A

PRACTICAL

TREATISE ON CONCRETE,

AND

HOW TO MAKE IT;

WITH

OBSERVATIONS ON THE USES OF CEMENTS, LIMES AND MORTARS.

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PREFACE.

The importance of concrete for building purposes, and the increasing attention given to that subject, has induced me to prepare this book. Past failures in building with concrete have caused much doubt and uncertainty as to the best materials for the purpose; with the object, therefore, of removing such apprehensions and imparting confidence, I offer this work to those interested in building operations. There have from time to time been repeated attempts to awaken the necessary interest on the suitability of various concrete mixtures for house-building; but the usual objection to novel processes has, until recently, succeeded in impeding progress. The variable character of the limes originally used for this purpose, and the ignorant manner of their application, naturally resulted in much dissatisfaction and loss. The introduction of a new material, together with a better understanding of the practical chemistry of the question, is gradually imparting confidence on this important subject. While builders were solely dependent on the various chalk and lias limes as the binding material for their concretes, much reliable progress was impossible; for the necessary intelligent manipulation to ensure success was never forthcoming. The natural cements were either too expensive or possessed of too dangerous properties to admit of their being generally used for such purposes; artificial cements, however, occupying an intermediate place between limes and natural cements, have fortunately enabled us to command the advantages of both without the separate dangers of either. Their first introduction was attended with much difficulty from interested opposition; but recent engineering works of great magnitude have proved one (Portland) of the artificial cements to be of great constructive value. There were doubtless several reasonable objections to the use of Portland cement from the frequent development of dangerous peculiarities due to and consequent on ignorant manufacture. Extended practical experience and increased scientific investigation have now established safe rules for the guidance of builders and all others interested in using it.

While discussing in the following pages the question of concrete preparations, I shall also endeavour to point out the various materials of a cementitious character which have been used through many ages for building purposes, so that local materials, when suitable, shall be used. Builders—professional and operative—have too frequently disregarded the claims of stones and limes in the localities of their operations, sometimes from ignorance, and occasionally through interested motives. Many specifications still specify materials and forms for using them which may, from our increased knowledge of their merits, be considered obsolete.

Vitruvius on this important subject wrote: "I do not decide what ought to be the materials for walls, because we do not everywhere meet with such as are most desirable; but we must make use of such as we can find." The Roman engineers and architects acted well up to this precept, as the remains of their buildings in various countries testify. Even in brick and stone structures the adherence to that rule will be attended with advantage; and in the case of concrete building it is still more applicable. The cost of carriage for materials is at all times a formidable item, and every care should be taken in reducing it to the lowest figures.

As it is necessary to understand thoroughly the relative values of the various binding agents used in concrete making, I have endeavoured to give the most reliable information regarding them, so that those desirous of further investigating the subject may command the necessary initiatory knowledge for their purpose. Such information is of necessity limited; but it may lead to a desire for more accurate knowledge, and thereby disencumber the subject of the dogmatism with which it has been generally associated. With that object I have discussed separately the various well-known limes and cements, and have added the necessary analyses and particulars for the purposes of elucidation, so that a clear understanding of their several properties may be arrived at. The chapters on cement-setting, concrete-mixing, and the machinery for that purpose, are of more general application, and may be considered as containing useful information on these several branches of the subject. Although the required knowledge to use concrete for house building is not very scientific or exact in its character, still the amount of success which may be expected will depend pretty much on the amount of intelligence which may be applied in its preparation.

HENRY REID.

October, 1869.

CONTENTS.

PRACTICAL TREATISE ON CONCRETE.

INTRODUCTION.

Building with concreted materials has been practised in every age; but the Romans gave the greatest consideration to the subject, and they constructed subaqueous works by that system thousands of years ago. Their name for a mixture of hydraulic mortar and broken stones was "signinum," and with that preparation they constructed various piers and harbours on the shores of the Mediterranean sea. Subsequently they added puzzolana, which imparted increased setting energy to the comparatively inert lime, with the advantage of improved hydraulicity. French engineers in modern times adopted a similar system; but in England, from a variety of causes, the matter has not received that attention which its importance deserves.

A difference of opinion exists as to the difference between bèton and concrete; and some writers endeavour to draw a distinction between the two, regarding bèton as being made with hydraulic mortar and concrete prepared from non-hydraulic limes. Others again consider the difference to be in the mode of mixture: when the cement or lime is first mixed with sand, before being incorporated with gravel, it is termed bèton; and when that preliminary operation is omitted it is called concrete. Such distinctions are too nice for practical purposes, and are alluded to only for the purpose of avoiding confusion in the use of the two terms. The names bèton and concrete may therefore be considered synonymous, as indeed their names imply; and we may regard the term concrete as generic, embracing all mixtures of whatever description used for building purposes. English cob, Irish dab, and their several varieties, as well as Spanish tapia and

Italian pisa, may be termed concrete, for they are respectively amalgamations of several materials. General Pasley has assigned the merit of introducing concrete in England to Sir Robert Smirke, who used it on an extensive scale in the foundations of Millbank Penitentiary; and in his work on cements relates the accidental circumstances which led that eminent architect to the adoption of the preparation. It is immaterial to us who was the inventor or adapter of one kind or other of the different varieties of concrete, although we may be justified in ascribing to it an origin of great antiquity. The use of conglomerate masses of clay only, or in combination with other materials, continued through many ages of the world's history until the discovery of iron working, when man was enabled by its agency to adapt and shape stone to the required forms. Subsequent chemical knowledge led to the use of cementitious materials for connecting or binding stones; and clay, bitumen, sulphates and carbonates of limes, and puzzolanas were severally used for that purpose. Advancing engineering and chemical science, conjunctively experimenting on the varied properties of limes and cements, have succeeded in the introduction of a cement possessing the valuable qualities of moderately quick setting and permanent induration.

Vicat, Pasley, and other practical investigators have ably assisted in this consummation by their painstaking and laborious researches on limes and artificial cements. Smeaton, however, in his experiments to ascertain the most suitable mortar with which to construct the Eddystone lighthouse, initiated the method which eventually resulted in the discovery of Portland cement. Although lime in combination with puzzolana or other volcanic products had been, from the time of Vitruvius, used to resist the injurious action of water, their beneficial conjunction was not satisfactorily explained until the time of the Eddystone experiments. Modern experience has somewhat modified Smeaton's conclusions, but, nevertheless, we may consider ourselves much indebted to him for a knowledge of hydraulic limes and the causes of their hydraulicity.

Chemical analyses of mortars and concretes prove the importance of a thorough and perfect amalgamation of the materials. Any negligent departure from the true principles of this process will assuredly result in disappointment. The best cements, sands, or gravels will not of themselves insure a good quality of mortar or concrete unless they are combined in an intelligent manner. The excellent quality of ancient mortar and concrete was consequent on the care bestowed in their preparation. The Romans considered good mortar an indispensable necessity, and Plinius tells us that lime was not allowed to be used until it had been slaked for a period of three years. The sand and prepared lime were then pounded in the "mortarium" and converted into a cement, our word mortar being derived from the vessel, which we still call a mortar, but now used for a very different purpose. The necessity for the expensive manual labour is now superseded by machinery, which, while successfully incorporating the materials, also accomplishes the desired separation of the particles of lime in the most perfect manner At pages 60 to 65 are analyses of ancient and comparatively modern mortars, a reference to which will clearly prove the importance of time as an indurating agent, provided the necessary precautions are observed to ensure that result.

There have been several attempts made to introduce lime and cement concrete for house-building, but, in consequence of the careless and irrational method adopted, the results were not of a satisfactory character. The subject is again becoming important, from the general desire to improve the condition of cottage dwellings for the working classes; and it is essential that the efforts of builders may be well directed in preparing the concrete for that purpose. An intelligent knowledge of the several mixtures and the reasons which govern their selection will, it is to be hoped, now secure success in building with concreted materials. Past failures have been owing to ignorant treatment of the lime, and great care must be taken to avoid in the future loss and disaster from a too ready dependence on the various machines devised for speedy construction. The aid of mechanical contrivances for lessening the cost of labour is an advantage, provided its adoption does not lead to a disregard of the chemistry of the process, which in this case is of much importance, and may be considered paramount.

French engineers have given much attention to the question of concrete, and they as well as Italian engineers generally employ it in much larger masses and for a variety of purposes for which we in England have hitherto considered it unsuitable. English engineers are, however, becoming more daring; and with a better knowledge and increased confidence in the cementing agent, apply concrete in works which a few years ago would have been executed in stone or brick.

Architects profiting by engineering experience now look upon concrete with more favour, and begin also to appreciate its merits. Facility of executing the most detailed ornamentation in Portland cement, mortar, or concrete, will ultimately secure its general adoption. In Germany great attention is bestowed on the preparation of a variety of articles in connection with building; and machinery of various kinds is used for moulding and shaping architectural details which in this country are performed by the expensive agency of the plasterer or stone carver. Pipes for sanitary purposes are made by machine, and for many reasons are most suitable for the conveyance of sewage. Many miles of sewers under the city of Paris have been constructed of "bètons agglomérés," a kind of concrete possessing many valuable peculiarities.

The several advantages secured in the construction of houses with concrete; and the facility with which the materials of almost every locality may be adapted for the purpose, is not the least important one. Improved means of resisting the climatal influences of our changeable atmosphere is commanded by the use of concrete walls, and numerous sanitary improvements are secured by its application. Its progressive hardening properties enable it to resist effectually the damaging influence of frost in the severest climates. Deleterious ingredients of the most vitiated atmosphere fail to disintegrate or otherwise damage it. The comparatively non-absorbent character of Portland cement and the improvement which it effects on any material with which it may be united, secure the maximum amount of comfort to the inmates of a house so constructed.

Although Portland cement may be considered the most valuable agent in preparing concrete, there are many other natural limes and cements suitable for that purpose. With the object, therefore, of simplifying the use of all well-known cementitious products, and to induce investigation in the search after others, the author has classified them under distinct heads for the purpose of ready reference, so as to prevent confusion in the study of the question. The chapter on lime and cement setting is offered with the view of awakening thoughtful investigation of that important subject. Unfortunately very little if any attention is paid to this matter, although it influences in a great degree the operations connected with building houses and works of construction generally. At all events it is considered of sufficient importance to warrant the space in this book occupied in its discussion.

LIMES.

The mineral from which limes are obtained occupies a large portion of the earth's crust and surface, few localities being without it in some form or other. Great Britain is especially favoured in having large deposits of varied character in chalk, magnesian, oolitic and argillaceous limestones dispersed through every district of the kingdom; the various geological formations in which carbonate of lime occurs, more or less influencing the quality of lime derived from their rocks. When used as mortar for building, its value is measured by the amount of certain impurities which it contains; and the following classification has been adopted to distinguish the several descriptions.

First: Rich limes, having 100 per cent. carbonate of lime. Second: Poor limes, 70 per cent. carbonate of lime, 3 per cent. silica, 26 per cent. sand, 1·5 per cent. alumina. Third: Slightly hydraulic, 80 per cent. carbonate of lime, 3 per cent. alumina, 5 per cent. silica. Fourth: Hydraulic, 82 per cent. carbonate of lime, 6 per cent. alumina, 11 per cent. silica. Fifth: Eminently hydraulic, 80 per cent. carbonate of lime, 6 per cent. alumina, 14 per cent. silica:—indicating as they diverge from a pure carbonate of lime an increase of silica and alumina, the two ingredients that give value to hydraulic limes. The first and second classes are inert, and possess a minimum degree of setting energy. The third, fourth, and fifth classes improve in value, and set with moderate energy either in or out of water. The time of setting of these five classes of limes ranges from three to fourteen days, without an admixture of sand or gravel. In selecting lime for concrete, it is advisable to reject that which is obtained from limestones having by analysis a less amount of silica and alumina than those of the second class. The use of pure limes is not advisable, from their extreme liability to absorb moisture; and when being slaked great care is necessary so as to obtain the utmost amount of comminution of their particles. The Romans overcame this difficulty in using rich limes by the introduction of foreign materials; they used puzzolana in Italy, trass in Germany and pounded bricks in England and France. Whatever quality of lime may be used it is necessary that it should be reduced to the finest powder, either by slaking or mechanical pulverization. In preparing it to mix with sand or gravel it is necessary to impart sufficient moisture to ensure the maximum amount of cementation. The process of absorbing carbonic acid from the atmosphere can only be successfully accomplished when the lime is in a hydrate state. A good illustration of the necessity of such a precaution may be found in the examination of the south side of buildings hurriedly built during hot weather. An inspection of the joints will show them to be in a powdery state, caused by the too hurried drying of the mortar: for it is only possible to convert a hydrate or slaked lime into a carbonate by the agency of moisture. Grout when properly prepared provides in a most satisfactory manner for the conversion of the hydrate into a carbonate; it is seldom, however, that the necessary amount of care is bestowed in its preparation to ensure that desirable result. The hardening of mortar is due to adhesive action, and not, as is sometimes supposed, to its cohesive properties. Sand or any dilutent or aggregate only exerts a mechanical influence in mortars; except when they are obtained from the disintegrated remains of rocks having a considerable percentage of carbonate of lime in their constitution. In such cases there is some slight reason for supposing that a favourable chemical influence is exerted in accelerating the crystallization of the carbonate.

In consequence of the indifference of builders to the qualities of mortars they use, no very satisfactory progress has been attained in their preparation in this country. Engineers and architects do not seem to attach enough importance to the subject, and, consequently, that which was considered all-important in ancient construction receives at our hands but indifferent treatment. A disregard of this subject has prevented the necessary diligent investigation of the merits of our lime and cement stones. The introduction of concrete buildings will in all probability lead to a desire for further information on the qualities of limes and the rules which should govern their selection. As a proper understanding of the question is only obtained by analytical observation, we here give a simple mode of analysis.

Pound the sample in a mortar, and then pass it through a fine sieve. Put 150 grains in a capsule, and pour upon it gradually diluted muriatic acid, stirring it during the time with a glass rod or piece of wood; add the acid until the effervescence ceases. Then evaporate the solution thus obtained by a gentle heat until converted into a paste. The mass is then diffused in a quart of water and filtered. That which remains on the filter is an impurity which may either be clay or sand. To ascertain this, separate them by washing or decantation. If clay, the lime will be hydraulic; if sand, weak and poor, like those of the second class. The weight of clay as compared with the original weight (150 grains) will determine the hydraulicity of the lime.

The object of the above analysis is to ascertain primarily the amount of lime in the sample. The residue of impurity is required to be carefully ascertained, for if sand, the limestone is comparatively worthless; should it be fine clay containing silica, the lime made from it will be found of good quality. To test the analysis before deciding on the adoption of an unknown lime, it is advisable to erect a small sample kiln and decarbonize about one-hundred weight of the stone, which quantity would be enough to prove in a more practical form the value of the lime. The search after and determination of the qualities of limes and cements is a duty required of the engineer and architect; and Vitruvius tells us that he sought for information on the subject from the works of the Grecian architects. Ignorance of chemistry, however, prevented him from arriving at any very satisfactory conclusions.

It is impossible to ascertain the lime value of any stone by a knowledge of its physiognomy. The hardness, fracture, colour, &c., may indicate its value as stone for building, but these qualities afford no guide when it is subjected to chemical change in its conversion into lime. It has been attempted to establish rules for the selection of limes by a knowledge of the quality of the stones; and when a good lime was required it should be selected from a hard stone, thus endeavouring to show that a hard crystallized limestone, of high specific gravity, would produce a lime which would ultimately equal in hardness the stone from which it was produced. There is no case which practically receives such a solution promised by that method; although in the case of blue lias and other argillaceous limestones some reasonable cause exists for the proposition of such a theory. The marbles do not make good building limes, and chalk—like them, nearly a pure carbonate—produces a rich lime poor in hydraulic properties, the one mineral being of a crystalline character and the other of an earthy nature. Modern science, however, can convert the latter, by a small admixture of clay, into a cement, the ultimate indurating capacity of which excels, in resistance to fracture or compression, the hardest bricks or stones.

As a guide to those who intend or are from necessity obliged to use lime for concrete, the following analysis of lias limestone from Lyme Regis in Dorsetshire is given below. Limestones which approach the nearest to this quality should have a preference:

Lime	44·35
Alumina and silica	17·30
Carbonic acid	34·85
Water	3·50
	100·00

In using lime it is necessary that it should be obtained fresh from the kilns, as it is then better than if kept exposed to the atmosphere, from which it freely absorbs moisture. Rich limes are more liable to depreciation from this cause than the poor or hydraulic ones, and it will be found that such tendency decreases in a ratio with the amount of alumina in their analysis.

The table of analyses at page 10 of various limestones in different localities in England and Wales may be found useful. It is compiled from reliable sources, and will indicate the lime resources of the various districts from which the samples have been taken.

The proportions of lime used with sand, gravel, or other materials to form concrete is variable, and must depend in a great measure on their respective qualities. If a clean sharp sand or gravel is obtainable, one of lime may be used with three of sand. Generally speaking, the more sand or gravel you can use the more satisfactory will be the result. To command the greatest advantage, however, with such a mixture it is necessary that the lime should be finely ground.

With the view of facilitating the study and practice of lime-mortar, and concrete making, the following examples of first-class mortars and their costs are given.

TABLE OF ANALYSES OF

Description.	Locality.	By whom Analyzed.	Carbonic Acid.	Lime.	Carbonate of Lime.
Magnesian... ...	Near York	Smithson Tennant	47·00	33·24	...
Ditto	Denton, ditto ...	Rev. J. Holme ...	...	...	63·0
Ditto	Eldon	Sir H. Davy	...	...	52·0
Ditto	Aycliffe	Ditto	...	...	45·9
Ditto	Portishead, near Bristol...	Dr. Gilby	...	...	53·5
Ditto	4 miles N. W. of Bristol...	Ditto	...	...	58·0
Ditto	Bolsover, Derbyshire	Professors Daniell and Wheatstone	...	...	51·5
Ditto	Huddlestone, Yorkshire	Ditto ditto	...	...	54·19
Ditto	Roach Abbey, ditto	Ditto ditto	...	...	57·5
Ditto	Park Nook, ditto ...	Ditto ditto	...	...	55·7
Oolites	Ancaster, Lincolnshire	Ditto ditto	...	...	93·59
Ditto	Bath Box, Somerset	Ditto ditto	...	...	94·52
Ditto	Portland, Dorset ...	Ditto ditto	...	...	95·16
Ditto	Ketton, Rutlandshire	Ditto ditto	...	...	92·17
Ditto					
Shelly Oolite ...	Barnack, Northamptonshire ...	Ditto ditto	...	...	93·4
Ditto	Ham Hill, Somersetshire	Ditto ditto	...	...	79·3
Siliciferous ...	Chilmark, Wiltshire	Ditto ditto	...	...	79·0
Carboniferous ...	Whiteford, Flintshire, N. Wales...	Dr. Clarke	40·10	49·65	...
Blue Lias	Holywell, ditto ...	Dr. J. Muspratt ...	...	...	71·55

At the London Docks in 1856-57, the lime was made from lias stone obtained at Lyme Regis and burnt at the works by the Dock Company. The best attention was given to its decarbonisation, and the mortar was prepared under the direction of the Company's engineer, and supplied by them to the contractors. There were four qualities; two first-class and two second class.

VARIOUS ENGLISH LIMESTONES.

Carbonate of Magnesia.	Iron Alumina.	Alumina.	Silica.	Bitumen.	Water & loss.	Oxide of Iron.	Residuum.	Iron and Clay.	Magnesia.	Remarks.
...	...	...	...	...	...	...	...	0·40	19·36	York Minster is built of this stone.
30·0	...	2·25	...	...	0·25	...	...	...	...	
45·2	1·1	...	...	...	...	...	1·7	...	...	
44·6	1·57	...	...	...	...	...	2·8	...	...	
37·5	...	...	...	...	1·2	0·8	7·0	...	...	A conglomerate in contact with the new Red Sandstone.
38·0	...	...	1·5		...	1·1	1·4	...	...	
40·2	1·8	...	3·6	...	3 3	...	...	...	...	Analyzed for the Committee appointed to decide on the most suitable stone with which to build the Houses of Parliament.
41·37	0·30	...	2·53	...	1·61	...	...	...	...	
39·4	0·7	...	0·8	...	1·6	...	...	...	...	
41·6	0·4	...	...	...	2·3	...	...	...	...	
2·90	0·80	...	...	Trace	2·71	...	...	...	...	
2·50	1·20	...	...	Trace	1·78	...	...	...	...	
1·20	0·50	...	1·20	Trace	1·94	...	...	...	...	
4·10	0·90	...	...	Trace	2·83	...	...	...	...	
3·8	1·3	...	...	Trace	1·5	...	...	...	...	
5·2	8·3	...	4·7	Trace	2·5	...	...	...	...	
3·7	2·0	...	10·4	Trace	4·2	...	...	...	...	
...	...	8·80	0·60	0·60	0·25	...	...	...	...	
1·35	...	3·52	20·1	...	0·5	2·21	Alkalies. 0·79		...	74·73 soluble, 25·27 insolble in acids.

No. 1, for first-class masonry:—

Slaked lime	70 bushels
Screened sand . . .	90 ,,
Forge ashes	10 ,,
Puzzolana	10 ,,
	180 bushels,

measured dry made 5·06 cubic yards of mortar, at a cost of 11s. 7d. per cubic yard. The wheeling, mixing, engine-power, fuel and repairs (no interest for wear and tear of plant) cost an additional 2s. 9d. per cubic yard. The total cost therefore was 14s. 4d. The mortar was ground 40 minutes in the mill.

No. 2 for first-class brickwork:—

The same proportions, having been ground only 20 minutes, made 5·29 cube yards at a cost of 12s. 9d.

No. 3 for second-class masonry:—

Slaked lime	70 bushels
Sand	110 ,,
Puzzolana	10 ,,
	190 bushels,

measured dry made 6 cubic yards of mortar, at a cost of 9s. 11d. per yard; the labour and mechanical cost being 1s. 8d., or a total of 11s. 7d. per cubic yard. The mortar was ground 20 minutes.

No. 4 for second-class brickwork:—

Slaked lime	70 bushels
Sand	120 ,,
	190 bushels,

made 6 cubic yards of mortar, at a cost of 7s. 3d. per yard, and the cost of mixing and machinery 1s. 8d., or a total of 8s. 11d. per cubic yard. The mortar was ground 20 minutes.

The cost of the lias limestone was 10s. 9d. per ton at the Docks. Welsh culm costing 21s. per ton was selected for burning, and the labour 4s. per day. These prices are more than usually unfavourable, and account for the high cost of the mortar.

The mortar used in the construction of the Liverpool Docks has been long celebrated for its excellence; and its well-established reputation, earned during a period of 30 years, has resulted from the careful attention bestowed in its preparation. Two qualities were prepared.

Best quality:

1	part of	slaked lime	.	by measure.
1	,,	sea sand	.	
½	,,	furnace ashes	.	

Second quality:

1	part of	slaked lime	.	by measure.
2	,,	sea sand .	.	
½	,,	furnace ashes	.	

Both mortars were well ground, and mixed in revolving pans, and cost from 8 to 10 shillings per cubic yard. The limestone (blue lias) was obtained from Holywell in Flintshire, an analysis of which appears in Table, pp. 10 and 11. It was burnt at the Docks, and the mortar was supplied to the contractor by the commissioners. It was one of the duties of the engineer to superintend its preparation.

In both of these important works it was considered necessary that the mortar should receive the most careful manipulation, and this was considered unattainable if entrusted to the contractor: so that the selection of stone, its decarbonization, and ultimate mechanical combination was confided to the Engineers, who have every reason to feel satisfied with the success attained.

Works of considerable magnitude are now being constructed at one of the ports (Saïd) of the Suez Canal with lime concrete. The lime is from Theil, in Ardèche, France, and is hydraulic in character. It is burnt, and sent in packages by the makers to the Mediterranean, where the contractors use it for block-making according to the following specification:

The blocks must be 3 metres 40 centimetres in length, 2 metres in width, and 1 metre 50 centimetres in height, or 10 cubic metres. Part of the jetties might be constructed with blocks of 4 cubic metres under the condition that the external parts be composed of 10 metres only. Both these kinds of blocks are formed of beach sand and Theil lime in the proportions of 325 kilogrammes of lime in a dry powder to 1 metre 3 centimetres of sand. The Company reserves the right of altering the admixture of lime to the amount of 25 kilogrammes more or less than the amount mentioned. The lime will be furnished by M. Savin, of the Farge, at Theil

(Ardèche), or by any person furnishing a lime of the same quality and accepted by the Company. All the packages must bear the mark of the manufacturer. The blocks must be dried in the open air for two months or less, as may be allowed under the orders of the director-general of the works.

The analysis of the Theil lime is as under :—

	Carbonic acid.	Silica.	Alumina.	Lime.	Oxide of iron.	Magnesia.
Unburnt ...	36·28	14·90		45·63	1·70	0·39
When burnt...	8.00	18·20	1·20	60·00	0·80	1·32

One of our best English hydraulic limes is that obtained from Aberthaw, which gives the following analysis :—

Carbonate of lime, 86·2; Clay, 11·2; Water, &c., 2·6.

It is advisable to remember that limes are weaker in cohesive than adhesive capacity, and in this respect they differ from the cements and puzzolanas; so that a much greater necessity exists for their being finely ground, so as to ensure the largest amount of diffusion throughout the mass of mortar or concrete. A very small proportion of lime will suffice to make a good mortar if this principle of dispersion is well performed. This observation has more especial reference to the rich or pure limes; for in the case of those of a hydraulic character the impurities of their constitution perform the part of disseminators, and so separate the atoms as to enable them to perform the highest degree of surface contact with the aggregates. Generally speaking, however, it will be found that a well-selected aggregate is superior to lime in its cohesive value. In the case of Portland cement it is otherwise, for bricks made of neat cement prove stronger than when mixed with sand or gravel. The dispersion of the particles of lime must not be brought about by the agency of water; for lime is easily injured by an excess of water, from its inability to eliminate it when setting. The advantage of a good porous aggregate is of great service under such circumstances, so as to absorb any redundancy of water, the retention of which would destroy the value of the lime as a matrix. Fat or rich limes have been—experimentally at least—benefited by grinding with them portions of the unburnt or core; but the advantage of such a mixture can only be measured by the value of the imperfectly-carbonized portion as an adulterant or aggregate.

The cohesive power of lime may perhaps be considered rather its capacity of crystallization; it adheres to a suitable body with which it may be brought in contact, and the ultimate process of forming crystals is built thereon.

PUZZOLANAS.

These natural cements are of volcanic origin, the name Puzzolana having originally been given by the Romans to the substances found by them at Puteolii, near Vesuvius. The colour is generally brown, but varies according to the locality in which it occurs; sometimes it is yellow or gray, and occasionally white, such as that found in Pausilipp and Vivara. The kind most highly valued is procured from the St. Paul quarry, near Rome, and Italian engineers usually specify that description for works of more than ordinary importance. It was used in the construction of the harbours of Leghorn and Spezzia. On the Rhine the Romans are supposed to have used, instead of puzzolana, a volcanic product called tufa, found in the Eifel mountains. In Britain, from the absence of both, they substituted pounded tiles or burnt clay. The importance of an ingredient in mortars having the capacity of imparting setting energy to the lime was fully recognized and well understood by the Roman builders. The Dutch used tufa from the Rhine, and called it trass or tyrass—meaning in their language a binding or adhesive substance. It is occasionally termed terrace, from the fact of the material having been excavated in retreating galleries, as slate is now worked in Wales and other countries. There is good reason for supposing, however, that the word terrace is a mere corruption of the original Dutch name tyrass.

Puzzolanas and their several varieties may be obtained in all localities where active or extinct volcanoes exist. The mass is magnetic, and loses water on being subjected to heat; and when so treated is completely decomposed by sulphuric acid. Their peculiar origin accounts for the variability of their analyses, and, in consequence, their extensive use is inadvisable unless when guided by the necessary discriminative knowledge. The following table of analyses of puzzolanas, of the best known sorts from various volcanic districts, will show the great difference in their several chemical values:—

These cementitious volcanic products have received from mineralogists a variety of names, the more familiar of which are puzzolana, travantine, tufa, tufa stone, trass, augite, leucite, and andecite, besides other names having a purely local origin. It is unnecessary to allude more particularly to their several peculiarities, as they always possess in a lesser or greater degree the property of imparting hydraulicity to rich limes. Attention is thus called to the subject of these hitherto neglected minerals for the purpose of directing attention to their plentiful existence in all districts of extinct or active volcanoes. The volcanic rocks of our own and other countries, although not possessing such valuable properties as puzzolana, may nevertheless be found to contain the necessary quantity of silica and alumina to render a weak lime fit for general purposes of concrete making. When puzzolana is found in a friable or sandy condition, it is more capable of inexpensive amalgamation with lime; and, although generally used in its natural condition, it is found that some qualities are improved by being slightly burnt. The analysis (No. 15, p. 17) of lava recently erupted from the crater of Vesuvius indicates that the natural process in producing these useful cements is unchanged. The proportions of silica, alumina, and lime are more perfect than in the older samples, and the excess of soda may be accounted for by the freshness of the erupted matter.

Trass, or tyrass, has been favoured with a distinct classification from some authors when treating of volcanic cements. It does not appear, however, to differ sufficiently from puzzolana to be entitled to that distinction, as the following table of analyses will show. It is more solid in character, and was used by the Romans instead of stone for building in the localities of its deposit on the Rhine; and it is assumed by some writers that it was only used for that purpose, and not as a cement. There is conclusive evidence, however, that the Dutch have used it for hydraulic works in Holland for nearly two hundred years. In 1682 a Dutchman named Van Santen erected a mill on the Rhine for grinding trass.

Table of Analyses of Puzzolanas.

Nos.	Silica.	Alumina.	Oxides of iron.	Lime.	Magnesia.	Potash.	Soda.	Chlorine.	Water.	Colour.	Analyst.	Where Found.
1	44·5	15·0	12·0	8·8	4·7	1·4	4·1	...	9·2	Brown	Berthier	Pit St. Paul, near Rome.
2	52·2	17·8	6·3	9·2	...	2·6		...	10·2	...	Rivot	Near Naples.
3	46·5	10·5	29·5	10·0	...	...	...	...	2·5	Brown	Vicat	Vesuvius.
4	46·0	16·5	15·5	10·0	3·0	...	...	...	3·0	Dark gray	"	Ditto.
5	44·5	15·5	12·5	9·5	4·4	...	...	...	3·3	Light gray	"	Ditto.
6	59·1	21·3	4·8	1·9	...	4·4	7·2	1·6	...	...	Elsner and Stegnel.	Ditto.
7	59·8	16·4	4·6	1·6	...	14·2	1·3	2·0	...	...	Elsner and Reinhardt	Ditto.
8	51·7	15·1	6·2	5·4	1·2	6·2	1·0	...	11·4	...	Abich	Nola.
9	52·8	15·8	7·6	3·1	0·8	7·7	2·9	0·2	9·3	Yellow	"	Pausalipp.
10	54·6	17·9	5·5	0·8	0·8	5·2	6·4	...	8·2	...	"	Epomeo.
11	54·4	15·4	7·7	3·2	1·5	7·5	2·9	...	7·2	White	"	Pausalipp.
12	56·3	15·3	7·1	1·7	1·4	6·5	8·8	0·3	6·7	...	"	Crater of Monti Nuovo.
13	45·5	16·0	11·7	5·0	3·2	4·1	2·3	0·4	9·4	Yellow	"	Island of Vivara.
14	51·0	13·7	13·6	7·1	4·7	2·9	2·9	...	4·6	White	"	Ditto.
15	39·0	14·0	13·0	18·0	3·0	1·0	10·0	...	...	Brown	Silvestri	Vesuvius, at the eruption in October, 1868.

There is another useful description of tufa found on the island of Santorin (the ancient Thera), from which it receives its name Santorin earth. Santorin has been celebrated from time immemorial as a centre of volcanic disturbance, and so recently as the year 1866 it was subject to such influences. The following samples of analysis of the earth exhibit an affinity to puzzolana and trass; but they differ considerably in their silica values, which will account for their being more friable, —such preponderance of silica imparting to them a resistive capacity to the action of acids; and for some purposes such a property is valuable.

There can be no doubt that although the above tables display only information of an exact kind of the cementitious volcanic products of Italy, France, and Germany, there are strong reasons for supposing that they exist in every quarter of the globe where analagous geological formations occur. Historical records limit our knowledge to the Roman period of its use, but it is supposed that the value of volcanic cement was known to extinct nations and peoples of whom no historic trace remains. On the South Sea Islands very large statues have been found, which could only have been built up by the aid of some cementitious agent.

The investigations of Roman architects were necessarily circumscribed, owing to their imperfect chemical knowledge; but the present advanced state of chemistry offers assistance in the acquisition of the most reliable data for the selection of limes and cements. The great natural causes operating in the production of mud lavas (puzzolana, trass, and Santorin earth) are explained in some degree by the following theory: —The internal agencies which produce volcanic action are exerted in ejecting portions of rock belonging to the trachyt formation; and that at least in Italy and the Archipelago from a submarine source, such influence being assisted by the simultaneous reduction of the land rocks; as is proved by finding both at Vesuvius and the Eifel mountains organic remains.

Obsidian, pumice and pearlstone are products of the trachyt formation, and the analysis in Table No. 1 of the rocks underlying the Eifel mountains, Santorin and Vesuvius, show a marked resemblance to these minerals, as Table No. 2 of their analysis will prove. Table No. 3 of pumice, andecite and Santorin earth partake so much of a common character as to

Table of Analyses of Trass.

Nos.	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Potash.	Soda.	Water.	Analyst.	Where found.
1	57·0	16·0	5·0	2·6	1·0	7·0	1·0	9·0	Berthier ..	From various localities.
2	48·9	18·9	12·3	5·4	2·4	0·4	3·6	7·7	Elsner ..	
3	57·5	10·1	3·9	7·2	1·1	6·4		..	Rivot ..	
4	54·0	16·5	6·1	4·0	0·7	1·0		..	Rivot ..	
5	46·5	20·7	5·6	2·3	1·0	15·50		..	Vicat ..	
6	53·1	18·3	4·5	1·2	1·3	4·2	3·7	12·7	Vohl ..	
7	54·9	8·7	14·8	1·7	1·0	..	9·4	9·5	Bley ..	

Table of Analyses of Santorin Earths.

Nos.	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Potash.	Soda.	Chlorine.	Water.	Analyst.
1	68·5	13·3	5·5	2·4	0·7	3·1	4·7	0·3	....	Elsner.
2	65·5	16·5	3·1	2·9	1·5	4·3	2·3	3·5	1·4	P. Schulze.

warrant us in attributing their production to the same primary agency. Indeed, the preceding Tables of analyses of puzzolana and trass still further confirm us in such a supposition. Microscopical observation indicates the existence of vapour cavities in erupted lavas, produced doubtless by their ejection from great pressure at a high temperature, in combination with acidulous compounds. The prevailing stone and glass cavities by which they are distinguished, may be considered as having been produced by subsequent crystallization; and in some measure accounts for the improvement of certain puzzolanas by the application of heat. The description of puzzolanas by Vitruvius is worthy of quotation.

"There is found in the neighbourhood of Baye, and the municipal lands lying at the foot of Vesuvius, a kind of powder which produces admirable effects; when mixed with lime and small stones, it has not only the advantage of giving great solidity to common buildings, but possesses the further property of forming masses of masonry, which harden under water. We may account for this property by the great number of burning soils and hot springs, which give evidence of an extensive subterraneous fire, occasioned by the inflammation of sulphur, alum, or bitumen. Thus the vapour of the fire and the flame passing through these beds of earth renders them light, and converts them into a withered tufa without moisture; so that these three substances (the lime, the stones, and the puzzolana), modified by the violence of the heat, on being mixed together, form a solid substance so soon as we add water. This mixture quickly acquires such hardness from the damp which it absorbs, that neither the dashing of waves, nor the action of water, are able to destroy it."

With these analyses for a guide, it will be possible to use many descriptions of burnt clays in the improvement of rich limes; and the utilization of many waste products of our manufactories is also possible for a like purpose. Vicat, the eminent French engineer, gave much attention to the subject of artificial puzzolanas before the introduction of Portland cements. He found, however, that there was danger and uncertainty attending their use, from the imperfect character of their indurating strength—more especially in hydraulic works where a prejudicial action arose from certain chemical ingredients in the water of the sea. For ordinary concrete building purposes, where a maximum degree of induration is

Table of Analyses of Volcanic Products.—No. 1.

Nos.	Silica.	Alumina.	Oxides of Iron and Manganese	Lime.	Magnesia.	Potash.	Soda.	Sulphuric & Muriatic Acids and Water.	Remarks.
1	68·35	13·92	2·28	0·84	2·20	3·24	4·29	4·64	Trachytic Porphyry.
2	67·09	15·63	4·97	2·25	0·97	3·56	5·07	0·45	Trachyt.
3	76·67	14·23		1·44	0·28	3·20	4·18	——	Normal Trachyt.
4	57·66	19·96	4·17	1·01	1·53	6·98	6·06	2·33	Phonolite.
5	61·71	19·24	3·51	1·19	——	5·50	7·38	1·43	Piperno.
6	65·09	15·58	5·76	2·61	4·10	1·99	4·46	0·41	Andecite.

No. 2.

Nos.	Titanic acid and Silica.	Alumina.	Oxides of Iron and Manganese	Lime.	Magnesia.	Potash.	Soda.	Water, Chlorine, &c.	Remarks.
1	61·18	19·05	4·55	0·95	0·19	3·50	10·63	0·34	Obsidian from Teneriffe.
2	62·25	16·43	4·49	0·62	0·79	2·97	11·25	0·53	Pumice from Teneriffe.
3	62·53	17·37	8·39	1·46	4·02	1·82	2·85	1·63	Do. from Island of Fernandea.
4	62·29	16·89	4·15	1·24	0·50	3·98	6·21	3·89	Do. from Ischia.
5	62·70	16·98	5·37	1·77	0·82	4·35	6·09	1·28	Obsidian from I. of Procida
6	62·04	16·55	4·43	1·31	0·72	3·66	6·39	3·84	Pumice from Campi Flegraci.
7	69·34	8·21	8·23	0·14	0·37	1·60	8·32	3·09	Do. from I. of Pantellaria.
8	69·79	12·31	4·66	1·68	0·68	2·02	6·69	2·93	Do. from I. of Santorin.
9	73·70	12·27	2·31	0·65	0·29	4·73	4·52	1·53	Do. from I. of Lipari.
10	74·05	12·97	2·73	0·12	0·28	5·11	4·15	0·53	Obsidian from do.
11	73·99	11·90	2·41	3·61	1·05	4·37		2·44	Pearlstone (avrge. of 5 samples).

No. 3.

Nos.	Silica.	Alumina.	Oxides of Iron and Manganese	Lime.	Magnesia.	Potash.	Soda.	Water, Chlorine, &c.	Remarks.
1	65·09	15·58	5·76	2·61	4·10	1·99	4·46	0·41	Andecite.
2	69·79	12·31	4·66	1·68	0·68	2·02	6·69	2·93	Pumice from Santorin.
3	68·50	13·31	5·50	2·36	0·73	3·13	4·71	1·76	Santorin Earth.

Table No. I.

Analyses of the Clays and other Cement-making Materials.

Nos.	Description.	Silica.	Alumina.	Oxides of Iron.	Carbonate of Lime.	Lime.	Potash and Soda.	Water.
	Very Energetic Substances.							
1	Trass from Andernach	46·60	20·60	12·00	......	3·00	5·00	12·80
2	Puzzolana from Italy	52·00	16·00	15·00	......	1·95	4·05	11·00
3	Ditto ditto	52·00	16·00	15·00	......	1·95	4·05	11·00
4	Artificial puzzolana, from a brown ochreous clay	42·06	28·67	12·33	......	......	......	16·94
5	Ditto from a white plastic clay ...	61·00	31·00	......	......	......	......	8·00
6	Ditto do. gray effervescing clay...	43·63	32·90	9·29	2·16	......	......	12·02
7	Ditto do. brown ochreous clay ...	43·40	26·00	18·60	......	......	......	12·00
8	Ditto do. red very effervescent clay	42·60	15·96	8·00	24·64	......	......	8·80
	Energetic Substances.							
9	Ochreous clay, sand washed out ...	43·60	28·40	13·00	......	......	......	15·00
10	Over-burnt ochreous clay	42·06	28·67	12·33	......	......	......	16·94
	Slightly Energetic Substances.							
11	Clay separated from the sand ...	48·40	24·60	11·00	......	......	......	16·00
12	Ditto ditto ...	47·60	22·00	10·40	......	......	......	20·00
13	Brown psammite of mid. quality ...	60·80	15·20	9·00	......	......	......	15·00
	Inert Substances.							
14	Quartzose sand	100·00	......	......	......	......	......	......
15	Ochreous clay, heated to pasty fusion	42·06	28·67	12·33	......	......	......	16·94
16	Scoriæ of large furnaces	37·00	19·00	6·40	......	38·60	......	......

not requisite, such artificial compounds may under favourable and special circumstances be advantageously employed. The following tables, from Vicat on Cements, throw much light on the relative values of certain kinds of clays mixed with rich limes.

TABLE NO. 2.

Showing the behaviour of the several substances when mixed with certain portions of rich Limes.

Nos.	Rich Lime in Paste.	Powdered Puzzolana.	Time in Setting.	Needle Penetration.	Observations.
	Proportion of Mixture		Days.	Inches.	
1	Two	One	8·00	0·0889	Splintered when struck with the needle.
2	Two	Three	2·50	0·0728	Ditto.
3	One	Three	3·00	0·0827	Ditto.
4	Two	Three	1·00	0·0787	Ditto.
5	Two	Three	2·50	0·0984	Ditto.
6	Two	Three	2·00	0·0866	Ditto.
7	Two	Three	2·50	0·0984	Ditto.
8	Two	Three	1·00	0·1181	Ditto.
9	One	Three	3·00	0·2045	Needle penetrates without splintering.
10	Two	Three	9·00	0·2657	Ditto.
11	One	Three	18·00	0·3555	Ditto.
12	One	Three	6·00	0·3228	Ditto.
13	One	Three	17·00	0·4016	Ditto.
14	One	Two	Never	Soft	
15	One	Two	Never	Soft	
16	One	Two	Never	Soft	

All the samples had been immersed in water for one year before they were submitted to the test. The mode of testing adopted by Vicat was that which is commonly known as the needle-penetrating system, and essentially consists of the measure of penetration made by a needle of peculiar construction falling by impact on the briquette or sample. That mode of testing is superseded by the more convenient and reliable one now generally adopted by English engineers of submitting the samples to tensile strain, by which means the resistive capacity to rupture is readily and accurately ascertained.

The selection of clays for conversion into artificial puzzolanas will be limited to those containing the necessary amount of alumina. A good index whereby to measure the approximate qualities of clays is afforded by an examination of the rocks from which they had been originally disintegrated or their locality of detrition. A careful examination of burnt clay bricks will sometimes enable the investigator to dispense with the necessity of accurate analysis.

There is an interesting circumstance in connection with the introduction of Italian puzzolana into this country which may be considered worthy of mention. Until 1757 German trass had been occasionally used by engineers in England, and the properties of puzzolana were comparatively unknown. Smeaton had been about that time studying Belidor's "Architecture Hydraulique," and there found evidence of the superiority of puzzolana to trass. Fortunately at this time a cargo of puzzolana had been imported from Civita Vecchia by a merchant, who offered it at the price usually paid for trass. Smeaton purchased the cargo, which was used by him in the construction of the now celebrated Eddystone lighthouse. It was mixed with Aberthaw lime in the following proportions:—Two bushels of slaked lime, which had been previously reduced to a fine powder, were used with two bushels of puzzolana without any admixture of sand. The slaking of the lime had been carefully performed at the lime works, and the powder was sent in air-tight casks to Plymouth, from which place it was taken to the lighthouse in the required quantities.

This lime retained its properties so well, from the careful manner in which it was packed, that a surplus quantity remaining was used seven years afterwards by Smeaton in executing the most critical part of the works for improving the navigation of the river Calder.

Smeaton's experiments and example led to an extended use of puzzolana, and its successful combination with all kinds of limes induced further research, which ultimately resulted in the introduction of Portland cement.

The following table of Smeaton's hydraulic mortars, showing their proportions and cost, affords striking evidence of the great attention paid by him to that important subject. Their great expense was due in some measure to the care bestowed in their preparation.

HYDRAULIC MORTARS.

Nos.	Descriptions of Mortar.	Slaked Lime Powder.	Puzzo-lana.	Sand.	No. of Cubic Feet.	Cost Cubic Foot.
						s. d.
1	Eddystone mortar. . .	2 bus.	2 bus.	..	2·32	3 8
2	Stone mortar	2 ,,	1 ,,	1 bus.	2·68	2 1½
3	Ditto, second quality .	2 ,,	1 ,,	2 ,,	3·57	1 7½
4	Face mortar.	2 ,,	1 ,,	3 ,,	4·67	1 4
5	Ditto, second quality .	2 ,,	½ ,,	3 ,,	4·17	1 1
6	Backing mortar	2 ,,	¼ ,,	3 ,,	4·04	0 11

The following table of experiments made by General Treussart with mortars composed of various portions of puzzolana, trass and sand, will afford information of the value of the combination. The prisms or bricks experimented upon were of the following dimensions: 2 inches by 2 inches, and 6 inches long; and were immersed in water for one year before being submitted to the test. The limes were rich or fat in quality, and had been slaked to a powder before mixture with the puzzolana or trass. It was found that the lime was improved if kept for one month in powder, and that which was water-slaked gave better results than when slaked by the action of the air. The mode of breaking was by supporting the prisms 4 inches apart, and applying a suspended weight in the centre.

No.	Lime.	Puzzolana.	Trass.	Sand.	Time of harden-ing.	Weight suppor-ted be-fore breakg.
					days.	lbs.
1	Strasburg lime......1 vol.	...	1 vol.	1 vol.	5	411
2	Do. do. ......1 vol.	...	2 vol.	...	4	330
3	Do. do. ......1 vol.	1 vol.	...	1 vol.	4	499
4	Do. do. ......1 vol.	2 vol.	...	...	3	444
5	Vasselone lime......1 vol.	...	1 vol.	1 vol.	5	449
6	Do. do. ......1 vol.	...	2 vol.	...	4	385
7	Brunstal lime ......1 vol.	...	1 vol.	1 vol.	5	510
8	Do. do. ......1 vol.	...	2 vol.	...	4	535
9	White Marble lime..1 vol.	...	1 vol.	1 vol.	5	308
10	Do. do. ..1 vol.	...	2 vol.	...	4	407
11	Do. do. ..1 vol.	1 vol.	1 vol.	1 vol.	4	396
12	Do. do. ..1 vol.	2 vol.	...	...	3	367
13	Strasburg lime......1 vol.	2 vol.	...	...	4	495
14	Do. (paste)...1 vol.	2½ vol.	...	...	5	550
15	Do. (paste)...1 vol.	...	2 vol.	...	3 to 16	231 to 580

Burnt gneiss has been used instead of puzzolana in the harbour of Brest. Its analysis was as follows :—

Silica.	Alumina.	Oxide of iron.	Lime, Magnesia, Potash & Soda.	Hygroscopic water.
60·33	21·43	8·57	6·92	2·75

ROMAN CEMENT.

This cement was first introduced in the year 1796, when Parker obtained his patent for its manufacture. He probably was influenced in giving the name by which the cement is now generally known from a belief that it had been previously used by the Romans during their occupation of England. More recent information on the subject has, however, dispelled that notion; and accurate chemical analysis has demonstrated that pounded bricks was used by these enterprising people to mix with lime and sand for mortar—sometimes also puzzolana and trass.

Roman cement is made from the "septeria"—or clay balls as they are sometimes called—found in considerable quantities along certain parts of the Kent and Essex coasts. It is not used like the puzzolana, in its natural state ; but is subjected to calcination and afterwards finely pulverized before being in a suitable condition to be employed as mortar. It possesses the valuable property of setting quickly under water; and for that reason has been since its introduction successfully used in the construction of engineering works of great importance. The celebrated Thames Tunnel was—in its early progress at least—constructed with mortar made from that cement. Until the introduction of Portland cement in 1824, it was universally used for engineering and other works both at home and abroad. Although originally made from the "septeria" of the London clay, it is now manufactured from a variety of mineral products—stratified and unstratified—found in several districts of England and Scotland. The more generally known kinds of this cement are distinguished by local or other names. The following table of analysis of different well-known sorts indicates much similarity in their chemical ingredients, although the localities of their origin are widely separated.

No.	Names.	Clay.	Carbonate of Lime.	Oxide of Iron.	Silica.	Alumina.	Magnesia.	Remarks.
1	Parker's Patent Roman	45·0	55·0	...	...	...	...	Not now known by that name.
2	Yorkshire	34·0	62·0	...	...	...	...	Sometimes called Atkinson's & Mulgrave.
3	Sheppey (Kent) ...	32·0	66·0	...	...	...	...	Made in London.
4	Harwich (Essex) ...	47·0	49·0	...	...	...	...	Ditto.
5	Southend (Essex) ...	...	64·0	9·0	12·0	...	1·50	Ditto.
6	Calderwood (Scotland)	...	64·0	10·2	8·8	3·4	2·6	Made near Glasgow.

Besides the above cements there are various other localities in which the stone is procured—in the Isle of Wight, North Wales, and Staffordshire. It also occurs in considerable quantities in the strata of the coal formations in different parts of England. The United States of America are favourably circumstanced in having large deposits of this useful cement-stone dispersed throughout many districts of the country. The quality is generally good, and the accompanying table is here given to show its extent and the accuracy of details given in the analyses. The table is copied from Gillmore on "Limes and Hydraulic Mortars and Cements."

In the preparation of limes and puzzolanas there is not much care required to adapt them for building purposes, and certainly no special skill necessary to convert them into the best condition for mortars. With Roman cement, however, great care is required to convert the stone into cement, and its decarbonization can only be entrusted to experienced men. The suitable mechanical appliances for its proper pulverization involve considerable outlay, which, in conjunction with kilns and mills, requires a large outlay of capital, which is necessarily permanently sunk in the business. The expense of obtaining the stone is also considerable, and when procured by the process of dredging from the sea the cost is greatly increased. From these unavoidable circumstances the erection of Roman cement manufactories is

TABLE OF CEMENT STONES,

Where Obtained.	Carbonic Acid.	Potash	Soda.	Silica, Clay, and insoluble Silicates.	Silica.	Alumina.	Oxide of Iron.	Peroxide of Iron.	Carbonate of Iron.
Utica, Illinois	...	·62	·88	25·20	...	6·16	...	2·02	...
Sandusky, Ohio	...	·40	12·10	19·66	...	3·14	...	3·86	...
Cumberland, Maryland ...	...	1·54	4·64	24·74	...	16·74	...	6·30	...
Shepherdstown, Virginia ...	...	...	...	17·84	...	4·60	...	1·70	...
From High Falls, Ulster, New York. Layer No. 9	...	...	...	18·52	...	2·18	...	1·86	...
Ditto „ 10	...	...	...	29·34	...	5·74	...	1·76	...
Ditto „ 11	...	...	...	39·74	...	6·00	...	1·44	...
Ditto „ 12	...	...	...	19·64	...	7·52	...	2·38	...
Ditto „ 13	...	...	...	26·00	...	4·64	...	1·86	...
Ditto „ 14	...	...	...	28·08	...	5·72	...	5·38	...
Ditto „ 15	...	...	...	18·46	...	4·22	...	2·32	...
Ditto „ 16	...	...	...	27·70	...	2·34	...	1·26	...
Ditto „ 17	...	...	...	11·10	...	2·52	...	1·42	...
Lawrenceville, Ulster County, New York...	...	...	...	19·80	...	4·40	...	·76	...
Akron, Erie County, New York	...	...	...	33·80	...	3·96	...	·88	...
Points-aux-Roches, Lake Champlain		·0333		...	20·07	1·7		...	...
Near Hancock, Maryland ...		·3000		...	27·1	1·5		...	...
Vassy (France) cement ...	...	...	...	...	14·0	5·7	...	...	11·6
Theil (France) limestone ...	36·28	...	...	...	14·90			1·70	
Theil (France) ditto when burnt	8·00	...	...	...	18·20	1·20		·80	
From Balcony Falls, Rockbridge County, Virginia (raw)	30·4	·120	...	...	34·22	7·800		...	...
Ditto ditto (burnt)	...	...	...	...	49·53	11·288		...	...

PRINCIPALLY AMERICAN.

Carbonate of Lime.	Lime.	Carbonate of Magnesia.	Magnesia.	Sulphuric Acid.	Chloride of Potassium and Sodium.	Phosphates, &c.	Brown Oxide of Magnesia.	Hygrometric Water lost at 212° F.	Water and loss.	Excess (—) or loss (+).	By whom analyzed.
58·84	...	...	10·38	·48	...	...	...	·40	...	— 4·98	Prof. E.C. Boynton
40·54	...	...	17·98	·72	...	...	...	·38	...	+ 1·22	Ditto.
41·80	...	...	4·10	2·22	...	...	...	·60	...	— 2·68	Ditto.
58·25	...	11·16	...	·74	3·26	...	...	·20	...	+ 2·25	Ditto.
43·30	...	26·04	...	1·96	4·24	...	...	·20	...	+ 1·70	Ditto.
33·54	...	20·80	...	1·02	5·80	...	...	·16	...	+ 2·04	Ditto.
30·74	...	14·48	...	·66	7·42	...	...	·24	...	— ·72	Ditto.
30·72	...	35·10	...	·64	4·10	...	...	·18	...	— ·28	Ditto.
28·48	...	32·86	...	1·18	4·72	...	...	·26	...	...	Ditto.
43·32	...	14·52	...	1·60	2·78	...	...	·20	...	— 1·60	Ditto.
37·50	...	35·62	...	·20	1·68	...	...	1·40	...	— 1·40	Ditto.
46·00	...	17·76	...	·26	4·02	...	...	·22	...	+ ·44	Ditto.
40·00	...	39·04	..	·22	4·06	...	...	·26	...	+ 1·38	Ditto.
33·90	...	34·06	...	·32	4·78	...	...	1·56	...	+ ·42	Ditto.
35·60	...	19·26	...	·50	6·18	...	...	·14	...	— ·32	Ditto.
58·3	...	22·6	...	...	...	...	...	...	1·666	...	Lt. Caleb Huse.
65·0	...	5·3	...	...	...	...	...	...	·8	...	Ditto.
63·8	...	1·5	...	...	...	...	...	...	3·4	...	Not named.
...	45·63	...	·39	...	...	...	...	...	Water and bitumen 1·10	...	Ditto.
...	60·00	...	1·32	...	...	...	...	...	10·48	...	Ditto.
...	17·33	...	9·51	...	...	...	...	...	Water and organic matters ·500	+ ·06	Ditto.
...	25·15	...	13·77	...	...	...	...	...	...	+ ·26	Ditto.

not attempted unless where a large consumption is secured and favourable water carriage or convenient ports for its economical shipment to distant parts. During the most flourishing period of the Roman cement trade it had to contend with the heavy cost of carriage; and owing to its great liability to deterioration when manufactured it never really could be considered a cheap cement.

Another disadvantage attending its use was the smallness n quantity of sand or gravel with which it could be safely mixed. In important works it was seldom reduced with sand; and in the construction of the Thames Tunnel it was generally used neat. For the arches it was so used, and in the piers one volume of cement to half a volume of sand; for the foundations, one volume of cement to one of sand. The tunnel would not have been built if this or a similar quality of cement had not been accessible. Roman cement was particularly suitable for work wherein great expedition was so essential, and until the introduction of Portland it was invariably used. During the stoppage of these works in 1828, caused by the river breaking in, the breach was filled by throwing large quantities of Portland cement into the river, which enabled the contractors again to resume operations after the water had been pumped out.

The primary process in the manufacture of Roman cement is that of calcination—or more properly speaking decarbonization; for unless that operation is successfully accomplished, unsatisfactory results follow. The point of excellence is when the stone can be reduced to the minimum weight; should that result be unattained, the cement will either be raw on the one hand, or vitrified on the other. In both cases its best properties are destroyed. When burned with due discrimination, it never should exceed in weight 80lbs. per imperial bushel, and that only when fresh ground. If exposed to the air it readily absorbs moisture, and becomes lessened in value. Thorough and perfect pulverization is essential, and when that operation is accurately performed the highest value in strength will be obtained. When the cement-stone has been properly burnt it will not be sensibly diminished in bulk; but if carried beyond that point the contraction of the mass is apparent. Over-burning also results in rendering the cement languid and slow setting, as well as prejudicially affecting its ultimate induration.

The question of pulverization has received much attention at the hands of American engineers, and they are so impressed with the importance of extreme fineness that they stipulate all cements used for engineering works shall be capable of passing through a No. 80 gauge (6400 meshes to the square inch), leaving only a residue of 8 per cent. Such reduction is seldom practised in this country, in consequence probably of the indifference of engineers and architects to the subject. It is not the interest of manufacturers to press this question, for the cost of mechanical reduction forms a considerable item in the expense of manufacture.

Roman cement will always be found most serviceable in hydraulic works where heavy and slow-setting Portland cements are used, to protect the exposed joints from the injurious action of running or moving water. Before a knowledge of the natural cements was understood, Smeaton used plaster of Paris to protect the joints of the Eddystone lighthouse from the action of the waves. Medina cement—another variety of Roman—is made from stone found at the Isle of Wight; it possesses in a high degree the property of quick setting, and is now extensively used by engineers for protecting Portland cement joints in exposed situations.

The following table exhibits the value in tensile strength of Roman cements. The five samples submitted to test were obtained from their several makers for the purpose of ascertaining fairly the usual marketable article, and in furtherance of that object, without any intimation of the intention of the experimenter. The results are somewhat dissimilar, which may in some measure be accounted for from some of the samples of cement having been longer kept in the warehouses of the manufacturer than others. Their average weights were 80lbs. per bushel.

No.	Description.	Breaking Weight per square inch.			
		7 days.	1 month.	6 months.	1 year.
1	Roman cement, made in London	89 lbs.	108 lbs.	167 lbs.	144 lbs.
2	Do. do.	89 „	116 „	209 „	286 „
3	Do. do.	54 „	160 „	112 „	120 „
4	Do. do.	60 „	96 „	194 „	212 „
5	Medina, made in the Isle of Wight	41 „	136 „	183 „	212 „

The cement was gauged next, and the samples immersed in water. The test was a tensile one, and performed with the testing machine now generally used by English engineers.

At one time Roman cement was considered an article of sufficient importance to require special legislation for its protection; and during the premiership of the late Sir Robert Peel serious intentions were entertained of imposing a prohibitory tax on all foreigners found dredging for the cement-stone off the English coast. The necessity of such a measure was shown to be unnecessary, as even if a deficiency of cement-stone occurred, a cement (Portland) could be made from chalk and clay, the supplies of which, in this country at least, were practically inexhaustible. These representations led to the abandonment of the intended protective policy; and subsequent experience has proved that the new cement is not only better, but it has now almost driven the Roman from the market.

There is every reason to believe that cement-stone may be found in many districts where extensive deposits of clay exist; and more especially in those formations analogous in character to the London and Kimmeredge clays. The stone should not be selected unless containing 40 per cent. of carbonate of lime, with varying proportions of alumina, silica, magnesia and oxide of iron. The simple form of analysis given in the chapter on Limes will answer also for the purpose of approximately testing the values of cement-stones.

Roman cement is not now much used for engineering works except for the special purposes before mentioned; but for concrete to build houses it may under certain conditions be advantageously employed. Its property of quick setting causes its use in careless hands to be attended with danger. In combination with lime it might be extensively adapted to the purposes of house building with concrete where maximum strength was not sought for, and where a cheap matrix could only be used. This cement is liable to speedy deterioration if exposed to the air when ground; and if from unavoidable causes any length of time must elapse between the burning and using it is more desirable to keep it in an unground state, and if carefully packed in air-tight casks it may in that condition be kept good for a length of time. In some cases it may be found necessary to burn the stone in the locality where it is dug or quarried and grind it where required for building purposes. In all cases where an unknown quality of cement is used it is advisable to ascertain, before undertaking extensive works, the exact proportions of sand with which it can be safely mixed; and a very simple plan for this purpose is to cement several pairs of good bricks together, and, after certain intervals, ascertain the amount of force required to separate them. The following table will give some idea of the results which should be obtained by that mode of testing:—

No.	Name of Cement.	Force required to tear asunder pair of gray stock bricks.			
		1st week.	2nd week.	3rd week.	4th week.
1	Atkinson's	23 lb.	28 lb.	30 lb.	31 lb.
2	Medina	23 "	27 "	29 "	30 "
3	Harwich (Roman) . . .	14 "	20 "	26 "	34 "
4	Portland	15 "	33 "	48 "	59 "

PORTLAND CEMENT.

This cement is of comparatively modern origin, and had during the earlier period of its manufacture much opposition and prejudice to contend with, more especially from the Roman cement makers, whose interests were injuriously affected by its introduction. If engineers and architects in this country had possessed any feeling of pride akin to that displayed by Vicat and Treussart in France, or Pasley and Smeaton in England, the reputation of Portland cement would have been long since established, and the qualities and advantages of this material placed beyond cavil or question. Even now—nearly fifty years after its discovery—its valuable properties are but indifferently understood; and notwithstanding the initial investigation of Smeaton and the subsequent experiments of Vicat, the question of hydraulic cements is comparatively neglected. Such indifference is probably owing to the change of practice among modern engineers and architects, who take less interest in the out-door business of their professions and depute the control of details to irresponsible subordinates: or it may be in consequence of the more eminent members of the profession having thrust upon them an amount of work the conscientious and personal supervision of which is impossible. Doubtless the tendency of this age is towards concentration of force, regarding quantity more than quality. This policy, however, will not bequeath to posterity such works as St. Paul's, the Eddystone Lighthouse, or the Menai Bridge; for modern works are not conceived in the same spirit or executed by such untiring personal industry as that which influenced Wren, Smeaton, and Telford when carrying out their celebrated structures.

Portland cement had its origin in the desire for a mortar that would speedily set and harden under water. Lime itself—although the base of all cements—unless mixed with some argillaceous ingredient, does not possess that faculty, and hence the necessary addition of puzzolana, trass, and fossil sands to impart to it the virtue of hydraulicity of which in its pure state of carbonate of lime it is deficient. The earlier researches after such a cement were more especially directed to the preparation of a mortar for submarine structures, and without regard to buildings on land. It is upwards of two thousand years since the first desire arose, but it has been reserved for modern scientific industry to complete the work originated in an antiquity so remote.

This cement, now generally known as "Portland," is artificial in character and is made by an intelligent combination of carbonate of lime and fine clay of a peculiar character. These two simple and inexpensive materials are of almost universal obtainment, and produce, when subjected to the necessary manufacturing operation, a double silicate of lime and alumina. This product is then subjected to a high degree of mechanical pulverization, producing at the completion of that process the Portland cement of commerce. Unlike Roman cement, it is most valuable when heaviest—unless that condition has been attained by spurious manufacture—and also differs from that cement in its slowness of setting. The heaviest qualities set the slowest, and ultimately attain the greatest amount or strength of induration; and in a ratio with the amount of departure from these conditions will the mortar with which the cement is made be found weak and deficient in ultimate indurating capacity. While possessing such valuable characteristics it requires an amount of intelligence when being used, and also differs materially from Roman cement, which if imperfectly made or too long kept will only produce the usual defects pertaining to imperfect mortar. It is otherwise, however, with some qualities of badly-made Portland cement, more especially when it results from an excess of carbonate of lime; for, in addition to disintegration of mortar, distortion of the work takes place from the mechanical force exerted by the imperfectly-slaked lime. Such dangers are practically impossible, however, when the necesary protective agency of thoroughly testing the cement before being used is adopted. The name Portland was given to this cement by its patentee and inventor (Aspdin) from its close resemblance to the stone of that name, and not as has been supposed from its having been originally made from the oolite limestone of the isle of Portland in Dorsetshire.

There are some natural Portland cements, especially those of Boulogne in France, which resemble in their properties the real or artificial Portland; so also some of our best blue lias varieties of limestone approach in their analytical value to the Portland cement, especially those obtained at Rugby in Warwickshire. The analysis of the natural Boulogne approaches very nearly the artificial Portland, as the following table will show:—

No.	Description.	Lime.	Silica.	Alumina.	Oxide of Iron.	Magnesia.	Sulphate of Lime.
1	Portland Cement (artificial)...	62·0	23·0	8·0	4·0	—	—
2	Natural Portland of Boulogne	65·15	20·42	13·87	—	0·58	Trace.

The marl from which the natural Portland cement is made is obtained from one of the layers of the Kimmeridge clay, situated about 160 feet below the strata in which the Boulogne pebbles or "septeria" are found. In some of its characteristics the natural Portland resembles the artificial; but in the most important one, of retaining its normal bulk while setting, it is deficient, for it contracts considerably during that process. The mass from which it is made is homogeneous, which reduces the cost of conversion into a cement; but it varies in character, and consequently cannot always be relied upon from the fluctuating amounts of alumina and silica with which it is mixed, an objection common to all natural cements. In the manufacture of artificial cements of the Portland type it is possible, under a good system of manufacture, to ensure even results, and from that circumstance the value of the cement is much increased. The simple character of the two materials from which it is made facilitates the process of conversion. Their general quality is indicated by the following analyses :—

CHALK.

Lime, 56·5; carb. acid, 43·0; water, 0·5.

CLAY.

Silica, 68·45; alumina, 11·64; carb. of lime, 0·75; oxide of iron, 14·80; soda, 4·00.

The proportions used are from 65 to 75 per cent. of chalk, and from 25 to 35 per cent. of clay, according to their several qualities. Any kind of chalk may be used; but the clay should not contain more than 14 per cent. of iron oxides.

The manufacture is not one of haphazard, but requires the exercise of special care, which, when intelligently bestowed, ensures a good quality of cement.

Much indifference has been until recently displayed by consumers in regard to the quality of Portland cement, and in consequence of such supineness many doubtful, and even dangerous, preparations have been brought into the market. During the last ten years many important works of a public character have been executed, in which large quantities of high-class Portland cements were used, more especially the main drainage works of London and the several embankments of the River Thames. In the latter especially, large masses of concrete walls were constructed of a quality superior to the best brickwork, at about one-third of its cost. The cement on these works was used under the strictest supervision, and from the precautions adopted it was impossible that any cement of a doubtful or dangerous character could reach the point where it was required. Such security was only obtained by a rigorous adherence to the tests, which were substantially these :—

First. The cement should weigh at least 110 lbs. per imperial straked bushel.

Second. It must be finely ground, and be able to pass through a No. 50 gauge sieve, leaving only a residue of 10 per cent.

Third. When mixed up neat and immersed in water it should, after seven days, be capable of resisting a tensile strain of 200 lbs. to the square inch.

The above compound test consists substantially of three elements, a strict adherence to which is necessary; the first being to test the hydraulicity of the cement; the second to prove its fineness, so that the utmost amount of value shall be realised from its facility of extreme diffusion through the masses of mortar or concrete; and the third its strength. It is necessary to insist upon the enforcement of these separate divisions of the test, for it is possible a bad quality of cement may pass one or other of them unchallenged. When, however, the whole test is implicitly adhered to, the engineer, architect, or builder may rest satisfied that no bad cement can be used on works so controlled. The general adoption of the above mode of testing would soon bring about an improvement in manufacture, and eventually result in directing the attention of builders to a better knowledge of the materials of construction with which they have to deal.

Portland cement possesses the valuable property of resisting the deteriorating influences of atmospheric action, and may be kept for a lengthened period before being used; it is, therefore, better adapted for exportation to distant places, and will continue good in any climate. It can be used with larger proportions of sand or gravel than any other cement, and that quality, together with its high amount of ultimate induration, renders it in reality the cheapest cement for concrete making. The proportion of sand to make first-class mortar is usually three of sand to one of cement, but for ordinary purposes the proportion may be increased to eight of sand or gravel for mortar or concrete; indeed, large engineering works are now being executed in concrete with these proportions. Our present knowledge of the maximum degree of induration to which this cement attains is unavoidably imperfect, but from experiments made on samples varying in age from one week to two years the following results were obtained. The cement weighed 123 lbs. per bushel, and the samples were immersed in water until tested:—

NEAT CEMENT.

Age 1 week	363	lbs.	per square inch.
,, 1 month	416	,,	do.
,, 3 months	469	,,	do.
,, 6 months	523	,,	do.
,, 9 months	542	,,	do.
,, 12 months	546	,,	do.
,, 2 years	589	,,	do.

MIXED WITH AN EQUAL VOLUME OF THAMES SAND.

Age 1 week	160	lbs.	per square inch.
,, 1 month	201	,,	do.
,, 3 months	244	,,	do.
,, 6 months	284	,,	do.
,, 9 months	307	,,	do.
,, 12 months	318	,,	do.
,, 2 years	351	,,	do.

These experiments prove that the increase of strength or resistance to rupture is rapid; in the case of neat cement being equal to an improvement of 61 per cent. in two years, and, when mixed with an equal volume of sand, reaches 119 per cent. of improved strength. The cement used in these experiments was of a high character, and selected for the purpose of showing that an increase of weight gives a corresponding improvement in value. The contrast was more apparent, however, in other experiments performed with cements of different weights. Cement of 106 lbs. weight resisted a tensile strain of 210 lbs. to the square inch, and cement of 130 lbs. weight per bushel could not be broken under a strain of 406 lbs. per square inch, indicating thereby an improvement in tensile strength of nearly 100 per cent. by an increase in weight of 24 lbs. to the bushel. Its capacity of resistance to compression is also very remarkable, as the following experiments will show:—

Bricks were made of neat cement 9 inches by 4½ inches by 2¾ inches, and subjected to hydraulic pressure at the following ages :—

At three months old they were fractured by a pressure of 65 tons ; at six months old, by a pressure of 92 tons ; and at nine months old, by a pressure of 120 tons. The pressure was applied in their bed, having a superficies of 38·25 square inches. To establish a comparison between these results, obtained from cement and other building materials of a high character, the following experiments were made, resulting as follows :—

	Exposed surface. Sq. inches.	Average crushing weight. Tons.
Oldham red bricks	39·33	40
Medway gault-clay bricks	40·50	17
Do. pressed	—	48
Stafford blue brick	27· 9	50
Fire-clay brick	34·85	65
Wortley blue brick	34·76	72
Portland stone	39·94	47
Bramley Fall stone	39·94	91
Yorkshire landing	38·28	96

Showing that a neat Portland cement brick at nine months old exceeded in value the best known building materials of this country ; and it is just possible that a greater age may yet indicate an increase of strength, an advantage our experience does not lead us to expect from bricks or stones. Heavy cement is necessarily slow setting ; and these experiments, coupled with the best engineering experience, prove indisputably that without weight you cannot obtain great strength.

Portland cement can be made from 80 lbs. to 130 lbs. weight per bushel, but these weights may be considered the two extremes. The light cement will set too rapidly, and the heavy one too slowly, for general purposes. The cost of the cement is governed by its weight and fineness ; the heavier it is, and the nearer it approaches to an impalpable powder, the greater will be its cost. The use of either of these two extreme qualities of cement is not recommended. The safest and most generally useful quality is that which weighs 110lbs. per bushel; that cement, well ground, represents the best average quality of manufacture, and from its use may be obtained all the ordinary advantages required for building purposes. Until recently much confusion arose from the difficulty attending the practice of selling and buying cements by a measure of capacity. The price per bushel led to the production of a cement of light specific gravity, so as to fill the sack regardless of the quality of the material put into it. More intelligent experience, however, has established the more sensible practice of selling Portland cement by weight, so that it is now sold at so much per hundred pounds weight; and while the consumer is thus protected against paying a high rate for inferior quality, the manufacturer is justly paid according to the value of his production. In short, quality and not quantity is sought for, and weight is now regarded as the only test of excellence.

The testing machine shown on Plate 1, fig. 1, is that now usually employed on engineering works to prove the quality of cement before being mixed for mortar or concrete. It is simple in character, and acts as a successful check against the use of cement inferior in quality or dangerous from imperfections in manufacture. The machine requires to be accurately constructed, and its cost is therefore too great to ensure its adoption in works of a moderate character. Under such circumstances, the cement should be purchased from manufacturers who will guarantee its quality, and be held responsible for the damage which may be sustained in the use of an article of inferior quality. Even if used under such precautions, it is well to ascertain, by the following simple experiments, the quality of the cement:—

Make up two circular cakes of neat cement, six inches in diameter and half an inch thick, with the smallest quantity of water; when they are sufficiently set to permit of their removal from the board on which they were mixed, put one of them into water, and the other in the open air. After twenty-four hours' immersion examine the water cake carefully, and if there are no indications on its surface of cracks or hair-like fissures, it may be considered free from an excess of lime and thoroughly hydraulic in character. The cake in the open air should be light gray in colour, but if it proves to be yellow and ochrey, the cement contains too large a proportion of clay, and is deficient in tensile strength. Such a quality is not absolutely dangerous, although falling short in the more valuable properties of a good Portland cement. Portland cement of this quality may be used; but if the water cake cracks, and the air cake is of a whitish gray colour, the cement should be at once removed from the works. If professional and practical builders were to exercise a little more careful supervision in the selection of cements, we should soon cease to hear complaints about badness of quality, for the manufacturers would not produce an article which, when faulty, would fail to find a purchaser.

The theory of the formation of Portland cement, or rather the conversion of the simple mineral into an artificial product of so much value, has received much attention from eminent chemists. The chemical process produced in the kilns by the applied heat used for decarbonization is simplified by the accurate mechanical mixture of the chalk and clay; and clay, when so mixed with chalk, melts easily before the lime becomes caustic and surrounds each particle of lime with a vitreous covering like a small bubble. These thin bubbles show under the microscope the flaky structure of most cements. Many cements, however, do not appear flaky when submitted to microscopic observation, and yet possess all the properties of good cement. In such cases it is thought that the clay melted when the carbonic acid was being expelled from the chalk, and so prevented the formation of the bubbles. If the process of melting be carried too far the whole silicate is slacked, and a lime glass is formed with an insufficient quantity of caustic lime. In that case its porosity is less, and its hydraulicity impaired.

Portland cement may be considered indigenous to England, from the abundance of the raw materials; and although other countries, especially France and Germany, have introduced its manufacture in certain limited localities, this country can always command the supply to every market of the world. Large quantities are produced in Germany, but the absence, or rather scarcity, of chalk necessitates a more complicated system of manufacture, involving the employment of a higher class of manual labour. The following analyses of German Portland cements by Feichtenger show that they do not vary much from the English samples :—

	No. 1.	No. 2.
Lime	57·18	55·78
Magnesia	1·32	1·62
Alumina	9·20	8·90
Peroxide of iron	5·12	6·05
Potash	0·58	0·75
Soda	0·70	1·06
Silica	23·36	22·53
Carbonic acid	1·90	1·46
Sulphuric acid	0·64	1·85
	100·00	100·00

A remarkable result was obtained in experimenting on the relative strength of pieces of brickwork built 2 feet 6 inches and 8½ inches square when joined with gray-stone lime and Portland cement. The piece built in Portland cement withstood a pressure of 100 tons, whilst that built with gray-stone lime only stood a pressure of 25 tons.

MATERIALS AS AGGREGATES FOR MORTARS AND CONCRETES.

However reliable the information as to the qualities and nature of limes and cements may be, it is necessary to a complete understanding of the processes of mortar and concrete making, that the operator should be well acquainted with the peculiarities of the aggregates to be introduced into the several mixtures. Hence the desirability of some general information as to the chief characteristics of the various minerals usually employed for that purpose. Such knowledge is necessary to prevent an ignorant combination of unsuitable materials. In localities where the naturally prepared gravels and sands exist, little discrimination is necessary; but in those districts barren in such resources, considerable care is required to determine what quality of aggregate shall be used. A knowledge of geology and mineralogy will facilitate the efforts of the builder in the selection of the most suitable kind of aggregate; and to those who have acquired such useful information no very particular description of the various suitable materials will be necessary. The majority of those engaged in building operations are, it is to be feared, notoriously deficient in such knowledge, and for their guidance and information the following observations on the qualities of suitable materials for aggregates are offered.

In almost every district in England, Scotland, and Ireland there are deposits of gravel and sand naturally prepared for the purposes of mortar or concrete making, but their variable characteristics require a certain degree of discrimination in their use. The various natural forces, in accomplishing the formation of beds of sand or gravel, have occasionally produced materials of an injurious character, such as loam and clay, which should be rejected from all mortar or concrete mixtures. When sand or gravel is obtained from the beds of streams or rivers, the soluble clays and loams are generally washed away by the action of the water leaving them (sand and gravel) free from injurious admixture, and when in that condition they may be used with safety. The more rapid the velocity of the stream the cleaner will be the gravel or sand. Thames ballast, as it is generally called, makes one of the best known compound aggregates for concrete, and has been used for such purposes for a lengthened period with great success; so also are the gravels obtained from pits or excavations on its banks suitable for all variety of building purposes. The extensive alluvial deposits in its valley are, generally speaking, well adapted for mortar or concrete. The source from which the flints have been derived is easily understood on tracing the course of the river from its rise in the Oxfordshire hills until its velocity is checked by tidal influence. Flints when found under such favourable conditions may be used without danger; but when freshly excavated from the chalk in which they are embedded are not so suitable. They should then only be used in combination with a considerable proportion of good sand, so that their non-absorbent defects may be as much neutralized as possible. Their hard glassy surfaces offer but little attraction for the adhesion of the lime or cement; and their non-porosity renders them unsuitable, unless under unavoidable circumstances, as an aggregate. Gravel, therefore, in its various forms may be considered as the most suitable material for an aggregate, from its generally being of a suitable size and requiring but little preparatory manipulation.

Rocks of every geological formation are more or less adapted for concrete purposes, and may be used in the absence or scarcity of gravel. When any choice is possible, a preference should be given to those rocks possessing an average amount of porosity over those of harder texture and deficient in the more valuable absorbent properties. Kentish ragstone, although hard and crystalline in texture, is a most suitable aggregate to use with Portland cement, and, when carefully amalgamated, it is difficult to detect the junction of the two materials, so perfect is the cementation between them. Chippings from the Bath, Anston, and other oolitic limestones, are also valuable aggregates; and in the manufacture of Buckwell's patent granitic breccia stone their value was fully developed under intelligent supervision. Pavement so made was satisfactorily tested in the severest manner when laid down on a portion of the footway of King William-street, City, London, where it stood the test of that incessant traffic during a period of fourteen years. In the absence of rocks of boulder or other stones in any locality, and where clay abounds, it will be necessary to convert that material into a suitable aggregate by burning. Where fuel is abundant the process will not be a costly one, and some clays, when properly treated, make excellent ballast. If the clay is highly tenacious the expense of conversion will be inexpensive, and even if the clay is sandy and refractory the cost will be but trifling. When clay is thus converted it is especially adapted for mixture with rich limes, to which it imparts a considerable degree of setting energy, as is shown by the Table of ancient Roman mortars, pages 64 and 65. Chalk may be used in conjunction with cement, but when so adapted it should first be deprived of its latent amount of moisture, which can readily be expelled by submitting it to a temperature of 120 degrees. All chalks contain twelve per cent. of moisture, which they part with at that heat. Beach shingle can be used when properly reduced to the necessary size, and even if mixed with a small portion of shells it may be used with advantage. Broken bricks or brickyard refuse, as well as slag and scoriæ from iron furnaces, is sometimes mixed with cement; but the use of the latter with rich limes should be avoided. Foundry slag, finely ground, has been mixed with hydraulic limes with advantage. In constructing the Sunderland Docks in 1835 two parts of hydraulic lime were mixed with powdered slag; some of the backing and filling of the rough ashlar work was joined with the slag by itself. The water was kept from it for two days, and it eventually attained a stony hardness.

There are many valuable mineral deposits at present disregarded which would prove useful in works of construction if their properties were accurately ascertained, or any exertion made to discover them, such as the following sandy clay found at Rivières in France. It contains 32 per cent. of chalk, and is at present used in the manufacture of bricks and tiles by the following curious process. The bricks and tiles when moulded in the usual way to the required form are burnt in furnaces, from which they are not withdrawn until sufficiently cooled. They are then drenched or soused with water, and in 24 hours afterwards become so hard as to be fit for building. On being first taken from the furnace they are tender and require delicate handling. It is the only instance known to the writer where so beneficial a natural combination of materials occurs; and their well-balanced proportions indicates that the process by which they were amalgamated must have been effected by the agency of water. The particles must exist in a high state of comminution, or the heat necessary for the decarbonisation of the chalk would flux the alumina and sand. It would be difficult if not impossible to so accurately combine similar materials by artificial means as to secure the results so satisfactorily performed by the natural process.

In the selection of materials for aggregates it is necessary to examine their power of capillary attraction, so that you may guard against the danger of employing one too porous in character. In the absence of such precautions a material might be employed so spongy as to rob the lime or cement of its water of hydration, and thereby prevent its obtaining a proper degree of induration. Even different bricks afford varied powers of adhesion, as the following experiments with blue lias mortar will show. Two moderately-glazed blue Staffordshire bricks were joined together, and at the expiration of one month were pulled asunder by a force of 40 lbs. per square inch; two hard gray stocks were similarly treated, and broke at 36 lbs. per square inch; soft place brick under similar conditions separated with a strain of 18 lbs. per square inch: thus in the case of the stock bricks indicating a difference in adhesive power of 50 per cent. In another series of experiments three pairs of stone blocks of equal sectional area, viz., a pair of granite, a pair of Portland roach and a pair of the ordinary Portland stone, were severally joined with Portland cement. On separating them it was found the relative amount of adhesion was as follows: Granite 11, Portland 12, and the Portland stone 16; such results being in proportion to the porosity of the stones. The Portland stone may be considered as the safest texture and a diminished value of adhesiveness is developed in descending the scale, as witnessed in the case of the soft stock bricks. Any aggregate will of course be differently influenced in proportion to the amount of moisture it may naturally absorb; varying with the temperature and climate in which it may be used. The materials used as aggregates acquire increased density from becoming intimately connected with the matrix, and their size should be so regulated as to perfectly absorb from it the moisture or water of hydration. The amount of such beneficial action will much depend upon the nature and extent of the mechanical force applied in moulding or ramming the various ingredients together.

Fire-stone is a good aggregate, and it was found to exert an intimate combination with lime in the concrete works in constructing the harbour of Havre. In old masonry where it had been used the mortar could not be separated from it, owing to its adhesiveness; and pulverized fire-stone used with rich limes makes a strong mortar.

The object which should guide builders in the selection of aggregates is first the suitability of the material, and in a second degree the cost. However desirable it may be to obtain a cheap material, it is well also to consider its value for the purpose for which it may be intended. There are very few districts in this, or indeed any other country, utterly deficient in one or other of the deposits or formations from which aggregates may be selected. In any case it is necessary to consider the cost of carriage, which in nearly all buildings forms a considerable item of the expense.

LIME AND CEMENT SETTING.

Various theories have been offered as to the exact process which takes place in the hardening of the different varieties of mortars and concretes. The subject has at all times received much attention from the most eminent investigators; yet notwithstanding their experiments and researches in the attempt to elucidate the matter, considerable doubt and uncertainty still surrounds it. Indifference to acquire a knowledge practical in its character, has led to many blunders in the preparation of concretes and mortars; and with the object of imparting reliable information on the subject we will consider the various suggestions which have been advanced in accounting for the somewhat mysterious natural agencies which produce such wonderful results in the setting and hardening of limes and cements.

To prevent misunderstanding in the use of the terms setting and hardening, it will be necessary to define these two processes. The first, or setting, is that which imparts initial energy to any mixture of mortar or concrete, and enables it to eject or eliminate the superfluous water not required for its ultimate hardening. Setting, therefore, simply means the operation which continues until the mass has lost its plasticity and cannot be moved without fracture. The duration of the process depends entirely on the quality of lime or cement used, and may extend from a quarter of an hour to six days or even longer. Hardening or ultimate induration is the process which follows the setting, and continues for thousands of years, provided the necessary conditions have been duly observed in the preparation of the mortar. Otherwise the mass soon gives indications of decay, and in such cases produces a mortar or concrete of dangerous quality, which age, instead of improving, deteriorates.

Hitherto carbonic acid has been looked upon as the prime agent in hardening lime mortars, due to the avidity of the hydrate of lime for that acid—enabling the lime to become recarbonized and so resume its normal condition of carbonate of lime. The unconditional adoption of this theory leads to some embarrassment, from the absence of satisfactory proof of the perfect recarbonating of any lime mortar. The analysis of Phœnician, Greek, and Roman mortars in pages 60 to 65 indicates the nearest approach with which we are familiar to the lime resuming its original condition, especially in the case of the mortars from Cyprus. The limes in the Roman mortars, although 1700 years old, have not yet resumed their pristine condition; although the process of recarbonating is still progressing, and it would not be unreasonable to assume that it will eventually take place. Carbonic acid, if not the sole agent, may be considered an important one in the hardening of ordinary lime mortars. Eminently hydraulic limes and cements are, however, independent of such agency, being capable of attaining a maximum degree of induration without such aid. In partial opposition to the theory of recarbonating, there are eminent authorities who attribute the hardening of mortar to silicazation. The action as defined by them is due to the lime having the power of attacking sand and other forms of insoluble silica by long contact at a common temperature. Mr. Spiller, in his careful and minute analyses of the Roman mortar at Burgh (see page 63), failed to obtain any proof of such action in the exhaustive analysis instituted by him for the purpose of testing that theory: he only found 0·4 per cent. of soluble silica. Dr. William Wallace, in his examination of the Phœnician, Greek, and Roman mortars (see pages 62 and 63), concludes that the hardening is due to the recarbonating process, and is but slightly assisted by any action of the lime on insoluble silica. In confirmation of these conclusions it may be stated that Roman and Portland cements when used neat attain great hardness under circumstances which preclude the possibility of their receiving adventitious aid either from carbonic acid or insoluble silica. Again, plaster of Paris, Keene's and Parian cement, quickly harden; and such a result cannot in their case be due to carbonic acid or assistance from the bodies with which they may be in contact, for any of these cements will set and harden on glass or iron almost as well as on stone or brick. The more finely these cements are ground the higher are the results obtained, indicating that the more perfect diffusion of the atoms increases the energy of the cements and obtains the highest results of either compression or tensile strength, as well in the water as the air. Keene's and Parian cements are merely preparations of plaster of Paris, and are made by incorporating with the sulphate of lime certain proportions of alum and borax. The effect produced by this combination is shown by the following table of experiments :—

Keene's Cement (neat).						Parian Cement (neat).					
No. of bricks.	Age.	Surface exposed.	Crushing weight.	Tensile strength.	Remarks.	No. of Bricks.	Age.	Surface exposed.	Crushing weight.	Tensile strength.	Remarks.
	Mos.	Sq. inch.	Tons	Per sq. inch.			Mos.	Sq. inch.	Tons	Per sq. inch.	
30	17	9·0	13½	220lbs.	The bricks were for a part of the time in water.	12	16	9·0	15	242lbs.	The bricks put first in water for some days.

The above results were obtained without any admixture of silicious matter and free from contact with any substance that could impart fictitious strength. Gypsum or sulphate of lime therefore possesses, according to these experiments, a high value when properly applied. A knowledge of the value of this material was known to the ancients, for the analysis of the mortar from the Pyramid of Cheops (see pages 61 and 62) proves that not only was it used as a matrix, but fragments of the raw material were also incorporated with it as an aggregate. In such a climate as Egypt, plaster of Paris may be used with safety; but in more exposed latitudes its use would be inadvisable, in consequence of its liability to be injuriously affected by frost.

Rich limes when converted into a hydrate paste are deficient in recarbonating energy, and can only resume that condition when mixed with a porous aggregate to absorb their excess of moisture. In such limes the initial set is languid—even when mixed with powdered puzzolana (see Table of Puzzolanas, page 23); and in certain conditions an ultimate state of induration is unattainable.

The setting and hardening of mortar may be practically considered as a combined chemical and mechanical process, and the degree of perfection attained is regulated by the quiescent value of the several mixtures. Unless the mass remains undisturbed, the natural cohesive and adhesive forces are unable to exert their beneficial influence, and the perfect crystallization is consequently impossible. Rich limes, therefore, make weaker concretes and mortars than the poor or hydraulic limes; the former absorbing so large a quantity of water as in some cases to convert the mass into a paste. The rich limes have a great affinity for water, and do not possess the inherent power of again rejecting it. Hydraulic limes possess that faculty, and therein, to some extent at least, lies the difference between the two kinds of lime. That difference is modified when a high degree of comminution is practised with the rich limes, so as to permit of the greatest amount of diffusion of the particles of lime throughout the aggregate. A good example of the advantages obtained by extreme diffusion is shown in the preparation of "bètons aggloméres," when the lime is reduced to the finest texture by being passed, after slakage, through a finely-perforated sieve. The Roman practice of beating mortar was intended to overcome the tendency of rich limes to expand. Even Smeaton resorted to that practice in the preparation of his mortars for the Eddystone lighthouse. The process of deadening the lime is now attained by much less expensive and more perfect means. Any mode which accomplishes the separation of the particles of lime is beneficial, and in a ratio with the amount of dispersion will be the value of improvement obtained.

In cements the silicates of lime and alumina play an important part in the setting and hardening processes; and in the case of Portland cement it has been found that an addition of the soluble silicate of potash or soda imparts increased initial strength to the powdered cement, although there is reason to suppose without improving its ultimate value of induration. Portland cement may be considered an improved hydraulic lime, and occupies an intermediate position between the best hydraulic limes and the finest natural cements. The difference between the rich and hydraulic limes is well illustrated during the process of slaking. The former exhibit great violence on the application of water; but the latter when so treated have no such tendency, and any liability to increase of bulk soon disappears. The difference of action is explained by the absence of foreign matter in the rich limes and the existence of silica and alumina in the other; these materials exerting a beneficial agency in keeping apart the atoms of lime, and thereby reducing the expansive power to a minimum: hence the necessity of extinguishing this force previous to using common mortar. It is true that hot mortar will set faster, but such doubtful advantage is obtained at a sacrifice of its ultimate strength of induration, besides the too frequent attendant disadvantages of blowing and cracking. This point receives further elucidation in the case of cements. Fast or quick setting Roman or other natural cements never attain the hardness of Portland or other slow-setting artificial cements; and the result of engineering experience confirms the now unquestioned fact that the value of Portland cement especially increases in proportion to the slowness of its setting and final induration.

The natural process of incrusting rocks in the form of stalagmites and stalactites is due to the action of carbonate of lime conveyed in minute particles of solution by the agency of water in its percolation through limestone rocks. The water containing carbonic acid dissolves the calcareous rock, and thus produces a solution of carbonate of lime.

Many springs also contain soluble silica. The Geizer springs in Iceland are highly impregnated with that naturally abundant material; indeed the sea and almost all rivers contain variable proportions of it in a state of solution. The condition of the carbonate of lime thus conveyed and deposited must be one of extreme fineness, as it requires 10,000 parts of cold water to dissolve 1 part of it. The action in the case of stalactites is adhesive, and atom by atom is gradually deposited during the passage of the water over the rock, the slowest movements of the liquid effecting the largest deposits. Such operations are, however, under the most favourable circumstances very protracted, and at best only one-sided in character; and we should when accurately imitating this natural process in the preparation of mortars or concretes, attain even more satisfactory results. In observing the operations of nature let us also consider those of a somewhat analogous artificial character. Two pieces of wood cannot be by themselves simply joined together; but introduce glue between their surfaces, and a junction is speedily effected. Again, some metals can only be welded by the intervention of a third. So in chemistry two dissimilar and naturally antagonistic elements can only be brought into a state of harmony by the introduction of a third possessing, probably, properties foreign to both.

In these remarks it is intended to show the possibility of accomplishing satisfactory results when a rational mode is adopted to bring them about. In the natural process of forming the stalagmite, or petrifying the animal or vegetable substance, the utmost point of diffusiveness is reached, and if otherwise, the beautiful results we are familiar with would be unattained. Could we place a skeleton of any mortar or concrete within the influence of one of these petrifying or stalactite-forming springs, nature would show us with what perfection she can accomplish its concretion or agglutination of any mass, however eccentric its form or material. Ample evidence exists of the perfection attained by such natural processes in the formation of breccias and other similarly cemented mineral products. The process of nature is, however, easily understood, and if we but carefully consider the conditions under which it is performed, we shall readily acquire the means of imitating it. In forming stalactites the carbonate of lime is so perfectly dissolved by the primary chemical process that no difficulty is experienced in perfecting the concluding mechanical operation of attaching it to the suitable substance with which it may be brought in contact. In the case of the carbonate of lime solution, the vehicle of formation is generally of a rocky character, and always possesses sufficient porosity of texture to permit of the adhesive action being successfully performed. When soluble silica occurs in springs or flowing water, it energetically attacks whatever substances it may come in contact with; and whether vegetable, animal, or mineral, they are alike converted by its remarkable agency into varied forms of petrifaction without materially disturbing their original form of outline or shape. The success which attends these natural agencies indicates a course for us to follow in the preparation of mortars and concretes. Primarily we have endeavoured to show the absolute necessity of extreme diffusion of the atoms of lime or cement, so that the largest extent of surface may be impinged upon and brought within the influence of their adhesive action. Secondarily, the advantageous effect occasioned by the selection of proper aggregates (sand, gravel, &c.), so that by their porosity and suitability of form they may absorb or partake of the maximum extent of benefit from the matrices (lime and cement). The natural process is indeed slow; but it is a well-known fact that those bodies which are slowest in separating from their waters of solution become the most compact and solid. Portland cement, for instance, when heavy and of unexceptional quality, takes a long time to eliminate the water with which it had been rendered plastic.

As we have not yet reached so refined a point as to understand safely the mode by which we might apply our limes and cements in a soluble condition, we will consider the action which arises in the hardening of mortar made from lime and cement as now prepared. In the case of lime, we convert the caustic into a hydrate by the application of water, in the hope that from natural causes it will eventually be reconverted into a carbonate. This operation is usually so clumsily performed that the hydrate is over-watered, and becomes a paste incapable of eliminating its water of hydration, and therefore, in that case, insusceptible of being recarbonated. While endeavouring to avoid this danger, it is necessary to guard against an equally objectionable condition of the lime when an insufficiency of water has been used. A hydrate of lime can only be converted into a carbonate by the agency of moisture; but when an excess of water occurs, and in the absence of a suitable aggregate to absorb the superfluous moisture, the pasty mass is useless, without energetic capacity, and incapable of imparting any beneficial influence to any substance with which it may be in contact. If deficient in the necessary amount of moisture, the hydrate becomes pulverulent, incapable of being converted into a carbonate, and when retained in that condition imparts weakness to the mass which it was introduced to strengthen. Under such circumstances, the necessity of an accurate proportion of water is obvious; for if, on the one hand, you over-water the lime, a useless paste is formed; and if, on the other, you fail to supply the proper quantity, a dangerous powdery mortar is produced. Instructive illustrations of both these dangers may be found on a careful examination of old as well as new mortars. Cements are not liable to the same deteriorating influences, from their inherent power of ejecting the water used in rendering them and their mixture plastic, after the setting process has been determined or arrived at.

The above explanation of the action produced by the conversion of the hydrate of lime into a carbonate may be termed the chemical division of the processes, and can only be perfected by the succeeding division, which is one of a mechanical character. The established fact that hydrate of lime can only be converted into a carbonate when put in contact—directly or indirectly—with the atmosphere, so that it may imbibe the carbonic acid therein contained, renders it necessary to associate with the lime those aggregates possessing the required porosity. An aggregate should possess the property of capillary capacity to absorb the superfluous moisture from the lime, and assist in conveying the carbonic acid required for its induration. The penetrative power of carbonic acid is remarkable, and from careful observation it has been found to pass through large masses of brickwork. It was found when pulling down a wall at the London docks that it had penetrated a distance of 6 feet during a period of 30 years. In the Shadwell basin of these docks in a wall 11 feet thick, and of more recent construction, the same action was seen to be more perfect near the face; in that case the penetration along or through the joints of York landing or brickwork was as much as half an inch in a month; with Anston stone rather more; while along the bed of a joint in Bramley-fall granite or other coarse-grained stone, it amounted to an inch and a half in the same time; smoothness of surface being shown by these observations to be less favourable to its progress than the coarse-grained or rough stones. The penetration is greatest in the case of pure limes, and this power diminishes in a ratio with the amount of impurities in the lime; so that an eminently hydraulic lime has less attraction for carbonic acid than one made from chalk. The intense avidity of quick lime for carbonic acid is well illustrated in the practice of miners, who, when first entering a coal mine after an explosion, put layers of it in the bottom of the cages in which they descend, so as to purify the air before entering the workings, and thereby sensibly reduce the risk they run by entering so dangerous an atmosphere.

The subject of lime and cement setting is one of great interest, and considering its importance is but imperfectly understood. In the above remarks we have endeavoured to show the importance of extreme pulverization of the lime and cement if satisfactory results are desired. It may be said shortly that the minute fineness of the matrices (lime and cement) and their extreme division—which reduces them altogether to surfaces—imparts the faculty of being applied most intimately to the surfaces of the aggregate (sand and gravel), and of adhering thereto with a force proportionate to the nicety and closeness of the contact.

The study of this important branch of constructive science, will be much simplified by reference to the following Tables of mortars ranging from 120 to nearly 4,000 years old. They will show the amount of recarbonating which is accomplished under various conditions and combinations of materials. The Tables are prepared from reliable sources, and exhibit in a remarkable degree the influence of time in accomplishing the recarbonating of the lime without the beneficial influence of silica or alumina in conjunction with it. There was doubtless in many of them variable proportions of pounded clay, burnt and unburnt, which imparted artificial energy to the otherwise languid limes of which the majority of these ancient mortars are composed. The condition of some of the mixtures might also have favoured the absorption of the more soluble silicates of the aggregate, so as to give some degree of probability to the silicazation theory. It is an undoubted fact that limes, especially those of a pure character, are benefited by the application of any of the artificial soluble or crystal silicates; but we must be guarded in attributing any great value to the inherent capacity of the lime to extract indurating power from its aggregate. When in a moist state, the lime would probably dissolve a portion of any calcareous aggregate, as the natural process referred to in the formation of stalactites, but the low temperature of the mass would in a dry condition be unfavourable to the elimination of carbonic acid from any carbonate of lime aggregate.

Rich limes deficient in silica can be rendered hydraulic by the addition of "liquor of flints" "soluble quartz," "soluble glass," or any of these silicates in a finely-powdered state. The silicating action which takes place from such a combination is better when the silicate is in a soluble condition than when in powder. The effect produced by such an amalgamation is similar to the process or action which arises during the burning of Portland cement, when the mechanically-mixed materials are being reacted upon. The lime in that case is changed into a silicate of lime by the action of heat, and the silica in the clay unites with the lime. Subsequent pulverization completes the process, and produces the best known description of artificial hydraulic lime or "Portland cement." This cement when setting in water is subjected to a peculiar chemical action of a twofold character. In one action the aluminate of lime becomes hydrated, and in the other hydrated lime combines with the silicates. The aluminates and the calcareous silicates play different parts in the setting; the former simply becomes hydrated, the latter combines with hydrate of lime. Portland cement developes its more valuable properties in the highest degree when it is placed in a wet situation, and when in too dry an atmosphere great care is required to supply the necessary amount of water for its perfect crystallization. Otherwise it will be liable to degenerate into a powdery condition and become quite useless, if not dangerous. Many building stones are affected injuriously when placed in the interior of buildings, more especially Yorkshire landing, which prematurely decays and in a comparatively short time loses its compact laminated mineral character. Such a result was well illustrated in the paving of the halls and corridors of the old India House in Leadenhall-street, London.

The following analyses of ancient mortars are obtained from various sources: Nos. 1 to 9 are taken from Vicat on Cements (translated by Captain Smith), Nos. 10 to 18 from the *Chemical News*, vol. 11, and No. 19 from the Transactions of the British Association, 1868. The localities from which the mortars were obtained embrace a variety of climates and exhibit in a remarkable degree the attention paid by ancient builders to the quality of their mortars. The Egyptians are supposed to have used the mud of the Nile in conjunction with gypsum for the mortar in building the Pyramid of Cheops; and the Assyrians, according to Scriptural authority, used burnt bricks and asphalte or bitumen for mortar. It is a curious fact, and one worthy of attention, that the Roman architectural and engineering remains have been able to withstand the injurious influence of time and climate better than the Norman or mediæval buildings. This is doubtless due to the superiority of ancient mortar, which in the joints of the buildings, by its superior tenacity, maintained an even face to the walls and prevented the lodgment of water or the injurious influence of its dripping action.

In illustration of the recarbonating theory, it will be well to notice how far in the several samples of mortar that process has been accomplished :—

No. 1, although 600 years old, has only 73 per cent. of the necessary saturating dose of carbonic acid—carbonic acid being 5·0, and the lime 8·7.

No. 2, of the same age, only contains 24·3 per cent.; but from the fact of the damp foundations alluded to, the lime was probably in a semi-pasty condition.

No. 3, 1800 years old, 75 per cent.

No. 4, of the same age, 63½ per cent.; and

No. 5, not quite 42 per cent.

No. 6, 1800 years old, 87·4 per cent.

No. 7, 200 years old, 93·2 per cent.

No. 8, 120 years old, 83·2 per cent.

No. 9, nearly 4000 years old, 65·4 per cent. of the saturating dose of carbonic acid.

Sample 10, from the interior of the Pyramid of Cheops, was taken from the great chamber or the passage leading into it. Both specimens (10 and 11) present the same appearance—that of a mixture of plaster of a slightly pink colour with crystallized selenite or gypsum; they do not appear to contain any sand, the silicic acid being evidently in combination with alumina as clay. Part of the selenite was probably burnt, and the result mixed up with burnt lime, ground chalk, or marl, and coarsely-ground selenite.

No. 12 is supposed to be the oldest mortar in existence, and was prepared by the Phœnicians; it is exceedingly hard and firm, and appears to have been made of a mixture of burnt lime, sharp sand, and gravel, some of the fragments being about half an inch in diameter.

No. 13 is a cement that had been used for joining water-pipes; it is very hard, and perfectly white in colour.

No. 14 is taken from a part of the Pnyx, the platform from which Demosthenes and Pericles delivered many of their orations. It has been long exposed to the action of the weather, is very hard, and of a grayish white colour.

No. 15 is plaster from the interior of a temple; it has not been exposed to the weather, the temple being in a cave; it is of a pale cream colour, and moderately hard.

No. 16 is evidently composed of burnt lime and puzzolana; it is tolerably hard, and of a rather dark gray colour.

No. 17 has been exposed on one side to the action of hot volcanic mud, and is of a reddish colour, hard and firm.

No. 18, is of a pale reddish-brown colour, hard and firm.

No. 19, is a cement mortar from a mosaic forming the floor of the baths of Caracalla, Rome, hard and firm.

In speaking of the samples from No. 10 to 19 inclusive, Dr. Wallace says:—"These analyses appear to show that the lime in mortars and plasters becomes in the course of time completely carbonated, and does not form a combination consisting of Ca O, HO + Ca O, CO_2, a conclusion that has been arrived at by some authorities. It is curious that the mortar which is probably the most ancient (the specimens from a Phœnician temple) is by far the hardest and firmest; in fact, like a piece of rock."

No. 20, the only specimen from Roman remains in England is from Burgh Castle, Suffolk (the Garianonum of the Romans), and from the comparatively perfect character of the walls is worthy of a brief description.

"It is a mural erection in the form of an immense parallelogram, of which one side is wanting, being left unprotected on the river front. The massive walls are strengthened at the angles and at certain intermediate positions by towers, or solid cylinders, of masonry, which are uniform in height with the rest of the work, *i.e.*, about 15 feet, and measure from 40 feet to 50 feet in circumference, being larger at the top, and only in the case of the two corner towers being truly circular in form. The length of the wall on the eastern side, which is perfect throughout with a gate in the centre, I found to be 650 feet, whilst the north and south walls have fallen away in places, but their length may be roughly stated at 350 feet. The appearance of the whole is grand and picturesque; the walls, which are rubble masonry, and about 6 feet in thickness, are faced with flints and layers of red tiles set at intervals with great regularity, and the contrast of colour is heightened by parts of the work being overgrown with moss and ivy. The flints are arranged in tiers of four, and occasionally five, courses, and the red tiles invariably occur in triple layers with seams of mortar between. This order of construction is repeated some five or six times from base to rampart, with a cap of flints at the top, and the round towers or abutments present the same construction as the rest of the work. The walls vary in thickness, being, as already stated, generally about 6 feet, and are constructed internally of compact rubble, the stones being large, and the mortar presenting throughout the reddish colour due to admixture of pounded brick, which is considered to be characteristic of a Roman origin. The red tiles are of very fine texture, well burnt and compact, for none of them appear to have been disintegrated by frost; their dimensions are tolerably uniform only as regards thickness, which varies from 1¼ inches to 1½ inches, and they extend to various distances within the face of the wall, in some places 12 inches only, and at other places nearly twice that depth."

Mr. Spiller, in referring to the silicazation theory, says:—"To support my assertion that the lime has simply become converted into carbonate, I may mention that a special search for caustic lime by the nitrate of silver test, failed to indicate its presence, whilst all recent mortars show an abundant precipitate of the brownish-grey oxide of silver; that the Roman mortar triturated with pure water gives no alkaline reaction with turmeric paper; and, further, that the portion of carbonic acid found in the Burgh samples is, within the limits of experimental error, exactly the amount which is required to combine with the lime in order to form the neutral carbonate. I would remind those who are inclined to place reliance in the statements regarding the silicazation of old mortars that the proof is often wanting that the lime was itself free from soluble silica at the time of employment. Inference can only be safely deduced from cases where there is clear evidence of a fat lime having been actually employed in the fabrication of the mortar; for so many varieties of lime having modified hydraulic properties and gelatinising with acids are known to result from the simple burning of blue lias and other argillaceous limestone rocks, that the absence of soluble silica at the first moment of preparation should not be always assumed."

The above remarks and the results of the several analyses of ancient mortar will show the difficulty of accepting unhesitatingly the theory of silicasation. The recarbonating of the lime is in the course of time—as proved by these investigations—to be all but certain; and it is advisable therefore to abandon the belief of assistance from any alkaline action of the lime when in contact with the aggregates, or the likelihood of the mortar receiving any benefit from that agency. It is much safer to trust to the intrinsic merits of the matrices (lime and cement) alone, and apply the most intelligent and rational mode in their selection, so as to obtain the maximum chemical advantages they may afford. The aggregates should only be regarded as mechanical agents in favourably assisting the matrices to exert their highest value of chemical efficiency.

These analyses indicate the exact chemical constitution of the ancient mortars, and are besides interesting from their antiquity and historical associations. The following Tables of the physical characteristics of Roman mortars from the south of France, extracted from Vicat's work on Cements, exhibits their power of resistance to fracture.

The mode of testing is one seldom adopted in this country, although commonly practised in America and Germany. It consists of subjecting the prisms of mortar to fracture by a species of wrenching action imparted from a suspended weight (gradually applied by a stream of sand running into a box), placed on one end of the prism; the other being fastened down and kept in adjustment by two screws.

ANALYSED BY M. JOHN, BERLIN.

Mortar No. 1, 600 years old, from the cathedral of Brandebourg:—

Carbonic acid.	Lime.	Soluble silica.	Grains of quartz with sand and oxide of iron.	Water.
5·00	8·70	1·25	83·75	1·30

Mortar No. 2, 600 years old, from the church of St. Peter's, at Berlin, damp foundations:

Carbonic acid.	Lime.	Soluble silica.	Grains of quartz with sand and oxide of iron.	Water.
1·75	9·25	3·75	78·50	6·75

Mortar No. 3, from a Roman wall at Cologne, 1800 years old:

Carb. acid.	Lime.	Sol. silica.	Al. & iron dissolved.	Grains of quartz with sand and oxide of iron.	Water.
9·00	15·16	0·27	2·75	68·00	4·00

Mortar No. 4, from a tower, same locality and age:

Carb. acid.	Lime.	Sol. silica.	Al. & iron dissolved.	Grains of quartz with sand and oxide of iron.	Water.
12·00	24·00	0·25	2·75	56·00	5·00

Mortar No. 5, from a Roman concrete, on the Rhine:

Carbonic acid.	Lime.	Sol. silica.	Grains of quartz with sand and oxide of iron.	Water.
2·25	6·90	0·35	89·50	1·00

ANALYSED BY M. VICAT.

Mortar No. 6, from a Roman tower at Bologna, 1800 years old:

Silica.	Carbonic acid.	Lime.	Water and loss.
45·00	20·00	29·10	5·9

Mortar No. 7, from a tomb at Hyderabad, 200 years old:

Silica.	Carbonic acid.	Lime.	Water & loss.
50·00	20·00	27·5	1·9

Mortar No. 8, from a Dutch tomb at Masulipatam, 120 years old:—

Silica.	Carbonic acid.	Lime.	Water & loss.
51·5	19·2	26·6	3·6

ANALYSED BY DR. MALCOLMSON.

Mortar No. 9, from the Pyramid of Cheops, 3000 to 4000 years old:

Carb. acid.	Lime.	Alumina.	Sulphate of lime.	Sulphate of soda.	Insoluble substances consisting of alumina and crystals of selenite.	Water & carbonate of lime.
5·9	10·7	0·3	15·3	3·2	54·7	10·16

ANALYSED BY DR. WILLIAM WALLACE.

Mortar No. 10 from the Pyramid of Cheops (interior):

Silicic acid.	Carbonate of lime.	Alumina.	Oxide of iron.	Carbonate of magnesia.	Hydrated sulphate of lime.
5·30	9·47	2·41	0·25	0·59	81·50

Mortar No. 11, from the Pyramid of Cheops (exterior):

Silicic acid.	Carbonate of lime.	Alumina.	Oxide of iron.	Carbonate of magnesia.	Hydrated sulphate of lime.
4·30	9·80	3·00	0·21	0·79	82·89

Mortar No. 12, from Cyprus, from the ruins of a temple near Larnaca:

Lime.	Magnesia.	Sulphuric acid.	Carbonic acid.	Sesquioxide of iron.	Alumina.
26·40	0·97	0·21	20·23	0·99	2·16

Silicic acid and fine sand.	Coarse sand.	Small stones.	Organic matter.	Water.
16·20	3·37	28·63	0·56	0·54

Mortar No. 13, a white cement found in the same locality at a depth of 10 feet under the surface, used in joining red clay pipes:

Lime.	Magnesia.	Sulphuric acid.	Carbonic acid.	Alumina.	Silicic acid and fine sand.	Organic matter.	Water.
51·58	0·70	0·82	40·60	0·40	0·96	0·24	3·09

Mortar No. 14, ancient Greek mortars from a part of the Pnyx:

Lime.	Magnesia.	Carbonic acid.	Sesquioxide of iron.	Alumina.	Silicic acid and fine sand.	Water.
45·70	1·00	37·00	0·92	2·64	12·06	0·36

Mortar No. 15, from the temple at Pentelicus, near Athens:

Lime.	Magnesia.	Sulphuric acid.	Carbonic acid.	Sesquioxide of iron.	Silicic acid and fine sand.	Water.
49·65	1·09	1·04	38·33	0·82	3·90	3·07

Mortar No. 16, from Adrian's Villa, at Tivoli:

Lime.	Magnesia.	Potash.	Carbonic acid.	Peroxide of iron.
15·30	0·30	1·01	11·80	4·92

Alumina.	Silicic acid and fine sand.	Soda.	Organic matter.	Water.
14·70	41·10	2·12	2·28	5·20

Mortar No. 17, interior surface of a hall at Herculaneum:

Lime.	Magnesia.	Potash.	Carbonic acid.	Peroxide of iron.
29·88	0·25	3·40	23·80	2·32

Alumina.	Silicic acid and fine sand.	Soda.	Organic Matter.	Water.
2·86	33·36	3·49	1·50	1·00

Mortar No. 18, from the roof of the Latin tombs, near Rome:

Lime.	Magnesia.	Carbonic acid.	Peroxide of iron.	Alumina.	Silicic acid and fine sand.	Water.
19·71	0·71	13·61	1·23	16·39	36·26	8·20

Mortar No. 19, from a mosaic mortar in the floor of the Baths of Caracalla, near Rome:

Lime.	Magnesia.	Carbonic acid.	Peroxide of iron.	Alumina.	Silicic acid and fine sand.	Organic matter.	Water.
25·19	0·90	17·97	3·67	10·64	30·24	2·48	5·50

ANALYSED BY J. SPILLER.

Mortar No. 20, from the ancient Garianonum at Burgh, near Yarmouth, 1500 years old:

Sand.	Soluble silica.	Red brick and unburnt clay.	Lime.	Carbonic acid.
54·70	0·40	18·00	14·5	11·25

Sulphate of lime.	Carbonate of magnesia.	Chloride of sodium.	Water.
0·15	0·08	0·05	0·92

A piece of red brick, from the above, and used in building the walls, and also as an aggregate in the mortar:

Silica.	Alumina.	Peroxide of iron.	Lime.	Alkalies and loss.
72·7	14·0	10·0	2·1	1·2

Description and Where Obtained.	Composition of — Substances reduced to impalpable powder and forming the principal matrix.
MORTARS FROM LARGE OR MASSIVE MASONRY.	
FROM THE ANCIENT VESUNA.	
1. Taken from the Amphitheatre	The Matrix red; formed of white lime and a very small quantity of red puzzolana in impalpable powder.
2. „ the Baths	
3. „ the Tower of Vesuna	
FROM CAHORS.	
1. Taken from an ancient Theatre	Matrix of a dirty white, formed o a lime of the same colour.
2. „ the same	
3. „ a Temple	
4. „ a Roman Canal	
FROM NISMES.	
1. Taken from the Amphitheatre	Matrix sometimes gray, sometimes red, formed of a white lime and of a small quantity of red puzzolana in impalpable powder.
2. „ the Temple of Diana	
3. „ the Tour Magna	
FROM THE AQUEDUCT OF GARD.	
1. Taken from the masonry	Matrix earthy, prepared from lime and a terreous sand.
2. „ ditto.	
FROM VIENNE.	
1. Taken from the Amphitheatre	Matrix tolerably homogeneous, of a dirty white colour, composed of lime only.
2. „ the drains	
FROM UXELLODUNUM (at Cap Donac on the Lot).	
1. Taken from thick masonry	The matrix gray, formed from a gray lime only.
MORTARS FROM ANCIENT AQUEDUCTS, REVETMENTS, FLOORS, OR PAVEMENTS.	
FROM THE ANCIENT VESUNA.	
1. Taken from the Aqueduct of the baths ...	Matrix reddish, formed of a white lime and red brick-dust in impalpable powder.
FROM CAHORS.	
1. Taken from the Aqueduct of the baths ...	Matrix reddish, composed of a white lime and red brick in impalpable powder.
2. „ plastering of an ancient gate ...	
3. „ a basin	
FROM NISMES.	
1. Taken from the galleries of the Amphitheatre...	Matrix gray, composed of a white lime and charcoal powder.
FROM THE AQUEDUCT OF GARD.	
1. Taken from the revetment of the Aqueduct ...	Matrix whitish, composed of lime only.
2. „ same	
FROM VIENNE.	
1. Taken from an ancient Mansion revetment ...	Matrix reddish, composed of lime and red brick in impalpable powder.
2. „ „ pavement	
3. „ „ plastering	
FROM SARLAT.	
1. Taken from a Roman Aqueduct	Matrix reddish, composed of lime and red brick in impalpable powder.

OF SOME ROMAN MORTARS FROM THE SOUTH OF FRANCE.

THE MORTARS. Palpable substances imbedded in the matrix.	OBSERVATIONS.	Absolute resistance per square inch.
Quartzose gravel from the size of a pea to that of a walnut.	The mortar rich; coarsely amalgamated in it a multitude of lumps of lime were visible.	1. 85·30 2. 76·01 3. 95·37
Quartzose gravel from the size of a pin-head to that of a hazel nut.	The mortar rich; better worked than the preceding one; containing no puzzolana.	1. 60·35 2. 64·90 3. 53·94 4. 109·32
Quartzose and calcareous gravel from the size of a pea to that of a biggish hazel nut.	The mortar rich, and very badly mixed; a multitude of lumps of white lime visible in it.	1. 52·52 2. 79·56 3. 169·38
Quartzose gravel of the pretty nearly uniform size of a pea.	The mortar poor, ill-mixed; full of lumps of white lime.	1. 87·82 2. 45·69
Quartzose gravel of every dimension, from that of a pea to that of a good sized hazel nut.	The mortar rich; tolerably well mixed.	1. 82·85 2. 25·62
Quartzose gravel of every dimension.	The mortar rich; badly worked; full of lumps of lime.	1. 51·95
Fragments of red brick of the size of a walnut, in small quantity.	The mortar very rich; badly mixed; filled with a multitude of lumps of white lime.	1. 63·20
A small quantity of fragments of red brick of the size of a hazel nut.	The mortar rich; mixed in a middling degree; filled with portions of lime of a dirty white.	1. 115·86 2. 29·04 3. 96·64
Fragments of charcoal as big as a pea.	The mortar tolerably well made.	1. 127·11
Fragments of yellow and red brick of the size of a walnut.	The mortar very rich.	1. 43·96 2. 118·85
Fragments of red brick as big as a hazel nut.	The mortars tolerably well amalgamated.	1. 55·08 2. 78·85 3. 102·43
Fragments of red brick as big as a walnut.	The mortar tolerably well mixed.	1. 55·08

The size of the cubes operated on in the above experiments measured 18 inches by 2 inches by 3½ inches, and exhibit remarkable results when we consider the difficulty which must have been experienced in obtaining pieces of the necessary dimensions. It affords, however, another proof of the careful attention paid by Roman builders to the quality of their mortars, and the extreme caution displayed by them in rejecting sand of a soft or loamy character. None of the samples contain fine sand, and where the matrix is incorporated with a powder, it is only of a kind having the property of imparting setting energy to it. Puzzolana, brick-dust, and charcoal-powder severally appear as aids to the lime, and the aggregates are only remarkable for their coarseness and irregularity.

Cements placed in sealed glass tubes and favourably placed for crystallization, without being influenced by the action of carbonic acid of the atmosphere, only produced crystals of hydrate of lime; a crystallized silicate of lime was never produced.

PREPARATION OF CONCRETE.

In the preceding chapters the various characteristics of limes and cements (natural and artificial) have been described, and the conditions which should guide their use for the purposes of mortar and concrete making. The chapter on their setting, and the peculiarities which attend that process, is introduced for the purpose of showing that there is something more to understand than a mere knowledge of the physical character of the cements and the materials with which they are to be incorporated. If successful results are to be expected in the use of concrete, it can only be realised through a rational knowledge of the subject, and not from a rule-of-thumb practice. It is commonly supposed that any labourer, even the most ignorant, is qualified to mix up mortar and concrete—implying, by such indifference and carelessness, that the process is simple and unimportant, and therefore within the grasp of the meanest intelligence. It may be true that any common labourer can perform the mere manual part of the process, but it is necessary that he should be controlled and governed by an agency possessed of the required scientific or technical knowledge. In the manufacture of glass, the operation of mixing the raw materials and guiding their conversion into the marketable article is necessarily entrusted to the workmen; but the proportions of the ingredients are controlled by the higher and trained knowledge of the chemist. Again, in iron making, all the laborious departments of the process are performed by a low standard of intelligence; yet the desired result would be unattainable in the absence of the scientific rules and dicta of the analyst—without his experience and judgment the mere workman would labour in vain. In the manufacture of glass and iron, the mercantile necessity exists for an intelligent supervision of the various processes so as to ensure the acceptance by the consumer of the products; for their rejection would involve a loss which it would be impolitic in the manufacturer to risk. In the preparation of concrete for house building, the necessity is equally imperative for conducting the operation under the guidance of established scientific principles, leaving the mere manual department to the cheaper kind of labour. Improved mechanical contrivances obviate the necessity of mixing the materials by hand —unless where the work to be performed is so limited in extent as to leave no alternative—and manual labour is now simply confined and limited to mere transfer of the ingredients into the machine and from it to the work. Hitherto works in concrete have been regarded as the branch more especially belonging to the engineering section or department of the constructive profession, and only used by architects when more than ordinary stability was sought for in the foundations of important buildings. Increasing attention is now, however, directed to the construction of dwelling and other houses with this material, from a belief in its suitability for such purposes; and a better appreciation of its qualities has arisen from the fact of concrete exceeding in constructive value the best known descriptions of brick and stone. In some of the concrete mixtures, prepared with Portland cement, it will be seen, by reference to the experiments at page 39, that they exceed in tensile and compressive strength our most celebrated building materials.

While concrete was used only for foundations and in engineering works of a massive character, there was not much necessity for careful attention to its preparation, as the situations in which it was used were favourable to disguise its defects and failings. The old formula, therefore, and the mode of mixing the materials, and their proportions, may now be considered obsolete, from the improved knowledge of limes and cements, as well as the machines applied for mixture. Its adoption for works of construction less massive in character, above ground, involves the necessity of a more minute attention to the qualities of the ingredients of cementation, as well as the means by which they are incorporated.

The construction of houses with concrete is no novelty; the practice may be considered as the most ancient mode of building, and has been revived from time to time through all ages. In this country Mr. Ranger, some years ago, built many structures with his patent lime concrete blocks; two houses on the north side of Pall Mall, the College of Surgeons, Lincoln's Inn-fields, the porticoes of Wellington Barracks, and the guardhouse in the Birdcage-walk, St. James's-park; besides other structures, such as river and wharf walls. These buildings were constructed under what may be called the block system, in contradistinction to the monolithic or continuous building in frames or specially-adapted machines. So long ago as the year 1830 that principle had been successfully applied in France, where the architect M. Lebrun built for himself a dwelling-house on his estate at Alby (Department du Tarn) entirely of bèton. It consisted of six rooms—three on the ground-floor and three above—besides cellars and other domestic accommodation; all the floors and ceilings were arched and made entirely of bèton. Every detail of construction was made of bèton—even the arcades, cornices, and stairs, as well as all internal details of ornamentation. The bèton was composed of one part of hydraulic lime, from Alby, slaked by immersion; one part of clean sand and two parts of shingle, averaging one inch in size. The mortar was thoroughly mixed and then pressed into the case or frame; by this means the building rose about one foot in height per day. The arches were erected upon centres and the cornices formed from models. The faces of the walls were plastered with sifted sand and mortar, leaving a smooth face and sharp arrisses. The building was most successful, and cost less than one-half the price of brickwork. On the island of Santorin bèton has been used for cisterns, terraces, vaults,

&c., from time immemorial. The bèton of which the terraces —which in that country are the roofs of the houses—are constructed is composed of

Six parts of Santorin earth,
Two parts of lime mortar,
Eight parts fragments of stones,
One part of sand.

Vaults and arches are there constructed in the following simple manner:—A rough frame is erected and covered with laths or boards, upon which earth or small stones are placed and levelled with a trowel. Upon this is spread bèton of the following composition:—

Four parts Santorin earth,
One part lime mortar,
Eight parts fragments of stones.

In twelve days the framework is removed.

Both systems have their several advantages; and for ordinary purposes, such as the building of small cottages with lime or other inexpensive concrete, the former or monolithic one may be considered the cheapest; but when the use of cement concrete is determined on, there is much doubt as to the economy of employing frames or machines. An objection to this system arises from the difficulty of ensuring strength and quality of work from the necessity of hurried construction, during which there is no safe means of testing the character of the concrete. There is also the danger of diverting attention from the materials to the machinery of construction, by which they are put together in the building. Such machines have in reality no influence on the quality of the concrete, and bear a similar relationship to the building, in the hands of the builder, that the last does to the shoe when handled by the shoemaker—neither can possibly ensure quality of material. The speed which these machines promise is not the recommendation which should be recognised, unless it is accomplished without any sacrifice of the usual indispensable condition of quality. In concrete, for any purpose whatever, the first consideration should be excellence.

In the old books which treat of concretes there is not much information that can guide us in modern practice, in consequence of the change of circumstances caused by the discovery of cements and their properties. Limes of various kinds—according to the locality in which the works were executed—were employed, according to the practice of each locality in which they were used—shell lime slaked (by immersion in water or exposure to the air) and unslaked, occasionally in combination with puzzolanas and substances of a kindred character. The Romans generally used the pure lime, but in consequence of its liability to violent disturbance during the slaking process, it was afterwards mixed with various volcanic products, so as to neutralise the injurious effects likely to arise from such disturbing influence. The dangers attending the use of fresh lime were thoroughly appreciated by the Romans, for Plinius tells us that the use of slaked lime was interdicted until it had been kept three years. Vitruvius's specification for "cement" was one part of slaked lime to three parts of volcanic sand (*arenæ fossitiæ*) for hydraulic works, and one part of lime with two parts of puzzolana, for ordinary mortar. Even at that time the danger of using rich limes was well understood, and the remedies of keeping it or beating the mortar were intended to effect the object now accomplished by the extreme diffusion of the mass through mechanical agency. The sciences of chemistry and mechanics had not then indicated the necessity of keeping the atoms of lime apart by mechanical reduction, nor pointed out the advantage of the introduction of suitable foreign materials to check the tendency to expansion. A reference to the Table (pages 64 and 65) of the physical characteristics of old Roman mortars will prove, however, that even in the absence of such knowledge satisfactory results were attained. Notwithstanding the advantages of increased scientific knowledge, we notoriously neglect the careful study and consideration of that very dangerous expansive action in all limes, more especially the rich ones. The setting theories offered at page 47, will, it is hoped, simplify the subject, and assist in establishing a more reliable knowledge of the causes which lead to serious consequences attending the use of improperly prepared matrices (limes and cements). Suitable lime, for instance, can only be prejudicial in any mortar or concrete when mixed in an unfit state; for the atoms, when kept sufficiently apart, are harmless—a degree of impalpability to render them so is, however, necessary. Puzzolanas and Roman cements are not necessarily dangerous when coarsely ground, although in that condition they are used wastefully. Portland cement being an artificial compound, is subject to certain fluctuations of quality incidental to its details of manufacture; but even its most objectionable qualities receive mitigation on being subjected to a high degree of pulverization. Attention to this important detail of manufacture does not receive the attention it demands, partly in consequence of the indifference of the manufacturer, but more frequently from the ignorance of the consumer.

LIME CONCRETES.

Lime being the cheapest matrix—from its natural abundance and simplicity of chemical constitution—has been at all times a favourite material for the preparation of mortars and concrete. Its use under reasonable conditions, and for purposes to which it is adapted, is generally attended with satisfaction; but, owing to its inferiority in cementatious value to the natural and artificial cements, it should only be employed for works of secondary importance.

The proportions in which lime is mixed with gravel—and other aggregates—depends on its quality and mode of preliminary preparation; but no accurate or safe proportions can be determined on in the absence of a true knowledge of the chemical value of the several ingredients. Rich limes are weak in cohesive and adhesive capacity, and unless reduced to the finest powder will not exert much beneficial influence in binding the mass of concrete. With such limes, therefore, it is not advisable to incorporate more than three or four parts of aggregates. There are several methods by which the mixing of the materials is effected—both by hand and machine. The lime is usually obtained fresh from the kilns and slaked with water, or at once mixed with the aggregate, when both are wetted and turned over together, the whole operation in such cases being performed by manual labour. Such a treatment is, however, inadvisable, and should never be resorted to under any circumstances. It is impossible to so thoroughly effect the reduction of the lime by this slovenly process as to prevent the presence of large pieces of it in an unslaked condition, which will eventually prove highly prejudicial to the mass of concrete. The use of shell lime, therefore, is to be considered dangerous, and may be classed among the various and now obsolete practices abandoned because of their unsuitability. The best plan to extract the utmost value from lime as a matrix is to reduce it to the finest powder either by slaking or grinding. When so prepared, and evenly sifted through a fine sieve, it can be applied with the most advantageous results. The water necessary for the mixture should be carefully applied in the form of a spray either through a rose or some other equally good distributor, as no wash or superfluity of water should be permitted. The best means of reducing lime to the finest powder is by machinery; but as in all cases its aid cannot be forthcoming, the slaking process must be resorted to. When well slaked, and afterwards carefully sifted, good results can be obtained, although at a cost higher than that which would have been incurred if the lime had been ground. As different qualities of lime require variable amounts of water to effect their incorporation with the aggregate, attention must be given so as to avoid the dangerous practice of over-wetting. When lime thus carefully prepared is mixed with a favourable quality of aggregate, good and satisfactory results may be depended on. If the operator is satisfied that no disturbance will take place in the mass from unslaked lime, he may subject the concrete to a slight degree of pressure when putting it into the moulds or frames. As rich limes require more water than the poor ones, it is necessary to observe that there should be sufficient for their complete conversion into a hydrate, for, in the absence of the necessary quantity of moisture, the mass will have a tendency to disintegrate. These observations on rich limes for concrete making are offered for the guidance of those who may from circumstances be obliged to use them for such a purpose; but, owing to the many disadvantages attending their use, they should at all times be neglected if any other better matrix is obtainable at a reasonable cost. In combination with other substances, however, they become valuable, as is shown by the Table of Ancient Mortars, where it appears that the Romans resorted to many expedients to improve rich limes by combining them with powdered brick, and sometimes charcoal.

The poor or hydraulic limes are better adapted for concrete purposes, in consequence of the amount of silica which they contain. The blue lias varieties are the best; and when submitted to an amount of reduction which will enable them to pass through a No. 40 wire-gauge, without leaving more than 5 per cent. of residuum, they will be found a cheap and advantageous matrix. Slaking, in the absence of grinding machinery, may be resorted to as in the rich limes. Considerable misapprehension exists as to the desirability of keeping ground lime for any length of time before being used. The amount of injury which lime in a finely powdered condition receives from exposure, arises from its avidity for moisture. Unless, therefore, the air is excluded from it, and the situation in which it is kept be dry, no injurious effect of any extent will arise. Smeaton's experience on this subject is conclusive; for he used Aberthaw lime with great success in important engineering works after it had been kept in casks for seven years. The present use of Theil lime from France in the works of the Suez canal, is also confirmatory of the possibility of using lime after it has been some time reduced to powder. The precaution, however, must be insisted on of keeping it in barrels well-made, and their interior papered so as to exclude the air.

It is necessary here to explain the advantage which arises in treating the lime before it is mixed with the gravel or stones. Bèton, as before referred to, differs from concrete in its being subjected to two operations: first, the lime or cement is mixed with sand and treated as a mortar, to which afterwards is added the required quantity of aggregates. Concrete, however, as originally prepared in this country, only consisted of one clumsy operation of mixing the matrix and aggregate together. Hence it is more correct to say that bèton is essentially a French process, and concrete the somewhat analagous one in England. In both cases the mixture is accomplished with the same object, although with a difference of detail. There can be no question that the bèton process is the more perfect one, and, especially when the concrete is made into blocks or frames, offers great advantages over the other. When, however, it is used, as in engineering works, in large masses in trenches, it involves a double operation; first, the preparation of the mortar, which is followed by its incorporation with the larger ingredients, such as gravel, broken bricks, or stone. When moulding the concrete the mortar can be used simultaneously with the gravel, and under such circumstances with beneficial effect. Its use in this way secures the correct quantity so as to attain the object of a solid mass having a minimum of intersticial space. In all concretes it is necessary to adjust the proportions of lime, sand, and gravel, so that no vacuities will occur in the mixture. The larger the size of the aggregate the more necessary is it that attention should be paid to this point. With an aggregate of an average size of 2 inches it will be found that in every cubic yard there will be vacuities equal to 11 cubic feet; so that it is necessary a mortar (coarse or fine) should be equal in quantity to that intersticial space. Such amount of vacant space will, of course, vary with the size or particles of the aggregate, and the amount of shrinkage will also fluctuate accordingly. When in a dry state it will shrink less than when wet in proportion to its specific gravity. A silicious or quartzose sand has a specific gravity of 2·6, and a solid cubic foot of it would, therefore, weigh 162½ lbs.—a cubic foot of water weighing 1000 ounces. Sand of this kind—without being specially dried—when filled into a measure of a cubic foot only weighs, however, 75 lbs.; showing that the space between the grains was nearly equal to their own bulk. The weight of sand of the above specific gravity may serve as a good guide or standard in estimating the amount of mortar that should be mixed with gravel for concrete; for the difference between the weight of a cubic foot of the aggregate, when pressed together, and 162½ lbs. will indicate the void space remaining to be filled up. The amount of difference should be as accurately ascertained as possible, although it is safer to have an excess than too little of the necessary cementing material.

COMPOUND MATRICES FOR CONCRETES.

Lime has been used in conjunction with puzzolanas, trass, and pounded bricks for mortars and concretes for a long period of time, more especially in works of a subaqueous character. Artificial puzzolanas have also been adapted in various ways for the same purpose, but with doubtful success in sea works, from a prejudicial chemical action which arises when in contact with sea water. Several failures of French engineering works have arisen from this deleterious agency. Italian puzzolanas and trass have been successfully used with all varieties of lime, and where they can be obtained at a reasonable price may be used in the preparation of concretes for house building. Rich limes are more improved by it than the poor or hydraulic ones; indeed, in the case of the best poor limes, it is unnecessary. For German engineering works trass is much employed, and especially on the Rhine, where it is easily obtained at a moderate cost. General Treussart used it extensively in France in conjunction with energetic hydraulic limes, and for water works found the best results to be obtained by the following mixtures or proportions:—

30 parts of hydraulic, very energetic, measured in bulk, and before being slaked,
30 ,, of trass from Andernach,
30 ,, of sand,
20 ,, of gravel,
40 ,, of broken stone (a hard limestone).

The above proportions diminished one-fifth in volume after manipulation; the mortar was first prepared and the stones added afterwards. When Italian puzzolana was used instead of trass for the same description of work, the proportions were altered as under:

33 parts of energetic hydraulic lime, measured before being slaked,
45 ,, of puzzolana,
22 ,, of sand,
60 ,, of broken stones and gravel.

The two compositions vary in their proportions, and require different treatment before being used. The first should be at once used, and the other requires exposure for twelve hours before being put in place.

The following preparatory concrete mortars were used successfully in extensive German works:—

STRONG MORTAR.

2 parts of lime,
2 ,, of trass.

Or— 5 parts of muschelchalk,
3 ,, of trass.

BASTARD MORTAR.

2 parts of lime,
1 ,, of trass,
1 ,, of sand.

Or— 4 parts of muschelchalk,
2 ,, of trass,
1 ,, of sand.

WEAK BASTARD MORTAR.

3 parts of lime,
1 ,, of trass,
2 ,, of sand.

Or— 6 parts of muschelchalk,
2 ,, of trass,
3½ ,, of sand.

To these several mortars were added fragments of stones or bricks according to the quality of the mortar and the situation in which the concrete was intended to be placed. These mortars were used in the construction of harbour works at Nieuwe Diep for concrete works. The foundations of the Homberg-Ruhroster-Rhein-traject Anstalt was composed of—

3 parts of stiff lime,
5¾ ,, of ground trass,
12 ,, of broken stones (sandstones).

In this concrete there was a large preponderance of trass, as the lime used contained 16 per cent. of clay, and was only slightly hydraulic, setting slowly. A good concrete mixture used at Berlin was composed of—

4 parts Rüdersdorf lime,
3 ,, Brohl trass,
3 ,, angular river sand,
2 ,, gravel,
4 ,, fragments of stones,
6 ,, ,, of bricks.

A very good concrete was produced by mixing together—

2 parts freshly-burnt unslaked lime.
3 ,, trass,
2 ,, fragments of silicious stones,
2 ,, coarsely-ground iron slag,
1 ,, sand,
1 ,, gravel.

And another used in building the harbour of Cologne—

2 parts lime,
2 ,, trass,
2 ,, broken flints } not bigger than a goose's egg.
2 ,, ,, quartz }
1 ,, sand.

Another useful concrete mixture used with much success consisted of—

5 parts lime,
14 ,, puzzolana,
3 ,, gravel,
8 ,, broken stones.

Or—

9 parts slightly hydraulic lime (dry),
12 ,, puzzolana,
6 ,, clean sand,
16 ,, fragments of stones.

Santorin earth mortar concrete used at Trieste for the walls of the quay, consisted of:

7	measures	Santorin earth,
2	,,	well-slaked lime,
7	,,	broken stones.

Or—

14	,,	Santorin earth,
5	,,	lime,
12	,,	broken stones.

Or—

12	,,	Santorin earth,
5	,,	lime.
12	,,	broken stones,
2	,,	sand or gravel.

These proportions were also used at Venice, and made good concrete walls.

These combinations are not of much practical value in this country, from the scarcity of the volcanic products, but will merely serve as a guide where it may be intended to use their artificial equivalents in the shape of burnt clay, or some such analagous mineral substance. Roman cement, from its plentifulness and cheapness, may with some rich limes be used in this country; and when so used it should be first mixed with the lime, and then slightly wetted and allowed to remain for some time before being mixed with the aggregate. Great care, however, is necessary to prevent the lime and cement setting, and to avoid that danger a small quantity of water should only be used. In any case of such combinations, whether of natural or artificial puzzolanas, it should be remembered that strong or energetic puzzolanas should be mixed with weak or rich limes; and mild puzzolanas with hydraulic limes.

In these as well as in all other preparations of concrete it is necessary to observe that all foreign matters not belonging to the matrices or aggregates should be carefully separated; for the interposition of clay or any loamy earthy matter will weaken and damage the value of the mixture. Such objectionable ingredients while weakening the mass by their valueless character, likewise intervene between the particles of lime and cement, preventing their adhesion to the aggregate.

While on the subject of Puzzolana Concretes, it may not be out of place to quote a curious passage from Diodorus, who relates on the evidence of Polyclitus that in proof of the wealth of the Agrigentines, he describes the following:—"In the house of Gellias, at Agrigentum (near the site of the modern Girgenti in Sicily), there were a hundred vessels cut out of one and the same rock, each of them containing a hundred hogsheads; and that close to them was a certain vat made of white cement capable of holding a thousand hogsheads, out of which the liquor ran into the vessels." The white cement thus referred to was probably the white puzzolana obtained from Pausillip in the Island of Vivara.

When concrete is to be used in trenches, and not formed in moulds or frames, it should never be tipped from a height, but placed gently in position and carefully levelled. The old practice of throwing concrete from a height was attended with injury to the mixture from the tendency of the larger pieces of gravel to detach themselves from the mass while being tipped.

ROMAN CEMENT CONCRETES.

From the rapidity with which Roman cement sets, it is frequently employed in the preparation of concrete where much running water in foundations prevents lime or Portland cement concrete from setting quickly enough for such works. It cannot be used with a large proportion of aggregates, and is therefore under such circumstances seldom used for general concrete purposes. In house building with concrete it never can occupy, for this reason, a valuable position; its quick-setting properties requiring great care in avoiding the danger of disturbing its induration after the initial set has been accomplished. When necessary to use this cement for concrete, it is advisable to mix it with not more than four parts of aggregate in a dry state, and then carefully wet the mixture by a spray of water. Roman cement concrete should not on any account be rammed, as the action of the rammer would disturb the indurating action which speedily sets in.

The American engineers use the natural cements for concrete, and sometimes with lime, and their experience of such a combination is most satisfactory. In Gillmore's treatise on limes and cements the following mode of preparation and use is recommended:—"Natural hydraulic cement, to which, under circumstances requiring only a moderate degree of energy and strength, paste of fat (rich) limes is sometimes added, in quantities seldom greatly exceeding that of the cement, is almost invariably used as the basis of the concrete mortar; and the concrete when made is at once deposited in its allotted place, and well rammed in horizontal layers of about six inches in thickness, until all the coarser fragments are driven below the general surface. The ramming should take place before the cement begins to set, and care should be taken to avoid the use of too much water in the manipulation. The mass, when ready for use, should appear quite incoherent, containing water, however, in such quantities that a thorough and hard ramming will produce a thin film of free water upon the surface, under the rammer, without causing in the mass a gelatinous or quicksand motion."

"It will be found in practice that cements vary very considerably in their capacity for water, and that fresh-ground cements require more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for solidifying water is great. A too rapid dessication of the concrete might involve a loss of cohesive and adhesive strength if insufficient water be used."

The composition of the compound mortar used at Fort Warren was as follows:—

325 lbs. dry cement, producing 3·75 to 3·85 cubic feet of stiff paste; 120 lbs. Rockland lime, producing 4 cubic feet of stiff paste; 19½ cubic feet of loose sand, equal to 14½ cubic feet well compacted. These ingredients, when well mixed, made 18½ cubic feet of good mortar.

The mortar used in the construction of Forts Richmond and Tompkins, New York harbour, was made by hand; when required for stone masonry or concrete, it was composed of hydraulic cement and sand without lime.

"Each batch of mortar or concrete corresponded to one cask or 308 lbs. net of hydraulic cement powder. Four men constituted a gang for measuring out and mixing the ingredients, who proceeded to the several steps of the process in the following order:—

"First. The sand is spread in a rectangular layer of two inches in thickness.

"Second. The dry cement is spread equally all over the sand.

"Third. The men place themselves, shovel in hand, two on each side of the rectangle, at the angles, facing inwards. Furrows of the width of a shovel are then turned outwards along the ends of the rectangle until the whole bed is turned. The two men on one side thus find themselves together, and opposite the two on the other side, having, of course, left a vacant space transversely through the middle of double the width of a shovel. They then move back to their original positions in turning furrows as before, when the bed occupies the same space that it did previous to the first turning. The turning is executed by successively thrusting the shovel under the material, and turning it over about one angle as a pivot. Each shovel thus moves to the middle of the bed, where it is met by the one opposite, when each man moves back to the side in dragging the edge of his shovel over the furrow he has just turned.

"Fourth. A basin is formed by drawing all the material to the outer edge of the bed.

"Fifth. The water is poured into the basin thus formed.

"Sixth. The material is thrown back upon the water, absorbing it, when the bed occupies the same space that it did at the beginning.

"Seventh. The bed is turned twice by the process described above. If required for masons' use, the mortar is then heaped up, to be carried when and where required. If for concrete (the mortar occupying the rectangular space), as at first.

"Eighth. The broken stones are spread equally over the bed.

"Ninth. A bucket of water, more or less (depending upon the quantity of stones, their absorbing power, and the temperature of the air), is sprinkled over the bed.

"Tenth. The bed is turned once as before, and then heaped up for use. The act of heaping up, which is done with care, has the effect of a second turning.

"The time consumed in making a batch of mortar is a little less than twenty minutes; in incorporating the broken stones, ten minutes more.

"Where the mortar is required in very small quantities, to avoid deterioration, instead of proceeding to the fourth step of the manipulation, the mixture of cement and sand is heaped up and the water added, and paste formed with the hoe in such quantities as are required."

The composition of the above mortar was 308lbs. of cement powder, which produced 3·70 to 3·75 cubic feet of stiff paste, and 12 cubic feet of loose sand (equal to 9·75 compacted or pressed). These ingredients being incorporated produced 11·75 cubic feet of rather thin mortar.

The above accurately described method of hand-mixing indicates the necessity of a careful handling of natural cement mortar or concrete. It is only by such a reasonable and intelligent admixture that any satisfactory results can be expected. The Rosendale cement used for these mortars gave the following analysis:—

Silica, clay, and insoluble silicates.	Alumina.	Peroxide of iron.	Carbonate of lime.
19·80	4·40	0·76	33·90
Carbonate of magnesia.	**Sulphuric acid.**	**Chloride of potash and sodium.**	**Water and loss.**
34.06	0·32	4·78	1.56

These American cements are subjected to a high degree of pulverization, being required, under strict surveillance, to pass through a No. 80 gauge sieve (6400 meshes to the square inch), and not leave more than 8 per cent. of residuum. One solid cubic yard of raw stone yields on an average 2700lbs., or nine barrels of cement, exclusive of those portions rejected in assorting the burnt stone.

It will be observed that the natural cement, so abundant in America, differs from our Roman cements in their analyses; and in no case do they approach them in setting energy. It is, therefore, necessary to understand that an exactly similar treatment of it for mortar or concrete would probably be attended with less satisfactory results than those obtained by the American practice. It would be better, therefore, to mix the Roman cement and sand first before adding the water, which must be distributed equally through the mass until it assumes incoherency; it may then be mixed with the gravel or stones, when it will be necessary to add another quantity of water. The fact of our cement makers being heedless as to the fineness of the cement puts engineers and builders at considerable disadvantage. Such coarsely ground cement as we are supplied with in England not only fails to accomplish the desired effect, from its inability to distribute itself in sufficiently minute particles throughout the mass, but it also involves a loss in the coarser particles only performing the part of an aggregate in the mixture of mortar or concrete; for there is no secondary process or action, either chemical or mechanical, by which they can be transformed into a condition minute enough for any beneficial exertion as a cement. So that in all cements, when their value is being estimated, the fineness of powder should be considered as one of the principal elements to be regarded in arriving at their relative costs.

PORTLAND CEMENT CONCRETE.

Whatever advantages may be derived from the practice of preparing concretes with limes, puzzolanas and natural cements—according to their cheapness or abundance—they will bear no comparison in quality to that made from Portland cement. In the absence of this cement, or by reason of its excessive cost, and for unimportant works, any of the other mixtures may be used; but it is here distinctly pointed out that in all cases where practicable a preference should be given to Portland cement concrete.

Portland cement has an advantage to which no other cement can lay claim, by reason of the facility with which it can be made of any degree of setting energy—from 10 minutes to 2 or 3 days. An active capacity of quick setting is however obtained at a sacrifice of indurating strength; and it should therefore be at all times remembered that it is not otherwise attainable. The practice of making Portland cement of light specific gravity is now nearly abandoned, and an average weight of 110 lbs. the imperial bushel may be regarded as the most advantageous quality. Even a lighter weight than that would suffice, for all ordinary purposes of concrete making, if the cement was ground half as fine as the American engineers insist upon in the case of the natural cements used by them. When our manufacturers will produce a powder equal to the test of passing through a No. 40 gauge sieve, much more satisfactory results will be obtained than those with which we are now familiar.

For concrete in engineering works very large proportions of aggregates have been mixed with this cement. In the sea-forts of Copenhagen the following proportions were used :—

1 part Portland cement.
4 ,, sand.
16 ,, fragments of stones.

And a very usual proportion for foundations is one part of cement to 10 of sand or gravel. The proportions used in the works in connection with the Houses of Parliament was 1 of cement to 4 of sand. On the Main-drainage works, where special excellence, regardless of cost, was aimed at, the cement of the finest quality was used with only 1 of sand to 1 of cement. For foundations and backing of wharf or river embankment walls 1 of cement to from 6 to 8 of clean Thames ballast; and in those proportions the concrete only cost a little over one-third of the price of the best brickwork, for which it was in some portions of the work substituted.

The mode of preparation adopted in the case of the Thames embankment works was not calculated to extract the highest value from the cement; being the old and now obsolete method of mixing by hand and then tipping the concrete from a height into the trench prepared to receive it. The foundations were wet, and generally speaking an excess of water was used with the mass; but notwithstanding these shortcomings in its preparation the concrete attained great hardness. It is true the massiveness of the walls and the more than ordinarily favourable circumstances in which it was placed assisted in the accomplishment of such desirable results. The cement was first-class in character, and indeed under the extremely careful engineering supervision practised on these works it was impossible to use any other, and the ballast being well balanced in its proportions of sand tended also to the good results achieved.

In the absence of machines for mixing the materials the usual plan adopted is to spread the stones or gravel upon a hard surface, and upon these is spread a layer of the previously prepared mortar in the agreed proportions; the necessary amount of water is added, and the whole mass then carefully mixed and turned with rakes and hoes. There is some danger attending the supply of water, and it is advisable to thoroughly saturate the aggregate before putting the mortar on it. In all cases of concrete or mortar making it must be remembered that the smallest possible quantity of water should be used. When a heavy and slow-setting Portland cement can be commanded it is safest, as the danger of over-wetting is reduced to a minimum. The manufacture of granite breccia stone (before referred to) was a favourable example of careful concrete making conducted on the most scientific principles. A cement was selected of a weight up to 140 lbs. per bushel when it could be obtained, and with it was mixed chippings of Bath, Portland or Anston stone (obtained from the refuse of masons' yards) broken to a uniform size seldom exceeding 1½ inch in size, to these being added sufficient small or sandy portions to fill up the interstitial space. It was made up in batches of about half a cubic yard, and all the materials first mixed together in a dry state, proportions of cement varying with the quality of the cement and the purpose for which the stone is destined. It was slightly watered with a can having a fine rose, thus applying the water in a state of dewy fineness. At this stage of the process the mass was quite incoherent, and showed but slight indications of any capacity of setting, let alone induration. The mixture was then gradually and carefully put into the iron moulds, in thin layers, and rammed incessantly with heavy iron rammers. The percussion applied effected a thorough amalgamation of the mass with so small a quantity of water as to lead to a belief in the minds of the ignorant that the concrete when liberated from the moulds would be worthless. The result, however, was on the contrary most satisfactory, and large quantities of this stone (for it is well entitled to that designation) were used in London and its suburbs for paving. In addition to the portion in King William-street, City, London, a considerable surface was laid on the Terrace, at Lewisham in Kent, where it has been down for nearly fourteen years, giving great satisfaction in its wear.

Other forms beside paving flags were made; even drain-pipes and columns of considerable size. The moulds used for this kind of manufacture were highly finished, and strong enough to resist the pressure caused by the incessant impingement of the rammers on the yielding body of materials. The ramming was continued until the mass was absolutely solid. After fourteen days, and sometimes less, the moulds were unscrewed, and the stone carefully lifted by mechanical means—the stones made sometimes weighing half a ton. When more than ordinary strength was required, a small portion of the soluble silica of soda or potash was added; but this was quite exceptional, and it was doubtful if any increased strength was obtained, at all events not commensurate with the additional cost incurred.

In large works it is now customary to perform the operation of mixing by machine, and many complicated apparatus have been devised for that purpose. A very simple and inexpensive machine has been used with success in Germany of the following character:—

It consists essentially of a cylinder 12 feet long and from 3 to 4 feet in diameter, placed at an angle of 6 or 8 degrees. The cylinder was made of wood lined with sheet iron. The power was applied by a belt round the outside of the cylinder, obviating the necessity of a driving wheel or strap pulley. By means of this simple machine from 80 to 100 cubic yards of concrete could be mixed in ten hours. This machine may be called a concrete-mixing one, in contradistinction to the ordinary mortar mills or pug-mills. Where a mortar mill is in use on the works, and where the concrete requires to be moulded in blocks, the cost of their preparation will not be expensive; and good results may be obtained when due regard has been paid to the conditions which we have endeavoured to describe.

Portland cement is occasionally used in combination with finely-sifted slaked lime, as in the case of Coignet's "bètons agglomérés." The mode adopted in the manufacture of that substance is highly rational, and very satisfactory results are obtained. In some works performed in London, at the Thames embankment and for sewers, the mode pursued was as follows:—

Stone lime was used, and after being slaked with water, it was passed through an exceedingly fine sieve; the necessary quantity of Portland cement (a fluctuating quantity, according to the quality of work and its cost) was added, with a fine, sharp, clean river sand. The whole was then put into a specially constructed pug-mill, with the smallest quantity of water, and thoroughly amalgamated. From the pug-mill it was at once wheeled in barrows to the destined part of the work, and there spread in layers of about six inches deep, being carefully raked and slightly rammed. The works in question were executed during the winter, and although under such unfavourable circumstances, the centres upon which it was placed were struck in less than fourteen days without any damage to the arches. The cost of labour was considerable, and it was impossible to compete with Portland cement concrete in London, but in certain districts where that cement was costly it might be used with advantage. Large works have been constructed with "bètons aggloméres," and many miles of sewers have been built under Paris; arches of considerable span have been built, as well as houses and churches. It is mentioned here as an instance of the advantage of well-directed manipulation effecting successful results from comparatively inexpensive materials. There was no gravel used, and the largest piece of sand was not bigger than a pea. The appearance of the work was pleasing, and closely resembled some varieties of Bath stone in texture. By such a combination—and, indeed, in some qualities of the work without any Portland cement—the danger of using an imperfectly manufactured cement may be avoided; but the cost of sifting and subsequent mixture by the pug-mill, together with the levelling and ramming, runs into so much cost as to make it doubtful if it can be used with any advantage in a locality where Portland cement can be obtained at a reasonable cost.

From these instances of well-adapted application of materials, especially in the case of granitic breccia stone, it will be seen that much more satisfactory results in concrete making can be accomplished than is commonly supposed. In the manufacture of the stone it is apparent that that principle can only be applied through the agency of moulds; and notwithstanding certain fancied advantages realized by the machine or frame mode of structure, it is very questionable if equally sound construction can be secured. One very strong argument in favour of block making is the advantage of ascertaining the quality of the concrete before it is placed in position, an advantage not secured by frame building, which necessitates the uninterrupted continuance of the work, which, if executed with a bad quality of cement, would entail heavy loss. The quantity of cement required for blocks is less than that which must be used in the monolithic mass. Another great evil likely to arise in the adoption of machine-raised buildings is the use of light or quick-setting Portland cement, for with a good heavy slow-setting cement it would be impossible to secure the progress of the structure at a rate commensurate with the expectation that system raises in the minds of the inexperienced.

MACHINERY FOR MIXING MORTARS AND CONCRETES.

In making the various preparations described in the preceding chapters the degree of success will much depend on the accuracy of admixture of the various materials. Unless due attention is given to this important condition, neither good mortar nor concrete can be produced, for the best materials, improperly mixed, will be comparatively worthless. Until recently the operation of mortar and concrete mixing has been performed by manual labour; but the increasing magnitude of architectural and engineering works has necessitated the adoption of mechanical means with great advantage, not only as regards cost, but with considerable improvement in the quality of the mixed materials. Not only in this country, but on the Continent of Europe and in the United States of America, many ingenious machines have been devised for mixing mortar and concrete—pug-mills, horizontal and vertical stones, with other kindred contrivances, have been used with varying success.

At the Liverpool docks, where the mortar used in their construction has obtained a justly-deserved reputation, revolving pans are used, in which heavy cast-iron rollers rotate in a contrary direction to that of the pans. At the London Docks Extension (1856-57) pans seven feet in diameter were used, in which revolved two stones four feet in diameter, having a face or thickness of fourteen inches, hooped with one-and-three-quarter inch cast-iron. Four pans making fourteen revolutions per minute, each charged with seven cubic feet of mortar, prepared 72 cubic yards during every twenty-four hours; and it was found the space of forty minutes, or 560 revolutions, was the time of duration which realised the best and most satisfactory results in the quality of the mortar, the adhesive value of the mortar being depreciated if the revolutions were more or less than the above number Both of these mills were driven by steam power.

A horse mortar-mill was used at Fort Warren, Boston Harbour, U.S., by Colonel Thayer, of the description shown by Plate II. It consisted of a circular trench in which revolved a weighted wooden wheel 8 ft. in diameter, having an iron tire half an inch thick and 12 inches broad. The beam (8 inches square) on which the wheel was hung was 20 feet in length, attached to a fixed axis firmly imbedded in substantial masonry. To this beam the horse was yoked. The space F was large enough to contain 16 casks of lime, about 84 cwt., when converted into a paste. It was divided into 16 radial divisions, so as to facilitate the distribution of the proper proportions by the workmen. In a convenient position, a box 7 feet long, 5 feet broad, and 1 foot 4½ inches in depth was placed, into which the lime in quantities of 3 casks at a time was properly slaked. At one extremity of this box a small compartment was parted off, in which was fixed a grating to prevent the egress of the unslaked or imperfectly burnt lime. After the 16 radial compartments have been filled with liquid paste, the process of mixing begins by allowing the lime in one of the compartments to flow into the trench F, into which also is put one half of the required quantity of sand. The remainder of the sand is afterwards added, with the necessary additional quantity of water.

The preparation of mortar by the paste process is only resorted to when hydraulic cements or alkaline silicates are to be added; the cement in fine powder and the silicates in a soluble condition. These several ingredients are added to the lime paste immediately before the mill is set in motion, so as to insure their thorough incorporation. When natural cements of high initial energy are used, their incorporation is deferred until the last portion of sand is added, otherwise they would set before the mixture was perfected. The above preparation was only adopted where a high class quality of mortar was desired. For common mortars the lime was slaked in the ordinary way, and enough water added to produce a thick pulp.

A steam mortar mill was used in the construction of Fort Taylor, Key West, Florida, U.S. It was driven by a steam engine directly connected with the driving shaft on which was fixed the heavy fly wheel; a disadvantageous arrangement, precluding the application of the steam power for other purposes when the mortar mill was not required. This mill, with an applied power of from sixteen to twenty horses, could prepare daily as much as fifty casks (about 7 tons) of cement mortar. It would be unwise to use a mill of this description and capacity where only one half the above quantity of mortar was required. As American engineers usually mix equal quantities of lime and cement in making their mortar, the actual daily performance of the mill may be reckoned at 14 tons. In the absence of accurate information as to details, we may assume that the amount of mortar prepared was from 80 to 100 tons per day, according to the proportion of sand with which the lime and cement was incorporated.

The mill as shown by Plate V. consists of a pan supported by conical bed rollers, in which is placed two hollow cast-iron wheels which revolve in an opposite direction to the pan, imparting by this arrangement a compound or double capacity. Two spiral scrapers are fixed to the vertical driving shafts of the wheels, for the purpose of furrowing up the materials when mixing. Other necessary scrapers are placed so as to keep the faces of the wheels clear. Another scraper is attached to the horizontal shaft to keep the inner side of the pan clean, and throw the materials towards the centre.

The mill is used as follows:—The lime paste is first put in the pan and is ground while the sand and cement are measured out, mixed together, and then added. On account of the quick-setting character of the mortar prepared on the works where this mill was used, it was only necessary to grind the mixture from 7 to 15 minutes.

Such a mill as above described may be considered a compound grinding and mixing mill, and differs essentially from the incorporating or mixing machine, of which the following is an example:—

It is represented in Plate III., and was used on the works in connection with the drainage of the Boulevard de Sebastopol, Paris. It consists of a sheet-iron hopper A, closed at the bottom by a disc B, surmounted with a cone C, to which is imparted a quick rotary motion by the cog-wheel D. There is a rectangular opening in the hopper 8 inches wide, the height of which can be increased or diminished by the ratchet and cog-wheel F. Below the hopper is a cylindrical spout G, in which revolves a screw having iron points attached at regular intervals. Water is supplied by means of the stopcock K, through the funnel J. Two men can work this machine by aid of the crank L. On the works in Paris a half-horse power was applied by a belt to the pulley O, and in a working day of ten hours it mixed 38 cubic yards of mortar, at a cost, including fuel, of 33 francs, or about 9d. per yard. The motion of the screw carries the mortar while being mixed to the outlet where it is discharged into buckets placed on the revolving platform M. By means of the crank N, the buckets pass under the opening in the spouts in succession. The materials are previously mixed in a dry state on an adjacent platform before being thrown into the hopper. The clay-cutter or pug-mill, used by M. Coignet in the preparation of "bètons aggloméré
s," is a slight modification of the common pug-mill used in brick-making, and performs successfully the admixture of cement, lime, and sand required for that excellent material. As with the previous machine, the materials of mixture are first mixed by hand in the required proportions before being put into the mill, and in this case a minimum quantity of water is used. The high character of "bètons agglomérés" is due as much to the intelligent manipulation which it undergoes as to the quality of the materials of which it is composed. The same proportions and kinds of cement, lime, and sand carelessly prepared would produce a mixture of a most unsatisfactory character, and from which no such results could be obtained as that produced in the case of "bètons agglomérés."

The most important object to be attained in using any of this class of machines is that of thoroughly amalgamating the materials. The necessity, in ordinary cases at least, does not arise for grinding or pulverising them, and not only may that action be considered superfluous, but in some cases positively dangerous. The sliding action of the metal surfaces induces frictional heat, which has a tendency to evaporate the water of mixture, resulting in the imperfections due to over-grinding.

It is well to avoid the use of such machines as impart this peculiar sliding action unless on works of sufficient magnitude to ensure their careful and intelligent supervision. The simple hand machines will be found useful in ordinary cases, and great accuracy of admixture may be realised at a comparatively small cost. The danger of excessive trituration of mortars is not sufficiently considered, and much mischief has been caused in consequence. Portland cement mortar when submitted to the grinding action of the mortar mill was much impaired in quality, and after repeated experiments, at the instance of an ignorant engineer, several attempts to thus prepare it were abandoned.

The most desirable method of mortar preparation should consist of two operations. Firstly, a thorough dusting of the aggregates with the matrix; and, secondly, a careful and perfect moistening of the mass by the spray or *dusting* of the smallest possible quantity of water. By the first process you place the various particles of lime and sand in accurate mechanical juxtaposition; and by the second is imparted the necessary amount of moisture to guarantee the perfection of the chemical process of agglutination, as more fully described in the article on lime and cement setting. Such a careful manipulation would not be more expensive than the system of mortar making which now prevails; but even if it were, the improved quality which would be obtained would more than compensate for any increase of cost.

In building the Dirschau Bridge, West Prussia, where the cement could be made contiguous to the works, the following machinery was used, combining cement grinding with the mixing of the mortar. The grinding machinery consisted of eight mortar or vertical mills, the pans of which revolved with a velocity of twenty-two revolutions per minute. The runners to each pan were provided with an adjusting arrangement, whereby the stones could be raised or lowered at pleasure. Each mill was attended by one man, who first put in the burnt cement, and when it was ground fine enough the water, and then the sand, was added in the proper proportions. When the cement and sand is thoroughly mixed, the mortar is withdrawn by means of a shovel—which is held in a contrary direction to the rotation of the pans—and placed in a hand-barrow, in which it is wheeled to the required points of the works for use. Under ordinary circumstances, such an arrangement is not desirable; but in all probability the engineer in charge of the works had special reasons for such an adaptation of the cement-grinding and mortar-mixing machinery. If the cement used was quick-setting in character, much danger was incurred by using it so freshly ground; and if of a slow-setting, hard-burnt nature, the machinery applied was inadequate to extract its greatest value. An application of such a principle is only possible where the necessary scientific control and experience is attainable at a reasonable cost.

Any of the above mortar-mixing machines may be used for concrete-making where the practice is adopted of mixing the aggregates with a previously prepared mortar, as in the case of bèton, and which forms the distinction between the French material and our English concrete.

For concrete-mixing there have been several machines used in this country, more particularly in the Main-drainage works of London, and in the works connected with the improvement of the River Tyne. These machines were, however, of an expensive and complicated character, and their use could only be possible on works of considerable magnitude. For ordinary purposes, and in connection with house building operations, much less complicated and cheaper machines are required, the simplest of which is one of the following description, used in the construction of the bridge over the River Theiss, Hungary. In this machine the mortar was previously prepared and thrown together with the stones, or aggregates, into a hopper connected with a cylinder open at both ends. The cylinder was 13 feet long and 4 feet in diameter, inclined at an angle of from six to eight degrees. The cylinder was made to revolve at a speed of twenty revolutions to the minute, the power to accomplish this being applied by a driving-belt placed round the exterior surface of the cylinder, which acted as a driving pulley, the inner surface of the cylinder being smooth and lined with sheet-iron. By this machine the thorough incorporation of 120 cubic yards of concrete was accomplished during a working day of ten hours. In conjunction with such a machine a mortar-mixing mill might be judiciously combined.

Another mixing machine used for making bèton is represented in Plate IV. A valuable feature in this machine is its portable character, which enables it to be used by hand, and can be readily transferred from one point of the works to another, thereby avoiding the cost of moving the concrete when mixed. The proportionate quantities of mortar and gravel are carefully measured and put into the machine at A, Fig. 1; the levers, *b*, *b*, Fig. 2, are then moved and the materials fall, and in descending through the several compartments are thoroughly mixed, in which condition they reach the bottom of the machine. If necessary the machine is moved to another spot, when it is again charged and the same operation repeated as before.

REMARKS ON BUILDING BY FRAMES.

In considering the relative values of various building substances, it should be borne in mind that concretes, when properly prepared, do not attain their extreme or maximum strength for many years, so that when instituting any comparison between artificial masses and stones or bricks, due allowance should be made for an increase of ultimate strength. Natural or artificial agencies have usually perfected their operations before stone or bricks are adapted for building purposes; the former during the course of many ages, and the latter by the application of heat. Notwithstanding the application of the best practical and scientific knowledge to the selection of building stones, we are unable to obtain from any source those which will resist the prejudicial influences of our smoky atmospheres. An increasing desire for high-class architectural decoration tends to aggravate this state of things, owing to the greater susceptibility of highly-wrought stone to the degrading action of a vitiated atmosphere. So much has this evil increased of late years, that there seems but little hope of obtaining permanent beauty of outline through the agency of natural stones. Artificial cements, and the compounds into which they are introduced, offer under the most favourable conditions the required material, which, while securing accuracy of form, resist all injurious climatal action, besides attaining a degree of hardness which our present knowledge does not enable us to define.

It is with the object, therefore, of impressing upon all those interested in building substantial structures the great importance and necessity of an intelligent knowledge of cements and their relative values that this book is written. The author's practical experience and knowledge of the subject induces him to offer reliable information for the guidance of those who intend building in concrete. The subject, although not novel, nevertheless possesses an amount of fascination which, when ignorantly undertaken, may lead to much loss. Already a tendency has arisen to accept unquestioned the various concrete-forming machines which promise the erection of houses with marvellous rapidity. It is in such a direction, therefore, that danger is to be apprehended from a too eager desire for a speedily constructed house, regardless of the more important question of the quality and character of the materials with which it is put together. These remarks are not made with the view of questioning the merits of the several building machines, or the credit due to their inventors, but for the purpose of claiming for the materials that consideration which their primary importance demands. However excellent the machine is it cannot secure in the smallest degree the quality of the concrete, which, again, is dependent on the cement. Therefore, in addition to selecting the most meritorious machine, the intending builder should secure the best quality of cement, as well as the most judiciously combined aggregates in the neighbourhood of his building. The cement should be procured from a manufacturer who will guarantee its quality, and take the risk of losses which might arise from its use if of imperfect quality.

The recent impetus given to building houses of concrete is in some degree due to the facilities offered, and the advantages secured, by the various concrete-forming machines, which are calculated to lessen the cost of construction by the substitution of ordinary for skilled labour. This is the direction in which much good will be effected, by enabling the class likely to be most benefited by improved dwellings to aid in the work of constructing better homes for themselves and families. A twofold advantage of this kind is well calculated to improve the character and condition of the agricultural labourer especially. The ingenious and labour-saving machine would have been unable of itself to increase the desire for building in concrete. Portland cement, a comparatively modern discovery, has, by its great merits, accelerated the acceptance of the constructive apparatus. Its advantages have been amply tested in engineering waterworks, where monolithal blocks weighing upwards of 300 tons have been successfully built up by its agency. Such satisfactory results have not been realised, however, without the exercise of considerable care; for it must not be disguised that Portland cement, when carelessly made or injudiciously used, is dangerous for constructive or any other works for which it is applicable. Against such dangers, therefore, the author considers it necessary to caution those using this cement for concrete purposes, as when carelessly treated disastrous results are likely to ensue. In erecting buildings by the machine sufficient time cannot elapse between the preparation of the concrete and placing it in position; therefore, no opportunity is afforded of ascertaining if the concrete is perfect in character and safe to build with. The risk in consequence arises that when the house is built, and even long after its completion, faulty developments may arise which might endanger the structure without the possibility of remedy. The true antidote for such a casualty is only to be found in a stringent test of the cement before being used, either through the agency of the testing-machine or by the method described in the chapter on Portland cement, page 40.

On well-conducted engineering operations, where large monolithal blocks are prepared, not only is the cement scrupulously tested, but a subsequent opportunity is afforded of proving the quality of the blocks before being permanently placed in their destined site. They are usually allowed to remain for three or four months exposed to the air, and in some cases submerged in water before being used. Under such favourable circumstances it would almost be impossible to sustain damage from the use of Portland cement on works so carefully supervised; for improper or faulty cement would, even when undetected by the test, prove incapable of resisting the air or water exposure during the interval that would arise between the fabrication of the block and its final deposition in the building. If such safeguards could be commanded when hurriedly building concrete houses by machine, no exception could be taken to their use, for the timely development of over-limed or cracking cement would prevent the concrete being permanently fixed.

The advocates of machine-building rely on the ability of the machines to use ordinary labour instead of high-priced skilled labour, and regard that as the salient point of advantage in their system. The cost of the materials and the expense of mixing them, is not reduced by the aid of the machine, neither can their quality or excellence be secured thereby; so that against the merit of substituting unskilled for skilled labour, is to be put the cost of machine, royalty for its use, and the expense of altering its position from time to time as the work proceeds. In the erection of cottages, simple in form and without architectural pretensions, probably much advantage can be realised; but in works requiring minuteness of detail and variety of outline, the saving effected is somewhat doubtful.

It would appear, therefore, that the advantage offered by the machine is its capacity of substituting concrete for brickwork, so that its claim to superiority will fluctuate with the market price of bricks; the balance will be more in favour of the machine when they are dear, and the reverse when cheap. There is, however, a disadvantage which must not be overlooked in using machines to build at the high pressure speed of eighteen inches per day, which involves the necessity of using a quick-setting cement to the exclusion of the best heavy, slow-setting quality, by which only you can secure a high indurating strength.

Having thus endeavoured to point out the advantages and disadvantages of using the machine for building, we will shortly refer to the system of building with blocks.

Blocks may be made of any size or form, and moulded with extreme accuracy by the aid of iron or wooden moulds. The labour required to fill, ram and empty the moulds, can be of the cheapest kind, and even women and boys may be employed for that purpose when necessary. The blocks could be made at convenient intervals and allowed to remain for months or years before being used. Less water can be mixed and a larger proportion of gravel or other aggregate introduced into the block. This system would commend itself in some districts where employment of labour is intermittent and uncertain.

In such localities, during periods of idleness, the unemployed might be advantageously engaged in moulding blocks which would readily find a market for house building and other purposes. No imperfect block could be, by this arrangement, used, or a bad quality of cement employed, for sufficient time would be permitted to detect the shortcomings of the one and the other.

GENERAL OBSERVATIONS.

The suitability of Portland cement concrete, especially for house-building purposes, is now so generally acknowledged that it is almost superfluous to describe or enumerate its many advantages over bricks and stones for ordinary erections. It is, however, desirable to explain more fully the leading benefits to be derived from its use:—

First. Increased strength.

Second. Reduced cost.

Third. Additional facilities for the flue, and heating or ventilating arrangements.

Fourth. Resistance to atmospheric influences, and from its comparative non-absorbence, the capacity of resisting damp whether internal or external.

Fifth. Reduced cost in details of construction, more especially in plastering, carpentery and joinery.

Sixth. Durability from its ultimately becoming crystallized, and instead of deteriorating with age becomes harder and stronger.

Seventh. Flat roofs with inexpensive covering may be constructed owing to the increased strength of the walls.

Eighth. Fire-proof when the timber necessary in construction is judiciously arranged.

Ninth. Impermeability to sound.

Tenth. Possibility of adopting non-skilled labour in the preparation of the concrete and placing it in the walls.

Eleventh. Capacity of resisting attacks of vermin.

Twelfth. High and equable internal temperature secured by reason of the non-absorbent nature of the materials.

Thirteenth. Purity of atmosphere in the rooms in consequence of the walls being able to resist the absorption of the animalised gases.

Fourteenth. Advantageous condition of the walls to obtain the most economical application of heat for warming, as no waste of fuel is incurred in first evaporating the moisture—a common source of expense in ordinary brick structures.

Fifteenth. Expedition in construction, as a house built of Portland cement concrete may be inhabited when the walls are completed. No delay need arise in drying, as the cement concrete possesses the property of exuding the water of mixture so soon as it sets.

Sixteenth. Avoidance of dust from the disintegration of mortar. This is a fertile source of annoyance in all brick-built houses, with their innumerable joints made of bad lime-mortar.

Seventeenth. Facilities for warming or ventilating floors of concrete.

Eighteenth. Cheap form of roof may be made of concrete.

Nineteenth. General improved facilities for the most advanced sanitary appliances for comfort and health.

The above list of advantages has special reference to construction of dwellings; but there are other and many varied uses to which Portland cement concrete may be applied, such as improved walls for gardens and other inclosures. Pavements and roadways of all descriptions may be made with good Portland cement concrete. For such, or, indeed, for any purpose where such a material is applicable, it is necessary that the cement should be of first-rate quality, and its mixture or combination with the gravel, shingle or other aggregate, should be carefully performed.

In Scotland several successful trials of pavement have been made, and in the city of Edinburgh, where it has been submitted to upwards of two years' test with much public satisfaction, as the following extract from the *Edinburgh Daily Review* of 4th June, 1869, will show:—

"We had occasion to describe the concrete pavement on George-the-IV. Bridge when laid down (1866), and referred afterwards to the large measure of success which has attended the experiment. Mr. Mitchell, the eminent engineer who contrived this description of roadway, has obtained the concurrence of the Road Trustees for a trial of the concrete pavement under new conditions. The experiment on George-the-IV. Bridge has been sufficient to show that the new road is more economical than either the old pavements or the macadamised road, in consequence of repairs being seldom needed. It is also smoother and easier for cattle and carriages, and more comfortable for pedestrians, from the absence of dust and mud. But it had one disadvantage; greater labour and cost had to be expended in breaking it up when it was necessary to get at the gas and water pipes imbedded in the soil. Mr. Mitchell's contrivance for overcoming this difficulty, as may be seen at present by passengers along George-the-IV. Bridge, is to prepare the concrete pavement in blocks 4 feet long and 2 feet 6 inches broad. These are placed about an inch apart and the interstices closely filled with thin slabs of concrete, which can easily be picked out when the large blocks of concrete require to be raised."

The only objection, therefore, after some years' experience of a Portland cement concrete pavement was from its being too hard to be *destroyed* to gain access to gas and water pipes. This disadvantage will eventually be overcome when sanitary progress has sufficiently advanced to insist upon the construction of subways for the reception of the necessary pipes which may be required for the domestic comfort and health of our town populations. The requisite imperial legislation must, however, keep in advance of such improvements, to prevent a repetition of such destructive operations as were performed on the Southwark Street constructed by the Metropolitan Board of Works. In that case, after a most elaborate and perfect system of subways to receive pipes had been constructed, and above them an excellent granite roadway laid on a bed of first-class Portland cement concrete, the water or gas companies broke up the street to lay down pipes. Some misunderstanding had occurred between the Metropolitan Board and the gas and water companies as to the amount of the latter's contribution to the outlay or interest thereon incurred by the former.

Although this country commands greater facilities than any other for the manufacture of Portland cement, and has in unlimited abundance suitable materials with which to make it, yet we have been the last to acknowledge the advantages of concrete except for foundations and sea works. America, France—even Denmark and Sweden—are before us in the practical use of concrete for buildings of all descriptions, and in Germany extensive building operations of various kinds are carried out in Portland cement concrete.

It is difficult to account for such indifference to the use of a material possessing so many inherent properties of undoubted and tried value. Probably the use of stock bricks, from the facility with which they are made on the ground where buildings are to be erected, has had much to do with this non-appreciation of concrete. Portland cement concrete has, however, all the advantages possessed by the brick, besides other useful qualities peculiar to itself; for no locality is deficient in the necessary aggregate, and none certainly beyond the influence of a cement supply.

There is perhaps no more important advantage among the many which may be advanced in favour of the use of Portland cement concrete than that secured in connection with sanitary improvement. Even if it was more costly than brickwork, and possessed less ultimate structural capacity, its hygienic value suffices to claim for it a high position as a constructive material for house building purposes. A non-absorbent and washable wall has long been considered a desideratum, and the most enlightened sanitary reformers have always regarded a house imperfect wherein that quality is wanting. When such views were first propounded their accuracy was questioned, and the conclusions arrived at by their advocates were received with scepticism. Recent experience has now, however, conclusively settled that plaster walls, with their accompanying accumulation of poisonous paper, is highly detrimental to health; and in hospitals, where medical science recognises and can control their structural arrangements, all such dangerous walls are scrupulously eschewed. Second only to the internal condition of the walls is the question of their external perfection. If you secure non-absorbency inside you cannot fail to check the absorption externally, for under the most favourable circumstances these two indispensable securities against disease must necessarily co-exist. Let us hope that if not in this, at least in the next generation, plastering, limewashing and painting of walls will be regarded as dangerous, and that the impetus now given to concrete buildings will hasten that much-to-be-desired consummation.

French hygienists fully recognise the evils consequent on damp walls, and the following extract from Devey, "Hygiène de Famille" (page 401), shows that in France the subject receives that attention which its importance demands:—

"And more especially to the stones of the wall, particularly those of a porous nature; there they are condensed when fresh with the humidity of transpiration. The ventilators which renew the air are almost without effect with regard to the mephitism of the walls. Disinfecting vapours cleanse the atmosphere of the impurities with which it is impregnated; but in general the infection of the walls escapes their action.

"However applicable these explanations may be, it is certain that there exists, according to the energetic and picturesque expression of Moses, '*lepra domonum*,' a leper of houses, a leper of walls, which, although it does not injure them, is no less to be dreaded for sanitary reasons. The mephitism of the walls results from the accumulation and infiltration in the walls of the miasmas of the surface in the interstices of the stones, the mortar, the plaster, &c. &c. There are formed, so to speak, nests of miasma, which are hotbeds of infection, acting as a poison upon the blood. When they have once taken possession of a house their persistence and obstinacy is really fabulous. We will cite some examples to support this view. Under the ministry of Lamoignon de Malsherbes the dungeon of Vincennes ceased to be the State prison. Many years after their liberation some former prisoners returned to visit the place of their captivity; they were struck by observing exactly the same odour which prevailed there during their incarceration. A doctor, Sainte-Marie, attended a person suffering from gangrenous affection, to which she fell a victim. Two years afterwards, on revisiting the place to attend another invalid, he found the same gangrenous smell, the smell *sui generis*. Some years ago at Lyons, in one of the public charities, an epidemic of puerperal fever broke out. Fifteen or eighteen women recently delivered succumbed in a few days; the place was emptied, and workmen began to clean it. As the plaster of the walls and ceiling was detached a most fetid odour was exhaled. We have heard Dr. Polinière, administrator of hospitals, say that the smell was so strong as to remind him of a dissecting theatre or room. When the place was thus cleaned the epidemic ceased. After what we have said the reasoning is easy: in order to destroy the miasmas which cause the mephitism of the walls and ceilings of hospitals, the old mortar and plaster should be removed at times and disintegrated stones replaced, according to the recommendation of Legislator Lebrun.

"These measures are of great importance where any one suffering from phthisis, dysentery, cancer, gangrene, or other infectious maladies has lived for some time. In large towns, and especially in old quarters, the mephitism is endemic and may be recognized by any one."

The eminent English hygienist, Edwin Chadwick, C.B., in the concluding paragraph of his able report on Dwellings and their arrangement at the Paris Exhibition, 1867 (page 317), says :—

"On the whole, viewing collectively the various models and collateral appliances presented for examination in the present Exhibition, there will be found in it the means of very important advances in the improvement of the dwellings of the great mass of the people, in the means of relieving them from the cesspool smell or the bad drain or sewer emanations and smell, from the foul wall smell and from the wall vermin, from the damp wall, from the smoke nuisance, from a great proportion of the waste of fuel and the loss of heat, from stagnant and vitiated air, from deterioration of good water supplies, from much of the exclusion from sunlight; and it is proved that by new appliances their dwellings may be made cooler in summer and warmer in winter, and that, too, not only without any increase, but with a very material reduction of direct expense. I say of direct expense, because when the losses from excessive sickness, premature disability, and premature mortality are taken into account, a great portion of the common dwellings of the wage classes, though they may be cheap to construct, are indirectly and eventually dear to use. By dwellings with the improvements specified, the rates of insurance against sickness, disability and mortality would be reduced nearly one half. With clean, light, bright, warm, comfortable and healthful dwellings; with the habits of personal cleanliness, sobriety and frugality to which such conditions would conduce, new and improved populations would arise. To one accustomed to inspect town-schools in the lower districts, the comparative condition, external as well as internal, of the dwellings may, to a considerable extent, be inferred by the comparative aspect and condition of the children. Already, in neighbourhoods where partial sanitary improvements have been made for a few years, school teachers mark an improvement in the condition and quality of the children received from them, who are less squalid, less ugly and less vicious, and more apt for instruction. It is now generally admitted by all who have attended to the subject, that moral and social advancement is dependent on physical improvement, and that on the sanitary improvements of dwellings."

On the subject of cottage-building, the same authority in another part of his report (page 261) observes that:

"Those who visit the common crowded dwellings of the wage class in our towns, even when they are unoccupied, are aware that the walls have a peculiar depressing musty or fœtid smell. On visits after severe epidemic attacks, in some of these dwellings a peculiarly offensive smell has been perceived; and on inquiry what that could be from, the answer has been that it was the 'dead man's smell.' The dead body had been too long kept near the wall in a state of decomposition before it could be removed for interment, and the fœtor inhered to the wall. In the course of the service under the Public Health Act, when the occupiers were nearly all struck with fever, we have in some cases ordered all to be removed and the walls and ceilings to be limewashed. But it has occurred that the performance of this service has been obstructed or neglected with respect to particular houses; and in those alone, and with fresh occupants, the fever has broken out again, thus demonstrating the condition of the 'leprous house,' and the efficiency of the work of purification. Walls lathed, plastered and papered are even worse for such tenements. The laths rot, the size of the paper decomposes, and the paper itself harbours vermin. The condition of some houses of this construction is horrible. To admit of the cleansing of the walls by limewashing, in Miss Burdett Coutts's, in Mr. Peabody's, and in other model dwellings, the walls have not been plastered or papered. In some instances the sanitary orders are that the walls shall be limewashed twice, and in other instances as often as four washings a year are deemed necessary. The occupiers greatly dislike these bare brick walls. In new hospitals the evil is in a great measure prevented by facing the interior wall with some hard and smooth surface, generally of the best non-absorbent and washable cement. As a principle all interior cottage walls should be made washable. Besides the evil arising from absorbency of the animalized gases by walls of the common construction, there is another great source of evil attaching to walls of the common brick and the common soft stone construction—the absorbency or retentiveness of water or damp. In England the common bricks absorb as much as a pint or a pound of water. Supposing the external walls of an ordinary cottage to be one brick thick, and to consist of 12000 bricks, they will be capable of holding 1500 gallons, or 6¼ tons of water when saturated. To evaporate this amount of water would require nearly a ton of coal well applied. The softer and more workable stones are of various degrees of absorbency, and are often more retentive of moisture than common brick. Professor Ansted states that the facility with which sandstone absorbs water is illustrated by the quantity it contains both in its ordinary state and when saturated. He states that even granite always contains a certain percentage of water, and in the dry state is rarely without a pint and a half in every cubic foot. Sandstone, however, even that deemed fit for building purposes, may contain half a gallon per cubic foot, and loose sand at least two gallons. When water presents itself in any part of such material it readily diffuses itself by the power of capillary attraction, by which (it is observed in some walls in Paris) it ascends 32 feet from the foundations. Walls of such absorbent construction are subject to rising wet by capillary attraction, as well as to the driving wet of rain or storm. To guard against the driving wet on the coast, expensive external coverings (weather-slate) are used; but these do not stay the interior rising wet. This wet, having to be evaporated, lowers temperature; damp walls or houses cause rheumatism, lower strength, and expose the system to other passing causes of disease."

In London it is admitted that houses, even of the better class, cannot safely be inhabited in less than nine months. Indeed, registrars of deaths are aware that an extra death rate is, after all, usually attendant on their first occupation. The majority of bent figures in our villages are due to the infliction of rheumatism from damp.

An experienced traveller in England laid down a rule to avoid bedrooms with northern aspects, which, having less sun upon them, were, when unoccupied, the most damp, and if the bed touched the wall there was the most danger of a damp bed. To keep out the damp an extra quantity of fuel is necessary; the evil is the greater with the poor, who are often obliged to leave their rooms without the fires which the more wealthy are enabled to have kept up.

In Paris, notwithstanding its particularly dry subsoil and its drier climate, the sanitary or insanitary evils of the common architect's constructions appear to be even greater than in London. I was assured by a Parisian builder of considerable experience that it was unsafe to occupy any new house in Paris in less than a year after its construction, and that there were houses in Paris which would never be dry "in their lives" and would always afflict their occupants. In going over the new model dwellings for the Emperor we observed marks of damp upon some of the walls, though they had been erected nearly two years. The concièrge who showed them to us was suffering from a grievous rheumatic affection, and I was informed that the occupants had much illness amongst them from having occupied the houses "too soon."

These extracts show that the advantage of a house built of non-absorbent materials effects great pecuniary saving as well as securing the best conditions of health to their occupants. When built of good Portland cement concrete, no interval of time need elapse after the building of the house and its tenancy. The above extracts from such eminent and trustworthy hygienic authority deserves attention at our hands, and the facts adduced in support of the necessity of dry and non-absorbent houses and walls is incontrovertible.

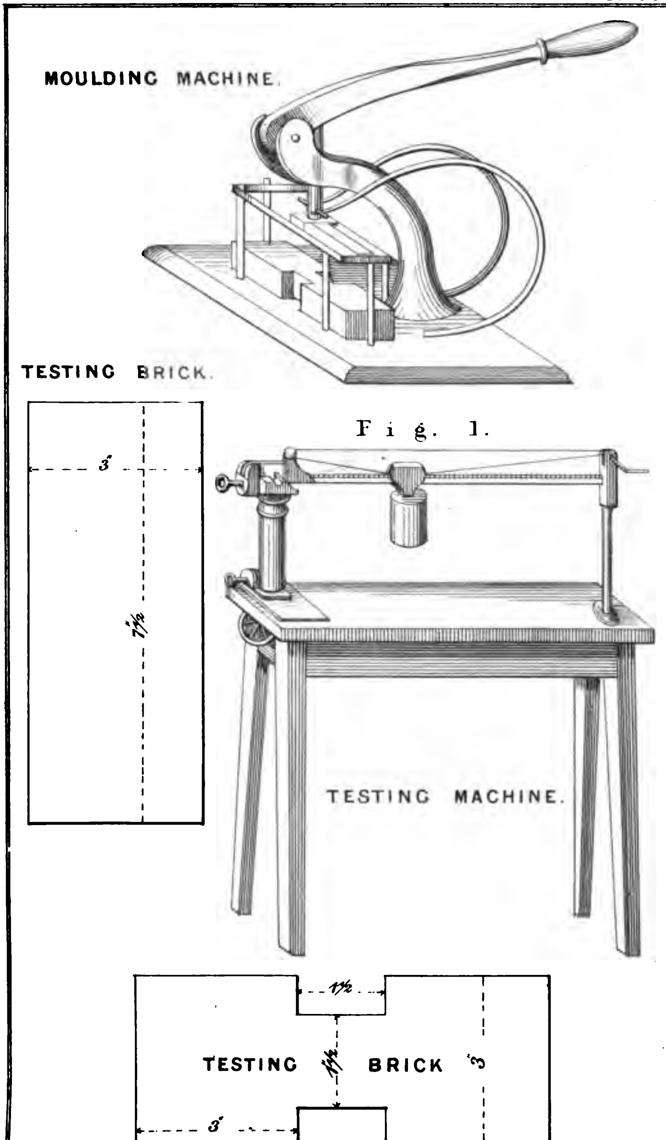
Much attention has been given of late years to the question of terra cotta and earthenware for purposes of construction —the former more particularly as a decorative agent, and the latter with reference to the wall and other more substantial parts of construction. The advance made in this direction is not, in England at least, satisfactory or encouraging. Beauty and accuracy of form in articles not requiring exposure to the vicissitudes of our climate can be readily secured; but when the necessary density is produced to withstand severe climatal influences it is obtained at a sacrifice of regularity of outline inconsistent with true architectural excellence. The cost of producing terra cotta renders its application prohibitory unless in pretentious buildings of importance, and then only as veneering aids to external or internal embellishments. It never can take an important position for general building purposes unless in the immediate neighbourhood in which it is manufactured. Cost of carriage and waste by breakage, with other minor objections, will prevent its general adoption now that the manufacture of Portland cement has attained so reliable a character. There is no kind or description of ornamentation now attainable by means of terra cotta which cannot more trustworthily be reached by Portland cement either in its pure state or in its various combinations of mortar and concrete. Accuracy and security of outline is unquestionably attained in the most satisfactory manner, and even the desired requirement of colouring is within the possibility of attainment. Another important advantage we may claim for Portland cement decoration is the facility of testing its value previous to any expensive outlay. Such a safeguard is not ordinarily possible in the case of terra cotta, where already in some of its recent decorative applications symptoms of disintegration are developed. Even the stone decorations of this country are liable to much deterioration in consequence of injurious atmospheric action. The natural tendency of stones to absorb moisture increases such damaging influence; for, in combination with the water so absorbed, there are conveyed in minute particles various chemical impurities which accelerate the process of disintegration and decay.

It is not contended that Portland cement, in its purest condition even, is perfectly non-absorbent, nor in its various mixtures free from such objections. Indeed, no mineral substance can be found possessing such perfection as the power of effectually and completely resisting prejudicial atmospheric influence. It may be safely advanced, however, that a good quality of ultimately hardened Portland cement concrete will absorb a minimum of moisture, fluctuating necessarily with the nature of the aggregate as well as the quality of the cement with which it may be incorporated. By experiments with a sample of first-class Portland cement, with which 100 parts of cement powder was mixed with 35 parts of water, it was found that 11¼ per cent. of it was retained in chemical combination with the cement to complete the final process of crystallization; proving that the amount of water rejected during the setting process was about two-thirds of that used in rendering the cement-powder plastic; shewing that a very small amount of latent moisture is retained in the hardened mass, and the quantity which it may afterwards be capable of absorbing will depend on the porosity of the concrete, the extent of which will indicate its capillary capacity. An unusually porous aggregate will be beneficially influenced by being mixed with Portland cement, as the silicates and aluminates will, when in a fluid state, fill its pores, rendering it less liable to absorb moisture. At this point of our argument we may fairly consider the relative merits of the monolithic and block-making systems of concrete building.

By the present imperfect system of mortar-making, it is usual to mix about equal volumes of cement and water, and as we find by experience that only one-third of the water remains permanently fixed in the hardened cement or concrete, it follows that two-thirds of the water has been evaporated, leaving its previously occupied space void. Thus a smaller quantity of water would proportionably reduce the vacant space, and consequently lessen the porosity of the mass, thereby improving its non-absorbent character. This result is consequent on the fact of Portland cement possessing the valuable property of retaining its normal shape, notwithstanding the ejection of the water of plasticity; different qualities of Portland cement requiring varying quantities of water. The light cements take more water than the heavy ones, and of course when thoroughly dried display greater porosity of texture; so that it is an advantage when a minimum quantity of water can be used with concrete. In monolithic building this desideratum is not attainable, as the frames are unable to resist the pressure which would be required to solidify a lightly-watered mass. Block making, however, developes to the utmost degree all the most valuable properties of the cement, which are secured by a minimum amount of moisture, as the strength of the moulds is able to withstand the utmost amount of pressure from the impingement of the rammers on the concrete mass. The "granita breccia" pavement previously referred to at page 44 is a good example of perfect blocks from the use of iron moulds. One other important advantage secured by the use of moulds is in being able to use a larger amount of gravel or other aggregate, as there is no necessity to remove the blocks for some days after they are moulded.

THE END.

Plate 1



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Newbery & Alexander, lith. 43, Castle St. Holborn.

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HORSE MORTAR MILL USED AT FORT WARREN. U.S.

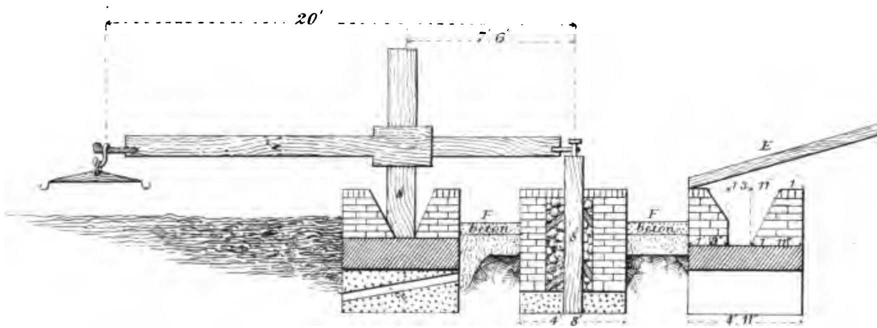

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Plate III.

MORTAR MILL USED AT THE DRAINAGE WORKS, BOULEVARD DE SEBASTOPOL, PARIS.

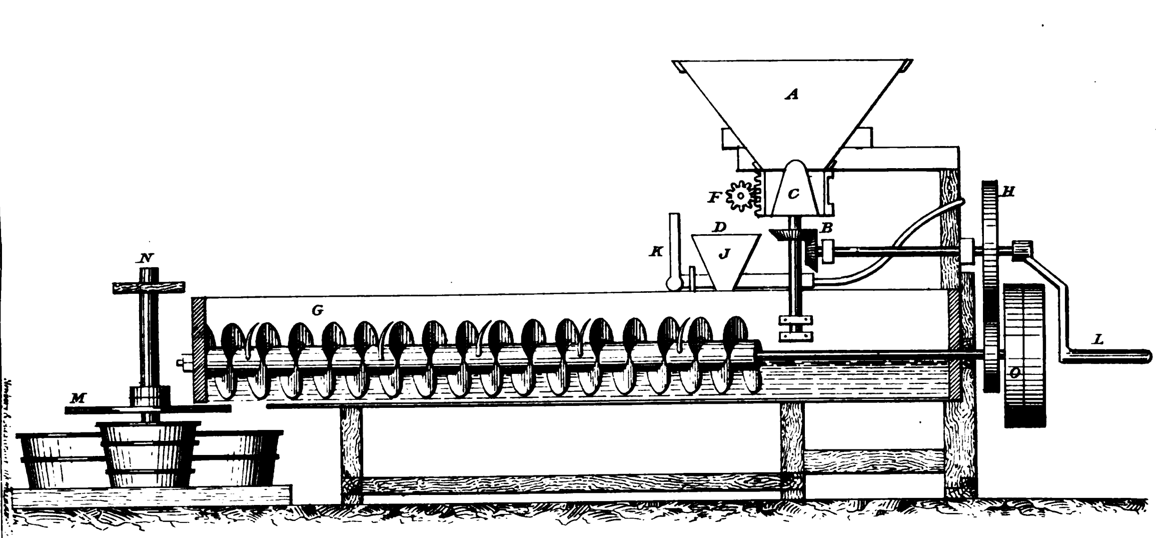

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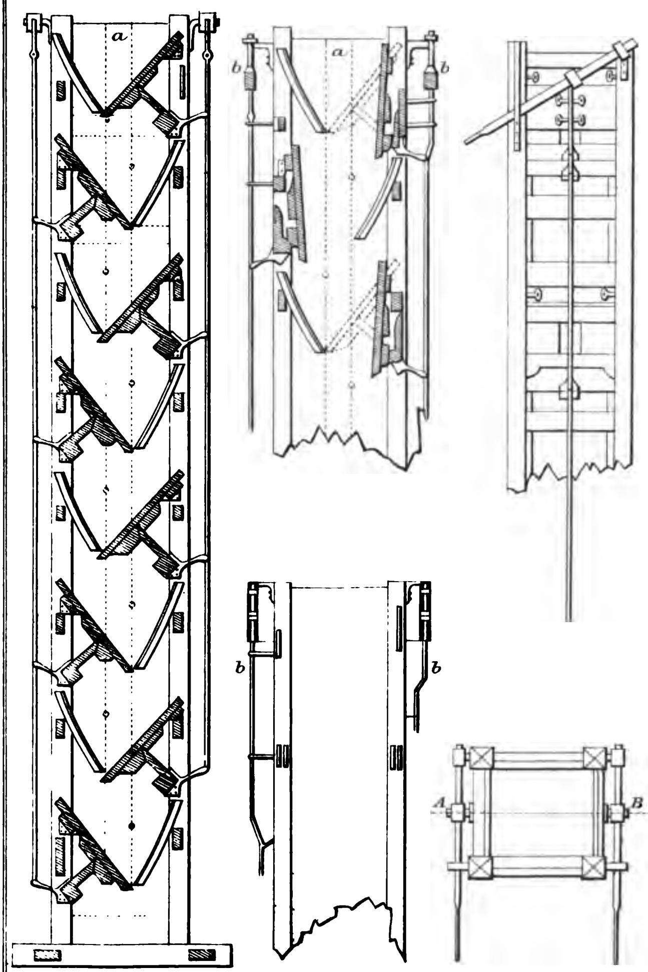
Plate IV

CONCRETE MIXING MACHINE.



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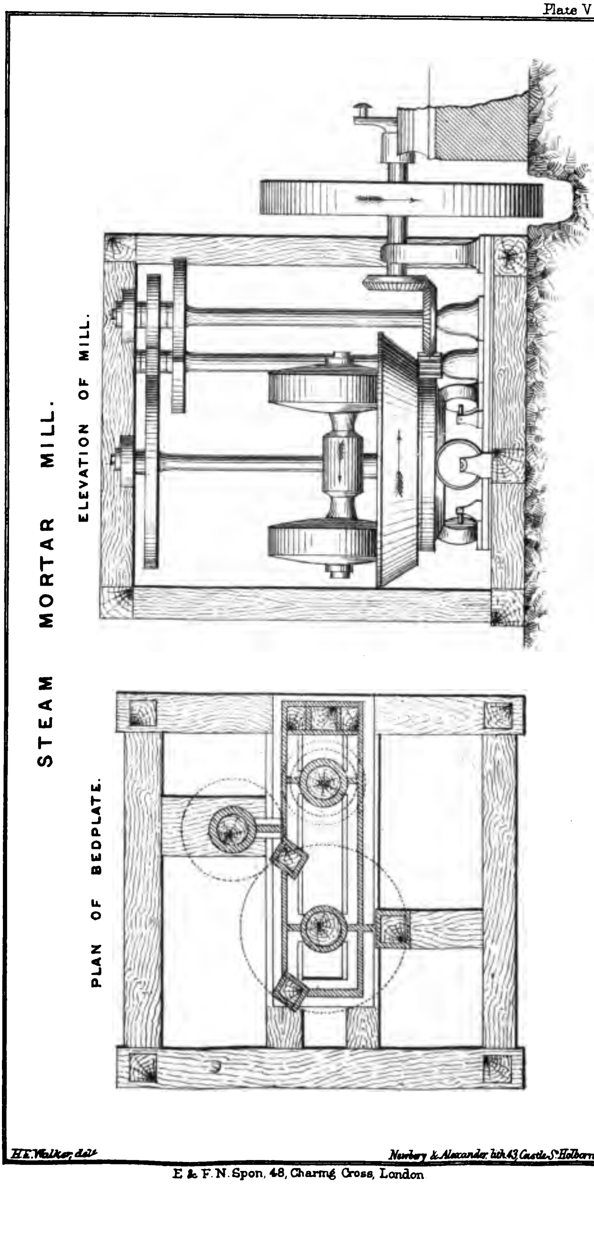

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