness throughout; but it is not so, for it is worked in pannels, (918,) each of 6 feet 6 inches high, and 4 feet 10 inches wide, showing a break of half a brick, and as these pannels are four in number, the dimension is set down as $4)\begin{matrix}6 & 6\\ 4 & 10\end{matrix}$ in $\frac{1}{2}$ a brick DD, which shows that the product of this dimension is to be taken 4 times over, and the DD indicates that the sum so obtained, and $\frac{1}{2}$ a brick thick is to be deducted from the amount of the $2\frac{1}{2}$ brick-work last measured: DD being the common mark to denote deduction or subtraction. Each of these pannels is surmounted by a semicircular arched opening quite through the $2\frac{1}{2}$ brick wall for lighting the lower story. Hence the dimension 4) 4 feet 10 inches, in $2\frac{1}{2}$ bricks DD for 4 semicircles, which shows that the area of a semicircle of 4 feet 10 inches in diameter is to be found in square superficial feet (176), and is to be deducted at $2\frac{1}{2}$ bricks thick from the $2\frac{1}{2}$ brick wall. Each of these semicircular openings is finished or ornamented by a gauged arch, (see gauged and camber arches in the chapter on arches,) which is charged by superficial measure, obtained by bending the measuring rods over the central part of such arches, which gives a length of 7 feet 6 inches as set down in the second column, to be multiplied by 9 inches, the width of such arch, which is 4 inches or $\frac{1}{2}$ a brick thick. No deduction is however made from the quantity of ordinary brick-work on account of this 4 inch work, which may thus appear to be taken twice into the computation, but this is not the case. The 4 inch gauged arch is measured in with the general mass of brick-work, and this accounts for the surface of the arch being taken in superficial measure only, without any regard to its thickness; an allowance being made upon the superficial measure, and not the solid work of such arches, for the extra trouble in constructing them; and as these arches occur 4 times, all of the same size, the dimension 7 feet 6, is preceded by 4) in the first or left hand column, which shows that the dimension is to be taken or multiplied 4 times.

The three next dimensions are all alike in length, and apply to the underground footings of the north and south walls, which are measured separately by the rods, and being found alike, there is no occasion to repeat the writing of the dimensions in the book, but they are preceded by 2) in the first column, to indicate that they are to be reckoned twice in the casting up as before explained (898). And the same observation applies to the next dimension 29 feet 6 inches by 11 feet 2, being the length and height of the two end walls up to the first floor or set-off; but two deductions in $2\frac{1}{2}$ bricks it will be seen occur in the south wall, for a gateway and a window made through it, as expressed by the two dimensions 9 feet 6 by 8 feet 6, and 4 feet 6 by 3 feet 3 inches; and these are followed by the two single dimensions 5 feet and 12 feet, being the lengths of the two gauged arches over these openings, to be treated as before.

The two succeeding dimensions give the lengths and heights of the three exterior walls, (one of them being taken twice,) and which are taken separately, because these walls are thinner than those that preceded, being only $1\frac{1}{2}$ bricks thick. In the walls six windows occur having arched or semicircular tops, consequently each window requires two dimensions, viz: 10 feet 6 inches high by 5 feet wide for the lower or rectangular part, and a single dimension of 5 feet being the diameter of the semicircular head. These dimensions have 6) prefixed to them, because the same sized windows occur six times over, and that is likewise the case with the semicircular gauged arches that surround them. The two next dimensions (the latter having 2) prefixed) give the dimensions of the three walls of the upper story, which might have been taken at once with those of the lower story, because no set-off occurs, and they are still $1\frac{1}{2}$ bricks thick; but on account of the convenience of taking the height of this part from one of the windows, it was made a separate dimension. This upper range of walling, like the last, contains six air holes or ventilators, but as they have straight, instead of arched tops, and are all alike, they can be expressed by the simple entry of $6)^{4\ \ 0}_{2\ \ 3}$, and the like of the six windows, 6)5 feet 3 by 3 feet 6. The six gauged arches over these windows, each 3 feet 9 inches long, need no explanation after what has been stated concerning the others.

The last wall to be measured is the triangular gable end which finishes the west wall of the building, and which is only 1 brick thick. This has but one dimension 56 feet 8 inches set against it, which is the entire length of the building, but in the right hand column of remarks, it is stated to be a pediment of 1 brick thick, rising to the height of 14 feet in the centre. A pediment is always a triangular form, consequently this portion of wall is a triangle having a base of 56 feet 8 inches long, and a height of 14 feet, and its superficial area must be found by Problem XXX (173).

Each raking or sloping side of this triangular wall measures 32 feet, therefore 2)32 or 32×2, will give the quantity or length of cutting to the ramps of this wall (920), to make it agree with the slope of the roof. Lastly, a semicircular arched window of 13 feet diameter occurs in this pediment, which has to be deducted from the 1 brick wall, and then the superficies of a 14 inch gauged arch over the same must be added, which completes the measured work. Fourteen stone window sills it appears were fixed in the different windows, and these have to be charged at a certain price for each according to their size and length.

944. The foregoing is but a short example of the method of making entries in a measuring book, and these entries will, of course, become extensive in large buildings. It will be observed that while these measurements are taking and entering in the book, the third column is constantly neglected, or left blank or open. But when the measurement is finished, all the dimensions have to be worked out or squared on waste paper or a slate, and the results so obtained are the quantities to be set down in the third column. Thus on multiplying the first dimension 58 feet 6 by 1 foot 6, the product is 87 feet 9 inches, which is entered in the third column, and the same applies to the three dimensions that follow. The fifth dimension is 6 feet 6 inches by 4 feet 10 inches, the product of which would be 31 feet 5 inches. But this dimension is preceded by 4) in the first column, showing that it must be multiplied or taken 4 times over, thus producing 125 feet 8 inches, which is accordingly entered in the third column, and the sixth and seventh dimensions are treated in the same manner. The 8th, 9th, 10th, and 11th dimensions being preceded by 2) are, for like reasons, doubled before they are set down. The dimensions from the 12th to the 16th having no coefficient or multiplier prefixed to them, are treated as simple quantities, and of course are entered as their actual results; but the 18th, 19th, and 20th are multiplied by 6, and so on of the others that follow.

945. In this way the whole third column of the book is filled up, and that accomplished, the contents of this column has to be parted or separated into distinct parcels or columns, each containing the same kind of work, which operation is called *abstracting dimensions*, and this is done in a separate book prepared for the purpose called the abstract book, which is ruled in a number of vertical columns, one of which is appropriated to each variety of work, and the next adjoining column to the deductions from that same

kind of work, and the columns are headed accordingly, as in the following example.

946. Abstract of brick-work done at Jefferson Medical College, Philadelphia, as measured 27th July, 1832, as per dimensions entered in Measuring Book, No. 40, beginning at page 1.

4 Bricks.	4 Bricks DD.	3½ Bricks.	3 Bricks.	2½ Bricks.	2½ Bricks DD.	½ Brick DD.	2 Bricks.
87 9		43 6	43 1	632 7	36 8	125 8	906 8
88 6		44 3	44 3	649 0	80 9		944 0
					14 8		
176 3		87 9	87 4	1281 7	132 1		1850 8
				132 1			371 10
				1149 6			1478 10

2 Bricks DD.	1½ Bricks.	1½ Bricks DD.	1 Brick.	1 Brick DD.	Super. of gauged arch.	Feet run of cutting to ramps.	Sills set.
315 0	637 6	54 0	396 4	63 0	22 6	64 0	No. 14.
56 10	663 9	113 3			3 9		
					9 0		
					29 3		
371 10	1301 3	167 3	396 4		18 0		
	167 3		63 0		24 6		
	1134 0		333 4		107 0		

947. The order of succession of the columns in the abstract book, need not be attended to; the usual method of making the entries, being to take the dimensions as they occur in the measuring book, and write them off into the abstract book, heading the column in which they are entered, whenever a particular kind or thickness of work occurs for the first time; and then entering all repetitions of the same work as they occur in the same column. Thus the measuring book begins with 87 feet 9 inches

of work 4 bricks thick; and accordingly the first column of the abstract book is headed with "4 bricks," and the dimension 87 9 is written in the column under it. The next column to the right is headed "4 bricks DD," and is for deductions in four brick-work, of which there are none in the example, consequently the column remains blank throughout; and it is only introduced here, to show where the deduction column should be placed.

The next dimension is 43 feet 6 in $3\frac{1}{2}$ brick-work. The third column is therefore so headed, and the amount set down in it; and so of the fourth column, which contains the third dimension, 43 feet 1 inch in 3 bricks; and as no deduction occurs in the examples, either in the $3\frac{1}{2}$ or 3 brick-work, so the deduction columns have purposely been left out. The fourth dimension is in $2\frac{1}{2}$ brick-work, and the fifth column of the abstract book is allotted to it; but the example offers two distinct kinds of deduction from this variety of work, viz: one of only half a brick thick and the other of the whole thickness, therefore two distinct deduction columns here become necessary, one of which is headed "$2\frac{1}{2}$ bricks DD," and the other "$\frac{1}{2}$ brick DD." In this manner every distinct kind of work, and every deduction from such work has a separate column appropriated to it, so that all the dimensions of the measuring book become classified and arranged; which being done, each column is to be separately cast up at its bottom, and the sum will show the total quantity of work of each particular kind. Thus we find that we have a total of 176 feet 3 inches superficial of work 4 bricks thick, and 107 feet super. of gauged arches, &c. in the whole building. When deductions occur, the sum of the deductions must be subtracted from the sum of similar work. Thus by the fifth column it will appear that we have 1281 feet 7 inches super. of work $2\frac{1}{2}$ bricks thick: but the sum of the $2\frac{1}{2}$ bricks DD column, is 132 feet 1 inch, which sum must be subtracted from 1281 feet 7 inches, and will leave 1149 feet 6 inches of actual work to be paid for. The same thing occurs in the seventh, ninth, and twelfth columns containing respectively 2 bricks, $1\frac{1}{2}$ bricks, and 1 brick-work.

948. Having thus abstracted, or sorted, the several varieties of work, the next operation is to reduce them all to the standard thickness of one and a half bricks, in order to get the work into rod measure, and

The Rule for Reduction

is to *multiply the superficial measures obtained by the number of half bricks in the thickness of the work, and divide the product by 3, which will give the superficial standard, or rod measure.*

The first quantity, 176 3, in the abstract book must, therefore, be multiplied by 8, because the work is 4 bricks, or 8 half bricks thick, and the product must be divided by 3, viz:

176 ft. 3 in.×8=1410 ft.÷3=470 feet superficial.

The second quantity, 87 feet 9 inches, being in $3\frac{1}{2}$ bricks, must be multipled by 7 (half bricks), and be divided by 3.

87 ft. 9×7=614 ft. 3 in.÷3=204 feet 9 inches.

The third quantity, 87 feet 4 inches, being in 3 bricks, has to be multiplied by 6 for division; but it may be here remarked that whenever the thickness of a wall amounts to an even multiple of the standard thickness, a shorter operation may be adopted; because it is only necessary to multiply the superficies given in the abstract book by the number of times the standard thickness is contained in the work, and this of course will give its reduction. Thus 87 feet 4 inches of work 3 bricks thick, is evidently the same as twice that quantity at $1\frac{1}{2}$ bricks thick, or the standard thickness is contained twice in the thickness of the wall, consequently this dimension has only to be doubled or multiplied by 2, making 174 feet 8 inches of reduced work.

The fifth column contains work $2\frac{1}{2}$ bricks thick, which, of course, has to be multiplied by 5 (half bricks).

The seventh column is work $\frac{1}{2}$ brick thick, consequently no multiplication is necessary, but the gross quantity is at once divided by 3, because work in $\frac{1}{2}$ a brick thick, is only equal to one-third of the standard thickness.

The eighth and ninth columns contain work in 2 bricks, and this is multiplied by 4 and divided by 3.

The tenth and eleventh columns contain brick and a half work, and this requires no operation upon it, since the superficial measure is of the proper standard thickness in the first instance.

The twelfth and thirteenth columns are work in one brick, consequently equal to only two-thirds of the standard thickness. We may, therefore, take two-thirds of the measured quantity; or may obtain that same result by multiplying the measured quantity by 2 and dividing by 3.

The fourteenth, fifteenth, and sixteenth columns require no explanation. The fourteenth gives the sum of the superficial measure of all the gauged arches about the same building; the fifteenth the lineal measure of all the cutting to ramps; and the sixteenth the number of stone window sills set. The first of which is to be priced at per foot super.; the second at per foot running measure, and the last at per piece.

949. All the dimensions being thus consolidated and reduced to a brick and a half thick, the several reduced quantities have now to be added together, and their sum will be the number of super-

ficial feet at reduced thickness, and this being divided by 272 will give the number of rods of work. The remainder (if any) must be again divided by 136 or 68, to obtain half and quarter rods, and the final remainder will be superficial feet, each to be charged at the 272nd part of the value of a whole rod of work.

950. From the above observations, it will appear, that all doors, windows, and other openings made in walls, are subject to deduction from the quantity of work; but no deduction is made for bond timber, or small holes left for receiving the ends of girders or other timber. No deduction is made for fire-places and their flues or chimneys, in valuing work for labour and mortar, or labour only, because it is considered that the extra labour and trouble in their formation, is equivalent to such deduction. But when work is done finding all materials, the quantity of material that would be necessary to fill up such openings, should be deducted.

951. The value of brick-work is determined in the following manner.

In London 4,500 bricks are allowed to each rod of reduced brick-work, being an ample quantity to cover waste.

$37\frac{1}{2}$ struck bushels of quick lime, and

54 heaped bushels, or 66 struck bushels of sand.

The hire of one bricklayer, and one labourer to mix up mortar and carry the materials, including the use of scaffolding, ladders, tools, &c. is considered equivalent to ten dollars for each rod of work of the best kind; therefore, knowing the price of labour and materials, the net cost can be obtained, and upon this, 15 per cent. is added for profit to the master.

The bricks of the United States being smaller than those of London, more mortar joints as well as more bricks will be necessary for the same bulk of work. This addition amounts to from $\frac{1}{5}$th to $\frac{1}{4}$th upon such work as the writer has examined.

952. The most usual manner of contracting, and paying for brick-work in the United States, is by the 1000 bricks laid, or if measured, the measurement is taken in cubic feet, and charged according to the nature and neatness of the work. The following particulars may assist in ascertaining the value of work.

	Bricks.
A bricklayer and labourer can, in a day, lay in inside walls with rough joints, - - - - - -	1,200
In external walls with joints struck smooth, - - -	1,000
In front walls with facings, taking facing and backing together, - - - - - - - - -	500
In arches to vaults, cellars, &c. - - - -	750
In paving flatwise, including levelling the ground, -	2,000

One cask of lime (3¼ bushels), and two cart loads of sand (27 bushels), will lay 1,000 bricks in mortar.

17 London, or 22 Philadelphia bricks, make a cube foot of brick-work laid in mortar.

The value of brick-work laid by the thousand, in party or internal walls, with rough joints, is nearly as follows, in New York and Philadelphia.

1,000 common hard bricks delivered at the work,		$5 75
1 cask of good lime,	do.	1 12½
2 loads of sand,	do.	50
Bricklayer ¾ of a day,	- - -	1 12½
Labourer ¾ of a day, -	- - -	75
Use of scaffolding and tools,	- - -	12½
		9 37½
	Profit, - -	1 62½
		$11 00

or 11 dollars per thousand, producing 46 cubic feet at 24 cents per foot.

For brick-work in neat external walls with struck joints.

1,000 common hard bricks delivered,	-	$5 75
1 cask of best stone-lime,	- - -	1 50
2 loads of sand,	- - - - -	50
Bricklayer one day,	- - - -	1 50
Labourer one day,	- - - -	87½
Use of scaffolding and tools,	- - -	12½
		10 25
	Profit, - -	1 75
		$12 00

or 12 dollars per thousand, producing 46 cubic feet at 26 cents per foot.

In vaults and arches all will remain the same except the bricklayer, who will be allowed 1¼ day. And in the very best facing work, laid with fine mortar joints in the best manner, the bricklayer and labourer will require 3 days each to the 1,000 bricks.

A superficial foot of facing to fronts will take 8 bricks.

A superficial yard, or 9 square feet of paving will take 42 bricks.

One bushel of Roman or Hydraulic cement, mixed with two bushels of clean sharp sand, will lay 150 bricks; or will cover 4 square yards of plastering on brick-work.

As before stated, 306 cube feet of brick-work make a rod of work reduced to the standard thickness.

Fire-work, from the extreme care and nicety requisite in its execution, is seldom measured, but is done as day work. This is also the case with all small jobs which cannot be worked in a speedy and straight forward manner, or which require more time and attention than is necessary in building regular walls. *Under pinning* to walls is of this description, being the building of small portions of wall at a time, from the foundation up to a wall, or frame building previously erected, for the purpose of supporting and sustaining it. The whole foundation of a building, when defective, is sometimes renewed in this way by taking down a small portion of the old wall at a time, and replacing it with new work well wedged up, before another portion of the old wall is taken away.

With the above data and particulars, it is presumed no difficulty can arise, either in the measuring or setting a value upon any kind or quantity of brick-work.

Section 3.—*Of Carpentry.*

953. Carpentry is the art of cutting out and fixing together pieces of timber for the purposes of architecture, constructing machinery, and in general for all considerable structures, which operation goes under the general name of *framing timber.*

Although carpentry is confined to wood-work exclusively, it requires frequent assistance from the metals, particularly iron, as in straps, ties, screw-bolts, wedges, &c., in order to give greater strength to the work. With the making of these articles, of course the carpenter has nothing to do, but it is a part of his business to fix and apply them judiciously in their proper places.

954. Carpentry is divided into two distinct branches, called *Carpentry* and *Joinery,* and the workmen who pursue them are called Carpenters and Joiners, but the two branches are almost constantly conjoined and followed by the same workmen. Carpentry is the art of framing or putting timbers together so as to produce strength, stability and duration, without regard to neat finishing, except only in the joints or parts of union, the remaining part of the timber being left rough as it comes from the saw. Joinery, on the contrary, is the work of putting small pieces together in a smooth and finished manner, planing the surfaces, forming mouldings, and other ornamental work in which beauty is more important than strength. The work of the joiner, therefore, generally follows that of the carpenter, and is frequently used to hide the unsightly appearance of his work.

Thus in building a frame house, the putting up of the studs or quarterings that are to form the external parts and internal partitions, the joists for receiving the boards of the floors, and the preparation and fixing of the roof to receive shingles, tiles, or other covering, would all be styled carpenter's work: But the making and fixing (called *hanging*) of all doors, window sashes, shutters, shelves, and even the planing and laying of the floor boards are the province of the joiner. It will thus appear that while taste, combined with neatness of execution, constitute the chief perfections of a joiner, that the carpenter must, in addition to these qualifications, possess science and skill to judge of the strength of the materials he has to use; and should also understand the effects that will be induced by the weight and pressure of separate pieces acting against each other when conjoined; he must know how to distribute these forces to the greatest advantage, and also how to unite the pieces together so as to produce the greatest strength out of a given quantity of material. On this account the carpenter ranks as the highest grade in the two branches, for scientific carpentry is among the most beautiful of the applications of the principles of mechanical philosophy to the useful purposes of life.

955. In England a third kind of workman has been introduced by the Engineer, who, in addition to the usual qualifications of the carpenter and joiner, has higher attainments, and is more versatile in his operations. That is the *Millwright.* Carpenters who are in the habit of building houses and ordinary buildings, generally work in straight lines, and construct that which has to remain stationary. They cannot therefore be expected to be so expert in constructing circular work, or be so well acquainted with the strength and other qualities of that which is to move, as one who devotes his whole time to such business. A carpenter who might build an excellent and durable house, would probably fail in his first attempt to make a good coach-wheel, much more to construct a perfect water-wheel for a mill, to hang it on its shaft, and construct the cog or toothed wheels it has to drive. Such business belongs particularly to the millwright, who is brought up and educated for this sort of business. He is generally a good and perfect workman in wood; but a good millwright is also able to work at the forge, to turn, to set out work with accuracy, such as the forms for the teeth of wheels to move into each other with the least friction, and he should understand pump-work and hydraulic machinery. In constructing a mill or manufactory in England, the external building is alone entrusted to the ordinary class of masons, bricklayers, carpenters, and other workmen, and the millwright is called in to put up and fix the steam engine,

water-wheels, or other machinery that has to perform the mechanical operations. This class of workmen, from their scarcity and skill when good, are paid at a higher rate of wages than any other artificers in the building line.

956. As a knowledge of carpentry is more useful, and indeed necessary to the Engineer than joinery, so the observations about to be made will be confined almost exclusively to that branch of the business.

The theory of carpentry is founded on two distinct portions of mechanical science, namely, a knowledge of the strains to which framings of timber are exposed, and a knowledge of their relative strength. The first of these may be investigated by the mechanical laws which regulate the composition and resolution of forces, and the last must be derived from principles such as have been laid down in the third section of our ninth chapter.

957. To take the simplest example, suppose a body or any part of a body to be at once pressed in the two directions *a b*, *a c*, Pl. VI., Fig. 185, and if the intensity or force of those pressures be in the proportion of these two lines, the body is affected in the same manner as if it were pressed by a single force acting in the direction *a d*, which is the diagonal of the parallelogram *a b d c* formed by the two lines, and two others drawn parallel to them; and the intensity of the force represented by *a d*, will have the same proportion to the intensity of each of the other two that *a d* has to *a b* or *a c*. To make this still plainer, let us suppose *a b* and *a c* to be two sticks or pieces of wood, supported at the points *b* and *c* while they touch each other at *a*, and suppose a weight to be applied upon them at *a;* then their joint power to resist that weight will be as *a d*, consequently the longer *a d* can be made, and the greater resistive power they will possess. But *a d* can only be lengthened by diminishing the angle *b a c*, or making it more acute, and the maximum of elongation will be when *a b* and *a c* come into contact with each other or form no angle at all, or an infinitely small one, for then *a d* will be equal to their conjoined length, and the pressure will be exerted in the direction of their length or in the most favourable position for strength. If, on the contrary, the angle *b a c* was rendered very obtuse, as in Fig. 186, then the diagonal *a d* becomes much shortened and their power of resistance proportionably decreased until the angle is so opened as to become a right line, when all power of resistance vanishes, and they will be incapable of sustaining their own weight, since they are supposed to be free or not attached together, or to the points that support their ends. This general principle may therefore be considered as established, that the more open or obtuse we make the angle against which any thrust

or force is exerted, and the greater are the strains which are brought on the struts or ties which form the sides of that angle.

958. A *strut* in carpentry is any piece of timber that is subjected to a compressing force in the direction of its length, and which consequently acts and becomes effective by its stiffness. A *tye*, on the contrary, is any piece that is subjected to an extending force, or the place of which might be equally well supplied by a rope. In framing it is sometimes difficult at first sight to determine whether a piece of timber is a strut or a tye, but the question will generally be answered by considering whether a rope or flexible chain could supply the place of the piece, and if not, it must be a strut.

959. The combinations of pressure are of so much importance that they must be farther examined by some practical examples. Thus suppose an upright beam *b a*, Fig. 187, pushed in the direction of its length by a load *b*, and abutting on the ends of two beams *a c*, *a d*, which are firmly resisted at their extreme points *c* and *d* which rest on two blocks, but are not fastened to them: These two beams can resist no way but in the directions *c a*, *d a*, and therefore the pressures which they sustain from the beam and load *b a* are in the directions *a c*, *a d*. We wish to know how much each sustains? Produce *b a* to *e*, taking *a e* from a scale of equal parts to represent the number of tons or pounds by which *b a* is pressed. Draw *e f* and *e g* parallel to *a d* and *a c*; then *a f* measured on the same scale will give the number of pounds by which *a c* is strained or compressed, and *a g* will give the strain on *a d*.

960. It must be remarked that the length of *a c* or *a d* has no influence on the strain arising from the thrust of *b a*, while all the directions remain the same. The effects, however, of this strain, are modified by the length of the piece on which it is exerted. This strain compresses the beams, and will therefore compress a beam of double length twice as much, and this may change the form of the assemblage. If *a c*, for example, be much shorter than *a d*, it will be proportionably less compressed. The line *c a* will turn about the centre *c*, while *d a* will hardly change its position, and the angle *c a d* will grow more obtuse by the point *a* sinking down. The artist will find it of great importance to pay minute attention to such circumstances as these, that he may learn to know the change of shape necessarily resulting from mutual strains. By such changes, strains are often produced in places where there were none before, and frequently of the very worst kind, tending to break the beam across. To show what a prodigious change in strength may be produced even while the timbers remain the same, let us suppose one of the pieces of tim-

ber referred to in the last figure, to be altered in its relative position as shown by the dotted lines at *a*D in the same figure. This change will increase the strain on both the pieces, for *a g* will be nearly doubled, and *a f* will be four times greater than before, because now *e f* must be drawn as *e*F to be parallel to *a*D. The diagonal line *a e*, it is true, will not be varied in length, but the line *e f* will be greatly elongated, and thus change the proportion that before existed.

961. So far we have supposed the beam and weight *a b* to be placed above the two inclining pieces of timber, and pressing vertically upon the point of their contact; but it will be evident that the effect of pressure will not be altered if we take away this beam and weight, and in lieu of it attach a rope at *a*, which rope may be represented by the line *a e*, while to the lower end of this rope we fix a weight *w* that shall be exactly equal to the weight of the beam and weight *a b*. Nothing, as regards pressure, will be altered by this change, and the parallelogram *f a e g*, with its diagonal *a e*, will still remain the proportional representative of the forces. Or we may take the half of the parallelogram or triangle *f a e* for their representative, since the side *a e* is to the side *a f* as the weight *b* or W is to the pressure in the direction of *a f*: also as *a e* : *f e* : : the weight to the pressure in the direction of the beam *a g*. There is, however, no necessity for supposing any extraneous weight *b* or W to be applied to these beams, since their own weight will keep them in their positions, and is frequently the only load to be guarded against.

962. These simple principles lead at once to a consideration of the construction of the roofs with which buildings are covered, for roofs are generally formed of sloping timbers disposed nearly as above described, and so placed for a two-fold object, viz: obtaining strength and throwing off rain and snow, which is well accomplished by the inclined position.

963. The sloping timbers of a roof are called *rafters* and opposite rafters, or *a pair* of rafters are usually of the same length, and made to slope in the same angle, so as to throw their meeting or angular juncture (which is called the *ridge* of the roof) into the central line, or midway between the two walls on which the roof is supported. In this manner the weight of the roof, which is all it has to bear or sustain, is equalized or thrown equally on the two opposed rafters, and the two walls that support them, as in Fig. 188, where *k* and *l* represent the two rafters meeting in a point or ridge at *m*, and resting on the side walls *n n*. The effects of gravitation upon such a construction will be equal on each part of each beam, but its general effect may be represented by a plummet or other line *m o* let fall from the ridge at right

angles to the horizon, and by drawing lines parallel to each rafter from any one point *p* in this perpendicular, those lines, as *p k* and *p l*, will be equal to each other, thus showing that the strain on the two rafters is equal. Still as gravity will be constantly acting on such a roof, tending to depress it in the direction *m o*, it cannot be a strong or stable structure, and will even endanger the building on which it is placed: For, admitting the rafters to be stiff and inflexible, they can give way in no manner but by spreading or extending at their feet, or lower points *n n*, and if the weight of the roof is greater than the strength of the walls can withstand, there is no doubt but that this effect will take place, and that roof and walls will both come to the ground. There are, however, several methods of giving strength to such a structure, and two of these were constantly resorted to in the reign of pointed, or as it is generally called, Gothic architecture. The first of these was the application of a buttress or counter-fort to the outsides of each wall at all those places where such a framing of timber was used, thus giving strength to the walls at the places where it was required, as in Fig. 179, where it will be perceived there is nothing to withstand the lateral spreading of the rafters *s t* but the strength of the walls, assisted by their buttresses, and on this account the ridge angle of such roofs was always made acute.

964. Secondly, a cross beam called *a collar beam*, was introduced to tie the two rafters together near their central parts, as at *q* in Fig. 189: or lastly, a beam is placed horizontally from one wall to the other, with the feet of the rafters let into it, as at *r r* in Fig. 190. This produces the greatest possible strength, for now any tendency that the feet of the rafters may have to spread is converted into a horizontal strain upon the beam *r r*, which ties the two feet of the rafters together, and removes all strain except weight from the supporting walls. This same cross beam by being notched down upon pieces of timber placed longitudinally upon the top of each wall, and extending their whole length, also answers the purpose of tying the two opposite walls together, and preserving their distance asunder. Such a beam is therefore very properly called a *Tie* or *Tye* beam, and converts the whole frame or piece of framing into a triangle *r s r*.

965. The triangle is the strongest form that can be produced in framing, and is therefore the figure that should always be aimed at in putting timbers or other beams together where stability is the main object to be obtained. This will be readily understood by inspection of Fig. 191, in which let *t v*, *t w*, and *w v*, represent three slats or strips united together by three common screws or nails, one being put at each angle so as to form a triangle of wood: and it will be found that such triangle will be im-

mutable as to shape or figure; but if any one screw, as that at *w* be withdrawn, then the form of the whole assemblage becomes mutable, for the pieces *t w* and *v w* will then be capable of revolving in entire circles round the screws at *t* and *v* as centres or pivots, as marked by dotted lines. But so soon as the screw at *w* is restored to its place, or made to hold the two ends *w* of the two pieces *t w* and *v w* together, the assemblage is only capable of taking the single immutable form shown in the figure. No change can take place at the angle *t* unless the ends *w* and *v* are permitted to recede from or approach each other, and that is prevented by the interposition of the piece *w v*, supposed to be immutable as to length; no change can occur at the angle *v*, on account of the action of the immutable piece *t w*, and in like manner no change can occur at *w*, by reason of the piece *t v;* consequently so long as the three pieces are incapable of varying in length, the figure formed by them will be invariable in form, notwithstanding the three joints by which they are attached may all be pivots upon which any pair of pieces would be free to revolve in circles before the third junction or attachment was made.

966. From this simple principle two of the most important rules for the framing of beams or timbers are derived, viz:—

1*st.* All timbers united together in a piece of framing should be so disposed as to form triangles, having in every place the largest or most obtuse angles that the nature of the construction will admit of.

2*ndly.* Precautions must be taken to prevent any of the beams or pieces forming the sides of such triangles from bending, or otherwise changing their length.

967. A few examples will show the importance of attending to these rules in practice. Thus in the construction of a common field gate, as shown in Fig. 192, such gates usually consist of two square upright styles or pieces of wood *a* and *b*, with thinner rails *c* and *d* morticed into them at top and bottom, so as to produce a rectangular frame of wood, hung by iron hinges to the fixed post *e*. The piece *a* will maintain its position, being supported by the hinges; but *b* will be at least six or eight feet from *a*, to which it is only attached by the rails *c* and *d*, or perhaps by another central rail between the two, and as these pieces have considerable weight, and great leverage on account of their length, and nothing to support them but the strength of the mortices, or other joints, at the angles, the end *b* of the gate will soon sink down in spite of any strength of joints, and the whole gate will change its rectangular shape for the rhomboidal one, shown by the dotted lines in the figure, in consequence of which it will drag on the ground and be difficult to open. We may attempt to strengthen such a gate

by nailing vertical slats or palings upon the rails, but this will only increase the evil by adding more weight to be supported, while all the joints being rectangular ones, will admit of turning like the pieces that compose a parallel ruler. But if we introduce a triangle into the frame by using a diagonal bracing piece, as shown at *a b*, Fig. 193, it will be impossible for the end *b* of the top rail *c* to sink or fall, without producing a sensible compression or diminution of the length of the piece *a b*, which we thus see is a strut or beam liable to longitudinal compression. Its strength will also support the style *b*, which will also uphold the bottom rail *d*, and thus while the joints hold good, no part of such a frame can give way from the effects of gravitation or weight.

968. Ignorant carpenters who know that such a diagonal brace is always introduced into a well made gate, but do not consider the nature of its action, frequently reverse the proper position of the brace, which will be done in Fig. 193, simply by attaching the hinges to the style *b* instead of *a*. The brace will now point downwards instead of upwards, and it is now converted into a *tye* instead of a *strut:* for in this position it will be subject to a longitudinal strain of extension instead of compression, and hence its place and assistance would be as well supplied by a chain as by a stiff bar. As joints can seldom be made as strong as entire timber, so in this case the action of the strain will be chiefly felt in the joints, which usually give way, and then the frame will droop or change figure as readily as if no brace had been applied.

969. It is of great importance that the rectangular figure given to the water gates of canal locks should be correctly preserved, therefore precautions are always taken in their construction to insure this effect. Fig. 194 represents one of these gates. They usually consist of two upright posts *e* and *f*, *f* called the quoin or hanging post, and *e* the mitre or shutting post, both made of large and strong square timber, united together by horizontal rails or cross timbers morticed into them, as at *g g g g'*, and *i* is the bottom iron pivot or gudgeon upon which the gate turns, the upper part of the quoin post being kept in its proper vertical position by a strap of flat iron that surrounds it, as at *k;* lastly this frame is covered with two inch oak, or other sufficiently strong plank *m m*, closely jointed, to prevent the passage of any water. Such a gate must of course be very heavy, and as its bottom rail *g'* moves very nearly in contact with the bottom or floor of the lock, if the gate should loose its square shape by the mitre post *e* sinking down, the bottom would drag upon the floor, and prevent the possibility of opening or shutting it. It is moreover exposed to another inconvenience, viz: that the whole gate is sometimes nearly covered by water, and occasionally left dry; and as nearly all timber is

lighter than water, the gate will be lifted or borne upwards from its tendency to float when covered with water, or will hang with its full weight when dry. Such gates, from their weight, require considerable force to move them, and a lever becomes necessary for that purpose, and that lever is made to answer the double purpose of affording power to move the gate, and to balance it upon its posts. It is therefore called the *balance beam*, and is usually formed out of an entire stem of a tree, squared only near its top, and left round, or of the full size, at the root or lower end. It is fixed as at *n l*, the end *n* being morticed into the inner side of the mitre post, while the quoin post mortices into it, and the tail or heavy butt end *l* projects over the land at the side of the lock, thus answering the purpose of a lever for moving the gate, and at the same time balancing or nearly balancing the weight of the gate to which it is adjusted, by adding iron weights near the end *l*, should it not be heavy enough, or cutting away a part of the timber should it be too heavy. In this way, therefore, the gate may be so balanced and supported as to destroy any tendency it might have to sink and drag, therefore the planking is very frequently nailed in vertical directions upon the rails, but the writer prefers fixing it diagonally, as shown at *m m* in the figure, because then the planks become so many diagonal braces which render the gate much stiffer and less capable of changing its figure.

970. In constructing square framed buildings the usual mode of proceeding is to prepare four sills, in the first instance, of lengths correspondent to the size of the intended erection. These sills are morticed on their upper side to receive tenons or tongues to be formed on the lower ends of the angle posts and intermediate studs or quartering. The mortice holes being made, the sill is bedded in mortar upon a brick or stone foundation made level, and prepared to receive it, as at Fig. 195, in which *o* is the sill with the studs and angle posts put in their proper places, their upper ends being likewise morticed into an upper horizontal piece of timber *p*, in this case called a *plate* or *capping piece*, the use of which is to hold the several vertical pieces together in their proper parallel positions. If, however, all the studs and angle pieces are parallel to each other, and at right angles to the sill and plate, so as to form a series of rectangular openings, there will be no strength or stability in the erection, for a gust of wind, or any small force applied against the side of such a building, even when covered with boarding, would drive all the studs and upright pieces out of their perpendicular positions, which done, they would have no strength or support beyond what the morticed joints could afford them, and the whole building would probably fall. But if only two diagonal braces are applied to the opposite sides of the central studs alone,

on each side of the building, in the form shown by the dotted lines at *r* and *s*, triangles will be introduced into the frames, and with them stability will be produced; for now the central stud can neither move towards *r* or *s*, and as that cannot move, so likewise the plate *p* will be incapable of moving, and as all the studs are morticed into this plate, so general stability is produced to the whole, by merely giving stability to a single post or stud.

971. This arrangement is not always convenient, because it may interfere with a door that may be required in the centre of the building, nor will it afford such effectual assistance as if more diagonal braces were used. But so long as the principle is preserved, it matters not how the braces are disposed, so that they are kept as long as possible, and all acute angles in their positions are avoided. A B and C, Fig. 196, exhibit three forms in which diagonal braces may be disposed in framed work without interfering with doors or windows, the studs being shown by single lines, and the sills, angle posts, and plates by double ones. In A the braces extend up to the plate and meet in a point abutting against each other, by which the greatest length of brace or largest triangle is produced. In B the angle posts only are braced, without any of the intermediate studs; and in C the angle posts and a middle post are braced, as well as the plate, in order to produce greater strength for an upper story, or heavy roof.

972. It has been already stated (966) that to produce the strongest framing, triangles must not only be formed, but care must be taken to prevent any of the pieces forming the sides of such triangles, (and especially that side that is to become the brace,) from bending or otherwise varying in length. Timber is not much subject to vary in length from natural causes, therefore the great point to be attended to, is to keep the pieces from bending or changing figure, a defect they will be subject to, even from their own weight, if long, but which is very effectually resisted by the position of the studs; for when diagonal braces are used, the studs do not run in one length from top to bottom by the sides of such studs, but are cut off to the bevel or diagonal of the braces, and are nailed to them both above and below; being thus brought into the same plane with the braces themselves, they, very effectually, preventing their bending. This is, at the same time, an economical process as regards timber, since many short pieces, and pieces of various lengths can be brought into use, which would otherwise be useless.

973. The effects of bending to be guarded against seldom occur in small constructions, in which any required degree of strength and stiffness can be obtained, but only in large erections where the timbers are very long and heavy, and consequently liable to swag

or bend by their own weight, or the loads placed upon them. Thus in the triangular roof shown at Fig. 190, we may imagine the tye beam *r r* to be so long, that instead of preserving its right lined form, it may sink or swag into the curved form indicated by the dotted lines in the figure. A pillar or prop, such as would prevent this effect, if placed under the centre of the beam, might be detrimental to the room below, and is therefore inadmissible; but in its place we may substitute the Y shaped iron rod, shown at *s t*, in the figure, so formed that the upper arms of the Y may either pass through, or hook over, the upper ends of the two rafters *r s*, while its lower end passes through the centre of the tye beam, and terminates in a screw and nut at *t*, by the turning of which that beam may be drawn upwards, and be restored to its original straight form. The weight of the central part of the beam will thus be thrown upon the two rafters *r s*, *r s*, being thus converted from a perpendicular into an oblique strain; and if these rafters are sufficiently strong and stiff to bear the load without bending, there need be no doubt of the stability of the construction, which would now be called a *truss* or *framed truss*. The iron tye just spoken of, is of such vast importance in the framing of trusses, or construction of trussed roofs, that it is by way of distinction called a *king post*, and although here spoken of as being formed of iron, is much more frequently made of wood; although several instances have occurred of large roofs being constructed with iron king posts.

974. We may, however, suppose the roof to be so large that the rafters *r s* must be so long as to be incapable of supporting their own weight without swagging, and giving a concave surface to the covering of the roof, and in such a case this construction must not be relied upon, but supporting aid must be given to the central parts of the rafters; and this is most commonly done by oblique struts from near the bottom of the king post, placed so as to be nearly perpendicular to the direction of the rafters, as shown by Fig. 197, in which *a* is the tye beam, *b b* the rafters, and *c d* a timber king post. The feet or bottoms of the rafters are let into the tye beam by proper mortices and tenons to be hereafter described; and this letting in does not take place at the extreme ends of such tye beam, but at such distance from them as will prevent the lateral strain of the rafters from pushing away the portion of wood that resists their pressure. The tops of the rafters, it will be seen, do not touch or abut against each other, but are let into *shoulders* cut out of the king post, near its top *c*, in such a direction as to be at right angles with the length of the rafters, while the bottom of the king post is morticed through the centre of the tye beam. The struts *b d*, *b d*, for sustaining the rafters are inserted, as nearly as may be, under the

middle of their lengths, and the lower ends of these struts rest upon shoulders cut out near the bottom of the king post at *d*, such shoulders being made at right angles to the direction of the struts. The king post is always made broader than it is deep, in order to admit of the formation of these shoulders without becoming too much weakened. It might be formed of a rectangular piece of timber, or one that is flat on all its four sides, as indicated by the dotted lines in the figure; but as this would add greatly to the weight of the piece, it is customary to cut king posts into the form drawn in the figure, which leaves ample strength with diminished weight; and lightness is an object which should be sought in the construction of every roof. The back and front of the king post are, however, left flat and parallel, and its thickness is usually the same as the width of the tye beam to which it is attached.

975. A truss, such as has been described, fulfils every condition of strength and stiffness that can be required in a roof not exceeding a span of twenty or thirty feet, provided the size of the timbers are well proportioned to each other, and the joints are well and securely made; for the tye beam cannot sink in its centre, being upheld by the king post. The king post is upheld by the rafters, and they are prevented from bending or changing figure by the struts, consequently the entire weight of this truss (with the exception of the two halves of the tye beam) is relieved, or changed from lateral into longitudinal condensing pressure. The great points to be attended to in the construction of this truss, are the security of the joints at the feet of the rafters, which are assisted by their own weight, and the attachment of the bottom of the king post to the centre of the tye beam at *d*, which is weakened by the weight of the tye beam, and therefore requires great care. This joint, instead of being made a common mortice and tenon pinned together, is usually further secured by a strap of flat bar iron, so bent as to pass under the tye beam and up the two sides of the king post, to which it is firmly spiked or nailed.

976. It may appear that the diagram of the roof given in Fig. 197, does not accord with the form in which roofs are generally seen, on account of the feet of the rafters being placed a considerable distance within the tye beam, so as to leave breaks or flat places at *e e*, while the shingling, slating, or other covering of a roof generally oversails or projects beyond the perpendicular range of the external walls, so as to throw rain water some distance from them, as shown by the dotted line *f*. This difference of form arises from the whole roof not being constructed in the manner described; for that would render roofs too heavy, expensive, and unnecessarily strong. The truss that has been described may be called the back-bone or support of the roof, instead of the

roof itself, which is generally a very light construction, independent of, but supported and upheld by these trusses, which, on this account, are called the *principals* or *trussed principals* of the roof, and they are therefore few in number, and are usually placed at from seven to ten feet asunder, according to the magnitude of the building, or the weight of the material with which it is to be covered. On this account the timbers which we have called rafters should, in fact, be called *principal rafters*, because they are not the rafters of the roof, but the rafters of the framed truss or principal that is to support the roof, and by way of distinction, the rafters of the roof are always called *common rafters*. A principal rafter must be a stiff and strong piece of timber, cut thicker at its lower than at its upper end, because the load near the ridge of a roof is less than near its base; while common rafters are parallel, or of the same size from one end to the other, and are usually made of common quartering, or scantling of 4 by $2\frac{1}{2}$ inches square. A very common method of preparing principal rafters is, to select a whole stick of die square timber, suppose of 10 by 12 inches square, and long enough to make one, two, or any given number of rafters without waste. It is then *slit* or sawed through the middle of its length into two pieces, say of 12 inches wide by 5 inches thick, and being cut into proper lengths for rafters, one oblique cut is made through the flat side as in Fig. 198, by dividing the two ends of the piece, suppose into 7 and 5 inches, so that two principal rafters are produced at once, without waste of timber, 5 inches thick, but with the lower ends 7 inches deep, while the upper ends are but 5 inches square.

977. The form of truss for the principal, having been decided upon, the actual roof is built upon it by means of what are called *purlins*, being long pieces of square timber placed in horizontal directions at equal distances apart along the upper surfaces of the principal rafters, as shown at *g g* in Fig. 199, which only exhibits a transverse section, or end view of them. When joints are necessary in the length of a purlin, they must always take place upon a principal rafter. The purlins project considerably above the principal rafters, because these timbers are merely notched on to each other to prevent their slipping, being let about half an inch into the principal rafters, while the rafters are let about as much into them before they are nailed. The purlins being fixed the common rafters succeed, and these rest upon the purlins in their middle parts, as at *g g*, while their upper ends are cut bevel, so as to fit against the two parallel and vertical sides of an inch and a half board, or two inch plank *h*, called *the ridge piece*, that is let into notches cut to receive it in the tops or crowns of all the king posts. The ridge piece should rise at least three or four

inches above the tops of the common rafters when tiles or slates are used, in order that they may abut against it, when they are covered with a capping of sheet lead or copper nailed and dotted (649,) on to the top of the ridge; but with shingles this precaution is seldom necessary. The lower ends of the common rafters are cut bevel, to fit on to the flat top of a plate or piece of timber called a *pole plate*, which, like the purlin, runs the whole length of the building, and is supported on the ends of the tye beams, as at *i* in the figure, or upon the tye beams and wall between them conjointly; or wholly upon the walls when the tye beams are not long enough to carry them. But the tye beam often projects beyond the wall, and affords the means of attaching a cornice under the eaves of the roof as at *f* in Fig. 197. It sometimes terminates within four inches of the outer face of the wall, so as to be covered with brick-work, and is thus hidden as at *i*, Fig. 199, or the wall sometimes finishes with a parapet or dwarf wall hiding part of the roof, as at *l*, Fig. 199, in which case the rain that falls on the roof is confined, and then gutters of sheet lead or copper become necessary. Such gutters require a boarded bottom, which is supported upon bearers, being small pieces of board nailed on to the sides of every common rafter as at *m*, and varying in height so as to give the necessary fall or descent to the bottom of the gutter. *k k k k* in both the last figures shows a section of the wall plate before spoken of (924) as extending along the entire length of the top of the wall, and upon which the tye beams are *corked* or halved, in order to make the roof stable in its position, to equalise its pressure over the whole length of building, and to tie or connect the two exterior walls together.

978. The common rafters, instead of being merely bevelled and nailed down at their feet as at *i*, Fig. 199, are very frequently *bird's mouthed* on to the pole plate, or cut into the form of a notch, such as is shown at Fig. 200, in which *a* is part of the side of a rafter, and *b* a section of the pole plate on which it abuts, and to which it is nailed down. This effectually prevents the rafters slipping away and getting out of their places at their feet. To render rafters more secure they should also be notched or halved on to the purlins. All rafters should be in single pieces, if possible, and every joint of a rafter (if joints are necessary,) must be upon a purlin.

979. Fig 201 shows a side view or elevation of a *naked roof*, such as has been described. The term *naked* is applied to all roofs, floors, partitions and other pieces of framing that are intended to be covered with boards, shingles, lath and plaster, or other covering, before such covering is put on. The end A of this roof shows the termination of a square or common span roof

over the pediment or gable end of a building, in which the bricks or other materials of the wall are ramped to suit the rake or angle of the roof, consequently no framed principal is here necessary, but the ridge piece *h*, purlins *g g*, and pole plate *i*, are all supported in their proper places by the brick-work at A. The end B, on the contrary, shows the termination of a *hipped* roof, or that which is placed over a building, the walls of which do not rise into a gable, but terminate in horizontal courses, and then the end of the roof has the same slope or inclination as its sides, and it is bounded by two sharp edges or ridges which meet together at the common top or ridge, and are called the *hips* of the roof; while if two portions of roof meet and intersect each other at right angles, as is very commonly the case, a hollow or concave angle will be produced, and that is called a *valley.*

The shaded lines at *k* and *l* show the positions of the principals within the roof, and *a a* are the ends of the two tye beams upon which they are framed. One of these framed principals must be placed under the intersection of the hips and the plain roof, as at *l*, and the other may be placed in any convenient position; but the usual method is to divide the whole length of the straight roof into equal parts of from six to nine feet each, and to put a principal truss under each. The further they are set apart, and the stronger the purlins must be, since the whole weight of the *exterior roof* rests upon them, and the whole weight of the *entire roof* uponlthe principals. It is not at all essential that a principal shou d come under a common rafter, therefore no attention need be paid to their respective positions. *q q* in the figure show the common rafters placed over the purlins and resting at their tops against the ridge piece *h*, and at their bottoms upon the foot or pole plate *i*. These rafters are all of the same size from top to bottom, as well as in respect to each other, and they should be placed at fifteen inches from centre to centre, or one foot in the clear from each other, when the tiles, shingles, or other covering is fixed upon laths, or small slats nailed horizontally upon the rafters; but if they are covered with inch boards, which is always the case when a roof is slated, and frequently when it is shingled, the rafters may be put eighteen inches or even two feet apart. The short rafters that occur in hips like those near B are called *Jack Rafters.*

980. The roof is finished by nailing slates or shingles upon the boarding or laths above described, in doing which care must be taken that no two joints occur over each other. The operation commences from the eaves or lower edge of the roof, where two courses of covering are always necessary, in order that the up and down joints of the first course may be covered by the middle of

the plates that form the second; afterwards in proceeding upwards only one course is necessary, because all slates, shingles, or other plates used for covering, should be so long as to reach more than half way under those that are placed above them. The length of the plate or shingle therefore regulates what is called the *gauge* of the roofing, that is the distance between the lower edge of any one plate, and of that which is next above it. Thus shingles are said to be put on to a 5, 6, or 7 inch gauge, meaning the distance between one horizontal range and another, or the length of shingle that is exposed to view. Slates are frequently so large as to admit of a 10 or 12 inch gauge, or even more.* The tiles that are used in England, whether plain or pantile (490) require no boarding, but are constantly laid upon strong laths called double fir laths, or pantile laths, without nails. Shingles are fixed by nails, called shingling nails, and the operation is performed by the carpenter; while tiling, on the contrary, is the work of the bricklayer. Slates, from their being thin and brittle, require a certain degree of skill in the cutting, making the nail holes, and laying, so as to prevent waste, and on this account their use is considered a separate branch of business in England, and is performed by *the slater*. Iron nails are used to fix shingles, and endure as long as the shingles will last; but as good slates may be considered everlasting, (unless broken or injured by accident,) they ought to be fixed with copper nails, that do not rust away. Roofs are occasionally covered with sheet lead, copper, or zinc, in all which cases they must be covered with planed boarding, and the long joints in the metal should be vertical, and not soldered, but so constructed as to admit of expansion and contraction (648).

981. The building may be so extensive that the form of trussed principal, shown in Fig. 197, may be insufficient; because cases frequently arise in which the tye beam may have such a great length, that although supported in its middle, it may swag at both ends between the middle and the walls; or the principal rafters may

* In England where slates are very generally used for covering the best buildings, they are split and cut at the quarry into square plates, and are sold and distinguished by the following singular names, depending on their quality and size.

Doubles, are - - - - - - -	1 ft. 2 inches	by 0 6
Ladies, - - - - - - - - -	1 „ 3 „	by 0 8
Countess's, - - - - - - - -	1 „ 10 „	by 0 11
Dutchess's - - - - - - - -	2 „ 2 „	by 1 3
Queen's, (also called Rags,) - - -	3 „ 3 „	by 2 3
Imperials and Patent, - - - - -	2 „ 8 „	by 2 2

They are sold by the 100. The quantity necessary to cover a square of roofing of the first four kinds will weigh from 6 to 7 *cwt.* The large slates being also thicker will weigh from 7 *cwt.* to a ton. The word Patent applies to the mode of fixing and not to the slate.

be so long as to be incapable of being supported by a single brace or strut. This last evil may be remedied by dividing the length of the rafter into three instead of two parts, and applying two struts on each side of the king post, instead of a single one, but this will not relieve the tye beam, therefore another form of truss must be resorted to, and such a one is shown at Fig. 199, and is called a truss with *king and queen posts*.

In this truss all the same parts occur as in Fig. 197, with the addition of the two queen posts *p p* and their extra struts *r r*. The king post is formed and placed as before, but its struts *s s* instead of bearing up the rafter immediately, bear under shoulders formed on the upper part of one side of each queen post *p p*, and thus effectually prevent them from sinking, while the lower ends of the queen posts being morticed into, and firmly attached to the tye beam at that part where it stands most in need of support, maintains it in its place, and a pair of secondary or queen struts *r r* being applied from shoulders near the bottoms of the queen posts, support the lower portion of the rafters. Such a principal truss will, therefore, be competent to the support of a roof having a span or distance between the external walls of from 30 to 40 feet.

982. Such are the general principles upon which all roofs are constructed, and the two examples given are the forms that are generally used; but the form admits of many modifications, and as these principles of roof construction run through most of the varieties of heavy framing, such as the construction of wooden bridges, the centring upon which stone arches are built, and many other cases, we shall enlarge upon this subject, in order to render the others more simple and intelligible, when they come under consideration.

983. Thus, for example, a considerable saving of timber will be produced in a roof not exceeding 30 feet span by leaving out the king post and its struts, as shown in Fig. 199, and supporting the tye beam in two, instead of three places by using the queen posts only with a straining beam between them, as shown by Fig. 202. All the principal timbers in this design, are likewise much shorter than in those that preceded, and this is frequently a desirable object. The principal rafters *t t*, for example, instead of proceeding up to the ridge of the roof stop short and abut against shoulders near the tops of the queen posts, and instead of abutting against each other or against the ridge piece, they transfer their pressure to the horizontal beam *v*, in this case called *a straining beam*, and the rafters are stiffened and supported near their centres by the oblique struts at *t t*, which take their bearings against the feet of the queen posts. One purlin is placed over each strut, and another is supported on the top of each queen post. Upon

these the common rafters are placed as before, but they run up to the ridge piece against which they abut and are nailed. In this roof, its weight is converted into a compressing force tending to shorten the two principal rafters, and the straining piece; and should any apprehension exist of the latter bending under the force exerted, it may be stiffened and assisted by a single stud, fixed as dotted in at *u*. The feet of the struts *t t* may also press so strongly against the feet of the queen posts as to endanger the breaking off of the tenons by which they are attached to the tye beam; but this difficulty will be met by introducing a beam called a *straining sill*, as at *w*, driven tightly in between the two queen posts. Neither of these latter expedients were, however, thought necessary in the roof from which this drawing was taken, and which was constructed by the celebrated Smeaton over a water mill on the Ravensbourne river at Deptford, near London.

984. The roof of the Chapel of the Royal Naval Hospital at Greenwich, near London, which was designed by Mr. Samuel Wyatt, is an excellent example of a roof on this construction, and as it has stood a number of years without any symptoms of change of figure, and has been much admired for its simplicity as a piece of carpentry, we have given a representation of one of its trussed principals in Fig. 203, and shall subjoin the scantlings or sizes of the timbers made use of in its construction. One peculiarity of this roof is, its nearly flat top, which is an advantage when it is not desirable to show a high roof above a building. In the last century a fashion or mode of building existed, in which most enormous roofs (frequently nearly as high as the perpendicular building) were exposed to view; while now the custom is to conceal the roof, either entirely, or to a great extent. This roof is likewise without common rafters, which become unnecessary, because the whole of it is covered with sheet lead. This permits the *pitch*, or central elevation, to be lower than is usual in roofs; for if the directions of the rafters should be carried up until they meet at the point *i*, the height of this point above the tye beam *a a* would only be equal to one-fourth of its length, instead of one-third, as is usual in tiled or shingled roofs. The trussed principals are set 7 feet apart, and parallel to each other; and in lieu of common rafters a number of small purlins or horizontal bearers, each 6 inches deep and 4 inches wide, are fixed at 1 foot asunder, as shown in the drawing, and upon these, boards with vertical joints are nailed to support the lead.

	Inches.
a a, Is the tye beam 57 feet long, (the clear span between the walls being 51 feet,) its scantling is, - -	14 by 12

	Inches.
c c, Queen posts, - - - - - - -	9 by 12
d, Struts or braces, - - - - - - -	9 × 7
e, Straining beam, - - - - - - -	10 × 7
f, Straining piece to receive the struts, - - -	6 × 7
g, Principal rafters, - - - - - -	10 × 7
h, A *cambered*, or bent piece to produce weather on the platform, - - - - - - - -	9 × 7
b, An iron screw bolt to support the tye beam, -	2 × 2
The horizontal ledgers for supporting the boarding are,	6 × 4

This is a beautiful roof, and contains less timber than most others of similar dimensions. The parts are universally admitted to be well proportioned and disposed. It has been thought that the iron screw bolt is unnecessary, but it adds great stiffness to the whole.

985. The roof of the Theatre, in the great manufacturing town of Birmingham, in England, designed and executed by Mr. George Saunders, of London, is generally admitted to be one of the boldest and lightest roofs in Europe, and has been much extolled as a fine specimen of carpentry, for which reasons the construction of one of its principal trusses is given in Fig. 204. The clear span of this roof, or distance between the supporting walls, is 80 feet, and the principals are set 10 feet apart; but oak corbels, 9 by 5 inches square, shown at *a a* in the figure, are built into the wall at every five feet for the purpose of giving support to an inner plate or string of timber 9 inches square, which runs along the whole inside of the wall, as shown at *b*, to assist in supporting the tye beams and the roof, which also rests upon the usual wall plate *c*, being 8 inches by 5½ square. The scantlings of the timbers of this roof are as follow:—

	Inches.
d, The pole plate, - - - - - - -	7 by 5
e, Tye beam, - - - - - - - -	15 × 15
f, Straining beam, - - - - - - ·	12 × 9
g, Principal queen posts, in the shaft, or exclusive of the projecting shoulders, - - - - -	9 × 9
h, Minor or secondary queen posts, (in the shaft,)	9 × 7
i, Principal rafters, - - - - - - -	9 × 9
k, Common rafters, - - - - - - -	4 × 2½
l, Principal struts or braces, - - - - -	9 × 9
m, Secondary do - - - - - -	9 × 6
n, Purlins, - - - - - - - -	7 × 5
q, Straining sill, (bolted down to tye beams,) -	9 × 5½
s, Ridge piece, - - - - - - - -	9 × 5½

In this roof the straining sill *q* gives a firm abutment to the principal braces, and as the length of this piece is 19½ feet, that being the distance between the principal queen posts, it affords roomy work shops, extending the whole length of the building, and lighted by sky-lights for the carpenters and other workmen connected with a theatre. There is also a beam on each side, bolted to all the tye beams as at *r*, the intention of which is to prevent the total failure of so bold a trussing, if any of the tye beams should fail at the ends by rot. This is further guarded against by the introduction of the internal plate *b* supported on corbels: because experience shows that no part of a roof is so likely to give way as the ends of tye beams bedded in the walls (665,) where they are deprived of a free circulation of air, and are often exposed to confined humidity from the leaking of rain water, from condensed vapour running down the inside of the roof, or from imperfections of the gutters.

986. The roof of Drury Lane Theatre in London, is, however, allowed to be, perhaps, without equal in the world for lightness, stiffness and strength, and we shall therefore close our account of large roofs by giving a table of the scantlings of its timbers, the disposition of which is shown by Fig. 205. This beautiful structure was designed by Mr. Edward Grey Saunders, an Architect of London, and brother to the designer of the last described roof. The span between the walls is 80 feet 3 inches, and the principal trusses are 15 feet apart. The main beams, which are of fir, are trussed in the middle space by oak trusses 5 inches square, an operation that has not yet been described, but will shortly come under consideration. (See 1022.) This became necessary on account of the great width that was required for workshops, the central opening being 32 feet wide. At the same time the great distance of the trusses from each other, and the peculiar form of the roof, permitted many large rooms to be constructed on each side, with flat ceilings and vertical windows through the walls instead of sky-lights, and yet without any interference of the timbers of the roof, which were wholly concealed in the partitions between one room and another. The main trusses are so judiciously framed that it was computed that each would safely sustain a load of 300 tons, and the division of the whole into three parts, caused the real or exterior roofing to be very light. The strains are admirably kept from the side walls, which are even firmly bound together by the introduction of what may be called two sets of tye beams, one above the other. The following were the scantlings made use of.

	Inches.
a a a, Three separate tye beams for the upper, or external roof, each - - -	10 by 7

	Inches.
b, Principal rafters of the upper roof, - - -	7 by 7
c, Three kings of ditto (full measure including shoulders,)	12 × 7
d, Struts of ditto, - - - - -	7 × 5
e, Purlins, - - - - - -	9 × 5
f, Ridge pieces, - - - - -	10 × 3
g, Pole plates, - - - - - -	5 × 5
h, Gutter plates framed into the beams, - -	12 × 6
i, Common rafters, - - - - -	5 × 4
k, Scarfed tye beam to the main truss, which is trussed in its central division, - - - -	15 × 12
m, Principal braces to ditto 14 by 12 at bottom diminishing to - - - - - -	12 × 12
n, Struts to the braces, - - - -	12 × 8
p, Straining beam, - - - - -	12 × 12

The main tye beam *k*, instead of resting upon the wall plate as usual, is caulked or notched down upon a double parallel pair of plates running the whole length of the building; and instead of this bearing upon the wall, it rests upon the ends of two vertical timbers built into the walls, and bearing on long templates beneath. The principal braces *m m*, terminate so far short of the inside walls as to allow room for horizontal beams *x x*, which connect one principal truss with another, and upon these vertical timbers *z z*, 10 by 7 inches square, stand to support an internal plate *y y* for supporting the outer ends of the tye beams *a a*, and thus relieve the thin upper walls from a great part of the pressure they would otherwise be subject to. The pieces *z z*, and inner plates *y y*, are similar in use and effect to the inner plate and corbels of the Birmingham roof, but much more effective in construction, because the pieces *z z* have a much firmer bearing. The windows for lighting the side rooms are placed in the upright walls between the pieces *z z*, and the side walls rise in coped parapets so far above the springing of the upper roof, as to entirely conceal it from spectators in the streets below. This theatre was entirely destroyed by fire, and has been rebuilt. The present roof varies very little from that of Birmingham Theatre, above described.

987. A very common expedient in the building of houses or other erections in which it is desirable to conceal, or nearly conceal the roof, is to give it a form similar to the upper part of Drury Lane roof, or more frequently to divide the opening into two equal parts, with a ridge over the centre of each, when the roof, from its peculiar form, is called an M roof. In this case a girder is necessary to bear up the middle of the M, which is

formed of two simple span roofs, with a gutter of metal between them.

988. Roofs are sometimes extended to very large spans without columns or supporters of any kind under them, but such are not often required. The largest roof ever executed was that of the Riding House built at Moscow, in Russia, in 1790, by the Emperor Paul I. The span was 235 feet, and the slope of the roof but 19 degrees. The principal support of this immense truss consisted in an arch formed of curved pieces of timber indented or joggled together (855) in three thicknesses, strapped and securely bolted together with iron. The principal rafters and tye beams were supported by several vertical pieces notched to the curved rib, the whole being stiffened by diagonal braces. The disposition of the parts of this roof is extremely ingenious, but it was made of scantlings too slight for the immense extent of its span, and it settled so much as to be deemed unsafe. A further account of this roof, with a large engraving of its form and construction, will be found in Tredgold's elementary principles of carpentry, American edition of 1837.

989. Another very bold, and at the same time simple mode of roofing is that devised by Sir Robert Seppings, Surveyor of the British Navy, for covering ships of war while building or repairing in the dock slips. These roofs are framed from whole timber disposed as in the common king post truss, Fig. 197; but so formed that the two halves of what would be the tye beam in such a roof, are made to serve as, or become the principal rafters on one side of another pair of similar trusses, built at each of its ends in continuation of its length. Such roofs have been constructed at Plymouth, Deptford and Chatham dock yards, with a clear span of from 90 to 110 feet, and covering a space 150 feet wide. An engraved representation, with a description of this kind of roof, applicable to covering all large spans for other besides naval purposes, will be found under the article "Dock," in the supplement to the 4th and 5th editions of the Encyclopedia Britannica.

990. Notwithstanding the great advantage derivable not only to roofs, but to the buildings they cover, from the use of tye beams, there are cases in which they are inadmissible without great loss of room, at least in height. Thus it may be necessary to give the ceiling or covering of a room an arched or *coved* form, the curve of which might rise into the angle of the roof, but cannot do so on account of the interposition of the tye beams. The curve must therefore be formed wholly below such beams, or else they must be dispensed with. One method frequently resorted to for getting height in the angular span of the roof is shown at Fig. 206, Plate VII., in which *a b* and *c b* are the two principal

rafters without a tye beam, the place of which is attempted to be supplied by the two oblique tyes *a d* and *c d*, which cross and halve into each other at *e*. This may appear efficient, but is at the same time a bad form of framing. The natural tendency of all rafters is to sink or swag in their middle parts *d d*, and here, consequently, they require support. The oblique tyes are securely fixed to the foot of one rafter and the centre of the opposite one, and as the natural spread of the roof will constantly draw upon the tyes, that draught is transferred to the centre of the rafters, which, instead of being supported in their middles, will be forcibly drawn inwards and downwards, and as the angles *b a d* and *b c d* are very acute, a strain similar to that described in the latter part of paragraph 960, and illustrated by the dotted lines in Fig. 187, will be produced. The tyes will also be liable to break off at *e*, where they are weakened by being halved into each other; because if the roof spreads at all, the line *a e c* will be drawn nearer into the direction of a right line, to prevent which, it will be obvious that the points *b* and *e* ought to be tyed or connected together.

991. By the introduction of a king post this truss may be materially improved, as shown by Fig 207, which is one of the principals designed by the writer, and used in the additional part of Jefferson Medical College, before referred to (942). In this a king post *f* is introduced, having a nearly horizontal strut *g* on each of its sides so as to appear like a collar beam, but which is intended to resist compression, instead of acting as a tye, its object being to maintain the king post in a vertical position, and at the same time to give some support to the central part of the rafters, the upper halves of which are sustained by the shorter oblique braces, which also abut against the king post higher up. The long oblique tyes are fastened to the feet of the rafters as before, but instead of proceeding to the opposite rafter they stop short a little beyond the bottom of the king post, to which they are notched or joggled, one on the one side, and the other on the other, and then bolted through, and iron strapped together. The equal straining forces of these tyes being thus transferred to the two opposite sides of the king post will draw in opposite directions and neutralize each other, and they cannot descend towards a right line, being supported by the king post. The true regular curve of the ceiling is obtained by *blocking out*, that is, nailing longitudinal scantlings of such different sizes as may be required to the undersides of the oblique tyes for the purpose of obtaining the exact curve required, and for receiving the laths and plastering with which the ceiling is to be finished.

992. Before proceeding to describe other applications of car-

pentry, it will be convenient to say something in this place on the manner of joining timbers together, on the iron work necessary to assist such joints, and on the process of trussing beams to give them greater stiffness.

It will be quite obvious that in the construction of such large roofs as have been already described, no timber can be procured of sufficient length in single pieces to form the tye beams and other extended parts, consequently two or more sticks of timber must be united together by their ends, or in the direction of their length, and this operation is called *scarfing* timber, and is performed in various manners. The most common method of scarfing or joining beams longitudinally is called *lapping* or *halving*, and sometimes *ship lapping* timbers. This consists in cutting away a sufficient quantity of one beam on its upper side, and an equal quantity of the one that is to be joined to it on the under side, so as to let the diminished end of one piece overlap the diminished end of the other, and then joining the two together by nails or wooden pegs or pins, which in carpentry are called *tree-nails*, as shown by Fig. 208. This kind of joint is constantly used for uniting foundation sills that are supported upon hard and level foundations, bond timbers, wall plates, and the pole plates of roofs, but it would not answer for timbers exposed to longitudinal compression or extension, especially the latter; because the only strength to resist separation in this case is that of the nails or pins. It will, however, answer against a strain of compression provided the shoulders or vertical joints are made to fit each other very truly, and the pieces are fastened together by iron screw bolts and nuts, or by square hoops or bands passing round them.

993. The best scarf against longitudinal extension, as in tye beams, is that shown by Fig. 209, where the upper and under beams are cut or let into each other in the manner shown in the figure. The under beam has a tongue or tenon formed at its extreme end like *a*, with a corresponding notch for its reception in the upper beam, and the end of the upper beam is similarly treated in respect to the lower one. To permit these tenons to pass into the notches provided for them, it is necessary to cut away a portion of the intermediate part of the joint at *c*, equal in length to the sum of the length of the tenons, in such manner as to form a square hole through the middle of the joining of the two beams, and this is afterwards filled up by a piece of oak or hard wood, called a key, fitting the hole, and driven tightly into it. The effect of this key is to drive the tenons *a* and *b* home to their shoulders, and to prevent the possibility of the pieces separating again. Such a joint will be capable of withstanding longitudinal extension, which will have the effect of compressing the key laterally, and in order

to enable it to withstand such pressure with the greatest effect, the thickness of the key ought to be equal to one-third of the entire beam.

994. This scarf will also withstand lateral pressure from above or below, as in floors; but the joint most frequently used for this purpose is the oblique one shown at Fig. 210. Its principle is the same as that last described, but the joint instead of being parallel to the top and bottom, is oblique, and instead of the tenons being cut with shoulders, the ends of the pieces fit into angular notches from which they cannot withdraw when the key is driven into its place. When it is desirable to render the timber stiff against a lateral pressure in all directions, the ends of both pieces should terminate in angular forms, and be received in angular notches, as shown at Fig. 211, which is a view of the top of a beam scarfed as in Fig. 210, but with angular terminations. This form of scarfing should never be used for pillars, or for resisting a compressing strain, because the sharp terminations of the uprights will act as chisels to split open the notches, and the one side will be constantly sliding over and protruding itself beyond the other, unless the joint is bound round with iron.

995. None of the scarfs above described can, however, equal the strength of an entire beam, because at least half the timber must be cut through in all of them. But they may all be made much stronger by long straps of flat iron, fixed to the outsides of the joints by screw bolts or screw hoops. The only way of joining beams, so as to get the complete strength in timber alone, is by a method apparently more clumsy and unsightly, but which is much used in ship building, and is called *fishing a beam*. It consists in applying a long piece of timber, equal in area and size to the beams to be joined to one side of the joint, as shown at A in Fig. 212, or two pieces of half the area, one on each side of the joint, as at B in the same figure, such pieces being bolted through, hooped, or otherwise securely fixed upon the joint. This joint will, of course, withstand longitudinal compression; but if extension is required, as in tye beams, the scarfs shown by Figs. 209 and 210 may be adopted, and they may be fished on one or all sides of the joint. In long tye beams where straining sills are introduced, such sill by being bolted down becomes a most efficient fishing to a joint below them.

996. The union of several pieces of timber in angular or other directions, when extension of length is not the object to be obtained, is sometimes effected by lapping, but more generally by what is called *morticing*. A mortice joint always consists of two parts, viz: a tongue or projection from the end of the piece to be joined, which is called the *tenon*, and a hole made through the other

piece, either on one side or passing entirely through the piece called the *mortice*, or sometimes the *mortice hole*, to distinguish it from the complete joint which is also called a mortice, and the junction is usually secured by driving one or two wooden pins or tree-nails transversely through the joint, as shown by Fig. 213, where A shows the mortice, and B the tenon formed on two beams which are intended to go together in a right angled direction, *c c* being the pins driven into holes bored transversely through the morticed piece, and passing through corresponding holes shown on the tenon. The mortice has generally a width equal to one-third of the thickness of the beam, and ought to be kept as far as possible from its end to allow sufficient wood at *d* to prevent the hole splitting out. If it is necessary that the end *d*, of the one piece, should be flush or flat with the outer edge of the other piece, this is obtained by making the shoulder *e* of the tenon B wholly on one side, but when this is not essential, a shoulder is left all round the tenon; and the mortice hole will be stronger, if it can be made considerably within the timber instead of being near its end.

997. There are different modes of forming and uniting mortice joints, varying with the purposes for which they are intended. In all of them it is essential that the mortice and tenon shall fit each other accurately, or as it is technically called, be without *shake*, meaning ability to move about. The joint shown in Fig. 213 is very good and effective, where the load or strain to be borne is an external pressure upon the outsides of either of the beams, but would be unfit for uniting a king post to a tye beam, because in that case, the natural tendency of the tye beam is to descend in its middle and withdraw itself from the tenon of the king post, and the only resistance to such withdrawing would be in the strength of the pins, instead of the tenon. The best joint for this last purpose, or for all cases where the tendency is to draw the tenon out of its hole, is that shown by Fig. 214, in which one side of the tenon C of the king post is cut into a sloping or inclining direction, and the other left straight with the side of the timber. The mortice hole D has a correspondent form given to it, but is made so much wider than the tenon, that its broad or lower end can just pass into its upper or narrow part. When so introduced a wooden key *f*, in Fig. E, (which is a view of the joint when put together,) is tightly driven, and this forces the inclined side of the tenon against that of the mortice hole, and thus prevents the possibility of the tenon being withdrawn, so long as the key retains its place. In addition to this, pins may be driven through the joint, and an iron strap applied round it, when it will be impossible for the parts to give way, except by breaking.

998. Another method of fixing a tenon is by end wedging, as

shown at Fig. 215, which represents the joint put together. The tenon *g* in this case should be long enough to reach quite through the mortice hole, and having one or more saw cuts made in it, an acute wooden wedge *h* is drawn into each of them, (frequently with glue.) This splits the end of the tenon in a slight degree, not sufficiently to injure its strength, if judiciously executed, but to spread it out and make it press so forcibly against the sides of the mortice hole, that it cannot readily be withdrawn, and if the mortice hole is made a trifle wider next the wedged end, than at the other, the tenon will be very effectually fixed. In the construction of machinery, it is not always possible to carry the tenon through the piece, so as to wedge it on the opposite side, and then nearly the same effect can be produced by what is called *fox-tail* wedging. In this the mortice hole (which should spread laterally as it descends) is not cut through the piece but stops short of the opposite side, as in Fig. 216, and the tenon *i* being made to fit the mouth of the hole very neatly, two saw cuts are made in it; and two wedges are put slightly into them, when the piece carrying the tenon is driven by a mallet into the mortice hole, and the heads of the wedges coming into contact with its bottom, are driven into the tenon and cause it to spread, as it is introduced into its place. Such a joint, if neatly made and put together with glue, will be as strong as solid wood. Tenons are very frequently made with two or more tongues, and a corresponding number of mortice holes to distribute the strength of the joints over a large surface. Indeed dovetailing, which is so extensively used for uniting the angles of boxes by cabinetmakers, and for larger constructions by millwrights, is closely allied to morticing and tenoning.

999. In pinning mortices together, the tenon should be driven into its mortice hole as far as it will go before the pin holes are bored, and then they must not be carried through the joints, but merely down to the tenon, so as to mark it, when it ought to be withdrawn and the holes be continued through the other cheek of the mortice. The holes are then made through the tenon, not exactly where they have been marked, but each about one-eighth of an inch nearer to the shoulder of the tenon. The effect of this will be that in putting the joint together, as the two holes do not exactly coincide, driving in the pins will draw the shoulder of the tenon close and with great force against the side of the piece to which it is to be connected, and will thus produce a closer and stronger joint than could otherwise be obtained.

1000. The mortice joints that require the greatest care and attention are, however, those that are oblique, and subject to great strains, as in uniting the foot of a principal rafter to a tye beam. In such joints the thrust is not only an oblique one of immense force, but it comes into operation very near the end of the beam, where there is sometimes not sufficient timber to resist its action. At first sight it may appear that letting the whole foot or lower end of the rafter into the tye beam would produce the most effective joint, but in this way the whole surface of the rafter cannot be brought into a thrusting action without cutting so deeply into the tye beam as to impair its strength very materially, as will be seen in Fig. 217, in which the part *k* is quite ineffective, and must remain so, unless the rafter is let down so far as to leave so little wood at *m* that the strength of the tye would be destroyed, unless it was very considerably larger than the rafter. It therefore becomes necessary to convert the lower end of the rafter into a tenon, thus giving up a portion of its pushing surface, in order to obtain a sufficient strength of resistance; and several forms of tenon have been devised for this purpose, some of the best of which are shown at F, G, and H, Fig. 218. At F it will be seen that the whole body of the rafter descends but a very small distance into the tye beam; the remaining portion of it being cut into a tenon that passes about half way into the beam, and that the end *l*, both of the rafter and its tenon, are cut off at right angles to the direction of the rafter, or to its axis or line of pressure. When the abutment *l* occurs very near the end of the tye beam there may be danger of the portion of wood between the end of the hole and that of the beam breaking out by giving way to the lateral pressure, consequently every precaution should be used to carry the bearing points as far as possible into the body of the beam, and this is in some measure accomplished by the form shown at G, in which there are two bearing shoulders in the depth of the rafter, placed one behind the other, in addition to the tenon which unites them. H is a form that may be adopted when no part of the rafter is let into the beam, but a tenon only is used. That tenon, whatever may be the thickness of the rafter, may have a thickness equal to one-third of the tye beam, and by having two shoulders of different depths, one behind the other, it will take a very firm hold. The mortice joints of rafters to tye beams are seldom pinned through, because the weight of the rafters and the roof they support are amply sufficient to hold them down, and pins might interfere with the rafter taking its full bearing on the solid wood.

1001. Struts, braces, and other pieces destined to bear great compressive loads, will need no other mortice than that which is sufficient to keep them from sliding laterally out of their places, in the event of their becoming loose from contraction of materials, or the load they have to sustain being relaxed by any cause. The more flat and regular the surfaces of such pieces can be made and the more efficient they will be, therefore struts are very frequently well fitted and nailed into their places instead of being morticed; or, if a mortice joint is used, it ought to be one with a short and thin tenon, merely to retain the parts in their places rather than to produce resistance.

1002. All joints that are subject to great strains should be strengthened by iron ties or straps, and particularly the junctions of principal rafters and king or queen posts with tye beams; and the general form of such iron ties will be seen in all the representations of roofs we have given, see Figs. 197, 199, 202–3–4 and 5, in all of which *y* represents the ties of rafters, and *x* ties of king and queen posts. The latter, as commonly used, are very simple, being merely a bar of flat iron three or four inches wide, and from five-eighths to three-quarters of an inch thick, so bent that it may embrace or pass under the tye beam and up the two sides of the king or queen post, as shown by Fig. 219, in which *n* is a side view of a king post with a double tenon at its lower end passing through the tye beam *p*, drawn as a transverse section, and both surrounded by the iron strap or stirrup *o q q* passing from two to three feet up each side of the post, and corked or turned outwards at its upper ends *q q*. These corkings are made for the purpose of resting upon square iron staples which are driven into the sides of the post. Another pair of similar staples, are usually driven over the strap lower down, and its fixing is finished by a few spikes driven through holes left in it for the purpose. We thus have a strong and expensive strap of iron to assist the strain upon the joint, which by its mode of fixing is reduced to the strength of a few nails. In using such irons, I have generally had the corkings made longer, and turned inwards instead of outwards, so that they may pass into holes made to receive them in the timber of the king post, the staples and nails being applied as before, and now such a strap cannot sink without tearing its corkings out of the timber. The best form for a king post strap is, however, that which is shown at Fig. 220, in which J is a side view and K a section. J shows the side of the strap or stirrup, which is similar in every respect to the one just described, except that it has no corkings at its upper ends, but in lieu of them the ends are expanded, and punched with opposite rectangular holes, for the purpose of receiving the *gib r*, and cross keys or wedges *s*, shown in the sectional figure K. A hole corresponding in size and position to those in the iron is made through the timber, its bottom being rather above the bottoms of the holes in the iron, and into this the gib is introduced and dropped, its office being to retain the two plates of the stirrup close to the sides of the post, and to form a hard bottom for the wedges to work upon. The wedges are then introduced and driven, by which the tye beam and king post are drawn into perfect contact; and should a shrinking or settlement afterwards take place, the wedges always afford the means of tightening up the joints.

This same figure at J also shows the form of a king post with its shoulders, crown, or head piece, and notch for the ridge piece, and *t* is the form of an iron strap that is usually spiked on to each side of the crown for more firmly uniting it with the tops of the principal rafters.

1003. Another mode of uniting timbers, and especially of strengthening mortice joints, is shown by Fig. 221. The mortice is made as usual, but the tenon must not extend quite through it. When put together, an augur hole is bored through the joint and up into the post to be united, as at *v*, and an iron screw bolt being passed up this hole, works into a large iron screwed nut, introduced by a side hole *u*. The head of the bolt works through a flat iron plate *w*, which must be larger than the mortice hole, that it may take bearing all round on solid wood.

1004. The mode of fixing iron stirrups to unite the feet of principal rafters with tye beams, as shown at *y* in the figures of roofs, and on a larger scale by F in Fig. 218, is very often erroneous; because such straps are frequently strongly spiked, or otherwise fixed to the tye beam at right angles to the rafter; consequently it may be presumed that the lower ends of these straps are immoveable. But the change that takes place in the position of a rafter by being loaded and exposed to the action of time and humidity is a partial sinking, and extension or spreading towards the end of the tye beam. A stirrup so placed has only the power of keeping the rafter down in its place, which it does not require, but cannot counteract either of the defects just mentioned; for should the rafter sink, it will be disengaged from the iron, and should it extend, the iron will bend and follow it, or break off at *x*. All iron tyes should be so placed, that they may be able to resist the change they are intended to counteract, in the direction of their length; consequently such a tye ought to be placed as nearly as possible coincident with the direction of the tye beam, or at any rate in a much more sloping form than is generally met with, and of course it should be let into a notch on the upper surface of the rafter to prevent its sliding upon it. Fig. 222 shows a stirrup so fixed, and instead of being nailed to the sides of the tye beam it terminates in loops or eyes, through which, and the beam, a strong screw bolt is passed, which not only attaches the stirrup more strongly to the beam than nails can do, but permits a motion by which the tie can adjust itself to any varying strain between the beams, without danger of its breaking off.

1005. The principles that have been explained will render very few observations on the construction of floors and ceilings necessary. A floor is a flat platform of timber, generally formed by placing beams across any opening to produce strength, and covering them with close-jointed boards, to obtain a flat continuous surface. Ceilings, on the contrary, are the coverings of the tops of rooms, which, in like manner, are formed by fixing beams of less strength, upon the under sides of which, laths are nailed to receive lime plastering, or they are occasionally covered by thin boards. The timber beams thus used to support floors are called *joists*, or sometimes *floor joists*, to distinguish them from those used for ceilings, which are *always* called *ceiling joists.* Ceilings are, however, very frequently formed upon the under sides of the floor joists, when, of course, separate ceiling joists become unnecessary.

1006. When the span to be floored over does not require joists of greater length than from ten to fifteen feet, the joists are simply pieces of timber laid from one wall or support to another; and for the reasons before given, (807,) such joists are always thinner than they are high or deep. Of course it is quite necessary that all their upper sides should be perfectly flat and level, that they may afford an even bearing for boards to be put upon them; and as the width of scantlings are seldom attended to by sawyers with such precision as to render them fit for this purpose, the necessary equality of depth and consequent even surface is produced by cutting away parts of their under surfaces, where they take their bearings upon the bond timbers, templates or breast summer, prepared to receive them; for floor joists ought not to rest on brickwork, but on a plate of timber worked into the bricks to receive them. When the size of openings is larger than above named, the middle of the line of joists will require support, and this is obtained by one or more *girders* or whole timbers passing from one side of the building to the other.

1007. Girders are differently disposed according to the nature of the building to be produced; but they should always be die square, and their ends should rest on templates of wood, or cast iron worked into the side walls. In rooms that are longer in one direction than in another, the girders should always extend between the two nearest walls, and they ought not to be scarfed, but should, if possible, be formed of single pieces of timber.

1008. Long whole sticks of squared timber will rarely be found quite straight, and when curved (probably from want of even bearing during its seasoning,) they are said to *camber*, or to have a *camber*, and timber that is so cambered is generally selected for girders; and in using it, the convex side is laid upwards, for all new floors that are large and unsupported from below, ought to be so laid that they may be convex upwards to a small extent. In this way the floor will probably become level by time and use, for as all long timbers, when only supported at their two ends, will naturally sink or swag by their own weight, the reduction of the camber by this means produces a flat surface; while if the floor had been made perfectly flat in the first instance, it would very likely become concave in its central part.

1009. In mills, store-houses, manufactories, and such buildings as generally fall under the superintendence of the Engineer, and where strength rather than beauty is required, the joists are usually merely laid across the top of the girder, at right angles to its direction, with no other preparation than merely notching their under edges down upon the top of the girder to such an extent as will produce an even surface for the boarding when placed on their tops. Or sometimes the tops of the girders and bottoms of the joists are notched or halved into each other, which prevents both from shifting out of their places. This construction, however, interferes materially with the headway in rooms, and causes the building to be higher than it otherwise need be, particularly if ceilings have to be made under the floors. Thus let *a a*, Fig. 223, represent the transverse sections of two girders, each 14 inches deep, and *b* the joists laid upon them, suppose 9 inches deep, with $1\frac{1}{2}$ inch boards nailed upon them, then the distance from the bottom of any girder to the top of the floor it supports will be $24\frac{1}{2}$ inches, and should a ceiling flush with the bottoms of the girders be required, then this height will be entirely lost in each floor. The usual manner of ceiling such a floor is, however, to nail the plastering laths immediately on to the under sides of the joists, leaving nearly the whole girder visible by projecting into the room below. If a flush ceiling is required, or one to hide the girders, that is produced by morticing slight ceiling joists *c* in between the girders, and so close to their under sides that the laths nailed upon them may pass over the girders without producing any projection. It is not, however, deemed right in good buildings, to form plastered ceilings immediately upon the under side of floor joists, because plastering is brittle and liable to crack, and even give way from the concussions and vibrations of the floor above; but when separate ceiling joists are adopted, the plastering becomes much more detached, and less liable to derangement.

1010. The floor, represented in section by Fig. 223, may be considerably diminished in height by notching each of the joists about four inches on to the top of the girder, and notching the girder down about an inch at each crossing of the joists. This will lower the floor five inches without materially affecting its strength. But the usual method that is adopted in house building, and other erections where height of rooms is desirable, is to compress the whole thickness of the floor into the depth of the girder alone; and this is done in two ways. One is to mortice the ends of every joist into the sides of the girders, letting the tops of all be flush or even to receive the floor boards, in which case the joists are called *bridging* joists, and the other is to introduce strong joists morticed into the girder at about six feet asunder, such joists being as deep as the girder itself, and called *binding joists*, and then to notch down the common or bridging joists upon them in directions parallel to the girders themselves, separate ceiling joists being used in both cases. The floor framed with binding and bridging joists, takes rather less timber than that with bridging joists alone, for notwithstanding the binding joists are deep, yet they are few in number compared with the cross or bridging joists, which may be made small in consequence of their short bearings. The saving is not material, but it is thought that greater strength is obtained out of the same quantity of timber, in consequence of the girder being less maimed by mortice holes: But it will hereafter appear that if these holes are properly placed, they abstract less from the strength of a stick of timber than might be supposed.

1011. Holes are very frequently required to be left through floors and roofs for the passage of chimney shafts, wells for staircases, trap doors, the introduction of sky-lights, &c., and when these require to be wider than the distance between one joist or rafter and another, a cross piece must be introduced to carry their ends, and such piece is called a *trimmer*. Fig. 224 shows the distribution of the parts of a common floor, *d d* being a brick wall with a wall-plate, string of bond timber, or template worked into it to receive the ends of *e e*, which are common joists, but *f* being a fire place, the joists could not be carried into it without danger of being burnt, therefore a trimming or binding joist, stronger than the others, is fixed on each side of the chimney, as at *g g*, and *h* is a *trimmer* morticed into these two side joists for carrying the ends of the intermediate joists, thus keeping them out of the reach of any detrimental action of the fire. The space *h* between the front or *breast* of the chimney and the trimming piece is filled up with curved or arched brick-work for supporting the hearth. A girder *i* is introduced to support the rafters at about every eight or nine feet, when the length of the room is such as to render this precaution necessary. When the rafters are so long as to be capable of vibrating laterally, a floor may be rendered more stiff and steady by driving short stretching boards, as at *k k* between every joist; and when it is necessary to cut off the transmission of sound through a floor, it should be *pugged.* That is, inch strips are nailed on to each side of every joist about six inches below their upper surface, to support short pieces of board to be fitted in between them, and with which the whole surface of the openings must be covered. The spaces between the joists are then filled in with saw-dust alone, or made up into a paste like mortar with wet clay. If the wet composition is used, it must be allowed to become dry before the flooring boards are nailed down.

1012. The best wood for flooring boards is yellow pine or oak, and in good buildings they ought to be inch and half thick, at least, before planed. The boards are only planed (or *dressed*) on their upper surfaces and two edges, and as the perfection of a floor is to be perfectly flat and free from inequalities, that is brought about by what is called *gauging* the under sides of the boards, an operation that is much easier to make perfect, and requires less labour than would be attendant on planing the entire under surfaces of the boards. It consists in rebating or cutting away, by a plane made for the purpose, about an inch in width from the under side of every board at both its sides, as much of the wood as will make the finished edges of all the boards of exactly the same thickness, as proved by a gauge or measure made for the purpose. That done, the projecting intermediate quantity of wood on the under side of the board is cut away by an adze, so as to unite the two gauged edges in a right line at that part that comes over every joist; consequently when boards so prepared are laid, and nailed upon the joists, they must form an even surface, provided the joists have been correctly laid.

1013. The best floors are laid with *battens,* that is, narrow boards cut out of the middle of the timber, so as to be of uniform colour, and quite free from sap. They are distinguished as *best, second best,* and *common.* The best are entirely free from knots, shakes and cross-grained fibres; but small knots and irregularities are admitted in the second best. They run from four to seven inches wide, after which width they loose their name, and are boards. The reason for using such narrow pieces as battens in the best floors, is, that they are less likely to curl or warp, and to shrink than wider boards. Floors are distinguished by different appellations depending on the manner in which the boards are laid, such as *folding* or *straight joint floors, rebated floors, grooved and tongued floors,* and *dowelled floors.* The first is the most cheap and common method of laying boards. The edges of the boards being well jointed by the plane, that is, made as perfectly right lined as possible, the first is laid in its place upon the joists, and fastened by driving two flooring brads through it into every joist. The next board being now put down in its proper place, is driven into close contact with the edge of the first by a screw or lever apparatus made for the purpose, or by the application of wedges, and is nailed down while subject to this pressure. The same operation is continued until the whole floor is covered. If the boards are not long enough to reach the entire extent of the room, the end of one board must abut against the end of the other, and such joints are usually broken as in brick-work, that is, abutting joints should not be contiguous, but should be carried some distance along the side of the next whole board; but all abutting joints must come over a joist, so that the ends of both boards may be supported. Flooring brads are tapered iron wedges without heads, which would disfigure the floor, and when the nailing of a floor is finished, these brads are punched or driven below the surface that they may be out of the way of the smoothing plane which is passed over the floor to remove any ridges or small inequalities in the joints, and give a last finish. Flooring boards ought to be planed, and set by under exposure to the air in a dry place long before they are nailed down, because all boards will shrink with time in dry places, and this often proves inconvenient in straight jointed floors, because when the joints open, they permit wind, dust, and the water with which floors are washed, to pass through them, to obviate which rebated or ploughed and tongued floors are adopted.

1014. A *rebate* (pronounced rabbit,) in joinery is a longitudinal right angled indentation made in the edge or side of any thing, by a tool called a rebating plane. Thus the cavity that is formed in window sashes to receive the glass and putty is called a rebate; and in like manner if we cut away half the surface of the edges of two boards to a certain depth, as at *k l* and *m*, Fig. 225, such boards would be said to be rebated on their edges. Half the thickness of the board is cut away from the upper surface at *k*, and half from the under surface at *l*, consequently if these two edges should be applied to each other they would form the overlapping joint shown at *m*, which is called a rebated joint, and such is a rebated floor, in which the boards, being so fitted together, are pressed and nailed as before described.

1015. The *groove and tongue joint* is still more close and effective against the passage of air or water. In this, one edge of each board is double rebated, or rebated from each side, so as to leave a projecting tongue or fillet, as at *n*, Fig. 226, in the middle of the thickness of the board, equal to about a third of its substance; and a corresponding groove or cavity is cut on the other edge of each board, as at *o;* consequently when two edges so prepared come together a joint like *p* is produced. The groove is cut by a tool called a plough plane; hence it is a common expression to say a groove is ploughed out of a piece of stuff: and, indeed, the joint itself is as frequently called a ploughed and tongued joint, as a grooved and tongued one.

1016. The double groove and slip, or tongue joint, produces the same effect as that last described, and is more common, because it takes less labour to produce it, and wastes less boarding. In this joint both the edges of each plank are grooved or ploughed out, and the slip or tongue is a separate strip of wood, so wide as to be capable of filling both grooves, when the edges of two boards are put together. Neither of those joints are so good for floors as the rebate, because in that, half the thickness of the board is left, while in the groove and tongue joint, each projection has but one-third of its thickness; consequently, this joint is most liable to be broken by concussions upon the floor, or by its settling out of its level position.

1017. Dowelled floors, which are always used in the best finished rooms, are put together by a more slow and tedious process. The battens are usually straight jointed, and half inch holes being made exactly opposite to each other in each of the two edges that are to come together, round pins or dowels of wood, fitting the holes, are put into them, as before described for fixing stone-work. (888.) The first board is nailed down at its outer edge only, so that the nails may be hidden by the skirting or wash-board with which the best rooms are always surrounded. The other side of the board is then nailed, not through the top of the board, but obliquely through its side, and so of all the other boards in succession: for the first board being fixed down, the dowells of the next will hold one side of it, and the oblique nails hold the other; consequently in such floors, not a single nail appears. The dowells are always placed, one between each joist, and frequently one over each joist in addition.

1018. The manner of morticing joists into girders is a subject that demands particular attention, because, as before observed, (940,) if this is judiciously done, it does not abstract sensibly from their strength. Referring to what has been before explained (788) respecting the effects that take place when a horizontal beam is subjected to pressure from above, it will be recollected that the fibres in the lower part of such beam are thrown into a state of expansive strain, while those in the upper part are put into a state of compression. That being the case, if a cut or division should be made about half way through the beam from its upper edge, the beam would be very materially weakened; because, now all that which was resisting matter has been removed, and the two sides of the cut would come together. But if after making such a cut we fill it up again with any hard matter, capable of affording the same, or a greater resistance to compression than the wood could do before it was removed, the strength of the beam will not be impaired in the slightest degree. This was fully verified by some experiments of Du Hamel. He took six scantlings of willow thirty-six inches long and one inch and a half square, and having supported them by props under their two ends, he applied weights to the middles of the pieces to bend and break them, and found that they all broke with an average force of 525 *lbs.* Six similar bars were then cut one-third through from the top, and the cuts being filled up with wedges of hard wood struck in with a little force, they were submitted to pressure, and broke with an average force of 551 *lbs.*

Other six similar bars were cut half through, and being treated in the same manner, broke with 542 *lbs.*

Six other bars were cut three-quarters through, and broke with 530 *lbs.* being a very close approximation to the strength of the bars before any cut was made in them.

A similar bar, cut three-quarters through, was loaded until it nearly broke, when it was unloaded and the wedge taken out. A thicker wedge was now substituted and driven in, so as to make the bar straight again by filling up the space occasioned by the compression of the wood, and the bar being now loaded, broke with 577 *lbs.*

From these experiments it is clear that more than two-thirds of the thickness of a beam (perhaps nearly three-quarters) contributes nothing to its strength when subject to the strain and circumstances just described.

1019. We learn further, that as the actions of a beam, subjected to lateral pressure, are opposite, one part being compressive while the other is dilative, that little or no action takes place at the axis of fracture, or line where these two forces meet and become neutral by changing into each other; consequently we may take away the solid substance to a certain distance around the axis of fracture by boring a hole or otherwise, without sensibly impairing the strength of the beam.

These principles, therefore, point out very clearly how joists should be morticed into girders, because if a mortice joint is well made the tenon ought to fit the mortice hole very closely and correctly. If the mortice hole is made near the top of a girder, it will weaken it, because a portion of the solid wood, necessary to resist compression, has been taken away; but if the tenon that is put into that hole fills it tightly, that will at once supply the deficiency, because now the tenon becomes the wedge referred to in Du Hamel's experiments, and will restore the strength of the piece.

Again, if instead of making the mortice hole near the top of the beam, we make it in or near the axis of fracture, or rather below the middle of its depth, we may carry the hole quite through, and yet not impair the strength of the beam; but in this case the tenon must be confined to small dimensions, and would be liable to break off close to its shoulder.

1020. The form of tenon which experience has dictated, and which is constantly used by all good carpenters for uniting joists to girders, is in perfect accordance with all the principles above stated, and gives the greatest possible strength to the joist, without impairing that of the girder. It is technically called *housing in a mortice,* and its form is shown by Fig. 227, in which A is the end of a joist, and B a transverse section of the girder to which it is to be joined, showing also a section of the mortice holes cut into its opposite sides. The tenon has no side shoulders, but is made the full thickness of the joist. Its long tongue *r* is generally square, and should be placed as nearly as may be, opposite the axis of fracture of the girder B. If it was of the same size throughout, as indicated by the dotted lines, it would be very deficient in strength, but by giving its upper shoulder an angular form *s r,* it is not only strengthened, but the load the joist may have to sustain becomes supported by above half the depth of wood, and this quantity is increased to about three-quarters by the angular projection left in the under shoulder at *t,* so that the only ineffective part of the joist is between *t* and *v;* and when the girder is deeper than the joist, that becomes nothing, because the tongue *r* will be lowered. The mortice holes in the sides of the girder are cut into exact correspondence with the form of the tenon, and this will maim the beam in the smallest degree, because no solid wood is taken from its under, and very little from its upper part, owing to the sloping direction of the housing; and the main strength of a beam we have seen, is posited in its extreme sides. The chief cutting away occurs at, and near the axis of fracture, and there less solid wood is necessary than in any other place.

1021. As timber is limited by nature in the extent of its growth, it frequently happens that sticks of sufficient strength and stiffness cannot be obtained for the construction of large works, especially for the girders of floors, which, from their nature, will not admit of the means of support already described, as applicable to the tye beams of roofs; and when this is the case such extraordinary large beams must be *built up,* or the largest beam that can be obtained must be *trussed.* Building a beam is joining a number of beams together by the processes already explained under the names of scarfing

(992), and joggling (855), and is extensively used in the construction of the masts of large ships, and in the stupendous timber bridges erected in different parts of the United States, and which in point of skill and boldness of conception and execution, are equal to any thing of the kind in the world.

1022. Trussing a beam is the introduction of certain stiff, compact, and strong materials into the inside of it, for the purpose of increasing its strength and stiffness, and as these materials are disposed in forms accordant with those already described for giving support to the trusses of roofs, the process is called *trussing*. To construct a trussed beam, two large sticks of timber must be procured exactly the same in dimensions; or one large stick may be sawed longitudinally through its middle so as to convert it into two equal pieces, according to the size and strength required in the beam to be produced, and the deeper these pieces can be got from top to bottom the better they will be for the intended purpose. The simple truss is produced by letting scantlings of oak or other hard and compact timber into these pieces, in the form and manner shown at L, in Fig. 228, which represents one of the above mentioned pieces, and *a a* are two scantlings of oak four inches square, let into the piece by carving or chiselling out two channels or cavities, corresponding with the size of the oak pieces, and placed in the angular direction shown in the figure. These channels are only half as deep as the oak is thick, therefore the oak pieces, when introduced, project half their thickness out of the first piece of timber, and a similar pair of channels is cut in the second piece, so that when the two halves are laid together they can meet and touch, and the oak pieces will be completely hidden between them. An iron abutment bolt, having shoulders at right angles to the directions of the oak pieces, and a head that spreads over them, is also let into the middle of the pieces, as at *b*, and the oak pieces abut against it, while their lower ends come into contact with flat and acute wedges of iron or hard wood *c c*. The two halves of the beam being put together, with the several pieces just named between them, are held in permanent contact by a number of iron screw bolts and nuts passed through holes indicated by black dots in the figure, so that the beam, when finished, looks like the figure marked M if viewed from one side, and like N in plan, or when viewed from above. The scantlings of oak are sunk into grooves that fit them, to prevent the possibility of their becoming shorter by bending; and by tightening the nut of the bolt *b*, and driving the wedges *c c*, it can be brought to any required degree of compression, and an effectual truss will thus be produced; for the bottom of the beam, between *c c*, will act the part of a tye beam, the bolt *b* of a king post, and *a a* two opposite principal rafters, and as the centre of a beam so trussed cannot descend, without compressing and shortening the pieces of oak, so of course such a beam must be much more stiff than another without such preparation. Accordingly trussed girders and breast summers are frequently used.

The principal points to attend to in trussing a beam, are the selection of a material for the truss that will afford ample resistance to compression, to give the pieces good and immoveable abutments, and make the angle of the truss as little obtuse as possible. Hard and well seasoned oak is, on this account, generally used for the trussing pieces, but cast iron is often resorted to, and to diminish its weight, the form shown by Fig. 158 is adopted, but is terminated by flat plates or flanches at the ends, to increase the abutting surfaces. Iron trusses of this form require a very small portion of the beams to be cut away, because it is not necessary that the two inner faces or *cheeks* of the beam should come into contact. When the trusses are of wood, the central abutment is frequently made of hard wood also, when it should have the dovetailed form, shown at O, to prevent its rising upwards in the beam. But the iron screw bolt before mentioned is better, because it admits of tightening up the truss in any degree after it is put together, or in case of the beam sinking by the effect of time. The wedges *c c* are likewise often made of wood, but are better of wrought iron, because thin wood is very liable to split and crush under a heavy strain. The wedges should be made as broad as possible so as to distribute the pressure over a large surface of the section of the beam, but their width ought not to exceed one-third of the width of the beam. The wedges should also be placed at considerable distances from the extreme ends of the beam to prevent the timber that supports them being split and forced out of its place, for if the end abutments, or either of them give way, the power of the truss is gone. These wedges should, therefore, never be on the walls, or in places where the timber is liable to decay; but they may be put two or three feet within the walls, as timbers seldom break near their supported ends, and require assistance about their centres. This circumstance likewise assists in permitting us to make the angle of the braces less obtuse; since the nearer the abutting points *c c* are together, and the greater the depth of the beam in the centre, and the greater will be the power of the truss.

1023. Another method of improving the position of the angle, and thereby obtaining a longer trussed beam than can be made by the introduction of the simple truss just described, is to use a compound truss consisting of two braces as before, with a straining beam between them, as shown by Fig. 229. All that has been said on the construction of the former trussed beam applies equally to this: the only difference in their form being, that instead of the two braces meeting and abutting against a single bolt or key, they abut, in this construction, against two such bolts or keys, which are kept asunder by the interposition of the straining piece *d d.* This piece will have a constant tendency to spring upwards, or rise out of its place, but is restrained from doing so at its two ends by the heads of the abutment bolts at *d d.* The piece may, moreover, be made wider than the braces, so that it may be housed throughout its whole length on both sides in the two cheeks of the beam, or it may be held down by T headed or staple bolts passing through the beam, and fixed by screw nuts on its under side.

Notwithstanding a beam is strengthened and stiffened by trussing, still this process does not give so much additional strength as it is generally supposed by workmen to do, on account of the great obliquity of the braces of the truss, unless the beam is short, or the point of the truss is carried above it, which is frequently done when the height of the building permits a considerable loss of room beneath the floors. Thus Fig. 230 shows a timber girder so framed, in which all the parts will be obvious after the description already given. In using a girder of this kind, the joists cannot evidently be morticed into it, but a series of binding joists *a a a a* are blocked up upon the top of the girder by pieces of timber *b b*, and then common bridging joists are fixed upon them, as at *c c*, having their upper surfaces even or level with the highest part of the truss, so that the flooring boards can be laid without any interruption.

1024. Trussed girders are frequently made of cast iron instead of timber, especially in mills and manufactories; but if the span is large, cast iron alone should not be trusted. This metal will bear an immense strain of compression, but being brittle, it is less trustworthy against extension, especially if subject to jars or concussions, therefore the tye beam, or part exposed to an extending force, should be of bar or malleable iron. Fig. 231 is a principal beam or bearer so constructed. The cast iron is disposed in three plates or pieces, with flanches to them, so that they can be put together with iron screw bolts and nuts, by straight joints at *d d.* The end pieces may both be cast from one pattern, and large perforations are left through all the plates to produce lightness. A wrought iron tye bolt *e*, having a head at one end and a screw and strong nut at the other, (or a hole through the bolt and a strong iron wedge or key,) by which the bolt is drawn straight and tight, will effectually prevent the truss from sagging or dropping in its middle. This bolt should pass through long sockets cast near the feet of the truss, and it is better to hang the bolt up by eye-bolts or staples, to the under side of the cast iron, not only to prevent its sagging, but likewise to check its vibrations. The casting, although spoken of as being made in three pieces, will be better made in two, or even in a single piece, provided the opening is not too large. Such an iron truss is only used to give support and assistance to a floor of wood, iron, or any other material; therefore small girders or binding joists will have to be placed transversely over it, as at *ff*, and common joists are then put over them in the same way as if no iron truss had been introduced.

1025. In the construction of a common king post roof, all the pieces, except the king post, are kept in a state of compression, and that in extension; but the principles will not be affected if extension is substituted for compression, provided proper materials are selected to withstand the force; and accordingly this mode of construction is very commonly adopted for the beams of steam engines, thus producing a lighter and more economical beam than could be obtained in any other way. Fig. 232 exhibits the form of such an engine beam, in which the parts *g g*, *h h*, are of cast iron, by no means strong enough to answer the intended purpose, but by fixing and straining the four wrought iron bolts *i i i i* by means of screw nuts formed upon their ends for the purpose, a vast increase of strength and stiffness will be produced; for now no part of the cast iron beam *g g* can bend without straining or breaking some of the rods *i i i i*. The cast iron projections *h h h h* add nothing immediately to the strength of the beam, but perform an important office in maintaining the right lined direction of the wrought iron rods, and preventing their vibration.

1026. It seldom happens that timbers cannot be procured of sufficient length to reach across an opening to be floored over, but as this case may occur, Fig. 233 shows a means by which short timbers may be employed. One end of each piece works into a wall and the other ends are halved, or fitted upon each other in a manner that will be sufficiently obvious on inspecting the figure. By an extension of the same principle a large naked floor may be constructed.

1027. The dimensions of timbers to be introduced into roofs may be very accurately ascertained, because the weight of the roof itself, and of the materials with which it is to be covered, are ascertainable quantities, and may, therefore, be considered as given; and, in general, nothing requires to be added to the amount of this load, except a provision for the weight of snow that may fall and lodge upon a roof, which ought to be provided for, and this will more than amply cover the weight of a few men who may be engaged in occasional repairs. But if a roof is in any place that is likely to be crowded with spectators of any public exhibition, allowance must be made for such occurrence. Indeed, all roofs ought to be made considerably stronger than is necessary for the support of their own materials. With floors the case is very different. In general they cannot have the support that is given to roofs, and yet they are subject to much more mutable loads, because a room may sometimes be empty, and at other times may be crowded with persons, or may be converted into a warehouse or depository for heavy goods. Of course, therefore, floors require to be made much stronger in proportion than roofs, and the following rules for proportioning timbers, extracted from Tredgold's Elementary Principles of Carpentry, may be found useful. In the following rules for roofs, the *pitch*, or height of the roof, is considered as one-third of the base or span.

1028. Tye Beams.—To find the scantling of a tye beam that has only to support a ceiling; the length of the longest unsupported part being given.

Rule.—Divide the length of the longest unsupported part, by the cube root of the breadth; and the quotient multiplied by 1.47 for fir, or by 1.52 for oak,* will be the depth required, in inches.

Example.—Let the longest unsupported part be 17 feet, and the thickness of the beam be 9 inches. Then the cube root of 9 is 2.08 very nearly; therefore $\frac{17\times1.47}{2.08}=12$ inches, the depth required.

If the tye beam has to support rooms formed in the roof, then the rule for its depth will be the same as for girders, which see.

King Posts.—*Rule.* Multiply the length of the king post in feet by the span of the roof in feet. Then multiply this product by the decimal 0.12 for fir, or by 0.13 for oak, which will give the area of the king post in inches: and dividing this area by the breadth will give the thickness; or by the thickness will give the breadth. The scantling thus obtained applies to the shaft, or small part of the post, exclusive of the spreading haunches or shoulders.

Queen Posts.—The rule is the same in principle as for king posts, but is worked differently, because the king has the whole tye beam to support, and the queen only a part of it; therefore multiply the length of the queen post by the proportional part of the length of the tye beam that the post has to support; and this product multiplied by 0.27 for fir, or 0.32 for oak, will give the

* The constant numbers used as multipliers in this and the following rules have been taken from a comparison of many roofs and other constructions already executed, and known to stand.

area of the post in inches. Its thickness or breadth will be found as above.

Principal Rafters presumed to be strutted or supported under each purlin.

Case 1st. To find the medium or average scantling when there is a king post in the middle.

Rule.—Multiply the square of the length of the rafter in feet, by the span of the roof in feet; and divide the product by the cube of the thickness in inches. For fir multiply the quotient by 0.96, which will give the depth in inches.

Case 2nd. To find the average scantling when there are two queen posts.

Rule.—Multiply the square of the length of the rafter in feet by the span in feet, and divide the product by the cube of the thickness in inches. For fir multiply the quotient by 0.155, which will give the depth in inches.

The thickness of principal rafters is generally the same as that of the king post; consequently depth only has to be determined, and average scantling is here mentioned, because principal rafters generally taper or diminish (976), the depth at the top being about an inch less, and at the bottom an inch more than that at the centre.

Straining Beams.—In order that this beam may be the strongest possible, its depth should be to its thickness as 10 is to 7.

Rule.—Multiply the square root of the span in feet by the length of the straining beam in feet, and extract the square root of the product. Multiply the root by 0.9 for fir, which will give the depth in inches. To find the thickness, multiply the depth by 0.7.

Struts and Braces should be placed as nearly perpendicular as possible to the action of the strains they have to withstand.

Rule.—Multiply the square root of the length supported in feet by the length of the brace, or strut, in feet; and the square root of the product multiplied by 0.8 for fir, will give the depth in inches; and the depth multiplied by 0.6 will give the breadth in inches.

Purlins.—No part of a roof is more likely to give way than the purlins. They seldom break, but they sag or sink between one principal truss and another, thus destroying the uniform flat surface the face of a roof ought to preserve. To obviate this they ought not to be pinched in scantling, nor should they be morticed into the principal rafters, as sometimes done, but should lie over them, as already described (977). They ought likewise to be put on in as long lengths as can be conveniently obtained.

Rule.—Multiply the cube of the length of the purlin in feet, by the distance the purlins are apart in feet; and the fourth root of the product for fir will give the depth in inches. Or multiplied by 0.04 will give the depth for oak; and the depth multiplied by 0.6, will give the breadth.

Common Rafters are seldom or ever calculated, because common quartering or scantling of 4 by $2\frac{1}{2}$ inches, is amply strong enough for all purposes. But for small roofs to be boarded and shingled, or covered with light materials, a smaller size may be used with safety.

Common rafters and purlins should be made of straight grained pine or fir, in preference to oak, elm, or other woods; because it is less liable to warp and twist with the sun's heat than most other kinds of timber.

1029. *To Estimate the size of Timbers for Floors.*

Common or Bridging Joists.—As the strength of joists depends much more on their depth than their breadth, all joists should be thin and deep. Indeed, there is no advantage in thickness beyond what will give sufficient stiffness to avoid lateral vibration, and afford a sufficient surface for nailing the boards to. Common joists need therefore never exceed three inches in thickness, nor should they be made less than two inches. The thickness having been determined, the depth alone has to be sought by the following

Rule.—Divide the square of the length in feet by the breadth or thickness in inches, and the cube root of the quotient multiplied by 2.2 for fir, or 2.3 for oak, will give the depth in inches.

Binding Joists and Trimmers.—These admit of two cases.

Case 1st. To find the depth, when the length and breadth are given.

Rule.—Divide the square of the length in feet by the breadth in inches, and the cube root of the quotient multiplied by 3.42 for fir, or 3.53 for oak, will give the depth in inches.

Case 2nd. To find the breadth, when the depth and length are given.

Rule.—Divide the square of the length in feet by the cube of the depth in inches, and multiply the quotient by 40 for fir, or by 44 for oak, which will give the breadth in inches.

These rules suppose that the distance between the binding joists is six feet: if the distance apart be greater or less, the breadth, given by the rule, must be increased or diminished in proportion; but binding joists should never be more than six feet apart.

Girders.—As the dimensions of girders are frequently controlled by the dimensions of the timber that can be procured for them, two cases may occur, viz:—

Case 1st. To find the depth of a girder, when its breadth and the extent of span, or opening to be covered, are given.

Rule.—Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 4.2 for fir, or by 4.34 for oak, will give the depth required in inches.

Case 2nd. To find the breadth, when the length of bearing and depth are given.

Rule.—Divide the square of the length in feet by the cube of the depth in inches, and the quotient multiplied by 74 for fir, or by 82 for oak, will give the breadth in inches.

In these rules, the girders are supposed to be ten feet apart, and this distance should never be exceeded; but should the distance apart be less or more than ten feet, the breadth of the girder should be made in proportion to the difference of distance.

1030. Ceiling Joists require to be no thicker than is necessary to nail the laths to, and two inches will be quite sufficient for that purpose.

To find the depth of a ceiling joist, when the length of bearing and breadth are given.

Rule.—Divide the length in feet, by the cube root of the breadth in inches, and multiply the quotient by 0.64 for fir, or 0.67 for oak, which will give the depth required.

If two inches be fixed upon for the breadth, (and that is the common size,) the rule for ceiling joists of fir becomes very easy; for then half the length in feet is the depth in inches. The distance apart of these joists is generally from ten to twelve inches in the clear; but this must be regulated by the length of laths that can be procured, so that they may nail on without waste, or the trouble of cutting them. Laths are usually four feet long, and are sold in bundles containing one hundred each. One bundle, with five hundred lathing nails, will cover five yards superficial of ceiling.

Ceiling joists should be in long pieces, notched and nailed on to the bottoms of the binding joists. A ceiling so put up is less liable to crack than when the joists are shorter and morticed into the sides of the binding joists, which are not only weakened by the operation, but much more time is necessary for its performance. They should be made of pine, fir, or such wood as will not warp and twist.

So far, we have only considered such framings as can be strengthened and stiffened from above as in roofs; or such as depend wholly upon their own strength, as in floors and partitions between rooms, or in the sides of framed buildings; but there are many cases in which entire or partial support can be derived from below, and these lead to another important branch of carpentry, which is

The Construction of Wooden Bridges.

1031. There are many places in which bridges may be desirable, but at which stone cannot be procured; and others in which stone bridges would be found too expensive: and as those of timber may answer every purpose, and the construction of wooden bridges is intimately connected with the two subjects last under discussion, a few observations upon them may, with propriety, be introduced in this place.

Wooden bridges have their advantages and disadvantages; they are much less costly than those of stone, brick, or iron; for the mere centring necessary to build these, will, in most cases, cost as much as the expense of constructing an entire bridge of timber; and they are, moreover, much more speedily executed. On the other hand they are much less durable, owing to the natural decay of materials; and when once they do begin to fail, they become very troublesome and expensive, and require constant attention; because the parts that give way first are generally those least seen, as being less exposed to air and light, and they are frequently the most troublesome to get access to for repairs. Frequent interruption of the public passage likewise occurs, since it often happens that the bridge has to be shut up during the progress of its repairs.

1032. In newly settled countries, timber bridges are generally used, because such countries frequently abound in timber, which is of comparatively little value; and cheapness and expedition of construction are both objects of importance. But as such countries advance in population and riches, the timber bridges, when they decay, are seldom replaced with the same material, but those of greater duration are resorted to. The one construction may be said to be for present use, while the other is building for posterity. Of this, two bridges of London offer a good example. London Bridge, so called, because for many centuries it was the only bridge across the River Thames, in that city, was first built of timber about the year 994, and 169 years afterwards it was in such a state of dilapidation as to be unfit for use; and it was therefore rebuilt of timber in 1163; but a portion of it having been washed away, it was determined to adopt a bridge of stone, which was began in 1176, in the reign of Henry IInd., but was not finished until 1209, under King John, so that it was thirty-three years building; and in 1830 it was taken down, after having sustained the immense traffic of London for upwards of 620 years, notwithstanding it was built on the worst principles, and with little or no attention to science. This bridge had the most severe test, for it was one of the greatest thoroughfares in London, and was constantly covered with loaded carriages, and passengers of all descriptions; the river, where it was built, was 900 feet wide, and subject to a tide rise of about 8 feet, but owing to improper construction, the water way was contracted to 194 feet, by the introduction of 18 enormous stone piers, which supported 20 small arches, so that twice in every 24 hours, or whenever the tide-water retired, a most tremendous torrent was rushing through the arches, and such a one as must have carried away any bridge unless constructed of the most refractory materials. It therefore produced a formidable impediment to the navigation of the river, and was on this account removed and replaced by a magnificent stone bridge of only five arches, which, of course, offered very little opposition to the passage of the water or its navigation, and on the completion of this new bridge the old one was taken down by contract, and the workmen employed declared, that it was so well put together, and was formed of such good materials, that it might have stood for centuries to come, had not its foundation been greatly injured by the violent cataracts of water that flowed through its arches and washed the soil away, and laid bare the piles upon which the piers were built. These excavations required to be constantly filled up with block chalk, as they occurred, and this operation was not only a great source of annual expense, but tended to the further injury of the navigation. These circumstances are mentioned here merely to show the advantage and durability of a substantial stone bridge, and to put them into comparison with another bridge across the same river, only a few miles to the west of it, called Battersea Bridge, which was erected entirely of timber, about 100 years ago. This bridge, which is a great thoroughfare, is a private joint stock concern, supported by tolls upon all traffic and passengers that go over it; and such were the constant expenses of its repairs, that the tolls were scarcely sufficient to meet them; a constant succession of new timber and labour being necessary. It is estimated that within the period of 15 or 20 years every piece of timber is renewed, so that it may be said the whole bridge is rebuilt every 20 years. Of late, parts of the timber have been replaced by cast iron, and this may have the effect of rendering it more durable. In England no bridge is ever covered over by a roof or side walls to afford protection against weather, which salutary precaution is adopted in the United States, Germany, and many other countries, and no doubt assists in giving a greater duration to timber bridges than they could otherwise possess.

1033. The principles of carpentry and framing, as already laid down, apply so completely to the construction of bridges of timber, that little more can be said on this subject, further than to show the several varieties of construction that have, from time to time, been adopted, and to point out their respective advantages and disadvantages, as well as the local circumstances that are most essential to each of them.

1034. Timber bridges may be divided into several distinct forms or modes of construction, and we will consider them accordingly, from their most simple to their more complicated constructions.

The simplest and most obvious bridge, which requires neither skill in framing, or application of any mechanical principle beyond that of mere strength, is formed by laying two, or any greater number of trees or pieces of squared timber across the stream, from one side to the other, placing them nearly parallel to each other, and at right angles to the stream, and fixing other smaller pieces upon their tops, pointing in the direction of the river, putting them either close together, so that they may be covered with earth to form a roadway, or else placing them at greater distances, so as to serve as joists upon which planking may be fixed, either to be used in its naked state as a road, or to be covered with earth or gravel, in which latter case side boards will be necessary to keep the materials of a uniform thickness, and prevent their falling over the edges into the water below. Such a bridge may have rails placed at its two sides, for the protection of passengers, and will answer every purpose for short distances, provided the girders or main bearing timbers have sufficient strength; and that strength may be augmented by placing these timbers nearer together, or even in contact, or by using two layers of such timbers one upon the other.

Still in this construction we are limited to dimensions; because it seldom happens that timber of uniform size can be obtained of more than fifty or sixty feet in length, and if they were to be used in such lengths, they would sag or bend downwards in the middle, and would have so much elasticity, when a load came upon them, that they would vibrate up and down, and thus exclude the possibility of forming an earth or stone road above them. The simplest way of obviating this inconvenience is to drive a row of perpendicular piles into the bed of the river, making the length of the row in the direction of the stream, and placing one pile under each bearer; or else using fewer piles and surmounting them with a cap or sill of timber, upon which the middles of all the bearing timbers could rest, and in that way perfect steadiness and stability may be given to the bridge, because if a single row of such piles, placed in the centre of the pressure, may not be sufficient, other similar rows may be placed parallel to each other, at as small intervals as may be necessary to insure perfect stability.

It may appear that such a bridge is only applicable to very narrow rivers or valleys, because we are limited by the usual length of timber which ought to be used in single or entire pieces; but this is by no means the case, because the same rows of piling that have been spoken of as applied to support the middle parts of the main bearers, may likewise be used to support the ends; or the bearers may break joint, instead of all terminating upon the same row of piles; so that the same sill or row of piles that supports the ends of the three pieces of timber may support the middles of another set of three bearers, and an intermediate part of a third set, and in this manner the bridge may be continued over a river of any width.

1035. Devoid of skill, beauty or science, as this mode of construction unquestionably is, it is, nevertheless, almost the only one that is resorted to for the construction of timber bridges in England. Battersea bridge, above referred to, is of this kind, although upwards of 300 yards long, and over the finest river in the country. The only difference being, that in the large wooden bridges of England, instead of using single rows of perpendicular piles to support the bearers or girders, a kind of pier is formed by driving several parallel rows of piles very close together, and cross bracing and tying them together with oak planks about four inches thick, placed diagonally so as to act the part of struts and braces, thus producing strength and stiffness, preventing the piles from getting out of their perpendicular positions, and enabling them to resist the impulse of the current running against them, as well as the shocks of floating ice, and heavy laden craft or vessels which occasionally run foul of them. All these braces or tyes, and indeed all parts of wooden bridges, must be put together with screw bolts and nuts, wedges, or other contrivances such as will permit of the parts being taken asunder; because they will decay in time, and it will be necessary to take out and replace parts without disturbing or maiming those that remain; and this could not be effected if the work was firmly nailed or spiked together.

1036. It may not be possible to introduce rows of piles into a river for affording support to a bridge without impeding its navigation, particularly if it is narrow, and whenever this is the case we have no alternative left but to resort to the rules of carpentry for obtaining artificial support, and this can be done in several ways. Thus, for example, let *a b*, Fig. 234, be a section of a stream to be crossed. We must, in the first place, build foundations either of stone, brick, or timber, on the opposite sides of the water, as at *c c*, for supporting or carrying the bridge, and these, called *abutments* in bridge building, ought never to be of timber, on account of its liability to rapid decay when in contact with the earth, particularly near water. *d e f* is a side view of one of the beams of the bridge supposed to be so long as to be incapable of bearing a load upon it without swagging or vibration, but by applying two angular struts *e c*, from the middle of the beams, and letting their lower ends rest upon offsets or shoulders made to receive them at *c c* in the abutments, the main bridge beams will be effectually supported. Should the struts *e c* be so long as to endanger their bending, they may be stiffened by tye or bridle pieces introduced, as dotted in at *g g*. When the opening to be crossed is very wide, the angles *d e c* and *f e c* will become very acute, and thus diminish or destroy the efficacy of the struts, unless their abutments can be obtained in very low positions, or the platform of the bridge is raised so high as to render it inconvenient of access; for one point to be attended to in the formation of all bridges is avoiding any sudden or abrupt rise or fall upon the bridge, which ought to assimilate, as nearly as possible, with the road of which it forms a part. The struts may be considerably shortened by adopting the form shown by Fig. 235, in which the length of the bridge is divided into three instead of two parts, and a straining beam is introduced between the struts for their upper ends to abut against, and this principle is still further carried out in Fig. 236, in which two pair of struts, with separate straining beams, are used. In both these designs the principal bearing beams may be in two or even three lengths scarfed together, because they should be bolted through to fasten them to the straining beams, and this will materially assist the joint, which must be made over such beam.

1037. The common roof framing is applicable to the formation of bridges, because the two side or exterior bearing beams may be framed with king posts and struts, as in Fig. 237, and if transverse joists are laid over the top of the tye beams they will sustain the floor or platform of the bridge, while the framing will form side parapets or fences, particularly if filled in with rails or paling, as shown in one half of the figure. And when a river is not navigable, or subject to floods, the principle of the roof truss may even be inverted by turning the struts into tyes, and placing the king post beneath instead of above the tye beam, as in the figure where *h* is the inverted king post, and *i i* instead of being struts, are chains or bars of iron drawn tight by screw nuts upon their ends. Such a device will evidently bear up the king post and support the middle of the tye beam, but is not so good or trust-worthy as the king post truss in its ordinary form, and is therefore never used. The principle of roof trussing should, however, be constantly resorted to in making the side guard fences or parapets of all timber bridges, and is in common use for this purpose in the form exhibited by Fig. 238, in which it will be seen that a straining beam is introduced between two short queen posts, in order to avoid the unsightly height of a king post. A long bridge may be constructed by a series of these trusses joined end to end, even without connection, provided each junction is supported by a pier of timber, bricks or masonry, and the spaces between one straining beam and another may be filled up by pieces that appear as continuations of them, so as to produce a continued top rail to the side fences, as shown in the figure. It need hardly be stated that this construction of bridge in which the support is wholly from above, may be united with that shown by figures 234, 235 and 236, where it is from below, whenever the bridge is sufficiently elevated above the stream to place the under struts out of the reach of floating ice, and then a much stronger construction will be obtained of the form shown at P in Fig. 238.

1038. Another expedient that is frequently resorted to for producing additional strength in truss-framed timber bridges, is to divide the road longitudinally into two carriage ways, with a foot road between them, or into four parts, consisting of two carriage roads in the middle, and two foot paths, one on each exterior side. The partitions used to produce these divisions are framed trusses exactly like those on the exterior sides, so that by this last mode of division five parallel sets of trusses can be carried up above the platform or road of the bridge without producing any obstruction to its passage, instead of the two exterior ones as first described, and in this way the strength and stiffness of the bridge is very much increased.

1039. It is the custom in the United States, as well as in some parts of Germany and France, to cover timber bridges by roofs and side walls, which greatly preserves the timber by protecting it from weather. But this covering answers another important end; that of permitting trusses which rise high above the roadway, to be used without producing an unsightly appearance. They become necessary for the support of the roof, and at the same time afford the means of *hanging* the roadway up to them, in addition to the other means of supporting it, as already described. Thus a bridge, such as is shown at Fig. 238, may have a set of additional king post trusses placed on each of its sides high enough to carry the roof, while cross-beams proceed from the bottom of each king post under all the main bearers, so as to render the former, or any other trussing, nearly if not quite unnecessary. In fact, the principles of the common framed truss admits of so many modifications and applications, that it would be in vain to attempt to describe them all.

1040. When the navigation of a river, or other causes, forbid the erection of piers in the stream, and it happens to be so wide that a truss might be unsafe, other modes of construction must be resorted to, and the polygon or arch are found the most effective; but in using these, a great additional expense is thrown into the construction, for a centring or support of some kind, to uphold the materials until the arch is completed, now becomes necessary, but was not required in any of the constructions before referred to.

1041. Three distinct means are employed for forming this kind of bridge, viz: a series of hollow boxes, the sides of which that are to come into contact with other boxes, being inclined or sloping, so as to produce a wedge-like figure similar to the stones of which arches are formed. A series of stretching beams with a radial piece between each, and tye beams below, or a combination of bent timbers scarfed and joggled together, so as to produce a real timber arch. The platform or roadway of the bridge either passes over the whole of these, or is suspended between them.

The principle of the first of these constructions is shown by Fig. 240, in which it will be seen that these boxes are not made with close sides, but of the angles of boxes only, with cross braces to stiffen and strengthen them. By this means much material is saved and the construction rendered much lighter. This mode of construction requires so much good and expensive workmanship, and introduces so many mortice joints near the ends of the pieces, being the most unfavourable positions for both strength and duration, that on these accounts it is hardly ever used for wooden bridges, but it forms the leading feature in many that are made of cast iron, because in that material the angles can be cast solid and great strength obtained. This mode of construction will, therefore, be more fully described when we arrive at the subject of Cast Iron Bridges.

1042. The second mode of construction is shown by Fig. 241, in which *a b, b c, c d,* &c. are stretching beams, made either of single or double beams abutting against radial pieces *b e, c f, d g,* &c. called in this case bridle beams or pieces, the lower ends of which may proceed quite down, or very nearly down to a right line that would join the springings *a* and *h;* the lower ends of the bridle pieces are connected by timber or iron ties *a e, e f, f g,* &c. This framing is very simple and possesses great strength, while all the pieces are kept in a perfect plane with respect to each other, but the difficulty is to preserve this figure, since there is nothing by which this can be effected, except the mortice joints, which, from the nature of the construction, must be shallow. In order, therefore, to use this framing with success, two of them must be used bolted or hooped together, and so arranged that the bridle pieces of the one truss may come half way between those of the other, in which case the straining beams will break joint, the joints of one set of pieces coming against the middles of those of the other set. By this means, and using several parallel ribs, connected together at proper distances, by diagonal struts disposed as in Fig. 242, a stiff and strong arch may be produced. The beautiful timber bridge over the Schuylkill at Fairmount, near Philadelphia, which was unfortunately destroyed by fire on the 1st of September, 1838, offered a very fine and judicious example of such diagonal bracing. It was among the lightest, boldest, and most beautiful specimens of carpentry in the world, being a single arch of 340 feet 4 inches span, without any other support than what was derived from the two end abutments.

The recent destruction of this bridge renders it desirable to preserve some record of its formation, and the construction of its framing is therefore shown by Fig. 243. It was designed by Lewis Wernwag, and one of its peculiarities was that every large piece of timber was sawed lengthwise in two, in order to examine its heart, and see that no rotten, shakey, or bad timber was introduced into it. By this means mortice holes were avoided in the main timbers, as the tenons passed between, instead of through them, but were let in a sufficient distance on both sides to preserve them in their positions. This expedient likewise proved a great preservative against dry rot, because all the timbers were so distant from each other as to permit a free circulation of air between them, except in the actual joints, and they were kept close by iron screw bolts. There was a great quantity of bar iron used in this bridge; for the main arch consisted of three double rows of main timbers, laid three deep, or one above the other. Near to these, their corresponding halves were placed face to face, but with the tenons of what may be called the king posts between them, the whole being key joggled and bound together by wrought iron hoops. Twenty-nine king posts arose nearly in a radiant direction from the arch so put together; and side braces were applied on each side of each king post, spreading to the full extent of the adjacent openings, and taking their abutments under shoulders near the tops of such posts, thus producing the crossing of the braces shown in the figure; and at each crossing or intersection the braces were bolted together. Between the tops of every king post, a straining beam is introduced, thus preventing the tops of the posts from approaching each other; and consequently the arches below from changing their figure. The curvature of the arches were further preserved by their extreme ends abutting against solid blocks of masonry built in the form shown in the figure, to receive them; and in order to give greater weight and stability to these abutments, they were carried considerably above the top of the springing of the arch; therefore the roadway instead of being directly upon the arches, was kept hollow or above them for the distance of six bays or openings before it intersected the general curvature, as shown by the dotted line *a a*. This floor was supported by transoms or cross pieces, bearing upon shoulders cut in the sides of the king posts, and bolted to them. A tye beam passed over the tops of every row of king posts to support them in their vertical and parallel directions, and to carry the roof with which this bridge was covered. It was also boarded up on the outsides so that none of the timber framing was visible, except from within.

From the above described mode of framing, each space between one king post and another becomes a complete vouissoir or form similar to an arch stone; and a similarity may, at first sight, appear between this arch and that shown by Fig. 240; but in that mode of construction each vouissoir or wedge is separate, while in this bridge they are all united by the timber arches, as well as by having only one king post in common to two of them. The artist, however, not willing to confide in the mere strength of the timber framing, tied the whole together to the abutments by a series of iron tye bars, commencing in the first instance by a bar *b* let a considerable distance into the stone-work of the abutment and there firmly fixed, and from thence passing to the top of the first post, and from thence down to the bottom of the second. *c* is another tye fixed in like manner into the abutment and passing to the top of the second post, and from thence to the bottom of the third; and these tyes, it will be seen, are continued from the top of one post to the bottom of the next, throughout the whole length of the bridge, meeting and taking an opposite inclination when they arrive at the centre, and contributing considerably to the strength of the whole structure.

1043. Cross framing, by halving scantlings together and attaching them strongly to a top and bottom beam, or even to an intermediate one, as shown by Fig. 242, also produces a strong combination against vertical pressure, and at the same time makes a most safe and efficacious side frame for bridges, and it is therefore very commonly used for that purpose at the same time that it is affording suppport. The appearance somewhat resembles that of the framing of the Schuylkill Bridge, but its principle is different, and after what has been said on this subject, the student will have no difficulty in determining which of its parts are tyes and which struts, as well as seeing on what its strength depends.

1044. When speaking of hooping beams or trusses together with iron, it must not be supposed that such hoops are in one piece, like those used in making casks, but they always consist of two or four pieces put together with screws and nuts, as shown at P and Q, Fig. 244, which not only affords facility in putting them on, but likewise in tightening them at any future period, so as to accommodate them to any shrinking of the timber.

1045. The third mode of construction is that in which the timbers are bent and scarfed, and so joggled one upon the other as to produce a real arch of timber. This is the mode of construction that has been principally adopted in the United States, which possesses many bridges of this description of a magnitude and boldness of conception and execution, such as are met with in no other part of the world, Germany alone excepted. In contemplating these, one cannot help feeling a regret that such splendid works of art should be formed of a material so perishable as timber.

Fig. 245 shows a small portion of the wooden arch that was adopted by Mr. Bludget in building a bridge over the Portsmouth river, being a single arch of 250 feet span. In this, the pieces forming the arch are not in contact, but twice their own depth apart, thus constituting three concentric arcs D E and F, of which that in the centre at E, and the corresponding arches in two other sets, support the floor of the bridge. These circular ribs were selected out of timber grown in a curved form, so as to insure the grain of the wood running nearly in the direction of the arch, and they are connected together by pieces of hard wood *b* and *c*, and a wedge *a* driven between them, mortice holes being made through the curved pieces for their reception. The curved pieces are fixed and secured at their proper parallel distances, by notches cut on the outer edges of the two pieces *b* and *c*, as shown by dotted lines at *i*, and the mortice holes have a corresponding shape. The wedge *a* on being driven brings all these joints into close contact. Each curved arc is composed of two pieces of timber, laid side by side, each piece being about fifteen feet long. These pieces are so disposed as to break joint, that is, the end of one piece comes against the middle of that which is contiguous to it. Their ends are not scarfed but abut in a close joint, one against the other, and the two pieces are jointed together by transverse dovetail keys and joints as before. The positions of the transverse keys and wedges are shown at *l*, and Fig. 246 is a horizontal view or plan of one of these joints on a larger scale.

This is a very ingenious method of uniting work, and possesses the advantage of exposing every part to the free action of air, and permits any one piece to be taken out in case of its decay or failure, without disturbing the rest, which is a very material point to be attended to in the formation of all heavy framings exposed to weather: but the great number of mortice holes that are necessarily made through the main ribs cannot fail to weaken them considerably, and would prove highly detrimental, if the pieces were otherwise strained than by compression. The keys and wedges being tightly driven in, supply the place of the wood abstracted, and, therefore, render the mortice holes less objectionable. But the bridge is stated to be very flexible, and would no doubt be much improved by the introduction of horizontal oblique braces, to connect the three ribs.

1046. The most usual construction, however, is to place the timber arcs in contact with each other, and one of the simplest bridges of this kind is that at Wittengen, in Switzerland, slightly described by Mr. Coxe.* The principles of its construction are shown by Fig. 247. Its span is 230 feet, and although it rises but 25 feet in the middle, it is found amply strong enough to sustain all the traffic that passes over it. It consists of two great timber arches approaching to the catenarian form, and fixed parallel to each other upon rock abutments, with the roadway suspended between them. ABC is one of these two arches built up of seven courses of solid logs of oak, in lengths of 12 or 14 feet, and about 16 inches in thickness. These were picked of a natural shape suited to the intended curve, so that the wood is no where cut across the natural grain to turn it into shape. These logs are laid above each other in such manner that their abutting joints may be alternate, like those of a brick wall, simply built up by laying the pieces upon each other, taking care to make the abutting joints as close as possible. They are not fastened together by pins, bolts, or scarfings of any kind, but are held in their positions by iron straps or hoops, which surround them at the distance of five feet from each other, where they are fastened together by bolts and keys. The roadway is flat, or without any elevation in the middle, and is supported about the middle of the height of the arch, as shown by the line *a b c*, upon cross joists which rest on a long horizontal summer-beam hung to the bottoms of perpendicular pieces, which are bolted to the insides of the beams forming the arches, while their tops rise high enough to carry the plate *d d*, upon which the roof of the bridge is supported; the roof projects laterally over the arches to protect them from weather, and the three spaces between the uprights at each end have diagonal braces to assist the roof in withstanding the effects of wind. This bridge was the last work of Ulrich Grubenmann, of

* Travels, Vol. I., page 132.

Tuffin, in the canton of Appenzel, an uneducated carpenter, who rendered himself celebrated by the erection of several large works of the same kind, and particularly the much admired bridge over the Rhine at Schaffhausen, which he commenced in 1757, and finished in three years.

1047. The Schaffhausen bridge had two openings, one of 193 feet and the other 172 feet span, appearing to rest on a small rock near the centre of the river. When Grubenmann was applied to to erect this bridge, he was desirous of making it a single span of 365 feet from one side of the river to the other, but the magistrates deemed so large an arch in timber to be unsafe, and compelled him to take a bearing upon the central rock, which he unwillingly complied with. The bridge being finished, and publicly opened by the passage of loaded carriages, was declared to give complete satisfaction, and that being acknowledged, it is said that Grubenmann, in presence of his employers, took a thin board and passed it between the apparent abutment and the top of the rock, to show them that although it appeared to rest upon it, it did not in fact touch it, and thus that he had accomplished his desire of making it a single span. However this may be, it afterwards sunk by the compression of the timber, and took a solid bearing upon the rock, which no doubt afforded very material assistance in its support. This bridge was much admired as a most excellent piece of carpentry, but owing to the oak beams that came in contact with the stone foundations being placed too low, and not being exposed to air, they rotted, and the bridge began to settle. Grubenmann being dead, it was repaired in 1783 by Georges Spengler, another ingenious carpenter of Schaffhausen, who raised the whole bridge by means of screw jacks, and replaced the decayed timber. This was the only repair done to it during the forty-two years it existed, and it would probably have been in good condition at the present day, had it not been burnt by the French army in 1799. This bridge was not composed of arches, but was on the principle shown by Fig. 236, viz: a number of diagonal struts or braces with straining beams between them; but the roadway did not pass over the framing, but was suspended between separate parallel trusses by means of perpendicular tyes called *stirrups*, disposed at *i i*, Fig. 236, united at their lower ends to straight beams *m* appearing like tye beams, but having neither a strain of extension or compression upon them, since their ends may hang free of the abutment walls, their only office being to support transverse joists upon which the planks of the road are fixed.

1048. Whenever a bridge roadway is made of timber, it ought to be of two thicknesses of planking crossed, and so united together that the upper one can be taken up without injury to that below; because the upper planking wears out rapidly from the passage of horses and wheel carriages upon it, and therefore often requires renewal, for which provision should be made without the necessity of disturbing the under planking, or any of the main timbers of the construction.

When the roadway passes over the tops or crowns of wooden arches, and is required to be nearly level, it is best to support it upon joists which take their bearing upon perpendicular posts bolted at equal distances along the sides of the arches, or else morticed into sleepers which pass transversely over the tops of all the arches, and take even bearing upon them all.

1049. One great difficulty attending the construction of large timber arches arises from the lightness and elasticity of the material, in consequence of which, if a very heavy load is introduced upon a timber arch near to one of its abutments it may depress that part, thereby causing the opposite side to be elevated and change its figure; and although this effect may take place to so small an extent as to be invisible without close examination, yet it will rack and strain the joints, and cause them to become loose, and in time will prove very detrimental to the stability of the concern, and it must therefore be prevented as far as possible. Two methods have accordingly been adopted to meet this evil, one of which is to give much greater strength to the arch than is necessary for supporting the greatest load it may be expected to carry, by putting a great number of rings or arches of timber together in the manner already described; and the other is to use a weaker arch, and stiffen it by framing introduced within it, with a view to prevent the possibility of its changing its figure. The bridge built over the Delaware at Trenton, New Jersey, began in May, 1804, is of the latter description, and consists of five arches or openings extending across the river, which at this part is 1100 feet wide. It was designed and executed by Mr. Burr, is different from any timber bridge that preceded it, and has been much admired in Europe as a splendid specimen of construction. The superstructure consists of five parallel rows of arches of wood, which are segments of circles rising from their chord lines in the proportion of 13 feet to 100. One of these is placed in the middle of the bridge, and the others respectively at 11 feet, and 4 feet 6 inches on each side; thus forming two carriage and two foot roads. The ribs or arches are all formed of white pine planks from 35 to 50 feet in length, 4 inches thick and 12 inches wide, except the middle one, which is 13. These planks are bent and laid one over the other in close contact, and with all the joints broken until they form a depth of three feet through, and they are secured together by iron straps. This method was first introduced by Mr. Burr, and is believed to possess advantages over the method of forming arches by whole timber. To guard against the springing or elasticity of the ribs, rows of horizontal tye beams are introduced from one pier to the other, and these are connected with the ribs by diagonal timbers, which are continued above the spandrells of the arches, which are filled up with crossed or intersected timber in the form of diagonal braces connected with the roof plates, so that the ribs are stiffened both from within and without so effectually that it is next to impossible that they should change their form.

The platforms on which the travelling is performed are suspended from these arches by means of perpendicular iron bars which hook into eye bolts firmly fixed through the arches, at the distance of every eight feet in the three middle sections and sixteen feet in the two exterior ones. To the lower ends of these bars stirrups are appended, in which the beams lie that sustain the joists and flooring; diagonal braces are also used to connect the platforms with the tye beams, and thus prevent the swinging which they would otherwise be subject to. This bridge is supported by stone piers and abutments built so high above the highest rise of water as to place the structure out of danger from ice or freshets, and to permit the navigation of large craft beneath it. The whole is covered in and roofed so as to be effectually protected against weather. A general idea of the construction of this splendid bridge is given by Fig. 248.

1050. Many other timber bridges might be described, but the specimens selected, it is believed, will cover every variety of construction, and our limits prevent a description of the details such as the manner of joining the timbers, introducing and fixing the bolts and iron work, and many other particulars which alone might fill a volume. These matters may be safely left to the judgment of the Engineer, when he has obtained clear ideas of the manner in which pressures will act and the best means of opposing them. But to strengthen his confidence in his own opinions and plans, it would be well that he should carefully inspect, measure, and take drawings from some of the best bridges built, and of these numerous examples may be found in many parts of the United States.

1051. The greatest load to which a bridge is subject, is when it is crowded by human beings, and such a load amounts to about 120 *lbs.* to every square foot, independent of the weight of the bridge materials themselves, so that the actual load to be sustained should not be considered less than about 300 *lbs.* for every square foot of roadway; and such strength ought accordingly to be provided in every bridge that occurs in great public thoroughfares. Timber bridge building for such situations has long since been given up in England, and will no doubt gradually die away in America also, but still they must always be used in certain positions and for certain uses; and the most frequent occasion that the Engineer will have for them is in what are called *occupation bridges* and *shifting bridges* in canal work.

In the formation of a navigable canal, it very frequently happens that the cutting may run through a portion of a man's estate or farm, thus cutting off all communication between one part and another by the intervening water, and in such cases the land owner has a right to insist on the canal company putting him up such a bridge as shall enable him to have free access to, or occupation of his land. Such bridges not being on public roads, nor requiring any extraordinary degree of strength or elegance, are usually made of wood; and of course are maintained and kept in repair by the canal owners, unless a specific agreement is made to the contrary. When the canal is not in deep cutting, and its water comes nearly to the same level as the surface of the adjacent land, occupation bridges require considerable elevation in order that boats with high loads may pass under them, and such constructions as are shown by Figs. 234 and 235 may be sufficient; but to render them available it becomes necessary to construct long hills or inclined planes at the abutments in order to obtain easy accessible roads to them. Such hills are expensive in their construction, dangerous in their use, and often unsightly and inconvenient; therefore shifting bridges are frequently used in place of them. These bridges are not raised up above the ordinary level of the land and roads, but they shift or move away in order to let highly loaded boats, or vessels with masts pass through them.

1052. Shifting bridges are of two kinds, the *draw-bridge* and the *swing-bridge.* The draw-bridge is merely a wooden platform of sufficient width to allow the passage of horses, wheel carriages and passengers, and of sufficient length to reach from one side of the canal or water course to the other, or rather to reach from a jetty or projecting abutment built on one side of the water to a similar projection on the opposite side, because when these bridges are used it is customary to contract the water passage to the smallest extent that will permit the necessary vessels to pass, in order to make the bridge platform as short and light as possible; for a platform strong enough to bear heavily laden wagons must necessarily be heavy. This platform is so fastened by pivots or hinges at one of its ends to the jetty or projection, that it can be raised from its horizontal into a vertical position while vessels are passing, and this is done in two ways. One of these is to attach a chain to each of the corners of the unhinged side, to lead these chains over two iron pullies fixed on the hinged side at a height exceeding the length of the platform, and to let them terminate at a cylinder or windlass, having a cogged wheel and pinion to gain power, fixed on the hinged side, for raising and lowering the platform by the turning of a handle. The other method is to fix a compound framed lever of wood or cast iron, shaped like Figs. 249 and 250, over the platform *b*, such beam having strong iron pivots *a a*, which revolve on the tops of two posts fixed firmly in the ground at the two sides of the bridge. *c c* are two chains attached at their tops to the corners of the framed part of the lever, and at their bottoms to the sides of the platform rather beyond the middle of its length; and *d d* are two cast iron weights fixed on to the two arms of the lever for the purpose of nearly balancing the weight of the platform, and making it more easy to move. The platform should, however, have a preponderance, in order that it may lie steadily, when down, but the counterpoising weights assist materially in the ease and expedition of using the bridge, and are as important in lowering as in raising it; for if the platform is permitted to descend without counterpoise, it falls with a force that soon deranges itself, as well as the sill that is to receive it, and will stand in need of constant repair. When drawbridges are long, or are subject to very heavy loads, the ribs or joists of which they are composed should be slightly cambered or bent upwards in the middle of their length like *b*, Fig. 250, and they should not only have bearing sills *e e*, to carry the weight of the bridge, but abutting sills *f f*, so framed and fixed that they cannot recede from each other, and be placed so far asunder that they may not pinch or confine the ends of the platform, but allow it a full half inch of play. A heavy weight coming upon the platform will, however, so far call the elasticity of the joists into play as to partly straighten the platform and cause it to take abutments from these beams at the same time that it is supported by those below. The balance drawbridge, from its simplicity, ease and expedition of working, is much more used than that with a capstan.

When the canal or water course is very wide, two flaps or platforms, with separate apparatus for moving them, are hinged, one on each shore, and in this case they meet and abut against each other in the centre, and they must be curved and have good abutments on their land sides, to prevent them from spreading. Such drawbridges are very frequently introduced into the central or widest opening of stone, or other permanent river bridges, to permit tall masted vessels to pass through them.

1053. The swing-bridge is much more expensive in its construction than the drawbridge, but is very much used in canals, particularly for roads, when they are not sufficiently frequented to warrant the construction of a permanent brick or stone bridge. Their construction is such that the bridge never changes its horizontal position, but turns a quarter round upon a pivot, so that it may be turned over the water, or be pushed on one side so as to come over the dry shore. Fig. 251 is a ground plan, and Fig. 252 a side view or elevation of such a bridge. In these figures *a b* is the width of the canal or water course to be crossed, and *c d* the timber platform, which generally has side rails for the protection of passengers. The bridge, therefore, in appearance, is nearly similar to bridges of a stable construction, but by certain contrivances about it, it is capable of being turned from the position it holds over the water in Fig. 251 to that dotted in in the same figure. This is brought about by the means shown in section or profile in Fig. 252. *e* is a strong cylindrical pin or rod of wrought iron about three inches in diameter, its upper end being brought to an obtuse conical point, which should be of hardened steel, and its lower end is fixed into the centre of a cross *f f* of timber or cast iron, best seen in plan in Fig. 251, (the same letters of reference being used in both figures). The iron pin is braced to the cross by diagonal pieces of iron spreading in four directions, so that it cannot shift its perpendicular position in respect to the cross. To fix the bridge, a pit or cavity is sunk close to one of the edges of the canal, and in this a solid and level foundation of brick-work or masonry is laid, as at *g*, Fig. 252. The top of this must be quite level, and be five or six feet below the intended surface of the bridge. On this the cross is placed, and is bedded in mortar in such manner that its iron pin may be correctly perpendicular. This adjustment being made, the cross and iron pin are built in with level and solid brick-work two or three feet high, so as to bury the cross braces and part of the pin, until about thirty inches or three feet of its upper part can alone be seen. This is for the purpose of fixing the pin and giving it perfect stability. A flat ring of cast iron, at least six or eight feet in diameter, and perfectly smooth on its upper surface, which is six or eight inches wide, is next bolted down upon the brick-work by counter sunk bolts in such manner that the pin may be exactly upright and in the centre of the ring, the upper surface of which must be made truly level. The bridge itself is framed of three or four sticks of timber long enough to reach across the water, while they cover the iron ring. One of these pieces is shown at *c d*; they should have a slight camber upwards, and are attached together by being framed into strong end pieces, and are farther steadied and united by cross pieces between them, as well as by being planked over on the top. A transverse piece under *c*, Fig. 252, receives the top of the iron pin which works in a lump of brass or cast iron, with a conical hole fitted to the steel top of the pin. A strong timber frame *h* is supported by standard *i i* below the bridge, and is floored or made close on its under side, which also carries another cast iron ring, or axle-trees like arms, for the cast iron wheels or runners to turn upon. These should be at least four inches in diameter, and are so adjusted as to height, that when the bridge is placed on its pivot, these wheels may just touch and run upon the upper smooth surface of the lowest cast iron plate; and to render the motion more steady, the iron centre pin also passes through a hole bushed with iron in a strong beam that runs across the frame *h*. Lastly, heavy stones, or blocks of cast iron ship ballast are piled up between the bridge and the upper roller plate upon the boarded frame *h*, the whole of them being disposed, as at *l*, behind the iron pivot *e*, and they require to be added until their weight exactly balances or counterpoises that of the projecting part *d* of the bridge; which done, a man with one hand will be able to swing or turn a bridge capable of sustaining the heaviest laden wagon with ease. The bridge being adjusted, all the moving parts are surrounded by a cylindrical brick wall like the wall of a well, reaching up to the ground height, and the wooden floor or platform of the bridge must oversail or cover this work, so as to hide it, and prevent, as far as possible, the introduction of pebbles, dirt, or any thing that might impede the moving parts. A trap door should be formed in the bridge, or left through the brick-work, to admit a man to clean and grease the moving parts when occasion requires. The opposite end of the bridge is received into a large rebate made by two pieces of timber, seen in section at *m* and *n*, Fig. 252. These are of course placed on the opposite side of the water to the parts last described. The piece *m* takes the weight of the bridge, and for that purpose must be firmly bedded and bolted to a good brick, stone, or timber foundation, and *n* is an abutting piece for the bridge to shut against, which must of course be well stayed and supported in its place by nearly horizontal under-ground timbers resting against solid ground.

The abutment sill *n* is not placed at right angles to the central line of the bridge, but inclines a little to it, as shown at *n*, Fig. 251, and the end piece of the platform frame work takes a similar direction, the object of which is, that the abutting sill may act as a stop to the motion of the bridge and only permit it to open or swing in one direction. The inclined direction also acts the part of a wedge, and causes the bridge platform, when it is shut with some force, to jam up and become quite tight, so that the bridge may not be subject to motion when a load is passing over it. This wedging effect might, however, prove detrimental by throwing the bridge off its pivot on the opposite side, but this accident is guarded against by the back of the framing *i i* having strong circular ribs of timber fixed upon it; and these work about one-fourth of an inch clear of the inside of the circular brick-work, which is so supported on its back part as to offer a resistance to any motion. These bridges will occasionally set fast when they are closed or thrown over the canal, particularly when grit or pebbles get in between the wedge joint. A short post may, therefore, be set in the ground with a lever or handspike to start the bridge from its wedging, and when that is done, it ought to swing so easily that a child may move it.

1054. Swing-bridges are occasionally made wholly of cast iron, as at the shipping entrance to the London docks. In these bridges the roller plates of cast iron are fifteen feet in diameter, and all cast in one piece, and the great weight of these bridges renders it necessary to have chains and iron crabs, or tooth and pinion windlasses, to open and shut them. Such bridges are also made in two halves placed on opposite sides of the water, and are made to move in opposite directions, so that they meet and lock together in the centre. When double bridges are used they must be curved or half arched, with a slight rise in the centre, and in this form they require firmer abutments than have been referred to. This abutment is produced by long wedge-like pieces of cast iron, which are introduced between the moveable bridge and its solid abutments by a rack and pinion movement, and no load is permitted to go on to the bridge until they are put in their places. Of course they must be withdrawn again before the bridge can be moved.

1055. Every swing-bridge and drawbridge ought to have a small chain fastened to it, of sufficient length to lie upon the bottom of the canal and extend to a post on the opposite bank, to which it should be fastened, for the purpose of closing the bridge from the opposite side when it is left open. Loaded carts and wagons are often detained for hours when they arrive on the shutting side of a swing-bridge, and happen to find it open. This evil is entirely removed by a sunk chain, which enables a man to pull the bridge over to him, if open, and affords no obstruction to the passage of boats, as the chain will always find the bottom of the canal.

1056. The principles of carpentry already laid down apply to the construction of floors, partitions, frame buildings and roofs of every description; but we have yet to notice another important application of them, which is the construction of centring for the support of arches while they are building, and with this we shall conclude the present division of the subject.

Whoever contemplates the nature of an arch formed of bricks, stones, or other separate pieces of material, must be convinced that they could not be placed in the positions they are intended to maintain, without some artificial support for them to rest upon, until the arch is completed and made capable of supporting itself. And when that is done, this artificial support has to be removed in order to throw open the space, that has been arched over, without any impediment.

This applies equally to all arches or vaults from the smallest to the largest, and the artificial support that is thus made use of, is, as a whole, called the *centre,* or more properly *the centring of the arch.*

1057. In the construction of centring for small arches, little or no skill is necessary; and in all centring the two chief points to be attended to are, that its upper or bearing surface shall be very correctly formed to the figure assigned to it, whether it be a portion of a circle, ellipse, or any other curve; and that it shall be sufficiently strong to bear the weight of the materials the arch is to be composed of, together with the workmen, tools, and other things that may be placed upon it, without sinking or changing its form. The first is necessary, because as the bricks or stones are in succession placed immediately upon the upper surface of the centring, so of course the work, when finished, will exactly coincide with the form of such surface, and if any irregularities or inequalities exist in the centring, they will be transferred to the work, making it unseemly to the eye, and perhaps endangering its stability. The second qualification, strength and stability is necessary to the perfection of the first condition, because if a centre is made in the most true and perfect manner before it is loaded, and from weakness or bad fixing it changes its form or position from the gradually increasing load that is brought upon it, it will have just as bad an effect, or indeed worse, than if it had been badly formed in the first instance. Because bricks, mortar, and stone are inflexible materials, which admit of no change of form after they are set, without breaking. The first portion of work that is placed upon the centring will of course adapt itself, or will be adapted, to the exact form of the centre. But if by continuing the work and increasing the load, the centre is made to alter its figure, it may in the one case produce a thrusting or expanding force again the new work, and thereby cause its joints to crack, or it may sink or recede from that work and leave it without support, which will cause its settlement, thereby destroying its symmetry and beauty, as well as its stability.

1058. The principles of the construction of roofs already explained apply with certain modifications to those of centres; but the centring for arches is subject to many more difficulties than roofs, and require the exertion of skill and judgment to guard against them. The roof is a fixed construction, which when once put in its place is never afterwards to be disturbed, therefore any necessary precautions may be resorted to for making it stable and secure. It has only to be covered with such slight materials as will resist the action of rain, snow, or heat; and consequently they are never very heavy, and whatever their weight may be, it is distributed with equality over the whole surface. No change takes place in the load of a roof, except that which arises from snow lying upon it, or perhaps, occasionally, persons standing upon it. With arch centring the case is quite different. The centre is not a fixed or stable erection, but is one that has to be moved and taken away, as soon as it has performed its office, and that without injury or disfigurement of the adjacent work; consequently it cannot be let into it, or form any part of it. The work or covering that is placed upon it, so far from being light, is massive and heavy in the extreme; for, in the arches of large bridges, it is no uncommon case to have hundreds of tons of stone-work thrown upon the centre and depending wholly upon it for support. And the load cannot be equally distributed over the whole surface, because it has to be built up gradually from its lowest to its highest point, and is, therefore, a constantly increasing series, incapable of aiding or supporting itself until the key-stones are introduced; and even then, although the arch may be capable of standing by itself, the centre is not relieved from its weight, until it is lowered, or permitted to recede from the superincumbent work. For these reasons the construction of a good and effective centring, and the manner of fixing it so that it shall be perfectly stable and firm while in use, and yet be easily lowered a small quantity without changing its figure or its original firmness and stability, and finally, that it may be entirely taken down and moved without injury or danger to the work built around it, is considered as one of the most difficult tasks the Engineer has to perform, and as a masterpiece of workmanship in the artists employed in its execution. In fact, the beauty, stability, and duration of an arch constructed of proper materials and with good workmanship, is dependent entirely on the perfection of the centring upon which it has been built.

1059. Every centre consists of two principal parts or elements. One is called *the rib*, and this answers the important part of determining the form or curve of the arch and of giving strength and support to the whole fabric; and the other is *the covering*, or *lag-*

ging (as it is technically called), and consists of parallel boards, planks, or timbers, extending from one rib to another, or over several ribs according to the extent of the arch, and which is for the purpose of connecting the ribs together, and forming an extended smooth surface, upon which the bricks, stones, or other materials of the arch are to be built and put together.

1060. In small centres these parts or elements are usually nailed together and combined, so that the ribs and lagging constitute but one piece, and the whole is moved and set up together. But in large centrings, the weight and magnitude of the materials renders it necessary that they should be separate. Nay, even more, for a single rib of the centring of a large arch is so large and ponderous that it can seldom be moved in its entire state, but requires to be taken asunder, and carried in detached pieces to the place where it has to be used, and it must there be put together or rebuilt, taking care to place it so exactly in its proper position that it will require no alteration after its erection. Of course as many ribs as are needful will require the same treatment, and after they are all set up parallel to each other and adjusted so that their upper surfaces may bone perfectly in the direction of horizontal lines strained across them, and they are found perfectly out of winding, they are to be secured in their places by sloping or diagonal braces from one rib to the other, and then the lagging or covering may be placed and fixed upon them.

1061. No centre can be formed even for an arch of a single brick, or nine inches in thickness, without two ribs, viz: one at each end of the lagging; and the additional number of intermediate ribs must depend conjointly on their own strength, and the weight of materials they have to support. This problem can only be solved by the practical skill of the Engineer, aided by the rules that have already been given for determining the strength of materials, observing, in all cases, that it is better to err on the side of too much strength, than to trust to weak or nearly calculated structures. A large rib is always an expensive construction, but its first cost is nothing in comparison to the expense that will be incurred by its failure when in use, because if it sinks or changes its figure during the construction of the arch, there is no way of repairing the mischief that may arise, except that of pulling down all the previous work, strengthening the centre where it fails, and beginning the whole operation again. In large bridges it is customary to place the ribs parallel to each other and from three to six feet asunder, according to circumstances; and from what has already been observed upon them, it will be seen that their use and action is similar to the trussed principals of a roof; and as all the weight of the superstructure, including the lagging, is to be supported by the ribs, it will be equally evident, that the support of the whole centring, while it is in use, must be applied under the feet or abutment of the ribs and no where else.

1062. In all regular arches, such as portions of cylinders, or any curves which have the same dimension throughout, all the ribs made use of must be precisely of the same size; and as the load of work to be placed upon them will be very nearly equal in all parts, when the arch is finished, so the ribs should be of equal strength. It follows from this, that any mode of construction that is adopted for one rib will equally apply to all the others made use of; and hence in describing centres, we shall adopt the usual plan of giving a description of one rib only, and saying how often that rib is to be repeated, keeping in mind that however long the arch may be, the lagging runs the whole length of it upon the curved surface of the ribs, and in most cases at right angles to them; consequently no particulars, except dimensions, will be necessary in describing the lagging.

1063. In some cases it may be necessary to construct what are called *flewing arches*, or arches that are wider at one end than the other; or whose figure resembles a part of the superficies of a truncated cone. In this case the ribs must evidently not be of the same size, but must be formed with different radii of curvature. One rib must be made for the large end of the arch, and another for the small one, and these being set up parallel to each other, or in such other position as the two ends of the arch are meant to have in respect to each other when finished, lines must be fixed and stretched upon the curved surfaces of the two ribs at proportional distances from each other, and these lines will give the magnitudes of any number of intermediate ribs which it may be thought necessary to construct and place at any assigned distances between the two exterior ribs. The lagging must of course run in right-lined directions over the outsides of all the ribs, and will complete the conical or other diminishing surface which has to be given to the finished arch.

1064. It may here be observed, that with the exception of building bridges of one or of two arches, there is no necessity for providing a quantity of centring equal in superficies to the quantity of arch to be constructed, because centres may be shifted and carried from one place to another, as the work proceeds, which saves a great expense. Thus in constructing a culvert or cylindrical drain for carrying water, or making a long vault or passage under ground between two parallel walls that have to be arched over, a centring of from six to nine feet long, or even less if the opening be large and the centring heavy, will be all that is necessary. This centring is first to be fixed in its proper place at one end of the work, and the arch is then worked over its whole extent. That done, the centre is *struck* (which is the technical expression for releasing and taking down centring,) and it is moved forward very nearly its own length, taking care to leave an inch or two of one of its ends underneath, but in contact with the underside of the portion of arch that has been built. In this new position it is to be made straight and level and again fixed; when a second quantity of arch work equal to its length may be built upon it, when it is again struck, advanced, adjusted, and fixed, and is ready for a third length of work, and by this process the arched vault may be continued any required distance with only one short centring. The only rule that can be given for its dimensions in such cases is, that it must not be so long or so heavy as to require any extraordinary exertion to move or refix it, because, in these cases, there is generally not much room for action, and a danger of disturbing and breaking part of the former work, unless the shifting and refixing can be performed with great facility.

1065. In building a brick or stone bridge, of a single arch, over a river it is obvious that we must fix the entire centring at once, before the arch is commenced, and likewise in building a similar bridge of two arches, where the meeting or springing of both arches rests upon a pier in the middle of the river, and the other feet of the arches abut on the banks, two centrings, one for each arch, will be necessary, and they must both be fixed in their places before the arch is commenced. The reason of this is, that if only one centre should be used, resting upon the bank or shore at one end, and upon the pier, in the centre of the river, on the other, and an arch should be constructed from one to the other, it would be impossible to strike and move the centring when the arch is finished, without endangering its downfall, unless the central pier is exceedingly strong. For so soon as the centring is removed the lateral spread of the arch will come into play, and as it will be incapable of acting upon the solid stone abutment, all its lateral expansive force will be exerted against the pier in the direction in which it is least capable of resisting pressure, and it will be overset. But by having the two centrings fixed at once, both arches will proceed at the same time—an equality of load is induced on the two opposite sides of the pier, and when the centres are removed two thrusting forces, which are equal and diametrically opposite to each other, come into action at once and neutralize each other, and the pier, therefore, remains undisturbed.

1066. If a bridge of many arches has to be constructed, for the reasons above assigned, two centres only will be absolutely necessary, though the use of a third will be advantageous. In this case the two or three centres of the arches of one end or abutment of the bridge are first fixed, and the land, or abutment arch is first commenced from both its feet or abutments, and in doing this a part of the second arch must also be commenced upon the first pier so as to weight it down, and at the same time to throw an equal weight on both sides of it, by which its stability is much increased; and this effect will be further augmented by also working up a small part of the second arch upon the second pier, so as to balance the second centring and prevent its sliding away from the lateral pressure of the load placed upon it. By judicious and skilful management the loading may be so arranged that the first or land arch may be completed, when its centring may be struck and carried to the position of the third or fourth arch as the case may be, and then the second arch from the land may be completed, and in this way a bridge may be carried over a river until it arrives within two arches of the opposite side, when, if three centrings have been formed, one or two, as the case may be, can be fixed at once and worked up from the opposite shore to complete the work.

1067. This mode of proceeding does not often apply, because it is generally the case that the central arch of a bridge is larger than any of the others, and that they diminish in size as they approach the shores; and whenever this is the case the centrings cannot be interchanged, except by commencing operations on one side of the river and then moving to the other, and so on alternately, until the meeting is made at the central arch. It was, however, adopted by Mr. Rennie, the English Engineer, in the construction of Waterloo Bridge across the Thames, in London, which consists of nine semi-elliptic stone arches all precisely alike, each rising 35 feet and having a span or opening of 120 feet. The object of this similarity of dimensions in all the arches, is to obtain a perfectly level road or causeway over the bridge, instead of ascending and descending two hills or inclined planes, as is the case in most bridges.

1068. It sometimes happens that arches have to be constructed, for the sake of their strength alone, in places where they will never be seen; consequently their symmetry and beauty is not important, and in some cases the introduction and taking away of centring might be difficult, or even impossible. Thus, for example, if a very large window or opening has to be left in a high and heavy wall, but which we require to have a straight or right lined, instead of an arched appearance, there is no way of doing this except by throwing a timber or stone lintel or breast-summer across the opening, and building upon it. That lintel may be consumed by fire, may break, or will decay in time, and may thus endanger the wall. To guard against this we have only to build a quantity of work upon such lintel with a curved or semicircular termination above, but without any regard to the bond of the rest of the work, such curve springing from the perpendicular sides of the opening, or what is still better, from the extreme ends of the lintels. This work is to be used as a centring for turning an arch upon, and this is next to be done, when the wall may proceed upwards upon the arch, just as it would have done upon the lintel; and it will be evident that where such a construction is resorted to, the whole lintel may decay, or may be taken away, as well as the quantity of work that was used as centring, because now the arch will sustain the load instead of the lintel, and a new lintel can at any time be introduced.

1069. It frequently happens that arches are necessary for the support of the underground foundations of walls and other erections, and which might not be able to bear the great expense of regularly framed centring. Thus in digging the foundation for a long wall, the soil in general may be hard, solid, and trustworthy, but we occasionally meet with soft places, arising from springs, quicksands, or the ground having been before dug up, or recently made level, which would render it unsafe to carry the wall over them, and in this case it may be necessary to turn an arch from one hard place to another, thus passing over the soft and insecure places. This may generally be done by an *earth-centre*, i. e. by having a concave curved mould or pattern, formed out of thin plank to the shape we wish to give the arch, and then digging up and forming the ground so as to fit the curve of the mould. The earth so shaped must be well and solidly rammed down until the desired curve is obtained, and then a brick or stone arch may be built upon it just as well as upon a regular centring made by the carpenter, and upon the top of this the wall may proceed upwards with perfect security; for if the soft soil sinks away from under the arch, it will only be the same thing as taking the timber centre away from an arch constructed by the regular process.

1070. This mode of centring is constantly resorted to for covering over furnaces, bakers' ovens and cinder or coke ovens, the tops of which are an irregular kind of dome, which would be difficult to construct in carpentry. But the side walls being carried up perpendicularly, the body of the oven is filled with damp sand, which is raised up in a convex form to the exact shape the dome is intended to have, and the bricks are then laid as over any other centring. When sufficiently dry and set, the sand is dug away and moved through the door or mouth of the oven.

1071. After these preliminary observations we will proceed to describe the principles and construction of centring, as it is used and applied to the purposes above mentioned.

All centring is made of timber, strengthened where necessary by wrought iron straps and cast iron bearing plates, and the ribs are usually put together with wrought iron screw bolts with nuts and washers, for the facility of taking the parts asunder, and rebuilding them when they have to be erected or moved from one place to another. In this respect they differ from roofs, which may be permanently pinned or nailed together, because they are not intended to be moved after they are once fixed in their places.

1072. Small centres are generally made of two, three, or more ribs, with the lagging permanently nailed to their convex surface. The ribs should always be formed of two or three thicknesses of board or plank nailed together, with the grain of the wood crossed, or placed in such directions that one piece may assist the other in strength, and the lower part of the centring should be right lined, forming a diameter or chord to the curve above it, for the double purpose of making a tye to prevent the curved surface from opening, and also of affording a flat surface upon which the centring may stand and be supported in its work.

1073. In the formation of large centring for bridge building such constructions would be ineffectual, and we must have recourse to the principles of carpentry already laid down. The first and chief rule to be attended to, is to dispose every piece in such manner that it shall be subject to no strain, but what either pushes or draws in the direction of its length; and in all timber constructions the pushing or thrusting strain is decidedly superior in advantage to the pulling one; for when the straining force tends to draw a beam out of its place, it must be held there by a mortice and tenon, which possesses very trifling force unless when assisted by iron straps and bolts. Cases occur where it may be very difficult to make every strain a thrust, and the best constructors therefore admit of tyes; and, indeed, where we can admit of a tye beam connecting the two feet of our frame, we need seek no better security. But this is often inconvenient or impracticable. Should the river be navigable, such a beam would effectually stop all craft from passing up or down it, and as all rivers are more or less subject to freshes, it would occasionally be under water and liable to be carried away, and with it all the work above it, thus producing destruction of the most fatal description.

1074. With a view, therefore, of avoiding the danger of floods or freshes, and to permit the uninterrupted passage of trees, logs of wood, ice, and other matters that may float upon a stream, it is advisable to dispense with the use of a transverse or tye beam, and to keep the whole of the centring as high up out of the water as may be possible, without occasioning inconvenient slopes in the roadway over the bridge. Indeed, if a river is navigable, this elevation of the centring becomes absolutely necessary, and by considering and applying the principles of constructive carpentry, it will be found that abundant strength may be obtained without descending any very great distance below the underside of the arch; and, consequently, that ample space may be left for the passage of boats and other craft under an arch while it is in progress of construction. To form such a centring well, requires great judgment, and a scrupulous attention to the disposition and operation of all the pieces; for it is by no means an easy task, even for the experienced, to discern whether a beam that makes part of a centre is in a state of compression or extension. In the construction of a good centre, we have a number of separate pieces of timber all conjoined to produce two common effects, which are strength and stiffness, or immutability of figure. No piece should be introduced into this combination but what has a duty to perform, otherwise we should load the centre with additional weight, without a corresponding benefit; and all the pieces should be so disposed as will enable them to perform their duties with the greatest possible effect, or in other words, to be subject to longitudinal compression whenever it can be obtained, or to longitudinal extension, as the next best thing, when the first is impossible.

Every disposition likely to produce lateral pressure, and consequent bending of the pieces, must be carefully avoided, and the artist must not only be able to design and put his pieces together so as to produce these effects, but to judge by his eye-inspection and reasoning powers what effect they will have on each other—which will become compressed and which extended pieces—what the consequence of any piece giving way may be, and how it will affect the general structure of the whole; how defects may be strengthened or repaired, and if the whole is secure and immutable.

1075. The experienced artist will, in general, be able to judge of all these points by an accurate drawing to scale, in which the dimensions of the several parts and the materials made use of are noted down. But this cannot be expected in the young and unpractised. If therefore he should be called upon to carry works of this kind into execution, his safest plan will be, not to attempt any thing original, but to take advantage of the experience of others, and copy that which has been already done and found to answer its intended purpose. Here he will find the value of that precept laid down in a former part of this treatise (5), viz: the taking sketches and memoranda of the dimensions of materials and mode of putting them together of every thing he meets with that may be likely to occur to him in the progress of his profession. He will find a collection of such memoranda sketches or drawings of infinite use to him. If, however, he should be tempted to try his skill on an original design, it will be very advantageous not to trust solely to drawings, but to have a model made to scale, and to try the effects of weights disposed upon it as nearly as may be in the same places as the load will occupy on the large or actual construction. He will then, by the examination of the joints, be able to see which pieces are compressed and which extended. For, as before observed, this effect is sometimes difficult to ascertain in a drawing, and the experiment cannot be tried on a large scale upon the centring itself or even upon one of its ribs. They are so large and massive that no weights we could place upon them for experimental purposes would make the least impression, or bear any sensible proportion to the immense load of stone they are destined to bear when the arch is under construction: and the building of an arch is too expensive an operation to be considered an experiment. If a failure occurs, the arch is gone, and with it most probably the future reputation and fortune of the young artist who may have attempted it.

1076. We cannot have a stronger proof of the truth of this assertion, than our finding pieces introduced as struts (and having considerable dependence placed on them as such) in the designs of some of the most eminent Artists and Engineers, while in fact these very pieces are performing the part of tye beams, and should be secured and treated accordingly. Of this the much celebrated centring used for the stone bridge over the Loire, at Orleans, in France, as designed by M. Hupeau, in 1750, is an example. This bridge consists of nine semi-elliptic arches, the central one rising 30 feet, and having a span of 106 feet, and the end arches rising 28 feet, with 98 feet span. It is justly considered one of the most simple, elegant, and beautiful constructions of the kind that has ever been executed, and the centring used is described with admiration by all who speak of it. Still it was materially defective, as we shall afterwards see. The disposition of the timbers in this centre are shown at Fig 253, Pl. VIII., where it will be seen that its main timbers form parts of two polygons which are not parallel and concentric. They each offer five sides for the support of the work, and they are connected together by five strong tyes, with bridles or connecting pieces, which divide the entire rib into three trapeziums and two triangles. The central one has a king post and two diagonal braces. The two next adjoining have diagonal braces only, and the two narrow or triangular end spaces are connected by bridles only. The regular curvature for the arch is obtained by a curved timber *a a* passing over the whole rib in the same plane, and supported by blocks of timber between its under side and the upper sides of the polygon; and upon the top of this curved piece, called the *arch mould*, the timbers of the lagging are supported. This latter piece, with its blockings, has nothing to do with the strength of the rib, and is merely introduced to obtain regularity of curvature; all the strength must therefore be sought in the double polygon and framing below. This construction is on sound principles, provided we are certain that no change of figure can possibly take place, and the formation is beautifully simple, consisting of very few parts, and those of great magnitude; for each face of the polygons was upwards of 20 feet long, and the beams were 15 inches square. It therefore well deserves the character that has been given of it by those who have written upon this subject, as being one of the boldest attempts that has ever been made at this species of construction; but M. Hupeau appears to have been mistaken in supposing that both the upper and lower polygons would equally assist in supporting the load, and would be both thrown into a state of compression by it. This would have been the case, if the stone arch, which was six feet in thickness, could have been thrown over the whole centring at once, and thus have occasioned an equality of pressure over the whole at the same moment; because in that case, both the polygons would have been thrown into a state of compression, and one would have assisted the other. But masonry and brick-work are slow and progressive in their operation, and must be began from the bottom and carried upwards. The pressure, therefore, came upon the centring at its two feet or springings, and proceeded gradually upwards. The consequence of this was, that the centre changed is figure by the two haunches or springings sinking down, which had the effect of raising the crown or central part. Now, as the sides of the lower polygon were shorter than those of the upper one, they could not give way to the same extent, and the consequence was, that they were drawn away from their end attachments, and thus it was found that the lower polygon, instead of being in a state of compression, as was intended and expected, was in a state of expansion, and that its place would have been much better supplied by a series of iron bars, with screw nuts at their ends to tighten them, and make them act as tyes; for this turned out to be the sole operation of the lower polygon. The whole load was consequently carried by the upper polygon, and the wonder is, how an arch could be constructed at all upon such a centring. M. Hupeau, who designed this bridge and its centring, began the work, but died before it was much advanced. The completion of the bridge then fell into the hands of the celebrated French Engineer Perronet, and the trouble and difficulty he had in building the arches upon these centres will be noticed with more propriety in our next chapter, which is devoted to the building or construction of arches, and the simple, yet efficient contrivance that he resorted to for rendering these centres stable and effective, will then be described; and then it will be better understood, because we shall previously proceed to an examination of the principles upon which the strength of centres depend.

1077. It is obvious from what has been observed in the previous statements, that the strength and stiffness of all framing will depend upon the triangles into which the work can be resolved. And that the strain which one piece produces on the others that meet it in one point, depends on the angles of their intersection, and is greatest in obtuse angles and less in those that are acute, diminishing in proportion to their acuteness; and this suggests at once the general maxim, that in the construction of centres, as well as all other strong framing, we must avoid all obtuse angles as far as possible; and this conjoined with the principles that in every case where it is possible we must obtain longitudinal compression, or if this cannot be had, longitudinal extension. That we must in no case exert lateral pressure without an opposite countervailing force to oppose and equalize it, and we have all the general rules that apply to this subject.

1078. The ancients do not appear to have laid down any precise rules for the construction of roofs, and as the arch is a more recent invention, no general and distinct views for the construction of arches or their centrings were laid down until the beginning of the eighteenth century. Figures are preserved of the framework or centring employed by Michael Angelo in the construction of St. Peter's Church, at Rome, which is by far the largest christian church that has ever been erected in the world. It is surmounted by a dome of immense magnitude, but the centring used is said to display very little skill or science, and those for the arched roof of the church itself although better, are far inferior to others that have been employed in later times.

Sir Christopher Wren, an English architect, who died in 1723, and who stands pre-eminently distinguished as a philosopher, mathematician, and man of highly cultivated taste, was extensively employed in his profession in England, and constructed many of her noblest works, and among others the justly celebrated Cathedral of St. Paul, in London, introduced many improvements into the art of building. But unfortunately though his architectural works remain, and his literary ones are preserved, that does not appear to have been the case with his practical and executive modes of proceeding, or we should most probably have seen in them every thing that science, skill, and practice could suggest. We are told that his centring for the dome of St. Paul's Cathedral was a wonder of its kind; begun in the air at the height of 160 feet from the ground, and without making use even of a projecting cornice to rest it upon.

1079. The earliest centring that is described as being constructed upon scientific principles is by a French Architect M. Pitot, and it is so simple, and at the same time embraces so many of the points that are essential to the construction of a good and perfect centre, that its examination makes a very proper subject to commence upon. Its disposition for a semicircular arch is shown by Fig. 254.

This centre consists of two parts, an upper and a lower. The upper part is all that is above the horizontal stretcher or tye beam A A, and the lower part all that is beneath it. The upper part is a common roof truss with a tye beam and king post, but having two principal rafters instead of one on each side. The exterior rafter *b* is carried out as far as possible, consistently with its having a sufficient quantity of timber to abut against at the top of the king post and end of the horizontal stretcher. The distance between the king post and the insertion of this rafter into the stretcher is equally divided, and that point gives the proper place of insertion for the shorter or under rafter *c* on both sides of the king post; while its upper end has to be inserted as far up the king post as possible, not to interfere with the insertion of the upper rafter. The whole of this truss is next to be supported in the intermediate position of the arch which, it will be seen by the figure, is more than half way up from the horizontal line or springing. To obtain the position of the main stretcher A A, divide the whole semicircle into four equal arcs of 45° each, and 45° from the springing on either side will give the positions for the two ends of the stretcher, and the two remaining arcs of 45° or 90° will be occupied by the top truss. The support above referred to is obtained by four oblique struts, two on each side, as *d e*, *d f*. Their two feet *d* may be close together and likewise close to the exterior arch mould, (not yet described,) and the whole must be supported below on a sole or block *g* of hard compact timber, into which they are sufficiently let in to prevent their slipping or changing their positions, but not so deeply as to maim or weaken the soles. The soles are, in their turn, placed above other pieces of similar timber parallel to, and, if possible, larger than themselves, called beds, and between the bed and sole polished cast iron or hard wood wedges are introduced, so as to separate the bed and sole to a distance of from six inches to a foot or more from each other, according to the magnitude of the arch. Great care is necessary in the construction, selection of materials and placing of these wedges, because the whole weight of the centring and its superincumbent work rests upon them; and their use is to adjust the centre as to level and height, and afterwards to strike it when the arch is finished; because by striking upon the small ends of these wedges they may be made to retire in any necessary degree, or may be wholly withdrawn, when the soles will come into contact with the beds, and of course the entire centre will fall and retire from the arch, when it can be taken to pieces for removal. The oblique struts *d e*, *d f*, being thus well secured at their lower ends, are made to diverge to such an extent that they may be let in to the under side of the main stretcher A A, exactly opposite to the abutments of the feet of the long and short rafters, so that their action is immediately transferred and carried up to the king post. But if the arch is intended to be large, it is advisable not to let the two internal struts *d f* into the main stretcher at all, but to cause their upper ends to abut against the two ends of a horizontal straining beam *h* bolted with iron screw bolts to the lower side of the main stretcher, as shown in the figure, and this will not only afford an effectual support to the upper ends of the internal sloping struts, but will give strength to the main stretcher in that part where it most requires it. So far we have only considered the trussing work which is to give strength to the rib, without showing how the curved form for the arch is obtained, and this is the only objectionable part of the construction as laid down by M. Pitot. The curve is obtained by an exterior string of timber which surrounds the truss and is called *the arch mould*, because it must be cut to the exact form the inside of the arch is intended to have when finished. The arch mould is of the same thickness as the rest of the rib, but instead of being formed of solid timber like the other pieces, it is formed of two, and sometimes of three thicknesses of plank fastened together with tree-nails and iron screw bolts, the joints being in the plane of the rib, or in a vertical direction when the centre is set up for use. The reason of this is that by so combining thinner timber, great waste of material is obviated and additional stiffness obtained by the frequent crossing of grain. The arch moulds in this centre have but five principal abutments or points of support, viz: one at the top or crown, upon the top of the king post; two upon the ends of the main stretcher A A; and two at the bottom upon the soles *g g*. All the intermediate ones are obtained, by the double cheeks or bridles *i i i*. These are called double, because they consist of two pieces placed opposite to each other on the two sides of the rib, and they are notched down or halved upon the several pieces they pass and intersect, and these two halves are drawn together by iron screw bolts, by which means, if the shoulders are well and effectually cut, they form excellent braces to stiffen the straight pieces they intersect. Still their position and action is quite at variance with the principles laid down, since their effect will be to produce lateral instead of longitudinal pressure, a thing constantly to be guarded against. In building the arch, the weight of the masonry is wholly supported by the exterior arch mould, and it will have a tendency to sink; that tendency is transmitted directly by the bridles to the rafters of the upper truss, and to the oblique braces which support it below, and transmitted in the worst possible directions, or nearly perpendicular to the longitudinal direction of these pieces, or where it has the greatest power to bend them; and if they do bend, the strength and correct figure of the whole centre is gone. It happens, however, that a very easy and effectual remedy may be resorted to for obtaining all requisite strength in the upper truss, and it is astonishing that this did not occur to M. Pitot, but he does not mention it. Instead of letting the bridles be cut short at their lower ends so as to rest upon the rafters, we have only to lengthen them, and let the two central ones take their abutment upon haunches in the king post at its two sides. Another pair of bridles may be so introduced that they may extend down to the main stretcher at the point of intersection of the straining beam and inner oblique strut, and a very effectual support will be obtained, and an intermediate bridle may be introduced and be extended down to, and be made to bear upon the main stretcher at a point where it is well supported upon the straining beam, and then the upper truss will be rendered exceedingly strong.

In the lower compartment we have not the same advantage, because there is no means of stiffening or supporting the oblique struts against the lateral pressure thrown upon them, except by introducing long beams that shall extend to the opposite foot of the arch, and they would not only impede navigation, but would be too long to afford effectual support unless they were trussed to prevent their bending. The lower pair of diagonal struts may, however, be materially assisted by two iron tye bolts reaching from near their centres to the extreme end of the main stretcher above, and to the upper strut and arch mould near their feet on the sole. This precaution is, however, seldom necessary, as we shall see in our next chapter, because in the semicircular arch, the lowest 30° has very little of the weight of the arch to support, and the load only becomes oppressive as it approaches the crown, and in this centre the strength is abundant as soon as we have surmounted the first 45° and got upon the upper truss, which is very strong. This centre is not, however, given as a model of perfection, so much as to explain the nature and action of a trussed rib; and as we advance further in the subject we shall see how these difficulties must be met.

For the sake of keeping the figure as simple and intelligible as possible, the cheeks or bridles are only shown in one half of the arch, and the other half exhibits nothing more than the naked or unincumbered truss; but it must be kept in mind that in the complete centre, whatever occurs in one half, must also be introduced into the other; and that the two halves of the semicircle must be perfect counterparts of each other. It may likewise be here noticed that although this centre has been described for building a semicircular arch, it is equally applicable to the construction of a smaller arc of a circle, or to a semi-ellipse, with a very slight modification of its parts. For a smaller arc or segment of a circle, such for example as would occur if we imagine the springing of the arch to take place from the dotted line *k k* instead of the diameter, every thing would remain without alteration except the lower oblique struts *d e*, *d f*, and these would have to be so placed that they would make more acute angles with the horizon. But they must in no case be so far sloped as to cause them to pass beyond the direction of the right lined direction of the rafters, if prolonged and drawn upon them. To adopt this centring to an elliptic arch, no other alteration would be necessary than to give the arch mould the elliptic instead of the circular form. The king post would become rather shorter, and the main stretcher somewhat longer in the elliptic than in the circular arch, and as height of king post is essential in order not to give too obtuse an angle to the rafters, this may be obtained without detriment by giving the main stretcher a lower position than has been assigned to it in the circular arch—with these exceptions every thing else will remain the same.

1080. The manner in which a centring springs from its soles, and of supporting those soles upon the beds, has already been referred to, but no notice has yet been taken of the manner of supporting the beds upon which the whole stability of the centre depends. In Pitot's figure the centre is represented as resting by both its feet upon a projecting moulding below the springing of the arch, as shown in our figure 253; but this would not answer in practice except for small and light arches. Projecting mouldings are introduced into constructions for ornament alone, and seldom with any view to strength: consequently if we were to trust our centring upon them, there can be little doubt but that in most cases we should break away our ornaments and obtain no stability for the centre. The firm fixing of the beds is, therefore, an object that requires the utmost care and skill of the Engineer, because however good and perfect a centring may be it will become non-effective unless well fixed. For this purpose rows of piles are very frequently driven between one pier and another, and as close as possible to them, but this is not a good practice, for the load of a large centre with a nearly finished arch upon it is so enormous that piling can hardly be trusted to carry it. The piles may bend or sink deeper into the ground than was intended, and derangement must certainly follow, besides which driving a number of piles near the foot of a pier may disturb its foundation and future stability. The safest way, therefore, that can be adopted, is to support the beds upon strong vertical story posts with oblique braces, the bottoms of which rest on the offsets or footings that are constantly made, and which may be left wider than would otherwise be necessary, near the bottoms of the stone or brick piers, and to drive no more piles into the ground than are necessary for the purpose of supporting braces to hold these story posts in their proper vertical position. In this manner no vertical weight is brought into action upon the piles, which may therefore be comparatively weak, and need not be so driven as to endanger the foundations of the piers. The whole load is thus thrown upon the piers, and nothing can sink unless they go down, and should that be the case of course the whole bridge will be in danger. In order to give additional security to the beds, their foundation is made continuous and connected throughout the whole width of the arch, and it thus becomes a regular platform braced from end to end, while the bed blocks alone project from its upper surface, which may be floored for the convenience of getting at the wedges. The soles, on the contrary, are not continuous, but a separate one is applied to each foot of each rib, and these stand upon the projecting blocks of the bed platform, so that workmen can readily get at the wedges to use sledge hammers upon them in case they should require alteration, and in this manner the several ribs of the centre can be adjusted with the greatest nicety.

1081. The great trouble and expense that is incurred in producing a good and sufficient bed platform may be better judged of from inspecting Fig. 255, which is a sketch of the centring and progress of the new London Bridge, as constructed by Mr. Rennie, as it appeared early in the year 1828. Each arch was supported by nine parallel ribs, of the construction shown in the figure, placed six feet apart, and supported by an under framing extending one-third of the span of the arch, on each side, independent of the oblique braces, and the whole carried by a scaffolding of whole square timbers, crossing each other, and resting on piles driven to support them.

1082. Allusion has been before made to the centring used by Michael Angelo in the construction of the body of St. Peter's Church, and it will be found that it approaches very nearly to the principles laid down by Pitot as already described, but is superior to it; for the pieces are judiciously disposed, and every important beam is amply secured against all transverse strain. The only fault that has been found with this design is, that it is unnecessarily strong. Its general disposition is shown by Fig. 256. After what has been said of Pitot's centre, no particular description of this can be necessary, further than to observe that while Pitot's centre is mentally resolvable into two parts, this really consists of two separate and distinct formations, for the upper part is a regular roof truss with a separate and complete tye beam, which rests upon what may be called a collar beam, or flat top to the under truss, and these two are not connected in any way, but a row of cross wedges may be introduced between them for the purpose of lowering or even striking the upper truss, without at all disturbing the one that is below it, which is often a great advantage in the construction of large arches. It will be apparent to any one that the lower polygon *a g i h b* and its stretcher or collar beam *g h*, are useless and superfluous in this centre. Because if the king post does its duty, it is impossible that the middle of the tye beam can sag or drop, and its two ends are equally well supported by the nearly vertical struts *k k*, while its intermediate parts are upheld by the more sloping struts *l l*, none of which can shift from their places if properly framed. The only chance of danger is from the external walls or abutments at *a b* opening outwards, and this must be guarded against in their own strength, or by external support, or an additional tye beam between *a* and *b*. The lower polygon would not at all help or remedy this evil, because if the abutments should spread, the polygon would open and cease to be of any use at all.

1083. Having shown the form and disposition of some of the simplest kinds of centring, we will next examine a few of more complex construction; but previously to doing so, a few observations on the means of determining the strength and power of centres will be useful, and the form of M. Pitot's centre, as given in Fig. 254, affords a very good example, because in describing it, he gives the scantling or dimensions of the timber to be used for constructing the ribs of an arch 60 feet in diameter, presuming that the ring of stone-work, which is to constitute the arch, is 7 feet thick, and that each cubic foot of stone weighs 160 *lbs.* The entire weight of stone, that each rib will have to carry, according to this computation, will be 707,520 *lbs.* The thickness of the stone ring is, however, much greater than can be necessary in an arch of so small a span, for half this depth, or from $3\frac{1}{2}$ to 4 feet of stone would be ample, and would, of course, permit the rib to be made much slighter than the dimensions he has assigned to it. We shall, however, pursue the investigation in his own terms.

1084. It has been before observed, that in the semicircular arch, very little of the weight of the stone, which forms the lowest 30° on each side of the arch, is felt by the centring, because the lowest stones are so superposed that they support each other; and when they do begin to lean over, the friction upon their bedding joints prevents their sliding forwards so as to press with much force against the centring. On this account a considerable deduction from the weight of the entire ring of stone has to be made before we can determine the pressure exerted upon the rib, and M. Pitot computes that this diminution is equal to $\frac{3}{14}$ths of the entire load; consequently we shall only have to provide for the support of 555,908 *lbs.* of stone, that quantity being the remaining $\frac{11}{14}$ths of the entire weight, or 707,520 *lbs.*

The dimensions which he assigns to his timbers (all supposed to be of oak) are as follow:

The exterior ring, or arch-mould, consists of separate pieces of oak plank, bolted together so as to make it 12 inches broad, and 6 inches thick.

The main stretcher A A 12 inches square, and
The straining piece *h* of same dimensions.
The lower struts, 10 by 8 inches.
The king post, 12 by 12.
The upper struts, 10 by 6.
The bridles, 20 by 8.

M. Pitot assumes that a square inch of sound oak will carry 8,640 *lbs.;* but this is known to be very far below the usual strength of good oak, and he probably means that this load may be laid upon it, with perfect security, for any length of time. But to make his computation certain and free from risk, and on a supposition that the timber may not be quite perfect, but may contain knots, shakes, and other imperfections that may affect its strength, he even makes a still further deduction, and only assumes 7,200 *lbs.* as the measure of the absolute strength of each inch.

The load to be supported by each rib, as before stated, is $\frac{11}{14}$ths of 707,520 *lbs.* or 555,908 *lbs.* Now the two lower extremities of the arch mould being nearly perpendicular, and being prevented leaving that position by the framing on the one side and the arch stones on the other, will assist in supporting the load at the rate of 7200 *lbs.* for each square inch of surface. The dimension of this piece as given above, is 12×6, or 72 square inches; and 72 *in.*×7200 *lbs.* gives 518,400 *lbs.* as the quantity of support afforded at each end by this piece. And in like manner the sustaining force of each of the lower struts, presuming that they stand perpendicularly to the pressure, will be 576,000 *lbs.* The deduction for obliquity, will, however, not be material in the process about to be adopted, and leaving this for the present, the total sustaining power will be twice the power of the arch mould, or 1,036,800 *lbs.*, because it has two ends; and as there are 4 lower struts, we shall have to add 576,000×4=2,304,000 *lbs.* to this sum to obtain the total sustaining power, which will be found 3,340,800 *lbs.* to support 555,908 *lbs.*, the entire load, provided it pressed perpendicularly upon the supports; but it does not do so; consequently, we shall have to carry the investigation further to determine the value of the oblique forces, and this may be done on the principles before explained, viz: by deducing those forces to a parallelogram with sides proportionate to the forces, and thus obtaining a resultant.

1085. In order to compare the relative lengths of the sides of such parallelogram and its diagonal, it is necessary to make use of a scale of equal parts, by means of which we can set off the lengths of such sides in distances proportionate to the existing forces, and measure the results by the same divisions. Upon such a scale we may take divisions of any convenient size to express 576,000, and must set this quantity off upon each of the lower struts to express their sustaining force, which we will suppose done by the dotted lines *a, t a, s,* and as the exterior strut is assisted by the arch mould to the extent of 518,400 *lbs.*, we must set off a second quantity of this amount in continuation of the exterior right line as from *t* to *e*, which will make the entire length of one side of the parallelogram equal to *a e*, while its other side will be *a, s*; and now the parallelogram may be completed by drawing the lines *s x* and *e x* equal in length, and parallel to the lines opposite to them, and then drawing the diagonal *a x*, its length will express the conjoined supporting power of all the pieces, provided the pressure was exerted in the direction of the line *a x*. But this is not the case, because the stones are acted upon by gravitation, and the maximum of that force will be in a direction perpendicular to the horizon, and not in the oblique direction of *a x*. We must, therefore, let fall a perpendicular to the horizon as *x y* from the point *x*, so that it may pass by and cut a horizontal line *a b*, upon or parallel to the line joining the two feet of the rib in the point *c'*; then take the distance *a c'* and set it off on that horizontal line at *b*, so that *a c'*=*c' b*. From the point *b* draw a right line parallel to *a x*, and of similar length, and it will cut the perpendicular below *y* in the plate. Join *x b* and draw a line *a w* parallel to it, by which a large parallelogram *a x b y* will be produced, of which the line *x c y* is a vertical diagonal, and the proportional length of this diagonal will express the strength of the rib; because one of its sides *a x* expresses the strength of support on one side; and that operation has to be repeated for the other, and that is done by drawing the line *x b*, which, of course, is the representative of the strength on that side; therefore the lines *a x*, *x b*, are the given sides of the parallelogram, and their sum expresses the supporting force they will exert in their oblique directions; and the diagonal *x y* carried down to their point of junction, reduces the sum of the two oblique pressures to a single perpendicular one or resultant, and the proportionate length of *x y* upon the scale, will express the amount of force that is in existence to support the load. This length upon the scale will be found equal to 2,850,000 *lbs.*, and as the entire load, even without reducing it to the $\frac{11}{14}$ths before mentioned, is but 707,520 *lbs.*; we see that the dimensions of the timber as assigned by M. Pitot, are much too large; because the centring has upwards of four times the strength which is necessary for bearing the load; 4 times 705,520 being but 2,822,080 *lbs.* It should, however, be observed, that in the above calculation of the weight of the load, the quantity of stone is alone taken into account, without any allowance being made for the weight of the upper truss of the centring or its lagging, which in an arch of 60 feet span will be considerable; besides which, an allowance should be made for workmen, tools, and materials, and for concussions that may arise in fixing the work, all of which are borne upon the centring, and require it to be stronger than would otherwise be necessary.

1086. As the foregoing investigation applies only to the power of the lower struts, to support the upper part of the centring, together with the work that may be placed upon it, a like examination must be made of the upper truss of the rib, which, from its similarity to the general form of roofs, may be estimated by the principles already explained as applying to them, with this difference only, that the strength of the timber composing the arch mould must also be taken into account, for this number does not exist in roofs. The method of proceeding is as follows: The force of each strut is 432,000, and that of the curve is 518,400; therefore draw two lines from the top of the centre of the king post, the first *m v* parallel to the lower strut *c*, and make its length equal to 432,000, and the second upon the upper strut, and make its length *m s* equal to 432,000+518,000 or 950,000, complete the parallelogram *m s r v*, and draw a horizontal line *r k* from the lowest point of that parallelogram, cutting the vertical line *m q* in *k*, and make *k q* equal to *k m*. It is plain from what was done for the lower part, that *m q* will be the measure of the load that can be carried by the upper part; and this will be found equal to 1,160,000. This is a strength greatly superior to what is wanted, but not in so large a proportion as the under part, although the chief part of the load lies on the upper part. The reason of the great difference in the strength of the two parts, arises from the greater obliquity of the upper struts, which shortens the diagonal *m q* of the parallelogram of forces, and shows that M. Pitot was in error in making the scantling of the upper struts more slender than the lower, when in fact they should be stouter.

The strain on the stretcher A A is not calculated, but it is measured by *r k* when *m q* is the load actually lying on the upper part. Less than the sixth part of the cohesion of the stretcher is more than sufficient for the horizontal thrust; and there is no difficulty in making the foot joints of the struts abundantly strong for the purpose. The above computation, it will be seen, does not give the strains exerted upon each individual piece; but the load upon the whole, upon a supposition that each piece is subjected to a strain proportioned to its strength. The other calculation would be much more complicated, and is not necessary here. The directions above given, can of course be applied to centres differently constructed.

1087. When the principles of roof construction are not retained in the formation of centres, polygons, or opposite struts are generally resorted to. Hupeau's centring for Orleans bridge, before described by Fig. 253, is a frame composed of polygons; but in this, the sides of the inner and outer polygon are nearly parallel to each other, and the ends of those sides all terminate, one over the other, in lines that radiate nearly from the centre of the arch. Perronet, a very celebrated French Architect and Engineer, has preserved this mode of construction, and he built many of the finest bridges of France upon centres of this kind; but instead of making the adjacent polygons nearly parallel, he arranged his timbers in such manner, that the angles of the one polygon were brought into contact with the middles of the sides of the adjacent one, and he used at least three of such polygons. This disposition of parts, will be rendered plain by reference to Fig. 257, which is an exemplification of this mode of construction, but not a copy of any particular centre that has been used. In nearly all the examples of Perronet's centres, the inner and outer polygons are brought very nearly or quite into contact with each other at the springings, or opposite ends, which may afford facility in supporting the centring while in use, but cannot add to its strength. In our figure the sides of the outer polygon are formed of the pieces *a b*, *b c*, *c d*; and the next within by other pieces *h e*, *e f*, *f g*, and *g l*, so that the angles *e f g* of the second polygon, come in contact with the middles of the sides of the outer one, which of course carries the arch mould blocked up as before described. *h i k l*, Is a third polygon within the others, but parallel to the outer one, and its angles likewise come into contact with the middles of the sides of the intermediate one. By this construction the angles of the alternate trusses lie in lines pointing to the centre of the curve. King posts are therefore placed in this direction between the adjoining beams of the trusses as at *e f* and *g*. These king posts consist of two beams, one on each side of the truss, and they embrace the truss beams between them, meeting in the middle of their thickness. The abutting beams are morticed half into each half of the post, and when the king post intersects the middle of a truss beam, such beam passes through it by their being let into each other, after which they are bolted or keyed through with iron. In this manner the whole is united, and it is expected that when the load is laid on the uppermost truss, it will all *butt* together, forcing down the king post, and therefore pressing them on the beams of all the inferior trusses, causing them also to butt on each other and bear a share of the load.

1088. The bridge of Cravaut was built by Perronet on centring of this construction. The arches were elliptical, of 60 feet span and 20 feet rise. The arch stones 4 feet thick, and weighed 176 *lbs.* to the cube foot. The truss beams were 15 to 18 feet long each, and their section 9 by 8 inches. The king posts about 7 feet long, and each half in section 9 by 8 inches. The whole was of oak timber, and 5 trusses were used for each arch, placed $5\frac{1}{2}$ feet asunder. The weight of an entire arch was 558 tons, or about 112 tons upon each truss; and of this, nearly 90 tons actually pressed upon the truss. When this centring is examined by the method before pointed out (1085–6) it is found competent to sustain a much greater load than was placed upon it.

1089. The bridge of Neuilly, near Paris, is another of Perronet's works, in which the same kind of centring was used; but as the arches were larger, having a span of 120 with a rise of 30 feet, four polygons of truss beams were used. The stone arch was five feet thick, and the ribs were set six feet apart. The strut or truss beams in this centre were 17 by 14 inches scantling; the king posts 15 by 9 inches in each half, and the ribs were tied together by five horizontal divided beams, running from one rib to the other, 15 by 9 inches in each half, and eight entire beams of 9 inches square. The absolute weight of stone (without deduction for position) is 35 tons to each rib. The bridge was built upon this centring, which was strong enough to bear its load, but very deficient in stiffness, for it sunk upwards of 13 inches before the key stones were laid; and during the progress of the work, the crown rose and sunk by various steps, as the loading was extended along it. This want of stiffness arose from the use of four polygons placed so near to each other that they became nearly parallel, or presented very obtuse angles to each other and to the king posts. The centre would therefore have been much stronger had it consisted of fewer pieces, forming more acute angles.

1090. We shall conclude our observations on this branch of carpentry, with an account of the construction designed and used by Mr. Mylne, in building Blackfriars bridge, London, as this has been generally considered as the best and most efficient centring of any. It takes about one-third more timber than Perronet's plan; but it is beyond all comparison stronger. The leading principle of this centre is, *that every part of the arch shall be supported by a simple truss of two legs, resting one on each pier.* This principle is illustrated by Fig. 258, in which *a* and *b* are the two soles of the semicircular arch mould *a d c e b*. The truss in every place consists of two straight beams, one end of which rest upon the soles, while the two upper ends meet at the arch mould. Thus, *a c b* is one truss which supports the crown of the arch at *c*. *a d b* Is another truss crossing the first, and giving support to the point *d*. *a e b* Is a third truss to support the point *e*, and these trusses may be multiplied to any required extent. The only deviation from this plan that was made by Mr. Mylne in building the bridge was, that instead of causing all his struts to spring from nearly the same place, or from a small sole, (as done by Perronet in most of his centres,) he adopted an extended sole reaching from *h* to *g*, in Fig. 259, which is an elevation of this centre, as actually executed and fixed; and by this means Mr. Mylne was enabled to throw the most serious and detrimental pressure of the load, (which is the crown or upper part of the arch before the key stone is set,) upon the very foundations or lowest parts of the piers; thus preventing the possibility of their being forced laterally out of their places, which is one of the worst accidents that can befall a bridge while building. The other variation that he made was that of introducing stretching beams, which he called *apron pieces*, between the upper ends of the beams, instead of letting them abut against each other. These apron pieces served a most important purpose, for they gave better abutments to the braces than could have been otherwise obtained, at the same time that they rendered their meeting angle much more acute than it otherwise would have been, by which the strength of the truss was improved; and as these pieces were applied directly under, and were fitted and bolted to the curved arch mould, they made it much stiffer and stronger than it could otherwise have been made.

1091. The central or largest arch of Blackfriars Bridge was 100 feet span, and its arches are nearly semicircles, as they rise 43 feet above their springing. The timbers used as struts were 12 inches square, and as their length, in many places, was such as precluded the possibility of procuring them in single pieces, they were joined and made to abut on each other, such joints being secured by being grasped and held together by the double king posts *g h*, which were notched to fit the intersecting pieces, and held together by iron bolts. The frequent intersections that occur in this centring produced the necessity of letting many of the beams into each other, which must have weakened them considerably, and endangered their breaking by cross strains, if it were possible for the frame to change its shape; but the great breadth that was given to the trusses prevented such change, and the fact was, that no sinking or twisting whatever was observed during the progress of the mason's work, although the arch stones were more than six feet thick. Three points in a straight line were marked on the centres for this observation, and they were watched each day. The whole sinking of the crown, before setting the key stone, did not amount to an inch.

1092. One peculiarity in this centre is in its base and the mode of supporting it, and lowering it afterwards for striking. Mr. Mylne used the precaution of constructing very wide coffer dams for his piers, so that they were nearly twice as broad at their commencing bases as they were where they appeared above water, and after carrying up these bases with perpendicular sides until they became level with the bottom of the river, they then diminished by regular offsets upon every course, so as to produce an approximation to an inverted arch, as will be seen in Fig. 259. This gave him an excellent opportunity of obtaining abutments for the lower ends of a set of five struts *c c d*, upon which the sloping platform *a* was formed; and this carried the seats, or bed pieces, of stout oak, one of which was placed under each end of each rib of the centre. The upper surfaces of these seats were cut into a series of inclined planes, like a zigzag scarfing, and the under sides of the soles, or end timbers of the ribs, were also cut into a similar form, as shown between *f* and *e*, in the figure, and each face of the scarf was covered with a thick and smooth plate of copper. Between these two pieces was placed the striking wedge *e f*, (made black in the figure,) and this consisted of a series of wedges, one beyond the other, but all in one piece, formed of a large beam of hard oak, hooped with iron at the projecting end *e*, to prevent its splitting. The form of the wedges cut on this piece corresponded exactly with the inclined planes formed in the seat and sole. The striking wedges were so placed as to keep the seat and sole at the greatest possible distance from each other; but on driving in the end *e*, they would be permitted to approach, and the whole rib would thereby be slowly and gently drawn from its contact with the under side of the arch, without at any time losing any of the power by which it was supported, which is a most desirable object in the first striking of the centring of a large arch. A solid block of wood was introduced behind the end of the wedge at *f*, to prevent the possibility of its sliding inwards by the pressure of the arch. When the wedges had to be driven, after the completion of the arch, these blocks were removed, and the driving was accomplished by a heavy beam of oak capped with iron, and suspended by chains reaching from the lower beams of the rib to its central part, so that it would be used like the battering ram of the ancients. A few moderate blows with this implement produced the desired effect, and the wedge was driven, and the rib lowered in a few minutes. The wedges under all the ribs must be driven simultaneously, because if one rib had remained up, while the others were depressed, this would either cripple the arch, or break the remaining rib. It was suspected that the small space through which these wedges permitted the centring to descend would not be sufficient to allow for the settlement of the masonry; and, consequently, that the centres would not be released from the work; but Mr. Mylne had no such fear, and remained perfectly confident not only of the perfection of his centring, but of the workmanship of the arches also; and in this he was fully borne out, for none of his arches exceeded $1\frac{1}{4}$ inch in their settlement, while all those of Perronet, built upon his polygonal centres, sunk from 6 inches to $23\frac{1}{2}$ inches, which last settlement occurred in the bridge of Neuilly.

1093. In building Waterloo Bridge, London, (between 1811 and 1817,) Mr. Rennie adopted the principles of the Blackfriars Bridge centring, with the exception of such trifling alterations as would adapt it to an elliptic arch of 120 feet span; and the same striking wedges and means of supporting the seats and soles were used, with complete success.

In Westminster Bridge (built between 1739 and 1750) something like the same principle was taken by M. Lubelye, but his centre is by no means so strong and perfect as that of Mylne's, because only a single pair of struts take their bearings on the soles and meet at the arch. The other struts, which rise from the soles, proceed in right lines until they meet the arch mould, and from thence they transfer their pressure to the second strut, placed nearly at a right angle with the first, and terminating at its other end in some part of the arch-mould, where there is nothing solid to resist it. The ribs consisted of two parallel polygons of timber, about 12 feet apart, presenting seven sides to the arch, and stiffened between with the braces before mentioned, which are kept in their places by eight double king posts bolted together. These ribs had soles of their full width, which rested on a bed platform for carrying the seats of each rib; and the seats and soles were kept apart by separate wedges, placed transversely between them, but with long projecting points, so that when struck upon, they would release the wedges and permit the centre to descend. The bed platforms were level, and were supported partly by perpendicular struts rising from the offsets of the pier, and partly by long piles driven expressly for the purpose.

1094. The exactitude and perfection of workmanship that is necessary in the formation of the centres for large arches, makes it absolutely necessary that a strong and firm stage, floor, or platform should be constructed expressly for building them upon. This platform is made truly level by being built upon short posts that are let into the ground, and it consists of girders and joists that are afterwards covered with two inch plank, and made fair and smooth on the top surface. Upon this platform every part of rib is accurately drawn with black oil paint, or is slightly cut into the wood of the actual size of the several pieces; consequently the platform must be rather larger than the rib to be constructed upon it, and it must be so strong as not to be twisted or thrown out of level by the heavy timbers that are brought upon it. The pieces may be worked on the ground near the platform, but when finished are put together upon it, directly over the lines that have been drawn, in order to see that a perfect accordance between them takes place. Such a platform may seem expensive; but no expense should be spared to make a centring as perfect as possible, and when the ribs are finished and have been put together, the main timbers of the platform may be converted into lagging for the centre, since in large arches the lagging is usually composed of whole square timbers, ranged under the centre of each course of stones instead of planking.

1095. In pursuance of the plan previously adopted, the subject of carpentry will be concluded by some observations on the measurement and valuation of carpenters' work.

The measurement of carpenters' work is very simple, and depends upon the principles already laid down in several preceding places; but that of joiners' work, although more simple, inasmuch as it scarcely ever involves anything beyond lineal and superficial measure, becomes apparently intricate from the great variety of technical terms made use of in joinery to express the forms of things, or the articles made. Generally speaking, however, all doors, sashes, shutters, floors, stair steps, &c. with their architraves, surbases, jaumbs, soffits, and other articles made by the joiner, are measured by the surface they present superficially, and are charged at so much the square foot; the price being regulated by their intricacy and finish, which will occupy more or less time. If work is enriched with many mouldings, and a superficial price to include the whole cannot be agreed upon, it is a common practice to obtain a price, by measuring the ground-work as plain work, which is covered by well known prices, and then to add the extra mouldings and ornaments at so much per foot, running measure, according to their length. The price per foot super. of joiners' work is deduced from the quantity of that kind of work which a good and competent workman, with every convenience around him, ought to do in an hour, a day, or any stated portion of time; and in computing the value of such work the labour only is taken into account, without the value of the wood, or *stuff* consumed. This is called the *price for labour only.* But when the joiner provides stuff, its value must be added to that of the workmanship, and it is then called the *price for labour and materials.*

1096. Carpenters' work is done under three distinct contracts, called *labour and all materials;* labour and nails; and labour only. The first is when the workman provides the timber for his employer, and does all the necessary work upon it, at the same time providing the necessary materials such as glue, nails, screws, &c. for putting the work together. But locks, bolts, hinges, and other articles of ironmongery are never included, but constitute a separate charge, according to their number and value. The second head, *labour and nails,* implies that the employer provides all timber and other materials, except nails, and that the workman puts the work together and fixes it, he finding all such nails, spikes, or trenails as are necessary, but nothing else; and the third head is where every thing is provided by the employer, and the workman merely furnishes labour.

1097. The first mode of working is generally resorted to for all small jobs, in which it would not be worth the employer's while to purchase his own materials, especially as he might procure too much or too little, and every carpenter usually keeps a small stock of such materials on hand.

1098. The second mode, of finding labour and nails, is the one constantly resorted to in England for all building contracts; it has come into use from the very careless manner in which nails are treated by workmen, unless they have to pay for them. When this is not the case, as many nails are frequently spilt among the shavings and swept away as would complete the job, while in labour and nail work, a spare nail is seldom seen upon the ground. In England nails are likewise an article of ready sale; and are therefore frequently purloined by labourers, unless they are taken good care of.

1099. In the large cities of the United States, the two first plans are adopted as in England; but away from them, the mode of labour only, and the employer finding all materials is in constant use, notwithstanding it is the most wasteful and expensive process that can be used; for the employer is seldom as good a judge of the materials and their prices as the workman, nor does he know in what proportion they ought to be procured. He therefore often has a considerable stock left on hand when his work is completed, or experiences a scarcity of some articles in its progress which compels him to substitute one size for another, or one kind of material for another, so as almost to preclude the possibility of perfection in his operations.

1100. All carpenter's work, whether done by one or other of the above contracts, is measured and charged for by superficial measure, taken in what are called *squares*, that is, 100 superficial feet, or else by the single foot. Thus all naked floors, roofs, or partitions (979) are computed in squares and $\frac{1}{100}$ parts of a square, being superficial feet, and they are said to be worth a certain price per square, according to the distance apart of the joists, rafters, or studs, and whether they are morticed into, or simply notched down upon bridging joists, girders, &c. If a carpenter covers a naked partition with weather boarding, or a naked floor with boards or battens, still the measure and value is determined by the number of squares. A square of work is therefore worth a certain price for labour only; but if nails are also found, then the value of as many nails as ought to be used in a square of such work must be added. When the work is small and neat, it is taken in superficial feet instead of squares, while skirtings and many other things belonging more to joinery than carpentry, are measured and valued by lineal feet. It will thus be seen that the measurement of carpenter's work for labour only, or labour and nails, is very simple; but when all materials have been found, the above process must be gone through, and the price of the materials must be added, which increases the complication of the process, because not only the general surface, but each individual piece of timber that occurs in the work has to be measured and set down in three dimensions, viz: length, breadth, and thickness, to determine its cubic measure. The kind of timber must also be specified in the measuring book, provided the timbers used are of various kinds, with different prices per foot cube. The same ruling is used for the carpenter's measuring book as for the bricklayer's, (see 942,) and the columns are appropriated to the same purposes, viz: the first on left for coefficients, when pieces of the same size are often repeated, as in joists and rafters. The second column for the dimensions as taken; but these are always set down in three, instead of two lines or quantities, the breadth occupying the top line, the width the second, and the length the third; because to cube timber the breadth and width are multiplied into each other, and their product into the length. The third column is therefore left blank for receiving the cubic quantities, when afterwards computed at home, and this quantity must of course be multiplied by the coefficient, when one exists. The fourth column is filled up with the kind and quality of timber, as oak, pine, &c. and the form in which it exists in the work, as joists, lintels, rafters, &c. This dimension book not only requires to be cast up, but to be afterwards abstracted, (see 945,) in order that all the same quality of timber (or work if required) may be got together, when the whole quantities can be stated in single sums with the appropriate value set against each. The table given at paragraph 570, will often prove very useful in reducing these calculations into value.

1101. Piles used in foundations are valued at per piece, or by cubic measure; and, if their driving is contracted for, it is estimated by the foot run, according to their length, size, and the nature of the ground. Centring for arches is sometimes made and fixed by the square; but, in general, the Engineer considers this as work of too nice a nature to be trusted to contractors, and he prefers executing it as day-work by the best hands. Wall plates, lintels, and bond timber are measured by the cubic foot, under the denomination of fir or oak in bond.

1102. All timber used in foundations, naked floors, ceilings, &c. should be measured in presence of all parties concerned, as soon as fixed, because disputes frequently arise about the size and quality of timber after it is buried in the ground, or concealed by boarding or plastering, and these can only be arranged by undoing part of the finished work, occasioning delay, expense, and inconvenience.

1103. In measuring timber that is plained or wrought, the size of the piece before worked upon must be set down; also in pieces on which tenons or mitres have been cut, the length must be taken to the extreme end of the tenon or mitre, as these were as large as the rest of the stick before cut; and when the net quantity of timber found in any regular work is measured and set down, a twentieth part of the gross quantity is usually added, to allow for inevitable waste, on account of the ends of all planks, boards and sticks being split, shakey, and unfit for use; on which account they are cut off, which is also the case with the sides of boards, and many other pieces. This allowance would not, however, compensate for circular work, such as the ribs or arch-moulds of centres, and the curbs for sinking wells, for these, though curved, are cut out of straight wood, and as the curved pieces that come off are cross-grained and useless, so the actual size of the piece of timber, before converted, is always charged for, instead of the net quantity that occurs in the curved piece that is used.

1104. Journeymen carpenters and joiners are always expected to provide and furnish their own tools, the use of which is included in the price of their wages; but the bench they work at, and a grindstone for sharpening such tools, are provided by the employer, together with any tools that may be necessary for particular and uncommon operations.

CHAPTER XI.

ON FOUNDATIONS AND THE USE AND CONSTRUCTION OF STONE AND BRICK ARCHES.

Section I.—*On Foundations.*

1105. Large arches of stone or bricks cannot be built without the assistance of centring, such as has been described at the close of the last section on carpentry. Such centres are, therefore, a necessary appendage to every arch: as, however, they are not permanent, but are taken away as soon as the arch is finished, and are constructed of timber by the rules of carpentry, they have been described under that head, as belonging more particularly to that branch of art, than to the arch itself.

1106. No arch can be constructed until the two foundations that are to support it have been prepared, and the form and construction of these is subject to great variation. Thus an arch may rise or spring directly from the ground, in which case mere foundations will be necessary; and in such cases, they are called *abutments.* In bridges, and many other erections, the arches are elevated considerably above the level of the ground, and then the supports are called *piers.* In architectural constructions, arches are very frequently supported by columns—the entablature, (including the architrave, the frieze, and the cornice,) intervening between the tops of the columns and the springing or commencements of the arch; and this mode of construction has in some few instances been adopted in ornamental bridge building to save the heavy appearance of a pier of solid masonry. Macclesfield bridge of three arches, in the Regent's Park, London, designed by Mr. Morgan, is an elegant example of a bridge of this description. Before entering on the subject of arch construction, some attention must be given to the formation of the abutments or piers that are to carry them, which affords an opportunity of speaking of foundations generally, and making those observations upon them which were referred to in the note appended to Art. 902.

1107. The foundation of every wall or building ought to be depressed or sunk at least a foot or two below the general surface of the land, or much more if the building is large, in order to guard against the effects of frost, and to insure the soil from not being washed away by rains, or moved by other causes; and this depth should be increased if the erection is proposed to be made on an eminence. As a general rule, in making foundations for brick or stone walls, the upper vegetable mould, or soft covering soil of the land, should be cut through, and the excavation be carried down until the natural firm soil of the country is reached. Should the subsoil be rock or hard stone, no doubt need be entertained of the goodness of the foundation to bear its load; but that rock or stone ought to be under ground, because if it is exposed laterally to the action of the atmosphere or rains, it may moulder and decay with time. If no rock is met with, but the soil happens to be clay, gravel, or even sand, it may in general be trusted, provided it is ground, or land that has not been dug up and moved; for these several soils at the depth of from two to four feet beneath the vegetable surface mould, will in general be found hard and compact enough to bear almost any load, particularly if the earth pressed upon has no opportunity of moving or escaping laterally. Sand is almost proverbially a bad foundation to build upon; but it is only so when it is not confined, as in an open beach, where it is liable to be washed away, or even drifted by the winds, so that the wall may become undermined. But when sand is met with in the bottom of a foundation trench, in a tolerably dry state, and is to be covered on its upper surface with the intended erection, it may in general be trusted to as safely as soil of a more compact and fixed kind. If, however, sand contains a small portion of loam or clay, and is in the vicinity of a spring, or is otherwise mixed with a considerable quantity of water, it will be semifluid, and will possess the property of fluids of giving way to any pressure exerted upon it by rising upwards or expanding laterally, when it is denominated *quicksand*, and of course cannot be trusted as a foundation; and when this occurs, the trench must be dug deeper, and as much of the wet sand as possible being taken out by a swinging scoop or other means, its place must be supplied by hard stones or rubble-work, or even by driving piles; and in such cases the Beton or concrete mortar before described (929) may be applied with advantage.

1108. No made ground or embankment, that is, earth that has been shifted or moved to produce a level surface, should be trusted as a foundation for a heavy erection until it has had several years to settle and become hard and compact; for notwithstanding an embankment may have been regularly punned or rammed, yet it will always sink or settle to some extent. When, therefore, a building is required upon such a bottom, the foundation trenches should be dug through the made soil to the untouched earth beneath it. This would often lead to a heavy expense both in excavation and in brickwork; therefore the walls may be supported upon arches standing on piers, which alone go down to the solid earth. This expedient was resorted to in building the northern boundary wall of the yard of the new House of Correction in Cold Bath Fields, London, which extended over a large piece of hollow ground, which had for many years been made the receptacle for the rubbish of that part of the city, and consequently was all made or artificial ground to a depth of many feet. In this instance the arches sprung so low down that no part of them appeared above the level of the ground when finished, and the wall stood as firmly as if it had been built on solid ground.

1109. When a foundation trench has been dug even in natural ground, it frequently happens that the entire length may not be equally solid and hard. Should soft places occur without being very extensive, they may be arched over as above described, the arches taking their abutments upon such portions of wall as are built upon the solid ground. Whenever foundations appear doubtful, the solidity of the earth is tried by driving stakes into it, or by the use of an iron borer with a T shaped head, by which it is turned and forced downwards into the ground. Should its entrance be resisted, the ground may be deemed trustworthy; but should it pass easily, it will not be fit for building upon without some preparation and assistance.

1110. All foundation trenches should be perfectly level at their bottoms, and need not be wider than what is merely necessary for introducing and laying the stones or bricks in mortar. If, therefore, a foundation has to be formed in the slope of a hill, that foundation should not follow the slope of such hill, but should be cut in level steps, like a staircase, except that the level portions may extend considerable distances.

1111. When the erection about to be constructed is not a wall of equal thickness and weight throughout, but consists of piers with windows or openings between them, or of columns that are heavy, or have to carry large weights, the pressure on the foundation will not be equal, but will produce a greater strain immediately under such columns or piers than in other places. A footing or foundation of equal strength would, therefore, be subject to bend, break, or loose its right lined form. To resist such unequal pressure, inverted arches, or what are technically called *Inverts*, are resorted to. These are nothing more than the common arch, constructed of stone or brick, (but generally of the latter material,) but placed with the convex surface of the arch downwards, instead of in its usual position. Such arches, of course, require no centring for their construction, but the materials of which they are formed are supported either in regular curved foundations cut to a mould-board or template, if the ground is stiff clay, or any soil that will hold its shape without crumbling, or falling down, or more frequently in concavities formed in a brick or stone foundation which is commenced in the usual right lined horizontal direction. Fig. 260, Pl. VIII., shows such an arrangement as adopted round the Girard College, now building near Philadelphia, for supporting the immense massive columns of the colonnade that will surround that building. A regular level and straight foundation of brick-work is began at *a a*, and is carried up a certain height, when the inverted semicircles or segments *b b* are left in the wall, being accurately worked to their regular shape by mould-boards, or by sweeping strips, fixed to turn on the true centres of the required arches, when the openings are so large as to render a mould inconvenient. These concave openings are afterwards filled in with two, three, four or more concentric rows of arch brick-work *b b*, all terminating in the upper horizontal line *c c*. These hollow arches are afterwards filled in with horizontal courses of brick-work *d d*, so as to bring the top of the foundation wall to one uniform level *c e*, upon which the columns, piers, or other detached loads must be built, taking care to place each column or pier over the entire joint-springing of every two arches, by which means the load, that would otherwise bear only on the space directly under it, is distributed over the whole extent of the arch, the span of which must, of course, extend from the centre of any one column or pier to the centre of the one adjacent to it.

Inverted arches are also very useful in places where foundations may be liable to be undermined, disturbed, or carried away by a flow of water; and for this reason they are often adopted under the bottoms of canal locks, where, from the nature of the soil in which the lock is built, there may be a danger of its washing away. In such cases the inverted arch takes its springings from under the side walls of the lock, and forms the base or foundation upon which these walls are built; the inverted arch, of course, extending the full length as well as width of the lock.

1112. The greatest danger to be apprehended in a foundation of natural soil which may appear good, is from its not being equally hard and trustworthy in every part of its length. To obviate which, it is very customary to lay down thick oak, or other planks, to build upon; but this is by no means a good practice, unless the foundation is so deep as to insure such timber being constantly under water (665). When this is not the case the timber will soon decay; and whenever this occurs the wall is left without support, or perhaps partially supported, from one part of the platform decaying more rapidly than another. In all cases, therefore, where such assistance is necessary it should be obtained from large flat stones of the slab or lamellar formation (463); and some of the varieties of slate and York paving are excellent for this purpose. Such stones should be of sufficient thickness to sustain the superincumbent weight without breaking, and the more effectually to guard against this accident, they should be very carefully bedded, or be so placed on the ground as to leave no hollow places under them. This, in general, may be guarded against by digging the foundation trench wider than is necessary, making the bottom to fit or suit the under surface of the stone, (should it not be quite flat,) and then driving earth under the stone at its sides by a stone hammer, after it is placed.

1113. The ground under a foundation is sometimes of so loose and open a nature that it may not prove solid, even if excavated to a very considerable distance, and when this is the case the driving of *piles* may become necessary. Piles are usually made of whole round timber (548) cut to proper lengths, or of baulks, from which the rough bark and any projections have been hewn off, to fit them for passing more readily into the ground; and the descending end is pointed for the same object. Should the ground be hard or stoney, the end will require the assistance of a wrought iron point, which is formed with four spreading tails with holes through them for nailing them to the sides of the point of the pile; the upper end of the pile must likewise be encompassed by a strong wrought iron hoop, to prevent it from splitting in the driving. The points, or *shoes*, may be made of cast iron for soft, sandy, or clay soils, that being a cheaper material, and the point, or shoe, being lost for ever; but one hoop will serve for many piles, because it is only useful during the driving, and is afterwards taken off to serve for other piles.

1114. Piles are used for a twofold object, one of which is to condense or harden loose ground, which they do on the principle of the wedge, by inducing lateral pressure; the other is to transfer the load to a deeper part of the soil than that which has been laid bare, when it is found that the ground increases in solidity as it descends, or that a solid stratum of soil exists under that which has been laid open. To produce the first effect the piles need not be more than from four to six feet in length, and their lower part should be squared and gradually tapered from the point to the head, so as to give them the shape of elongated pyramids; and if charred, before driving, they will not only enter the ground more easily but will be more durable. For the second object the piles must of course be long enough to reach the hard ground from which the support is proposed to be derived; and whenever piles are long they ought to have but little taper or diminution of size, or the difficulty of driving them will be much increased. Every pile should, however, have some taper, because that affords material assistance in enabling it to support its load.

That timber should be selected for piles that is known by experience to be least liable to decay under ground, and it should be straight grained and tolerably free from knots, otherwise it will be liable to break in driving. Considerable care is also necessary in shaping the points to have the angles on all sides equal with their common summit in the centre or axis of the tree; for if this is not attended to, the pile cannot be driven in a perpendicular straight forward direction. Small piles are driven by a three hand maul, but large ones require a pile driving engine.

1115. The three hand maul is a very large mallet made of a block of hard wood hooped with iron; it has two handles, which radiate from its centre, and are so far apart that two men can work it, one holding each handle, and it has a third short handle opposite to these. A man stands at the short handle merely to assist those at the long ones in raising the maul from the pile when a blow has to be made, and it descends by its own weight, urged by the strength of the two men at the long handles, and has great power, but could not be used for long piles, which stand their full height out of the ground before they are driven. Pile engines vary in size and construction with the length and size of the piles to be driven, and consist of a contrivance for raising a heavy block of wood, or cast iron, to a certain height, and then letting it fall suddenly on the top of the pile, so that it may perform the office of a heavy hammer. Small pile engines are called bell ringing engines, on account of the weight (called the *monkey* when it is about 3 *cwt.* or less) being raised by a single rope which, after ascending to a sufficient height, passes over a large pulley and descends on the opposite side, where it is divided into six or eight smaller ropes, to each of which a separate man applies his force to raise the weight, and then they all slack out their ropes simultaneously, so that the operation appears very like that of ringing large bells by ropes. As the rise and fall of the weight is limited in this machine to the extent that the men's arms can reach, and the weight must be light in order that it may be raised without mechanical power, this machine is only applicable to driving such short piles as are generally used in inland places; but it has the advantage of working quickly and being easily moved from one place to another.

1116. In bridge building and other wet foundations, where longer and thicker piles are required, a more powerful machine becomes necessary. Its construction is nearly the same, but a heavier weight (now called a *ram*) is used, and it is drawn to a greater height that its blow may be more effective. The ram usually weighs from 5 to 8 *cwt.*, and it is held by a pair of spring nippers to which the elevating rope is fastened, while the elevation is produced by one or two men turning the handles of a crab (469). As soon as the ram is raised to the full intended height, the handles of the nippers are pressed together by two inclined planes, fixed on the top of the machine, which cause the nippers to open and release the weight, which falls free from the incumbrance of the rope, which is instantly lowered for lifting the weight again. The iron weight of a pile engine is cast with two square transverse holes, into which pieces of hard wood are firmly keyed to attach the weight to the guide posts for governing the direction of the fall. The ringing engine is generally made with only one post of four or five inches square, and at least one-third longer than the piles to be driven. Its lower end is firmly morticed into the middle of a strong timber sill, so as to give it the appearance of a large T square (33), with a square instead of a flat blade. The pieces of wood that are keyed into the weight have square holes in them for the upright piece to pass into, and a large pulley is fixed on the upper end of the upright post, over which the elevating rope passes; consequently the weight can only rise and fall by the side of this post. The use of the transverse sill is to afford a foundation for the engine, and to maintain the perpendicular position of the post in one direction. It is then retained in that position by three stays or guy ropes, with blocks and falls attached to the ground; and having been properly adjusted and fixed in its place the weight is raised and fixed in its highest position, and the pile to be driven being set in its proper perpendicular position close to the engine post, the two are slightly tied or lashed together, and continue so until a few blows have driven the pile deep enough into the ground to enable it to maintain its own erect position.

The larger engine is of the same construction, except that as the ram is very heavy and the range of motion longer, one upright pole might not be strong enough, and two are therefore used parallel to each other, and about five inches asunder; and the pieces of wood keyed into the ram now pass between them, and the weight is prevented escaping by iron pins driven through the projecting ends of these pieces. This construction also admits of diagonal braces being introduced, from near the ends of the sill to the outsides of the uprights, by which the machine is much strengthened. It is fixed by guy ropes like the smaller engine, and the uprights must be so much higher than the piles to be driven as to leave a fall of at least four feet on the head of the pile, for commencing the driving.

When piles have to be driven in rivers for bridge building, the engine must be supported between two strong boats or barges, firmly moored or fixed in their proper places, until a sufficient number of piles have been driven to afford a more stable mode of fixing it. It frequently happens that a large part of the work has to be done in barges, and the guy ropes and other fixings must then be attached solely to the barges, because should the water be subject to rise and fall from tides, or other cause, the ropes would not remain equally strained when otherwise attached.

1117. In the building of Westminster Bridge, London, a very complete machine for driving piles, invented by Mr. Vauloue, was used. It was built on a barge and worked by a horse who went round constantly in the same direction, and with the same speed during the rise and fall of the ram. It was a most complete and perfect machine, containing several curious mechanical principles, on which account it is described with a figure in almost every English book on mechanics. But being complicated and expensive, its construction has not been repeated, except in models to explain its principles. As a great number of pile engines are frequently at work at once when a bridge or large construction is going on, and as they require to be constantly shifted from place to place, as the work proceeds, or even to be altered in adjustment of position while a single pile is driving, in case of its not going straight, these machines require to be cheap, simple, as light and portable as possible, easily fixed and not readily put out of order. Now, none of these qualities belong to Mr. Vauloue's engine, while they all appertain to such as have been described; and the surest proof of their being the best machines is, that they alone have been employed in the numerous large bridges and public works that have been executed in London, Liverpool, and other large cities of England within the last forty years. The only difference that has been adopted has been that the ram has occasionally been raised by horse instead of human power, and the only alteration necessary in this case is that a horse mill or frame work, like that shown at Fig. 118, Pl. IV. must be provided, the drum, or cylinder, upon which the rope winds, being placed upon the central upright spindle *b* above the arm *i*, and that this drum should be loose or capable of revolving upon that spindle, but with a lever catch to lay hold of the arm with which the drum should be fixed or engaged, while the weight is rising, but by means of which it may be disengaged for the rope to run back for re-engaging the weight, without the slow and troublesome process of turning the direction of the horse, who may thus stand still until the weight is prepared for rising.

1118. As the pile descends into the ground, it ought, and generally will meet with increasing resistance: and this is met by the weight (which is always raised to the same height) having an increasing distance to fall through, as the pile recedes before it. A pile will frequently descend several inches with each of the first blows, but its rate of motion (which is ascertained by making chalk lines on the pile engine even with the top of the pile) will gradually decrease, and a pile is not considered as well driven and perfectly trustworthy, until it stops or refuses to go further, or at any rate makes an almost insensible progress. Thus, if a pile is not found to move a tenth of an inch after eight or ten successive blows of a heavy ram, it would only be throwing away time and money, besides, perhaps, splitting the pile if the operation should continue; and, of course, though such pile may not have been driven half its length, the driving operation would cease, and the pile may be sawed off to its proper level. But, on the contrary, if the pile goes fully down to its top, and has descended several inches at each of the last blows, then it would not be safe to build upon it, but it must be left and other long piles must be driven round it, at from twelve to eighteen inches from its outside. These may have the effect of fixing it in the ground, which is ascertained by shifting the pile engine over it again, and giving it a few more blows. Should it still drive, then other intermediate piles must be introduced so as nearly to fill up the space between the first and second sets; but, in general, piles seldom want such close approximation and should be kept at least their own diameter apart, not only to provide room for intermediate piles, but because when they are driven too closely together, the driving one pile will occasionally force those previously driven partly out of the ground, or at any rate will force up some of the intermediate soil, which is detrimental by loosening the ground.

1119. All piles should be placed in right lined rows, and when fully driven their tops are sawed off to a true level plane, because a timber sill or sleeper of sound die square timber, or thick plank, has to be placed upon each parallel row of piles, and is then spiked or trenailed down (992) to the top of each pile. The space between these sleepers should then be filled up with rubble-work, brick rubbish, or stones screened out of coarse gravel or other hard material, which should be well rammed into its place, or if the ground is springy may be grouted with mortar, mortar and cement, or wholly with cement, according to the nature of the soil, and the erection to be placed upon it, until the whole is brought to an even surface. Other pieces of timber are then laid at right angles across the sleepers, one over each transverse row of piles, and if these are distinct, one intermediate piece between each. This forms what the French calls a *grillage*, or grating, and transfers the load evenly over all the piles driven. These pieces are, in like manner, filled in between them, so as to produce a level surface for building upon. That surface is sometimes covered all over with thick plank, to render it more smooth and even, but this is merely multiplying the layers of timber without an equivalent advantage, and should a more uniform surface be required, it will be better to obtain it by putting the cross timbers closer together. Sometimes the sleepers and cross pieces are halved on to each other to produce a level surface in the first instance. But this is a bad practice. It is, in fact, buying large and expensive timber, and then by cutting it half or partly through, diminishing its strength and laying open its heart or centre to the immediate action of humidity and the causticity of the lime. For the same reason I do not approve trenailing the cross pieces, or producing more holes or weakness than is absolutely necessary; because if the platform is laid truly level, no piece will have a tendency to move from its first position, particularly when loaded with brick-work or masonry. But should the platform be necessarily sloping, as is sometimes the case in the abutments of bridges, then there may be reason for notching the pieces into each other to prevent their sliding, but this notching should in no case proceed to half the thickness for the mere sake of obtaining an even surface.

1120. While on the subject of piles, it may be stated that they are not only used to procure solid foundations, but occasionally as accessories to that end, by keeping back water or quicksand, and then they are called *sheeting piles*. Sheeting piles instead of being made of whole timber, are formed of thick plank, shot or jointed on the two edges, so that they may come closely together and form a water-tight, or nearly water-tight, joint. The more effectually to insure this, and the parallel position of the planks, their edges are frequently grooved and tongued (1015) into each other. They are driven by the same machine as other piles, but generally by the small or ringing engine, and to insure the contiguous edges keeping in close contact with each other, while driving, the angles of their points are all cut on one side only of the pile, as shown at Fig. 261.

1121. When foundations have to be sunk very deep, by which they get into the springs found in most land, or have to be made in wet places, it frequently happens that the water rises so rapidly, or that the sand and water, mixed together, are so fluid that they impede the progress of the workmen, so that draining by pumps or other means become necessary; and then it is that sheeting piles must be used to keep up earth, or to keep back sand and water. When any extent of such piles are necessary, guides for driving them, and afterwards retaining them in their proper positions, must be used. These guides are pieces of square timber placed horizontally parallel to each other, and as low as possible in the work. They are kept asunder by a short pile driven at each of their ends, to which they are spiked, or screw bolted. Their distance asunder must be about one quarter of an inch greater than the thickness of the sheeting piles about to be used, and which are formed of planks from two to five or six inches thick, according to the height and weight or quantity of water sand or loose earth they may have to sustain. The use of these guides is to direct and hold the piles in their proper places while driving, and to support them afterwards. The piles are, therefore, introduced between the two guides, and if long or high, a single guide rail, placed three or four feet over the lowest one that is on the outside of the expected resistance, will be necessary for the piles to lean against. When the resistance is great both the upper and lower guides should be of strong whole timbers; the bottom one may be stiffened by short piles driven close behind it at short intervals, and the upper one may be strengthened by diagonal struts or braces. While the sheet of piles is fixing there will be no danger of irruption, because the water and sand will flow out, or rise to a common level on both sides; but when completed and the water, sand, or mud is withdrawn from the excavation in which the work is to proceed, these materials may accumulate and rise on the opposite side of the sheet, and break it down or undermine its foundation, or may get round the sides unless the work is well executed and stayed or braced, so as to prevent its changing its right lined position in consequence of lateral pressure. The sides of the piles must be well planed and fitted so as to make water-tight joints, and by cutting the points of the piles into the form shown at Fig. 261, the piles are forced into close contact with each other while driving, an effect that is further assisted and promoted by binding the upper part of each pile, as it goes down, by a rope or light chain to the piles previously driven, as at *e e*, in the figure. When the water to be arrested is very clean and clear, the joints of sheeting piles sometimes require to be caulked with oakum, like the seams of a ship; but, in general, the clay and mud of the water settling in the joints, or smearing them over on the back side with wet clay will render them water-tight. The flow of water being thus conquered the excavation to be used for the building must be cleared of water by pumping or other means, and this is frequently a very expensive operation, as powerful pumps are often necessary, sometimes requiring the aid of a steam engine to work them; and when once pumping begins it should never cease by day or by night, for in a short cessation the water will gain or rise perhaps to its original level, and then all the previous labour is thrown away. It is not the mere water contained in the foundation pit that has to be drawn out, but in sandy soils all the water that the earth contains in a great distance around will percolate into a deep foundation, and the water in this way has laid dry every pump and well within a radius of about a mile from the place where the pumping was going on.

1122. When difficult foundations of this kind occur, (and they are not uncommon in building the locks for navigable canals,) of course the whole foundation cannot be laid open at once, and the Engineer must be satisfied with clearing a small part at a time, and getting in a small portion of the work, which, if of brick or stone must, of course, be laid in hydraulic cement, or if of timber, not secured by piles or otherwise, must be loaded with stones or earth to prevent its floating. Indeed it is often a safe precaution to load even brick or stone-work, after it is laid in such situations, with a quantity of the soil dug out of the adjoining part of the foundation, merely to give it additional weight, and prevent its being washed away or disturbed, although that earth will have to be moved again before the work can proceed. The great difficulty in these cases is to get the platform or grillage, or the few first courses of the foundation laid, for when that is done, and a good hard and level bottom is obtained, the rest of the work is comparatively easy. Of course in these, as indeed in every other kind of foundation, the largest and most massive stones, with the flattest surfaces, should be laid, in order that they may cover and distribute the weight that is afterwards to come upon them over as large a space as possible.

1123. When the foundation is wholly in water of considerable depth, as in building the piers of bridges, two distinct methods of proceeding must be adopted, depending on the nature of the bottom or foundation. Should the bottom be any thing but rock, *coffer-dams* are constructed, and the work will be comparatively easy; but, if the bottom is of rock, or of such hard materials as will make it impossible to drive piles into it, the difficulty is much increased, or the work may even be rendered impossible. A coffer-dam is a water-tight box, or casing, formed by driving piles of such length into the river, that while their lower ends may take good and firm hold of the ground, their tops may remain at least a foot or eighteen inches above the greatest height to which the water can possibly rise by tides, freshets, or other causes. Coffer-dams are necessary not only for the central pier, but for the ends or land abutments. For the former they are usually rectangular, and so placed that their sides may be parallel to those of the pier intended to be built; but for the land abutments they are usually semicircular, or half a polygon, and open on the land side, so that they can be walked or carted into, which affords facility for delivering the materials; but of course the piling and damming must proceed a sufficient distance inland to prevent the possibility of the water ever rising so as to flow over them.

The reason for making abutment dams half polygons, is for the sake of having straight string pieces and rows of sheeting piles, as will be presently described. With the exception of difference of form, all these dams are alike; consequently an account of the manner of forming one in a river will suffice for all.

1124. The first step is of course to sound the river for its depth, and to bore into its bottom with an auger to determine the soil to be expected; for by this alone can the length of piles that will be necessary be determined. This known, drawings to scale must be made of a plan and elevation of the proposed pier, with the dam surrounding it. The pier must be shown of the size it is to have above water, together with the footings or offsets that are below, and out of sight. This is next surrounded by the inside of the dam, which ought to be placed at least four or five feet from the work, to allow room for the workmen to pass with materials. The thickness of the dam is next set out by lines drawn parallel to those that indicate its inside, and this must vary with the depth of water and other circumstances; but ought in no case to be less than six feet, including the timber; and if the river is wide, and good puddling material can be readily obtained, it will be better to make it ten feet thick, because this part of the dam, when finished, is the only one that can be used for landing and storing stones, mortar, and other materials. Should the depth of water amount to more than ten feet, it will be advisable to give it a greater thickness, amounting to twelve or fifteen feet. Having thus set out the exterior dimensions of the dam in plan, the number of piles to be employed can be determined; for one must be placed at each angle or corner, and the intervening space between these must be divided into such equal distances as will come nearest to four or five feet each; at each of which points, a long pile has to be driven, so as to inclose the space with a rectangle of four sides or rows of piles, about four feet asunder. These first piles should be very strong, made of squared timber, (the size depending on their length,) and so long, that after driving from six to ten feet in the bottom of the river, their tops may be above the greatest possible elevation of the water. While this large or exterior rectangle of piles are driving, the smaller internal one that is to form the inside of the dam may also be going on, observing that most of the inner piles should be at the same distance asunder as the outer ones, and be placed exactly opposite to them, so that a line strained over the centre of two opposite exterior piles, may also pass over the centres of two opposite interior ones. The string beams are next fixed; and these are whole pieces of square timber notched and screw bolted to each pile very near their tops, and surrounding each rectangle in a horizontal direction; and similar pieces are placed opposite to them in the inside of the piles, and of course, can be fixed by the same bolts running through both pieces and through the piles. The inside strings are often made of half timber, or a stick sawed through the middle, their chief use being to guide the sheeting piles in driving, and for them to rest upon when finished; but those on the outside should be very strong, as they not only bind all the piles together, but are intended for a protection against ice, logs, or any thing that may float down the stream; and should it be subject to these, or be navigable, it will be advisable to drive other strong piles, and string them together exterior to the outer row, to act as *fenders* or defenders, for preventing vessels or other objects striking against the dam. The rectangles of piles with their uniting strings constitutes the frame of the dam on which its strength chiefly depends; and when that is finished, the driving of the sheeting piles commences. These piles, for coffer-dam work, are never less than four inches thick, and when the depth is great, should be six inches. They are driven in close contact with each other in the inside of the string pieces of the outer rectangle, and the outside of the strings of the inner one, so as to form two parallel cases or walls of sheeting piles, the bottoms of which must proceed at least six or eight feet into the bottom of the river, while their tops may be even with that of the main frame. If these piles have been well driven, and are close and water-tight, or nearly so, as they ought to be, pumping may be applied between these two walls to ascertain if the water within can be lowered or not. Whether it can or not, the puddling must now begin by filling up the space left between the two cases with good puddling earth, which, if the water can be sufficiently withdrawn by the pumps, may be worked, trampled, and treated as in a common puddle gutter (391). If, however, the water cannot be withdrawn, the puddling materials must be worked and prepared in a boat or barge on the outside of the dam, and thrown by shovels, or raised by buckets, and discharged into the space, in which, being heavier than water, they will subside—and they must be worked and pressed into a compact state by poles and rammers, worked by men from a scaffold made across the string pieces. In this way the space between the two rows of piles is filled up to the top, and covered with gravel, hard soil, or rough flooring, for walking upon, working and landing stones, timber, or whatever may be required for the progress of the work. A gib or crane is frequently erected on the top of each coffer-dam, for the purpose of hoisting stones and heavy articles; and as this swings or turns on pivots, it affords an easy means of landing such articles on the top of the dam, or lowering them at once into their proper places. It is also a common practice to construct a strong but temporary timber bridge, from the shore to the several coffer dams as they are finished, which bridge carries a rail-road, and is wide enough for a horse to work upon it. This affords a convenient means of transporting the building materials and tools from the shore to the work, as well as for the workmen to pass to and fro.

1125. The dam may now be considered as water-tight as it can be made in the first instance; and the pumps may, therefore, be fixed upon it, for drawing off the water within it, and discharging it on the outside. The pumps generally used are copper hand-pumps, placed two together, with a beam or lever over them, so disposed that as the piston of one pump rises the other falls. The lever has cross handles to it, so that several men may apply their strength at once at each end; and as the perpendicular lift is generally small, the pumps may be made of large diameter, such as twelve or fourteen inches. If the water makes rapidly in the dam, it will be cheaper to work the pumps by a small steam engine, which is generally placed on the shore, and its power is carried to the pumps by a swinging rod, generally called a flat rod shaft, which may be of wood, and is supported upon the temporary bridge. Should the dam be well constructed upon clay or any ground that is nearly impervious to water, the pumps will draw all the water from the inside of the dam and leave the natural soil or bottom within it exposed for digging or beginning the foundation with the same facility as if the work was doing on dry land.

1126. When the coffer-dam is emptied of its water, it will be subject to the pressure of the outside water, which will be very considerable when the river is deep; consequently there will be danger of its collapsing, by its straight sides bending inwards. To resist this accident, stretching beams of whole timbers are laid transversely across the dam, and are halved down on to the string pieces, and bolted to them and the piles, so as to connect them together, and also to connect the two opposite sides of the dam. And as the water is got down, additional string pieces of strong timber should be introduced horizontally at every three feet from the top. These may be spiked on to the inner sheeting piles to retain them in their places, and then additional struts, or stretching beams, may be introduced across the dam, from one side to the other, and be tightly wedged and nailed between the strings, so as to effectually prevent the sides of the dam from bulging inwards. It may seem that these cross pieces will be in the way of the pier as it is building, but this is of no consequence, for the building can go on until it reaches the first range of such cross pieces, and that done, short struts or stretchers are wedged in from the strings to the solid stone-work some inches below its top, after which the long stretchers may be cut away to make room for the work to be brought up until it reaches the next tier of stretchers, which are replaced, and moved as before.

1127. The foundation in the bottom of a coffer dam is formed just as if it was in land. The loose mud and soil at the bottom of the dam is dug out and drawn to the top in boxes or tubs by a rope and windlass, as in digging wells, and it will be advantageous to the dam to discharge it into the water close to it, which gives the piling an additional footing of earth; but when this may prove detrimental to the navigation or flowing of the river, it must be discharged into lighters to be carried away. If the soil is firm, and the sheeting piles have gone six or eight feet into it, that soil may be dug away, if necessary, to about half their depth. But this is a delicate operation, requiring judgment and experience, for if too much of the inner soil is removed, the feet of the sheeting piles may be forced inwards by the external pressure of the water, and the whole dam may be *blown up*, as it is called, and destroyed. Whenever, therefore, it is found that the inner foundation has to be sunk to near the bottom of the dam piling, a counter dam must be formed; that is, a rectangle of strong sheeting piles must be driven parallel to the inside of the main dam, and about two feet within it. These new sheeting piles should extend several feet lower than the dam piles, and be strengthened with string pieces and braces, and now the space between this counter dam and the external dam being filled up with gravel, clippings of stone, and any hard materials well rammed, so as to resist and restrain the outer piles from bulging inwards, the excavations may proceed downwards, in this internal dam, even below the bottoms of the main piling. This was the case in the building of Bewdley stone bridge, over the river Severn, in Worcestershire, in England. The foundation was not found trustworthy at the depth to which the dam piles extended, but by this expedient Mr. Provis, the Engineer, was enabled to carry the foundations about five feet below the extreme bottoms of the dam piles, and to seat them on a bed of rock. It sometimes happens that the coffer-dam is constructed upon sand, gravel, or other porous ground, and that the water will rise from the bottom and prove very troublesome; and in this case the internal dam may prove useful by filling the space between it and the main dam with puddle, and leaving as small a quantity of surface as possible for the water to rise through.

1128. In ordinary cases when the soil at the bottom of a coffer dam, after it has been dug into for a depth of three or four feet and made level, is not found hard enough to base the work upon, it must be piled with rows of piles, with caps or sleepers upon them, and be treated in every respect like the piled foundations before described (1119).

1129. All piers for bridges ought to have considerable footings, or cover much more ground at the foundation than when they appear above water, not only to give them greater stability but because the offsets are frequently useful as a means of supporting the timber centres upon which the arches are to be built. The length of piers must depend upon the width of the bridge; but their breadth should be as small as possible, consistent with necessary strength, in order that they may not choke up the width of the river. This is one of the great improvements in modern bridge building, for formerly there appears to have been a doubt as to the strength of the arch, while excessive and useless strength was given to the piers, of which London Bridge is an example. The ancient bridge had no less than 20 arches to pass over a width of 900 feet of water; and these small arches rested upon such immense piers that they contracted the water-way to 194 feet. This edifice has been replaced by a new bridge of five arches, with a water-way under them of 692 feet, so that the four piers and two land abutments now only abstract 208 feet from the width of the river. For the same reason that piers should be narrow, so likewise their ends must not terminate in abrupt flat surfaces, but should be made sharp, to cut or divide the water and deflect it under the arches. In navigable rivers the form of the ends is important, since they ought not to present sharp points that may be broken off by vessels running against them, or flat, which might injure the vessels. Some difference of opinion exists as to the best form to be given to them, and accordingly they occur of different shapes in different bridges, but the general forms on their plans are the equilateral triangle, the semicircle, or the true Gothic arch. This last figure was adopted in the new London Bridge, and appears the best; for the point is stronger than in the triangle, and its curves run imperceptibly into the right lined direction of the piers without any angle to be broken off, or to injure vessels, or produce an eddy in the flowing water.

1130. The pumping of a coffer-dam is always an expensive operation; for, however well it may have been constructed, there are few soils that will admit the driving of piles but what will permit a considerable quantity of water to percolate and rise upwards through the bottom. A stiff clay soil is almost the only exception. Pumping, therefore, when once begun has to be continued, day and night, without the slightest intermission; and all stones, timber, and other materials should be cut and laid, or fitted together before the pumping begins, in order that they may be fixed in their proper places without a moment's delay, so soon as the water is sufficiently drained to render the bottom accessible. Where piling has to be driven in a foundation that may be done as well through the water as not, provided the pile heads are kept above it, and the piles may also be cut off to a level under water by machines constructed for that purpose, consisting of a saw arranged in a frame, which is firmly bolted to the top of the pile. But to examine the pile heads, lay down the sleepers or grillage, and place the lower stones—the water should be so far removed as to render the piles and soil visible, or at any rate, for the workmen to stand upon them in their water-boots, and feel them with their hands. For a short period, therefore, before getting in the commencement of a foundation, it may be necessary to strengthen the clearing force as much as possible, by applying hand pumps, or bailing the water out with buckets in addition to the engine or other prominent pumping power, should that be deficient. But this extra exertion will be but of short duration, provided every thing has been properly prepared and got ready, and a strong gang of good workmen are concentrated upon the spot; especially as on such occasions the work is carried on, if necessary, by torch light in the night as well as in the day. In pumping a coffer-dam, or other wet foundation, the suction pipe of the pump is so constructed that it can be lowered as the excavation goes down; and as soon as the bottom is laid dry, or as nearly so as possible, a hole of a foot or more in depth must be sunk for that pipe to pass into. This hole is called the *sump*, and its object is to drain the adjacent foundation by its greater depth. The *wind-bore*, or lowest pipe of the pump should stand in a wicker-basket in this hole, to prevent chips, pebbles, and other small bodies entering the pump, as they would impede its due action.

1131. When a coffer-dam is constructed in a tide water, it should have an orifice through its side a little above low water mark; but which can be closed by a water-tight sluice or gate. By means of this, should the dam, at any time, become full of water by cessation of pumping or other cause, such water can be let off at low water, to the level of the bottom of the sluice; whereby all the pumping that would be necessary for this object is saved. Besides it is also desirable, whenever possible, to make the pumps deliver their water through this hole, instead of raising it over the top of the dam, for every foot in height that can be saved in delivering the water will be sensibly felt in the power and expense of working the pumps.

1132. As soon as the lowest course of stone-work has been got into its place and is fixed, the ground around it should be carefully rammed in, or puddled around, especially when the bottom yields much water; and that puddling will often require to be boarded over to keep it in its place; and the same caution is necessary with each succeeding course, until the work is brought up to a level with the general bed of the river; but as earth should be piled in the coffer-dam above this height, it might become an impediment to the flow of the river when the dam is moved away. As soon as the pier or other work is built above the height the water reaches to, all pumping is, of course, discontinued; and in tide waters, the men very frequently work what is called *tide-work*, instead of working constantly, *i. e.* the water is permitted to run out at the sluice, as the tide descends. At low water it is shut out, and the workmen begin their operations, and continue them until the water rises so high as to prevent their proceedings, and this will seldom happen until some hours after high water, even though no pump may be working, provided the dam and its bottom are tolerably water-tight.

1133. The coffer-dams are permitted to remain until the arches are finished, because their flat tops afford most convenient landing places for stones, timber, and other materials for building the superstructure, and scaffolding is erected upon them for that purpose. They are also highly useful as standing places while fixing the centring for the arches, and which frequently derive part of their support from them; and, lastly, they may become useful in the event of any settling or accident that may befall the piers from the weight or strain of the arch when built, which may render it necessary to examine, and, perhaps, to repair such piers, which may be laid dry for that purpose while the dams remain; but would be impossible, or very expensive after their removal. When, however, it is ascertained that the dams are quite done with, they are then removed, either by drawing the piles out of the earth, or by sawing them off as near as possible to the bottom of the water. The last is the most usual and certainly the best practice, because drawing piles frequently loosens the soil about the foundations and may do irreparable mischief. The only object of drawing piles is to save the timber, and remove obstructions to navigation, and when they are sawed, the tops are saved, while the bottoms, if drawn, will seldom or ever pay by their value for the labour and apparatus necessary for their extraction. All large fenders or distant piles may be drawn, and the best means of doing this is by the hydraulic jack, a machine constructed on the principle of the hydraulic press, and which was used for this purpose in a very satisfactory manner at the Waterloo Bridge of London.

1134. A great waste of large timber necessarily occurs in the construction of all large stone or other bridges, because the dams, fender piles, centring and lagging, temporary bridge scaffolding, &c. are all useless as soon as the bridge is finished. But such timber is generally large and not materially maimed, as all the works should be put together with screw-bolts. To meet this waste, a bargain is sometimes made with the contractor that he shall take away and allow for all spare timber and iron, at stated prices, on the conclusion of the work; or else it is usually sold by auction, being all convertible to similar work, or smaller purposes.

1135. When the bottom of the water is of hard and smooth rock into which piles cannot be driven, or where it is of sand, or such soil as would inevitably let water pass readily through it, coffer-dams cannot be constructed, or if made could not be kept dry by almost any pumping power. In which cases the caissoon mode of building must be adopted. A caissoon is a large chest of strong timber made water-tight, so that it will float like a boat, and the masonry or brick-work is carried on within it, until by its weight it sinks to the bottom. The bottom of the caissoon, of course, remains forever under the bottom of the pier, and becomes its foundation. It is a French contrivance, and is held in high estimation by the Engineers and Architects of that nation; but its chief advantage is the facility and accuracy with which a caisson can be built on dry land and be afterwards transported, piece meal, to the water, upon which it is put together. It is much cheaper than a coffer-dam, as the timber with which it is built is not only thinner but less in quantity, as it has but one wall instead of two. The labour of pile driving is saved, and from the greater perfection that can be given to the workmanship of the joints it may be made as water-tight as a boat or ship; and it therefore saves a great expense in pumping. The chief danger attending its use is that it does not afford the same examination and proof of the soundness and sufficiency of the earth foundation that is obtained in the coffer-dam, unless the diving bell is used for the Engineer and his assistants to descend to the bottom, nor can the bottom be cleared of its soft mud or be made level except by the use of a machine called a *dredging-machine*, which is built upon a large barge, and consists of a number of iron boxes attached to an endless chain, which is strained in a strong oblong timber frame fixed in a sloping direction to the side of the barge, with its lower end resting upon the bottom of the river. The edges of the iron boxes act like scrapers against the bottom of the river, and bring the soil up and discharge it into lighters moored to receive it, the boxes being kept in motion by a steam-engine upon the barge. These machines are now in common use upon all such navigable rivers as are found to fill up by deposits of sand or mud, and are found very efficacious for cutting straight channels for the water to run in, thus preserving the necessary depth for navigation.

1136. The earth foundation being rendered flat and smooth by this machine or otherwise, must be piled, if necessary, and the piles being cut off close to the ground, the foundation will be prepared for receiving the bottom of the caissoon, which is a strong grating of timber, floored over, and so contrived that the vertical sides which form it into a box, can be detached from it when necessary. The most considerable work, in which the caissoon mode of building has been followed, as the writer believes, is Westminster Bridge, London. The river at the site of the bridge is 1,223 feet wide, and the bridge, which consists of fifteen semicircular arches, supported on fourteen piers and two abutments, is built entirely of Portland freestone. Its width is forty-four feet; the centre arch is seventy-six feet span, and the others diminish four feet each as they approach the shores. It was built by M. Labelye, a French Architect and Engineer, between the years 1739 and 1750, and cost £389,000. From the nature of the ground in this place, as ascertained by several other bridges built near it, there could be no objection to constructing coffer-dams; but the caissoon was adopted in this case from a persuasion that it would be the cheapest mode of construction. This does not appear to have been proved in the sequel, for Blackfriars Bridge built near it, and which is 995 feet long, only cost £152,840; and the Vauxhall Bridge above it, and 860 feet long, formed of nine cast iron arches on stone piers, was finished for £150,000. These last two bridges were both built in coffer-dams, and although they are much shorter and have fewer arches, yet the difference in expense is not at all in the ratio of their length. Westminster Bridge also shows that the caissoon plan is not the best in point of security, and that the soil of the foundations should be more scrupulously examined than is possible without a coffer-dam, or some means of getting down to it in a nearly dry state; for after this bridge was finished one of the piers sunk so much deeper into the ground than the rest, that it was feared two arches would be lost, but they were saved by an ingenious device, applied in good time, and no symptoms of failure have since been observed.

1137. We cannot give a better account of the formation of caissoons, than by extracting that part of the history of the building of Westminster Bridge which relates to them, as published by M. Labelye himself. The caissoons had flat bottoms with six perpendicular sides, viz: two long ones, parallel to each other, and two shorter ones at each end, placed in an angular position to each other, so as to produce an irregular or elongated hexagon in plan. Their form was, therefore, nearly similar to the piers to be built in them, and parallel to their outsides. He says, "each caissoon consumed about 150 loads of fir timber. Their dimensions were nearly 80 feet from point to point, and 30 feet wide across between the sides. They were 10 feet deep and formed of timbers laid horizontally over each other, pinned with oak trenails, and framed together at all corners except the two salient angles, where they were secured by proper iron-work, which being unscrewed, would permit the sides of the caissoon, had it been found necessary, to divide into two parts. These sides were planked across the timbers, inside and outside, with 3 inch planks placed vertically. The thickness of the sides was 18 inches at the bottom, and 15 inches at top; and to strengthen them more effectually, every angle, except the two points, had three oak knee timbers, firmly secured by bolts. The sides were fastened to the bottom, or grating, by 28 pieces of timber called straps, 8 inches broad and 3 thick, on the outside, and 18 within, the lower ends of these straps being dovetailed to the outer curb of the grating, and were kept in their places by iron wedges, the purpose of which was that when the pier was built so high as to stand above low water mark, and the sides were no longer necescessary, by drawing these wedges, the sides would be released and they would rise by their own buoyancy, leaving the grating under the foundation of the pier."

"The pressure of the water upon the sides of the caissoon was resisted by a ground timber or ribbon, 14 inches wide and 7 inches thick, pinned down to the grating close to the sides; and the top of the sides was secured by a sufficient number of beams laid across, which being floored, served for the workmen to stand upon for hoisting the stones out of lighters, and lowering them into the caissoon. The caissoon was also provided with a sluice to admit the water.

1138. "The method of working was as follows: a pit being dug and levelled in the proper situation for the pier, of the same shape as the caissoon, but about 5 feet wider all round, the caissoon was floated to its position, a few of the lower courses of the pier were built in it, and it was then sunk once or twice to prove the level of the foundation. Then, being finally fixed, the masons worked in the usual method of tide-work. About two hours before low water the sluice of the caissoon, (kept open till then, lest the water flowing to the height of many more feet on the outside than on the inside should float the caissoon and its contained work out of its true place,) was shut down, and the water pumped low enough, without waiting for the low ebb of the tide, for the masons to proceed with their work. This continued until the tide had risen to a considerable height, the sluice was again opened, and the water admitted. And as the caissoon was purposely built but 16* feet high to save useless expense, the high tides flowed some feet above the sides, but without damage or inconvenience to the work. In this manner the work proceeded until the pier rose above the top of the caissoon, when the sides were floated away to serve at another pier."

1139. The other five large bridges of London, called the new London, the Southwark, Blackfriars, Waterloo, and Vauxhall, all built since Westminster Bridge by Messrs. R. Mylne, John Rennie, and James Walker, have been constructed by coffer-dams. These bridges were all constructed at a period when the closest attention was paid to science and perfection of workmanship, and this offers a conclusive argument that the coffer-dam mode of working is preferable to that by caissoons. An experiment was however made at the commencement of Vauxhall Bridge, before it was put into the hands of Mr. Walker, upon a new kind of

* This is an evident contradiction, as the sides are at first stated to be 10 feet high. It may be an error of the press, and that the height should be 10 feet or 16 feet in both places. Or perhaps 10 feet of strong walling was first constructed, and 6 feet more built upon it; but this does not appear from the description.

caissoon. The ground was levelled and prepared, and a grated and boarded bottom like that of other caissoons was prepared, and floated like a raft over the place where it was to be sunk. It was retained in that position by a number of straight piles driven at certain distances around it, but not touching it, so that the raft or bottom could float, and rise and fall with the tide, or pass to the bottom of the river without impediment. Instead of using wooden sides, to be afterwards detached, the external walling of the pier itself was built in brick-work laid in cement, but was kept of such thickness, by leaving the middle of the pier hollow, that the weight of these walls should be incapable of sinking the platform so deep in the water as to permit the water to flow over the tops of the walls which were carried up as the platform sank down. It was thought the platform could be lowered to the ground in this manner, and would exclude the water from the central cavity; or that what percolated might be pumped out; and as soon as the hollow pier was firmly seated on the ground, the inside was to be filled in with solid work. The expedient was ingenious, but it failed, because if solid work was filled in to produce strength the pier sunk too rapidly, and by keeping it hollow, to insure flotation, the lateral pressure of the water burst in the side walls, and the whole was reduced to a mass of ruins.

1140. The most difficult case that can occur for the construction of piers, is when the bottom of a deep river is of hard rock that defies the entrance of piles, and is at the same time so rough and irregular as to preclude the possibility of seating the bottom of a caissoon. In such places no bridge can be formed unless it consists of a single arch extending from one side of the river to the other; or the formation of the river is such that its course can be diverted from its channel at the place where the bridge is required, by the excavation of a new channel to draw off its water for a time, and reduce its depth to such an extent that the rocky bottom is made accessible, and that dams of timber and clay may be made from one rock to another, in order that the bottom where the bridge is to be built may be rendered dry enough for working upon; but this produces an expense so great that it is rarely resorted to.

Section II.—*On the Construction of Stone and Brick Arches.*

1141. Having constructed our side walls for the support of the arches intended to be built, or the necessary pillars or piers, in the event of being about to construct a bridge, or aqueduct, and having fixed the necessary centring for sustaining the arch in its progress of building between them according to the directions already given, we have next to take the arch itself under consideration, and in doing so shall divide the subject into four distinct heads. 1st. The form of the arch and names applied to the different parts that compose it. 2ndly. Its stability and pressure. 3dly. The materials of which it is to be formed; and 4thly. The methods of putting those materials together.

1142. The form and dimensions of the arch must of course have been decided upon before the centring, upon which it is to be built, could be constructed; consequently it may appear that this part of the subject should have been noticed in the chapter that describes centring. But inasmuch as a centre may be made of any form and dimensions, and as the stability, equilibrium and strength of the arch depends upon its own formation after the centring is withdrawn, this consideration belongs properly to the arch itself, and has accordingly been reserved for this chapter.

1143. The arch is comparatively a modern invention, for no trace of it is found in the architecture of ancient Egypt or Persia, or in the Druidical remains of England, and the lintel or long straight stone appears to be the only expedient resorted to for forming a top or covering to doors or windows over which it was intended to carry on the building. In the pyramids of Egypt long passages or galleries are found which travellers have described as arched; but they do not exhibit the regular or legitimate form of the arch, but are formed by what modern workmen called over-sailing or *corbling over*. The side walls are carried up perpendicularly to the necessary height, and then instead of continuing to build them in a vertical direction, each succeeding course of bricks or stones is made to project beyond the perpendicular on each side, taking care that the centres of gravity of each stone shall be within the perpendicular line of the face of the wall, so that these rows of stone may have no tendency to fall. The next courses above each over-sail in the same manner, which would have the effect of bringing the centre of gravity of the upper work so far before the walls that it would fall, but this may be prevented by carrying up solid work upon the tails of the projecting stones to such an extent that its weight shall be superior to that of the over-sailing work; the projecting stones being long enough to reach into such solid work. In this manner the two projecting masses of work may soon be made to meet and support each other, when there will be no danger of any of it falling, of which the existence of such passages in some of the oldest buildings in the world afford ample testimony. This mode of construction is shown by Fig. 262, which represents a transverse section of such a passage. In this mode of working the opening is covered by causing the covering-stones to *corble* over on one or both sides as desired, provided one perpendicular wall is higher than the other. Thus instead of taking the wall *b* as one of the sides, we may imagine the dotted line *c d* to represent a side, and then the covering will only extend over from the wall *a*, forming a kind of half arch.

This construction has however neither the form or principle of the arch, and the invention of this beautiful and useful auxiliary to the building art is generally given to the Greeks, as arches are met with in some of their most ancient temples. But even in these, the arch does not appear to have been introduced, as in the more recent constructions, for ornamental purposes, but merely for obtaining strength; for such arches were frequently hidden in the interior of walls, or used for covering drains. The pediments or triangular forms of the ends of the roofs of the Greeks may probably have led to, or suggested the construction of the arch, for the two sloping rafters of a roof leaning against each other will afford mutual support, provided their lower ends are prevented slipping outwards; and if two strong stones should be so disposed, they may be built upon and will bear a great load.

1144. The principle before adverted to in carpentry of introducing a horizontal stretching beam between the upper ends of two struts, may also be resorted to in stone-work, and then we shall have a figure approximating more closely to the form of an arch; and by supposing each of these stones to be divided and placed so as to present several sides of a polygon, an arch will be produced.

1145. The semicircular form of arch is the one that was adopted by the Greeks, and is likewise the form met with among the Saxon buildings in England, and this is also at the same time one of the strongest and most elegant forms for an arch. Its strength depends upon its springing or commencing upon a horizontal line which is its diameter; consequently a great part of the load acts perpendicularly on in the direction of gravitation; and therefore it has little tendency to spread, or exert lateral pressure against its abutments; and from the beauty of its form, it is the arch most frequently made use of by Architects for ornamental purposes. It has the same advantages when applied to bridges, but is not always admissible into their construction on account of the height it extends above its springing, which must always be equal to its radius; and this requires the roadway over the bridge to be so elevated, particularly in a bridge of a single arch, that the slopes, to reach the summit, may be inconveniently steep, unless the side banks of the river are considerably elevated above the water.

1146. In order to obviate this inconvenience an arch formed of a segment of a circle, or a semiellipse, may be adopted; and accordingly these forms are very frequently resorted to, and have their advantages and disadvantages. Both of them consume much less material to span the same opening than the semicircle; but the lateral pressure of the segment (which includes all arcs of circles containing less than 180°) is very great and increases rapidly as the angular measure of the length of the arc is diminished; consequently it requires buttresses or supports of greater strength and solidity to resist this force.

1147. The elliptic arch, on the contrary, from the flatness of its crown, becomes weak in that part, unless it is properly weighed down or loaded on its haunches, so as to prevent their rising, which is necessary to the descent of the crown. The production of this perfect equilibration of the parts of an elongated elliptic arch is therefore a matter of great importance and nicety.

The above mentioned are the forms of arch usually adopted in modern practice for constructing bridges and aqueducts, or for covering openings above which it may be desirable to build, and when strength and stability are required. But in architecture another variety of arch is frequently introduced on a small scale, such as covering over doors, windows, or other small openings, called the *scheme* or *skene arch*, and sometimes the camber arch. This partakes very little of the properties of the arch, and is used for ornament rather than strength, because an ordinary lintel composed of the same materials in one piece, and of the same dimensions as the arch, would, in most cases, exceed it in strength. This arch, as usually executed in bricks and stone, is shown by Fig. 263, in which it will be seen that its top and bottom deviate very little from right lines, though it is customary to give them a slight camber, or bending upwards, but so slight a one as to be scarcely perceptible to the eye; such, for example, as a rise or versed sine to the lower line of the arch of from half an inch to an inch in four feet.

The only circumstances therefore that entitle this construction to the name of an arch, is the wedge-like form of all the pieces that compose it. Bricks are sold under the denomination of *cutters* or *rubbers* for building these arches, because each brick has to be cut with a saw, or chopped by a small axe made for the purpose, and has its sides afterwards rubbed or ground upon a stone until it is made smooth, and accords perfectly with angular lines that have been previously set out upon a platform. Brick arches of this kind are, from their mode of construction, called *guaged* or *rubbed arches*, and they never extend through the entire thickness of a wall, but being used for ornament only, are confined to four inches in depth or the breadth of a single brick, and the hinder part of the wall consists of an ordinary rough arch, or a stone or timber lintel.

1148. The term, *rough arch,* when applied to brick-work, means an arch formed of bricks used in their ordinary form without being rubbed or cut into wedge-like forms; and is therefore opposed to the term cut or rubbed arch.

1149. Another form of arch has yet to be mentioned. It is generally, though improperly called the *Gothic arch,* notwithstanding it has been clearly determined that this arch was neither invented or used by the Goths in their constructions. It would, therefore, with greater propriety be called the pointed style of architecture, for this arch is formed by the intersection of portions of circles, and its crown is always an angular point more or less obtuse. The pointed style originated in Italy about the middle of the 12th century, and was soon afterwards introduced into France and Great Britain, where it arose so much in estimation, and was so frequently adopted, that some writers have improperly called it the old English style, a title that cannot belong to it, since it was imported from the continent of Europe. Its introduction, and the preference it obtained over the previously introduced Grecian style, appears to have given great offence to some of the early writers on architecture, and they applied the term Gothic to it, in derision and contempt, notwithstanding which this name has been very generally preserved and attached to it. Of late years the Gothic style has had many advocates and admirers among men of acknowledged taste, and a fashion has been established of imitating it in modern buildings. As its existence was long antecedent to the discovery and civilization of America, of course no original examples of it are met with in the United States, nor do I believe that a truly good and legitimate copy of this style of building has been constructed in this country, so as to impress the spectator with those ideas of beauty, grandeur, and magnificence which every one acknowledges to feel when he first enters the Abbey of Westminster or King Henry VIIth's Chapel, in London, the Minster at York, or the Cathedrals at Milan, Brussels, and many of the cities of Europe.

1150. On the first introduction of the pointed arch no particular rule appears to have been laid down for its formation, further than that it was always formed by the segments of two circles springing, or commencing from a horizontal line, and meeting at the crown or apex. Its several forms are shown in Fig. 179 of Plate VI. Thus the two arcs that form the arch are struck from the two centres *a* and *b*, each of which are placed the entire width of the window beyond its two sides, with radii *a c* and *b d* extending from the centres to the opposite side of the opening, and this gives the arch great height and an acute point, on which account this arch is frequently styled *lancet pointed.*

In the principal window the arcs are struck with radii *ef* and *fe* equal to the width of the opening, from centres *e* and *f*, in the vertical lines that form its sides; and if we wish to divide the opening of such windows into two or more compartments, as by the vertical lines, we must head or finish these with segments having the same radii as were used for striking the principal or external parts. Vertical divisions, like *g*, whether in their straight or curved parts are, in this style of building, called *mullions* or *munnions*, while all divisions that run horizontally are called *transoms.* Both these arches, as well as several other varieties of figure, were at first used indifferently or without rule; but towards the close of the 13th century the second form prevailed, and was generally used.

In the middle of the 15th century the pointed arch underwent a great change in England, and became much lowered, and its apex much more obtuse; for now instead of being formed by the meeting of two segments of circles, four were used; two being of large and two of small radii, as in the doorway of the figure which the French call the arch of four centres. Many examples of it occur in the Royal Palace of St. James, London, and in many other buildings of the same date. The radii of curvature differ so much in various arches of this form, that it is difficult to say that any precise rule was followed for their formation. In some examples the bottom of the door-ways appears to have been divided into four equal parts, and the large curves to be struck from the points *h h* each at one quarter of the width of the opening from its sides, the two other small segments that form the springings of the arch are from the points *i i*, which are perhaps arbitrary, though in some cases their radius appears to be one-eighth of the width of the opening. During the reign of Henry VIII. the pointed style ceased to be used in England, as a common or ordinary mode of building; consequently all erections of this kind, since that period, may be considered as occasional imitations, suggested by the taste or fancy of their constructors.

The above constitute all the forms of arch usually resorted to for the various purposes of building, but arches may be formed in a variety of other geometrical curves, such as the catenarian, cycloidal, parabolic, &c.

1151. Our next object must be to describe the mode of setting out arches of their real size, for the purpose of laying out and constructing the ribs of the centring. In small arches this is an easy operation; but in large ones, the radii of which are beyond the reach of compasses of any description, it is more difficult, or rather requires great nicety. A slight rope fixed in the centre of curvature, and of a length equal to the radius required, and having its opposite end carried round the portion of curve to be described, while it is kept evenly strained or stretched, suggests itself as the most convenient method of describing a portion of a large circle, because a pointed piece of chalk or steel scribing-point attached to the end that moves, will describe any portion of a circle upon a platform, and this is the process usually adopted, with the substitution only of a wire for a rope. A rope would not answer the purpose, because its elasticity would allow of too much expansion and contraction, which would be augmented by its twisting or untwisting, and its hygrometric property of changing length when damp or dry. Indeed there are many objections to a rope which it is needless to mention, while a black or soft drawn iron wire of about $\frac{1}{12}$th or $\frac{1}{10}$th of an inch in diameter obviates most of them. A black or soft iron wire is mentioned because hard wire, which is always polished, is more unmanageable. It has a springyness about it which renders it difficult to draw it straight without the exertion of great force, while a black or annealed wire is strong enough to resist such force as is necessary to keep it straight and stretched without extending in its length, and will yield to and preserve any form that is given to it. Wire is subject to expansion and contraction by heat and cold, but it will be in use so short a time that nothing need be apprehended on that score. With such a wire, therefore, a semicircle or an arc of a circle may be very correctly struck upon the platform before described, (1094,) by using due care and precaution. By the same wire a right line must first be laid down extending from the centre of curvature to the crown or summit of the intended arch, cutting or dividing the arch into two equal portions, and then another line must be drawn correctly at right angles to this first line, to represent the diameter (or chord, as the case may be) of the intended arch for the purpose of setting out the footings or abutments of the arch. That done, three parallel curves have to be described; the extreme or outermost one representing the under side of the arch as it is to appear when finished. The second one as much within the first as is equal to the thickness of the lagging proposed to be used, and which will of course represent the outside convex surface of the ribs of the centre, and the inner one will represent the concave or under side of such ribs.

1152. No difficulty will therefore arise in setting out any arch that is circular; but this is not so much the case with arches that are elliptical, and on this account the true ellipse is not often made use of, but other figures are resorted to which approach very nearly to the elliptical form, notwithstanding they are portions of circles. The manner of describing a true ellipse by a thread, the two ends of which are attached to the two foci, is well known, and this principle may be adopted and extended with considerable accuracy, to a large scale, by making use of a flexible iron wire instead of a thread, and attaching its two ends to the two points upon the platform which have been previously selected and fixed upon for the two foci.

There are several methods of producing curves that coincide so nearly with the form of the ellipse that they are frequently made use of in bridge building, and we give that generally used by artists. Draw a horizontal line *m m*, Fig. 264, to represent the transverse diameter of the oval and springing line of the arch, and upon the centre of this raise the perpendicular *n o p*. Take off the extent of the intended rise of the arch on a scale of equal parts, and transfer it into its proper place upon the perpendicular line, as from *o* to *n*. Then with radius *o n* from *o* as a centre, describe the semicircle *q n r*, and use its diameter *q r* as a base upon which to form the equilateral triangle *q r p;* prolong the two sides that extend to the horizontal line indefinitely as from *r* to *t* and *q* to *s*, and the three angles of the equilateral triangle will be the three centres from which to describe the three arcs of circles of 60° each. Consequently with radius *p n*, from centre *p*, describe the arc *s n t*, making it extend from one prolonged side of the triangle *p s* to the other *p t*. Then from *r* and *q* as centres, and with radii equal to the distance between those points, and the points where the last mentioned arc cuts the prolonged sides of the triangle, as *q s* and *r t*, describe the two arcs *s m* and *t m*, and the curve will be complete.

1153. In the last example the oval is made exterior to or circumscribing the semicircle; but by the same chain of reasoning it may be inscribed within it, but if this is desired, the radius of the semicircle must be made equal to the semitransverse, instead of the semiconjugate diameter, as follows: Fig. 265, first draw a horizontal line *v u* equal in length to the semitransverse diameter of the oval or span of the arch, and with that distance as radius describe the quadrant of a circle *w x y u* from centre *v*. Divide this arc into three equal parts as *w x y* and *u*, and join *x v* by a right line in order to determine the position of the next line *y z*, which must be drawn from point *y* parallel to *x v* and be prolonged until it intersects the perpendicular *w v* in the point *z*, and then will the points *a* and *z* be the two centres from which to describe the required oval, beginning with *a* as a centre and with radius *a u* describe the small arc *u b*. This will give a fixed point *b* in the line *z y*, and from *b* to *z* will be the radius of the large curve to be struck from centre *z*. In this example only half the figure is given, and only half the arch described; but the other half may be completed by repeating the same operations on the left hand side of the vertical line *w v z*.

In these examples the curves produced approach very nearly to the true ellipse, but are all a little without or are circumscribed upon that figure and only touch or coincide with it at three points, viz: the two springings, and the top or crown of the arch.

1154. Another expedient often resorted to for producing an oval of less eccentricity than the above is as follows, Fig. 266. Draw a right line *c d*, equal in length to the transverse diameter of the curve desired, and divide this line into three equal parts, as at the points *e* and *f*, and from each of these points as centres, in succession draw the two circles *c h f g* and *e i d g*, with same radius *f d* equal one-third of the length of the line and they will intersect each other at point *g*, from which draw two right lines or diameters *g h*, *g i*. Then with radius equal one of these diameters *g h*, from centre *g* describe the arc *h i* joining it to the previously existing arcs *c h* and *i d*, and the arch or half oval will be complete.

1155. We will now describe a more perfect process invented by Professor Robison, which coincides with the true ellipse in eight points, and furnishes the artist with the means of drawing an infinite variety of ovals. See Fig. 267. Draw a right line *j k* to represent the transverse axis or diameter of the proposed oval, and upon the centre of it erect the perpendicular *l m* for the conjugate axis crossing *j k* in *p* which is the centre of the oval. Then fix on the rise or semiconjugate diameter you wish to give the oval, and having measured this on a scale of equal parts, set off that distance on the perpendicular, as from *p* to *n*, and likewise transfer it from *p* to *q* on the horizontal line. Then draw a circle *j n q* passing through the three given points *j n q* (74) and now if from any point *r* short of *j* in the arc *j r n* be drawn a chord *r n* and if a line *r*, *s*, *m* be drawn, making the angle *n r s* equal to *r n p*, and meeting the two axes or diameters in the points *s* and *m*. Then *s* and *m* will be the centres of two circles, which will form one quarter *j r n* of an oval, as dotted in the figure; and being thus in possession of the two necessary radii, the other half of the curve may be obtained by setting off the distance *p s* towards *k* in order to determine the centre of the second small arc.

1156. Having thus shewn how the forms of arch most frequently made use of may be obtained, we shall in the next place examine the means of obtaining another form which is frequently referred to by writers, though seldom met with in practice.

Towards the close of the last century, the subject of the construction of arches engaged the attention of some of the most emminent mathematicians of Europe, and Dr. Hooke affirmed that the festoon or figure which a perfectly flexible chain or rope of equal weight throughout would dispose itself into, when suspended by its two extreme ends, would, if inverted, give the proper form for arches formed of parts which touched each other in the same points, because the forces with which they would mutually press on each other in this last case, would be exactly equal and opposite to the forces with which they pull each other in the case of suspension.

1157. This principle is strictly just, and may be extended to every case that can occur; but it produces an equilibrium that will admit of no kind of disturbance. If the chain is not of equal weight in every part or link, it will produce a curve that will not be similar and equally strong on its two sides. And if the chain is of equal weight throughout, and in a state of perfect equilibrium with itself in the first instance, so as to produce a perfect curve, and it is afterwards purposely loaded with different quantities of weight in different parts, the curve will be varied in its form, although it will take up a new state of equilibrium; for an effect of composition and resolution of forces will occur, and as each link of the chain may be considered as a pivot about which its parts can turn, so the form and symmetry of the curve will be destroyed, and it will become irregular, notwithstanding that it remains in a state of equilibrium with respect to itself. As, however, bridges are unequally pressed down by the earth placed upon them to form the roadway, as well as by the various moving loads that pass over them, of course the curve cannot be equally loaded in all places; and it is, therefore, improper for the formation of an arch unless some means are resorted to for rendering the figure immutable. Now, if we suppose that the chain instead of being made of moveable links should be composed of a series of blocks strung upon a cord, and so shaped that the sides which come into contact with each other shall be flat planes bisecting the angle that the cord would make at each joint, in that case we should produce an arch or curve of some stability, or one that would bear a little change of form without tumbling down, for the equilibrium of the original festoon obtained only at the points of contact, where the pressures were perpendicular to the touching surfaces which may be considered as infinitely small. Therefore, if the curve or sustaining line still passes through the touching surfaces perpendicularly, and we conceive those surfaces extended, the conditions that are required for equilibrium still obtain with this difference that we obtain an approximation to the stability of a body resting on a horizontal plane. If the perpendicular through the centre of gravity falls within the base of the body, it will not only stand, but will require some force to push it over.

1158. These conclusions obviously deducible from the principles of the festoon, shew that the longer the *meeting joints* are, and the greater will be the stability of the arch, or that it will require a greater force to break it down. Therefore it is of the greatest importance to have the arch stones as long as economy will permit. This principle appears to have been known to the older builders, who, with a view to obtain this auxiliary of strength without a profuse waste of material, made some of the rings of stone that composed their arches to project from six inches to a foot below the general face of the work, in the form of ribs, which are frequently found in gothic arches, apparently as if introduced for the sake of ornament alone, but which were no doubt meant to assist in supporting the work from the stiffness and stability they give to it.

1159. Such being the general principles upon which the form of the festoon arch depends, we will now proceed to explain how this curve, which is called *the catenarian arch*, may be obtained, and will remain in equilibrio when the weight of a road way is placed upon it.

Suppose it should be required to ascertain the form of an arch of this description, which shall have the span A B, and height F S, Fig. 268, and which shall have a road over it, the height and slopes of which shall correspond with the curved line C D E above it. Let the whole figure A C D E B be inverted so as to form a figure A *c d e* B. Let a chain of small brass wire, or any material of uniform weight and thickness, be suspended from the two points A and B, and let it be of such a length that its lowest point shall hang at, or rather below *f*, corresponding to F. Divide A B into any number of equal parts 1, 2, 3, 4, &c., and draw vertical lines cutting the chain in the corresponding points 1, 2, 3, 4, &c. Now take pieces of another chain of the same size, and hang them on at the points 1, 2, 3, &c. of the chain A *f* B, and this will alter the form of the curve. Cut or trim these pieces of chain till their lower ends all coincide with the inverted road-way *c d e*. The greater lengths that are hung near the ends A and B, will pull down these points of the chain, and cause the middle point *f* (which is less loaded) to rise a little and will bring it near its proper height.

It is plain that this process will produce an arch that is in a perfect state of equilibration in all its parts, under a load of homogeneous matter placed upon it, because the length of chain being various, will be in proportion to the weight of soil at corresponding positions, but some further considerations are necessary for making it exactly suit our purpose. It is an *arch of equilibration* for a bridge that is so loaded that the weight of the arch stones is to the weight of the matter with which the haunches and crown are loaded, as the weight of the chain A *f* B is to the sum of the weights of all the small pieces of chain hung to it, or very nearly so. But this proportion is not known beforehand; we must therefore proceed in the following manner: Adapt to the curve produced in this way, a thickness of arch stones as great as may be thought sufficient to insure stability; then compute the weight of such arch stones, and the weight of the earth and gravel with which the haunches are to be filled up and the roadway made; and if the proportion of these two weights be the same with the proportion of the weight of chain, we may rest satisfied with the curve now found; but if different, we must calculate how much must be added equally to, or taken from each appended piece of chain, in order to make the two proportions equal. Having altered the appended pieces accordingly, we shall get a new curve, which may perhaps require a little trimming of the bits of chain to make them fit the roadway, and the curve so obtained will be infinitely near to the curve required.

1160. Professor Robison tried this method experimentally on a large scale, the arch having a span or opening of 60 feet, and a rise or height of 21 feet, the arch stones of which were only 2 feet 9 inches long, and the arch loaded with rubble stone and gravel. A previous computation was made on the supposition that the arch was to be nearly elliptical. The distance between the points 1, 2, 3, &c. were adjusted so as to determine the proportion of the weights of chain agreeable to the supposition. The curve differed considerably from an ellipse, making considerable angles with the verticals at the spring of the arch. The real proportion of the weights of chain, when all was trimmed so as to suit the roadway, was very different from what was expected. It was adjusted, and this made very little change in the curve, and it was found that it would not have changed it two inches in any part of the real arch. When the process was completed, he constructed the same curve mathematically, and found that it did not differ sensibly from the mechanical construction. This result was highly satisfactory, since it showed that the first curve formed by about two hours labour, on a supposition considerably different from the truth, would have been sufficiently exact for the purpose, since it did not vary in any place three inches from the accurate curve, and was, therefore, far within the joints of the intended arch stones. Therefore this process which any intelligent workman, though ignorant of mathematical science may go through with little trouble, will give a very proper form for an arch subject to any conditions.

1161. The chief defect of the curve found in this way is a want of elegance, because it does not spring at right angles to the horizontal line, but this is the case with all curves of equilibration, as well as with segments of circles, and is of no consequence as to its strength, because in the immediate vicinity of the piers or abutments any form we please may be given to the curve, because the masonry is always solid in these places, and such a deviation from the curve of equilibration at its springings as will add to its strength by making it rise perpendicularly is even proper. The construction of that curve supposes that the pressure on every part of the arch is vertical; but gravel earth and rubbish always exert a degree of lateral pressure in the act of settling and retain it afterwards, and this will require a little more curvature at the haunches of the arch to balance it. What the extent of this lateral pressure may be, cannot be deduced with confidence from any experiments yet made, and to provide against it, it would perhaps be more proper to divide the chain itself into the equal parts 1 2 3, &c., instead of the horizontal line A B, for then the curve would approach nearer to its proper form.

1162. The Festoon or catenarian arch has not been much used, which is likewise the case with the Parabola, the Hyperbola and Cycloidal curves, as none of these appear to offer any advantages greater than what can be obtained from the circle or ellipse, and accordingly the semicircle, or lesser segment of a circle, and the semiellipse are the forms constantly used in bridge building, not only because they are more easily set out and built, and are liable to fewer errors of construction, but because it is thought they produce a more pleasing or beautiful appearance. The choice of the curve must be in a great measure governed by the formation and nature of the place in which the bridge has to be built; keeping in mind, at the same time, that the semicircular arch is, under most circumstances, the strongest, and produces the least expansion or lateral pressure on its foundations. If a river runs in a deep valley, below the level of the adjacent country, and the roads or approaches to an intended bridge are considerably above the water, then of course a semicircular arch, or even such an arch elevated upon piers of such height as will prevent any depression in the road at the bridge, would be preferred. But if the country is level and very little elevated above the surface of the river, a semicircle of wide span would produce a considerable hill to be surmounted; to obviate which, an elliptic arch, or a segment of small rise must be adopted; or the breadth of the river must be divided into a number of arches, which renders the construction more expensive, and may often produce an inconvenient obstacle to the flowing of the water. These considerations must be again influenced by the nature of the river. Should it be navigable, small arches are objectionable, and, if its vessels are masted, a high or semicircular arch may become necessary, notwithstanding the elevation of the road would render it objectionable. Again, if the river is subject to great and rapid floods or freshets, flat or low arches are very objectionable, unless they are so elevated upon piers as to place them above the greatest height the water can reach; for few accidents occur to bridges from the action of the stream against their piers, but they are washed away by the water rising so high that it cannot find vent through the arches, and therefore exerts its force in lateral pressure against the bridge itself. The elliptic arch not only has the advantage of admitting a low and level road, but a more important one, which is the small quantity of material it requires for its construction, the difference in quantity of masonry being as the radius of the circular arch is to the semiconjugate diameter of the ellipse which can be inscribed in it. Thus, for example, suppose an arch of 72 feet span is required. To make this a semicircle its radius and consequent height must be 36 feet. But if an elliptic arch rising 24 feet should be selected, 24 feet the semiconjugate diameter, is but two-thirds of 36 feet, consequently not only one-third of the cost of materials and labour will be saved by adopting such an arch, but the piers or abutments will be relieved from the same proportion of weight.

1163. In addition to the local circumstances above mentioned, which will influence the form of arch, its stability and pressure must also be taken into consideration, and as the several component parts of an arch and bridge have technical names appropriated to them, these must be previously explained, together with a few principles of the construction of arches that have not yet been referred to.

One of the first and most essential rules of construction is, that when an arch is composed of a number of separate blocks of stone or other material placed in contact with each other, the joints must be as flat and true as possible to insure entire and perfect contact; and all those joints must be perpendicular to the curve, (or to tangents to it at their point of contact,) which forms the inside of the arch. Of course, therefore, these joints must diverge or open as they recede from the water, consequently all the blocks that form an arch must be wedge-shaped, and all such blocks are called *voussoirs*. The under side of every arch is called its *intrados* or *soffit;* the former word being used when large arches, like those of bridges, are spoken of, and the latter for small arches, such as usually occur in buildings. The outside of an arch is in like manner called its *extrados* or *back*. Another line frequently parallel to this last is called the *archivolt.* It is the curve formed by the upper sides of the voussoirs or arch stones, and is parallel to the intrados when all the voussoirs are of equal length, otherwise it cannot be so. By the archivolt is also sometimes understood the whole of the voussoirs. The two lowest extremities of an arch are called its *springings* or *springing lines,* and these, like the voussoir joints must lie in directions perpendicular to the intrados, consequently all semicircular or elliptic arches will spring from horizontal surfaces, being parts of the diameter of the arch or ellipse. All segments of circles will spring from lines that are parts of radii of such arches, and all elliptic segments or other curves will spring from lines varying in their horizontal angles according to the extent of the segment taken, because such lines must be perpendicular to the part of the curve they intersect.

1164. In order to give an arch a firm seat or foundation upon its pier or abutment, they must therefore be finished at their tops in accordance with the directions of the springing lines. Piers for semicircles or semiellipses therefore finish with flat tops of large stone called *cushions,* while those for every other kind of arch must terminate in stones cut to the angles of the springing lines, and such stones, which are always selected of the largest and best kinds, when so finished are called *skew backs.* This, in some measure, influences the width of the piers, because when two arches spring from the same pier, a double skew back will be necessary, or one presenting an equal angle to each arch. We may consider such double skew back as composed of two right angles, having one perpendicular side (over the centre of the pier) common to them both; the flat top of the pier will then be their common or continued base, and the sloping faces will be their hypotheneuses. Now the sloping face or hypotheneuse must always be equal to the height of the voussoir that is to lie upon it, which determines the length of one side of the triangle, and as that is right angled, of course the height of the perpendicular and the base are also determined; and twice the length of the base will be the least width for a pier that two such arches can spring from, even when the arches are in contact with each other; but when they are distant, the quantity of their distance must be added to the width. So likewise a semiarch requires the width of its pier to be equal to twice the length of the voussoirs used to form the arch. The central voussoir of every arch is called its *key stone,* for reasons that will hereafter appear, and this stone is generally larger than the others that compose the arch. The angular surface between one arch and another is called a *spandrell.* The centre of an arch is called its *crown,* and a certain distance up each side, from the springing lines, its *haunches*, but their extent has never been accurately defined. The face of an arch is the termination that is presented at the sides of a bridge.

1165. The stability, strength, and pressure of arches have been differently treated and considered by different builders, authors, and mathematicians, and no subject has perhaps engaged more particular attention than this has done. Theorists have, in general, taken up and supported the arch of equilibration, as being superior to all others in its qualifications. But practical men, without denying, or attempting to dispute the truth and accuracy of the deductions that have been made, rest their security more upon positive strength than on nicety of balance or equilibration, and in so doing they have the sanction of some of the most able theorists and mathematicians. By an arch of equilibration is meant an arch composed of blocks of stone or any other materials, the weights and lateral pressures of which have been so exactly determined and calculated, that if they should be put together with smooth or actually polished joints, without any mortar or cementing matter, the arch would have no tendency to fall or even change its figure, and indeed could not do so without some extraneous force, because the pressures of all the blocks, (produced by the joint action of their weight, and lateral thrust,) are in a state of perfect equality or equilibration in every part of the arch. There can be no doubt but that such a state of universal equilibrium is highly desirable in every arch, and therefore ought to be sought for, as far as possible; but its perfect existence is almost incompatible with the nature of materials, as well as workmanship, and may sometimes interfere with the beauty of the design, or object of the designer. Thus the voussoirs that are shown surrounding the centring in Fig. 253, are all of one size; consequently this cannot be an arch of equilibration, for the five stones in the centre will have a tendency to fall, only equal to their weight, having nothing else to support, and in their tendency to descend, will produce lateral or thrusting pressure, which will be transferred to the lower stones on each side of them. The five next lower stones on each side have very little more to support them than the stones in the crown; they will therefore have an equal tendency to descend, augmented by the weight of the stones in the crown which they support, together with the lateral pressure of those stones; consequently the lower stones are more loaded than the upper ones, and will be acted upon by a greater force to throw them out of their positions. To make such an arch an arch of equilibration we must therefore lighten and diminish the size of the stones in the crown, while we augment the size and surfaces of those below. For in arches, the pressure (compounded of the weight of the materials, and their tendency to thrust or extension) augments from near the crown towards the springings; consequently the quantity and weight of material must increase in a similar ratio. In the new London bridge, part of which is shown by Fig. 255, something like this is attempted, and the voussoirs over the crown are shorter than those lower down, and it occurs in many other bridges, particularly in the magnificent cast iron arches of the Southwark Bridge, the centre arch of which spans 240 feet, and is therefore the largest arch in the world; at the same time that it is one of the flattest, since this enormous arch has a rise or versed sine of only 24 feet. The two side arches span 210 feet each, with a rise of 18 feet, and the main rib of cast iron, which forms the lowest member of these arches, is 6 feet high in the crown and increases to the width of 8 feet at the springing lines.

1166. The equilibrium of the various parts of an arch would be a matter of first rate importance, provided a large arch had to stand quite alone and independent of every other object, and was not subject to any change in the quantity or direction of the load pressing upon it; and if this was the case, there could not perhaps be a better method of determining the form of an arch and the roadway to pass over it, than that already given with the chain and appended pieces. (1159.) There is, however, a want of accordance between the exact vertical direction in which the pieces of appended chain will pull upon the drooping chain, and that in which the earth or other materials necessary to form the roadway press upon an arch. For earth and other materials, particularly if rain soaks into them, will not only press perpendicularly, but will exert a kind of hydrostatic or lateral pressure; and again, the load that comes upon a bridge is not uniformly diffused over the whole arch at once, but is progressive. It commences its operation by pressing down one of the haunches, while there is nothing to counterbalance it on the other side, it then comes over the crown and goes over the next haunch; hence the pieces of appended chain which are constant and equable in their strain, may nearly represent the action of the earth upon the arch, but are by no means a fair representation of the action of a moving load, which we are now supposing to be so great as to be capable of producing a sensible action upon the arch.

1167. The student will derive important information as to the nature of these pressures, and what takes place in an arch, as well as in the means of preserving its figure, by the simple expedient of bending a piece of cane or other flexible wood of 18 or 20 inches long, into the form of a semicircular arch, and securing it in that position by inserting its two ends into holes bored in a piece of flat board to receive them. If we press on one side of the arch so formed, the crown will descend, and the opposite haunch will swell or extend outwards, thus rendering the stick an irregular curve. Again, if we press upon the crown that will sink, but in doing so will extend or swell out both the haunches at once, so as to give the cane something like a semi-elliptic form, and it will be found that a very small force exerted, will produce these effects, thus showing that the cane arch can only sustain a small load that presses unequally upon it. Having tried this experiment, bore a few holes through the board in the line of the cane and near the centre of the arch, and having passed some strings through them, tye one string to the crown, and let the others radiate and be tied to the cane at equal distances on each side of the crown or centre, and let all the strings be then strained and tightly fixed in their holes in the board in such manner that the semicircular form of the cane may not be disturbed, and it will be found that the strength of the arch will be much increased; for now if we bear upon its crown the haunches cannot swell out, being restrained or kept in their positions by the strings; and in like manner if the pressure is made over one haunch, the other cannot rise for the same reason. This points out very clearly what must be done to give stability to a real arch. In the first place the ring or hollow half cylinder of masonry that forms the arch, must be of such strength and thickness as will prevent its crushing by the load we require to put upon it, and then that arch must be so tied down as to prevent the possibility of any casual load that may come upon it distorting or disturbing its figure.

This tying down cannot be accomplished by strings, as in the model, nor even by chains or iron bars, because they would impede the navigation, and there would be no effectual way of securing their bottoms. But weights applied upon the top of the arch, will produce exactly the same effect as strings or ties applied beneath it, and thus the very earth or other solid material that is applied to cover the arch, and to fill in the spaces or spandrells between one arch and another instead of oppressing, gives strength to the arch and enables it to bear unequal loads; for the heaviest wagon that can arrive on the crown of an arch, will weigh nothing in comparison to the weight of the quantity of materials that has been filled in between the spandrells; and as all this quantity of earth has to be raised before the two haunches can possibly expand, so of course, as that cannot be effected the arch will be stable.

1168. This mode of proceeding, though it may appear sound in principle, is not so, and could not be applied to practice without very nice adjustment, or some modification. Because notwithstanding loading the haunches will effectually prevent them swelling out in obedience to the power of a weight applied at the crown, still from the very form of the arch very little or no soil will be necessary upon its crown, while a very large quantity will be required over the haunches to fill in the spandrells and form a level road. The pressure of the earth will not therefore imitate the action of the strings in our model, for while we have two immense loads at the sides over the haunches, the crown or central tie is deficient, and we have nothing to counteract them; consequently the crown of the arch will rise in obedience to their pressure, by which the symmetry of the curve will be destroyed, and with it probably the whole arch. One of two things must therefore be done. Either the crown itself must be loaded until it is capable of balancing the pressure of the haunches; or, if the crown is not weighted, then the haunches must also be kept free from that quantity of load which would be prejudicial to the crown. An instance of the necessity of attending to this species of equilibrium occurred in Wales in the building of a bridge over the river Taff near Llantrissent, in Glamorganshire, known in the country by the name of the *Pont y ty Prydd,* and which is considered one of the most extraordinary bridges in Great Britain, while it is interesting on account of the history of its construction. The Taff, though by no means a wide river, runs between two rocks, and is in such a mountainous district that it is subject to great and rapid floods, and the first stone bridge erected across it consisted of three light and elegant arches, built in the valley by a Mr. William Edwards, an uneducated mason of the country, and was finished in 1746. It was much admired and gave general satisfaction, and Edwards was himself so satisfied with the stability of his work that he gave security for its standing seven years without needing repair; but in about two years and a half after its erection, a very heavy flood came on, bringing many trees, branches and other objects down the stream, and as these were stopped by the bridge, they formed a dam which impeded the water, and this rose to such a head as to wash the whole bridge away. Of course Edwards was compelled to erect another bridge; and he proceeded on his duty with all possible speed. Being determined on this occasion to make his work secure, he adopted a single arch, which was a segment of a circle the diameter of which was 170 feet. The span or chord of the arch was 140 feet, and in order to place it completely out of the reach and danger of all floods, he raised it 35 feet above the water. The rocky sides gave him excellent foundations or abutments for such an arch, and he had no difficulty in carrying it over from one rock to the other. All that now remained to be done was building the side walls and filling in soil over the haunches to procure a level road. This work proceeded and was nearly finished, when the soil placed upon the haunches, without an equivalent balance on the crown, proved too much for them, for they sunk, pushing the crown upwards so as to force the stones out of their positions, and in 1751, just when this second bridge was on the eve of completion, it was thus wholly precipitated into the water below.

Such a succession of misfortune would have disheartened most men, but it had not that effect on Edwards. He saw the error of his proceeding, and was fully aware of the cause of his bridge failing; and believing that there was no better and effectual way of making a bridge than the one he had attempted, he began his work again, and rebuilt an arch similar in every respect to the one that had fallen down; but instead of overloading the haunches as he had done before, the happy idea of introducing hollow brick tubes or culverts across his bridge occurred to him, and he accordingly built three of these in each spandrell, making the lowest nine feet, the middle ones six feet, and the inner ones three feet in diameter. These ran horizontally from one side of the bridge to the other, and formed six cylindrical holes or passages through it. Earth was of course rammed into the spandrells, under, around and above these culverts for the purpose of supporting them, and raising the road to its proper level; but the smaller weight of earth required in consequence of the span occupied by the hollow tubes or culverts, completely answered the purpose, and this third bridge, which was finished in 1755, is still standing a monument of the perseverance and ingenuity of its constructor, and is universally admired for its stability combined with its lofty, light, and elegant appearance.

1169. We perceive, therefore, that it would not be safe to construct the arches of a bridge of equal sized voussoirs, or even such a one as would be in a state of equilibrium with respect to itself; and then to fill in the spandrells or spaces between that and other arches with soil thrown in at random; for the quantity of soil necessary over the commencement and haunches of the arch is always so much greater than what can be placed upon the crown, that the greater load would overpower the lesser one, and by protruding the crown would cause the destruction of the arch. Some mode of securing the arch must therefore be sought, and such a one will be obtained by giving its two lower sides longer and more extended voussoirs; an expedient that brings the arch nearer to one of equilibration, and which may or may not interfere with the appearance of the external design. If it is desired that the appearance of the arch should be such as to present voussoirs of equal size, it will only be necessary to cut the end or face voussoirs that present themselves to view accordingly, and the side walls may be built upon them, notwithstanding the hidden voussoirs within the arch (and which bear more of the load than the exterior ones,) may have any length we choose to give them. In Westminster Bridge, London, every alternate voussoir has the appearance of being twice as deep or high as the intermediate ones; but it must not, on this account, be supposed that the bridge is so built. It is merely an appearance that is produced by cutting the external or facing stones in such manner as to produce this effect for architectural beauty alone. In Blackfriar's bridge the voussoirs are, with a similar object, made to appear all of one size, or the extrados and intrados are parallel, and each alternate stone seems entire and the intermediate ones in two pieces with a rusticated joint between them, while in fact the voussoirs next the key-stone of the centre arch are each six feet seven inches long, and each stone in succession gets longer as they proceed to the springing stones, which are between eight and nine feet long. This is the true principle for constructing a large arch; for if every voussoir as it recedes from the centre is made longer than the preceding one, the arch becomes so strong at its haunches that no load of earth that is necessarily placed upon it can derange it, besides which the spaces to be filled up with soil are greatly diminished by the stone that gives strength to the arch. Neither is it necessary that these large voussoirs should be all in one piece, for if that was the case, there would be difficulty in getting large stones in sufficient quantity. Large stones are always selected for the ring or face of the arch, as well as for its intrados; but within the arch, smaller stones may be used, provided they are as hard and incompressible as the rest, and that their points are made to radiate and coincide exactly with the directions of the joints of the larger stones. In Westminster bridge this principle was carried to such an extent that the voussoirs of the arches were carried out and extended until they met or intersected the perpendicular solid masonry of the piers, as shown at Fig. 269, so that no change of form could take place without first producing a compression of the pier; and in Blackfriars bridge, Mr. Mylne very ingeniously connected all the arches together from one end of the bridge to the other by causing a part of the weight of every pair of adjacent arches to rest upon an inverted arch that was constructed in the piers to receive them.

1170. It thus appears that the precise equilibrium of the arch itself, the necessity of which has been so strongly insisted on, and so largely written upon by several mathematicians of the highest eminence, is of little practical importance. The two authors now most relied upon on these subjects, are the late Professors Robison of Edinburgh, and Hutton of Woolwich. The last being author of the well known course of mathematics. The former wrote a new and original treatise of considerable length on the mathematical principles of arches and domes, for the supplement to the third edition of the Encyclopedia Britannica, and which has been embodied in the subsequent editions of that work; and the latter had great practical experience on the subject, combined with his mathematic knowledge, having been first brought into public notice by a report and scientific investigation that he made and published upon the cause of the failure and falling of the bridge at Newcastle, upon the river Tyne, in 1771, and having been afterwards constantly called upon professionally for advice in most of the difficult cases of bridge construction in England, for nearly half a century after that period. And he has, moreover, published a treatise on the principles of bridges which is justly admired and often consulted. Neither of these authors pay any regard to the principle of equilibrium, and Robison after describing the nature of the equilibrium of arches even goes so far as to say,* "Thus much will serve we hope to give the reader a clear notion of this celebrated theory of the equilibrium of arches, one of the most delicate and important applications of mathematical science. Volumes have been written on the subject, and it still occupies the attention of mechanicians. But we beg leave to say, with great deference to the eminent persons who have prosecuted this theory, that their speculations have been of little service, and are little attended to by the practitioner. Nay, we may add, that Sir Christopher Wren, perhaps the most accomplished architect that Europe has seen, seemed to have thought it of little value, since among the fragments of his writings that have been preserved, he takes no notice of it, and considers the balance of arches in quite another way." A few lines afterwards Professor Robison observes, "The general facts which occur in old arches are highly instructive, and deserve the most careful attention of the Engineer; for it is in this state that their defects, and the process of nature in their destruction are most distinctly seen. We venture to affirm, that a very great majority of these facts are irreconcileable to the theory."

1171. The principle adopted by Robison and Hutton, for determining the strength and pressure of arches, is the same as that applied to determining the lateral thrust of beams in carpentry

* Robison's System of Mechanical Philosophy, Vol. I., p. 634.

(957) in which each stone is supposed to possess sufficient cohesion or strength to enable it to preserve its form or figure against the action of its own weight, and any lateral pressures to which it may become subject, and a right line supposed to pass through each stone in the direction in which the pressure is exerted, may be called *the axis of pressure.* Such lines will be straight through each perpendicular stone, but will make angles with each other in adjacent stones, and of course such lines can be made use of as two sides of a parallelogram of forces for determining the resultant of their oblique action upon each other; consequently, if the cohesive strength of the stone, its weight, and that of the earth or other load to be put upon it, and the directions of the axis of pressure are known, these data will be sufficient for determining the thickness that must be given to an arch to enable it to bear a given load.

1172. It thus appears that there are three distinct ways in which the formation of arches may be viewed and considered, and these are summed up in nearly the following terms in the general scholium with which Dr. Hutton concludes the second section of his excellent little treatise on bridges. The first method is that which is derived from the consideration of the equilibrium produced by the mutual thrusts, weights and pressures of the arch stones, supposing them prevented from sliding on each other at the oblique joints, either by their roughness and friction, or by the cement joggles, dowells, or iron clamps let into every adjacent pair of stones, which give the arch the effect of one compacted frame, pressed on vertically by the weight of the superincumbent walls and load above it, and which seems to be the true and genuine way of considering the action of a load upon an arch.

The second method is the arch of perfect equilibration or balanced arch, computed on the supposition that the arch stones have their butting surfaces perfectly smooth, and at liberty to slide on each other. But Dr. Hutton observes this is little insisted on, because it is founded on suppositions which cannot exist in nature or art, and which consequently can never occur in the real construction of an arch.

The third method has for its principle the catenarian curve or festoon reversed, which is a strictly just and useful principle. This idea, when first proposed by Dr. Hooke, and afterwards treated upon by De la Hire in his *Traité de Mecanique,* went no further than balancing a single or thin arch formed by voussoirs only, without any wall to fill up the flanks, and was therefore hardly applicable to practical purposes. But this same principle as extended by Professor Robison, by appending chains and making their weight proportionate to the load as before described (1159–60) is so just and so easy in its practical operation, as to have rendered it useful and available. The equilibrium that any theory establishes, must, however, always be of a delicate nature, because it supposes the parts to touch only in single points, and may, therefore, be called a tottering equilibrium, since any other weight or force added at any one part, would press the arch out of its true balanced form, by shifting the points of contact. This is, however, prevented by giving considerable length to the voussoirs, by which stability is insured, because the altered figure will then find new points to bear upon, and hence, the longer the butting joints of the arch stones are, and the more stable and secure the whole fabric will be.

1173. As to the materials to be selected for building arches little can be said in addition to what has been before observed, since it will from thence be inferred, that large masses are to be preferred to small ones, on account of the larger surfaces they expose to each other; and as the force brought into action in an arch is one of compression, of course the hardest and least elastic materials are the best, while soft sand-stone or badly burnt bricks are among the worst things that can be used. A long tunnel which was cut through a considerable hill in the vicinity of London, with the view of obtaining a level main road, and called the Highgate Tunnel, failed entirely from one end to the other, and all fell in in a single night, within a week after the final completion of the work, owing to the bricks, of which the arch was formed, not being sufficiently hard to resist the pressure of the great load of earth that was above them. Timber is an objectionable material for forming arches, unless extraordinary care is taken to ventilate the abutments and preserve them from humidity, otherwise it will rot in these places, and the arch must sink or fall. Stone, from the magnitude of the blocks in which it can be obtained, is therefore decidedly the best and most durable material for large arches; and well burnt hard bricks properly disposed may be considered as the next best. Cast iron also appears to be a very excellent material, because the castings can be so arranged and put together with screw bolts, wedges, keys, and dovetails, that hollow or skeleton voussoirs may be formed with diagonal braces within them, so as to obtain all the strength of stone, with very extensive joining surfaces, and yet with a comparatively small weight of metal. Cast iron, when properly formed and disposed, will withstand an enormous force of compression, and the only doubts as to the propriety of its use arose from its liability to oxydation and consequent decay, and from its expansion and contraction with change of temperature. Metals when heated and cooled expand and contract with a force that is almost irresistible, (663,) and as a large arch must expose a very long and continuous surface to the action of the atmosphere, it was feared that an arch built of iron might expand and elongate, in hot summer weather, to such an extent as to push out its abutments, or cause its crown to rise, should they have strength enough to resist this motion; and that in winter, the arch would sink from the contraction of the parts, thus producing a constant motion in the joints which it was feared might fret and break them, and thus endanger the stability of the work. The experiment has, however, been tried on a sufficiently large scale to show that these fears are groundless; and that a perfectly stable arch may be constructed if properly managed and attended to. The oxydation is effectually prevented by keeping the iron well painted in its joints with earthy oil colours (675) and the effects of expansion and contraction are met by tying the pieces that compose the voussoirs firmly together transversely but not longitudinally. The voussoirs are connected with each other by dowells, or tenons and mortices, and are prevented sliding over each other or changing their positions by wrought iron keys or screw bolts, which are not drawn quite tight, because the play necessary in each joint will be very small, although the sum of all their actions may be considerable.

1174. The first bridge wholly of cast iron (with the exception of the connecting bolts and keys of wrought iron) that was ever attempted was placed over the river Severn, at Colebrooke Dale, in Shropshire, England, in 1779, by Mr. Abraham Darby, an iron master of that place. It is a single semicircular arch of 100 feet 6 inches span, and contains $378\frac{1}{2}$ tons of iron. The roadway is 24 feet wide, and is supported by five parallel ribs, each rib consisting of three concentric circles, connected together by radiating pieces. The lowest ring of each rib is a complete semicircle; the others are only segments, being terminated or cut off by the roadway. The roadway is covered with cast iron plates, and has an iron railing on each side. It stands upon iron foundation plates let into a solid but stratified rock. There is little of science in the construction of this bridge, if we except the enormous magnitude of the castings, as each inner circle of the rib is in two pieces only, each 78 feet in length. From the simplicity of its construction it was put together and finished in three months, and as it stands between two solid rocks the road leading to it is made up on each side by solid masonry.

1175. The next large iron bridge that was erected in England was over the river Wear at Sunderland, Durham. It was began in 1793 and finished in 1796. The stone abutments are 70 feet high above the ordinary surface of low water to the springing of the arch. The iron arch has a span of 236 feet, and is a segment of a circle 444 feet in diameter, having a rise or versed sine of 34 feet with its soffit 100 feet above the low water line of the harbour, therefore vessels with high masts can sail under it. The road over this bridge is 32 feet wide, with iron railings on each side. The bridge consists of six ribs, which are formed on a very different principle to those last described, for instead of working with pieces of iron of from 50 to 70 feet in length, each rib is here composed of no less than 125 small frames or skeleton voussoirs, each about two feet wide in the length or curve of the rib, and five feet deep in the direction of the radius. These hollow blocks, or voussoirs, are held together by wrought iron bars fitting into grooves, and hollow pipes of cast iron with flanches, having screw bolts passing through them, connect the ribs together. The framing thus forming the arch, is the sole support of the bridge, but to render the roadway (which is formed of timber covered with tar and lime and afterwards with marl) more flat, perpendicular posts of iron rise from the top of each rib and reach to the underside of the strong timber joists which are laid over each rib in the lengthwise direction of the bridge, their distance asunder diminishing towards the crown and being regulated by the diameter of a cast iron ring, which is introduced between each post, of such diameter that while the bottom of the ring rests on the top of the rib, its top may reach to and support the bottom of the timber joists, and the vertical iron posts are in contact with the two sides of each ring to prevent their flattening by pressure. This bridge contains only 260 tons of iron, of which 214 are cast and 46 wrought iron for fixing the parts together; and its cost was £27,000, including the immense abutments of almost solid masonry, 24 feet thick by 42 feet broad at the bottom, diminishing to 37 feet at the top. It has been much admired for its light and elegant appearance, and is justly esteemed a bold effort of art, and an incontrovertible evidence of what may be accomplished in cast iron, but still its principles are not good; 1st. because its frames are much too short, thereby multiplying the number of joints very unnecessarily, while the pieces that compose the frames are of unequal dimensions, which is also improper; 2ndly. the preservation of the due position of the frames is made to depend too much upon wrought iron bars and bolts, which should be as much as possible excluded from structures of this kind; 3dly. circles in the spandrells are not a good and effectual support for the roadway, because a circle is not a strong figure unless it is equally compressed on every part of its circumference, which is not the case in this bridge. For circles, disposed as in this structure, act rather as springs than as solid supporters to the road.

1176. The boldest conception that has ever been formed for constructing an iron arch was that of Messrs. Telford and Douglas, for building a bridge over the river Thames at London, in a single arch of cast iron, which was proposed to be a segment of a circle of 1450 feet in diameter, having a span or opening of 600 feet, and a rise or versed tier of 65 feet. The bridge was to consist of seven ribs, having a roadway upon them of 45 feet in width at the crown or centre, increasing in each direction until it should be 90 feet wide at each end. The design for this bridge, which was truly elegant, was submitted to the British Parliament with the estimate for its construction in 1801, and for some time serious thoughts were entertained of carrying it into execution. It was computed to require about 6500 tons of iron with 432,000 cubic feet of granite, and 20,029 cubic feet of brick-work for its abutments, and its total cost was to be £262,289. The possibility of its being put up so as to be a permanent erection, and its advantages and disadvantages were submitted to most of the eminent Engineers and mathematicians of England, who concurred in the possibility of its execution and stability; but after due deliberation in parliament it was thought too bold an experiment, particularly as a single arch did not appear so important to the navigation of the river as to warrant the risk of its failure in a part of the city where the permanent existence of a roadway was of great importance, and it was therefore given up, and the Southwark bridge of three iron arches was erected in its stead.

1177. This great work was confided to Mr. Rennie, who commenced it in 1813, and finished it in a most satisfactory manner from his own designs in March, 1819, at an expense of £800,000, including the purchase of land and occupied premises required to be pulled down for the avenues. This stupendous bridge consists of three cast iron arches which are segments of circles. The centre arch spans 240 feet, and the two side arches 210 feet each. The distance between the abutments is 708 feet, and the extent of each abutment is 71 feet, formed of solid masonry. The two piers in the river are 24 feet in width between high and low water lines, 75 feet long from point to point of the cutwater angles, and are 60 feet high from the bed of the river to the top of the parapet. Their foundations are sunk about 12 feet below the bed of the river, and rest on platforms of timber $2\frac{1}{2}$ feet thick, supported on the tops of 420 piles, most of which are driven 24 feet into the earth. The soffit of the centre arch averages 43 feet above medium low water mark, and the road over the bridge is nearly level, being paved in the centre 28 feet wide for carriages, and with a flag stone footway of 7 feet wide on each side. Many of the single castings in this bridge weigh 10 tons each, and the total quantity of iron is 5,308 tons. The castings used in this bridge were executed by Messrs. Walker & Co. of Rotterdam, in Yorkshire, above 200 miles from the location of the bridge, and the masonry and fixing was contracted for by Messrs. Joliffe and Banks, and such was the precision with which the work was executed that the centre arch only sunk $\frac{7}{8}$ of an inch on the removal of the centring. The strength of this bridge depends upon eight ribs of cast iron plates so proportioned as to form an arch of equilibration, and maintained in their parallel positions by four oblique iron braces in each arch running from the crown on each side to the abutments, and by a number of connecting pieces fixed between the ribs. The roadway, which is formed on cast iron plates, is supported by straight iron bars proceeding from the tops of the ribs, every alternate one of which is vertical, while the next radiates from the centre of the arch; and where these cross each other an arched tie is introduced to connect them together and add to the general stiffness of the fabric.

1178. Vauxhall bridge, built by Mr. James Walker between 1813 and 1816, consists of nine cast iron arches, each 78 feet in span, and rising 29 feet, forming with the piers, which are of Kentish rag stone, a bridge of 860 feet long, which was finished for £150,000. The arches of this bridge being smaller than the last no radiating bars are introduced to carry the iron platform of the road, which is supported upon the piers, the crown of the ribs, and by the verticle standards placed at equal distances on each side of the rib, tied together in the middle of their height by a horizontal string-piece, while their tops are united by Gothic arches, which gives the whole structure a very light and elegant appearance. Ten parallel ribs are used in each arch of this bridge.

1179. Cast iron bridges have been constructed in many other places, but the two above described have been introduced on account of their being the largest experiments yet made with this material; and as they have both stood the test of 20 years trial without any symptoms of failure or decay, either from expansion, contraction, oxydation or other cause, there cannot be better evidence of cast iron being a good and serviceable material for bridge building when properly used and disposed.

1180. It now only remains to make a few observations on the means of using or putting the materials together for the formation of arches, and the building of bridges. As arches of stone or brick must commence at their springings or abutments, so these demand the first consideration, since the stability and duration of every arch depends, in great measure, on their perfection. The first and greatest attention of the Engineer must consequently be given to the solidity of the foundations of his piers and abutments, by driving piles and removing all soft and slippery soil, until a firm and solid footing is obtained. This is especially necessary in bridge building, because it often happens that the banks of rivers are composed of sand or soft mud, brought down and deposited by the stream, and such loose soil is of course not trustworthy. It is therefore often necessary to carry the land abutments a considerable distance from the sides of a river, in order that they may take hold of, and be resisted by solid ground; and as this will occasion a great expense in masonry or brick-work, so land abutments are very frequently made hollow by introducing arches that stand vertically into them to save this quantitity of solid work. The approaches to every bridge should be made wider than the road upon it, to prevent accidents and allow facility of passing, and the parapet walls or other side fences are therefore generally made to curve or open as they leave the bridge, and those continued walls or side fences, when they arrive on solid ground, are called the *wings* or *wing walls* of the bridge. This circumstance offers an opportunity which should always be embraced, of making the abutments wider than the bridge itself, and thus the lateral pressure is extended over a larger portion of ground, and is the better able to withstand the pressure that may be exerted. Wing walls, therefore, although they may be thin above ground, and appear as if they were constructed merely for the safety of passengers, are frequently thick and massive under the soil, and are carried out in a diverging direction until they meet and abut upon solid ground, while they are united by a vertical arch next the bridge, in order that the lateral pressure of the bridge may be transferred to the solid ground; and if the bridge is wide, three or even four of such walls are built in the direction of the bridge, each pair of walls being terminated by an arch that presents its convex surface to the pressure. These walls may be horizontal in their courses, or depressed into the ground, according to the form of the arch, for a semicircle or semiellipse will require level abutments to spring from, while all others should incline like skew backs or have their joints and bottom foundations radiating or vertical to the entrados or inside of the arch, in order that they may receive the pressure in a direction as nearly vertical as possible to their surfaces. Each archstone or voussoir, before it is carried to its destination, must be regularly cut or dressed to the form of a wedge, the two beds or sides of which must also be so cut that when laid in its proper place the joints may radiate, so as to be correctly vertical to the entrados, while that which is to be the underside of the stone must be hollowed out, or have the concavity of the arch given to it, otherwise the entrados of the arch, when exposed to view by the removing of the centring, will appear as formed of small flat planes, thereby destroying the beauty and regularity of the arch. To obtain this precision of form, the large boarded platform before mentioned as being necessary for the construction of the centring, must be again resorted to. Upon this, the exact curve of the entrados must be accurately set out, together with all the voussoirs of their actual size, with the directions the joints are to take; and this done, thin mould-boards are fitted exactly to the lines so produced, and these are delivered to the masons that the stones may be cut to correspond with them. Should any one stone be too small to form a complete voussoir, another must be fitted to it, so as to complete the full size and carry out the directions of the joints; and stones so cut and formed must of course be used in positions, in the real arch, corresponding with those on the platform. The stone being finished a Lewis hole must be made in its upper part, in such a position, as to its centre of gravity, that it can be raised and lowered in, as nearly as may be, the position it is to occupy in the arch, so that when lowered into its proper bed, it may not require twisting, turning over, or shifting to such an extent as may disturb the cement or mortar previously spread in as thin a layer as possible to receive it. If the stones are large and heavy, the mere juxtaposition of the two faces with the interposed mortar will be sufficient to retain them in their places in small arches. When the arches are large and heavy, dowells or cramps, or even both, are made use of to connect the stones together so as to prevent the possibility of their sliding over each other. In building Blackfriars bridge, Mr. Mylne introduced a cubic foot of hard stone by letting it half way into each stone between every joint of the arch stones; and his piers, built of large blocks of Portland stone, are dove-tailed together by sound oak. In all cases the lower part of the spandrell or space contained between the springings of any two arches in a bridge, or between the arch and its land abutments, must be filled up with solid masonry, that one arch may bear or abut against the next to gain strength in the haunches. In Westminster and Blackfriars bridges, the joints of this filling in take the same radical direction as the joints of the voussoirs; but in the Southwark bridge, this filling in is in horizontal courses, but the voussoirs are knee-jointed, which answers the same purpose as to solidity and firmness; and in both the last bridges this filling in is surmounted by an inverted arch covering each pier, and working into the main arches, which effectually prevents the filling in from rising by the swelling of the haunches should they have a tendency to do so.

1181. In building an arch, since the work must commence from the springings or lowest points, the voussoirs must be piled or placed on each other with as little mortar as possible, each stone being made to slide into its bed if possible until its under side is brought into close contact with the lagging of the centring, and then it is driven into close contact with its fellow stone by the blows of a rammer or beetle used cautiously, because the vibration thus produced in a heavy stone, does more to settle it or bring it to its bearing than the force of the blows, which might break the stone. In commencing an arch as before observed, (1079,) little strain falls upon the centring for the first 25° or 30°, especially in semi-arches, as will be apparent upon inspecting the voussoirs composing the arch in Fig. 254, when if a perpendicular line (representing the direction of gravitation), should be let fall from the centre of gravity of any of the first four stones from the bottom, it would fall within the supported base of that stone; consequently, these stones would be upheld by those underneath them rather than by the centring; but as we proceed higher up, such lines would fall upon the centring. Hence it follows that both feet of an arch must be began and carried up simultaneously, otherwise an inequality of pressure will be induced upon the centring, which would cause it to bulge or protrude on the side opposite the load, thus deranging its figure. An arch must therefore always consist of an odd number of voussoirs built or piled upon each other until they meet at the top or crown, where the last space in the centre is filled up by a single voussoir, usually longer and larger than the rest, called the *key stone*, for it is this stone which locks up or finishes the arch, and enables it to stand after the centring is withdrawn. The key stone therefore requires to be cut very accurately to a template or mould board, fitted to the place it is to occupy, and it is sometimes introduced dry or without mortar, though a little finely sifted thin mortar is beneficial by enabling it to slide better into its place, into which it is rammed down, or urged by a heavy temporary pile of stones built above it.

1182. In pursuing the foregoing balancing plan of producing an equal load or weight on each side of the centring, perfect security is not always obtained, for unless the framing is perfectly strong and immutable in its figure, the loading of the haunches will cause it to rise in the crown, which was the difficulty that occurred to Perronet in building the stone bridge at Orleans in France, upon the much extolled centring of Hupeau as before described (1076.) See Fig. 253, Pl. VIII. On beginning to fix the stones of this arch in the usual manner, it was found that the top of the frame rose very much; it was therefore loaded with heavy stones on the crown to prevent this effect; and now it sunk as remarkably. This showed that the lower polygon was giving very little aid. M. Perronet then thought the frame too weak, and he inserted the long beam *b e* on each side, making a diagonal to the quadrangles, and very nearly in the direction of the lower beam *a b*, but falling rather below its line. He now found the frame abundantly strong, for the truss became completely changed, and now consists of only the two long sides with the short straining beam lying horizontally between their two heads. The whole centring now consists of one great truss *a e i b*, and its long sides *a e*, *i b* are trussed up at B *b* and *f h*. Had this simple idea been made the first principle of construction, this centring would have been excellent. The angle *a b e* might have been about 176°, and the polygon *b c g h* employed only for giving support to this great angle, so as not to allow it to exceed 180°. M. Perronet also found that the joints of *b c* into the foot of the post *e c*, were about to draw loose, and he was obliged to bolt long pieces of timber on each side of the joint embracing both beams. These were evidently acting the same part as iron straps would have done; a complete proof that, whatever may have been the original pressures, there was no abutment now at the point *c*, and that the beams which met there, were on the stretch instead of in a state of compression; consequently, their office would have been as effectually performed by iron rods as by stiff beams of timber. There is no objection to the crown of an arch rising in a very slight degree during its construction, because when the centring is struck that is the part that always sinks, and it may sink to such a degree as to bring the arch to its first intended regular form.

1183. The arch being finished, must next be examined on its upper surface to ascertain whether any of the joints have opened from a change of figure during its erection, and if so, where it will require loading or weighting to bring it back to its proper form; but no hard material should be introduced into such openings, because they cannot be effectually filled, and if the angular faces of the voussoirs have been properly shaped and well worked, such materials might prevent the stones from coming to a close and even bearing as they will otherwise do. The modern practice of loading an arch, is not to fill soil into the spandrells, for the reasons before given (1168). But to build brick walls parallel to each other, from one arch to another, in the lengthwise direction of the bridge, carrying them up to the height of the crown of the arch, and covering them over with flag or slab stones to receive the marl or other earth that is to form the bed of the road, or arching them over when stones cannot be procured. By this process, which was adopted in the Waterloo bridge, the arches are stiffened and strengthened at the same time that the haunches and facing walls are relieved from that pressure, which otherwise might prove detrimental to them; and should the weight not be sufficient in any part, it can always be increased by partly filling the channels between the walls with rubble stone laid in grout. When finished, the upper surface of the arches between these walls, must be carefully paved with bricks or flat stones laid in cement to prevent any water sinking or percolating into the arches and piers; and the parallel walls have drain holes left in them, over each pier, that they may communicate with each other; because stone bridges are never roofed over, and some rain water will always find its way through the roadway, and is collected in these recesses, from whence it is permitted to run off through small iron pipes introduced for the purpose between the stones of the arches, or may be carried down by pipes concealed in the facing stones of the piers.

1184. The bridge being so far finished, the centring should be released by relaxing its wedges before the facing, spandrell, and outside parapet walls are built upon the arches; because a trifling change of form in the arch may occur by its settlement, without impairing its strength, but which might crack and disfigure the external face walls; but if they are not built until the arch has taken its final set, there will be no danger of their being afterwards deranged or disfigured.

1185. The stones of the facing walls of bridges are differently disposed, according to the taste of the builder. Thus in Westminster bridge, the joints are all made to radiate in the directions of the joints of the voussoirs, until they intersect the piers, as shewn at Fig. 269. In Blackfriars bridge, the joints are horizontal and parallel, and the stones that intersect the extrados, are cut to its curve; while in the Southwark and new London bridges, the joints are horizontal; but instead of the intersecting joints being cut to the curve of the arch, the voussoirs of the haunches are made to project beyond the regular curve of the extrados, and are cut into horizontal and nearly perpendicular forms, so as to meet the face wall stones in the manner shewn in Fig. 255, and then the work is said to be *knee jointed.*

1186. The arches of a bridge are usually surmounted by a bold projecting cornice, which is introduced rather to add beauty than utility to the erection. Above this the parapet walls are built for the security and protection of the passengers, and in order that they may not obstruct the view of the water below, they seldom exceed 3 or 4 feet in height, and are finished by stone *balusters* with a capping or cornice above them, or by open palisades or railing of iron, to strengthen either of which the piers are usually carried up to the full height of the top capping or cornice which runs in common over them. A row of such balusters is called a *balustrade*, and such a one is applied to the sides of staircases; but the word baluster is frequently corrupted into *banister*, which is improper.

1187. From the nature of a voussoir, it will be apparent that ordinary bricks are unfit for constructing arches under all circumstances, because the necessary wedge-like form cannot be obtained from a solid having parallel sides. In a brick arch of small radius, even admitting that the bricks touch each other in the intrados, they must diverge or separate at the extrados, and the wide joint thus occasioned can only be filled up with mortar, a material not calculated to resist pressure under such circumstances. The large mortar joints at the back must be filled up by driving in wedges of slate or stone, but these often produce unequal pressure, tending to break the bricks, or to disturb the regular settling of the arch, by which its figure may be distorted and its strength impaired. If on the contrary, the arch is of very large radius, the brick joints will become so nearly parallel, that this inconvenience may not be felt; but the bricks must be very good, hard, and well burnt to sustain the enormous pressure of a large arch and the work above it without crushing, as in the case of the Highgate archway. Bricks are sometimes moulded in the wedge or voussoir shape, expressly for constructing arches, and then they are less objectionable.

1188. In order to meet these difficulties in constructing brick arches, it is customary to lay them in thin concentric rings which do not bond into each other. Thus the lowest ring may be of half brick or $4\frac{1}{2}$ inch work, made smooth on the top, and any number of successive rings of the same kind of work may be built upon it; in which case the radiating joints will be so short as to be nearly parallel. Or if the arch is large the bricks may be used endwise, thus producing nine inch rings to succeed each other. Either of these methods will produce a good and strong arch for ordinary purposes, especially if exceedingly thin mortar joints are used between the bricks. But when the load to be supported is very great, there will always be a danger in the rings not settling equally on account of the upper rings having more bricks and more joints in them than the lower ones, and should this occur the pressure may become transferred to a single ring while we suppose it to be borne equally by them all, and the arch may in consequence fail. The best and safest way of building a large brick arch is therefore to imitate voussoirs as far as possible by building blocks of brick-work of bricks placed with their ends towards the entrados, and four or five courses thick, and to alternate these with bricks, laid in rings, which may extend to two or three times the width of the voussoir, as shown above the centring in Fig. 257. This bonds the work better together, and produces a nearer approximation to the advantages of a stone arch than any other mode of using bricks.

1189. It was intended to have closed this chapter by some account of the suspension bridges which have been erected. But the work has extended so much beyond the bounds into which it was originally intended to be confined, that we must be satisfied with stating that these are bridges consisting of several iron chains, not formed of small links like cables, but of whole bars of iron jointed at their ends, passed over a high gate or tower, being the access to the bridge on each side of the river, while their extreme ends are firmly attached to large and ponderous stones, that are sunk a great depth into the ground on each side of the stream. The chains hang in parallel festoons over the river between the supporting towers, and carry a number of vertical bars of iron that are attached to, and hang down from them, for the purpose of supporting beams of wood or iron hanging horizontally in the direction of the stream, and serving as joists to support a strong planked platform or roadway that extends across the river. Five sets of chains are commonly used, and five sets of vertical suspending bars hang from them, thus dividing the width of the bridge or platform into two carriage-ways in the middle, and two foot-ways at the sides, which are separated from each other by fences in pannels attached to the lower ends of the vertical suspending bars. The most magnificent bridge that has ever been constructed on this principle, is at Bangor, in North Wales, over an arm of the sea running between the Isle of Anglesea and Cardiganshire, called the Straits of Menai. The width of water is so great that it was not deemed safe to place the obelisks or towers for supporting the chains upon the shores, but they, like other bridge piers, are built in the water, at the clear distance of 552 feet asunder. They are formed of massive stone and rise 173 feet above low water mark. These towers carry metal rollers on their tops over which the chains pass and then descend to the rocks on the opposite shores, to which they are very firmly attached. The platform or roadway is wholly of timber for lightness, notwithstanding which the chains, supporting bars, and platform between the two towers weigh no less than 650 tons, which immense weight is supported at the height of 121 feet above low water mark; so that very large ships sail under this bridge without striking their topmasts. This stupendous bridge, which is in the direct mail road of communication between London and Dublin, was designed and executed by Mr. Telford, and is found perfectly stable and secure, having withstood the test of much travelling and many heavy gales of wind. On the 23d December, 1835, a storm occurred that it was feared would have carried away the bridge, as it was thrown into so violent a state of undulation that parts of the platform were elevated and depressed as much as 16 feet. This gale lasted twelve hours, and on its termination all the mischief that was done was the breaking of some of the flooring planks, which were repaired the following day, at the cost of a few dollars.

1190. Several bridges on this construction have since been erected, and among others one over the Thames at Hammersmith, four miles west of London, by Mr. Tierney Clark, which is justly admired for its elegance of design. This mode of constructing bridges it is believed originated in China, where ropes, instead of chains, were used. The advantages attending them are, that they require no centring during their erection, and that they find their own state of equilibrium, in consequence of which, if temporary derangement of figure occurs it immediately corrects itself, which cannot be the case in bridges of the ordinary construction. Besides which, from the stability of their equilibrium, suspension bridges require much less material for their formation than any other kind of bridge, which, with the absence of centring, causes them to be much cheaper than any other mode of construction. In some cases the supporting towers are made of hollow skeleton framing of cast iron, supported on plinths or foundations of masonry or brick-work.

1191. Arches are often built wholly underground, for the purpose of supporting the earth after excavations have been made through hills for the purpose of carrying roads or canals through them, and they are then called *tunnels*. The Highgate tunnel (1173) was of this description. The grand junction canal in England, which connects the north and south part of the island together, runs through tunnels in several places, some of which are two miles long; and the celebrated tunnel under the river Thames in London, now in progress by Mr. Brunell, is to open a dry road communication under the river instead of over it. In tunnels, the arch work lines the whole opening both above and below, instead of extending over the top as in bridges. A tunnel, therefore, may be said to consist of an arch or vault, built or standing upon an inverted arch or vault. The term vault is used to express a continued or extended arch. An arch may be composed of a set of single voussoirs, or even need have no visible extent of soffit, as when an arch is introduced as part of a wall; but a vault always has extension, so that a room with an arched ceiling, is always said to be vaulted rather than arched over. In this sense the arch of a wide bridge may be called a vault. The height of tunnels is generally greater than their breadth, so that their transverse sections present an elliptic rather than a circular form, for when tunnels are circular, they are called *culverts*, which are used for conveying small streams of water under navigable canals and roads. A culvert, therefore, is a complete circular arch, or arch continued all round, as in Fig. 49, Pl. II., while a tunnel is generally an elliptic arch of the same description, notwithstanding which a tunnel may be circular. The Thames tunnel is not a regular ellipse in its section, but is oval or egg shaped, the upper part of the arch being more acute than the lower, which is considered the best and strongest form. In canal tunnels, the water occupies the lower or inverted arch, a part of which is taken off by a battered wall to support the horse towing path which extends through the tunnel, and must be wide enough for horses to pass in opposite directions. In a road tunnel, the inverted arch, or part of it, is filled up with hard materials to form the road; but a culvert or drain must be formed under the road, but within the arch, to convey away water if the land is so springy as to endanger the road being kept in a wet state. Should there be no means of conveying this water away by natural fall of the country, it must be raised artificially by pumping, or even by the constant working of a small steam-engine, which is the case with the Thames tunnel. As all tunnels are dark, except at a small distance from their open extremities, they are frequently lighted by lamps; and gas lighting is particularly applicable to this purpose, from the facility with which gas may be conveyed by tubes within the arch. When tunnels become so long that it would be expensive and inconvenient to remove the earth dug out, or the materials for the arch to be carried through the extreme ends, they are worked by shafts or vertical cylindrical holes like wells, through which the materials are drawn up or let down. These shafts are bricked round and left remaining for ventilation, to admit light, and to facilitate future repairs.

CHAPTER XII.

ON THE PRACTICAL APPLICATION OF THE FOREGOING PRINCIPLES.

Section I.—*Of Rail-roads.*

1192. The subject at which we have now arrived, would be endless, were an attempt made at pointing out even the most common and ordinary applications which the Engineer will have occasion to make of the principles we have endeavoured to lay down. We must, therefore, be content with pointing out a few of the leading objects to which his attention may be called. Road making is one of these, and it is presumed that the information conveyed in our 4th, 5th, 6th, and 7th chapters, when combined with practice, will prove amply sufficient on this head. As the perfection of roads consists in their being level, smooth, hard, and dry, all these objects are most effectually obtained by *rail-roads*, and accordingly their construction demands attention. Of the several modes of conveyance, navigation has been preferred as being the most economical; but there are many situations in which natural water courses do not exist, and in which artificial ones cannot be made from want of water, or such inequality in the surface of the country as will not permit its use, and then of course roads must be resorted to. Independent of this, there are reasons why a road, and particularly a rail-road, may be preferred to water conveyance even where it can be had. Among these a country may be subject to great drought in the summer, or to severe frosts in the winter, or to both of them, so that in the summer its rivers and canals may be dry, and in the winter may be frozen up, and thus rendered useless throughout a large portion of the year; but the first of these effects does not apply to rail-roads, and the second admits of remedy. 2ndly. Water courses are frequently more tortuous or crooked than roads, and as the resistance to bodies moving through water increases rapidly with their velocity, and is not felt to the same extent when passing through air, a much greater velocity of motion can be obtained by the same power on a road than on a canal or river. 3dly. Rail-roads occupy much less land, and occasion little inconvenience to land owners. They are executed much more cheaply than canals, cost less to keep them in repair when finished, and frequently possess the advantage of conveying goods and passengers to and from their required points without change or the expense of reloading, while in water conveyance, there is generally land carriage and reloading to the place of shipment, and the same again at the termination of the navigation to convey goods to their ultimate destination, while rail-roads often extend from one point to the other, and even into warehouses, and thereby produce saving of time, labour, and expense. The only disadvantage of a good rail-road is, that a given weight of goods requires a greater power to move it than on water, but as greater celerity is obtained, this additional power is kept in action during a shorter time, thereby frequently producing ample compensation.

1193. Railways differ from common roads, and derive their superiority from two particulars, first, greater pains is always taken in their construction to insure either a truly level surface, or one of uniform ascent and descent, without the undulations or inequalities to which the best roads are subject; and secondly, from the surface itself being hard, smooth, and free from inequalities. Canals appear to have existed from the most remote antiquity, yet it is singular that no account of the formation of a railway should be met with until about 1620, when it seems they were first adopted in the coal mining districts of Newcastle upon Tyne in the north of England, for conveying coal from the pits to the sea for embarkation. As immense quantities of coal were conveyed in carts heavily laden and constantly travelling over the same track or road, they would stand in need of constant and expensive repair, to avoid which it appears that timber sleepers were laid across the road at 2 or 3 feet from each other, and upon these long pieces sawed and well squared, were placed the whole length of the road, and on each side of it being fastened down by wooden pins or pegs, so that the cart wheels might run upon them. On the ordinary road, 17 *cwt.* was considered a full load for a horse and cart, but with this imperfect kind of rail-road, the load for one horse was increased to 42 *cwt.* It does not appear that wheels different from those used on common roads were adopted; consequently, the wear and tear of the timber tracks must have been excessive; and the only improvement that was made for many years, was that of facing the rails when finished with an extra covering of board for the wheels to run upon, and this could be taken up and renewed when worn out, without the more expensive operation of disturbing or renewing the substructure.

1194. The next improvement in order of time appears to have been the use of cast iron as a substitute for the wooden rails, and these were tried on a small scale at the Colebrookdale iron works in Shropshire about 1767, at the suggestion of Mr. Reynolds, one of the partners in that concern. About this same time cast iron wheels, turned in a lathe, and made with great truth and accuracy, began to be used, and then it was that the great advantage of these roads became apparent, for the advantage to be gained by a rail-road depends in a great measure on the perfection of the workmanship bestowed upon it, to make it truly smooth and level, and on making the carriages that run upon it as free from friction and inequalities of motion as possible; and in this a rail-road differs materially from a canal; for however roughly that may be executed, still, if it is capable of holding water, boats can navigate it with no other impediment than what the resistance of the water offers to their motion. But in a rail-road all depends upon exactitude and perfection of workmanship. If a plane be perfectly hard, smooth, level and straight, and the wheels of the carriage perfectly hard, smooth and cylindrical, the motion of such carriage can be impeded only by the resistance occasioned by the friction of its axles. It is therefore necessary, in the construction of railways, to ascertain distinctly those circumstances which together make up the great resistance seen in practice. By a reduction of these we are not only benefitted by a saving in the cost of draft, but by a proportional diminution in the expense of repairs, because if the rails are not well laid and steadily fixed, or their joints project, so as to produce obstacles to motion, while the wheels intended to run upon them are irregular or out of truth, such a railway will not afford the advantages expected from it, and will soon destroy itself by its own imperfections.

1195. On the first introduction of cast iron rails, it was believed this metal would not answer from its being brittle, and breaking under the enormous loads which it was found possible to draw upon it. This led to the next stage in improvement, viz: distributing the load into a train or number of carriages one behind the other, but connected together, and then the cast iron plates were found perfectly effective; for notwithstanding a single pair of parallel plates would not sustain the load, yet when it was distributed over a great number of them, they carried it without difficulty, and cast iron became extensively used.

1196. A rail-road or railway is nothing more than two continued lines of iron or other hard material laid or disposed on a road in such manner that the two opposite wheels of a carriage shall run one upon each of the lines prepared to support them; and to obtain the full advantage from this contrivance, these lines should remain right lines and parallel to each other, and incapable of sinking or varying from the position originally given to them; and the wheels should be perfectly round and true, move with as little

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friction as possible, and some expedient must be adopted for preventing the wheels from slipping off or leaving the lines so prepared for their support. We shall endeavour to point out the means that have been resorted to for obtaining these objects, and such others as are necessary to constitute a good and perfect railway.

1197. Railways are constructed in five distinct methods: 1st. of cast iron plates, which are flat and smooth on their upper surface for the wheels to run upon, but having a flanch or feather rising vertically on one side of the plate, so that its cross section presents a right angle or is like the latter ⌋. The wheels to run on these plates are simple cylinders, and the use of the vertical flanch or feather is to prevent the wheels from getting off the rails, for which purpose the projecting flanches in laying the plates must both be on the outsides, or on the insides of the double parallel track. 2ndly. Cast iron plates, with flat and smooth tops, but without any vertical flanches. When these are used the flanches are formed upon one side of each wheel, and the wheels are so disposed in pairs upon the same axletree that the flanches upon the two wheels embrace or take in the two parallel rails, or else the flanches must be placed inwards or next to each other, so that they may fit in between the two lines of rails. 3dly. Wrought iron bars of from two to three inches wide, and about three-fourths of an inch thick, having countersunk holes punched through them at from six inches to a foot asunder. These bars are fixed to rails or beams of timber by nails or spikes, with countersunk heads fitting the holes, so that when driven they may not project above or interfere with the regular smooth surface produced by the iron bars. This railway is the same except as to materials and construction as the second method, and of course the same flanched wheels run upon it. 4thly. Instead of providing a flat surface for the wheels to run upon, as in all the varieties above named, wrought or cast iron bars or rails are fixed with their thin edge uppermost, and standing some height above the level of the road, in which case the wheels may have single flanches as before, or a groove or cavity may be formed in the edge of the wheel by making it like a pulley, such groove being wide enough to receive the upper edge of the rails which are now called *edge rails*. 5thly. The edge rail may be used singly, if elevated by pillars above the road to such a height as to permit the load to hang down on each side of the rail, which constitutes Palmer's single railway.

1198. Whichever method of construction may be adopted, the preliminary and preparatory steps to be taken by the Engineer are nearly alike. A survey of the country and its map must be prepared. The several lines, (when more than one are contemplated,) must be carefully levelled in order to determine that which shall be selected as the most level and the most elevated, to insure the work from inundation, and because it is easier to convey loads down than up a slope. A profile of the surface of the intended line must then be made, and so much earth-work will be necessary upon this as will reduce the whole length of line to a dead or true level, or to a very gentle and uniform slope, by cutting through hills and filling up hollows. When large hollows or vallies occur, or when streams have to be crossed, bridges will be necessary for carrying the railway over; and as streams are generally found in low or depressed positions, the piers of such bridges frequently require to be carried to a great height, because a railway will not admit of those elevations and depressions which are of no importance in a common road where we should depress the road, or go down hill to the bridge, and up hill after having passed it. But in a rail-road the bridge must be brought up to the level of the road instead of accommodating the road to the level of the bridge. On this account a rail-road cannot always be carried in the straightest or nearest direction, but has to be conducted through the most level track of country, or very heavy expenses of earth-work must be incurred to render the line level. On this account forming tunnels through hills sometimes becomes necessary, both in rail-road and canal works, as without them works that require to be level might be effectually stopped, or would have to run in very circuitous routes to preserve their level.

1199. The necessity of keeping common roads dry has been before insisted on (418) but this is still more necessary in rail-roads, for the purpose of maintaining the level and right lined position given to the rails; for if some are supported on dry, and others on wet ground, the latter will inevitably sink, unless precautions are used to prevent it. One of the worst enemies a rail-road has to encounter is frost, for if ground is wet it will swell and heave up the rails that are placed upon it when it freezes, and these seldom settle down to their original bearings, so that the line is thrown out of level and adjustment. In all places therefore where injury from frost may be expected, the foundations or bearers of the rails should be piled, or buried so deep in the ground that frost will be incapable of affecting them.

The site of the rail-road being prepared, the method of laying down and fixing the rails is nearly the same, whichever kind of rail shall be adopted; for in most of them sleepers must be placed across the road for supporting them, and these may be of timber or stone, or a transverse timber sleeper may be let into the ground and a large heavy stone, or mass of rubble-work in mortar, may be sunk below each of its ends to give it a firmer bearing and prevent its sinking deeper. Both these materials are imperfect, for timber speedily decays and wants frequent renewal, especially when it is buried near the surface of the ground; and although stone is free from this defect, there is a difficulty in fixing the rails to it in such manner as will prevent their getting loose in consequence of the vibration produced by heavy loads passing rapidly over them. Holes have been drilled in the stones, and plugged with wood, to receive the spike-nails by which the rails are held down, but the swelling of the wood, by humidity, usually splits the stone.

1200. The first kind of iron railway that was used consisted of the first variety mentioned (1194), and the plates were each six feet long with holes cast in their ends, by which they were spiked down upon the wooden sleepers, the end of one bar touching or abutting upon the next throughout the line. These bars derived their stiffness and strength from the vertical flanch which projected upwards for guiding the wheels; and as all the first railways were worked by horses, the sleepers, between the parallel rails, were filled in with gravel, to form a path for the horses to walk upon. The inconveniences of this mode of construction were soon felt. The rails were too long to be stiff and strong, and the horses' feet disturbed much dust and small stones, which was thrown upon the iron surface, and was confined or prevented escaping on one side by the vertical flanch, so that this form of construction was soon abandoned.

1201. The second variety, or flat topped rail without a flanch succeeded. This was made four feet long, four inches wide at the top, and an inch thick; but such a rail would not sustain the required load without some assistance to strengthen it, and accordingly a semielliptic or parabolic feather or flanch at right angles to the vertical plane of the rail was cast on its underside, so that Fig. 157, Pl. V., shows the form of such a rail, and *a* and *b* are transverse sections of the two sleepers upon which it is nailed. To retain the carriage upon this railway, flanches now became necessary on one side of each wheel, and these were so placed as to hang down or project below the insides of the rails; and to diminish friction and the lodgment of grit and dirt upon the rails, their tops were rounded instead of being quite flat. This was the only kind of rail-road that existed for a number of years in England, and was found very useful and effective in the coal and quarry districts, where speed was not so great an object as facility of conveyance. The plates obtained the technical name of *tram* plates, and roads formed of them were called *tram-roads;* but the particular form of rail shown in the figure just referred to obtained the appellation of *fish-bellied rails*, from the shape of the feather under it, which being buried in the ground could be made of any depth necessary for the strength of the rail.

1202. The only objections to this kind of railway arose from the frequency of the joints, and the difficulty of fixing them permanently to the sleepers, because of the vibration produced by the carriages, and the whole being alternately wet and dry causes the nails to draw and become loose; and the liability of the cast iron bars to break when they are so loosened. This occasioned the adoption of the third variety of rail, consisting of common bars of wrought iron used of their full length, which is never less than twelve feet, and nailed down at short intervals, with nails that are countersunk into the bars, upon a railway previously constructed of hard and durable timber in long lengths, supported, as in the other railways, upon transverse sleepers well bedded and supported by the soil, or when that is soft, by longitudinal sleepers under their ends. As far as travelling is concerned this forms a most excellent railway, for none of the materials are so brittle as to be liable to break, and from the length of the parts the number of joints is greatly diminished, and the frequency of nailing prevents vibration and the parts becoming loose. From the elastic nature of the wood, loaded cars move very smoothly and pleasantly upon this road, and it possesses a great advantage, as to passengers, in the motion being nearly free from noise. It is therefore a good railway as regards the public, but a bad one for the proprietors, on account of the transient nature of the substructure, which, being wholly of wood, is subject to rapid wear and decay, and consequently to the heavy expenses of renewal.

1203. When a railway is laid down in a common road, it is necessary to keep all its parts at very nearly the same elevation as the surface of the road, in order that they may be crossed and passed over by common vehicles without obstruction. And this is also necessary for the preservation of the railway itself; for if it stood above the road, rails would frequently be broken or knocked out of their places, by common carts and wagons running against and crossing over them. This is, however, very detrimental to the action of the railway, because small stones and dirt will be constantly deposited on what ought to be a perfectly smooth surface, and in this way the effect of the rail-road may be diminished down to a state differing little from a common road. All the varieties of rail, so far described, are more or less subject to this defect, which becomes serious when horses are used, because their feet are constantly distributing mud or dust upon the rails, and rail-roads are known to work better in rainy weather, because the rails are then clean. Mr. Palmer tried an experiment on a branch of the

Cheltenham Rail-road while it was new and in perfect condition, to ascertain the resistance of mere dust upon the rails. The rails being swept clean, a carriage, with its load weighing 5,264 *lbs.*, was put in motion by the application of a force of 36 *lbs.;* but on covering the same rails slightly with dust 43 *lbs.* of moving force became necessary; thus increasing the resistance to motion by 7 *lbs.*, or upwards of one-fifth of the force necessary when the rails were clean.

1204. With a view to remove the resistance from dirt or grit lying on the rails, Mr. Jessop, an eminent Engineer, who was employed to form the public rail-road at Loughborough in Leicestershire, adopted the fifth kind of rail, which, by way of distinction, he called the *edge rail.* In this, instead of placing the plates flatwise upon the ground, they were placed with their edges upwards, and a rounded or elliptical form of greater thickness than the general bar was given to that edge, which was elevated above the surface of the road, and wheels with flanches were used to prevent the carriages running off the tracks. The edge rails first used were bars of cast iron from three to four feet long. The upper surface was thick and rounded like the handrail of a staircase, and was from two to two and a half inches thick, but this gradually tapered on each side, so as to reduce the under part of the rail to the form of a plate about three-fourths of an inch thick, and of a depth proportionate to the load it had to carry. Mr. Jessop, instead of nailing the ends of his rails to the wooden blocks or sleepers, as had been before done, lodged and united the two contiguous ends of each rail in a small block of cast iron made to fit and receive them, and which was called a *chair*, and these chairs were fixed to the tops of large blocks of stone properly bedded in the ground, thus producing a much more durable and stable construction, and a near approximation to the most approved form of railway now generally used.

1205. In October, 1820, Mr. John Birkinshaw, of the Bedlington Iron Works, Durham, gave the last stage of improvement to railways by obtaining a patent for wrought iron rails, and for improving their form and mode of application. Before this time common bars of wide and thin iron had been used in a few instances with their edges placed upwards, but they did not answer. Mr. Birkinshaw's improvement consisted in passing bars of iron of proper size and form, when red hot, through rollers like those shown in Fig 127, Pl. IV., but within dentations or grooves made in them corresponding to the shape of the intended rails. In this way, wrought bars with swelled and rounded tops similar in section to the cast bars before used, and with a flanch at the bottom to promote stiffness, can be produced in lengths of 12, 15 or 18 feet. These long bars are fixed in chairs at their extreme ends when two bars unite, and likewise at about every 3 feet of their intermediate length, and if these chairs are supported by blocks of stone of sufficient magnitude, well bedded and fixed in the ground, this construction offers as permanent and good a railroad as can be desired.

1206. The fifth modification of railway before mentioned consists in using only a single, instead of a double and parallel row of rails. This is an ingenious contrivance of Mr. Henry R. Palmer, a Civil Engineer of London, which he made public in 1824, and is stated to be cheaper than the double track, inasmuch as only one row of rails is necessary. The writer has doubts as to the economy in expense of this plan, because it appears to him that the iron columns and extra expense of fixing the single row of rails upon them, as he proposes, must be fully equivalent in expense, if not more so, than when two parallel rows of railing of the common kind are used.

Mr. Palmer proposes placing columns or supporters formed of flat cast iron, feathered or ribbed on both sides (624,) at about 10 feet apart, or in the event of cast iron being scarce or too expensive, driving wooden piles into the ground, or building stone pillars throughout the line of railway. The tops of these pillars must correspond with the level or plane of the proposed railway, which in no case must be less than 30 inches above the ground, but may be more as its surface undulates. Each column or prop carries a rectangular cleft on its top for receiving and holding the rails, which are proposed to be made of 3 inch deals, (549,) that is, pine planks 3 inches thick, and from 10 to 12 inches wide, which are to be laid edgewise in the clefts, their upper surfaces being covered by wrought or cast iron plates, which are saddle-backed or rounded on their upper sides for the wheels to run upon. These rails halve vertically into each other within the cleft, and a pair of cross wedges are placed in each of them under the planks, by means of which they can be accurately adjusted as to height and level, but no joint in the iron covering plates must occur over a joint or meeting of any two planks. Should any derangement in the level or line of surface of the planks occur after they have been in use a short time, it can be rectified by the cross wedges; but when the whole line has come to its proper set or bearing, the whole is to be firmly and permanently fixed by screw bolts passed through the cheeks or sides of the clefts, and the planks, to hold the whole together.

1207. The carriage proposed to be used upon this railway has but two iron wheels, with grooves in their edges fitting on to the iron protecting plates, and disposed one before the other, and fixed by proper diagonal bracing beams at 5 or 6 feet apart. The iron axletrees of the two wheels project on both sides about 3 or 4 feet, and two rods of iron are fixed on each side to each of them in such manner that their lower ends, formed into hooks, are a little below the upper surface of the rails, while they project downwards at right angles to the axletrees, to which they are fixed in an inflexible manner, one at each extreme end, and one as near to each wheel as the thickness of the posts and railway will admit. The body of a common wagon, or boxes made for the purpose, are hung on to the four descending hooks, and in these the load to be carried is disposed, as nearly divided as possible on the two sides in order that the two wagons may balance each other. In this disposition the centre of gravity of the load is so far beneath the surface of the rail or plane of suspension that there will be no tendency to overturn, and as the suspending bars are immovably fixed at right angles to the axletrees, no great nicety of balancing will be required, since it will require a considerable difference in weight to throw the supports much out of perpendicular, and a small deviation will be of no importance, because the top of the rail is rounded, and fits the similar formed groove in the edge of the wheel. Any number of these carriages can be yoked together to form a train, as in other railways, and the bottoms of the wagons need only be raised so far above the ground as will ensure their not striking against stones or other obstacles. The horse or other motive power is to be applied by a towing rope to the front carriage, such rope being so long as will not materially alter the line of traction or draught, with the varying elevations of the country, since in high or level ground the load will be below the horse, but in passing vallies may be several feet above him. The towing path is of course made parallel to the rail and close to the line of posts. The advantages proposed by Mr. Palmer are, that being a single line, it will cost less for its first erection and future repair than the usual double line. That it will be less liable to get out of order, and if it does get out of line, is easily readjusted by the cross wedges. Having only two wheels instead of four, there will be less friction, and the elevation of the rails will place them above the reach of coarse grit or snow. It requires less land for its construction, and may even be formed upon the side fence or wall of any bridge for crossing a river; and that it affords great facility for loading and unloading, inasmuch as common wagon bodies with crossbars to receive the hooks, may be used for conveying loads, and they may be taken from, or lowered down to a common carriage with ordinary wheels without discharging the load whenever common road transportation becomes necessary. The same crossing places may be adopted in this as in any other rail-road, and when it has to cross common roads, such roads may frequently occur so deep in the ground that this railway may pass over them like a bridge, or when this is impossible a single rail is made to turn up on a pivot at one end, or may be lifted out of its place. In fact, Mr. Palmer has provided for every contingency that can happen on a rail-road, and there is no doubt but that his plan is not only practicable, but may be useful in some cases.

1208. Now that rail-roads have become an object of national importance, not only for carrying great loads, but for a velocity of conveyance much beyond what was formerly contemplated, they are generally constructed upon roads formed exclusively for themselves, and on which no vehicles but those formed for the rail-road are permitted to travel, and this ought always to be the case when speed is desirable, and particularly when locomotive engines are used. Common carts and wagons passing in all directions over a railway, frequently injure it, besides which they may stand in the way and produce accidents; and when the road is exclusively railway, there is no necessity of keeping the rails down to the surface of the road, except in crossing common roads, since such depression is merely for the convenience of the passage of common vehicles; and when the rails are elevated, they will be more free from dust and impediment. Railways ought even to be fenced in, so as to prevent cattle getting upon them, as they frequently occasion delay and accidents.

1209. The form of wrought iron rail now most used and approved, is the edge rail, shewn in cross section at Fig. 270. The top part *a* and *b* for the wheels to run upon being gently rounded and about $2\frac{1}{2}$ inches wide. The figure at *a* has a double flanch or base running its whole length on each side, and *b* has this flanch on one side only, and *c d e* show the form of cast iron chair for receiving and holding the rails. It has a flat bottom plate to bed upon the bearing stone, from the middle part of which rises the projecting piece *e c d*. The opening *c d* should be wide enough to permit the bottom flanch of the rail to pass through it, so that a chair can be introduced under a rail without taking it up; and that done, the rail is fixed in its place by driving the very slightly tapered key or wedge *f*. The best way of fixing the chair to the block of stone, is to let the heads of iron screw bolts into holes in the stone, which widen as they go down, and to run them in with melted lead or iron cement, formed of iron borings, sal ammoniac and sulphur moistened with water and well caulked into its place. Nothing but the screwed part of the bolt projects, and that passes through holes in the bottom plate of the chair, which holes should be oval, to permit of lateral adjustment of the chairs to the right lined direction of the rails. It is further advisable to introduce a plate of thick sheet lead between the bottom of every chair and its stone support, as this not only produces a firmer seat, but prevents the nuts and keys becoming loose from the vibrations produced by rapid loads. One of these chairs and stone supporting blocks should be used at about every three feet distance, and the joining of two contiguous bars must always take place in a chair. Formerly, the plates were vertically halved and pinned together horizontally at each joint, so as to unite the whole line together, but this practice is bad, for the contraction and expansion of so long a line by changes of temperature, will throw parts of the line out of adjustment; but by the above method of wedging, each bar is independent, and the trifling change of length that occurs in each length is never perceived. The joining of the bars in the two parallel tracks of a rail-road ought to be broken, or not to occur upon an opposite pair of chairs.

1210. So far, we have only spoken of single rail-roads, but as it is impossible for carriages to move out of their tracks to pass each other, so one of two methods must be used to prevent the meeting of carriages on the same road. The first is that a set of flags or signal poles must be erected along the whole line, at such distances as to be visible from each other, and flags must be raised to signal that the road is occupied by a car or train, and thus restrain others from going upon it, except in the same direction; and the other is to provide short side rail-roads called *turn-outs* or *sidings*, so that one or other train may move out of the main track for a short time while the other is passing. In rail-roads of great traffic, neither of these are necessary, because two separate tracks are always provided, one being kept for passage in the one direction, and the other for the opposite direction. This of course is attended with double expense of every thing that regards laying down the tracks; consequently, in railways of less importance, the single road with turn-outs is generally adopted.

1211. The number of turn-outs or sidings, must depend on the nature and extent of the traffic; consequently, no rule can be laid down for the frequency of their occurrence; but they ought always to be placed in positions that command a long extent of view, so that trains may see each other and prepare for turning out long before they meet. The turn-out is nothing more than a short length of rail-road constructed on one side of the main line parallel to and as near to it as will permit the two trains to pass each other without contact. This short railway is connected with the principal line by curving or sweeping its two ends in such manner that they may come into and join with the main road. At each termination a long tapered cast iron wedge called a *switch*, is fixed on a pivot so that its point can turn from one track to the other, as shewn in Fig. 271, were *a b* represents part of the main right lined track, *d* the termination of a turn-out connected with it, and C the switch, which in its present position shuts up the turn-out road, and compels the wheels to continue in the track *a b*. But on moving the switch into the position *g*, shewn in another part of the same figure, the track *b e* will be shut up and the wheels will be constrained to move along *b f*, or into the turn-out, and will be brought back again into their former track by a similar contrivance at its opposite termination. These switches are usually moved by a series of partly underground levers, and a balance weight to fix them in the direction in which they may be placed. When trains meet away from a turn-out, there is no alternative but for that nearest to a turning out place to change its direction of motion, and go back again until it arrives at one. Such reversion of motion is produced by reversing the direction of power; consequently, rail-road cars and locomotive engines must be so constructed that they will move equally well in either direction. But when horses are used, the team must be detached and be yoked to the opposite end of the train. When a sudden turn at right angles becomes necessary, it is brought about by a *turning platform*, which is horizontal and sunk to the level of the rest of the railway, and circular that it may turn round in a circular brick cavity without impediment. The revolving circle must be of sufficient diameter to receive the four wheels of a loaded car when run upon it, and it is maintained in a perfectly horizontal position while it moves by a strong vertical iron spindle, and a number of sloping or diagonal braces that spring from its lower end. The platform turns upon the point of the spindle with so little friction, that it can be moved round with facility, and thus the car can be put into any direction for pursuing a new line of rail-road; but of course, the car must be stationary upon the platform during the operation.

1212. No rail-road of great length can be constructed without deviations from the right lined direction; and the curve, when necessary, should be as gentle or drawn from as large a radius as possible; first, because all motion tends to a right lined direction, and a loss of power always attends a deviation from that right line, particularly in long trains of cars; and secondly, there is danger of overturning, or at any rate running off the track from centrifugal force when a heavy body in rapid motion changes from a right lined to a curved direction, or *vice versâ*. The curves used are always circular, unless irregularities on the face of the country forbid such form, and the radii of the segments ought never to be less than 300 feet in length, and will be much better if they extend to lengths of from 1 to 2000 feet. Of course with such extended radii the ordinary method of describing circles or their segments by a line or wire fixed at the centre, and serving as a radius to be carried round, becomes impossible; consequently, such curves must be set out upon the ground by means of the theodolite, which for this purpose is placed in the centre of curvature; or if that should be impossible on account of woods, water, or other natural impediments to sight, may be placed in some point of the circumference, as nearly opposite as may be to the concave side of the curve desired. The telescope of the theodolite may then be moved round through equal spaces on its horizontal plate, such as 2, 4, 6, or even 10 degrees, and a radius having been measured by the chain from the position of the instrument to the point where the curve is to proceed from. The telescope must be moved a certain number of degrees, and a set of picket staves being set up in the direction in which it now points, a second radius exactly equal to the first must be measured in that direction. The extreme end of this new radius must then be joined to the first, by measuring a right line with the chain between the outer ends of the two radii, which line will evidently be the chord of the angle subtended at the theodolite, and we shall have produced an isosceles triangle upon the ground, the use of which is to determine the length of the cord, which should not exceed two or three chains. That done, there will be no occasion to measure other radii, but the telescope being moved through equal angular spaces, and the ends of the radii so produced being marked by pegs or picket staves, the one fixed chord that has been obtained must be swept from the point fixed in the last radius, until it coincides with the new one, and all the points at which such coincidence takes place, will of course be in the circumference of a circle having the radius first set out. This depends upon the principle in geometry, that equal angles always subtend equal chords of any one circle that is drawn from their common summits as a centre. And it equally holds good if the summits are on the opposite side of the circle, but then the chords will only subtend half the angles that would have been produced if measured from the centre.

1213. When once a mass of matter in rapid motion has had its motion changed from a right lined to a curved direction, it will more readily admit of the curvature being increased. Consequently, notwithstanding it is prudent to make the first change by a curve of very long radius, yet, after it has moved on that curve long enough to have acquired the motion proper to it, the curve may become gradually more bent, or be drawn with a shorter and shorter radius to produce greater deflection from the right lined direction. The opposite construction must be observed when changing from a curved to a right lined direction; consequently, if the curve has been gradually contracted, it must gradually open again or increase in radius when the curved direction is again to be converted into a right lined one; and every right lined direction must be so placed in respect to the curves, that they may always be tangents to such curves. When a very sharp turn is necessary, as for instance when a railway proceeds through the streets of a town, or into a warehouse, great length of radius is impossible; and the only way of compensating for this is by placing the exterior track, or that which has the largest radius, a few inches higher than the inner track. This will throw the carriage out of level, and cause the motion to be, as it were, round the base of a cone. The utility of this principle is fully exemplified in circus riding, where the horse and his rider moving rapidly round a circle of small radius, are constrained to lean considerably towards the centre to prevent their being thrown outwards by the effect of centrifugal force.

1214. The great alteration and improvement which has occurred of late years in the construction of rail-roads, is that formerly it was considered quite necessary to make the whole line, or as much of it as possible, a perfectly true or dead level. This level line was carried to as great an extent as nature, when assisted by art, would permit; and consequently required deep cutting in high ground, and much embankment, or raising up in low places to obtain the level. At the extremity of the longest continued level that could be obtained, when changes of elevation became necessary they were effected by continuing the railway either up or down a regular right lined slope, called an *inclined plane,* thus overcoming the difference of level all at once in a short distance, after which, the road resumed its wonted level character. At these inclined planes power became necessary both to draw the loads up, and to retard the natural velocity of descent in going down, and the cars or wagons were fastened to a rope or chain by which the power was exerted. In some instances, a double parallel railway was formed, and the rope by passing over a large drum or pulley, at their upper ends, connected them both, so that the weight of two or three empty cars descending, would draw one loaded car up, and the velocity of motion was regulated by a *brake* or apparatus to produce friction on the drum. This mode of proceeding answers very well, whenever there is a nearly equal weight of goods to pass in both directions, or where all the heavy goods have to descend, which is generally the case in mining operations. But if more weight has to ascend, than goes down, the counterpoising cars will soon all be at the bottom of the hill. To remedy this, horse power was applied to give motion to the drum and raise the carriages, the empty descending ones being used merely in assistance of the power. Horse power soon gave way to that of the steam-engine, and in all large concerns a stationary steam-engine was built at the top of each inclined plane, connected with a very strong endless rope, or one united at its two ends, which passed over a roller both above and below, so that as one half of the rope ascended by the power of the engine, the other descended, thus allowing loads to be moved in either direction by attaching them to the appropriate part of the rope.

1215. From the nature of such an arrangement, the inclined plane is necessarily right lined, and the rope is borne upon rollers to prevent its rubbing on the ground and wearing away, as it is not only an important element in the performance, but likewise in the expense of the machine, for such ropes are usually from five to seven inches in circumference, and are not unfrequently from one to two miles in continuous length. Such a length of rope is always difficult to manage on account of its expansion and contraction with different states of weather, which must be provided for in the construction of the machinery; and very serious accidents have frequently happened upon these inclined planes; sometimes from the breaking of the rope, but more frequently from the load being carelessly and insufficiently attached to it.

1216. Since the introduction of locomotive engines for drawing trains upon rail-roads, these costly and dangerous inclined planes have ceased to be formed, and stationary engines to be erected; because the increased velocity and momentum that is given to loads by the employment of locomotive engines, is found fully competent to carry them up inclined planes, provided the slope is not too steep; so that instead of going to a very heavy expense of cutting, or earth-work, to produce a great length of perfectly dead level, the natural surface of the country can be used to a greater extent than was at first thought practicable; and instead of accumulating all the rise or fall into a small space, and overcoming it all at once by an inclined plane, it is now distributed as evenly as possible over a great extent of line, thus diminishing the rise and fall to such an extent that it is barely felt in ascending, and should it become too steep for descent with safety, brakes are applied to the carriage wheels to increase their friction in moving, or even stop their rotation entirely, if necessary. Such a distribution of the varying level is called *graduating* the line, and the variations in level are called *grades*, which are said to be easy or steep, as the slopes are more or less gradual or rapid. As an instance of this mode of construction we may take the rail-road between Petersburg in Virginia, and the Roanoke river in North

Carolina, called the Greensville and Roanoke Railway. Going southwards from Petersburg it proceeds 3,219 feet, with a rise at the rate of 19 feet in each mile; it then begins to descend 13.70 feet per mile for the next 4,100 feet, after which it is dead level for the next 1,000 feet. It then ascends 32.20 feet in a mile for 8,750 feet, and then descends at the slow rate of 5.80 feet in a mile for 2,000 feet. It then ascends again at the same rate as before, viz: 32.20 feet in a mile for 8,800 feet, then descends 15.84 feet per mile for 3,000 feet;* thus rising and falling very gently through its whole extent, except near its termination, and there we find a descent of 50.16 feet per mile for 1,500 feet, followed by a steeper descent of 93.45 feet per mile for 9,100 feet, which again breaks into a dead level, 3,200 feet long, before it joins the river. The steepness of these last grades is certainly objectionable, but no better line could be found, and as they occur near the termination of the line at the Roanoke river, it is stated that the difficulty can be overcome by the going and returning Engineers helping each other, or by bringing lighter loads up the hill, and depositing them in a depôt or warehouse there, to be carried in larger quantities through the rest of the road.

1217. When locomotive engines were first tried in the collieries of the North of England, by Mr. Blenkinsop, one wheel at least of the engine had strong cogs, or teeth, round its periphery, and the railway, upon which it ran, was also a toothed rack, with its teeth placed upwards, in order that they might engage in those of the wheel. This precaution was deemed necessary for fear the wheel, to which the engine power was applied, might slip round upon the railway without giving motion, or motion with available force to the engine to drag loaded cars after it, and it is astonishing that this false notion should not have been removed by experiment for many years. Now it is well known that such teeth are unnecessary; that the periphery of the iron wheel may be turned in a lathe, and made quite smooth, and yet that it will hold upon an iron railway with sufficient friction to carry all needful loads, not only on level tracts but even up considerable inclinations.

1218. In the year 1829 the Directors of the Manchester and Liverpool Rail-road, in England, were desirous of setting the point at rest, as to whether stationary engines with ropes to draw the trains, or locomotive engines were the best to be made use of; and they therefore referred the full investigation of this subject to Mr. James Walker, one of the principal Civil Engineers of England, and to Mr. Rastrick, a manufacturer of steam-engines,

* Account of the Greensville and Roanoke Railway, in the Farmer's Register, Vol. V., p. 9. Petersburg, Va. 1837.

who immediately set about a minute examination, not only of the circumstances appertaining to the rail-road in question, but of several other railways in which both kinds of engines were used. The Manchester and Liverpool railway was generally so level, that none of its reaches contained slopes rising more than 1 foot in 880 feet, except in three places, where they constructed inclined planes. Two of these were each $1\frac{1}{2}$ miles long, the one ascending and the other descending 1 foot in 96 feet, and the third being a tunnel to pass through a hill for entering Liverpool fell 1 in 48 through a distance of $1\frac{1}{8}$ miles. From the pains Mr. Walker took in this investigation, and the quantity of valuable practical matter embodied in his report made in March, 1829, it is justly considered as a valuable document, containing all the best and most important information that could be obtained up to that date on the economy and management of loads upon rail-roads. The conclusions he arrives at are divided into distinct heads: 1st. The power of locomotive engines, or the quantity of work they are capable of performing. 2nd. Their consumption of fuel to perform that work. 3d. Their annual cost. 4th. The friction of ropes in stationary engines. 5th. The cost of such ropes. 6th. The wear and tear of wagons. 7th. The accommodation to the public. 8th. The comparative safety of the two modes. Each of these heads is separately discussed in an able manner, which our limits prevent us entering into, but the general conclusion is, that "taking the two lines of road as now forming and having reference to *economy, despatch, safety* and *convenience,* that the stationary reciprocating system is the best for putting the railway into complete working action at once; but should circumstances induce the company to proceed by degrees to proportion the power of conveyance to the demand, then locomotive engines are recommended generally on the line; but with fixed engines and ropes at the inclined planes, to draw up *the locomotive engines* as well as the carriages and goods."

1219. It thus appears clearly that at this period, locomotive engines were considered as incapable of surmounting inclined planes of considerable slope. One of the objections made to locomotive engines is that they seldom exceed 10 horses' power each, and an engine of this power generally weighs full 10 tons. The weight of the engine becomes a part of the load to be conveyed, and the power thus lost amounts to about one-tenth of the full power when moving the engine only $2\frac{1}{2}$ miles per hour. In the stationary engine all its power is disposable for drawing loads without any deduction for its own weight, and it may be kept constantly at work drawing a succession of loads, while on the locomotive plan, each train must have its own engine and separate fire, and by multiplying these, the expense of fuel will be greatly augmented. This is no doubt true, but against it, in the locomotive plan no ropes are necessary, and the friction and wear and tear of rope amply compensate for the increased expense of fuel, besides avoiding the danger of accident and delay from ropes breaking or becoming deranged.

1220. In consequence of this report the stationary engines were erected by the Manchester and Liverpool Company; but they publicly advertised a reward for the improvement of locomotive engines, the conditions of which were, that one engine should draw 20 tons on a level railway at the rate of 10 miles per hour, with a pressure of steam not exceeding 50*lbs.* on the square inch. This announcement caused several new engines to appear on the road in Oct. 1829, when they competed for the prize, which was awarded to the Rocket, which carried 9½ tons exclusive of its own weight, and that of its tender, 14 miles within the hour. From this time locomotive engines have been gradually improving, and in 1830, no less than ten were employed on this railroad, but within three years afterwards they were all thrown aside for new engines of nearly double power. The recent improvements in locomotive engines have therefore almost constituted them a new class of machines, while no improvements whatever have been made in fixed engines, in consequence of which, their use has been quite suspended.

1221. In June, 1831, an inclined plane was located at Parr's ridge, on the Baltimore and Ohio rail-road, and as this rose 197 feet in a mile, it was intended to place a stationary engine upon it; it having been considered as previously established, that no slope exceeding 35 feet in a mile could be surmounted by a locomotive engine. Some delay occurred in procuring the fixed engine, and horses were used for drawing up the necessary loads. In the mean time the improvement of locomotive engines had advanced to such an extent that it was determined to make trial of one upon this slope, and on the 22nd of March, 1836, the engine Andrew Jackson, weighing 8 tons 10 *cwt.*, and its tender 4 tons 7 *cwt.*, conveyed one double and three single cars, weighing 12 tons 18 *cwt.*, making, with the engine and tender, 25 tons 15 *cwt.*, up this inclined plane, which is 2,050 feet long, at the rate of 5 miles an hour, although the last 100 feet of the line rises 201 feet in a mile. The engine and train then advanced over the intermediate level, and commenced the ascent of the second inclined plane 3000 feet in length, 2800 feet of which rises 170 feet in a mile, and then 227 feet per mile. This inclined plane was passed over at between 5 and 6 miles per hour, until the engine arrived at the foot of the last slope, where it came

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to a stand; but by disengaging three single cars, weighing together 5 tons 1 *cwt.*, thus reducing the load to 20 tons 14 *cwt.* the engine advanced to the top of this slope in a steady manner. The steam during this experiment was equal to 63 *lbs.* on the square inch. Since this time the greater slope has been cut down and much reduced.

1222. It is obvious, therefore, that the efficient action of locomotive engines can now be extended to inclinations of a much steeper grade than was formerly contemplated, even a few years ago. But at the same time steep inclinations are very disadvantageous on rail-roads by losing power. Mr. Knight, to whom we are indebted for the foregoing particulars,* ascertained that if the friction is 12 *lbs.* per ton, which he estimates it to be, that the useful effect of an engine when moving on a level plane will be reduced to one-half in moving up an ascent of 25 feet per mile; to one-fourth on an ascent of 66 feet per mile; and to one-fifth at 92 feet per mile. Consequently, upon lines of great importance, where the higher velocities must be maintained in winter as well as summer, the grade should approximate as nearly to a level as practicable. Notwithstanding which, it is now believed that locomotive engines may be used on slopes of from 60 to 90 or 100 feet in the mile with greater advantages than was obtained from the fixed engines and inclined planes formerly employed.

1223. It may perhaps be expected that we should give some description of the improved form and construction of the locomotive engines above referred to; but the particular construction of steam-engines, mills and other machines, although a branch of the engineering profession, is one that is seldom attended to personally by the Civil Engineer, as he generally leaves the executive department to machinists, engineers and millwrights, who have regular workshops and devote themselves exclusively to the construction of such machines as he may order. To enter into such a minute description as would be useful to such persons, would occupy as many, if not more pages and plates than are contained in the present volume, on which account we must pass them over in silence. Should the public demand it, the author may probably be induced at some future time to publish a separate volume founded on his own experience of these practical subjects, but for the present we can only refer the reader to Nicholas Wood's Practical Treatise on Rail-roads, in which the older locomotive engines are described, or to the translation of a practical treatise on locomotive engines by the Chevalier F. M. G. de Pambour, 1836, in which their modern improvements to that date are

* See report of J. Knight, Esq., chief Engineer of the Baltimore and Ohio rail-road, appended to the tenth annual report of the president and directors of that company to the stockholders, October 7, 1836.

detailed. Valuable particulars of many other engines and machines will be found in Dr. Olinthus Gregory's Treatise on Mechanics, 3 vols.; and in Nicholson's Operative Mechanic; several of which works, it is believed, have been reprinted by Carey & Hart of Philadelphia.

Section II.—*Of Internal Navigation.*

1224. Next to roads and rail-roads, the object to which the attention of the Civil Engineer is most frequently called in this country, is the construction of navigable canals, or rendering natural rivers navigable. The question is frequently asked by those who have not considered the subject, why should artificial canals be constructed at great expense, in countries abounding with natural rivers? and why should not such ready formed water-courses be made available to the purposes of internal navigation? The reasons when investigated are sufficiently obvious. Rivers are the natural drains of a country for carrying off its superfluous water to the sea, which is the lowest level upon the earth, and to answer this purpose they must be inclined, so that their waters may descend. They therefore run through a continually descending line of country without any regard to a right-lined direction, and their courses are therefore constantly tortuous or crooked, while the water that flows in them runs constantly in the same direction, thus offering two obstacles to navigation, first by the distance between one place and another being increased by the bending of the stream; and secondly, as the stream always runs downwards, (except when rivers approach so near to the sea as to feel the effects of tides,) it will promote the passage of vessels in that direction, but will oppose considerable resistance to their moving in the opposite one. In addition to this, all rivers are more or less subject to freshets or floods, and the natural inclination is frequently so great as to cause the water to run off, and become so shallow as to be incapable of floating a boat for any long distance. Rivers likewise are seldom of the same width throughout, so that in narrow places violent torrents may form that would be dangerous to pass in one direction, and could not be passed in another during full water seasons. They also contain slopes or falls, with rocky and dangerous bottoms, and many other impediments to navigation that might be enumerated. The consequence is that it is frequently more troublesome and expensive to put a natural river into a good state for navigation, than it is to excavate and construct an artificial canal which shall be free from such objections; because in navigable canals the width and depth are uniform, and suited to the purposes required. The water is quite level and without current, consequently equally well suited to the passage of vessels in either direction. The line is made as straight and short as possible between the places of shipment and delivery, and a canal to be perfect should contain an equal, or at any rate an available quantity of water at all seasons of the year. Canals are therefore obviously more generally useful than rivers, unless they happen to be free from these natural obstructions, and then of course rivers are better than canals, as being generally more deep and wide, thus accommodating large vessels in greater numbers, and this generally applies to tide rivers where the current changes its direction twice in every night and day.

1225. The engineering operations for improving the navigation of such natural rivers as contain obstacles, consist in forming canals across necks of land, to cut off circuitous bends and form better and nearer connexions between the straighter parts of the stream. Cutting away and widening the banks or shores of narrow places, and cutting away timber or sharp rocks that might be dangerous to vessels, and deepening the shallow places by the dredging machine, (1135,) or other convenient means. These several operations by diminishing the resistance to the motion of the water and increasing the inclination of the bed, (which is the natural consequence of shortening the stream between any two given points,) will permit the surplus water of floods to escape more easily, but will be productive of the evil of making the river more liable to drought or shallows in short water seasons, consequently these alterations almost constantly require to be followed up by the introduction of dams or weirs and locks.

1226. A *dam* is a permanent obstacle to the passage of water, except over its top surface, and is built transversely across a river for the purpose of keeping back the necessary depth of water above it. The surface of the water which before had one general slope or inclination, is now rendered more level, and as this nearly level line will intersect the general slope of the river at some point behind the dam, another dam will be then necessary for the similar purpose of maintaining depth in the reach behind it. A river is thus converted, as it were, into a kind of staircase or series of nearly level reaches, each of which must contain water enough to float craft within itself whenever the general supply of water is such as to reach the tops of the dams; and whenever there is a greater quantity, the surplus will run over their level top surfaces. The connection between one reach and another is made by means of a lock, to be hereafter described, one of which must be constructed in, or form a part of each dam.

1227. A *weir* is likewise a construction formed across a stream and is similar in its purpose and effect to a dam, but is moveable instead of a fixed and permanent obstacle to the passage of the water, or one which can be put up and taken away at pleasure. It consists of a strong timber framing of long piles driven into the bed of the stream, so that their tops may project considerably above the greatest height the water can rise to, with diagonal braces to resist the weight of the water. Horizontal transverse beams are framed into the upright piles to support a set of paddles or shuttles, each about 10 or 12 inches wide, and jointed or planed flat; they are placed close together quite across the stream, their length being such as to reach to, and abut against a horizontal sill of timber laid entirely across the bottom of the river, and another line of timber nearer to, or above the surface, while their tops extend to such height as may be necessary for penning up the necessary depth of water. Each shuttle has a separate handle projecting upwards, to be taken hold of for placing or removing it. The weir requires a lock for the passage of vessels as well as the dam, and their operation on the depth of the river is the same; but the weir is better suited to streams that are subject to great and sudden freshets; because in summer or short water time, the whole weir is kept close or shut to retain as much water as possible; but in winter and floody seasons, any number of shuttles, or the whole of them may be taken up by means of a stage constructed for the purpose, and a barge to contain them, so that the whole area of the river, or any required part of it, can be opened for the passage of the water within a single hour. The river Thames in England, remarkable for the immense traffic that is carried on upon it, is very subject to heavy floods as well as to short water; but its navigation is constantly preserved through all seasons by about twenty of these weirs and locks built at convenient intervals between Richmond and Oxford, beyond which the navigation is continued by canal work. These weirs are kept close during summer, but are taken up in the fall and during winter, when there is no scarcity of water, and the navigation can be carried on through the weir, instead of the more tedious passage of the lock; and when the dry season approaches, the necessary height of water is maintained by putting down as many of the shuttles as may be necessary.

1228. On the subject of navigable canal formation, little can be added to what has been mentioned in the preceding chapters. The same survey of country, levelling, map and section, will be required as for a road or rail-road; but in selecting the line, the lowest instead of the highest land must be preferred, so as to avoid the expense and other inconveniences of deep cutting, and to insure a plentiful supply of water at all seasons. While a road should be located above or out of the reach of flood water, a canal on the contrary must be placed so low that the intended surface of its water shall be level with that of the river or stream that is to supply it, because water will not rise above its level, unless when forced to do so by the exertion of some expensive mechanical force. This constitutes the chief difficulty in locating or setting out a canal, because, notwithstanding it must be kept low, for the reason just stated, its side embankments must be so high as to be constantly above the flood water to which most rivers are subject. The effects of floods or freshets require to be most cautiously guarded against in canal work, for no earth work will stand against a rush of water over its top. If, therefore, a canal should be so located as to permit flood water to pass over it, there would be little doubt of its being destroyed; while, on the contrary, if the water rises to within an inch even of the top of the banks, but cannot get over them, it will be safe. On this account canals in low positions are frequently made much deeper and wider than necessary, for the mere purpose of obtaining a sufficient quantity of soil to raise the side embankments above the greatest possible height to which a flood water can rise; and *this precaution must ever be held in mind as the only means of securing and rendering the work durable,* when executed in positions liable to such accidents.

1229. The width and depth of a canal must be regulated by the size of boats intended to work upon it. To save needless expense in cutting, such boats are usually made very narrow and very long, which form permits them to carry considerable tonnage, and is rather beneficial than detrimental as they seldom have to turn, and expose but a small sectional area to the resistance of the water when moving. But when a canal has to receive vessels from other navigations, its width must be made in accordance, and should always be such as to permit two boats to pass without contact. A horse towing path, must always be provided on the top of one of the side banks, and this from circumstances may be obliged to change from one side to the other, but should do so as seldom as possible; and all changes should take place at bridges, that the horses may cross the water without delay. The bridge arches should be so wide as to permit the towpath to run under them, and they should be high enough to permit high and light cargoes to pass without obstruction, as well as for preventing accidents to persons standing in boats; but the span need not exceed what is necessary for the towing path and the free passage of one boat. The best form for canal bridges when built of brick or stone, is upright piers with an arch that is a segment of a circle, as this allows greater headway both for the towpath and cargo than the semicircular arch, although this last is very commonly used. The draw and swing bridge (576 and 578), are frequently placed over canals instead of permanent bridges.

1230. Whenever a canal has to descend from a high to a low position, and a plentiful supply of water from a river can be obtained at its upper end, no difficulty attends the execution. The descent or fall from one end to the other being ascertained, will determine the number of locks to be used; for the fall in each of these should, for obvious reasons, be equal, and should not, if possible, exceed six or eight feet to the lock; for if deeper, too great a strain is thrown upon the gates and other work by the lateral pressure of the water, and the time occupied in passing them will be unnecessarily prolonged. The contents of the locks should be equal, in order that the water discharged from an upper one may be just sufficient to fill those below without surplus, which would run to waste.

1231. As such canals are constantly descending by steps at each lock, it frequently happens that a lower reach of a canal may fall upon the same level as a lower part of its river of supply, or some other stream or rivulet near it, or it may be made to do so by a suitable quantity descending in its locks, and if so, water may be taken into it below as well as in the highest reach, by cutting a ditch or canal of communication between such river and the particular reach of the canal, and such communications are called *feeders*. All canals receive their water by feeders, which are level cuts, sometimes of miles in length; while at others, the canal itself runs into and joins the river, a part of which is frequently used instead of a canal, provided it is free from impediments and not subject to much variation in the height of its water.

1232. In order to maintain the water at one uniform height in canals, or rather to prevent its exceeding the maximum limited height, and thus prevent its overflowing the side banks, each reach of a canal should be provided with at least one *safety dam* or *tumbling bay*, which is a strong construction of stone, brick, or timber, formed in the side bank in a substantial water-tight manner, having a level top or surface that accords in height, and level with the highest surface the water is intended to have. This level must be some inches below the general level of the banks; consequently, if the canal should at any time receive too much water, it will not be retained above the top of the tumbling bay, but will discharge itself and run to waste. Of course, overfalls or tumbling bays must be placed in such positions that the waste water may be delivered into a river or some water course capable of taking it away without harm or destruction to any useful part of the work. Feeding rivers ought, when possible, to have thesame kind of over-falls, in order that they may be unable to send a greater height of water into the canal than may be beneficial to its operations. Feeding ditches if deep, should also have dams across their ends that communicate with the canals, and these should be built level with the lowest water that will render the canal available. By this precaution, the water can never run out of the canal into the feeding stream if it becomes low, and it will always furnish water when it contains more than their height. When canals receive additional feeding streams in their lower reaches, the lower locks may be made deeper than the upper ones if necessary, without detriment.

1233. Notwithstanding the total fall of a canal that is fed from its upper part only, should be equally divided among its locks, yet it does not follow that the locks should be at equal distances from each other. It may happen that a country will admit of a perfectly level line of canal for miles, and then may fall suddenly so as to require several locks which would accordingly be placed close together. Locks, therefore, are distributed into those parts of the line which stand in need of them, and where, from the natural declivity of the country, they can be executed with the least excavation and expense, and especially in such manner as not to involve the next reach below them in the heavy expense of deep cutting.

1234. The lock so often referred to, is an ingenious contrivance for floating vessels from one level to another without any other mechanical aid than the flow of the water itself. It consists of a chamber with upright parallel sides, and a bottom which forms part of the canal. Its length must be greater than that of the longest vessel that has to pass through it, its width is usually sufficient to contain two such vessels lying close and parallel to each other, and its depth must be equal to the difference in level of the upper and lower reaches of the canal, in addition to such depth of water as may be capable of floating the vessels when in their lowest position. The action of the lock depends on the established fact, that when two quantities of water communicate with each other, they will rise or fall to one common level, and its operation will be seen by inspecting Fig. 272, Pl. IX, (the frontispiece) which is a longitudinal section, and 273, which is a ground plan of a lock. In Fig. 272, let the dotted line *a* be the surface of the water in the upper reach of the canal, and *b* that of the water in the lower reach, *c c c* the coping or top of the wall forming one side of the lock chamber, *g* the bottom of the lock level with, or in about the same line as the bottom of the lower reach of the canal, *i* the bottom of the upper reach, both which are paved or boarded, and *e* and *f* two pair of gates which shut in a water tight manner, so as to confine any quantity of water that may be admitted into the chamber formed by them and the side walls and bottom. Each pair of gates contains a shuttle or valve *h*, which can be opened from above by a rack and pinion *k*, for permitting water to pass through the gates while closed. Things being thus arranged, suppose that a barge is floating on the surface of the upper water at *a*, and has to be lowered and passed into the lower reach *b*. The gates at *e* and *f* being both closed, the shuttles of the upper gates *e* must be opened, when water will pass through them from the upper reach into the chamber, and will soon elevate the surface *b* of the water within the chamber to the same level as that at *a*, and when this is done there will be an equal pressure of water both before and behind the gates *e*; consequently they can be opened by their balance beams *n l*, also shewn in Fig. 194, Pl. VI. (969,) and the barge can be floated from *a* into the chamber of the lock. The upper gates *e* with their shuttles, must now be closed again, and that done, the shuttles in the lower gates *f* must be opened, which will permit the water before confined in the chamber of the lock to flow out into the lower reach, thereby bringing down the surface of the water within the lock, and the boats floating upon it to its former level *b*, which is even with the surface of the water in the lower reach. There will now be an equality of height in the water before and behind the lower gates, so that they in turn can be opened and the barge floated into the lower reach. If, on the contrary, it is desired to raise a barge from the lower to the upper reach, the lower gates must be open—the vessel must float into the chamber—the lower gates and their shuttles must be closed—and now the shuttles of the upper gates are opened to fill the chamber with water and raise the vessel to the height of the upper reach, when the upper gates are opened, and the vessel proceeds.

1235. Whether a barge is raised or lowered through a lock it thus appears that the quantity of water necessary for the operation must be taken from the upper reach, and is never restored to it again, which is a reason for making the chambers as small as possible, consistently with the safety of the inclosed vessel or vessels; for if a lock is worked without any barge in it, the entire quantity of water necessary for filling the chamber must be let down, but if a barge or vessel very nearly occupies the capacity of the lock, it will hold the place of the water and the loss will be comparatively small. The great difficulty in general to be contended with in canals is want of water, especially if the feeding stream is occupied by water mills, and of course every precaution should be used to economize its useless expenditure. In large and deep locks a culvert of brick-work closed by a sluice at its upper end, is used to convey the water from the upper to the lower reach, as shown at *m n m*, Fig. 272. This culvert or iron pipe is constructed or built in the exterior brick-work, and prevents the splashing of water that attends the use of the upper gate sluice, whenever its position is above the water in the lower reach, which is the case in the drawing.

1236. The building a good, sound and durable lock is considered a nice operation, for it is attended with several difficulties, such as the difference in level between the two reaches of canal, which always produces a tendency in the water to percolate and insinuate itself behind the side walls and under the bottom, by which the soil is sometimes washed away and the work undermined. The unequal pressures to which the work is subject from the chamber of the lock being alternately full of water, and empty, the heavy pressure, and absence of any pressure at all alternately upon the gates, and particularly the lower pair, and the lateral pressure of the soil against the side walls, constantly pressing them inwards, together with the careless manner in which the heavy gates are often run together, with a head of water upon them producing great concussion constitute altogether an irregularity of force and pressure that it is difficult to guard against.

1237. The locks and weirs on the river Thames, between London and Oxford, before referred to, are under the care of, and are built and repaired by, the corporation of the city of London, who spare no pains or expense to make them as perfect as possible, and yet they are made wholly of timber strengthened by iron, which material, notwithstanding its liability to decay, is said on the experience of the city Engineers and surveyors to be the best and cheapest, on account of its being tough and more capable of withstanding the shocks and blows the work receives from the large and heavy craft that navigate the river, as well as the effects of floating ice in winter, and the locks are maintained by a tonnage toll paid by every vessel on passing them. In the London and West and East India docks, in which the locks are all capacious enough for large ships to pass through them, they are made of bricks with stone angles, copings and defending strings; and in the generality of canals the locks are of brick-work, with some parts of stone.

1238. In general the bottom of a lock may be laid with good sound timber upon piles, because this part is constantly covered with water. Short piles are therefore driven over the whole bottom at proper distances to support longitudinal sleepers, which are again crossed by transverse pieces, so as to form a grilliage, which is trenailed down upon the pile heads previously cut level. All the spaces between the gating must now be carefully puddled, unless that operation has been done before the grilliage is laid. The whole bottom is then covered with $2\frac{1}{2}$ or 3 inch plank, running lengthwise of the chamber. If the lock has to be finished in timber, vertical piles may next be driven at about two feet apart, to form the side walls, and these should terminate in a horizontal capping piece of timber running the whole length of the lock on both sides, and taking hold of all the piles by being halved into, or morticed upon them. The top or capping piece, or every third or fourth pile under it should, moreover, be secured by land ties, which are generally formed of whole round timber of from 12 to 20 feet in length, according to the nature of the soil, disposed as shown in Fig. 273, in which a is the stick of round timber so halved, dove-tailed or otherwise fixed to the vertical piles or to their capping piece, as to be incapable of drawing or giving way. The outer end of this piece is similarly dove-tailed or halved on to another but shorter stick of whole timber c, and immediately within this two piles d d, are driven into the ground, which should be in contact with the piece c, or else wedges must be driven between it and the piles, so as to render it impossible for the side walls of the lock to incline inwards without carrying the piece c, the piles d d, and a large quantity of solid ground with them. In using land ties, the piece a usually inclines downwards, so that its outer end, and the piece c, together with the piles, may be all covered with earth, so that no part of the tie appears out of the ground when the work is finished except the end that joins the side of the lock, and this even is frequently concealed in timber locks, and is constantly so in those of brick or stone, because in these materials the tie is connected to the wall by another transverse piece of timber b, which is built into the centre of the wall. The vertical piles to form the sides having been driven so as to range perfectly with each other, are planked with stout plank on the inside faces, or inside of the lock chamber, and the side walls when finished should be vertical, or very slightly battered back, and perfectly right-lined and smooth from one end to the other, with the exception of two recesses on each side marked x x in Fig. 273, which are to contain the gates when they are open; consequently their depth and extent must be governed by the thickness and radius of the gates. The object of these recesses is that when the gates are open the whole inside of the lock may be flat and smooth, and free from all projections that vessels might strike against, and thereby injure themselves or the lock. As, however, locks are always much narrower than the canals of which they form a part, their extreme ends must splay or open to the full width of the canal, and even some distance beyond it; and this is effected by forming oblique wing-walls which may be curved as at g g at the left hand end of the figure, or right lined, as at g g on its right hand end.

1239. The parts of a lock are the same whether it is built in timber, bricks, or stone, and having stated how a lock may be partly constructed in timber, we shall next state how it may be formed with other materials. In brick and stone locks it is not uncommon to make the floor or bottom of timber, but such timber should always be supported upon piles, unless the lock is built in stiff clay, or soil that will offer effectual resistance to the passage of water. Sleepers or joists will be necessary whether piles are used or not, because the flooring planks must be spiked or trenailed down to them. If joists only are used they must be placed transversely, that their two ends may work into the side walls for holding them securely in their places; and whether the bottom is formed of timber, bricks, or any other materials, the greatest care must be taken to render it impervious to the passage of water under the work by puddling, brick-work laid in cement grout, or beton, because there will be a considerable head or difference of level in the water to guard against in every lock; and if the upper water finds a passage behind or under the work, be it ever so small in the first instance, it will gradually enlarge, and there will be danger of the earth washing away, and the lock blowing up. Should the soil be stiff clay, a flat bottom of brick-work or masonry may be laid all over it, as shown in Fig. 272 by t t, and if bricks are used the safest and strongest mode is to work the upper or finishing course with bricks on end laid in cement. Should the soil be of a less trustworthy character, the bottom will be better if formed by an inverted arch, which may be either semicircular or semielliptic, the last form being adopted when from wetness of soil or other causes it may not be possible to sink deep enough into the ground to build a semicircular invert. The side walls of the lock chamber may stand upon the spring of this invert, but when the bottom is flat, these walls are built like all others, from a level foundation trench, piled and planked or not as may be necessary, but always commencing some inches below the extreme foundation of the bottom, and oversailing, or standing upon it for a half brick in thickness when it arrives at the upper level, to assist in keeping the floor or bottom down in its place. The side walls, though perfectly smooth within the chamber, should be built with buttresses or counterforts on the sides next the land, as shown at *y y*, to give them additional strength; to assist in which a land tie, such as already described, is also introduced near the top of every buttress, on both sides, in the manner shewn in the figure at a b c d.

1240. The lock gates are shown in plan in their real position, when shut by *e e*, which are called the upper, and f f the lower gates in Figs. 272, and in elevation in Fig. 273, and a front view of one of them is given at Fig. 194 of Pl. VI., already described (969,) to show the particular construction, such figure being an upper or short gate. The height of the upper gates must be such as will extend from the upper surface of the paved or planked bottom *i* of the upper reach, Fig. 272, to the extreme top surface of the water contained in that reach, while the lower gates f are about twice as high, or extend from the paved bottom of the lower reach d, to the full water level of the upper reach. These gates each consist of two strong vertical posts of oak or other strong timber *e* and *f*, Fig. 194, united together by the requisite number of horizontal timbers *g g g* of the same size, and then planked over diagonally, as at m, m; or sometimes the planks are fixed vertically, and one strong diagonal timber brace or strut in separate pieces is let in between the horizontal beams. The horizontal beams are not at equal distances from each other, but are put closer together near the bottom of each gate, because the pressure of water increases as its vertical height, consequently gates require to be much stronger near their bottoms than at their tops. This is shown in the figure. These beams are morticed into the vertical ones, and further secured by what are called T and L plates of iron, let in flush with the surface of the timber and firmly spiked to it in the positions shown in Fig. 194. The vertical posts e and f are formed of square timber, but the outer side of e is cut into a bevil form in order that it may meet and make a flat, smooth, and water-tight joint, called a *mitre*, with the similar post of the opposite gate, when both are placed in their proper angular positions in the lock and are shut, on which account these posts are called *mitre* or *shutting posts*. The nature of the joint they form is shown at n, n, Fig. 273. The other post f, Fig. 194, is called the *quoin* or *hanging post*. Its outer side is worked into the form of a segment of a circle, upon which the gate turns or rolls in a vertical curved cavity made to fit it, and called the *hollow quoins* of the lock. In brick locks the hollow quoins are always worked out of large free stones set in their proper places in the brick-work, as shown at z z z z in Fig. 273; but in timber locks they are frequently hollowed out of very large sticks of timber, or are occasionally made of cast iron with flanches or projections by which they may be fastened to the wood. At all events they must fit the quoin posts of the gates when shut so accurately as to permit little or no water to pass between them; and they are so fixed in the work of the sides of the chamber, that when the gates are quite open they will fall back into the recesses x x, without leaving the hollow quoins, and thus produce one even, smooth, and uninterrupted surface on the insides of the lock chamber. The gates are not hung by hinges, because it is necessary they should have some play, or freedom of motion by which they are permitted to adjust themselves into a water-tight position when the pressure of water comes upon them. They are therefore fixed by an iron gudgeon or pivot *i* let into the lower end of each quoin post, and which is received into a cast iron step or pivot hole fixed in the floor of the lock. The hole in this step is not cylindrical, but oval, so that the motion of the quoin post shall not be confined to a fixed axis, but may shaft an inch or more to allow for the mutual wearing away of the quoin post and hollow quoin by use, thus maintaining a tight joint for many years. The upper end of the quoin post is held by a small part of its top, above the gate, being made cylindrical, and this part is embraced by a flat iron strap *h* passing round it. This strap is in two pieces, one of which has long tails with corkings that are secured by lead or otherwise to the top of the upper stone or material of the hollow quoin, and the other piece is semicircular, but with long ends, fitting on to the fixed part, and attached to it by an iron gib and wedges, so that it can be moved at any time for taking out the gates, or can be adjusted so as to produce any requisite pressure between the quoin post and hollow quoin at pleasure. The great weight of the gates, and particularly of the lower pair, which are never covered by water on both sides, would cause them to sag or droop, and consequently to rub against the floor of the lock so as to render them very difficult to open; and would also injure their water-tight joints, if some expedient was not resorted to for preventing this effect. In the first place the planking is put on diagonally, as shown at m m, Fig. 194, or a strong diagonal strut is used, or both may be used conjointly, and secondly, the heavy balance lever n l, Figs. 194 and 273, is morticed into the mitre post, and upon the top of the quoin post, and the weight of its end l (which, by its length, also forms a powerful lever for opening and shutting the gates,) should be such as will exactly balance that of the gates when the highest head of water is upon them, thus counteracting any tendency the gates may have to sink or sag, and causing the moving of them for opening or shutting to be comparatively easy.

1241. When gates are very large, as when they occur in shipping docks, or ship canals, these *balance beams* must be very long and massive to be effectual, and they would not only be unsightly, but inconvenient from their long radius. In such locks they are therefore not used, but a strong cast iron wheel or runner is fixed in proper framing to one side of each gate, and this runs upon an iron rail-road or quarter circle of cast iron fastened upon the floor of the lock in the direction shown by dotted lines near x x x x, in Fig. 273, and these wheels answer the purpose of preventing the gates from sagging, while they diminish the friction of their motion. When gates are thus constructed they are opened and shut by chains attached to their lower parts, and these chains extend to, and coil round, a vertical shaft, the top of which terminates in a capstan that stands above ground, and is turned by handspikes or levers applied into its holes whenever the gates have to be moved. The capstan reaches to the full depth of the lock, and works in a cylindrical shaft or well, lined with brick-work, and is covered over on its top. These capstan wells are constructed in the brick-work of the sides of the lock, and are generally four in number for each pair of gates, two being placed on each side, one for opening the gate nearest to it, and the other for shutting the gate on the opposite side. The chains pass through iron pipes built in the side walls and making communications between the chamber of the lock and the wells, and the water of course enters these wells and stands at the same height in them as in the part of the lock to which they open.

1242. From the nature of lock gates, it will be apparent that they cannot be brought into contact with the bottom of that part of the lock in which they work, without producing such friction as would render them incapable of motion without great force, particularly as the bottom of every lock chamber becomes a depository for that quantity of mud and silt which will always flow more or less from the upper reach. The bottom of the gates must therefore be kept from one to three inches, according to the nature of the soil, and its being more or less stony above the floor of the lock; consequently no water-tight joint can be made between that floor and the bottom of the gates. This joint is therefore produced by a framing of timber called the *mitre sill* of the lock, which not only forms the necessary water-tight joints, but affords very useful and effectual support to the gates against the pressure of water to which they are subjected. The mitre sill has an appearance similar to the framed principal or truss of a roof. Its form in plan is shown at q in Fig. 273, which is the mitre sill of the upper gates, and at r, which is that of the lower gates, and the same letters of reference indicate the same parts in the longitudinal section Fig. 272, in which last figure it will be perceived that although the major part of the mitre sill stands or projects above the surface of the floor of the lock, yet that a part of it is let into, or is below that surface, to give it greater strength and render it more water-tight.

1243. The mitre sill consists of four strong pieces of timber, one of which is a tie beam running transversely across the lock, and being so long that its two ends may work into the side walls under the hollow quoins. Two others are in the nature of principal rafters which meet in a point in the centre, and tenon into the tie beam at their two feet in such manner that they may make the same angles as the gates, and be parallel and close to them, for on these pieces the water joint depends; and the fourth is in the nature of a king post, and joins the meeting of the two rafters with the centre of the tie beam, by which the expansive tendency of the rafters is in some measure prevented. The whole mitre sill being strongly framed together is laid horizontally in the work, and firmly built in, the interstices between the pieces being filled in with brick or small stone work, laid in cement. The water-tight joint at the bottom of the lock gates is not therefore formed by their bottoms coming into contact with the floor of the lock, but by the insides of the lowest horizontal beams coming into close contact with the vertical outsides of the rafters of the mitre sill; therefore the placing and due adjustment of this part of the lock is of the greatest importance; and to prevent the mitre sill from giving way to the sudden concussions that may arise from a careless shutting of the gates, which close with great violence, owing to the difference of level of the water on the two sides of the gates, the tie beam of the mitre sill is partly buried in the solid masonry of the aprons of the lock, sometimes made wholly of timber upon brick or stone foundations; or if the aprons are built wholly of these materials terminated by arches, as shown in the plan Fig. 273, in which it will be seen that the lower apron extends farther than the upper one, because the lower apron from the greater height of its gates requires more strength, and may be continued to any distance without detriment to the lock, since this apron is built wholly in the bottom of the lower reach of the canal, while the upper apron, if continued, would not only project into the chamber of the lock, and require it to be made longer, thereby increasing its expense, but might prove dangerous to boats, by one of their ends lodging upon it while the water was high and it was concealed by it. To prevent the occurrence of such accidents to vessels, the upper apron is therefore made short, or extends as little into the chamber of the lock as possible, and has its edge or *arris* rounded, as shown in the section Fig. 272, so that if the end of a vessel should lodge upon it, it will gradually slide off.

1244. The part of a lock which requires the greatest attention on the part of the Engineer and builder is the dam and upper apron, together with the upper wing-walls, because these have to sustain the whole head of water due to the fall in the lock, and must therefore be made very strong to resist the blows and concussions of descending boats often carelessly navigated, and must also be perfectly water-tight. The dam consists of a solid block of brick-work or masonrys, Fig. 272, even though all the rest of the lock should be of timber. This must be built of the hardest and soundest materials laid in hydraulic mortar or cement, and should be supported on piles to prevent the soil under it from being washed away or disturbed. The upper wing-walls g g require the same attention, and should not only run quite across the full width of the canal, but some distance into the dry land on each side of it to prevent the possibility of the upper water getting either behind or through them. The more effectually to prevent this, both the outsides of a lock should be carefully puddled throughout its whole extent, whether it be built with timber or masonry, and this renders the use of buttresses and land ties the more necessary; because all the soil in contact with the lock sides is in the first instance in a semifluid state, and will therefore be more likely to cause the sides to *cave* or incline inwards. It will likewise be observed in the plan, Fig. 273, that the lock sides vary in strength and thickness, independent of the buttresses, and this is because different parts of these sides are exposed to different forces. The greatest force, and that which requires the most particular care to guard against it, is the tendency to lateral spreading in the lock gates from their angular position when shut, and this requires that the hollow quoins and the work that surrounds and supports them should be stronger than any other part of the work, particularly in that direction which is the resultant of the two forces in action, viz: the tendency of the water to press forward in the direction of the lock, and the lateral spread of the lock gates which will act in a direction at right angles to it. The hollow quoins should therefore be well supported in the descending direction of the canal and on their two sides; and next to these the wing-walls will require attention from the weight of water and concussions to which they are exposed.

1245. The lateral pressure produced by the head of water on the lock gates will vary with the angle the gates make with each other, and Engineers are not well agreed as to what this angle should be to produce the best effect. If the angle is too acute, the head of water will not produce pressure enough to close the mitre joint, and drive the quoin posts home into the hollow quoins, and the lock cannot be made water-tight; and on the contrary, when the angle is too obtuse, so as to let the two gates come nearly into a right line, the pressure becomes so enormous that the mitre joints and quoin posts become bruised and maimed, and soon give way. The rule which the writer has adopted from his own experience, and has found to answer well, is to make the angle such that the king post of the mitre sill may be one-fifth of the length of the tie beam or width of the lock chamber when the head of water to press on the gates amounts to five feet, or any height more than that and less than nine feet. When the pressing head is under five feet a more obtuse angle is necessary to produce close shutting, and then one-sixth of the width will be better. But when the head is very great, as above nine feet, the king post may have one-fourth of the width, and will produce close joints.

1246. It is needless to say any thing on the construction of the sluices that are formed in gates, and the rack and pinions by which they are worked, to open passages for the water from one level to another, further than that they are better made of cast iron than of wood, because the former material is less liable to wear, and to swell and become fixed. A broad plank is usually fixed on the convex side of each gate, which not only serves as a bridge or scaffold for opening these sluices, but as a foot bridge for passing over the canal whenever the gates are shut. A vertical groove, *o o*, above the upper gates, and a similar one, *p p*, below the lower gates, from three to four inches wide, should also be worked in stone or sound brick-work in every lock. These are called *stop plank grooves*, and are for the purpose of receiving and retaining pieces of three or four inch plank cut to a proper length to fit into them, and planed or jointed on their edges so that if any repair becomes necessary to the lock, or the gates should require to be taken out, this can be done without the loss of all the water that is above the lock; because by introducing the stop plank, and smearing their joints with clay (if necessary) before the gates are taken up, most of the water can be saved.

1247. When canals have an immense traffic of boats running in both directions upon them, double locks are formed to avoid delay. That is to say, instead of contracting the canal into the width of a lock, and terminating it by wing-walls, two locks are built parallel to each other, and close together, being only divided by a thick and substantial wall, which thus becomes the side in common of them both: one lock is reserved for boats passing upwards while the other is kept for those going downwards, so that no delay or confusion is occasioned. Such is the construction of the locks on the Regent's canal which encompasses the whole northern part of London, and unites the Grand Junction canal which branches into the northern parts of the island of England with the river Thames below its bridges, and thus opening a direct communication between the shipping port of London and all other parts of the country.

1248. It has been before stated that whenever a canal descends regularly from a high to a low position, and has a plentiful feeder at its upper extremity, there is little difficulty in its execution. But it is frequently necessary to carry a canal over a high ridge or an elevated country, and then it is that the skill and investigation of the Engineer are called into action. A canal of this description differs in no respect, either in its locks or in itself, from that already described; but since all locks can only work whether the traffic is ascending or descending, by water running from a higher reach into the lock, and from thence into the next reach below it, it is evident that all the necessary water must be supplied from the upper reach. Whenever, therefore, a canal has to pass over an extent of elevated ground, it must look downwards in each direction from the highest point, because from that all the water to work in both directions must be supplied; and the difficulty of executing canals of this description arises from the general scarcity of water courses, or efficient feeders, in the high lands. It frequently happens that a long line of perfectly level canal can be formed in elevated positions, but it seldom occurs that sufficient feeders can be found there to supply the double lockage downwards from each end of this elevated line, which is called a *summit level.*

The Grand Junction canal before referred to, is of this description, for it rises gradually from London to near the centre of the island, and then falls again in proceeding northwards to Manchester and other northern manufacturing districts; and it happens that no water can be obtained by natural means to supply its summit level, which, therefore, depends on large reservoirs which have been excavated to catch rain water, and the power of a large steam engine which works pumps and elevates the water of a neighbouring river, whenever the natural supply becomes insufficient. The Regent's canal at London is similarly circumstanced, and is supplied with water from the river Thames whenever its other sources fail. Water thus artificially supplied is always expensive, and such means of obtaining it should never be resorted to when it can be procured by natural means.

1249. Before constructing a canal of this description, a nice calculation becomes necessary; first to determine as nearly as may be, what the quantity of traffic such a canal is likely to have, and what income it will yield in the shape of tonnage tolls. Against this must be placed the cost and maintenance of pumps, and of a steam engine, water-wheel, or horse power to work them.

The number of boats expected to pass, and the size of the locks, will determine the quantity of water necessary for working such a canal; and this being fixed upon will determine the size of the pumps, and the number of hours they must work each day to yield the supply, from whence its expense will be easily deduced, and it may be determined whether such a canal will be profitable or not. The difficulty, however, is generally confined to the upper reach alone; because as the canal descends feeders will generally be found to supply its lower reaches, and therefore it often happens that notwithstanding a summit level may be attended with great loss, yet it is resorted to and constructed for the mere purpose of continuing a long line of communication that may be profitable at its lower ends, and yet would, perhaps, be useless if broken off in its central part; it therefore becomes profitable to submit to a small loss for a general good.

In some instances where a summit level cannot be obtained without inordinate expense and inconvenience, the two descending canals are united by a rail-road over the intervening high land, which continues the line with no other inconvenience than the unshipping and reshipping of the goods.

1250. From the difficulty of obtaining water in summit levels, and positions where it is very scarce, the attention of Engineers has been turned to the improvement of canal locks, with a view to prevent their wasting the full quantity of water they are capable of containing every time that a boat is passed. The directors of the Regent's canal thought this so valuable a desideratum that they offered a large reward to any person that would contrive a lock which should waste no water, and a scale of smaller rewards for others in proportion as they diminished the loss. This brought forward a number of devices of great ingenuity, all of which depended more or less on the principle of having adjacent reservoirs connected by culverts or pipes with the main lock chamber, into which solid plungers were introduced, to expel the water into the lock chamber when it was required to rise in it, while it was made to fall by withdrawing such plunger. The committee judged the contrivances of Col. Sir William Congreve and Mr. Busby to be the best, but they were all too complicated or difficult of execution to be carried into practical effect, although one lock on Sir William Congreve's plan was built. It was very costly, and failed from the side walls giving way for want of buttresses or land ties, in consequence of which it had to be taken down, and was not rebuilt again.

1251. The best, most simple, and efficient lock for saving water, was in use antecedent to these new contrivances, and as it is simple, and has been tried and found to answer the purpose, we shall describe that alone. It is called the *side pound*, or pond *lock*.

This lock differs in no respect from those already described, except that it must have a number of ponds or reservoirs of different depths built in water-tight brick-work or other material, as near to it as possible, and each of these reservoirs must have a pipe of communication with the chamber of the lock, and a sluice or penstock for shutting the water communication. The usual manner of building these locks has been to place three reservoirs on each side of the lock, and of course there must be six sluices or penstocks, but we shall only describe three of them, for that description will equally apply to any greater or lesser number. Looking at the plan, Fig. 273, we may suppose *v u w* to be brick culverts or iron pipes leading out of the side of the chamber of the lock, at three different heights, indicated by the same letters in Fig. 272, into three separate reservoirs formed near the side of the lock, and that each passage has a sluice by which it may be closed. We will further suppose that all the reservoirs are empty, and that it is desired to pass a boat from the upper to the lower level. The commencement of the operation will be similar to that of any common lock; for first, both the upper and lower gates of the lock must be closed, unless the water within the chamber has been previously let in and stands at the full height of the water in the upper level, when the boat may float into the chamber; but should this not be the case, the chamber must be filled with water from the upper level as usual, before the boat can pass into it. The upper gates and their sluices being closed, the water must be let out in order to depress the boat, but instead of opening the sluices in the lower gates and letting the water out into the lower level, as before described, the sluice that closes the orifice and passage *w* is opened, and the water passes into the highest side reservoir, and continues to do so until the water in it attains the same level as that within the chamber of the lock; and whenever this occurs, the sluice of *w* is closed, and that of the passage *u* opened, by which the central reservoir will be filled; when *u* is in like manner closed, and *v* is opened to permit the remaining quantity of water to run off. As, however, the orifice *v* is placed on a level with the water surface of the lower level, it cannot carry off all the water that is necessary, because the water in the reservoir rises as much as that in the chamber is depressed until the two quantities attain a common level; therefore *v* must be closed as soon as this is effected, and the remaining quantity of water must be run off into the lower level, by opening the sluice *h* in the lower gates, and this last quantity of water will be all that will be wasted. In the event of a boat having to be passed *up* the canal, the working of the sluices are exactly the reverse of what has just been described. The boat passes into the lock from below, and the lower gates and their sluices being closed, the orifice *v* is first opened, when all the water contained in its connected reservoir will run back again into the chamber of the lock, when *v* must be closed, and *u* opened to introduce the water of the central reservoir. *u* Is then closed and *w* opened to admit the highest water, which will, however, be insufficient to fill the chamber of the lock up to the water level. This last filling must therefore be obtained by opening the sluices in the upper lock gates. The deficiency of water arises from the reciprocal rise and fall of the water in the lock and the reservoirs, for whatever may be their size, the water running into them can only rise the precise quantity that it falls within the lock and vice versâ. It follows, therefore, that the superficial area of each reservoir should be at least equal to that of the lock between its gates, for if less the quantity of water run out would be of little avail. For the sake of keeping the description simple, we have only spoken of three orifices and three reservoirs on *one side* of the lock, but four or five can with equal ease be introduced on *each side* of the lock, taking care to make their discharging orifices on different levels which follow each other at equal and regular intervals; and as the saving of water is proportionate to the difference in their level, the real loss may be greatly reduced. This modification of lock was contrived by Mr. James Playfair of London, and answers the purpose of saving water very effectually, but it is, nevertheless, objectionable on account of the loss of time required for working it. The rapidity of a flow of water is always governed by its perpendicular descent, therefore in the common lock, the rush of water on first opening the gate sluices is very great, rendering the culvert *m n m*, Fig. 272, necessary, when the difference of level is great; but as the water in the chamber reaches the height of either the upper or lower levels, its velocity constantly decreases, and at last disappears, thus rendering a loss of from seven to ten minutes inevitable in passing a boat through a common lock. In the side pound lock just described, especially when it has many reservoirs, the difference of level of the water in the chamber, and that of the reservoir that is opened to receive it, is always small, and the water consequently flows slowly and languidly, and with no greater velocity from an upper than a lower reservoir, therefore, independently of the time necessary for opening and shutting many sluices, the operation of this lock must be very slow.

1252. The only means that has yet been contrived for obtaining greater celerity of movement, is by plungers, which are large hollow water-tight boxes loaded with stones so as to cause them to sink into brick or stone chambers which communicate at their bottoms with the chamber of the lock. Their magnitude must be such, that when raised up out of the water, they will cause such a depression in its height as will bring it level with the water in the lower reach; while by sinking them, the water is protruded into the chamber to a height equal to that of the higher reach. These plungers are balanced to diminish their effective weight, and are raised and lowered by appropriate machinery. The simplest plan of assisting a summit level or canal that is likely to suffer for want of water is to construct very spacious ponds or reservoirs, when the form of the country will permit them, at such elevation that water can be taken from them by its natural fall whenever required. Such reservoirs may depend on rain water for their supply, and every spring and brook that can be made available should be carried into them.

1253. When canals open a communication between the central part of a country and the sea or a large tide river, they commonly terminate in a large *basin* in which ships and smaller vessels may ride for loading and unloading without blocking up and impeding the river, and such basins when large are called *docks*, or *wet docks*. Docks must contain sufficient depth of water to float the kind of vessels they are intended to contain, and should be surrounded by perpendicular, or nearly perpendicular walls on all sides, to preserve the banks and permit vessels to come close to them. These walls are of brick-work or masonry slightly battered on the front, and having offsets, buttresses and land ties next the ground side, with strong iron rings for mooring vessels. Sometimes the side walls are wholly lined with timber, by driving strong piles, and planking them on the front, when the walls are said to be *campsheeted*. When timber is used it should terminate in a very strong capping piece, and brick-work or masonry should finish with a coping formed of massive and heavy stones clamped together, in order that they may not be disturbed or broken by the heavy loads that come upon them. The ground behind the walling frequently requires puddling to render it water-tight, and should be made up level with the top of the walls, or be rather above them, and be formed into a gentle slope to keep it dry. This serves as a wharf for depositing goods for shipment, or as they are received from ships, and ought to be of considerable width. Within it, a road should be formed, amply wide enough for two carts to pass; and beyond this warehouses, with open roofed sheds, may be constructed for depositing goods; and if the whole is surrounded by a high wall with two gates, one for carriages to pass in, and the other to go out, such an arrrangement will be found very convenient for ports of extensive trade, as affording great facility for transacting business, and great security of property; and such are the London, West and East India docks of London, and many others of similar construction in different parts of the world.

1254. To maintain a sufficient height of water in wet docks that communicate with tide water, as well as to prevent the vessels from rising and falling, which is inconvenient in their loading and unloading, *tide locks* are employed. The tide lock is the same in principle as the common lock before described, except that only one pair of gates are necessary, although two are frequently used. The gates must of course be large enough to permit the passage of all such vessels as are to be admitted into the dock; and when a single pair of gates is adopted their salient angle points inwards or towards the dock. The gates are opened to permit the entrance of the tide water as it rises, but are shut as soon as it reaches its greatest height; consequently when the tide water of the river or sea recedes or falls, the full high water elevation is maintained within the dock or basin, but of course the single pair of gates cannot be opened under this head of water, and no vessel can pass in or out until high water occurs again; and then the water on the outside being of the same height as that within, or nearly so, the gates may be left open for the passage of vessels. As this occurs twice in every twenty-five hours, it occasions no inconvenience. Large docks should have two locks, in different positions, in order that a line of vessels may enter by one, while another passes out by the other without interfering with each other. And the gates must have sluices or side culverts through the walls, because the height of tides vary at the same place with different times and seasons. If the external tide water rises higher than the confined dock water, it will force open the gates and gain the same level without any artificial assistance; but should the external water be less elevated than that within the dock, the preponderance of force within might prevent the opening of the gates when required, and in that event the sluices must be opened, and so much of the inclosed water be permitted to run out, as will produce the necessary equality of level.

1255. Mr. Fulton, to whom the world is indebted for the first practical application of steam to the purposes of navigation by the formation of steam-boats, proposed the introduction of dry inclined planes as a means of transferring loaded boats from one level to another, when the difference was too great to be accomplished without several locks and great expense; and several of them have been executed, and employed in Great Britain with success. Mr. Fulton published a separate work on this subject, illustrated with plates showing the necessary details for carrying his plans into effect. The inclined plane is an iron rail-road projecting some distance into the canal, and the carriage, called a cradle, that runs upon it, has wheels, and is formed to fit the bottom of the boat, and being lowered upon the inclined rail-road beneath the surface of the water the boat is passed into it, and secured by proper iron fastenings when the rope or chain of the carriage is drawn up by a steam engine or horse-power capstan placed at the top of the inclined plane. The rail-road proceeds in a similar manner some distance into the upper reach of the canal, into which the cradle and boat must be lowered until the water is deep enough to float the boat. Boats are raised and lowered in this manner upon inclined planes which rise from one to two hundred feet at once, but of course this mode of transference is more liable to accidents than when locks are used; but saves something in time, and much in the expense of building locks.

1256. In the formation of canals, they sometimes have to cross deep vallies or rivers, and not unfrequently streams or rivers which may even be navigable. The piling up or embankment of earth would be impossible in this latter case, and in the former one there might be a difficulty in procuring the necessary quantity of soil, and if it could be procured, its removal would be attended with very heavy expense. The canal will therefore be more economically and better continued by an *aqueduct*, which is a bridge composed of timber or stone piers, but instead of being covered by a roadway, it is formed into a duct or trough wide and deep enough to float any boat that can navigate the canal of which it forms a part.

All that has been said upon bridge building of course applies to the formation of aqueducts, and in addition to that, it may be observed, that great care is necessary in the formation of the water-course to prevent its leaking. Aqueducts are sometimes made wholly of brick or stone, sometimes wholly of timber, and occasionally of either of the above materials, but with the water channel composed of cast iron plates, put together by flanches with screw bolts and nuts, so as to produce permanently water-tight joints. If the piers or supporting posts are of timber the aqueduct or water channel should be of timber also, because such supporters will be liable to decay, to warp and to change dimensions; therefore perfectly inflexible materials, such as brick or stone-work ought not to be placed upon them. In forming timber aqueducts, the transverse beams that support the floor must project on each side to a distance fully equal to the depth of the water trunk, (which need never exceed four feet,) in order that oblique braces or struts may be introduced to maintain the perpendicular timbers to which the inside planking is nailed in their proper upright positions. The bottoms of these upright pieces may mortice into the transverse beams, while their tops are let into a string of large whole square timber running the whole extent of the aqueduct, and projecting a few inches over its inside, to protect the planked sides from being injured by boats striking against them in their passage. The projecting ends of the bearers also serve to support the floor of a horse towing path on each side of the water trunk, which should be placed at least a foot below the projecting side sills, to prevent horses slipping into the trough; and the two outsides of the towing path should be protected by railing so framed as to assist in supporting the path, which is first planked longitudinally, and afterwards covered with short transverse planks, to be moved or repaired as they wear out.

1257. The best and most substantial method of building an aqueduct, (when expense is not an object,) is to form it, piers and all, of masonry or brick-work, with elliptic or segmental arches, worked up to a perfectly flat surface on the upper side, upon which the side walls of the channel are afterwards erected. In brick or stone aqueducts clay puddling cannot be resorted to, because the construction should not be such as will allow the puddle to be kept constantly moist, without which it will not continue water-tight. The retention of water must therefore depend entirely upon the soundness of the work, and the materials used must consequently be the very soundest bricks, or stone, that can be procured, laid or built wholly in good hydraulic cement, which must be made thin, and worked in close but full joints. The bricks may be rendered more impervious to water, by dipping each of them as used in liquid cement, and by grouting the work at every second course, and after it is finished by plastering the surface to at least half an inch thick with Roman cement and clean sharp sand. The brick-work should also be three bricks thick to enable it to resist percolation, and withstand the pressure of the water; and to promote these effects, the side walls should have narrow offsets or footings of about two inches wide in every second course, on both sides, for eighteen inches or two feet from their bottoms; but if a lining of cast iron plates as before mentioned, is used, the inside walls must be straight and perpendicular, or may have a slight and regular batter.

The platform upon the arches must be as much wider than the intended water-course as will leave a towing path on one or both of its sides; and the usual manner of building aqueducts in brick or stone is to erect four parallel longitudinal walls upon it, of less thickness than above mentioned; the two inner walls being the sides of the water-course, and the two outer and thinner ones being flush or even with the face of the work, while the spaces between them are filled in with grouted rubble-work or beton, the top of which forms the towing paths. The two external walls are carried up as parapet walls, or they may be finished by a balustrade or railing for the safety and protection of the horses and passengers. When this mode of construction is adopted, a large and solid mass of work of the full width of the towing paths, and of a height equal to the full depth of the water trough is necessary on each side, consuming much material and throwing great weight upon the piers; besides which there is often difficulty in discovering the position of and repairing leakages when they occur in the water trough. The writer therefore suggests that the two objects to be attained, which are effectual support to the trough walls, and elevated platforms for the towing paths, would be equally well obtained by dispensing with the two outside walls and the rubble-work or beton, and running a series of arched vaults along the platform, the radius of the arches being nearly equal to the depth of the water trough. The spandrells of these arches may afterwards be filled in by the parapet walls, and the arches themselves being covered over with marl or any proper soil, will form the towing path, with much less weight, and expenditure of expensive material than in the other forms. The axis of these small arches being at right angles to the trough walls will give it effectual support, and as the arches need not be closed at their outer ends, they afford the means of examining and repairing nearly the whole of the trough walls at all times without digging up the towing path, or disturbing the regular traffic.

1258. The above particulars, in addition to what has been stated in the body of the work, under the heads of *Land Surveying*, *Levelling Earth-work*, and construction in *Masonry*, *Brick-work* and *Carpentry*, it is presumed, when combined with some practice, will enable any one to survey a line for, set out and execute a canal, and with this we shall close our account of the operations of the Engineer.

To those who are acquainted with the subject, it will be evident that many objects of the Engineer's profession are passed without notice; and to such it will be equally certain that these objects could not be comprised in a single volume, however much it might be extended. The principles that we have endeavoured to establish and explain are general, and apply to constructions of every kind, and it is believed comprehend a notice of all that generally falls under the direction and superintendence of a Civil

Engineer in the general acceptation of the term. It was stated in the introductory chapter that the occupations of the Engineer are so various that no one man commonly applies himself to the whole of them, but selects that for which he has the greatest taste and liking, or which his particular connexion may throw in his way. Still none of these subordinate branches can be followed with success without some portion of the knowledge which is attempted to be inculcated in the foregoing pages. To make use of even this information to advantage, a previous acquaintance with the general principles of natural philosophy is presumed, therefore no notice has been taken of the nature and operation of the mechanic powers, of the weight and elasticity of the atmosphere, and of the nature and effects of hydrostatic pressure and hydraulic machinery.

1259. In carrying on the operations which have been described, the Engineer may have occasion to construct pumps and other machines, and to plan or construct water wheels, windmills or steam engines, to obtain power to move them; and gearing or cogged wheels upon shafts to carry that motion and power from one place to another. All these involve the principles that have been laid down, such as the nature and strength of materials and the methods of building and framing them together; and when those principles are well understood, little difficulty can arise in planning the details. From the extent and variety of these objects, any attempt at such a description of them as might prove useful is impossible, and the student must therefore refer for the particulars of their construction to works devoted to their particular consideration, and among others Nicholson's Operative Mechanic, Buchanan on Mill-work, Gray's Millwright's Assistant, Dr. Brewster's Edinburgh Encyclopedia, and the supplement to the fourth and fifth editions of the Encyclopædia Britannica may be consulted with advantage.

THE END.

INDEX.

D.

E.

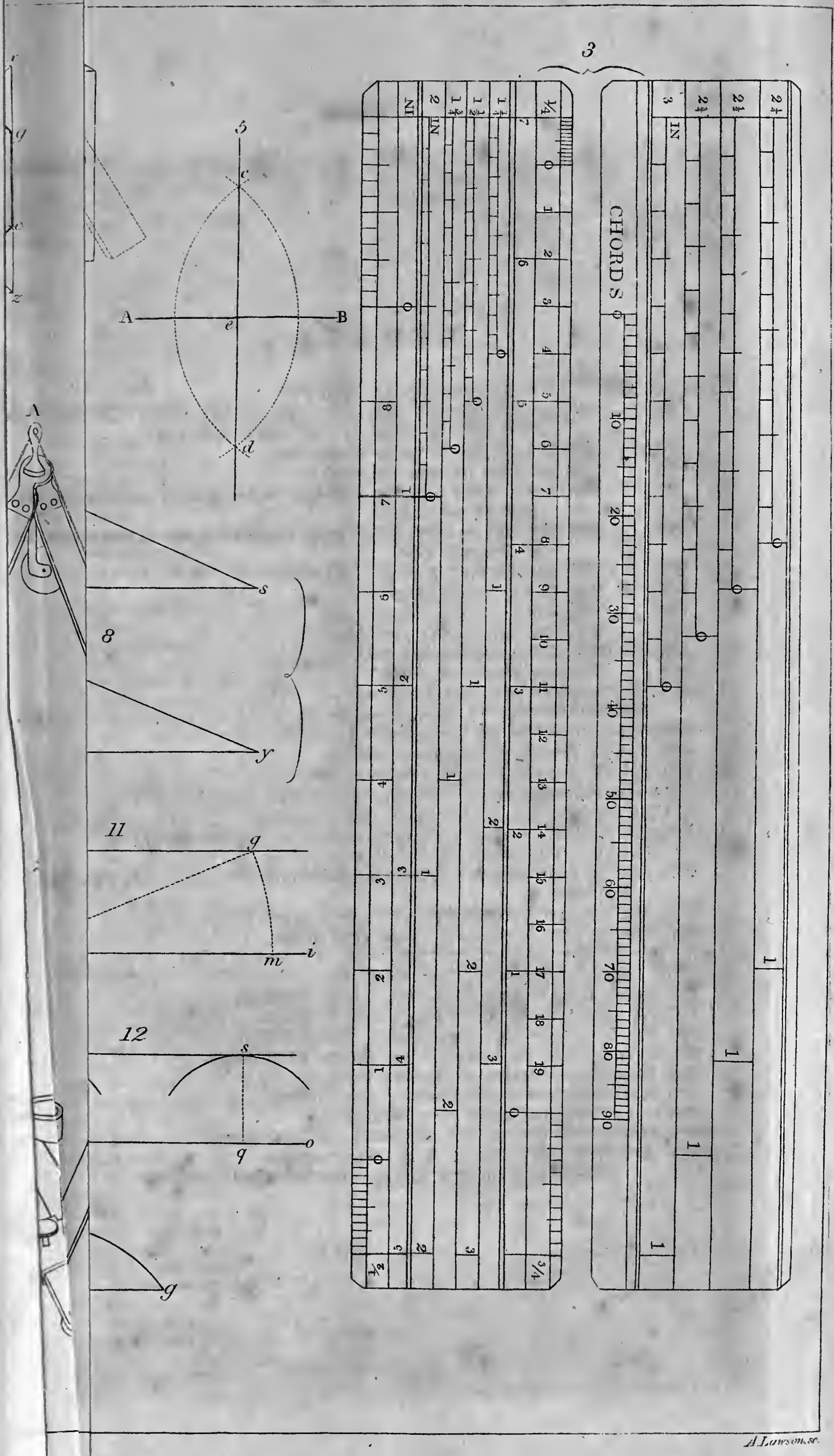
F.

T.

ERRATA.

Page 55, Art. 77, line 5, for radius *q v*, read *q r*.
56, 83, last line, for EF : EG :: EH : EI, or AB : CD :: CD : EI, read EG : EF :: EI : EH, or CD : AB :: AB : EB.
72, 122, line 14, for 83 feet, read 68 feet.
91, 175, last line, for line *x y*, read *x z*.
98, 198, line 6, after solidity, add the words, which multiply by the cube of one side.
99, 200, 201, 202, and 203, to multiply for *solidity* the factor should be 2^3, instead of 2^2.
106, 223, line 18, for 7.2, read 7.92 inches.
122, 259, line 4, for box *d*, read *f*.
123, 262, line 4, for Fig. 74, read 77.
124, 263, line 8, for (254), read (259).
128, 269, line 6, for Fig. 47, read 74.
152, 302, line 10, for 12, read 9.
157, line 2, from top, for level *i l*, read *i i*.
" line 20, from top, for filling, read fitting.
158, line 8, from top, for nut *p*, read *R*.
160, line 27, from top, for pivot *p*, read *h*.
169, line 12, from bottom, for 200, read 220.
171, last number in upper column of back sights should be 4.31.
174, line 9, from top, for between *c*, read between *i*.
178, line 25, from top, the *n* occurring twice in this line should be *r*.
" line 12, from bottom, for line *n*, read *r*.
262, line 20, from top, for three and three-quarters, read two and three-quarters.
304, Art. 545, line 7, for preservation, read preservative.
596, line 22, from bottom, for adopt, read adapt.
597, line 19, for position, read positions.
600, line 16, for deducing, read reducing.
601, line 8, from bottom, for number, read member.
603, Art. 1088, line 1, for Cravaut, read Cravart.
606, line 5, from bottom, for Lubelye, read Labelye.
607, to end of line 23, from bottom, add the word the.
614, line 8, from bottom, for line *e c*, read *c c*.
620, Art. 1119, line 14, for distinct, read distant.
623, 1123, line 14, for pier, read piers.
628, line 5, from bottom, for prominent, read permanent.
629, Art. 1132, line 7, for as earth, read no earth.
715, 1258, line 3, insert a comma after the word *Levelling*.

Pl. 1.



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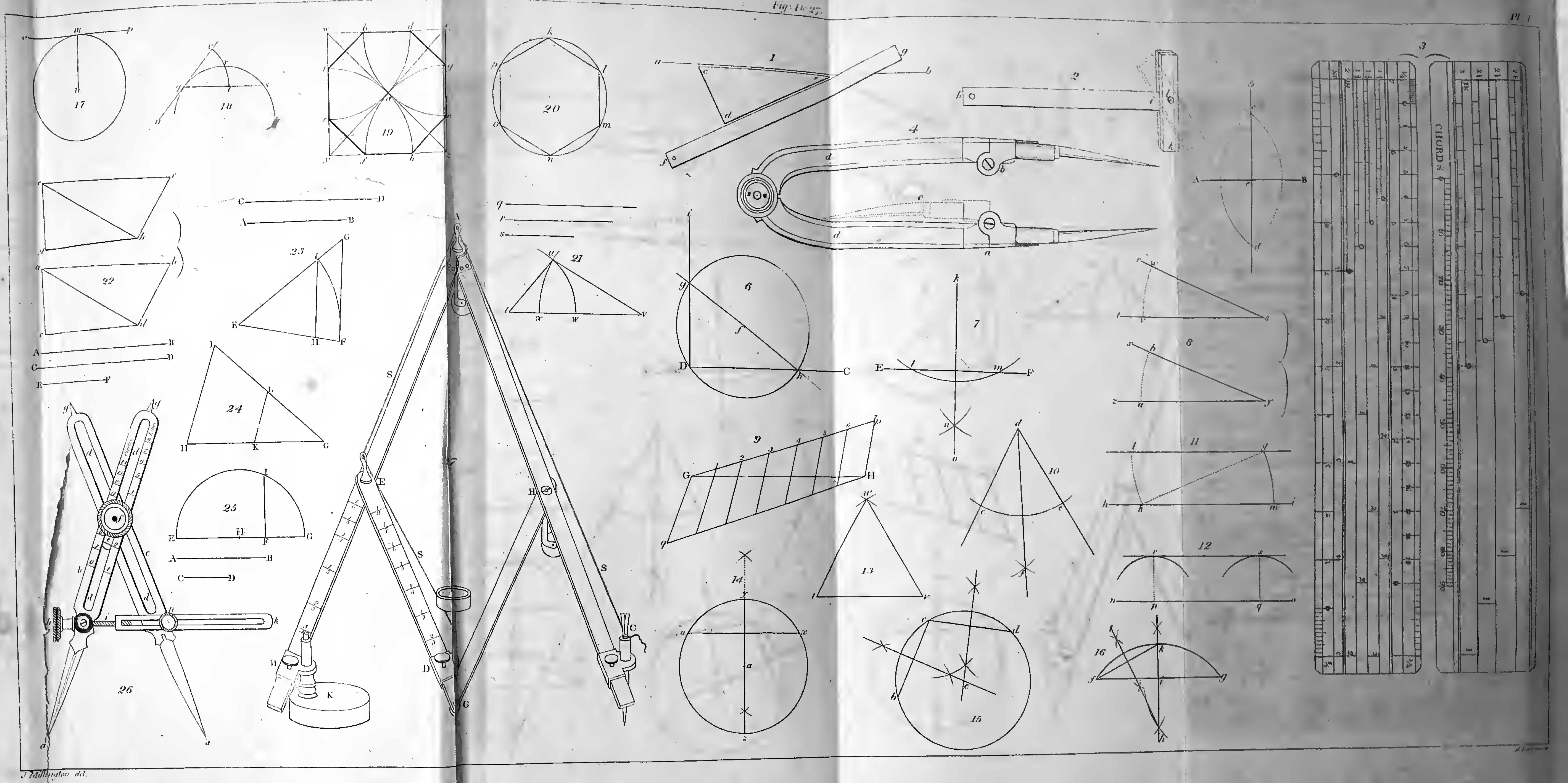
Fig: 1 to 27.
Pl. I
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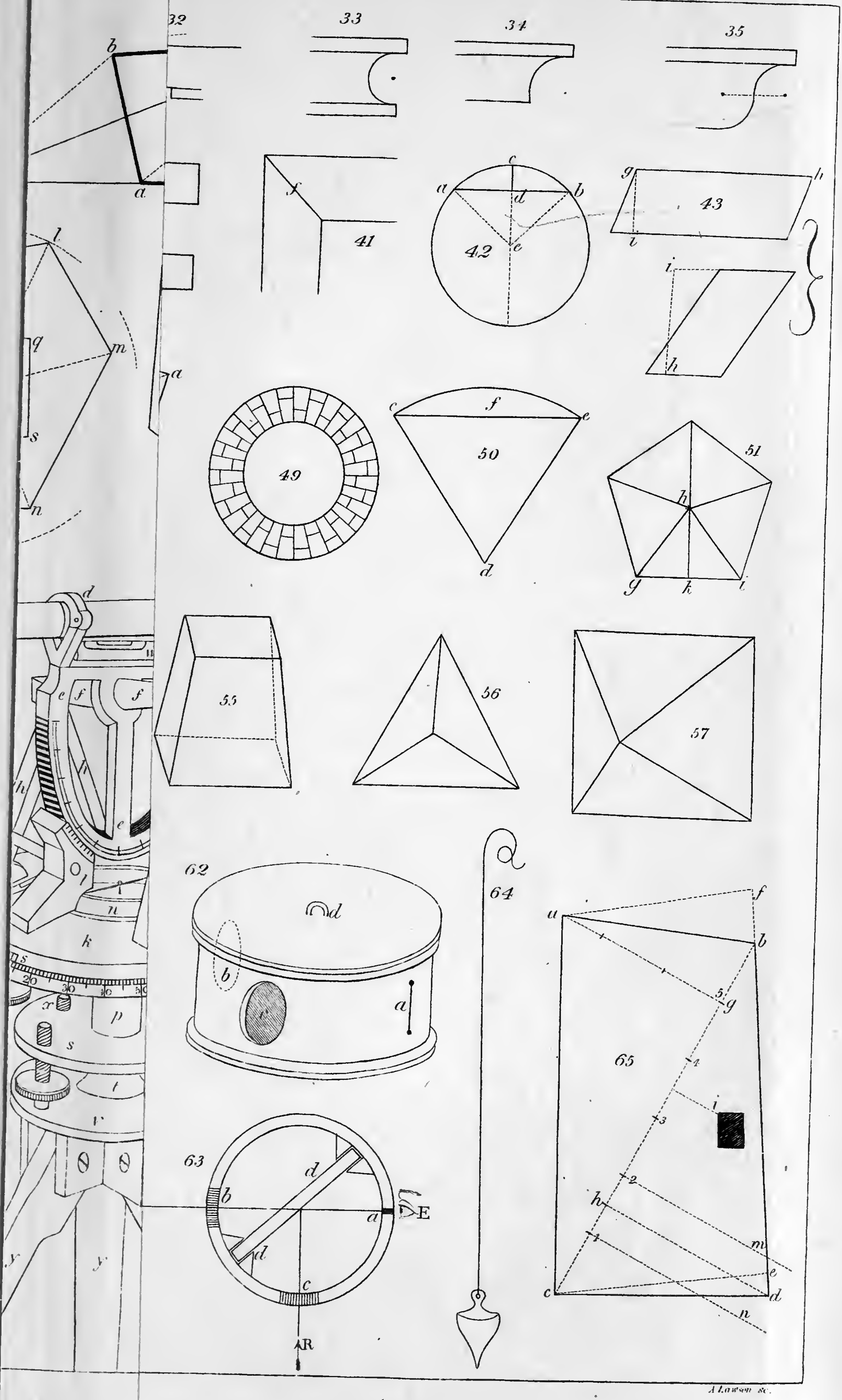
Pl. 11.



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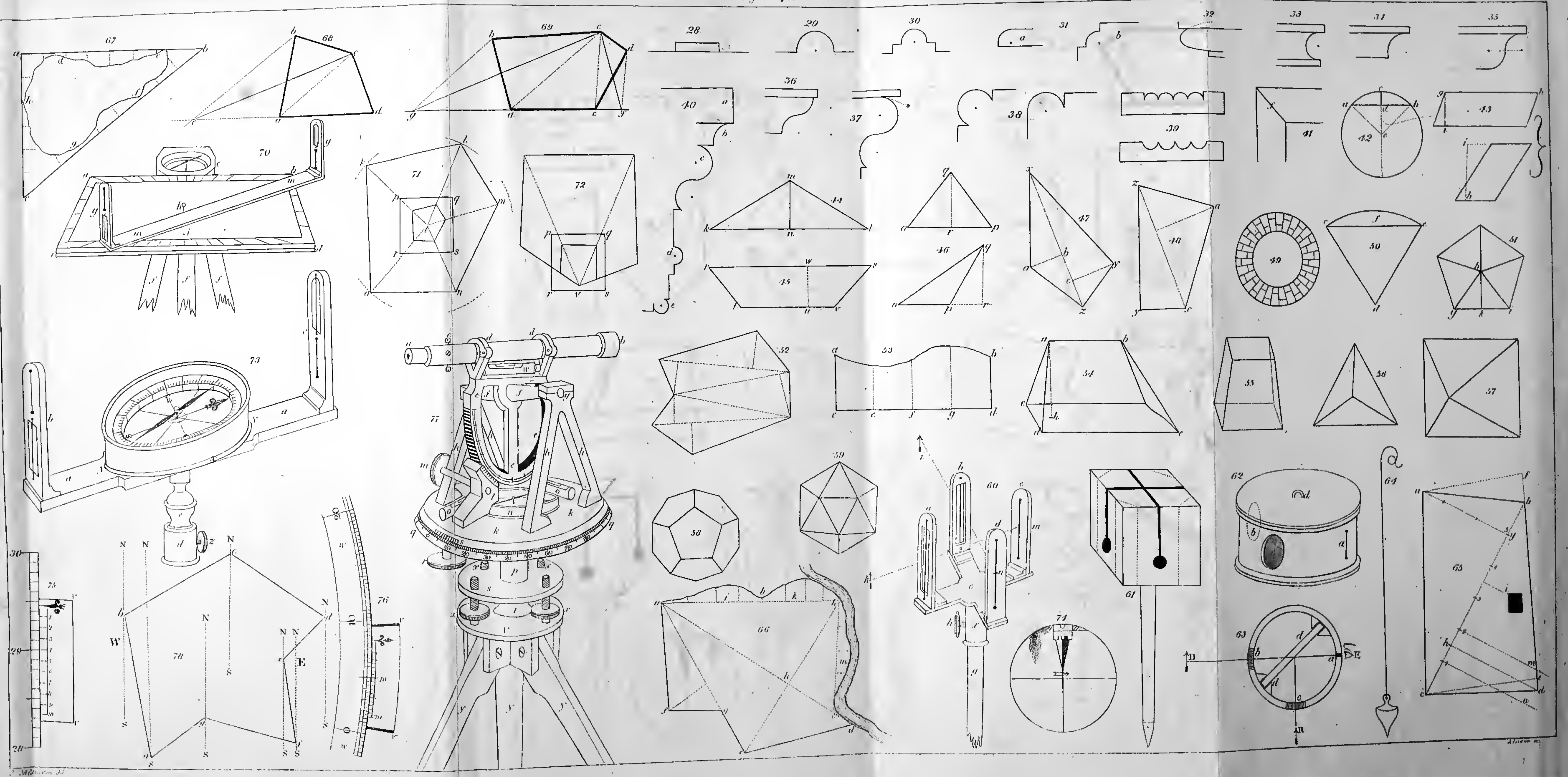
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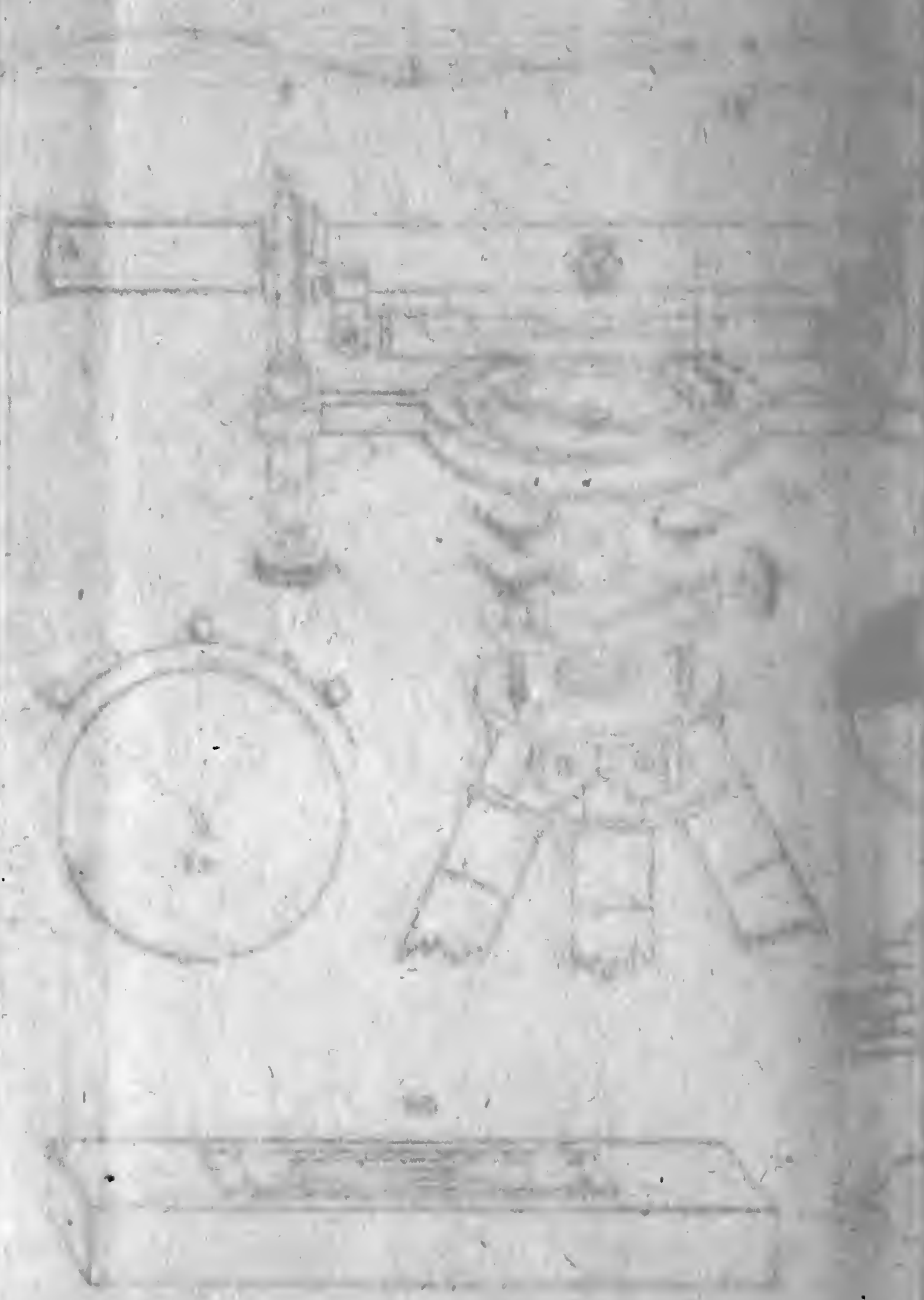

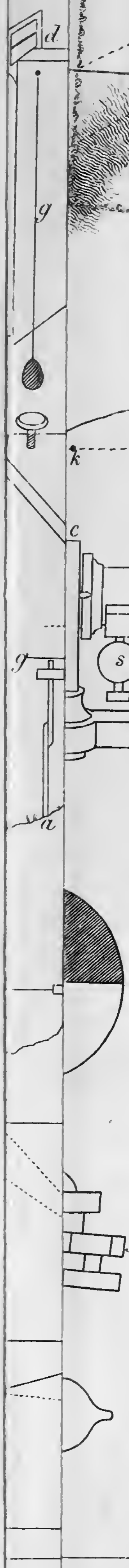

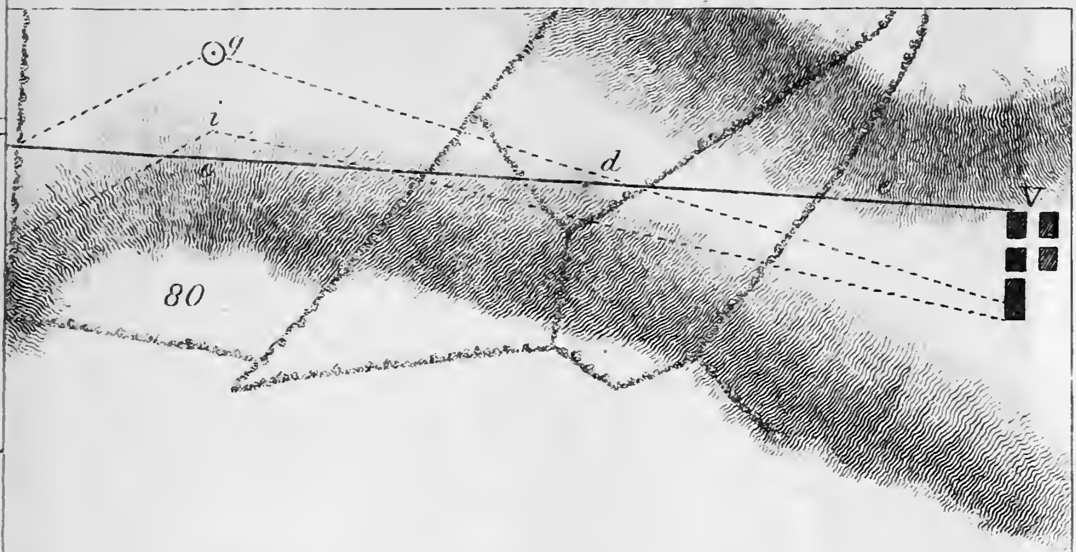

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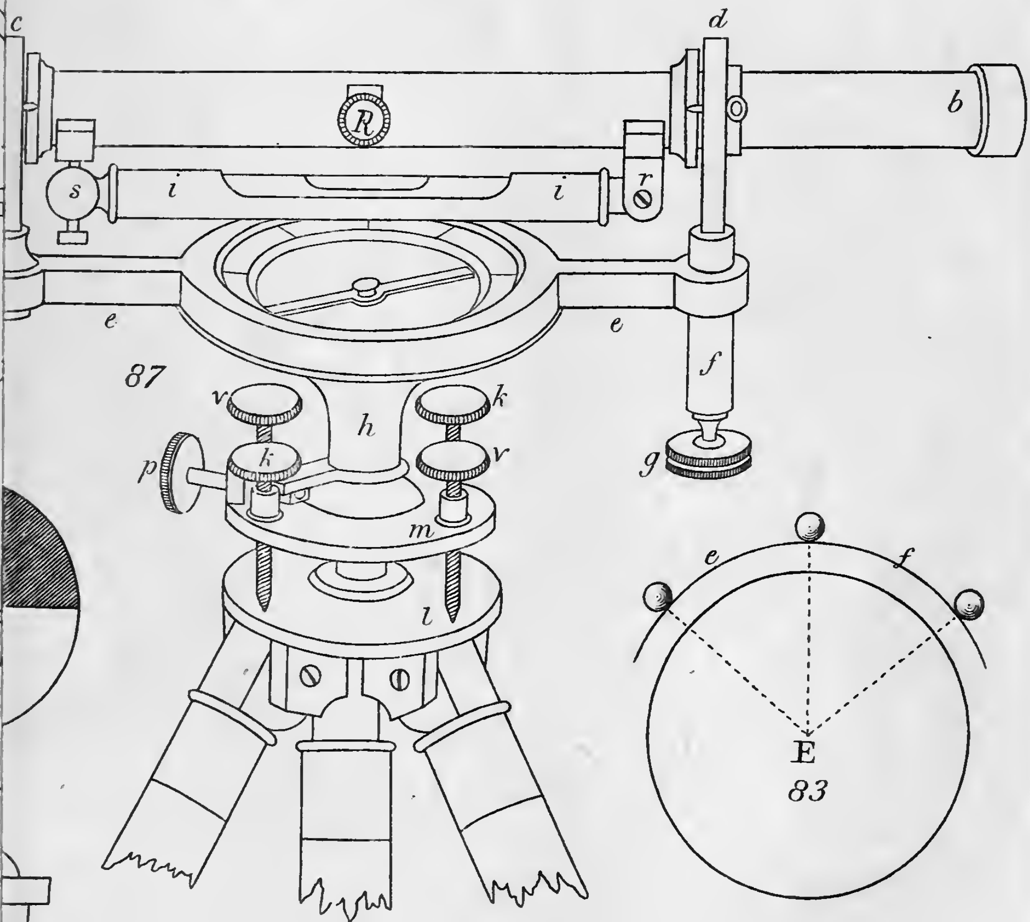

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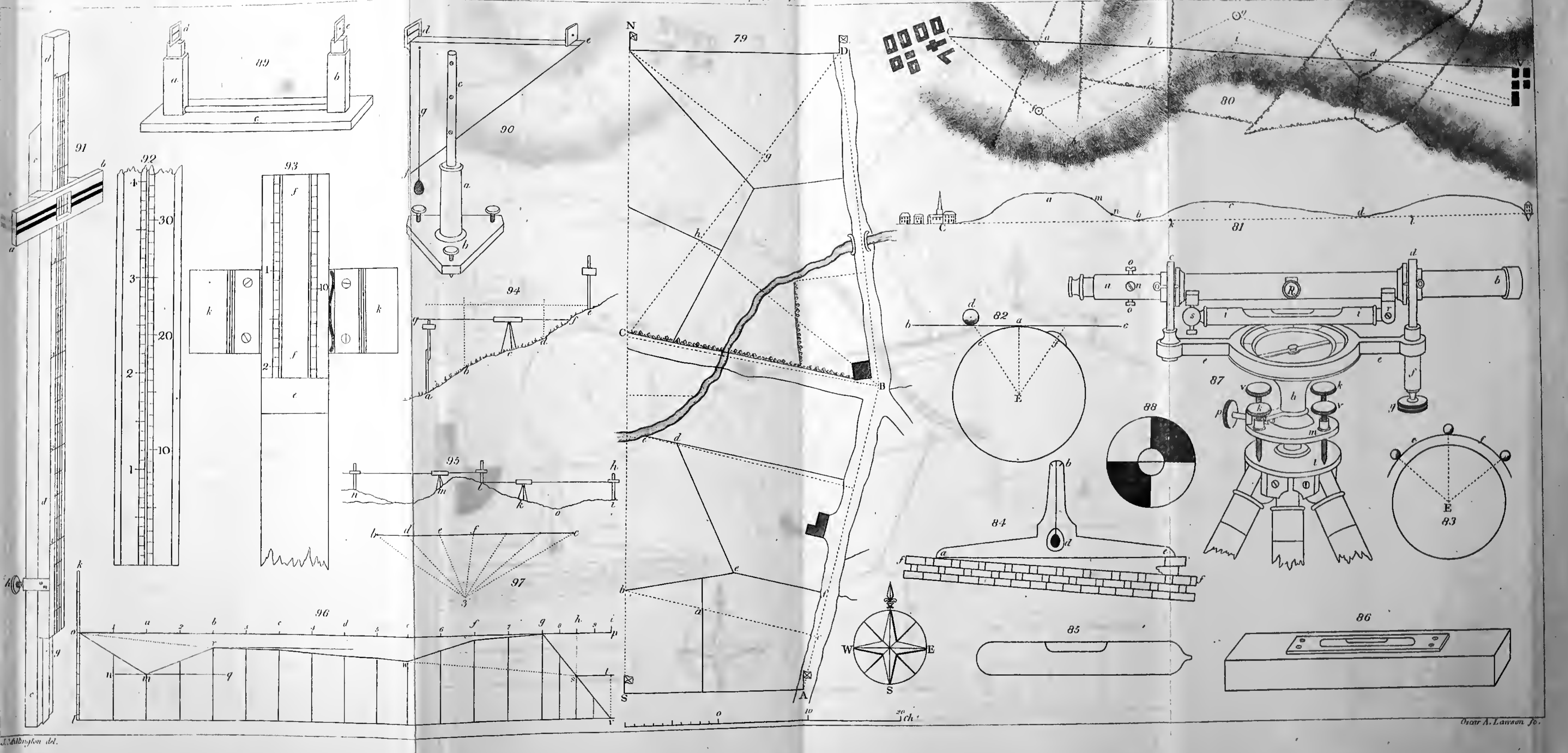

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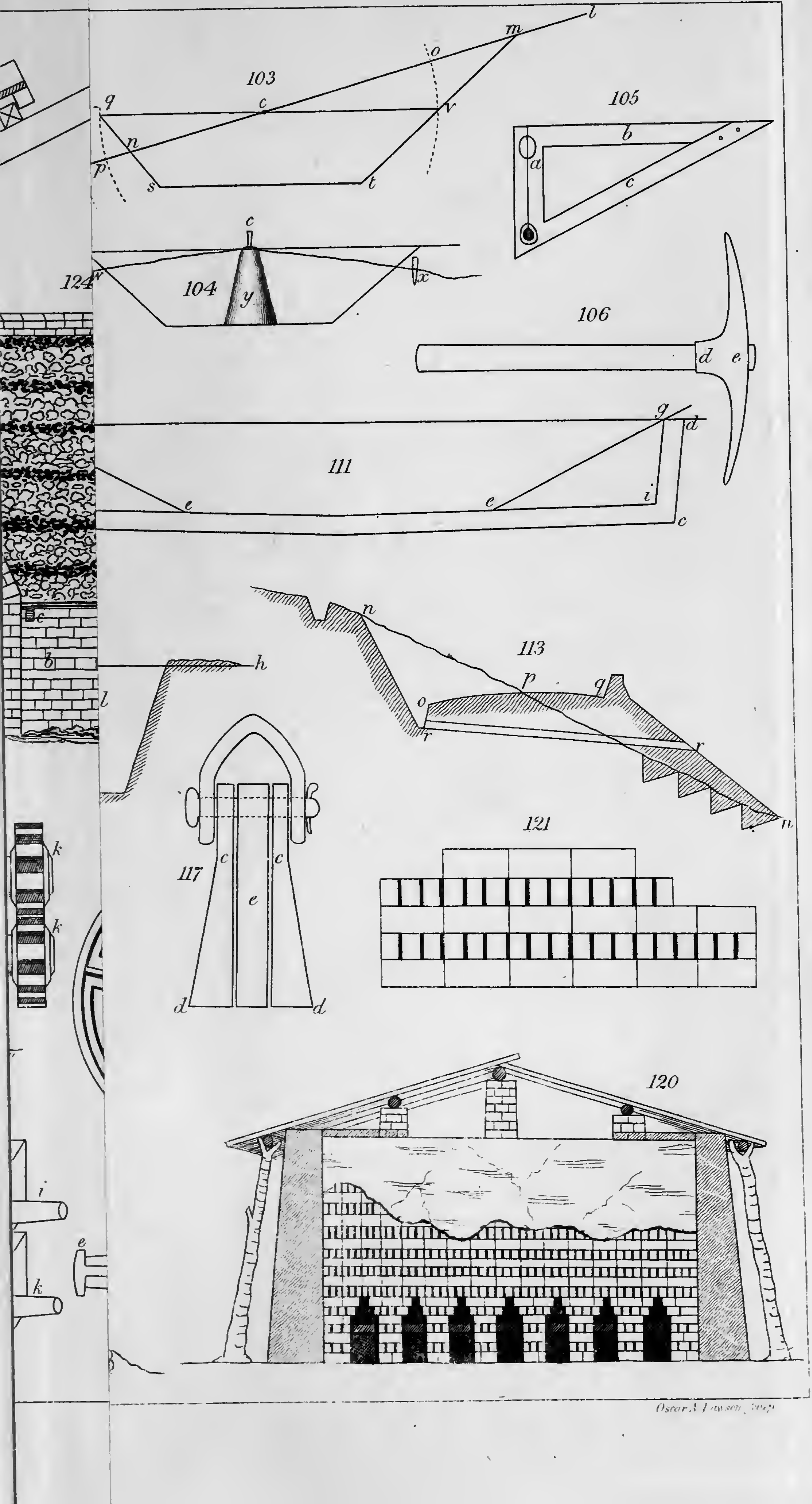
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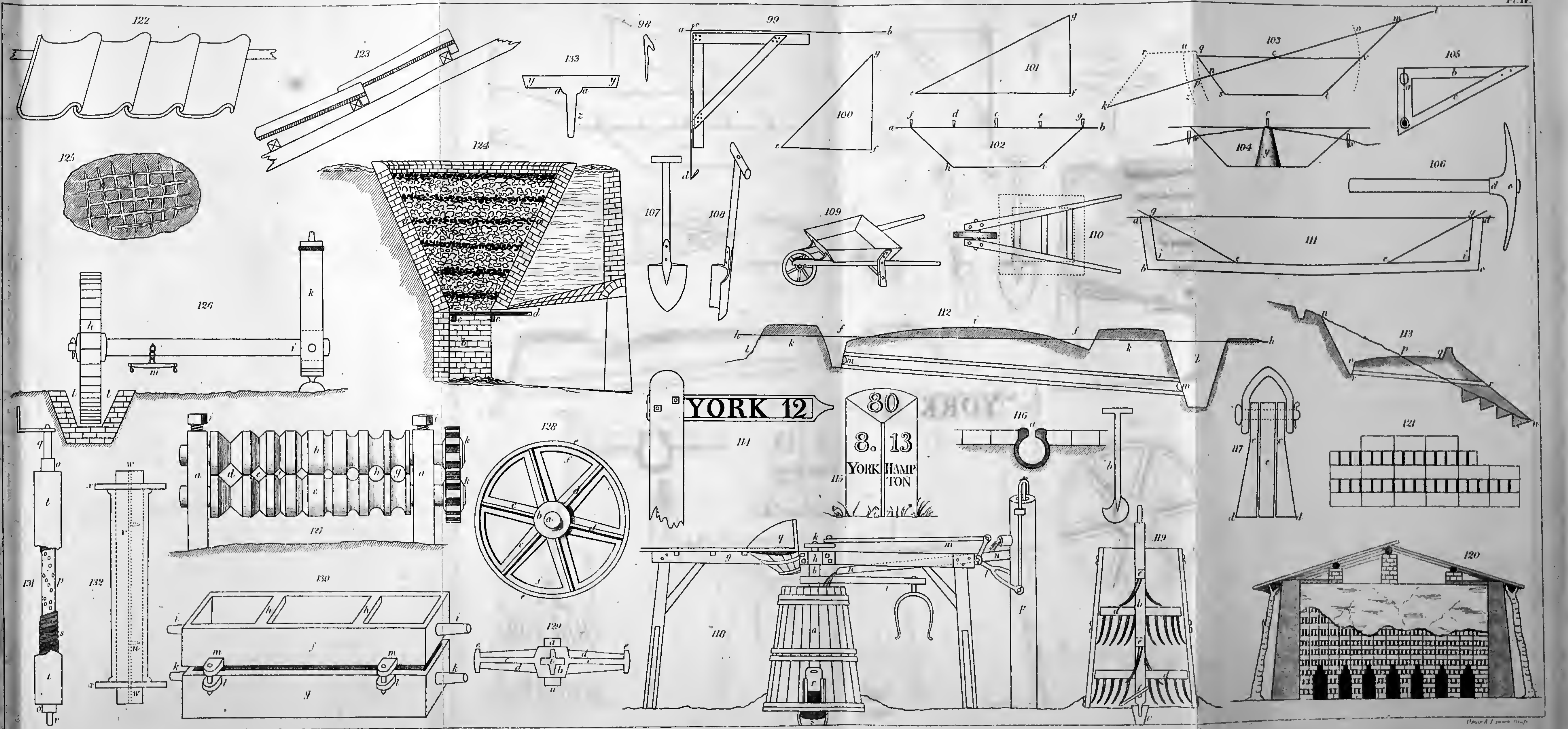

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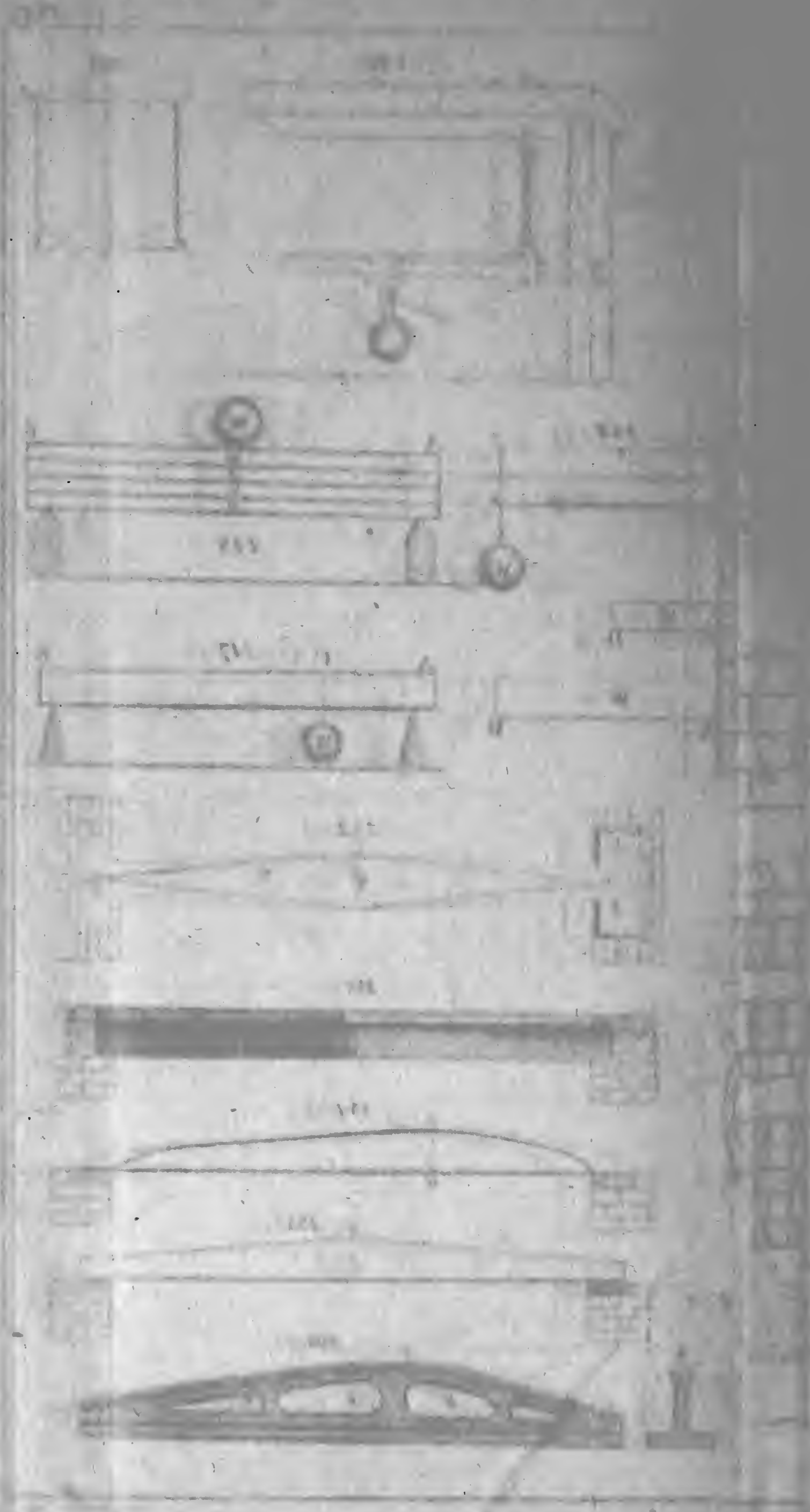

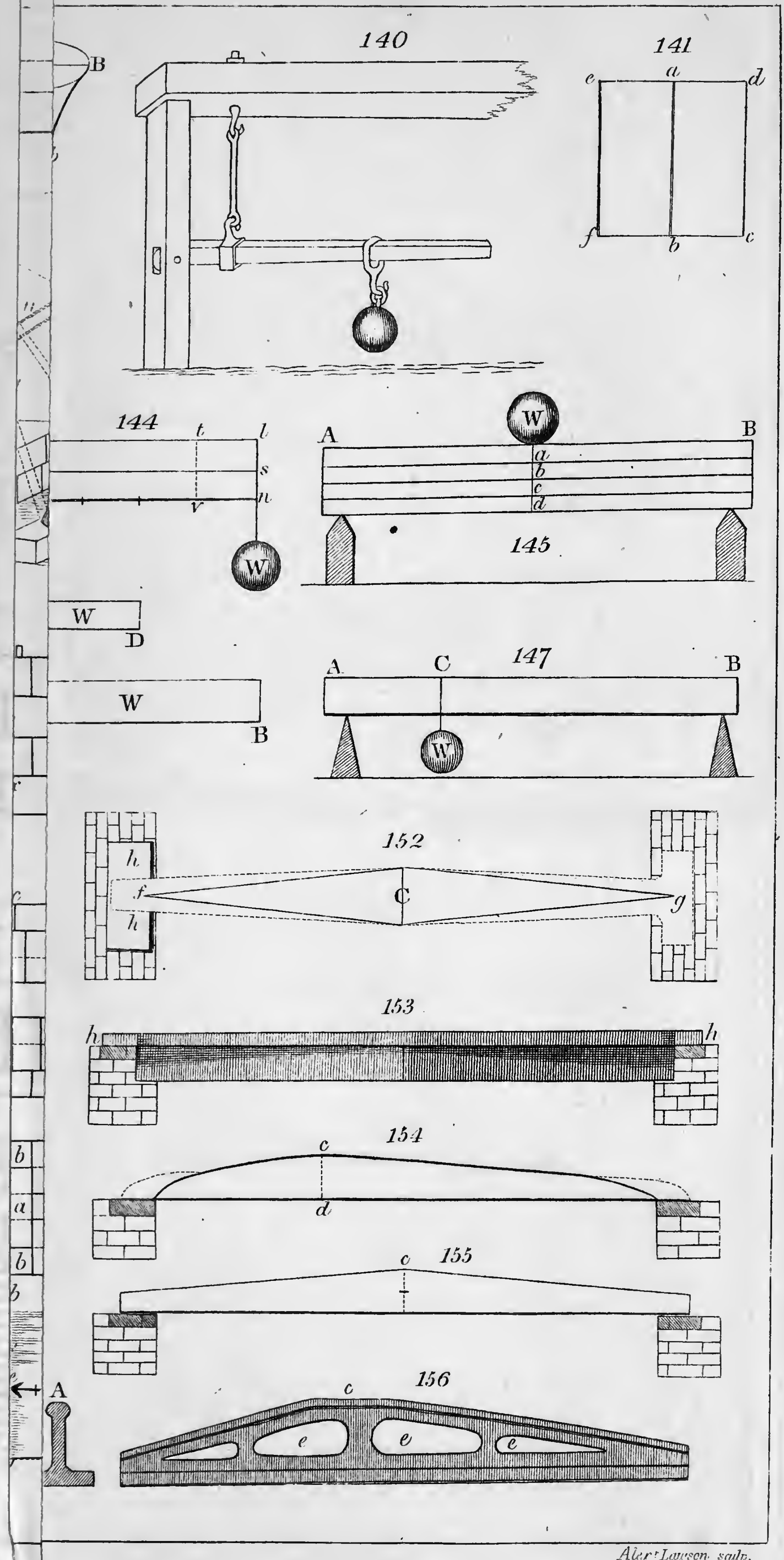

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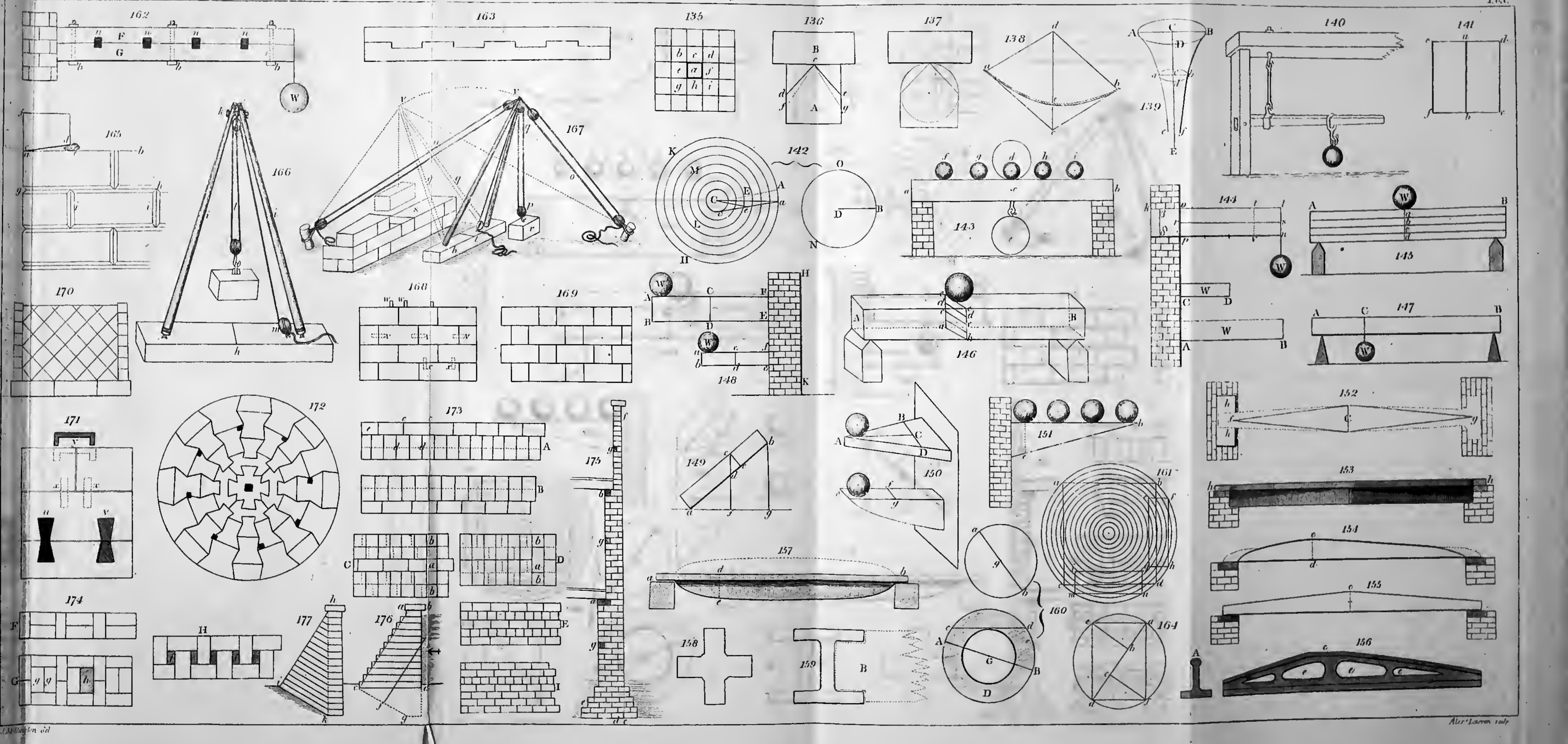

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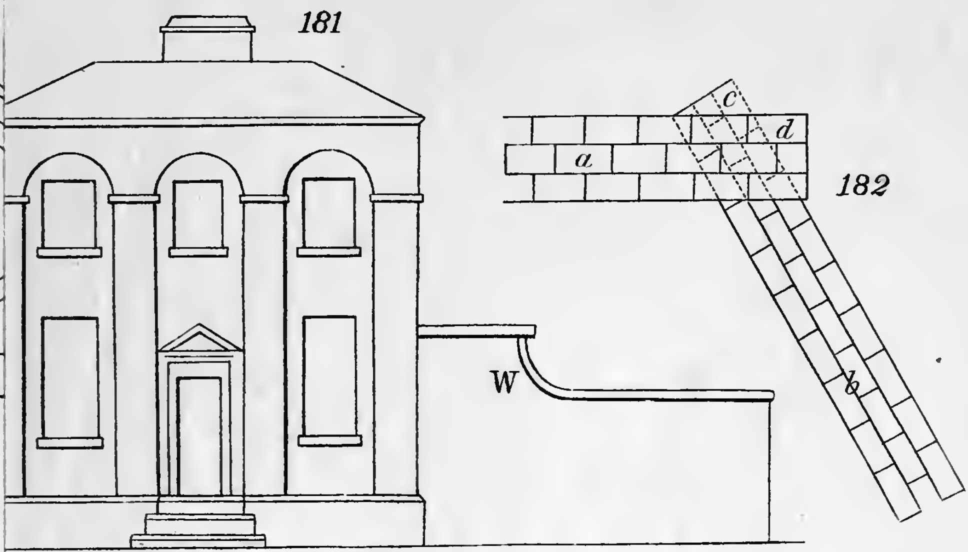

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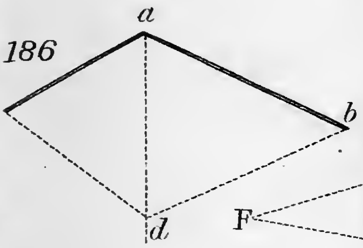

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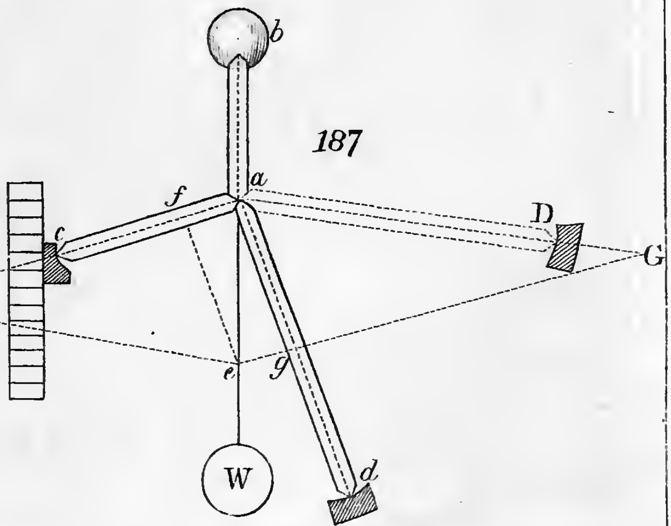

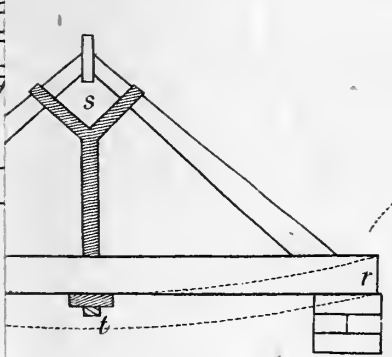

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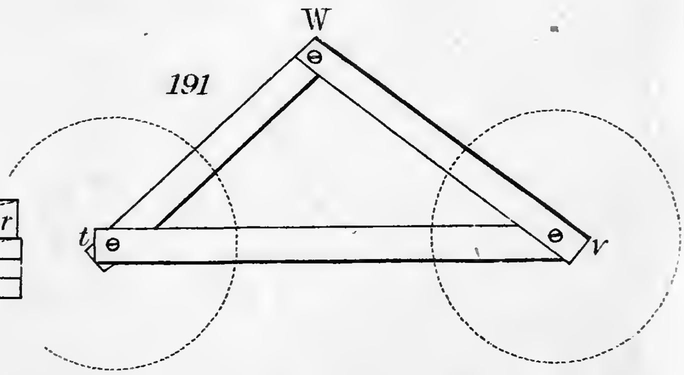

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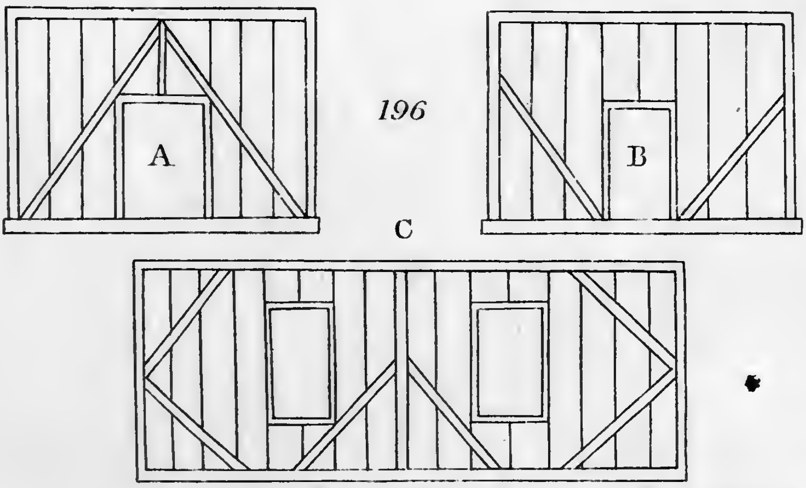

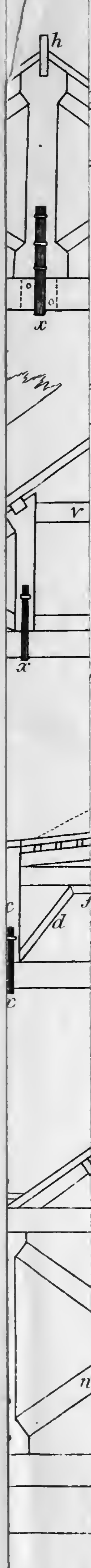

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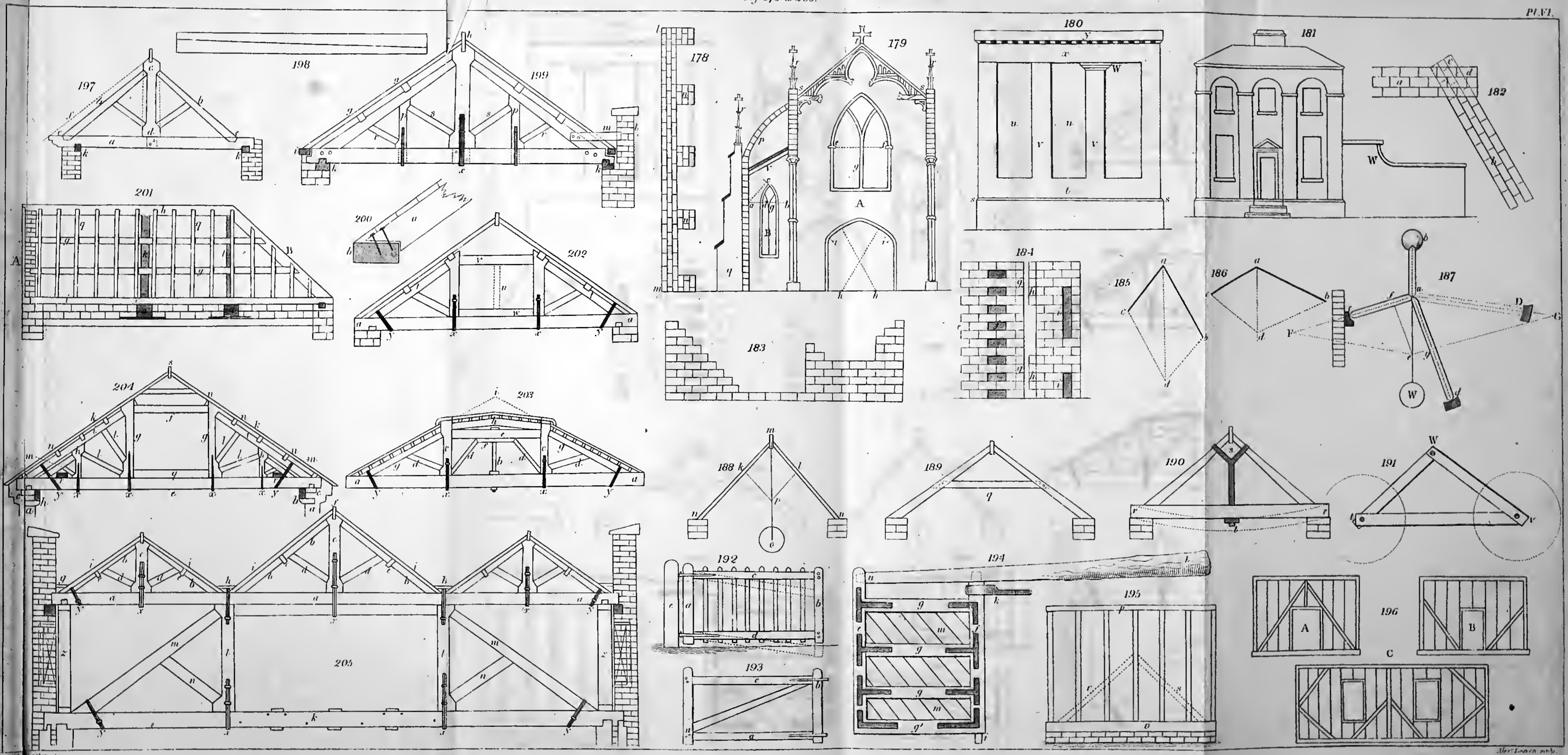
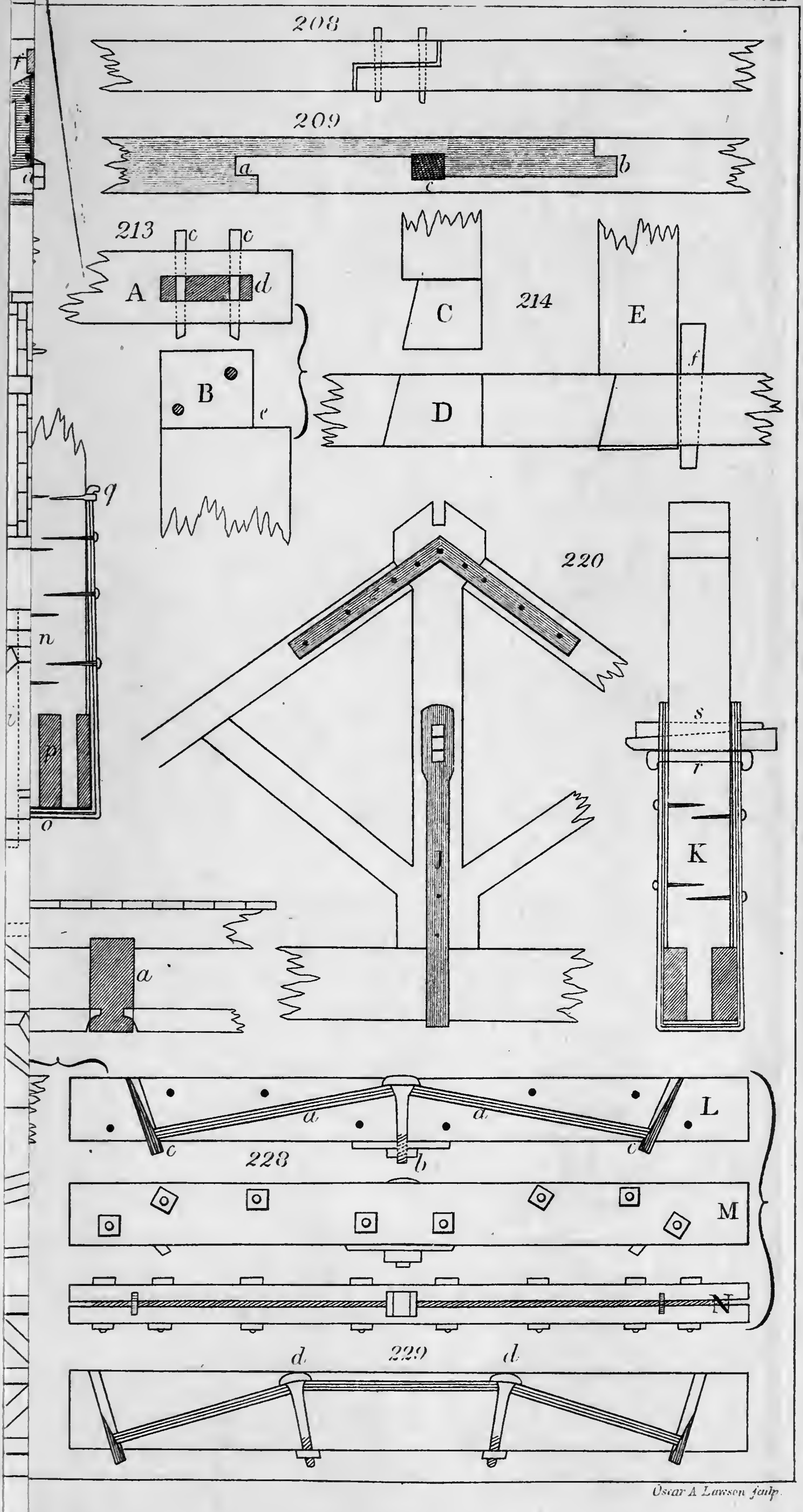
Pl. VI.





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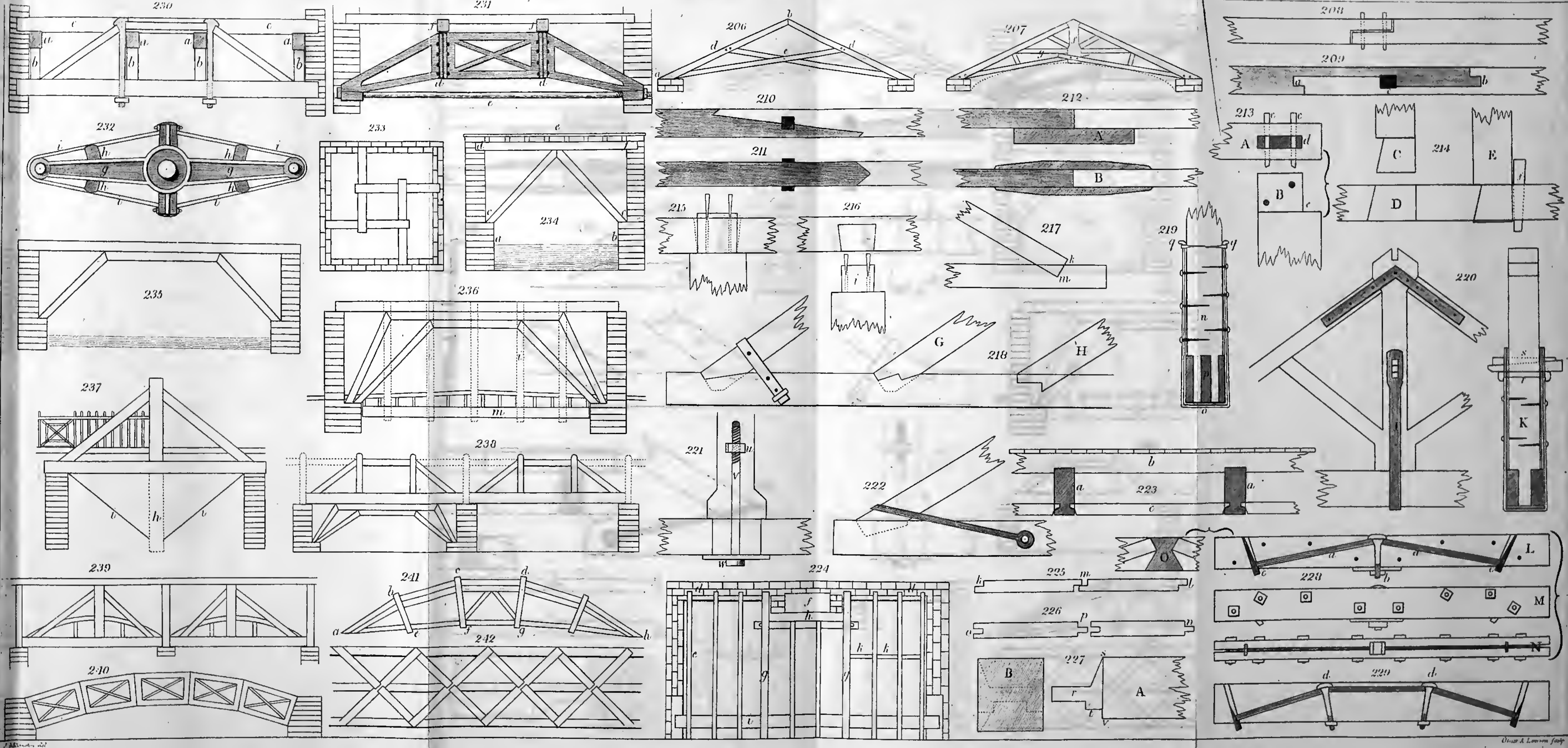

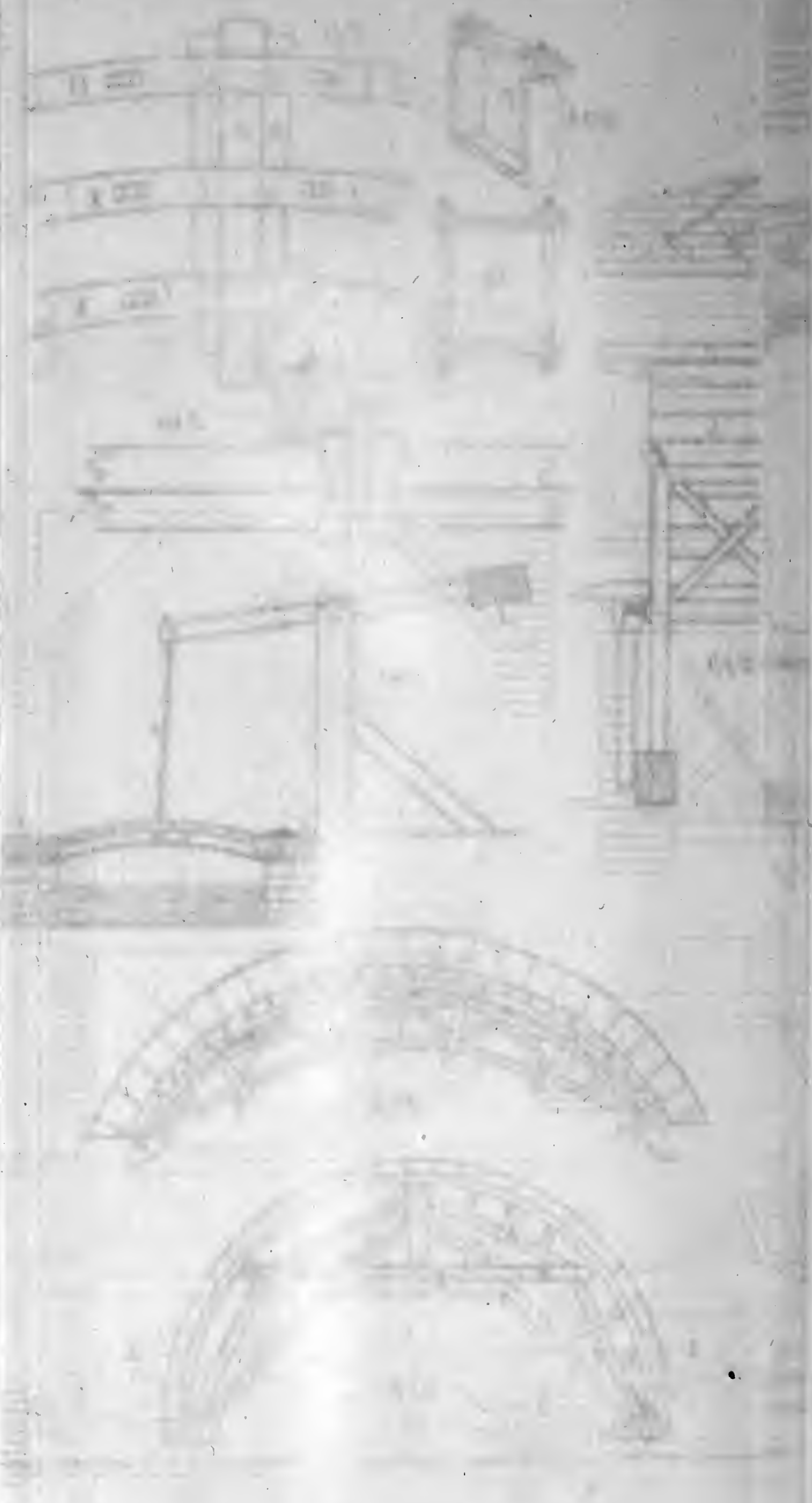

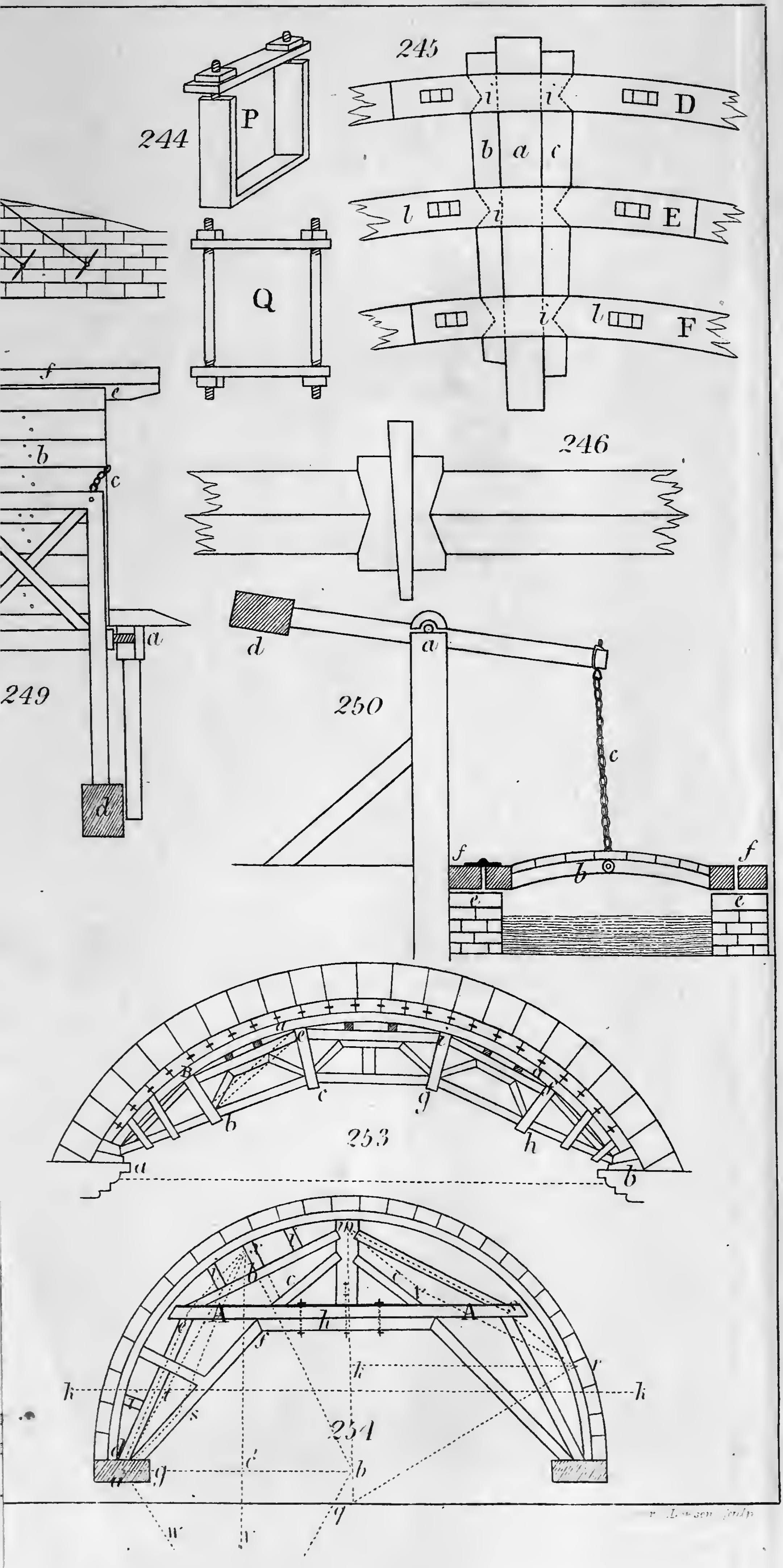
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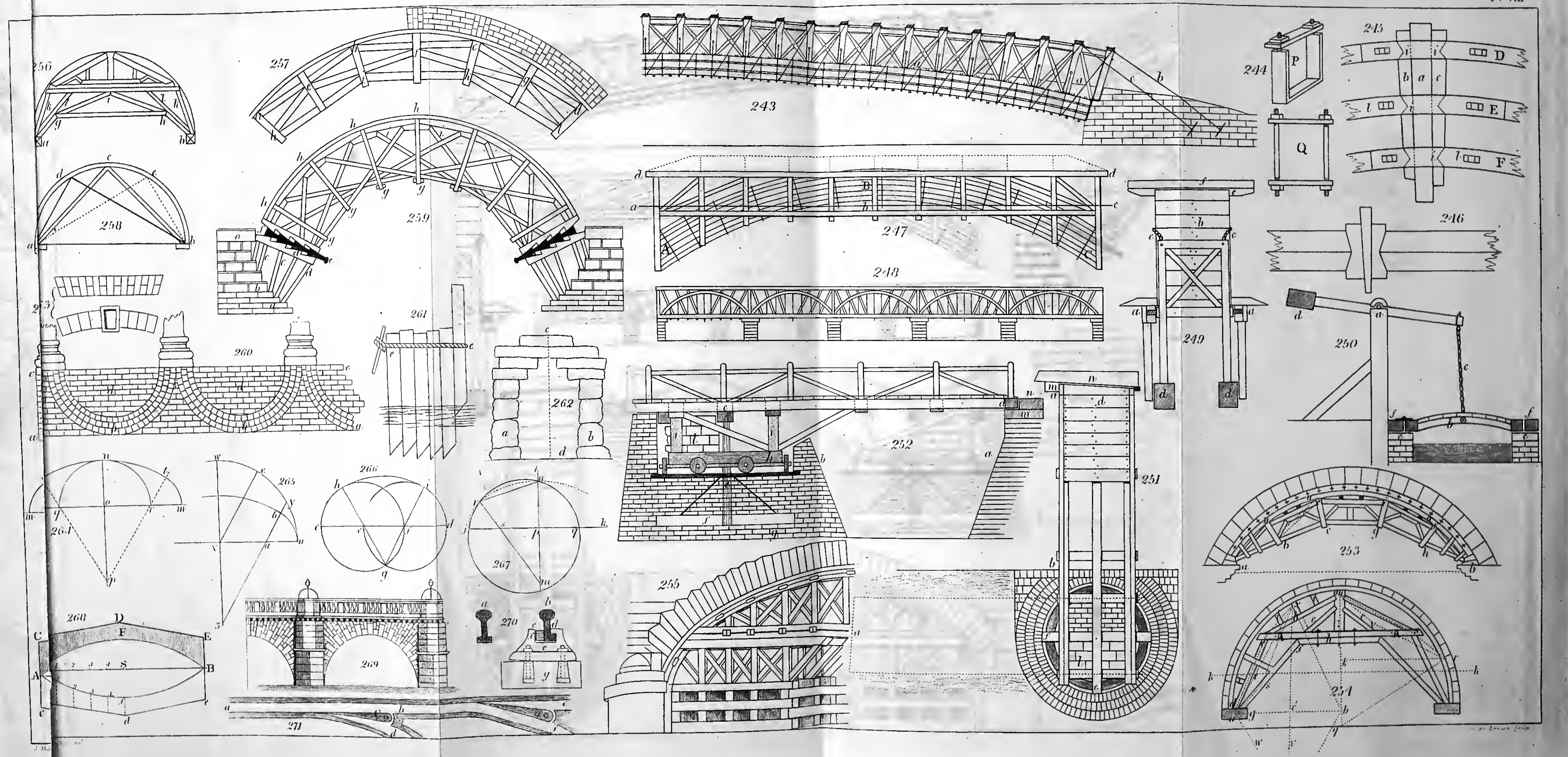
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