POPULAR HAND BOOK FOR CEMENT AND CONCRETE USERS

A COMPREHENSIVE AND POPULAR TREATISE ON THE PRINCIPLES INVOLVED AND METHODS EMPLOYED IN THE DESIGN AND CONSTRUCTION OF MODERN CONCRETE WORK.

A Standard Reference Book Covering the Uses of Plain and Reinforced Concrete. Everything of Value to the Concrete User is Given, Including Kinds of Cement Employed in Construction, Concrete Architecture, Inspection and Testing, Waterproofing, Coloring and Painting, Rules, Tables, Working and Cost Data.

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PREFACE

ALTHOUGH the literature of cement and concrete has expanded enormously during the past few years, it is, nevertheless, the conviction of the Publishers that there is still a place for a semi-popular book of this general type. Many of the technical works are either high in price or contain a great deal of theory, or devote so many pages to academic discussions of points, not yet settled by current practice, as to be imperfectly adapted to the wants of the non-technical reader.

On the other hand, with few exceptions, the popular books on the subject contain no systematic treatment of the subject of design, and fail to give any conception of the costs of different types of construction.

To compile material, all of which shall possess some definite value; to explain the principles of design and methods of construction in concise and, so far as possible, non-technical language; to describe the variation of costs for different kinds of concrete work; to give the reader a handbook that will prove interesting as well as useful; to bring home the great economic and artistic qualities of concrete as a building material; and finally to help in producing a better, higher grade of concrete work: these are the criteria which have helped to shape the character of this book, criteria difficult to satisfy and impossible of complete attainment. Just how far these purposes have been carried out can only be left to the judgment of the readers to decide.

In the preparation of the text, many sources of information have been consulted, including the standard text books on the subject, the published transactions of the American Society of Civil Engineers, the American Society for Testing Material, and the National Association of Cement Users; also recent files of the *Engineering News*, *Engineering Record*, *Engineering-Contracting*, *Cement Era*, and other periodical literature. Particular acknowledgment is also due to the publications of the Atlas Portland Cement Co., for many suggestions, tables, and other valuable data. The bulletins of the Universal, American, Vulcanite, and Edison Cement Companies have also been freely drawn upon.

In the preparation of the manuscript many suggestions were also received from individual sources, and particular acknowledgment is due to the following engineers, for valuable contributions and advice:

Mr. Reginald Van Deerlin, C.E., Chief Engineer Hennebique Construction Co.; Mr. James G. Ray, C.E., Consulting Reinforced Concrete Engineer; Messrs. Edmund P. Murray, C.E.; S. B. Balland, C.E.; and L. B. Manheimer.

The authors would also be glad to receive and to acknowledge, in future editions, further suggestions, criticisms, cost data, or examples of recent practice from any of their readers.

They especially solicit cost data in connection with all kinds of concrete work, and will acknowledge and publish same in future editions of this book.

Myron H. Lewis,

February, 1911. Albert H. Chandler.

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CHAPTER I

INTRODUCTORY

The Renaissance of Concrete.—The Concrete Age.—Concrete Architecture.—Concrete Literature.—The Future of Concrete.

The Renaissance of Concrete.—The history of concrete is a history of an ancient and highly developed art, long lost and forgotten during the dark centuries of the middle ages, and having a new awakening and renaissance nearly two thousand years later. Some of the costly and magnificent structures of concrete built by the Romans during the period of their supremacy still remain as time-defying evidence of their great skill as constructors, and as monuments to the utilitarian character of their art. As a seed planted in an arid soil springs to life at the first visiting of rain, so has concrete been born anew in the twentieth century when the state of industrial and constructive art became favorable to its development; and with such new life, it has reached a much higher state of development, and attained a wider application and a more permanent place in our civilization than was ever dreamed of by our Roman predecessors.

How broadly concrete has entered into our modern lives has been well put by Kerwin in an address before the National Association of Cement Users in the following words:

The Concrete Age.—"Our ancestors progressed from the Stone Age to the Iron Age; we seem to be passing from the Steel Age to the Cement Stone or Concrete Age. We tread on concrete walks, travel in concrete subways, over concrete bridges, live and work in concrete buildings, store our grain in concrete elevators, draw our water from concrete reservoirs and cisterns, sanitate our cities with concrete sewers, and are finally buried in concrete cases deposited in concrete tombs, and our numerous virtues are inscribed on concrete monuments."

It is certainly well that this development has come at a time when our rapidly disappearing forests have given serious alarm as to our future supply of timber, and what a boon the concrete industry will be to humanity and civilization throughout the world, cannot be appreciated so well to-day as it will years hence when the supply of timber has fallen far below the normal requirements.

Mr. Andrew Carnegie is probably best known as a philanthropist interested in education and free libraries, but it should not be forgotten that he is also probably the greatest living authority on questions relating to the production of steel, and that any statement made by him relating to the position of steel should carry great weight.

At the recent conference of governors and scientists at the White House, Washington, which was held under the chairmanship of ex-President Roosevelt, there was a discussion on the conservation of the natural resources of the United States, in the course of which Mr. Carnegie, speaking of iron, said:

"The next great use of iron is in construction, especially of buildings and bridges. Fortunately the use of concrete, simple and reinforced, is already reducing the consumption of structural steel. The materials for cement and concrete abound in every part of the country; and while the arts of making and using them are still in their infancy, the products promise to become superior to steel and stone in strength, durability and convenience, and economy and use."

For a great steelmaker to announce his conviction that concrete promises to become superior to steel and stone in strength, durability, convenience, and economy, is indeed a matter that should claim the attention of our economists.

The period of the most rapid development of the concrete industry was inaugurated when the value of the combination of steel and concrete was recognized. This combination, fortunate as Carnegie says, opened up a field of unlimited usefulness and gave to our civilization a new material, possessing nearly all the virtues of the materials hitherto employed in construction and few of their defects, and so superior in strength, heat-resisting, and other qualities as to make its universal adoption a matter of certainty.

Concrete Architecture.—It was at first these utilitarian qualities that were recognized and made use of by engineers, but another great step forward was taken when the artistic and æsthetic possibilities of concrete were recognized by architects and builders.

The recognition thus accorded has given the latter what it had sought almost in vain for centuries—a new style of architecture; a style entirely free from the hereditary tendencies of the ancient and mediæval styles, and which could be rendered possible only by the introduction of a new material, possessing properties entirely distinct from those whose possibilities had been studied and studied for ages. The essential features of the new style, which will be distinctive of the early years of the present century, are pointed out under the section on Concrete Architecture.

Concrete Literature.—Another potent influence in the modern development of concrete work is the broad-mindedness and liberality of the manufacturers of cement and cement products, in bringing home to the public the many marked advantages and possible uses of cement and concrete. Foremost in this class are the many publications of the Atlas Portland Cement Co., the excellence of which, from a typographical, authoritative, and readable standpoint, cannot be overestimated, and in the preparation of this volume the Authors have availed themselves of the Company's kindness in permitting them to extract a number of excellent tables and illustrations from their various publications.

The excellent series of bulletins issued by the American Association of Portland Cement Manufacturers are another source by means of which a wide dissemination of knowledge of the possibilities of cement has been effected, and from which the Authors have drawn some valuable material.

A great deal has been contributed to the industry by the numerous organizations formed for the promotion of knowledge on cement and concrete work. The cement shows held in various parts of the country during the past few years have also given an acceleration to the development of the industry. The proceedings of the

National Association of Cement Users at their Conventions during these shows have been brimful of new ideas and their annual bulletins have preserved the best of these for future reading and study. The Authors have also used these books in drawing material for this volume.

The cement and concrete press of the country have done a great work in spreading widely the gospel of concrete, defending it against attacks by its older but worried competitors and keeping the building public informed of the latest developments in this rapidly growing field.

The Future of Concrete.—Many other influences have contributed to the growth of the concrete industry and these are discussed in the appropriate sections of the book. No doubt the future will witness many new contributing causes, and there is every reason for believing that the future holds out the most brilliant prospect for this apparently homely but invaluable building material.

We can prophesy that future ages will be grateful to the present one for the renaissance of concrete, for with it, as time goes on, will come more beauty in our structures, more healthful conditions of life resulting from the sanitary nature of the material, more buildings of historic fame, and temples far more creditable to our architecture; for when the present monumental structures of timber, steel, and iron shall have succumbed to the corroding hand of time, our concrete structures, built of more enduring stuff, will still live and endure to tell the story of the rebirth of concrete in the twentieth century.

CHAPTER II

.KINDS OF CEMENT AND HOW THEY ARE MADE

Common Lime.—Lime Mortar.—Hydraulic Lime.—Puzzuolana.—Hydraulic Cements. —Theory of Setting.—How Natural Cement is Made.—How Portland Cement is Made.—White Portland Cement.—Slag Cements.—Plaster Cements.—Choice of Cements.—How Portland Cement Comes.

Limes and cements which are used to unite brick, stone, and concrete are nearly all derived from the roasting of pure and impure limestones and can be grouped into three classes.

1. Common, fat, or quick lime, which hardens in air.

2. Hydraulic lime, which hardens in air when slaked, and sets on the addition of water, either when exposed to the air or submerged.

3. Hydraulic cement, which, when water is added, sets either in air or under water and acquires great strength.

Common Lime.—Common lime is a combination of calcium and oxygen, and is obtained by driving off carbon dioxide gas from limestone. When it contains not more than about 12 per cent of impurities, it has the property of absorbing water with great avidity.

The process of absorption of water is accompanied by a great rise of temperature, by the evolution of hot and slightly caustic vapors, and finally by the reduction of the lime to a powder. The powder thus formed is called **slaked lime,** and the operation of adding water to quicklime is thus known as **slaking.**

Good lime comes in hard lumps, and contains but little dust. When slaked, its bulk increases from 2½ to 3½ times its original volume, while the amount of water which it will absorb is nearly 1/4 of its weight.

When just enough water is added to lime to cause it to slake, it forms a powder; when more water is added it forms a paste. Lime mortar is made by mixing the paste of slaked lime with sand, and is extensively used in the building trades.

The ordinary method of slaking lime consists in first placing the lumps in a layer, 6 or 8 inches deep, in either a water-tight box, or a basin formed in the sand, and then pouring upon the lumps a quantity of water equal to 2½ to 3 times the volume of the lime.

In slaking lime, it is important that enough water be added, but not too much. If too much is added, the slaked lime is reduced to a semi-fluid condition. If not enough, the addition of water during the slaking chills the lime and renders it granular and lumpy. Covering the bed of lime with a tarpaulin or with a layer of sand retains the heat and accelerates the slaking. All the lime necessary for any required quantity of mortar should be slaked at least one day before it is incorporated with the sand.

Lime Mortar.—The paste of slaked lime is mixed with from 2½ to 3 volumes of sand to form mortar. Sand is used to reduce the cost, and to prevent the mortar from cracking. It also causes the lime paste to spread out in thin films around each grain and thus enables it to harden. Too much sand should not, however, be used, as it tends to make the mortar porous.

The hardening of lime mortar is a double process and consists of:

1. The formation of crystals, as the lime gradually dries out.

2. The slow formation of carbonate of lime or limestone through the absorption of carbonic acid from the air.

Lime mortar acquires strength only by the absorption of carbonic acid. This is a slow process, and does not take place unless there is a free circulation of air to carry the carbonic acid to the mortar. Hence in a thick wall, lime mortar will harden only after the lapse of years or perhaps never.

Lime mortar can neither harden nor acquire strength when used under water or in soil that is constantly wet, because slaked lime cannot crystallize until it dries out, and it cannot absorb carbonic acid when submerged.

Lime mortar is also weak, because the absorption of carbonic acid is a very slow process, especially in the interior of the mass. The surface hardens, but the interior remains soft. The carbonic acid penetrates about 1/10 of an inch into the joint the first year, forming a skin or film which opposes its further absorption, except at a decreasing ratio. So slow is its penetration after the surface film has formed, that the Scotch have a proverb, "When a hundred years are past and gane, then gude mortar turns into stane."

Hydraulic Lime.—Hydraulic lime is obtained by roasting a limestone which contains from 15 to 25 per cent of silica and alumina.

In hydraulic limes, there are two principal constituents:

1. Free slaked lime; 2. Lime chemically combined with silica and alumina.

When a limestone containing silica and alumina is roasted, the two latter elements combine with a portion of the lime, forming silicates and aluminates of lime. The rest remains as free lime in an uncombined state.

When treated with water the free lime is slaked. The action is, however, retarded by the silicates and aluminates, and is much less energetic than that of fat lime. When mixed with water to form a paste, hydraulic lime can be used in the same way as common lime. When so treated the free slaked lime in its composition dries, hardens, and slowly absorbs carbonic acid on exposure to the air. The free lime also causes it to crack when used without sand, but the swelling and cracking are much less pronounced than in the case of fat limes.

When used in water or in damp places, the actions of common and hydraulic limes differ greatly from each other. While common lime remains soft, hydraulic lime sets with more or less rapidity. Its property of setting is due to the crystallization of the combined lime, the free lime being inert if not actually washed away by the action of the water. The crystallization of the combined lime and consequent hardening of the mortar is identical with the reactions which take place in hydraulic cement. Hydraulic lime is, however, much inferior to cement in respect to reliability and strength, and is in consequence but little used in the United States.

Hydraulic lime is commonly slaked at the manufactory and shipped in the form of powder. It may be kept without injury in this form if covered and protected from the air.

Puzzuolana.—The term "Puzzuolana" is commonly applied to a class of materials which, when made into a mortar with either fat or feebly hydraulic lime, impart to the lime the property of setting on the addition of water. This set will take place both when submerged and when left exposed to the air.

Puzzuolana is a material of volcanic action, which derives its name from Pozzuoli, a city of Italy near the foot of Mount Vesuvius, where its properties were first discovered. It was extensively used by the Romans in their hydraulic constructions, being pulverized and mixed with slaked lime and a small amount of sand for the formation of hydraulic mortar.

HYDRAULIC CEMENTS

Hydraulic cements, which are the kinds used in concrete construction, may be classified according to the method of manufacture, under three general headings:

1. **Portland cements.**
2. **Natural cements.**
3. **Puzzolan or slag cements.**

The term **Portland cement** is commonly used to designate hydraulic cement formed by burning a mixture of limestone and clay in proper proportions to the point where they begin to fuse or melt. The materials then combine chemically and form a hard clinker, which when ground to a powder acquires the property of setting under water.

The term **Natural cement** is commonly employed to designate a large number of widely varying products formed by burning natural rock without pulverization or the admixture of other materials. When thus roasted a clinker is formed, which when ground to a powder acquires the property of setting under water. The materials used for this purpose are limestones which contain silica, alumina, and iron oxide in quantities greater than would be needed for Portland cement.

There are many brands of natural cement. Perhaps the most familiar are Rosendale, Utica, Akron, and Roman cements.

Puzzolan or Slag Cements are formed by the admixture of slaked lime with ground blast-furnace slag. The slag has approximately the composition of a hydraulic cement, but lacks a proper proportion of lime to give it the property of setting under water. These cements are sometimes called puzzolana cements, on account of their resemblance to the Puzzolana of Italy.

The Setting of Cement.—When cement powder is mixed with water to a plastic condition, a chemical action takes place which causes the materials to solidify or *set*.

The setting of cement, according to the general theory, is probably due to the action of water in releasing the lime from its chemical union with alumina. This free lime, the moment that it is liberated, is in solution in the water, but owing to the rapidity with which it is liberated the water soon becomes supersaturated with hydrated lime, and the latter crystallizes out in a network of crystals which binds the particles of undecomposed cement together. This action causes the first hardening, or *initial set*, as it is called.

After the initial set has taken place, cements slowly increase in strength. The final hardening is due to the slower liberation of lime from its union with silica. This lime also crystallizes out and the network of crystals so formed also serves as a binder to hold the particles together. Hydraulic cements increase in strength with time, the increase extending over months or even years. This increase is due to the slow setting of the coarser particles.

The whole subject of cement setting is, however, yet in a controversial stage. Dr. Michaeles, one of the world's leading cement experts, does not accept the *crystallization* theory, but advocates what is termed the *colloidal* theory or the formation of mineral glue in the process of hardening. While to many the theory of setting appears to have only a passing value, the question is really of great importance to the cement manufacturer, as the process, if the colloidal theory were true, could be much simplified and the cost of manufacture largely reduced.

HOW CEMENTS ARE MADE

The difference between Portland, Natural, and Slag cements is best illustrated by comparing their methods of manufacture as described in Table I.

Manufacture of Natural Cement.—Natural cement is produced by the burning at low heat and subsequent pulverization of natural limestone, no preliminary mixing or grinding being required. This natural limestone is composed of an argillaceous carbonate of lime containing varying amounts of silica, alumina, and iron oxide. In the process, the carbon dioxide of the lime stone is almost entirely driven off and the silica, alumina, and iron oxide unite with the lime to form various compounds. When this burned mass is finely ground to a powder and mixed with water it hardens or sets, either in air or under water.

TABLE I.—OUTLINE OF PROCESS OF MANUFACTURE OF HYDRAULIC CEMENTS

Portland Cement.	Natural Cement.	Slag Cement.
1. Grinding of raw materials. 2. Proportioning and mixing. 3. Burning. 4. Grinding of the clinker.	1. Burning of the natural rock without pulverization. 2. Grinding of the clinker.	1. Cooling of hot blast-furnace slag by sudden immersion. 2. Grinding. 3. Mixing with slaked lime.

Quarrying and Crushing.—Since the rock in its native state contains the proper proportion of the ingredients for natural cement, it is only necessary to break up the quarried rock into convenient sizes and load it into the kiln. In order to insure uniformity of product, it is common practice to mix rock from various layers in the quarry, so that the deficiency of any element in the rock from any particular stratum may be corrected by a corresponding excess in another stratum. The rock is broken up in ordinary rock crushers and conveyed either by belting or tramway to the loading platform at the top of the kiln.

Burning and Grinding.—The kiln used in the manufacture of natural cement is usually of the vertical continuous mixed-feed type and is built of masonry or iron lined with fire brick. The crushed rock and the fuel, which may be either anthracite or bituminous coal of good quality, are spread in the kiln in alternate layers and the mass is burned at an average temperature of about 1,600° F., depending upon the character of the rock. After removal from the kiln the mass is sorted, all underburnt and overburnt clinker being rejected. The material thus rejected usually represents about one-fourth of the total. The calcined rock is then crushed in a pot crusher or other rotary type, and screened. The finer materials are removed to the bins, while the coarse particles go through a further process of grinding. The product then passes to mixers, by means of which a uniformly fine product is assured.

From the storage bins the material is passed through chutes, and then to the bags or barrels in which it is packed for final shipment.

Manufacture of Portland Cement.—Portland Cement is produced by burning to incipient fusion, a mixture of finely ground argillaceous and calcareous material, and the subsequent pulverization of the clinker thus obtained. It will be seen, therefore, that Portland cement differs from natural cement not only in the character of the raw material employed, but also in the quantity of heat required in its manufacture.

The Raw Materials.—The materials should contain approximately the following quantities of the essential ingredients:

Silica, 21–24 per cent; alumina, 6–8 per cent; lime, 60–65 per cent; with small amounts of iron oxide, magnesia, sulphuric and carbonic acids, and water. These materials may be either limestone and clay, marl and clay, chalk and clay, or cement rock and limestone, the last named being the most commonly used.

Processes.—The method of mixing of the raw materials in preparation for their calcining has given rise to two processes, known as the *wet process* and *dry process* respectively.

The first is best for soft or wet material such as marl and clay, or chalk and clay. The combined mass is mixed in a vat or wash mill with a large excess of water. The lumps are broken up with agitators and the particles are so finely divided as to be held in suspension by the water. The stuff is then drawn off into a settling basin and the resultant slurry moulded into bricks which are dried and finally calcined in stationary kilns. Owing to the introduction of rotary kilns, the above method has been, to a great extent, superseded by a semi-wet process which is substantially as follows:

The Semi-wet Process.—The marl or chalk is passed through a disintegrator and run into storage basins, while the clay is dried and pulverized and mixed with the proper proportion of marl in pans, enough water being added to give the mass a thick, creamy consistency. The wet mixture is then ground either in a pug mill or edge runner and run into slurry tanks, where it is constantly stirred by means of pedals or compressed air. The wet slurry is then pumped directly into rotary kilns and burned at a high temperature.

The rotary kiln consists of a brick-lined steel cylinder varying from 50 to 200 ft. in length and from 5 to 12 ft. in diameter. By means of appropriate machinery it is slowly rotated at an average speed of one revolution a minute. The cylinder is usually slightly inclined to the horizontal so as to facilitate the movement of the material to the point of discharge. The raw material is introduced at the upper end, and in passing through, it is calcined to all *clinker*, leaving the kiln at the lower end as hard, glassy lumps ranging from sand to pieces one inch in diameter. The fuel used is generally finely pulverized coal, which is blown in at the lower end, forming a sheet of flame extending through the cylinder. When properly burned, the clinker should appear in the form of an irregular ball of greenish-black color, with faint metallic lustre, and contain but few large pieces.

This clinker, red hot when it emerges from the rotary, drops into a conveyor which passes under water jets, cooling the clinker. When thoroughly cool, the clinker passes to the crusher and is then ready for grinding. The material undergoes a preliminary grinding which reduces it to a fineness such that it will pass through a No. 20 or 30 sieve. This is usually done by the ball-mill. A second grinding renders the material fine enough for 90 per cent to pass through a No. 100 sieve, this finer grinding being accomplished by either a tube-mill, Griffin mill, or Lehigh Fuller mill.

The powder is then conveyed to a stock-house and seasoned for a time, and finally passes into the discharging bins whence it is weighed out into bags or barrels as required for shipment.

The Dry Process.—In the dry process, the material is conveyed from the quarry to the mill and is crushed to pieces varying from dust to two inches in diameter. It is then placed into storage bins and the proper proportions decided upon by chemical analysis of samples taken from various portions. An extremely accurate mixture is obtained by using an automatic weighing machine of the tandem type. The mixture is conveyed to a dryer which usually consists of a rotary cylinder worked on the same principle as the rotary kiln, heat being supplied by a small furnace. The temperature is sufficiently high to cause all moisture to be driven off. The material is then ground to a fineness which will permit it to pass through a screen having 20 or 30 meshes to the linear inch; then is passed on to the fine grinder where it is still further reduced until from 80–90 per cent will pass a screen of 100 meshes to the linear inch. From the grinding machines, the finely powdered material is conveyed to bins from which it is automatically fed into the rotary kiln for calcining; the roasting to a high temperature and the subsequent grinding of the clinker thus formed being the same as in the *semi-wet* process already described.

White Portland Cements.—Within recent years Portland cements of pure white color have come into the market. Such cements cost about four times as much as ordinary Portland, owing to the expense of manufacture. They are, however, so well adapted to the attainment of architectual and artistic effects as to have come into extensive use for the following purposes:

1. Building ornamentation.—For exteriors, steps, railings, columns, doorways, windows, casings, cornices, and panels.

2. Stucco.

3. Concrete building blocks.

4. Interior Decoration. Staircases, wainscoting, panels, reliefs, floors.

5. Statuary.—An improved substitute for plaster in reproducing statuary figures and groups for galleries of casts, or exterior and interior decoration.

6. Cemetery Work.—For monuments, vaults, columns, urns, etc.

7. Parks and Grounds.—For fountains, seats, railings, walks, bridges, etc.

8. Tile, Mosaic, etc.—In the production of white or delicate tints and as a cement in place of Keene's cement.

9. Colored Concrete.—Permits the use of bright or delicate colors.

10. Painting iron work or concrete.

11. Stainless mortar. For laying up Bedford limestone, sandstone, or marble.

12. Setting and pointing between blocks or slabs of white marble, limestone, or brick.

White cement is mixed with white sand, crushed white quartz, ground marble (not dust), or ground white limestone to produce white concrete or white artificial stone. For the development of this material, credit is due to the Sandusky Portland Cement Co., and to the Vulcanite Cement Co., who are the pioneers in its production.

Slag or Puzzuolan Cement is produced by the mixture of granulated blast-furnace slag and slaked lime, and the reduction of the mass to a fine powder.

Slag of proper composition, as it comes from the blast furnace, is sprayed with a stream of cold water under pressure; the water granulates the slag and also combines with the elements contained therein, causing evolution of sulphuretted hydrogen and the formation of lime. The slag is dried and then ground, first in a Griffin mill and then in a tube-mill. The lime is burned from very fine limestone, slaked, screened, and dried, and is then incorporated with the slag. The resulting material is fine enough to permit 95 per cent passing through a No. 200 sieve. Caustic soda is added during the slaking of the lime in order to produce a quick-setting cement.

Plaster Cements.—The activity of the cements previously discussed is presumably due to the formation of crystals containing lime and water. There is another class of cements, the activity of which is due to the crystallization of lime, water, and sulphur when chemically combined. This substance is called calcium sulphate or gypsum. When heated and reduced to powder, it is known as *plaster*, *plaster of Paris*, and *white cement.*

Plaster is used for interior walls, ceilings, and decorations; also for reproducing works of marble, pottery, and bronze. Plaster is either quick or slow setting. The former, when mixed with its own weight of water, sets in five minutes, while the latter, under similar conditions, takes fifteen minutes. Plaster heated to redness and mixed in the ordinary manner, will no longer set; but if, instead of applying a large quantity of water, the smallest possible portion is used, it will set in ten to twelve hours, and become extremely hard.

The compressive strength of plaster is about 120 lbs. per sq. in. Plaster adheres to itself better than to stone or brick. The adhesion to iron is from 24 to 37 lbs. per sq. in.

The quality of plaster may be tested by simply squeezing it with the hand. If it coheres slightly, and keeps in position after the hand has been gently opened, it is good; but if it immediately falls to pieces, it has been injured by damp.

Plaster forms the basis of many white cements, which are usually laid in two coats; the first of cement and sand is about 1/2 to 3/4 in. thick. The second coat is thinner and is composed of neat cement without the admixture of sand.

Portland cement with a large proportion of sand, as much as 90 per cent being used, is useful for interior work. It may be used as a backing for a thin floating of the white cements. White Portland cements are also used as a final coat where great durability and strength are required.

Among the best known gypsum cements are Parian Cement, Keene's Cement, Martin's Cement, and Adamant. These all have plaster of Paris for their base, and are eminently suited to interior work. They can all be brought to a good surface, and can be painted.

Parian Cement is hard and quick-setting and well adapted to withstand rough usage. Keene's Cement is harder than the other kinds made from plaster of Paris, and is much used for pilasters, columns, etc.

At the present time Portland cement almost exclusively is used for exterior plastering and stucco work.

Choice of Cements.—The selection of the proper grade of cement to be used in any given structure is, to a great extent, dependent upon the character of the work. That cement should be selected which will give the best and most permanent results consistent with the limits of cost of the work in question. A few general rules may be formulated for guidance in making a selection.

Portland Cement should be used in mortar and concrete for structures subjected to severe or frequently recurring stresses; for all work laid under water or which will come into contact with water immediately after placing; for masonry exposed to the action of the elements. The White Portland is eminently fitted for high-class ornamental work as already stated.

Natural Cement may be used in concrete for dry unexposed foundations with moderate compression; for backing or filling in massive concrete or stone masonry; for sewer foundations and for sub-pavements of streets. It is also adapted for use in mortar, for ordinary brick work, and for ordinary stone masonry where the chief requisite is weight or mass. It should *never* be used in work under water, in marine construction, in columns, beams, floors, or other members subjected to severe or suddenly applied stresses. *Puzzolan or Slag Cement* is limited to use in sea water, and generally to structures constantly exposed to moisture, as foundations of buildings, sewers and drains, and in the interior of heavy masonry or concrete. It is unfit for use when subjected to mechanical wear, abrasion, or blows, and should never be used where it may be exposed to the action of dry air for long periods. Under such conditions it will turn white and disintegrate, owing to the oxidation of its sulphides at the surface.

Hydraulic Lime is extensively employed on the Continent, especially in France, in the form of Beton-Coignet (a mixture of hydraulic lime with sand and cement).

Common Lime mortar is usually limited to brick work and to chimney construction in frame houses.

Lime and Cement Mortar is suitable for ordinary brickwork, for light rubble foundations, and for building walls.

Portland cement, owing to its greatly superior strength and reliability, is rapidly displacing all other kinds of cement, and it will continue to do so even more rapidly as its cost is lowered. In the following chapters, Portland cement is always referred to unless another is specifically mentioned.

How Portland Cement Comes.—Portland cement comes in paper bags, cloth sacks, or wooden barrels. The best way to handle it for the average user is in cloth sacks. The manufacturers charge more for this kind of a package, but allow a rebate for the return of the empty bags. The bags must be kept dry and untorn, and shipped back by freight, in exact accord with the requirements of the cement company. Paper bags tear too easily and cause a big percentage of loss, especially on small jobs where any carrying has to be done. Barrels are too bulky to handle easily and are too large a unit for measuring. The weight of the shipping units of cement varies slightly, but in general a paper or cloth bag contains 95 lbs. of cement, and four such bags make a barrel of 380 lbs.

How to Keep Portland Cement.—Cement must be stored in a dry place. It absorbs moisture from the atmosphere with great readiness, and soon becomes lumpy, or even a solid mass, when kept in a damp place. Such cement is useless and must be thrown away. Lumpy cement should not be broken up and used again, even if this can be readily done, as it has lost by far the greater part of its adhesive value. In storing cement, throw wooden blocks on the floor, place boards over them, and pile the cement on the boards, covering the pile with canvas or pieces of roofing paper.

CHAPTER III

PROPERTIES, TESTING, AND REQUIREMENTS OF HYDRAULIC CEMENTS

Description of Tests.—How the Tests are Made.—Standard Requirements for Natural and Portland Cements.

Properties of Hydraulic Cements.—The properties of a cement which are usually examined to determine its constructive value, are: first, color; second, weight; third, activity; fourth, soundness; fifth, fineness; and sixth, strength.

Color indicates the thoroughness of burning and the presence of impurities. With Portland cement, gray or greenish-gray is an indication of good quality. A yellowish shade indicates underburned material; bluish-gray an excess of lime; and brown, an excess of clay. For decorative purposes, white Portland cements, having all of the properties of gray, are also employed. In these the color does not indicate any inferiority in strength or setting power.

Natural cements are generally brown, in light or darker shades. A light color generally indicates an inferior underburned rock.

For any particular cement the **weight** varies with the degree of heat in burning, the degree of fineness in grinding, and the density of packing. Other things being the same, the harder-burned varieties are the heavier. The finer a cement is ground, the more bulky it becomes, and consequently the less it weighs. Hence light weight may be caused either by laudable fine grinding or by objectionable under-burning.

A barrel of Portland cement, containing 3.8 cu. ft., should weigh about 380 pounds net; natural cements weigh from 250 to 300 pounds net per barrel.

The **activity** of a cement is determined by its rate of setting. For most purposes, where immediate setting is not required to prevent disturbance of the mortar before hardening, the moderately slow-setting cements are found most convenient, as they need not be handled so quickly and may be mixed in somewhat larger quantities.

Soundness is the most important quality of a cement, as it means the power of the cement to resist the disintegrating influences of the atmosphere or water in which it may be placed. Soundness refers to the property of not expanding, contracting, or cracking during the time of setting. These effects may be due to free lime, free magnesia, or to unknown causes.

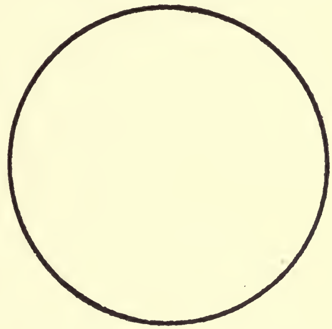

FIG. 1.—Showing Normal Cement Pat in Good Condition. (After W. Purves Taylor.)

The question of **fineness** is wholly a matter of economy. Cement, until ground, is a mass of partially vitrified clinker, which is not affected by water, and which has no setting power. It is only after it is ground that the addition of water induces crystallization. The coarse parts of the cement may be considered as practically inert material which sets only after the lapse of months or years if at all. It is the impalpable powder which gives the cement its value, and if this be omitted, the cement is worthless.

FIG. 2.—Pat Showing Shrinkage Cracks Due to Overwet Mixture or Too Rapid Drying.

It is possible to reduce a cement to an impalpable powder. Fine grinding is, however, expensive. The proper degree of fineness is reached when it becomes cheaper to use more cement in proportion to the aggregate, than to pay the extra cost of additional grinding.

The **strength** of cement is usually determined by submitting a specimen of known cross-section to a tensile strain. The reason for adopting tensile tests is that comparatively light strains produce rupture. This will be referred to later.

HOW CEMENT IS TESTED

Having outlined the nature and properties of hydraulic cements, we now propose to take up the methods that may be employed by the cement user to determine whether the material he purchases is up to the standard and fit for use.

The testing of cement for use on extensive work has become an art in itself and only men experienced in the work can obtain results that are uniform and reliable. It is therefore not intended to go into details of apparatus and methods employed by the skilled

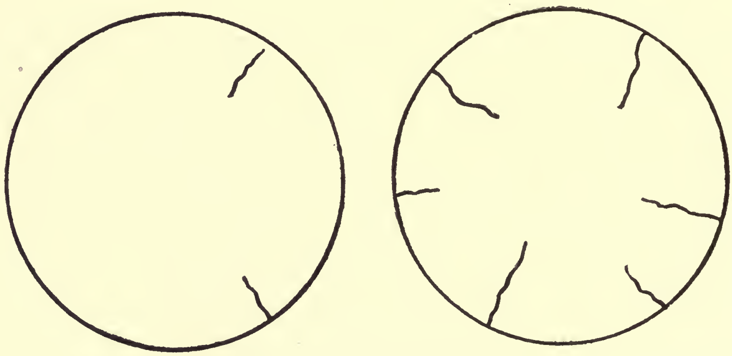

Fig. 3.—Pats Showing Cracks Due to Incipient Disintegration and which Warrant Rejection.

tester which are of little use to the practical cement user, but an idea of what is done is of general interest.

Physical Tests for Cement.—On all large works, an inspector is kept at the mills to watch the process of manufacture, and special laboratories are provided for making both chemical and physical examinations. As already stated, the physical examination is employed to determine whether the cement possesses the necessary requirements to make it fit for use. Thus a good cement:

First.—Should be sufficiently well ground. This is referred to as a test for fineness and is made by passing the cement through sieves of varying meshes. In a good Portland 98 per cent should pass through a No. 100 sieve, having 10,000 holes to the square inch. The finer the cement is ground the greater will be its hydraulicity, and the greater the proportions of sand that can be used with it.

Second.—Setting.—Cement which sets much too rapidly or does not set rapidly enough may not be fit for use. This may be due to the presence of too much gypsum or the cement may not be sufficiently hydraulic. Furthermore, a quick-setting cement may be desired for certain work and slow-setting for other. To determine the setting properties it is customary to prepare pats about 3 inches in diameter and 1/2 inch thick in the middle and with thin edges on glass plates, and allow them to set. When the pat just resists the pressure of a needle $\frac{1}{12}$ inch in diameter weighted with 1/4 pound it is said to have had its *initial set.* This is usually within 1/2

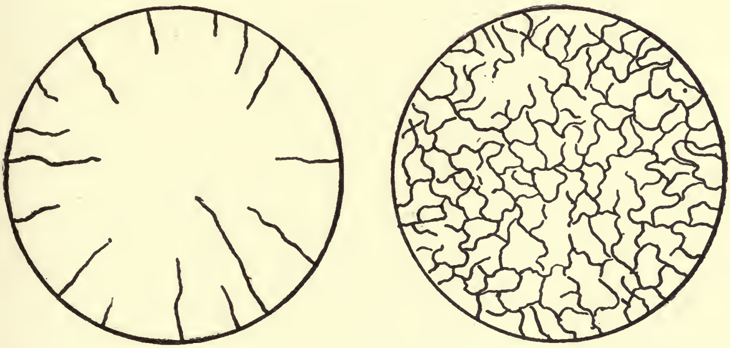

FIG. 4.—Pats Showing Cracks of Complete Disintegration which Begin by the Radial Cracks Shown in Fig. 3.

hour to 1 hour and the process of manufacture may be regulated to obtain the required time of initial set for the work in hand. Cement for use under water or in freezing weather should be quick-setting. When cement has once received its initial set after being mixed for use, it should not be remixed with water or retempered for use, as the setting properties and strength have been greatly disturbed, although when hardened cement is reground it still possesses considerable setting power. The *final set* of cement occurs when it can just resist the pressure of a needle 1/24 inch in diameter weighted with 1 pound. The time of final setting varies from 3 or 4 to 10 hours; the quick-setting cements are usually stronger at first, but the slower-setting cements acquire greater strength than the others in course of time.

An excellent method of testing for setting is to prepare a ball of cement and allow it to set protected from sun and wind. At the end of 20 minutes it should be soft and pliable, damp and not warm on exterior surface. At 10 hours it should be dry, firm, and hard enough to resist pressure of thumb nail. If it hardens or heats in less than 20 minutes the cement should be rejected, as it will set before the concrete is put into place. A cement which will not set in 10 hours will cause difficulty in placing the concrete and a satisfactory cement should set within these limits.

The heating referred to is due to free lime and, if in excess, the cement should not be used. Storage will convert the free lime into a hydrated condition in time, and it can then possibly be used.

Both the pat and ball tests are also serviceable in determining the presence of free lime. This free lime causes heating when mixed with water and also expands in volume, causing cracking of the pat or ball. When used in the work, over-limed cement may cause disintegration.

The *presence of free lime* can better be determined by subjecting the pat or ball to a hot steam bath for an hour or two, after which it should still remain sound and free from cracks. The presence of lime may also be determined by treating the cement with muriatic acid 3 parts, water 1 part, cement 1/3 part. A good cement will effervesce about two seconds. If it effervesces continually it contains too much limestone or natural cement and should not be used.

Cement in the laboratory is also subjected to what is known as the "Specific Gravity" test made by special apparatus and not available to the cement user on the work. The usual specific gravity of a good Portland is about 3.2. A much greater value shows overburning and a lower quantity indicates underburning or adulteration.

The test most frequently quoted is that for *tensile strength* which, like the previous one, cannot usually be made by the cement user, as time and apparatus are required, while uniform and reliable results depend upon the skill and experience of the tester. The tests are made by moulding briquettes into shape like a figure 8 having a cross-section in the centre of exactly 1 square inch. These briquettes are allowed to set either 1, 7, or 28 days and sometimes for even longer periods running into many years. They are then broken in testing machines. The briquettes are made both of pure cement and of cement mortar mixed with varying proportions of sand. These tests are of value because long years of experience have fixed certain values which a good cement should obtain and although pure cement is little used in practice, a standard is thus fixed which serves as a basis of comparison for different cements.

Tests are also made on large works by moulding beams, slabs, blocks, and columns of various mixtures of concrete, which are later subjected to special machines, and broken by bending, shearing, or compression, and the actual strength determined.

It is proper to say here that to the credit of American cement manufacturers, the consumer need have but little fear of the quality of the cement he uses. The great bulk of cement of any of the standard brands will pass the ordinary requirements. Moreover the cement work in most structures is never subjected to anything like the stresses that the strength tests show it is able to withstand. It is only in work where very high unit stresses are employed, such as in reinforced concrete structures that the actual strength of the material is really approached. It is due largely to the uniformly good quality of cement turned out that the greatest confidence has been established in the mind of the consumer as to its use without testing, and it is due largely to such confidence that the cement industry owes its rapid growth, for without it the present phenomenal expansion would have been impossible.

The ordinary cement user should be particularly careful about two things in a newly received shipment of cement. In times of great building activity when the cement mills are run up to full capacity, there is danger of having the cement too fresh, and in such cases he should order it a month or so ahead of time so as to improve it by storage as already referred to. The second thing is to see that the cement has not been injured in transit or storage, for if dampness has reached the cement it will be lumpy and partially set and its usefulness be largely destroyed.

REQUIREMENTS FOR CEMENTS

The following are the requirements for natural and Portland cement prepared by the National Association of Cement Users, after an exhaustive study of the subject.

STANDARD REQUIREMENTS FOR NATURAL CEMENT

Definition.—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

Fineness.—It shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve.

Time of Setting.—It shall not develop initial set in less than ten minutes, and shall not hard set in less than thirty minutes, or in more than three hours.

Tensile Strength.—The minimum requirements for tensile strength for briquettes one inch square in cross-section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	*Strength, Lbs.*
24 hours in moist air	50–100
7 days (1 day in moist air, 6 days in water)	100–200
28 days (1 day in moist air, 27 days in water)	200–300

ONE PART CEMENT, THREE PARTS STANDARD SAND.

7 days (1 day in moist air, 6 days in water)	25– 75
28 days (1 day in moist air, 27 days in water)	75–150

Constancy of Volume.—Pats of neat cement about three inches in diameter, one-half inch thick at centre, tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another is kept in water maintained as near 70° F. as practicable.

These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, should remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

STANDARD REQUIREMENTS FOR PORTLAND CEMENT

Definition.—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

Specific Gravity.—The specific gravity of the cement ignited at a low red heat shall not be less than 3.10; and the cement shall not show a loss on ignition of more than 4 per cent.

Fineness.—It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

Time of Setting.—It shall not develop initial set in less than thirty minutes; and must develop hard set in not less than one hour, nor more than ten hours.

Tensile Strength.—The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	*Strength, Lbs.*
24 hours in moist air	150–200
7 days (1 day in moist air, 6 days in water)	450–550
28 days (1 day in moist air, 27 days in water)	550–650

ONE PART CEMENT, THREE PARTS SAND.

7 days (1 day in moist air, 6 days in water)	150–200
28 days (1 day in moist air, 27 days in water)	200–300

Constancy of Volume.—Pats of neat cement about three inches in diameter, one-half inch thick at the centre, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another is kept in water maintained as near 70° F. as practicable and observed at intervals of at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for five hours. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no sign of checking, cracking, and disintegrating.

CHAPTER IV

CONCRETE AND ITS PROPERTIES

What Concrete Is.—Kinds of Concrete.—Function and Effect of the Cement, Aggregates, Water, Chemicals, Weather Conditions, Gases, Sewage, etc.—Laws of Strength and Permeability.

CONCRETE is an artificial rock, made by uniting sand, broken stone, gravel, etc., by means of lime or cement. Its principal ingredients are as follows:

1. The matrix or mortar; consisting of cement and sand mixed with water.

2. The coarse aggregate; broken stone, gravel, etc.

Concrete made with good Portland cement, in proper proportions, becomes so hard and strong that when pieces are broken, the line of fracture will often be found to pass through the particles of stone, showing that the adhesion of the cement to the stone is greater than the strength of the stone itself.

Kinds of Concrete.—While concrete is generally composed of cement, sand, and broken stone or gravel, the following special combinations are also used:

1. Rubble concrete, also called Cyclopean masonry.
2. Cinder concrete.
3. Asphalt concrete.
4. Reinforced concrete.

In constructing massive walls and dams, a reduction in cost may often be obtained by introducing large stones into the concrete. Concrete of this character is called *Rubble Concrete* or *Cyclopean Masonry.* The percentage of rubble stones employed varies from a few per cent to over half the volume. The saving effected comes partly from the reduction in the cement required per cubic yard of concrete and partly from the saving in crushing.

Cinder concrete is used where great strength is not required. Its most valuable properties are its light weight and the resistance which it offers to heat. It is therefore used for fireproofing and light floor construction.

Cinder concrete is weak and porous. It is not adapted to reinforced work because it is so porous that it does not protect the steel from corrosion. When used, great care must be taken in the mixing and proportioning of the ingredients. A rich mixture of cement should always be required.

Asphalt or *tar concrete*, in which broken stone or cinders are mixed with asphaltum or tar instead of cement paste, is used for

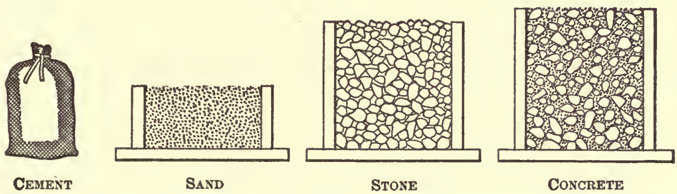

FIG. 5.—Relative Proportions of Ingredients for a 1 : 2 : 4 Concrete Mixture. Note that the volume of Concrete is but slightly larger than the volume of Stone, the Cement and Sand filling the voids.

waterproofing and for lining reservoirs and constructing mill floors. Such mixtures differ in degree only from the asphaltic cements that are employed for street pavings. Their most valuable properties are, imperviousness to water and elasticity.

Reinforced concrete, in which concrete is combined with steel or iron to develop the elastic properties of the latter and at the same time utilizing the great compressive resistance of the former. This is fully discussed in Chapter XVI and those following.

FUNCTION AND EFFECT OF VARIOUS AGENCIES ON CONCRETE WORK

In considering the properties of concrete and how it is affected by various agencies, it is well to keep clearly in mind what concrete actually is and what its constituent parts actually are. The sand and gravel is natural rock disintegrated by natural forces. The broken stone is natural rock disintegrated by artificial forces. The water is just ordinary H_2O which is clean and free from acids or alkalis. The cement has already been described.

An ideal concrete is a mixture with a minimum percentage of voids. This result is obtained by grading the aggregate and mixing in such proportions that the voids in the coarsest aggregate are filled by a finer aggregate, the voids in which are, in turn, filled by a still finer aggregate, the cement itself being so finely ground that its granules will completely coat those of the finest aggregate. When this condition obtains, the set will produce a mass of everlasting stone.

Many experiments have been made to show the effect on the strength of concrete of the admixture of various materials such as loam, clay, lime, plaster, peat, puzzolan, cement, salt, sawdust, soda, sugar, alcohol, glycerine, and tallow. While some valuable practical use is made of such admixtures, the results are largely of theoretical interest.

Cement is the vital element of concrete. Upon its quality the strength and durability of the concrete largely depends. It binds the particles of aggregate together, helps to fill the voids, gives density, and according to its strength or weakness, imparts like qualities to the concrete.

Influence of the Aggregates.—Crushed quartz, crushed brick, crushed terra cotta, crusher dust and sand have all been used as the finer aggregate in concrete, the use of sand being most prevalent.

While the properties and selection of sand are fully discussed in the next chapter we may state here that sand should be coarse rather than fine, and of graded rather than of uniform size in order that a dense concrete shall result. It is customary to specify that sand shall be free from clay or loam. In a rich mortar, the surplus cement furnishes enough fine material for the density required. The addition of clay tends to increase the density and the strength, particularly in lean mixtures. Five per cent may be allowed. A similar effect is produced by the addition of a small quantity of hydrated lime or waterproofing compound to cement mortar, the density and water-tightness being increased.

For the coarse aggregate a variety of materials are in common use. Crushed stone, such as trap rock, granite, limestone, conglomerate, sandstone, and slate, also gravel and cinders, give satisfaction. Trap and granite give a hard wearing surface to the concrete, and are useful as aggregates in all classes of concrete work. Gravel and conglomerate are almost equally valuable. These are fully discussed in Chapter V.

Function and Influence of the Water.—The function of water in mixing concrete is to develop the chemical activity of the cement. The proportion of water used has an important bearing on the results attained. Both the time of setting and the strength are affected. A very fine cement will require a larger proportion of water than a coarser cement, in order to give the same degree of consistency. Too little water will produce a weak mortar, as part of the cement will be unaffected. Too much water will cause a slight decomposition of the cement, some of which will pass off in solution, and thus weaken the mortar. The phenomenon of "Laitance" is the result of an excess of water. This is particularly noticeable when concrete is deposited under water, a white scum appearing at the surface.

"The effect of different proportions of water upon the ultimate strength depends chiefly upon the density of the resulting mortar; the consistency which produces with a given weight of the same materials, the smallest volume, after setting, of Portland cement paste or mortar, gives the highest strength. Dry-mixed mortars usually test higher than wet after short periods, as they set and harden more rapidly, but more uniform results in practice can be attained with plastic mixtures."

Experiment has shown that coarse, medium, and fine sand require respectively 3 per cent, 9 per cent, and 23 per cent by weight of water. "In many classes of structures where there is an excess of strength, cheapness in placing, the appearance of the surface, or the proper inbedding of reinforcing metal may be of primary importance. In such cases the quantity of water must be suited to the attendant conditions."

Dry concrete may be employed in dry locations for mass foundations, which must withstand severe compression strain within one month after placing, provided it is carefully spread in layers not over 6 inches thick and thoroughly rammed.

Medium wet concrete is adapted for ordinary mass concrete, such as foundations, heavy walls, large arches, piers, and abutments.

Very wet concrete is suitable for rubble concrete and for reinforced concrete, such as thin walls, columns, floors, conduits, and tanks. *Grout* or *liquid concrete* is discussed in Chapter XXXI.

Effect of Coloring Matter.—Various coloring matters, such as carbon black, iron oxide, ochre, ultramarine, marble dust, and white sand are used in concrete for æsthetic effects. As a rule, the color is not permanent. The effect of these ingredients upon the strength of the concrete varies with the material used. They may be mixed dry with the cement and then submitted to the usual tests. If of mineral origin, their addition in small quantities will not affect the concrete. They rather increase its density. If of vegetable origin, they are apt to impair the strength. In general, it is safe to specify that coloring matter shall be made from metallic oxides free from sulphur. Five per cent of materials of a mineral character may be allowed.

Effect of Oils.—Mineral oil when mixed with concrete forms an emulsion with the alkali and water, resulting in a less brittle mortar and one much more free from expansion and contraction cracks. The oil also has the effect of delaying the initial and final set somewhat and of decreasing the strength to a small extent. The use of animal or vegetable oils is not recommended, because the result is the formation of acids, which are apt to cause disintegration of the concrete. Oil emulsions have formed the basis of many waterproofing compounds and when mineral oils are used they add to the density and quality of the work.

Fire-resisting Properties.—Concrete possesses great fire-resisting properties. In a severe fire when subjected to a heat as great as 2,000° F., concrete is injured to a depth of perhaps one inch, its body being unaffected. Two inches of good concrete is ample protection against fire for I-beams or steel rod reinforcements. "When brick and terra-cotta are heated, no chemical action occurs, but when concrete is heated up to 1,000° F., its surface becomes decomposed, dehydration occurs, and water is driven off. This process takes a relatively great amount of heat. It would take about as much heat to drive the water out of this outer quarter inch of the concrete partition, as it would to raise that quarter inch to 1,000° F. Now a second action begins. After dehydration, the concrete is much improved as a non-conductor, and yet through this layer of non-conducting material must pass all the heat to dehydrate and raise the temperature of the layers below, a process which cannot proceed with great speed."

Effect of Weather Conditions.—Heat hastens and cold retards the set of cement. Therefore, a quick-setting cement should be employed in winter and a slow-setting cement in summer. The sun's heat will cause too rapid evaporation which must be guarded against as it weakens the concrete.

Severe cold or frost rarely causes greater damage than surface disintegration. The setting process discontinues at freezing, but starts again when the temperature rises above the freezing-point. This does not injure the concrete, but merely prolongs the attainment of its ultimate strength. *Alternate freezing and thawing, however, absolutely ruin concrete.*

Salt water, up to a 10-per-cent solution for concrete, delays the set, but does not weaken the concrete. If a stronger solution is used the salt is apt to work to the surface and cause unsightly stains.

Effect of Sea Water.—Sea water is objectionable for gauging mortars and concrete not because of its salt, but because the magnesium sulphate in water reacts chemically with the lime in the cement, forming various compounds and resulting in the gradual rotting of the cement and the eventual failure of the concrete. A dense concrete protected from the action of the sea water until the cement has thoroughly set is in little danger of injury.

Some concrete masonry has remained intact for a very long time in sea water; on the other hand, structures subject to similar conditions have been ruined in a few years. Experience has shown that the cement for use in marine construction should be as low as possible in aluminum and lime. Puzzolan material is a valuable addition to the cement, as it unites with the lime to form insoluble compounds upon which the sulphuric acid of the sea water finds difficulty in making an impression. As little gypsum as possible should be added for regulating the time of setting. Sand containing a large proportion of fine grains is unsuitable altogether, as the per cent of voids is dangerously large. The concrete should be proportioned to secure as great a density and impermeability as possible, thereby excluding chemical action from the interior of the mass.

Effect of Gases, Acids, Sewage, etc.—Gases have little or no effect upon the durability of the concrete, unless the peculiar character of the aggregate happens to have a chemical affinity for the particular gas to which it is subjected. Certain surface effects have been noted in concrete arches and tunnel linings, which have been exposed to the hot gases from passing locomotives, but in no case has the integrity of the concrete mass been threatened. The great objection to gases is the resulting disfigurement of the surface.

Strong acids will affect a concrete surface, but with a silicious or igneous aggregate, the effect will be a slight surface etching. Marked disintegration has been noted in concrete exposed to certain kinds of sewage. The conditions favoring disintegration are alternate immersion of the concrete surface in the sewage and exposure to the air. Sewage contains large amounts of sulphuretted hydrogen in solution. When the level of the liquid falls, it leaves the concrete wet with this solution, which may cause oxidation and disintegration.

Alternate rise and fall of the liquid level erodes the decomposed cement and exposes new concrete to the attack of the acid. The effect being cumulative, the integrity of the concrete mass is eventually threatened. These effects will not be found unless the sewage in question is of a highly corrosive character, and where there is no free air supply to induce rapid oxidation.

Here, as in previous cases, disintegration will not occur in a dense and waterproof concrete, only slight surface injury being possible. (See Chapter XXX.)

The following comments on this subject appeared in *Engineering Contracting* of June 15, 1910:

"Failures recorded chiefly in Montana and Colorado demonstrate with certainty that concrete can be completely disintegrated by alkali water and that no brand of cement is less susceptible to damage than others. They also show conclusively two other facts: (1) That porosity of the concrete increases the chances of disintegration and, (2) that porous brick and porous stone suffer equally.

"The alkali solution must penetrate the concrete if it is to be dangerous. It is known, however, as certainly as may be, that the condition of porosity is essential to the disintegrating action of alkali whether the material be concrete or brick or stone. The obvious preventative is, then, to provide against the penetration of the concrete by the destructive salt-laden water, and this brings us around to the undetermined problem of making an impermeable concrete.

"There are cases where an acid water or an acid sewage has destroyed a cement structure by contact, and also cases where such a contact in no way injured the structure, but where serious injury has been caused by gases above the waters after escaping from them; so that, in one case the cement has deteriorated only below the water surface, and in the other it has deteriorated only above it.

"The preventative, as in the former case, if practicable, is to exclude the objectionable element, or to give the cement a protective coating or lining.

"The effects of the gases produce an entirely different condition. The most serious of these is that of the sulphuretted hydrogen which may be converted into sulphuric acid in the sewer above the water. This acid transformed the carbonate of lime in the cement joints into sulphate of lime, a soft, friable gypsum, which gradually caused the complete destruction of the binding quality of the mortar.

"In this case, no doubt, a good forced ventilation might have prevented the formation of sulphuric acid, or the sewer might have been given a vitrified lining, or it may be possible to apply a coating which will protect sewers from this sort of destruction.

"Structures have been protected against injury from sulphuric acid and other organic acids in peat or similar soils by a complete covering of three layers of asphalt paper.

"The foregoing data seem to indicate the following inferences:

"1. When the immediate agent of destruction is carried by water, disintegration will be found below the permanent water surface. If such water is flowing inside of a structure, as in a sewer (acid or alkali factory waste), the disintegration will be inside and as far as the water penetrates the material. If the water is ground-water in alkali soil, swamp, or peat, the disintegration will be on the outside and chiefly between high and low ground-water levels, and may penetrate porous material toward the inside of the structure.

"2. When, on the other hand, the agent of destruction is caused by gases (generally sulphuretted hydrogen), arising from waters, whether on the outside or the inside of a structure, the disintegration will take place above the permanent water surface."

Strength of Concrete.—The strength of concrete as has already been stated, depends upon the mixture employed, character of mixing, care in placing and protecting the work, and upon the age of the concrete.

The strength of plain concrete is principally in resisting compression or crushing forces, and in this direction it can withstand very heavy loads, 500 lbs. per square inch being an average safe working value, which is used in computations for various purposes.

While it possesses a good deal of resistance to tensile stresses, it is not economical to employ concrete when such stresses are to be taken care of. As will be seen later, steel performs this duty admirably and in the combination of the two, an excellent new material results, possessing the combined virtues of both.

The loads which can safely be placed on concrete structures of various kinds are discussed in the respective chapters of the book.

In 1904 and 1905 the Aqueduct Commissioners of New York had an elaborate series of tests made on the strength of concrete, and the following laws were deduced relative to strength and permeability of concrete.

1. The largest size stone makes the strongest concrete under both compression and transverse loading, *i.e.*, an aggregate whose maximum size stone is 2 1/4 in. diameter gives stronger concrete than an aggregate with 1 in. maximum size, and the 1-in. stone gives a stronger concrete than a 1/2-in. stone.

2. The largest stone makes the densest concrete. Concrete made with stone having a maximum diameter of 2 1/4 in. is noticeably denser than that with 1-in. stone, and this is denser than that with 1/2-in. stone.

3. Round material like gravel gives under similar conditions a denser concrete than broken stone.

4. Sand produces a denser concrete than screenings when used with the same proportions of stone and cement.

5. Cement, sand, and gravel concrete is stronger than concrete of cement, screenings, and broken stone, probably because of this greater density. Concrete of cement, sand, and broken stone, however, is found to be stronger than concrete of cement, sand, and gravel, although the latter mix is denser, thus indicating a stronger adhesion of cement to broken stone than to gravel.

6. In ordinary proportioning with two given kinds of aggregates and a given percentage of cement, the densest and strongest mixture is attained when the volume of the mixture of sand, cement, and water is so small as to just fill the voids in the stone. In other words, in practical construction use as small a proportion of sand

and as large a proportion of stone as is possible without producing visible voids in the concrete.

7. Permeability or rate of flow through concrete is less as the per cent of cement is increased, and in very much larger inverse ratio.

8. Rate of flow is less as the maximum size of the stone is greater. Concrete with maximum size stone of 2 1/4 in. diameter is in general less permeable than one with 1-in. diameter maximum stone, and this is less permeable than one with 1/2-in. stone.

9. Concrete of cement, sand, and gravel is less permeable—that is, the rate of flow is less—than concrete of cement, screenings, and broken stone.

10. Concrete of mixed broken stone and sand is more permeable than concrete of gravel and sand, and less permeable than concrete of broken stone and screenings, which indicates that for water-tightness less cement is required with rounded sand and gravel than with broken stone and screenings.

11. The rate of flow decreases materially with age.

12. Rate of flow increases nearly uniformly with the increase in pressure.

13. Rate of flow increases as thickness of concrete decreases, but in a much larger inverse ratio.

CHAPTER V

SAND, BROKEN STONE, AND GRAVEL FOR CONCRETE

Selection of Sand.—Tests for Sand.—Washing Sand.—Mixture of Bank Sand and Gravel.—Broken Stone.—Gravel.

THE importance of selecting good aggregates for concrete is second only in importance to the selection of cement, forming as it does by far the greater part of the structure. The gradation in size, proportioning, etc., of these materials, which is treated later, have, as has been seen, an important bearing upon the density and economy of the work and all reasonable means should be taken to secure as good material as is available.

Selection of Sand.—The value of sand for concrete depends largely on its coarseness, graduation in size of the grains, and cleanliness. Fine sand contains more voids, more surfaces to coat, and requires more cement and water than coarse sand.

The sharpness of the grains of sand has little to do with its value. It has commonly been supposed that sand should be sharp. This, however, is one of the theories which have been exploded. In fact, there are many arguments in favor of coarse, round-grain sand. Compactness is what is desired, giving density to the mortar; round grains compact more readily than sharp grains, and the cement will cling to the surface of round grains as well as sharp grains, the character of the surface being identical. Sharp sand is only of value as indicating a silicious sand.

Good sand cannot be easily defined, or an inflexible specification written, as sands of various properties may make equally good concrete. All things being equal, a coarse sand containing a large percentage of coarse particles is far superior to a fine sand in which few coarse particles are present.

The best sand is that which, when mixed with cement and water in the required proportions by weight, produces the least volume of mortar. Economy can be practised in the matter of the selection of sand. It will nearly always pay the concrete constructor to haul sand even from a considerable distance, paying a higher price, provided he cannot get a sand in the immediate locality of the work, which sand is so graduated in size of grains as to give the greatest density.

Sand containing vegetable matter is of doubtful quality, as a small quantity may sometimes prevent hardening. The kind of impurity is really of more importance than the quantity.

How to Test for a Clean Sand.*—Two rough tests are as follows: (*a*) Pick up a double handful of moist sand from the bank; open the hands, holding them with the thumbs up; rub the sand lightly between the hands, keeping them about 1/2 inch apart, allowing the sand to slip quickly between them. Repeat this operation five or six times, then rub the hands lightly together so as to remove the fine grains of sand which adhere to them, and examine to see whether or not a thin film of sticky matter adheres to the fingers; if so, do not use the sand, for it contains loam. A further test is to scrape some of this matter from the fingers on the end of a penknife and take a little of it between the teeth. If it does not feel gritty or sharp it indicates vegetable loam, which is bad. Do not use this sand, or if no other can be obtained test it further to make sure that there is not sufficient loam present to prevent the cement from getting thoroughly hard.

The sand for the test given above must be moist, just as it comes from the bank. When dry the dirt will not stick to the fingers, hence this test cannot be used. Some idea can be obtained, however, by the appearance of the sand, even if it is dry. If it looks "dead," an appearance which is caused by the particles of dirt sticking in little lumps to the grains of sand, sometimes also making the grains of sand stick together in little bunches when picked up, it is almost a sure sign of vegetable matter, and the sand should not be used. Fine roots in a sand will also indicate the presence of vegetable matter.

(*b*) Make up two 6-inch cubes of concrete, using the same cement and the same sand and gravel or stone as will be used in the structure to be built, and mixing them in the same proportion

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* From "Concrete Construction about the Home and on the Farm," published by The Atlas Portland Cement Co.

and of the same consistency. Keep one block in the air out of doors for 7 days and the other in a fairly warm room.

The specimen in the warm room should set so that on the following day it will bear the pressure of the thumb without indentation, and it should also begin to whiten out at this early period. The specimen out of doors should be hard enough to remove from the moulds in 24 hours in ordinary mild weather, or 48 hours in cold, damp weather. At the end of a week, test both blocks by hitting them with a hammer. If the hammer does not dent them under

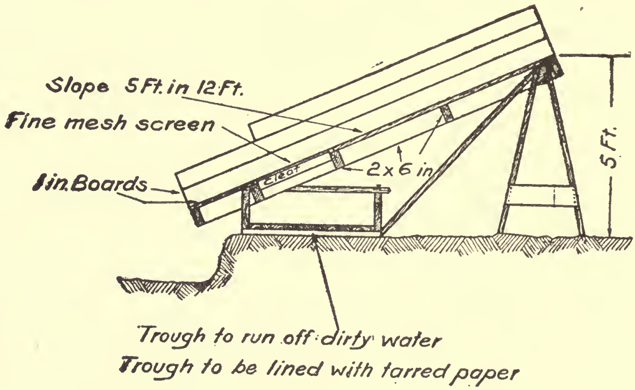

FIG. 6.—Washing Trough for Sand and Gravel.

light blows, such as would be used for driving tacks, and the blocks sound hard and are not broken under medium blows, the sand, as a general rule, can be used.

How to Wash Sand.—Sand cannot be washed simply by wetting the pile of sand with a hose, for this only washes or transfers the dirt to a lower part of the pile. Sand, provided it is not too fine, can be satisfactorily washed, however, by making a washing trough. For sands a screen with 30 meshes to the linear inch is necessary to prevent the good particles from passing through it. This must be supported by cleats placed quite near together, or it will break through. The sand is shoveled on to the upper end of the trough by one man, while another one can wash it with a hose. The flow of water will wash the sand down the incline, and as the sand and water pass over the screen the dirty water will drain off through the screen, leaving the clean sand for use. By this arrangement the dirt which is washed out cannot in any way get mixed with the clean sand.

Natural Mixtures of Bank Sand and Gravel.—Very often the sand and gravel found in a bank are used by inexperienced people, just as it is found without regard to the proportions of the two materials. This may be all right in some cases, but generally there is too much sand for the gravel or stone, so that the resulting concrete is not nearly as strong as it would be if the proportions between the sand and gravel were right. It is better then to screen the sand from the gravel through a 1/4-inch sieve, and then mix the materials in the right proportions, using generally about half as much sand as stone. By so doing a leaner mix can be used than where the sand and gravel are taken from the bank direct. The cost of the cement saved will more than pay for the extra labor required to screen the material. For example: Using even a very good gravel bank, a mixture one part cement to four parts natural gravel must be employed instead of one part cement to two parts sand to four parts of screened gravel. So much more cement is thus required with the natural gravel that a saving of one bag of cement in every seven is made by screening and remixing in the right proportion.

Crusher Screenings.—Screenings from broken stone make an excellent fine aggregate, which can be substituted for sand unless the stone is very soft, shelly, or contains a large percentage of mica.

Broken Stone for Concrete.*—The purpose for which the concrete is intended must always influence the selection of the stone. For a very strong concrete, a hard stone without any surface scale is necessary; a rich mortar will not entirely counterbalance a deficiency in the strength of the stone. For a medium strong concrete the hardest stone need not be insisted upon, but rather one to which the mortar will best adhere, such as some of the limestones. For fireproof construction some of the limestones and rocks containing feldspar should be avoided; good boiler furnace cinders have proved best for fire-resisting concrete.

For all classes of concrete, stone breaking in cubical form is far better than one breaking in flat layers such as shale or slate, it

* Condensed from paper on "Concrete Aggregates," by Albert Moyer.

being almost impossible to ram or tamp such stone into as dense and compact a mass as that breaking in cubical fracture.

The size of the stone aggregates depends on the purpose for which the concrete is to be used. For large masses of concrete, 2-1/2-inch stone is usually considered the maximum size, but for 12-inch walls and the usual class of concrete construction, 3/4 inch will be found sufficiently large. Quarry tailings, etc., in crushed stone, are not a detriment, as is commonly supposed, but in fact a decided advantage, for the reason that the voids are thus reduced, giving greater density and consequently greater strength.

Material which is foreign to the stone, such as vegetable mould, scale, or loam, which cling to the surface will reduce the strength of the concrete. Numerous tests conducted during the last several years by competent engineers have shown that clay in small proportions, not over 15 per cent, when well mixed in the mortar, does not reduce the strength of the concrete; in fact, tests have shown that the strength has been increased. This applies particularly to the leaner mixtures. If carefully mixed, therefore, the clay will not cling to the stone, but will become part of the mortar, and in testing for proportions of stone, sand, and cement, the amount of clay present should be figured as part of the mortar and not as part of the stone.

Gravel for Concrete.—Gravel is often superior to broken stone, being usually found graded from coarse to fine; the roundness of the pebbles lends aid to compactness. It is not likely to bridge and leave holes in the concrete. The percentage of voids is usually less than in broken stone; the quartz pebbles are harder, stronger, and less liable to fracture.

Sandstone pebbles are not considered as good as the better grades of crushed stone. The usual argument against gravel is that the mortar is not supposed to adhere as well to the surface as to that of freshly broken stone. This is one of the theories which is practically due to the appearance of the surface to the eye or touch; the adhesion of mortar to limestone of a smooth surface, may be far greater than to sand stone or rougher materials. If roughness was the only requirement for adhesion it would seem impossible to cement together two pieces of glass.

From the standpoint of durability, gravel must be superior to stone for the reason that, by the laws of the survival of the fittest and by process of elimination, nature has supplied us with the most durable. Short-time tests for compression strength usually show broken stone concrete to be superior, but long-time tests of from six months to a year show gravel concrete on an average to be equal if not stronger. In construction work where tensile or other stresses are to be cared for, as may occur in reinforced concrete, crushed gravel should be used. The cement will adhere more readily to crushed than to the rounded, polished surface of the gravel.

CHAPTER VI

HOW TO PROPORTION THE MATERIALS

Nature of the Problem.—Voids in Concrete.—Methods of Proportioning.—Tables for Proportioning.

Nature of the Problem.—A great deal of study has been given to the question of proportioning the materials of concrete, and most of the study has been directed to one end; viz., to find a mixture that will give the maximum density and strength with a minimum amount of cement. The difficulties in arriving at any definite rules for obtaining this result arise from the great variation in the various elements affecting the work, no two materials being exactly alike, and rules deduced from one set of experiments being of very doubtful value when applied to other conditions. Although a good deal of care in proportioning is warranted, to obtain the best mix with any given material, too great refinement is unnecessary and the theoretical methods which have been gone into with such great detail in many of the books on concrete work have more of an academic interest than a practical value.

The principal thing to bear in mind in order to obtain the densest possible mixture is to eliminate the voids in the concrete mass, and to do this, it is desirable that the sand and gravel be well graded from coarse to fine and enough cement be used to obtain a rich mixture. Plenty of water, to obtain a wet mix, should be employed, as water will drive out the air entrained between the particles of the aggregates. The density, strength, and watertightness of concrete will be increased in accordance with the richness, variation in size of aggregate, and with the plasticity of the mixture. Mix rich and mix wet to obtain the best work.

The question of proportioning is, of course, also dependent upon the use to which the concrete is to be put and in many locations density and strength may not be the prime requisites, and then a very small percentage of cement will suffice to obtain a hardened mass; as low as 5 per cent has given a strong concrete.

How to Proportion the Materials

Voids in Concrete.—American engineers proportion concrete mixtures by measure, thus a 1:2:4 concrete is composed of 1 volume of cement, 2 volumes of sand, and 4 volumes of broken stone. Both the sand and the coarse aggregates employed for concrete contain voids or empty spaces between their particles. In a perfect mixture the cement would fill the voids in the sand and coat each grain, while the sand with its coating of cement would fill the voids in the aggregate and also cover each stone with a film of mortar.

In practice, it is impossible to fill all of the voids in concrete. In the first place, the cement and sand cannot be perfectly distributed, and in the second place, the water used in the mixing causes the sand to swell, thus increasing the voids about 10 per cent. This swelling is due to a film of water between the grains, and this film cannot be entirely displaced by the cement. When the water evaporates after a wall of concrete has set, voids always remain throughout the mass, and some shrinkage of the mass occurs.

A rich mixture is obtained when the cement is somewhat in excess of the quantity that would, theoretically, be sufficient to fill the voids in the sand. Sand and gravel contain from 30 to 50 per cent of voids, while the voids in broken stone range from 40 to 50 per cent.

The proportion of voids may be approximately determined in either sand or broken stone in the following way:

Wet the loose aggregate thoroughly; fill a vessel of known capacity with the material, and then pour in all the water the vessel will contain. Measure the volume of water required and divide this by the volume of the vessel. The quotient represents the proportion of voids.

Method of Proportioning.—The ordinary mixture for watertight concrete is about 1 : 2½ : 4½ which requires 1.32 barrel of cement per cu. yd. of concrete. The most scientific method for proportioning the ingredients is that known as the *Mechanical Analysis.* In this method the available materials, including the cement, are separated into various sizes by means of a series of sieves. Curves are then plotted on cross-section paper which indicate the percentages of the whole mass that pass the several sieves. From a study of these curves, the proportions of the different ingredients are determined. This method is, however, not available in the usual course of concrete work.

In hand-mixing, cement is generally measured by specifying the number of bags to a batch. Machine mixers frequently have automatic measuring devices. When removed from the bag or barrel, cement occupies about 15 per cent more space than when in the original package; or a 1 : 2 : 4 mixture measured by counting the number of bags will be 15 per cent richer than a 1:2:4 mixture, which is proportioned by measuring the cement loose. Hence in determining the proportions, the methods of measuring the cement should be considered and specifications should clearly provide how this shall be done.

Volume of Barrel of Cement.—The difference between the volume of a barrel of cement when measured packed and loose, and variations in size and weight have been subjects of extended controversy and often bitterness between engineer and contractor, and has resulted in much friction and litigation. The tendency now is to fix an arbitrary but average value for the volume of the cement barrel as a standard, and have this used as a basis on all concrete work. The value of 4 cu. ft. to the barrel is preferred, the actual volume being about 3.75 cu. ft. packed and 4.2 cu. ft. loose. The fixing of such a standard of value is highly desirable, and would be of great benefit to engineers and contractors alike.

Proportions by Formula.—A number of formulas have been introduced for proportioning the sand, cement and stone and it is worth the cement user's while to take note particularly of the one here given, as it is exceedingly simple and may save much trouble in proportioning. While proportioning by formula is not employed as frequently as proportioning by rule of thumb, the method has been employed to work out some excellent tables for proportioning concrete and these tables are extremely useful in estimating the amount of cement required on any particular job as well as for other construction purpose.

The simplest formula for this purpose is:

$$B = \frac{27}{n\,g} \qquad C = 27\,\frac{s}{g}$$

B = number of barrels of cement per cu. yd. of concrete.
n = number of cubic feet in barrel of cement as specified.
g = number of parts of gravel to 1 part cement as specified.
C = number of cubic feet of sand per cu. yd. of concrete.
s = number of parts of sand to 1 part of cement as specified.

This formula assumes that the voids in the gravel are filled by the sand and the voids in the sand are filled by the mortar, and therefore the results are approximate.

Thus for a 1:2:4 concrete, when 1 bbl. cement is specified as 4 cubic feet,

$$B = \frac{27}{4 \times 4} = 1.7 \text{ bbls. cement.}$$

$$C = 27 \times \frac{1}{\frac{1}{2}} = 13.5 \text{ cubic feet sand.}$$

The following table was computed by Gillette's formula, giving the quantities of cement, sand, aggregate, and water required to produce one cubic yard of wet concrete:

TABLE II.—Ingredients in One Cubic Yard of Concrete.

Voids in Sand, 40 *per cent.* *Voids in Stone*, 45 *per cent.*

Proportions by Volume.	1:2:4	1:2½:4½	1:2:5	1:2½:5	1:3:5	1:3:6
Per Cent of Voids in Concrete....	10%	8%	12%	12%	12%	14%
Bbls. Cement: Measured Packed per cu. yd. of Concrete, 1 bbl. = 3.8 cu. ft....................	1.46	1.32	1.25	1.20	1.13	1.00
Cu. yds. Sand per cu. yd. Concrete	.41	.46	.35	.42	.48	.42
Cu. yds. Stone per cu. yd Concrete.	.82	.83	.88	.84	.80	.84
Approximate per cent of water for wet mixtures................	13%	12½%	13%	12½%	12%	12%

In Table II, the approximate amount of water required for a wet mixture is expressed as a percentage of the combined weight of sand and cement. These percentages are, however, only approximate. More water is required in dry than in moist atmospheres, and more in summer than in winter. A wetter mixture is also required when the material cannot be tamped. While a dry mixture is theoretically the stronger when carefully deposited and well tamped, yet a wet mixture is more frequently employed because stronger under working conditions. Wet mixtures flow readily into the corners and angles of the forms and between and around the reinforcing bars, with only a small amount of puddling and slicing.

TABLE III.—MATERIALS FOR ONE CUBIC YARD COMPACT PLASTIC MORTAR BASED ON BARREL OF 3.8 CUBIC FEET.

From "Concrete Plain and Reinforced," by Taylor & Thompson.

Relative Proportions by Parts.		Relative Proportions by Volume.		Packed Cement Barrels.	Loose Sand Cubic Yard.
Cement.	Sand.	Cement Barrel.	Sand Cubic Feet.		
1	0	1		8.31	
1	½	1	1.9	6.73	0.47
1	1	1	3.8	5.01	0.71
1	1½	1	5.7	4.00	0.84
1	2	1	7.6	3.32	0.93
1	2½	1	9.5	2.84	1.00
1	3	1	11.4	2.48	1.05
1	3½	1	13.3	2.20	1.08
1	4	1	15.2	1.98	1.11
1	4½	1	17.1	1.80	1.14
1	5	1	19.0	1.65	1.16
1	5½	1	20.9	1.52	1.18
1	6	1	22.8	1.41	1.19
1	6½	1	24.7	1.32	1.21
1	7	1	26.6	1.23	1.21
1	7½	1	28.5	1.16	1.22
1	8	1	30.4	1.10	1.24

CHAPTER VII

HOW TO MIX AND PLACE CONCRETE

Methods of Mixing.—How to Mix by Hand.—Materials Required for Two-Bag Batch.—Mixing by Machine.—Placing the Concrete.—Protection of Concrete After Placing.—Placing Concrete Under Water.

THE proper mixing and placing of concrete is fully as important as is the proportioning of its ingredients. Two general methods are in use:

(1) Hand mixing; (2) Machine mixing.

MIXING CONCRETE BY HAND

The making and placing of concrete by hand is divided into the following operations:

1. Loading into barrows, buckets, carts, or cars, which are used to transport the cement, sand, and stone to the mixing board.

2. Transporting and dumping the materials.

3. Mixing the materials by turning with shovels and hoes.

4. Loading the concrete by shovels into barrows, buckets, carts, or cars.

5. Transporting the concrete to place.

6. Dumping, spreading, and ramming.

Hand mixing is used for small batches. The stone and sand are measured in bottomless boxes and the cement by counting the number of bags to a batch, each bag representing a quarter of a barrel.

As hand mixing is so largely employed throughout the country on the smaller jobs, the following detailed description is given, and if carefully followed, any intelligent person should be able to secure a satisfactory mix. In this description * we have taken as a basis a "Two-bag Batch" of 1:2:4 concrete. The amount of material required is given in the Tables IV and V.

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* This description is adapted from Bulletin No. 20, published by American Association of Portland Cement Manufacturers.

Concrete Board.—A concrete board for two men should be 9 feet x 10 feet. Make it out of 1-inch boards, 10 feet long, surfaced on one side, using five 2 inch x 4 inch x 9 foot cleats to hold them together. If 1 inch x 6 inch tongue-and-groove roofers can be obtained, they will do very nicely if fairly free from knots. The object of the surfaced board is to make the shovelling easy. The boards are so laid as to enable the shovelling to be done with, and not against, the cracks between the boards. The boards must be drawn up close in nailing so that no cement grout will run through while mixing.

Knot-holes may be closed by nailing a strip across them on the under side of the board. It is a good precaution against losing cement grout to nail a 2 inch x 2 inch or 2 inch x 4 inch piece around the outer edge of the board. Often 2-inch planks are used in making concrete boards, but these are unnecessarily heavy and very cumbersome to move.

Placing the Concrete Board.—The concrete board is a manufacturing plant, and the advantages of its location should be carefully considered. Generally it is best placed as close as possible to the forms in which the concrete is to be deposited, but "local conditions" must govern this point. Pick a place giving plenty of room, near the storage piles of sand and stone (or pebbles). Block up your concrete board level, so that the cement grout will not run off on one side, and so that the board will not sag in the middle under the weight of the concrete.

Runs.—Do not use any old boards that are handy for the wheelbarrow runs. Make a good run, smooth, and at least 20 inches wide if much above the ground. It is surprising how this one feature will lighten and quicken the work.

Tools and Plant.—List of tools and plant to be used in mixing, giving sizes, quantities, etc.

Concrete Board for 2-Bag Batch, 9′ x 10′ in size.

9 pcs. $\frac{7}{8}''$ × 12″ × 10′0″, surfaced one side and two edges. (Any width of plank may be used; 12″ is specified only for convenience.)

5 pcs. 2″ × 4″ × 9′0″ rough.
2 pcs. 2″ × 2″ × 10′0″ rough.
2 pcs. 2″ × 2″ × 9′0″ rough.

Concrete Board for 4-Bag Batch, 12′ x 10′ in size.

12 pcs. ⅞″ × 12″ × 10′0″, surfaced one side and edges. (Any width of plank may be used; 12″ is specified only for convenience.)
5 pcs. 2″ × 4″ × 12′0″ rough.
2 pcs. 2″ × 2″ × 10′0″ rough.
2 pcs. 2″ × 2″ × 12′0″ rough.

Runs.—2″, 2 1/2″, or 3″ plank 10″ or 12″ wide.

Measuring Boxes for Sand and Stone or Gravel.

For 2-Bag Batch 1 : 2 : 4 Mixture:

4 pcs. 1″ × 11½ × 2′0″ rough.
2 pcs. 1″ × 11½″ × 4′0″ rough.
2 pcs. 1″ × 11½″ × 6′0″ rough.

NOTE.—The 2 pcs. 4′0″ long and the 2 pcs. 6′0″ long have an extra foot in length at each end to be made into a handle.

For 2-Bag Batch 1 : 3 : 6 Mixture:

2 pcs. 1″ × 11½″ × 2′0″
2 pcs. 1″ × 11½″ × 3′0″
2 pcs. 1″ × 11½″ × 5′0″
2 pcs. 1″ × 11½″ × 6′0″

NOTE.—The 2 pcs. 5′0″ long and the 2 pcs. 6′0″ long have an extra foot in length at each end to be made into a handle.

For 4-Bag Batch:

Double cubic contents of boxes and order lumber accordingly.

Shovels.—No. 3 square point.

Wheelbarrows.—At least two necessary for quick work; sheet-iron body preferred.

Rake.

Water-barrel.

Water-buckets.—2-gallon size.

Tamper.—4″ x 4″ x 2′6″, with handles nailed to it.

Garden spade or "spading" tool, as shown in Fig. 13.

Sand Screen.—Made by nailing a piece of 1/4″ mesh wire screen 2 1/2′ x 5′ in size to a frame made of 2″ x 4″.

Mixing.—With the mixing board placed and the "runs" made, the concrete plant is ready.

First load your sand in wheelbarrows from the sand pile, wheel on to the "Board," and fill the sand-measuring box, which is placed about two feet from one of the 10-foot sides of the board. When the sand box is filled, lift it off and spread the sand over the board in a layer 3 inches or 4 inches thick. Take the two bags of cement and place the contents as evenly as possible over the sand. With two men start mixing the sand and cement, each man turning over the half on his side. Starting at his feet and shovelling away from him, each man takes a full shovel-load, turning the shovel over. In turning the shovel, do not simply dump the sand and cement but shake the materials off the end and sides of the shovel, so that the sand and cement are mixed as they fall. This is a great assistance in mixing

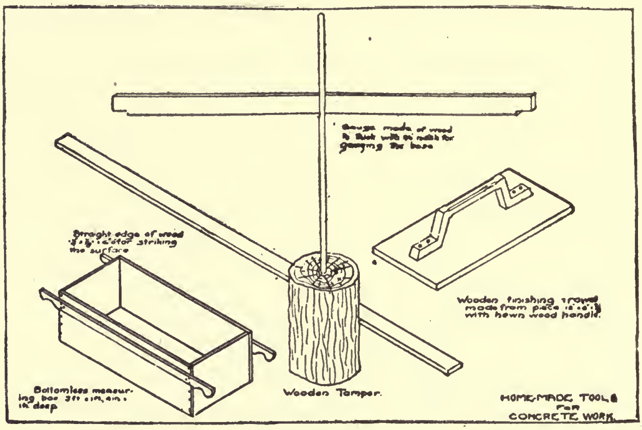

FIG. 7.—Homemade Tools for the Concrete Worker.

these materials. In this way the material is shovelled from one side of the board to the other.

After the last turning, spread the sand and cement out carefully, place the gravel or stone measuring box beside it and fill from the gravel pile. Lift off the box and shovel the gravel on top of the sand and cement, spreading it as evenly as possible. With some experience equally good results can be obtained by placing the gravel measuring box on top of the carefully levelled sand and cement mixture, and filling it, thus placing the gravel on top without an extra shovelling. Add about three-fourths the required amount of water, using a bucket and dashing the water over the gravel on top of the pile as evenly as possible. Be careful not to let too much water get near the edges of the pile, as it will run off, taking some cement with it. This caution, however, does not apply to a properly constructed mixing board, as the cement and water cannot get away. Starting the same as with the sand and cement, turn the materials over in much the same way, except that, instead of shaking the materials off the end of the shovel, the whole shovel load is dumped and dragged back toward the mixer with the square point of the shovel. This mixes the gravel with the sand and cement, the wet gravel picking up the sand and cement as it rolls over when dragged back by the shovel. Add water to the dry spots as the mixing goes on until all the required water has been used. Turn the mass back again, as was done with the sand and cement. With experienced laborers, the concrete would be well mixed after three such turnings; but if it shows streaky or dry spots, it must be turned again. After the final turning, shovel into a compact pile. The concrete is now ready for placing.

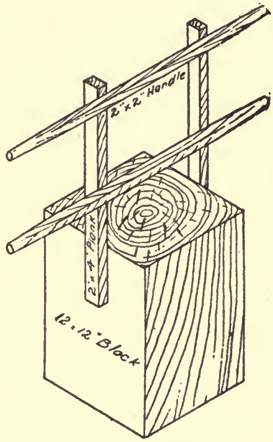

FIG. 8.—Homemade Concrete Tamper.

Mixing Natural Mixture of Bank Sand and Gravel.—Spread out the mixture of sand and gravel as much as the board will readily permit, add enough water to wet the gravel and sand thoroughly, spread the cement evenly in a thin layer over the sand and gravel, and turn over, as described previously, at least three times, adding the rest of the water necessary to get the required consistency while the materials are being turned. It requires some experience to work up a natural mixture of bank sand and gravel, and if at all doubtful about the concrete made from it, first screen the sand from the gravel and then mix in the regular way.

Number of Men.—For the above operation only two men are required, although more can be used to advantage. If three men are available, let two of them mix as described above and the third man supply the water, help mix the concrete by raking over the dry or unmixed spots as the two mixers turn the concrete, help load the wheelbarrows with sand and stone or gravel, etc.

If four men are available, it is best to increase the size of the batch mixed to a four-bag batch, doubling the quantities of all materials used. The cement board should also be increased to 10 feet x 12 feet, as shown under "Tools." In this case the mixing is in the middle of the board, each pair of men mixing exactly as if for a two-bag batch, except that the concrete is shovelled into one big mass each time it is turned back on to the centre of the board. When more than four men are available, the rest may place the concrete, make new runs, load wheelbarrows, etc., taking the concrete away from the board as fast as it is mixed. In this case another small concrete board should be placed next to the big "board," so that in the last turning the batch can be shovelled over on to the small board for placing, making room on the big board to mix the next batch. The small platform need be only just big enough to hold the pile of mixed concrete.

TABLE IV.

Showing the Quantities of Materials and the Resulting Amount of Concrete for Two-Bag Batch.

Kind of Concrete Mixture.	Proportions by Parts.			Two-Bag Batch.						
				Materials.				Size of Measuring Boxes. Inside Measurements.		
	Cement.	Sand.	Stone or Gravel.	Cement.	Sand.	Stone or Gravel.	Concrete.	Sand.	Stone or Gravel.	Water in Gallons for Medium Wet Mixture.
				Bags.	Cu. Ft.	Cu. Ft.	Cu. Ft.			Gallons.
1 : 2 : 4 Concrete	1	2	4	2	$3\frac{3}{4}$	$7\frac{1}{2}$	$8\frac{1}{2}$	2′ × 2′ × $11\frac{1}{2}$″	2′ × 4′ × $11\frac{1}{2}$″	10
1 : 3 : 6 Concrete	1	3	6	2	$5\frac{3}{4}$	$11\frac{1}{2}$	12	2′ × 3′ × $11\frac{1}{2}$″	3′ × 4′ × $11\frac{1}{2}$″	$13\frac{1}{2}$

MIXING CONCRETE BY MACHINE

Machine mixers are more efficient and economical than hand labor and are used exclusively on all large jobs.

In machine mixing, the making and placing of concrete is divided into the following operations:

1. Transportation of the raw materials to the stock piles or bins.

2. Transportation from the stock piles or bins to the mixer.

3. Proportioning, mixing, and discharge of the batch into buckets, cars, or other vehicles.

4. Transportation from the mixer to the work.

5. Dumping, spreading, and ramming.

TABLE V.

Showing the Quantities of Materials and the Resulting Amount of Concrete for Two-Bag Batch Using Natural Mixture of Bank Sand and Gravel.

Kind of Concrete Mixture.	Proportion by Parts.		Two-Bag Batch for Natural Mixture of Bank Sand and Gravel.				
			Materials.			Size of Measuring Boxes.	
	Cement.	Natural Mixture of Sand and Gravel.	Cement.	Natural Mixture of Sand and Gravel.	Concrete.	Mixture of Sand and Gravel.	Water in Gallons for Medium Wet Measure.
			Bags.	Cu. Ft.	Cu. Ft.		
1 : 2 : 4 Concrete.........	1	4	2	7½	8½	2′ × 4′ × 11½″	10
1 : 3 : 6 Concrete.........	1	6	2	11½	12	3′ × 4′ × 11½″	13½

The plant required depends upon the size of the job. Boats, cars, cableways, conveyors, derricks, hoists, and other appliances are frequently employed for transportation purposes.

Types of Mixing Machines.—The following types of mixers are in general use:

1. Batch mixers ..... { *a.* Tilting mixtures. *b.* Non-tilting mixtures.

2. Continuous mixers. { *a.* Hand proportioning of ingredients. *b.* Machine proportioning of ingredients.

3. Gravity mixers.... { *a.* Trough form with deflectors. *b.* Hopper form.

1. In the *batch* mixers, a charge of cement, sand, aggregate, and water is put into the machine, which mixes and discharges the batch before taking in another charge.

In *tilting* machines the concrete is discharged by raising one end of the drum and causing the mixture to flow out by gravity.

In *non-tilting* mixers, steel deflectors are provided in the drums, which plough through and pick up the batch as the drum revolves. To discharge the batch, a chute is provided. When this chute is tilted so that one end projects into the mixer, the material picked up by the deflectors drops back on to the chute and runs out.

The special features of the batch mixer are as follows.

1. It is suitable for either a constant delivery of large quantities of concrete, or for small quantities at irregular intervals. It is, therefore, the only type fit for light work such as reinforced concrete.

2. The exact proportions specified for the concrete can be assured with the greatest accuracy.

3. The engineer can at any time check the proportions being used.

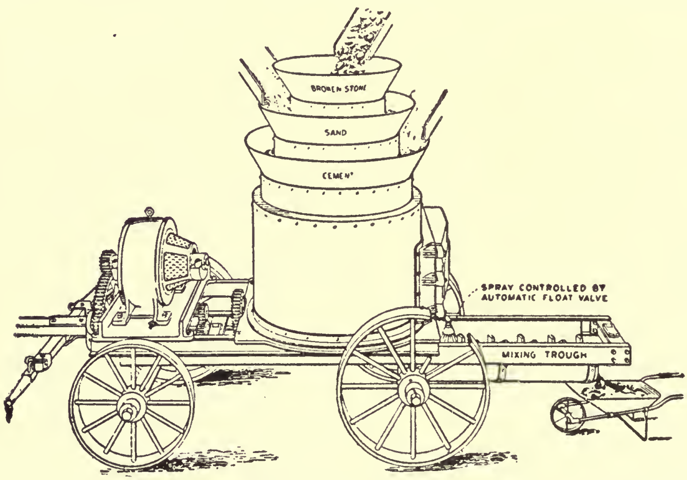

FIG. 9.—Concrete Mixer with Automatic Measuring Devices. (English Type.)

4. The amount of water can be measured exactly.

5. The amount of mixing given to the concrete is under the control of the engineer, and by specifying a definite number of revolutions of the drum, or a definite time, a perfect mixing can be assured.

6. A preliminary dry mixing can be given, if desired, by the machine.

7. The different materials may be fed to the mixing apparatus separately. There is therefore no necessity for hand mixing before feeding.

2. *Continuous mixers* are those in which the cement, sand, and stone are fed to the charging hopper in a continuous stream, while the mixed concrete is discharged in another continuous stream.

In one form of continuous mixer the cement, sand, and stone properly proportioned are shovelled directly into the mixing drum. In the other form, these materials are dumped into separate charging hoppers and are automatically fed into the mixing drum in any relative proportions desired, the proportioning being accomplished by the machine.

Special features of the continuous mixer.

1. It is of use chiefly where large quantities of concrete have to be delivered without intermission, as in the construction of sea and dock walls, foundations, etc. It is not suitable where only small quantities of concrete are required at irregular intervals, as in the case of block-making or reinforced concrete-work.

2. No method of continuous measuring is capable of the same accuracy, for all the materials concerned, as is measuring in boxes or skips.

3. It is impossible for the engineer to exercise the necessary supervision over the proportions of the ingredients used.

4. The amount of water in the concrete will depend somewhat on the rate of running of the machine, and cannot be accurately measured.

5. The amount of mixing given to the concrete is not under the control of the engineer, but is fixed chiefly by the makers of the machine.

6. The materials cannot be satisfactorily mixed together dry by the mixer before being wetted, although the attempt to do this has been made by delivering the water at some distance from the feed opening.

7. All the materials must be fed into the mixer simultaneously, since there is a continuous movement from end to end, and if fed separately they would travel separately along the machine. This means that a preliminary dry mixing by hand is necessary before feeding into the machine.

3. *Gravity mixers* are constructed in two general forms. The first form is a trough whose bottom and sides are provided with pegs or other deflectors which give the material a zig-zag motion as it

flows along. The second form consists of a series of hoppers, set one above the other, so that the batch is spilled from one into the next and is thus mixed.

With a good mixer the output depends upon the methods of

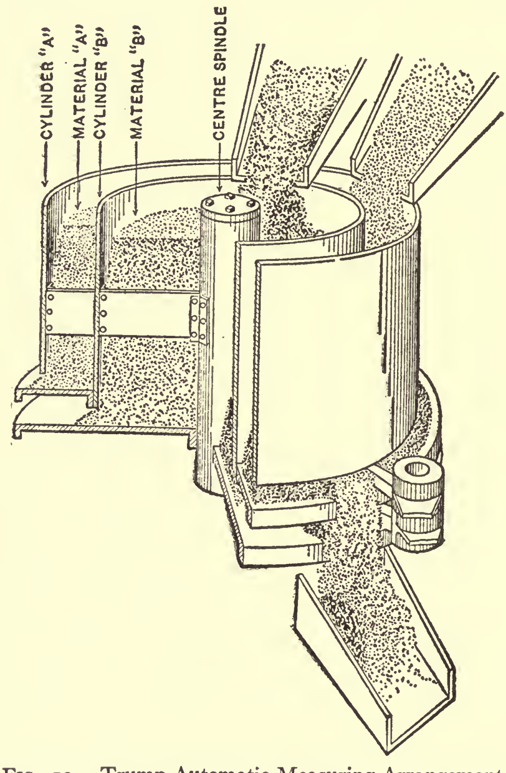

Fig. 10.—Trump Automatic Measuring Arrangement.

conveying the materials. On a well organized job, a batch mixer will average about 300 batches in ten hours.

On large jobs with labor at $2.00 per day, the labor cost of putting concrete in place is about 50 cents per cu. yd. When mixed by machine and deposited by hand, this cost will run from 75 cents to 90 cents per cu. yd.

Precautions in Mixing.—In mixing concrete by machinery the important points to be observed are:

1. That the specified proportions of the ingredients are fed into the mixer at all times.

2. That the quantity of water is uniform and of proper amount to produce the desired consistency.

3. That the ingredients are thoroughly incorporated before leaving the mixer.

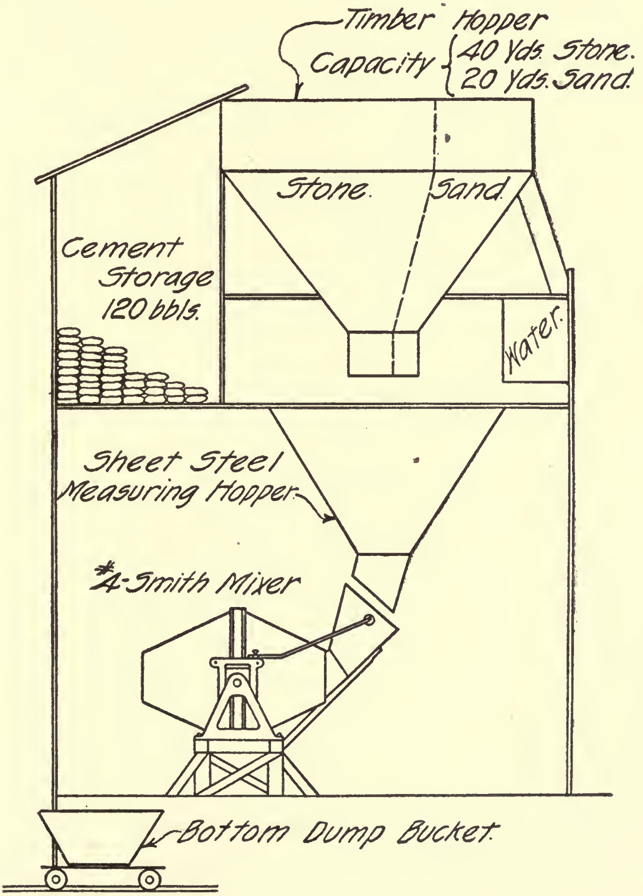

FIG. 11.—Typical Arrangement of Concrete Mixing Plant. (Atlas Portland Cement Co.)

4. That the entire contents of the mixer are taken out at each emptying.

5. When the mixer is stopped it should be flushed with water and no concrete partially set or otherwise should be permitted to remain in it.

6. The mixer should be located as near the work as possible.

7. The concrete should have a low fall when leaving the mixer, not giving the ingredients an opportunity to separate.

8. If transported the concrete must be carried in water-tight cars or barrows.

9. As soon as placed the concrete should be well compacted, all corners being thoroughly filled.

10. The forms must be firm, unyielding, have the closest possible joints and smoothed on the inside.

11. A richer concrete should be deposited near all exposed surfaces.

12. The work should be supervised by a competent inspector.

PLACING THE CONCRETE

How Placed.*—After the concrete is properly mixed it should be placed at once. Concrete may be handled and placed in any way, best suited to the nature of the work, provided the materials do not separate in placing. Hand-mixed concrete may be properly placed by shovelling off the concrete board directly into the work, by shovelling into wheelbarrows, wheeling to place and dumping, by shovelling down an inclined chute, or by shovelling into buckets and hoisting into place. Concrete should be deposited in layers about 6 inches thick unless otherwise specified.

Consistency.—There are three kinds of mixtures used in general concrete work as follows:

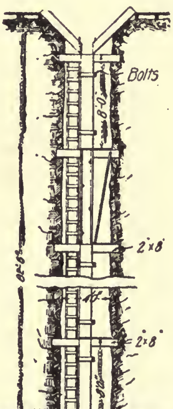
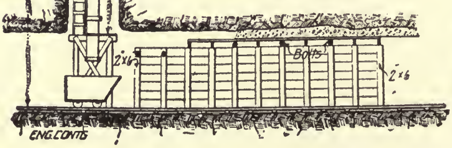


FIG. 12.—Gravity Mixer for Lining Tunnel.

1. *Very Wet Mixture.*—Concrete wet enough to be mushy and run off a shovel when handling. Used for reinforced work, thin walls, or other thin sections, etc.; no ramming necessary.

2. *Medium Mixture.*—Concrete just wet enough to make it

* See foot note page 47.

jelly-like. Used for some reinforced work, also foundations, floors, etc. Ramming with tamper or treading with feet necessary to remove air-bubbles and fill voids. In concrete of a medium consistency, a man would sink ankle-deep if he were to step onto the top of the pile.

3. *Dry Mixture.*—Concrete like damp earth: used for foundations, etc., where it is important to have the concrete set up as quickly as possible. This must be spread out in a 4-inch to 6-inch

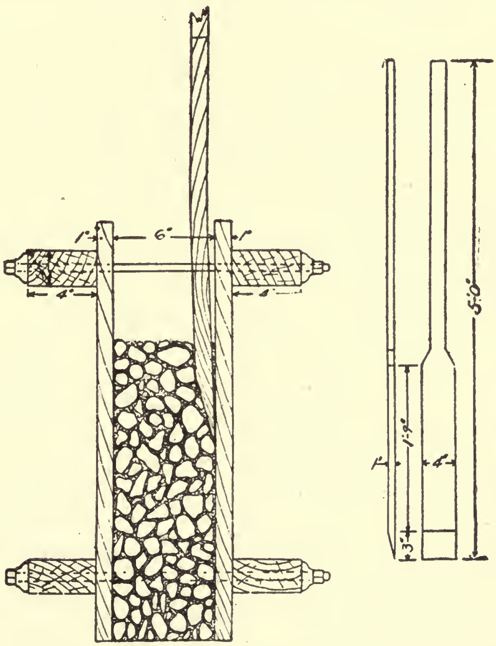

FIG. 13.—Spading Fine Material Adjacent to Form.

layer in placing and thoroughly tamped until the water comes to the surface.

Spading.—Concrete of any of the three degrees of consistency mentioned above should be carefully "spaded" next to the form where the finished concrete will be exposed to view. "Spading" consists of running a spade or flattened shovel down against the face of the form and working up and down. This action causes the stone or gravel to be pushed back slightly from the form, and allows the cement grout to flow against the face of the form and fill any voids that might be there, thus making the face of the work present an even, homogeneous appearance. Where the narrowness of the concrete section, such as in a 6-inch silo wall, prevents the use of a spade, a 1-inch-by-4-inch board, sharpened to chisel edge on the end, will do as well. Only sharpen on one side and place the flat side against the form as shown in illustration. In the case of a dry mixture, "spading" must be done with greatest care by experienced hands to get uniform results, but with a medium or wet mixture it is very easy to obtain first-class work; indeed, with a wet mixture

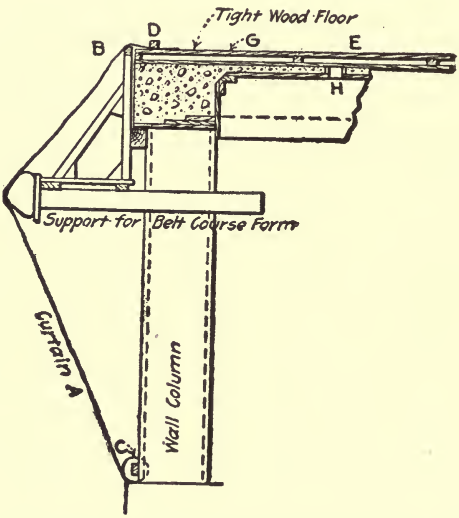

FIG. 14.—Enclosing Building with Canvas Curtains to Protect the Concrete.

spading is required only as an added precaution against the possibility of voids in the face of the work, and is really necessary in few cases.

Cleaning the Concrete Board.—When the day's work is done, carefully clean all the tools, especially the concrete board. Remove with a shovel all the loose cement, sand, and stone. Then scrub the board with a broom and water. If this is not done, small particles of stone are glued to the board by the cement, and render shovelling the next day most difficult.

Protection of Concrete after Placing.—Green concrete should not be exposed to the sun until after it has been allowed to set for five or six days. Each day during that period the concrete should be wet down by sprinkling water on it, both in the morning and afternoon. This is done so that the concrete on the outside will not dry out much faster than the concrete in the centre of the mass, and should be carried out carefully, especially during the hot summer months. Old canvas, sheeting, burlap, etc., placed so as to hang an inch or so away from the face of the concrete will do very well as a protection. Wet this as well as the concrete. Often the concrete forms can be left in place a week or ten days; this protects

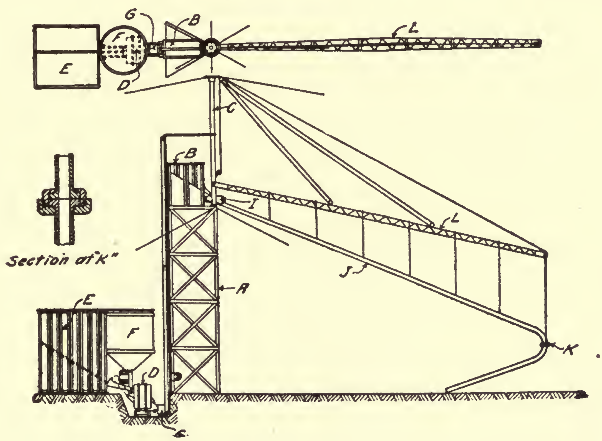

Fig. 15.—Method of Depositing Concrete by Chutes.

the concrete during the setting-up period and the above precautions are then unnecessary.

Placing Concrete in Freezing Weather.—When concrete is to be placed in freezing weather, one or more of the following methods should be employed to protect it from injury:

1. Lowering the freezing-point of the mixing-water.
2. Heating the sand, stone, and mixing-water.
3. Covering and housing the work.

Common salt is most frequently employed for the purpose of lowering the point at which the water will freeze. The rule is to add salt in the proportion of 1 per cent of the weight of the water for each degree F., below 32°. In no case, however, is it good practice to add more than 10 per cent of salt.

Sand and stones are heated either in portable heaters or in bins.

When bins are employed, steam pipes are used to thaw out the materials.

Methods of covering concrete to protect it from light frosts include the use of sacking, shavings, straw, and manure. In cold climates, frame buildings that completely house in the construction are frequently erected. Such buildings are heated and the temperature kept well above the freezing-point.

Placing Concrete Under Water.—Mixed concrete if emptied loose and allowed to sink through water is destroyed; the cement paste is washed away and the sand and stone settle on to the bottom more or less segregated and practically without cementing value.

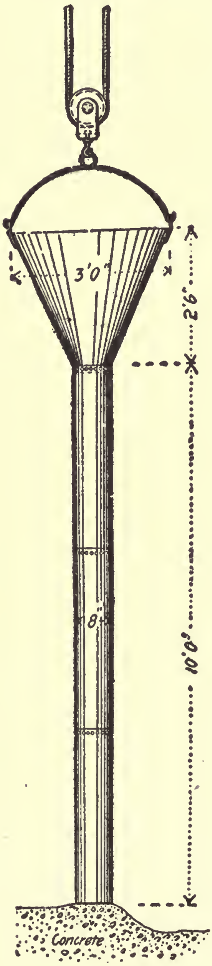

Fig. 16.—Tremie Tube for Depositing Concrete under Water.

To overcome these difficulties, the following methods are employed for depositing concrete under water:

1. Depositing in closed buckets
   - *a.* Bottom dumping.
   - *b.* Revolving buckets.
2. Depositing in bags........
   - *a.* Bottom dumping bags.
   - *b.* Bags to be left in the work.
3. Depositing through a tremie.
4. Grouting submerged stone.

Buckets for depositing concrete under water are provided with covers, so that the water cannot flow in and wash out the cement as the material is being lowered. Bottom dumping buckets also possess an unlocking device to open the bottom doors and allow the concrete to pass out. Revolving buckets are turned upside down before emptying.

Two methods of depositing concrete in bags are available to the engineer. In the first method a bag of heavy tight-woven material is filled with concrete and emptied at the bottom, the bag serving like the buckets as a means of conveyance.

In the second method bags of paper or loose-woven gunny-sack are employed. The bags are filled with concrete and are left in the work, the idea being that the paper will soften or the cement ooze out through the openings in the cloth sufficiently to bond the separate bagfuls into a solid mass.

A tremie consists of a tube of wood or sheet metal, which reaches from above the surface to the bottom of the water. It is operated by filling the tube with concrete and keeping it full by successive additions, while allowing the concrete to flow out gradually at the bottom by slightly raising the tube to provide the necessary opening.

Masses of gravel, broken or rubble stone deposited under water may be cemented into what is virtually a solid concrete by charging the interstices with grout forced through pipes from the surface. The grout employed is a 1 : 1 mixture of Portland cement and sand, with sufficient water to form a thick paste. This is readily forced through 2 in. pipes into depths of 50 ft. and over.

In heavy subaqueous operations concrete is also placed by constructing a coffer dam around the site, pumping out the water, and working in the dry or by placing large specially prepared blocks by means of derricks, the setting being done by divers. A new method has recently come into use for building subaqueous concrete walls, by means of pontoons constructed on shore, floated into place and sunk by means of ballast.

CHAPTER VIII

FORMS FOR CONCRETE CONSTRUCTION

Kinds of Forms.—Pressure of Concrete on Forms.—Dressing and Lubrication of Forms.—Design of Forms.—Removing Forms.—Cost of Forms.

THE design and construction of forms are among the most difficult of the problems imposed upon the worker in concrete.

Forms should be stiff, strong, and economical in labor and materials. They should be built with a view to economy in taking down rather than to cheapness in erecting or in first cost. Roughly built forms which cannot be removed without being ripped to pieces are always expensive.

Kinds of Forms.—The principal kinds of forms in general use are as follows:

1. Simple braced forms.
2. Wired and bolted forms for walls.
3. Forms made of studding and matched boards.
4. Panel forms.
5. Column forms and braces.
6. Forms for beams and slabs.
7. Arch centres.
8. Special, collapsible facing forms and templets.

Forms are most commonly constructed of wood, which must be planed and oiled to present a smooth surface, since the concrete takes the impress of any irregularity that presents itself. Stiff, close-grained woods are the best, such as white pine, yellow pine, spruce, Oregon pine, or redwood. Hemlock should not be employed, as it is rough, splintery, and weak. Oak is hard to nail, expensive and imprints grain marks on the concrete even when the form is well oiled.

Forms should be constructed in such a way as to avoid the use of nails whenever possible. Braces are seldom less than 1 in. thick and it takes hard driving to get spikes through them. Whenever possible, blocks or wedges held in place by thin nails, should be substituted for the large spikes so often employed.

Lagging and panel strips are made of 1 1/4 to 2 inch stuff, short struts and braces of 2 x 4 inch timber, while long struts range from 4 x 4 to 8 x 8 inch sectional area.

Simple braced forms are used for foundations, retaining walls, and ordinary construction. They consist of from 1 to 1 1/2 inch boards, which are supported by 2 x 4 inch studs, set about 2 feet apart. The studs are also braced with 2 x 4 inch diagonals. The diagonal braces are held in position by posts driven into the ground.

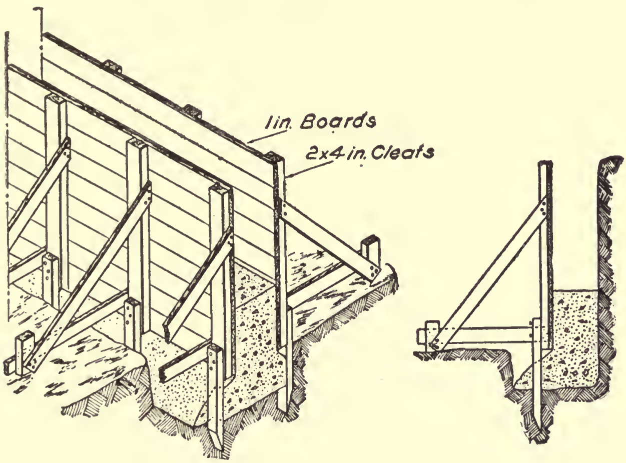

FIG. 17.—Simple Forms for Cellar Walls. This type is faulty in that the braces are nailed to the sides.

"As a rule it is best to drive a line of posts and to lay against them a heavy timber or thick plank. This provides a stiff support against which braces may be placed at any point when needed. At any sign of giving way in the forms, intermediate braces may be quickly introduced without the delay consequent upon driving new posts."

"Bracing is not good practice for the holding of wall forms in place." Failures of such forms are frequently caused by the giving way of the posts due to the yielding of earth. Earth is a poor material to depend upon for holding forms rigid, and bracing is only excusable when the form can be secured from but one side and that usually the outside. In all narrow forms, the studding on opposite sides should be tied together by bolts or wires.

In all braced forms, the posts against which the ends of the diagonals rest should be driven deep. "They should also be driven as nearly vertical as possible. The usual way is to drive them on a slant," but experience has shown that vertical posts are the stiffer, especially when the ground is poor. "The top soil is seldom able to carry much of a load," hence the brace should be driven deep in order that it may obtain sufficient anchorage.

Wired and Bolted Forms.—Forms, when used on both sides of a narrow wall, should be tied together by wires or bolts. The wire

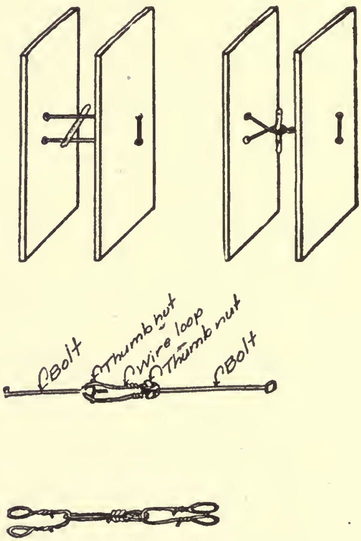

FIG. 18.—Showing Method of Wiring Forms.

is preferably passed twice through the forms, the ends twisted together and any surplus cut off with nippers, while the wire is tightened by twisting the two strands together inside of the forms, a stick being employed for the purpose. Before it is drawn up, a wooden spacer of length equal to the required width of the wall is placed beside the wire, where it is left until the concrete reaches that height, after which it is removed.

Wired forms are much more secure than those which are merely braced. They possess, however, the following objectionable features:

1. The ends of the wires are exposed when the forms have been removed.

2. The wooden spacers are sometimes left in the concrete.

3. The wire gives a little, as the concrete is tamped, causing the form to bulge. There is no practicable way of taking up this give.

To overcome these objections bolts are frequently employed instead of twisted wire. Wooden spacers can be removed as soon

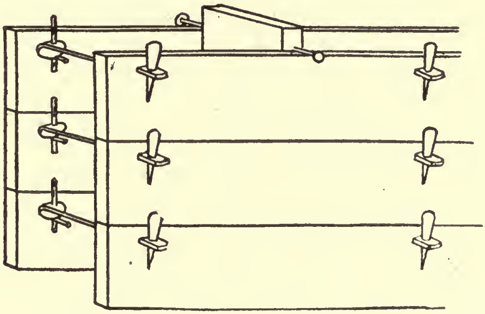

FIG. 19.—The Dietrich Plank Holders.

as the bolts are tightened, while the give can be taken up by tightening the nuts on the bolts. Such bolts are withdrawn after the forms have been removed and the holds are filled with cement paste mixed with some waterproofing compound. This method is, however, objectionable where an impervious seal is required, as the oil placed on the bolts to permit of their removal prevents a watertight bond between the post and the body of the wall.

To avoid this difficulty a number of arrangements are in use whereby two short bolts are connected to wire loops in the body of the wall. The wire loops remain in the wall, so that the main portion is solid and impervious, while the shallow holes, left on each side when the bolts are withdrawn, are filled with cement paste to preserve its sightliness. Mr. Ernest McCullough uses a device consisting of two thumb-nuts connected by wire loops into which the threaded ends of the bolts are placed. They are then screwed up until the head of the bolt bears against the face of the form, which is protected by a washer. See Fig. 18.

Forms Made of Studding and Matched Boards.—Two designs are in use:

1. Where the boards are nailed to the inside of the studding and the form erected as a unit.

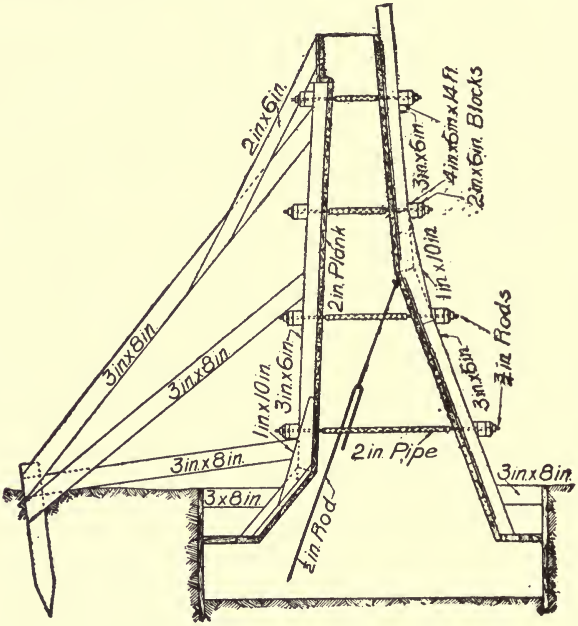

FIG. 20.—Forms for Reinforced Concrete Retaining Wall.

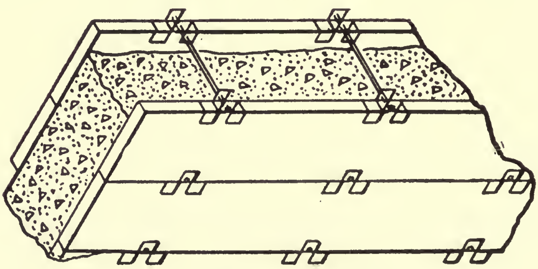

FIG. 21.—The Farrel Plank Holder.

2. Where the studding is erected and braced, and the boards set one at a time without nailing. This design is much more convenient for pouring, as the concrete is only the width of a board below the top of the form, which is built up as the work proceeds.

Good inspection, however, is required to insure proper construction and bracing where form work and placing of concrete are going on simultaneously.

Panel Forms are an amplification of the "board-by-board" method, several boards being fastened together and erected as a unit, or united by nails and braces into box-like forms. The following types are in general use:

a. The Ransome panel consists of a number of boards, which are fastened together by cleats on the back and held in position by slotted frames or studs. The studs are set opposite each other and are bolted through at top and bottom. Spacers are also set in position to keep the frames the proper distance apart. As soon as the panel has been filled with concrete, "the lower bolt is withdrawn,

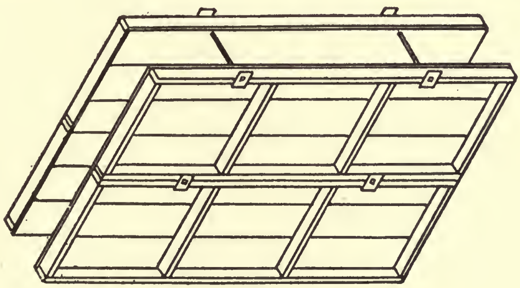

FIG. 22.—Panel Method of Framing for Wall Construction.

and the slotted frames raised to a height as great as may be obtained when the upper bolt reaches the bottom of the slot. The lower bolt is then passed through the upper part of the slot with a new spacer to preserve the interval, and work is recommenced."

b. Framed panels consist of 1-inch boards braced with 2 x 4 inch wales and uprights, the panels being about 12 feet long by 4 feet in height. For any wall at least two lines of panels are employed, and for high walls, three sets should be available to avoid delays to the work. The panels are braced by bolts and spacers. Bolts are placed at the top of the forms, and are provided with large washers which also bear against the bottom of the superimposed forms and hold them in position when placed.

Column Forms.—For columns it is customary to provide a vertical trough and to brace the forms by horizontal frames made of

2 x 4 inch stuff. These frames are of several types of which the following are in common use:

a. Timber frames which consist of four strips, one on each side of the column. These are held together by means of lugs and hardwood wedges.

b. Bolted frames which consist of two strips on opposite sides of the column form. These are tied together by bolts. The strips

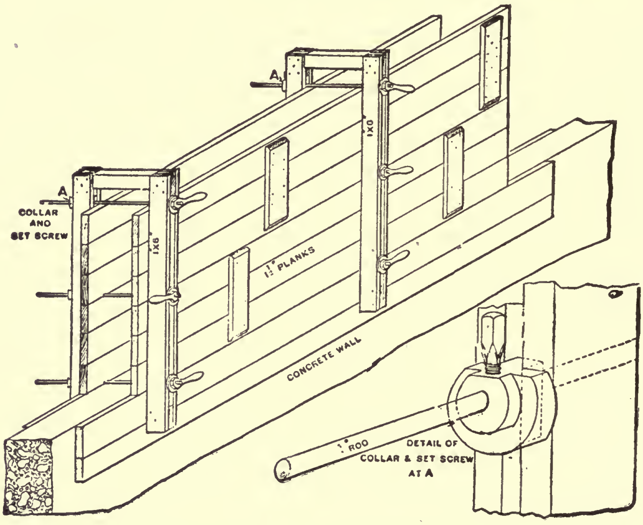

FIG. 23.—Movable Wall Forms.

exert pressure on opposite sides of the form, while the other two sides are secured by hardwood wedges between the bolts and the form. These are placed as close as possible to the ends of the bolts.

c. Clamped frames, in which metal clamps are used to hold the form together, as the Hennebique Column Form Clamp.

In some cases the sides of the form are made up of narrow strips. This is to facilitate the reduction in size of the columns from floor to floor. In warm weather there is no need of having more column forms than one complete set for one story. Each of the narrow strips represents the reduction in diameter of the column from one story to the next.

In removing forms the column moulds are taken down first. It is therefore necessary to so design the details about the tops of the forms as to permit of their removal without in any way disturbing the beam and girder moulds.

Beam and Slab Forms.—Beam forms are horizontal troughs made of 1 or 1 1/4 inch lumber. The bottom piece rests on two 2 x 4 inch stringers which in turn are supported by 4 x 4 inch caps resting on posts. The side pieces are braced with 2 x 4 inch horizontal strips at top and bottom, and by vertical and inclined

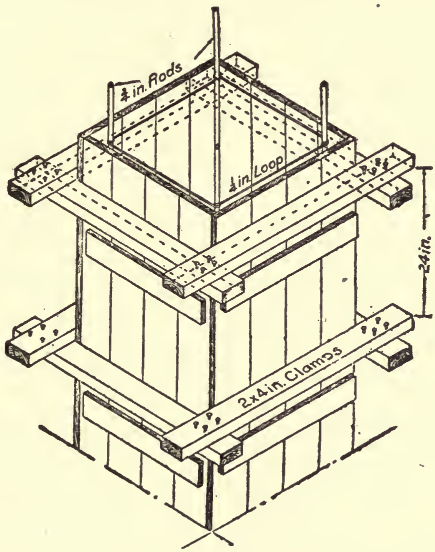

FIG. 24.—Column Form and Method of Bracing.

webbing of the same size. For shallow beams, a lighter construction can be employed.

When the floor slabs and their supporting girders are built monolithic, a 2 x 4 inch strip is nailed along the outside of the beam forms to carry the flooring for the slabs. Cross bracing is also wedged between the girder forms in order to stiffen the construction and to assist in carrying the loads to the parts under the girders which support the entire load. The middle of the floor slab form is further supported by a 2 x 4 inch piece resting on the cross bracing.

In removing beam and girder forms, the posts should be taken from only one girder at a time, and as soon as the form for this has been removed, the posts should be immediately replaced and wedged up. By this procedure, danger of failure of concrete through poor workmanship is much diminished, as a defective member is supported by the members on either side of it until the defect can be remedied.

"An essential thing about arch centres is that they must be perfectly rigid so that the arch will not be stressed in the slightest

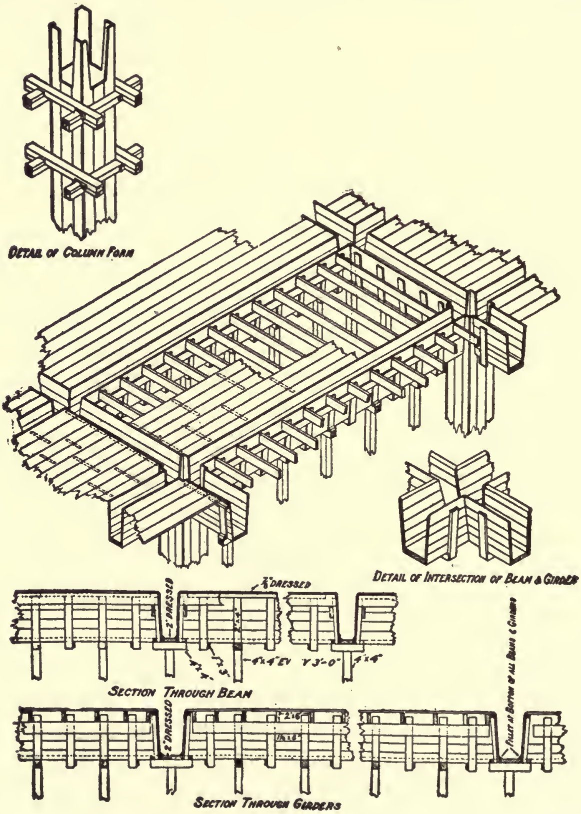

FIG. 25.—Typical Forms for Reinforced Concrete Factory Floors.

degree before the concrete attains a perfect set, and yet they must be so placed that their removal will be accomplished without injuring the surface of the concrete and without straining the arch. All centres must be dropped away from the arch readily. Salvage of material is an important item, but as a rule the salvage is higher with arch centres than with forms for buildings. Much of the material consists of posts and sway braces, and these require but little cutting."

Special Forms.—Pressed steel forms are used to a limited extent in concrete column, girder, and slab construction and their use is likely to increase in the near future on account of the rapid rise in the price of lumber. The chief difficulties in the use of such forms are their liability to leakage, tendency to rust and possible injury by dents in removing.

Centering.—Collapsible centres which consist of a steel or timber shell supported by interior bracing and so constructed that the shell can be readily removed and placed in a new position are extensively used for pipes and conduits. Several forms are built, of which the following are examples:

Half round steel centres on circular conduits.

Full round steel centres for monolithic construction.

Box centres for concrete culvert construction.

Shaft lining and tunnel centering.

Centres for cut and cover conduit construction.

A facing form is a steel plate which is placed on edge at the proper distance back from the lagging and the space between filled with facing mortar. The form is finally lifted up and the backing and facing thoroughly bonded by tamping them together. It is used when a mortar finish is required, of greater thickness than can be obtained by spading the coarser aggregate back from the surface of the forms.

Pressure of Concrete on Forms.—The forms for concrete must be strong enough to withstand the pressure of the "soupy" mass, and girder forms must be stiff enough so that their deflection as the weight increases will not cause partial rupture of the concrete or sagging of the beam.

Experiments have shown that forms designed on the assumption that the pressure produced by wet concrete is equivalent to that of a fluid weighing 80 pounds per cubic foot are reasonably safe.

"In ordinary walls where the concrete is placed in layers, computation is not usually necessary, since general experience has shown that maximum spacing for 1-inch boards is 2 feet, for 1-1/2 inch plank is 4 feet, and for 2-inch plank is 5 feet. Studding generally varies from 2 x 4 inches to 4 x 6 inches, according to the character of the work and the distance between the horizontal braces or walling."

Dressing and Lubrication of Forms.—Dressed lumber should be employed for all exposed surfaces in order to give a smooth finish. Dressed timber also permits tighter joint construction, and facilitates the removal and cleaning of the forms.

All forms for concrete require a coating of some lubricant to prevent the concrete from adhering to the wood with which it comes

TABLE VI.

Showing the Pressure on Forms Produced by Concrete at Various Depths.

Depth in Feet.	1	2	4	6	8	12	16	20	24
Pressure on Vertical strip, 1 foot wide in pounds......	40	160	640	1440	2560	5760	10240	16000	23040
Pressure on 1 square foot in pounds..............	80	160	320	480	640	960	1280	1600	1920

in contact. Crude oil is generally employed for the purpose, but any grease that will spread evenly and fill the pores of the wood will answer equally well. The use of lubricants reduces the cost of removing the forms and also gives a smoother finish to the concrete. Forms should not be removed until the concrete has attained sufficient strength to carry the load. Wet concrete sets more slowly than dry mixtures, and concrete is slower setting in cold weather than it is when the weather is warm.

For walls, the forms should be left up from 1 to 5 days; for slabs, from 6 days to 2 weeks; for beams and girders, from 2 to 4 weeks; and for large-sized arches, from 1 to 3 months.

Design of Forms.—The following formula is employed in designing forms and is recommended by Sanford E. Thompson: Assume

1. Weight of concrete, including reinforcement, 154 lbs. per cu. ft.

2. Live load—75 lbs. per sq. ft. upon slab; 50 lbs. per sq. ft. in figuring beam and girder forms; and struts.

3. For allowable compression in struts use 600 to 1,200 lbs. per

sq. in., varying with the ratio of the size of the strut to its length. If timber beams are calculated for strength, use 750 lbs. per sq. in., extreme transverse fibre stress.

4. Compute plank joists and timber beams by the following formula, allowing a maximum deflection of 1/8 inch:

$$d = \frac{3}{384} \frac{W l^3}{E I} \quad \ldots\ldots\ldots \quad (1)$$

and

$$I = \frac{b h^3}{12} \quad \ldots\ldots\ldots \quad (2)$$

in which

d = Greatest deflection in inches.
W = Total load on plank or joist in pounds.
l = Distance between supports in inches.
E = Modulus of elasticity of lumber used.
I = Moment of inertia of cross-section of plank or joist.
b = Breadth of lumber.
h = Depth of lumber.

For spruce lumber and other woods commonly used in form construction, E may be assumed as 1,300,000 pounds per square inch.

Formula (1) may be solved for I, from which the size of joist required may be readily estimated from formula (2).

Time to Move Forms after Placing.*—The proper time for removing forms depends upon the character of the construction. The following rules are applicable to ordinary practice:

Walls in mass work: one to three days, or until the concrete will bear pressure of the thumb without indentation.

Thin walls: in summer, two days; in cold weather, five days.

Slabs up to 6 feet span: in summer, six days; in cold weather, two weeks.

Beams and girders and long span slabs: in summer, ten days or two weeks; in cold weather, three weeks to one month. If shores are left without disturbing them, the time of removal of the sheeting in summer may be reduced to one week.

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* By Sanford E. Thomson.

Column forms: in summer, two days; in cold weather, four days, provided girders are shored to prevent appreciable weight reaching columns.

Conduits: two or three days, provided there is not a heavy fill upon them.

Arches: of small size, one week; for large arches with heavy dead load, one month.

All of these times are, of course, simply approximate, the exact time varying with the temperature and moisture of the air, and the character of the construction. Even in summer during a damp, cloudy period, wall forms sometimes cannot be removed inside of five days with other members in proportion. Occasionally, too, batches of concrete will set abnormally slow either because of slow-setting cement or impurities in the sand, and the foreman and inspector must watch very carefully to see that the forms are not removed too soon. Trial with a pick may assist in reaching a decision.

Beams and arches of long spans must be supported for a longer time than short spans because the dead load is proportionately large, and therefore the compression in the concrete is large even before the live load comes upon it.

Cost of Forms.—The cost of form work per cubic yard of concrete depends largely on the thickness of the walls. With very thin walls the cost for forms is comparatively high, and for such work a method of estimating which is based on the surface area should be employed.

There are three methods of estimating the cost of form work:

1. In cents per cubic yard of concrete.
2. In cents per square foot of surface area of concrete.
3. In dollars per 1,000 ft. B. M. of lumber used.

The cost of form work is made up of the cost of the lumber and the labor of framing, erection, and removal of the forms. Lumber costs from $20 to $30 per 1,000 ft. B. M., and if used three times, the cost of the lumber will range from 2 to 3 cents per square foot of surface area of concrete.

Ordinary forms for walls and mass work can be erected and taken down for $10 per M. For beams and arches the labor cost is much higher. Such work cannot be even approximately estimated from any rule of thumb, but must be carefully computed from the detailed plans of the structure; taking account of the size of the job, the special difficulties to be overcome, and the prevailing cost of common and skilled labor in the locality.

SECTION II

CONCRETE ARCHITECTURE

CHAPTER IX

THE ARCHITECTURAL AND ARTISTIC POSSIBILITIES OF CONCRETE

A New Style of Architecture.—For a century or more architects have been vainly trying to create a new style of architecture; back and forth they have vacillated, but never forward. They have tried every possible combination of the ancient masterpieces but without results; and it seems that again, as in the fable of old, the hidden treasure was not in foreign lands but right at our own door,—beneath our very feet. It is a recognized principle of architecture that *the material* of which a structure or monument is made is (after the idea or need that called it into existence) the main factor in determining the form, color, and structure of the monument. This being true, it is likely that a material, having so many characteristics that no other material has, is certain to introduce many new features into a structure and finally create a new style of architecture; and this is especially probable because designs hitherto attainable in other material only at great expense, can be obtained so cheaply in concrete.

It is so easy to obtain very high ornamentation in concrete that it is necessary for the artist to exercise self denial in refraining from unmeaning display for the sake of show. The popular notion that architecture is the heaping of pretty things onto a structure to hide its construction is wrong. True art is always the result of a clear and forceful expression of the idea and use of the structure. Expression in art must be obtained by making some parts plainer than others, thus bringing out the richness or elegance of the main idea. Make your structure look like what it is,—concrete; solid, strong, substantial, beautiful. The ornamentation chosen tastefully to accord with the idea expressed and with the natural surroundings, construct with a feeling of modesty, dignity, simplicity, and repose, and you will have a design alive with purpose that will live through the ages.

Mr. R. VanDeerlin, Chief Engineer, Hennebique Construction Company, says:

"Concrete, with the aid of steel, is adaptable to almost every kind of structure, not only economically but architecturally. Unfortunately it has been handicapped by the attempt to force it to imitate other materials. This probably results from its plasticity and reluctance to depart from well recognized methods of architectural design. Being generally composed of stone for an aggregate, it somewhat naturally suggests that the same line of design would be appropriate for concrete as has become the recognized standard for stone. Such, however, is not the case, as there is a material difference in the general appearance. After the temptation to imitate is overcome the plasticity of concrete makes it not only an excellent building material but also an architectural one as well.

"The most striking examples of architectural beauty are noted for their simplicity and freedom from confusing details and effects that distract the attention from the keynote of the design. Previous to this century, the limitations of building operations have made it necessary to have the size of the units of construction small in order to keep the cost within bounds. This gave definite construction joints which were accentuated and developed along certain lines to create certain impressions. Now that concrete is available, it is no longer necessary to have these lines or joints and they can be eliminated entirely or used only where they are really an architectural benefit. Simplicity in concrete design is to be desired also from an economical standpoint, because one of the most expensive items in concrete construction is the form work. The cost can be trebled easily if the forms are complicated.

"*The future of concrete treated architecturally lies in a development on surfaces and not lines.* Who, for instance, would prefer a concrete bridge, built to represent one of cut stone to one where the concrete is honestly shown on pleasing surfaces, free from the lines which are supposed to represent the joints of the stones, and only showing the lines which are there for purely architectural reasons.

If it were possible to economically eliminate the joint lines from the stone bridge, it is very probable that no one would ever have attempted to use similar artificial lines for effect. Compare a concrete tower treated as a monolith with one built to imitate stone. The plain surface is far more pleasing than the other. Compare also the many pleasing concrete-surfaced houses with those constructed with the rough concrete blocks.

"When the problem of arranging the structural parts of a building is considered, there is no material that so readily lends itself to the

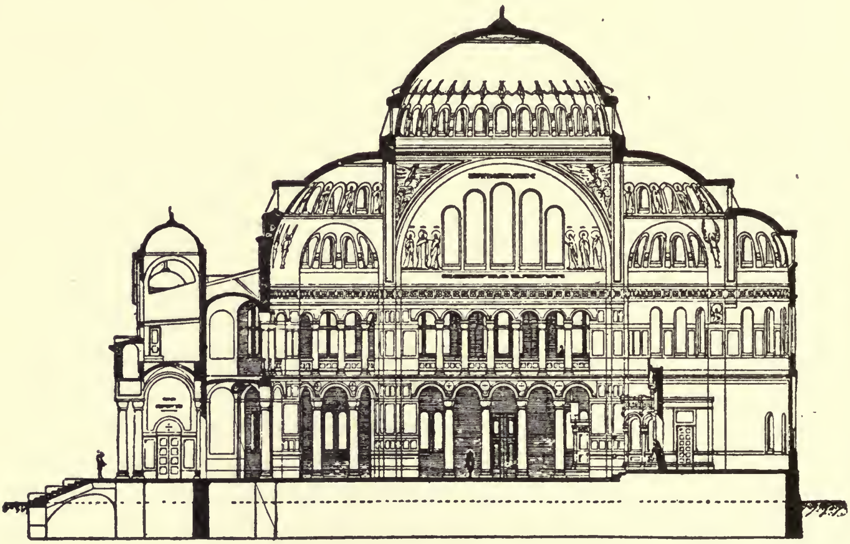

FIG. 26.—Section of Reinforced Concrete Cathedral at Poti, Russia. Showing Architectural Possibilities on Important Edifices. (Hennebique.)

required adjustment as reinforced concrete, both economically and effectively. If a perfectly flat ceiling is desired, the structural floor can be designed in the mushroom system or constructed with terra-cotta and concrete. The slight additional expense of these two methods over an ordinary slab-and-beam construction is less than the cost of an expanded metal lath and plaster ceiling, as plaster can be very easily applied directly to the surface of either. If the rooms are small the doubly armed panel allows them to be freed from projecting beams as the beams can be placed over the partitions. This system is also adaptable to large rooms, where paneled ceilings are desired."

Concrete block architecture and handsome stucco effects, both of which are treated in succeeding chapters, have come into extensive use, the former now emerging from a period of doubt and suspicion following the influx into the market of poorly made material, a question which will be discussed later on.

The preparation and artistic treatment of concrete surfaces have done a great deal in developing the architectural possibilities of concrete, and much credit is due to the pioneers in bringing out the many beautiful surface finishes. It is only necessary to go to sections like Long Beach on the Long Island southern coast and see the varied styles of beautiful concrete residences, to realize that a new architecture has been born, which, owing to its economy and fireproofness, as well as beauty, will supplant the classics of bygone days.

CHAPTER X

CONCRETE RESIDENCES

The Use of Concrete for Residences.—Best Method of Obtaining Architectural Effects.—Stucco and Reinforced Concrete for Residences.—The Edison Poured Concrete House: Cost of Different Types of Residences Compared.

As stated in the previous chapter, the architectural treatment of concrete, until recent years, was limited to an attempted imitation of stone masonry, which tended to cheapen its appearance and to destroy its character. As an imitation of stone, concrete is not an artistic success. There is a sameness to its appearance, an air of sombreness, an absence of light and color that destroys its architectural value.

Within the present century the secret of the artistic use of concrete has been revealed, and with this discovery has come such recognition by architects and owners alike, that concrete has already taken its place within the front ranks of building materials, and its growing use is indicative of a future whose possibilities and benefits to humanity are transcendent.

The secret of the successful use of concrete for architectural purposes consists in such treatment of its surface as will serve to bring out its true character and to reveal its hidden beauties. These methods are in part described in the chapter on "Artistic Treatment of Concrete Surfaces," and consist in the use of carefully chosen aggregates; tooled, scrubbed, etched, or pebble-finished surfaces, stuccos of varied tints and textures; the artistic use of half-timber framing, of columns, cornices, pediments and balusters to lend variety; and an attractive shingled or tiled roof to form an effective covering.

Concrete is now employed in the construction of all classes of residences, such as bungalows, costing from $500 to $1,000; cottages, from $1,500 to $2,500; moderate priced houses from $3,000 to $5,000; and palaces in which the cost of construction requires five, six, or even seven figures for its expression.

Kinds of Concrete Residences.—In these different classes of residences, Portland cement mortar and concrete are used in one or more of the following forms:

1. Hollow concrete blocks.
2. Monolithic concrete.
3. Stucco.

Concrete Block Residences.—Hollow concrete blocks have outnumbered all other forms in which concrete is employed in residential construction, owing to their cheapness and ease of construction. Their description and manufacture will be found in Chapter XIII.

Early manufacturers of concrete blocks were unfortunate in trying to mould the surfaces in imitation of quarry-faced stone, and the effect of their efforts was to produce a structure without beauty or variety. "A rock-faced stone is the result of an actual treatment of the stone with tools, and no two rock-faced stones are alike. There is variety to the surface." But with concrete blocks the variety is lacking. "Even when several rock-faced moulds are used and the blocks are made of different patterns, it generally happens that several having exactly the same face from the same mould come together, and that is exceedingly noticeable."

Surface Finishes for Block Residences.—The best architectural effects in concrete block residences are produced with the following surfaces:

1. Perfectly plain surfaces.
2. Roughened, or pebble-finished surfaces.
3. Surfaces produced by casting in sand moulds.
4. Surfaces of pure white color or delicately tinted.

Some of the finest, as well as the least expensive residences are now constructed of plain blocks, the façades being relieved by columns and cornices in moulded concrete, the roofs covered with ornamental tiles of red or other warm tones, and the piazzas having concrete rails and balusters of appropriate design.

Roughened surfaces are produced by scrubbing, etching with acid, and treating with wire brushes, the object being to destroy the film of surface cement and to expose the aggregate. By the use of granite chips, colored gravel, crushed marble, or coarse white sand, various effects are obtained, and the architect who possesses originality and a knowledge of the possibilities of his material, can produce striking and artistic effects at a very moderate cost. These will be treated further in Chapter XII.

Casting in sand moulds is generally confined to mouldings, balusters, columns, and other ornamental features. "Sand moulding gives, perhaps, the handsomest ornament of any kind of moulding process, the surface texture and detail of the block being especially fine."—(Gillette.)

Surface tints are best produced by the use of colored gravels. Pure white surfaces are obtained by using facing mortars composed of white limestone or crushed white marble and white Portland cement. Such mortars can also be tinted with delicate colors by the use of appropriate pigments.

Monolithic Residences.—Houses having solid walls of monolithic concrete are best treated by making the surfaces of the walls unbroken without attempting to imitate masonry or joints in stones.

The following methods of surface treatment, which are more fully explained in Chapter XII, are well adapted to such construction:

1. Spading the concrete so as to cause the grout to flush to the surface of the forms. This prevents the exposure of the aggregate and any defects can be remedied by trowelling and grouting after the forms have been removed.

2. Roughening the surface by scrubbing, etching with acid, tooling with bushhammers or pneumatic hammers, etc.

3. Use of colored aggregate or of granite chips, white quartz pebbles, or other special materials which are exposed by scrubbing or tooling.

4. Surfacing with mortar or stucco.

5. Tinting.

Stucco Residences.—Any mortar employed as an exterior surfacing for walls is called stucco. Cement stucco is extensively used both for renovating old buildings and improving their appearance and in new construction. The methods of application are fully described in the succeeding chapter.

The classes of residences in which a stucco finish is of advantage are as follows:

1. Old houses composed of wood, stone, brick, concrete, or other materials in which the surface is worn or decayed.

2. New houses composed of wood, stone, brick, concrete, or other materials, in which the surface is left rough or unfinished.

3. Houses having hollow walls of expanded metal, terra cotta or concrete tile, or other fabric, and covered inside and out with mortar or stucco.

Portland cement stucco is easily applied to any material such as wood, brick, stone, etc., by covering the surface with a metal fabric over furrowing strips to serve as an anchorage for the mortar. Wooden lathing can also be employed for this purpose, and in the case of frame houses spaces can be left between the boards to serve as a key.

Stucco is composed of: (*a*) cement and sand; (*b*) white Portland cement and either white sand, crushed white quartz, ground marble, or ground white limestone; (*c*) cement and granite chips; (*d*) cement and colored gravel; (*e*) cement and pebbles, etc. White stucco is also readily tinted with delicate colors by the admixture of colored pigments.

Concrete for residences, whether in the form of hollow blocks, or monolithic walls, requires waterproofing. Basement walls should be surrounded by a bituminous shield, or a waterproofing compound should be mixed with the cement employed in the blocks or walls since it is desirable to render the entire exterior surface as impervious to moisture as possible. In old leaky buildings, a coat of damp-resisting paint on the exterior surface will be effective.

Reinforced Concrete, which is extensively employed in factory construction, is coming into use for dwellings in order to permit of lighter walls and partitions. The reinforcement is chiefly in the form of expanded metal or other fabric which is nailed to the studding on both sides, thus forming a support for the plastering. In pretentious houses, rods are also employed to distribute the loads over foundation areas and to prevent temperature cracks. Concrete beams are employed only to a limited extent in residences, as the interior joists are almost invariably of wood, as are also the floors, purlins, rafters, and roof trusses. While this is the present practice, it is, however, no criterion of the state of the art a few years hence, when it is probable that the "all-concrete" house will have ceased to be a novelty.

Special Architectural Features.—At present concrete is used to a limited extent for roofing purposes in the form of slabs and tiles, although red terra cotta tiles and wooden shingles are chiefly employed for pitched roofs and tin plates or gravel for flat roofs.

Concrete houses, especially those of a suburban character, are frequently built with a prominent roof of steep pitch, large piazzas, bay-windows and the English half-timbered construction above the lower stories. This consists of wooden strips around the windows forming the trim and radiating from the upper windows to the roof. These strips are also used as mouldings and serve to bring out the lines of the gables, adding much to the appearance of the dwelling.

Other decorative features of concrete houses are the columns, rails, and balusters of the piazzas which may be of wood or concrete, preferably the latter; the free use of dormer windows in the roof, chimneys of concrete blocks or of monolithic construction in harmony with the general design, horizontal mouldings between the stones, prominent lintels, and massive cornices.

The use of concrete in interiors is at present confined chiefly to stairs, panels, fireplaces, and bath rooms. Stairs are reinforced with bars and surfaced with a white mortar or are tinted to harmonize with the woodwork of the halls; fireplaces are built of concrete bricks moulded and tinted to any desired shade; while concrete slabs and tiling or mosaic laid in white Portland cement mortar is used for mosaic floors, wainscoating, bath-rooms, and fireplaces, taking the place of Keene's cement which it excels in strength and durability.

Edison Cast Concrete House.—Thomas A. Edison, the electrical wizard, has experimented for several years in developing a substantial and cheap house of cement, and has published the following particulars of his work:

"I believe a cement house can be built by machinery in lots of 100 or more at one location for a price which will be so low that it can be purchased or rented by families whose total income is not more than $550 per annum. My experiments have proven that it is possible to cast a house complete in six hours by pouring a very wet mixture of gravel, sand, and cement into iron moulds having the form of a house, and after the removal of the forms or moulds, leave standing a complete house with a fine surface, plain or ornamental, all in one solid piece, including the cellar, partitions, floors, roof, stairs, mantels, veranda—in fact everything except the windows and doors, which are of wood and the only parts of the house that are combustible.

"The house is to be heated by boiler and radiators in the usual manner, the plumbing to be open and jointed by electric welding.

"The experimental house has the partitions arranged to give, besides the cellar, two rooms on first story (one to be used as a living room and the other for a kitchen); the second story to have two rooms and bath; the roof story to have two rooms. When large numbers of houses are made, the partitions can be changed to make more rooms. Once the house is cast, however, no changes can ever be made—nothing but dynamite could be used to remove a partition without great expense.

"With a few simple additions to the iron forms, a great many variations in the type of the houses can be made. For instance, by adding or subtracting iron sections, the house can be made smaller and cheaper. By adding sections, the number of stories can be increased, or it can be widened or lengthened. By a few additional forms, the whole appearance of the veranda can be changed. A contracting company having the smallest unit possible to permit of cheap and rapid production, must have six sets of moulds with the other necessary machinery. From these iron sections almost any variation in the size, appearance, and ornamentation of the row of houses can be made. The concrete could be tinted with any kind of color, but the general type would be the same. The units might be divided and thereby three complete moulds for one type of house and three sets for an entirely different type, would be secured.

"This scheme of constructing houses cheaply and in quantities does not permit of the building of one house at a time, for the reason that the moulds are heavy. The machinery necessary to handle the materials as well as for the erection of the iron moulds, is large and expensive.

"The hardening of the cement requires four days. While one house was hardening the men would either have to remain idle or be laid off during this period, and this would not be practicable; whereas, if the full unit of a minimum of six sets of moulds, and machinery was in operation, the thirty-seven men necessary could be employed continuously erecting, pouring, and removing forms from one lot to another, at a minimum of expense.

"Houses of this type, I believe, can be built for $1,200 each, in any community where material excavated from the cellar is sand and gravel, so it can be used. If the sand and gravel must be obtained elsewhere, the cost will be much more. A change in the forms can be made so that a house can be built that will look just as well, but smaller, at a less cost. On the other hand, by addition to the forms, houses costing $2,000 or $3,000 or more can be built.

"To give a rough idea of the cost, I estimate that six sets of iron forms for the house I am to build will cost about $25,000 per house —a total cost of $150,000. The cranes, traction steam shovel, conveying and hoisting machinery, I estimate, will cost $25,000 additional, making a total investment of $175,000. With this machinery twelve (12) houses per month can be made every month in the year, with the aid of one foreman, one engineer, and thirty-five (35) laborers. This gives one hundred and forty-four (144) houses per year for the unit. If I can prove this, then the labor cost per house will not exceed $150 each.

"If we allow 6 per cent interest and 4 per cent for breakage on the cost of the forms, and 6 per cent interest with 15 per cent depreciation on machinery, the yearly expense will be about $20,000. Dividing this into the 144 houses built in the year, gives approximately $140 per house, for cost of moulds and machinery. 220 barrels of cement will be mixed with the sand and gravel excavated from the cellar, and will provide sufficient material to build the house. Allowing $1.40 per barrel for cement, adds a further sum of $310. The reinforcing steel rods cost $125; and the heating system and bath $150. These items total $875. This leaves a margin between that sum and $1,200 of $325 to provide for doors, windows, etc., painting, and the correction of any possible defects.

"If the houses are smaller and 225 can be built in the year for the same investment and labor, it will, from the above data, be easy to approximate the cost per house; the same is true with larger size houses.

"These houses will be waterproof and dampproof. The roofs, after the forms are removed, are painted with a paint made of cement tinted with red oxide of iron, which hardens and never deteriorates. Cement can be tinted to any color and any shade of that color, and the inside or outside can be painted, and is permanent. The cost of the paint for the whole house, inside and out, including roof, will be very small.

"Should the experiment succeed, I will, without cost, furnish all plans, give full license to reputable building corporations without cost, as I am not making these experiments for money.

"I think the age of concrete has started and I believe I can prove that the most beautiful houses that our architects can conceive can be cast in one operation in iron forms at a cost, which by comparison with present methods, will be surprising. Then even the poorest man among us will be enabled to own a home of his own—a home that will last for centuries with no cost for insurance or repairs, and be as exchangeable for other property as a United States Bond."

The following table, compiled by the National Fireproofing Co., gives a good idea of the comparative cost of various classes of residences.

COMPARATIVE COST OF VARIOUS TYPES OF RESIDENCES.

(*A* $10,000 *frame residence is taken as a unit.*)

Frame construction, all wood.	$10,000
Brick outside walls, wooden interior.	11,000
Stucco or expanded metal, wooden interior.	10,250
Hollow terra cotta blocks, stuccoed, wooden interior.	10,500
Hollow terra cotta blocks, stuccoed, fireproof throughout, except roof.	12,000
Hollow terra cotta blacks faced with brick, fireproof floors.	14,000
Brick walls, fireproof floors.	15,000

Houses can be built with terra cotta blocks for walls and floors with wooden roofs at a cost of twenty-two cents per cubic foot; if built with wooden floors and roof, at eighteen cents per cubic foot.

CHAPTER XI

MORTARS, PLASTERS, AND STUCCOS, AND HOW TO USE THEM

The Art of Stuccoing.—Lime Mortars and Plasters.—Interior Plasters and Plastering.—Gypsum Plasters.—Portland Cement Plasters or Stucco.—Exterior Lathing and Plastering.—Application of Stucco to Stone.—Stucco on Brick.—Stucco on Concrete.—Quantities of Materials for Stucco.

THE art of using mortars is as old as civilization; the pyramids of Egypt contain plaster work executed at least four thousand years ago; very early in Greek architecture a true lime stucco of thin white composition was employed as a ground on which to paint their decorative ornament; the Romans were familiar not only with lime and plaster, but with hydraulic cement as well.

There is every reason to believe that originally these stuccoes were intended to cover up and protect inferior building stone and sunburned straw brick. The archæology of stucco would tend to show that from an artistic standpoint this method of decoration was a development of the wattled buildings, which were plastered with clay and different muds hardened by being baked in the heat of the sun. Therefore, in this instance, the use of clay plaster over wattled houses was to protect an inferior building material.

At the present time, mortars and plasters are among the most familiar materials employed by the builder. These consist of three general classes, which, however, grade into each other when mixed in different proportions:

1. Lime plasters.
2. Gypsum plasters.
3. Portland cement plasters or stucco.

Lime is used for interior plastering where the walls are to be papered; gypsum or plaster of Paris, where a white or hard surface is desired; and Portland cement mortar for exteriors where strength and durability are required.

Lime Mortars and Plasters.—As already explained in Chapter II, lime is produced by heating a pure or nearly pure limestone in a kiln to such a temperature as will drive off the carbonic acid gas and leave calcium oxide or "quick lime." When water is added to quick lime it changes from a lumpy condition to a soft, impalpable powder known as "slaked lime." When more water is added, the slaked lime becomes a paste, and this paste is mixed with sand to form a mortar.

Mortar for plaster work is usually composed of slaked lime, mixed with sand and hair. The sand should be hard, sharp, gritty, and free from all organic matter. Pit sand is generally sharp and angular and is preferable to river and sea sands, which are more rounded and are apt to contain saline particles that may cause efflorescence.

Hair is used as a binding medium to increase the cohesion and tenacity. Good hair should be long, strong, and free from grease or other impurities. Ox hair is generally used, although sometimes adulterated with the short hair of horses. Substitutes for hair include manila fibre and sawdust.

Interior Plastering.—Lime mortar, when used as a plaster for walls and ceilings, is placed preferably in three coats on wooden or metal laths. On brick or tile walls, and in residence construction two coats are often considered sufficient, and for rough plastering, one coat. Three-coat work makes a straight, smooth, strong, and sanitary surface for walls and ceilings when properly executed. The processes employed for the different coats are as follows:

1. Scratch coat.
2. Brown coat.
3. Finish.

First or Scratch Coat.—The first or scratch coat should be from 3/8 to 5/8 of an inch thick, composed of 1 part of lime paste to 2 of sand, and 1 bushel of hair to 2 of lime. The plaster should be stiff enough to cling and hold up when laid, yet sufficiently soft and plastic to go through the interstices between the laths, leaving a trowelful partly overlapping the previous one, the one binding the other.

Scratching consists in scoring the surface of the first coat to obtain a key for the following one. It is done with a wooden or iron scratch, which may have from one to five points. The first coat should be allowed to stand for an hour or two so as to allow the stuff to become firm, after which the surface is cross-scratched diagonally, the scores being about 1 1/4 inch centre to centre. Scratching with a single point is more easily controlled and less likely to make the scores too deep than is the case where a four- or five-pointed scratch is used. It requires, however, considerably more time for the operation. Scratching with the point of a trowel should not be permitted. The use of a trowel as a scratch is detrimental to the strength of the mortar, as its sharp edge cuts the hair. It also leaves a smooth and narrow key, which presents no means of attachment for the second coat.

When the first coat is applied to brick, stone, or concrete walls, the superfluous mortar in the joints should be raked out and the walls roughened to form a bond; the walls should also be well swept and thoroughly wetted to prevent the absorption of water from the mortar.

Second or Brown Coat.—The brown coat should be from 3/8 to 5/8 of an inch thick and should contain 1 part of lime to 3 of sand and 1 bushel of hair to five of lime. Before the second coat is applied, the scratch coat should be well swept to clean off any dust that may have accumulated and a damp brush passed lightly over the surface to prevent the absorption of moisture from the second layer. The object of the second or brown coat is to form a straight surface for the finishing coat. The process consists of the following operations:

a. Plumbing and levelling "screeds" to act as bearings for the floating rule and running mould.

b. Filling in the spaces between the screeds.

c. Scouring.

d. Keying the surface for the finishing coat.

Screeds are the guides on the margins of walls and ceilings between which the plastering is placed. They consist of narrow strips of plaster, which are leveled in the case of a ceiling, or tested by plumb line in the case of a wall. Large surfaces on walls or ceilings should be divided into bays by narrow screeds placed from 6 to 9 feet apart. This affords more freedom and regularity for filling in and ruling off the bays.

Filling in consists of laying the intervening spaces between the screeds with mortar, and then ruling the surface straight and flush with the screeds by means of a floating rule. In this operation, two men are required for each bay. These work the rule up and down with a cutting motion, keeping it in a slightly angular position, so that any surplus stuff will not fall on the man below. A rule should not be worked on either of its face edges, as by so doing it becomes round and uneven. The filling in and ruling off is continued until all the walls are completed.

Scouring.—This consists in consolidating the surface by sprinkling it with water and rubbing it vigorously with a hand float. The work should be done as soon as the surface is firm and before it becomes dry. The operation is of great importance, as it tends to prevent cracks in its own body and in the subsequent or finishing coat. The float is applied with a rapid circular motion, using a little fine mortar to fill up any small holes or inequalities that may have been left after the floating rule. The floating should be scoured twice, or for best work three times. The final scouring should be continued until there is little or no moisture left on the surface. From three to five hours should be allowed to elapse between the first and second scouring; and at least twelve hours between the second and last.

Keying.—This consists in roughening the surface by means of a wire brush or a hand float with the point of a nail projecting about 1/8 inch beyond its sole. A tool, called a "devil" is also employed for this purpose, and consists of a small float with four nail points projecting from the sole.

Third or Finishing Coat.—The application of the final coat consists of three operations, as follows:

a. Laying.

b. Scouring.

c. Trowelling.

The material employed for the final coat is called setting-stuff and consists of lime putty and washed, fine, sharp sand, in the proportions of 3 parts of sand to 1 of putty. Lime putty may be kept for an indefinite time without injury if protected from the atmosphere, but when exposed an inert crust is formed by the action of the carbonic acid gas which it absorbs from the air.

The setting stuff is laid in two coats, the second following immediately upon the first. The laying is best done with a skimming float, which leaves the face of the first coat rougher to receive the second than if done by a laying trowel. The second coat should also be laid with a skimming float, which leaves a more open grain for the purpose of scouring.

Scouring the Finishing Coat.—This consists of sprinkling with water and rubbing vigorously to consolidate, harden, and render the surface of a uniform texture and evenness. The work should be well and thoroughly scoured, twice with water and an ordinary hand float and finally with a cross-grained float, which, having sharp square edges, cuts off all inequalities and leaves the setting with a uniform and even surface. The scouring is continued until a dense, even and close-grained surface is obtained for the trowelling.

Trowelling.—This is the final operation and follows immediately after the scouring. The plasterer sprinkles water on the surface and works the trowel in long and vigorous strokes, first downwards and upwards, and then crossways or diagonally. Water is applied with a brush, and the operation is repeated, using the water more sparingly, and finishing or trowelling off with an up-and-down motion which should leave the surface free from "fat" or "gleet." The finishing coat should average 1/8 of an inch in thickness, and should not be less than 1/6 nor more than 3/16 of an inch. If too thick, it is liable to crack and flake; and if too thin, to peel. Where extra strength is desired, the first coat of the setting should contain a little white hair, which does not show through the last coat.

Colored Finish.—A beautiful color and brilliant finish for walls may be obtained by mixing an equal quantity of sifted marble dust with setting stuff and using this as a final coat. Ordinary finish is greatly improved by substituting a part of marble, alabaster, or gypsum dust, equal in bulk to half the sand generally used. The marble dust should be as coarse as the sand. Brick dust is also used for coloring, while ground glass, when added, produces a sparkling surface. Any of the pigments employed in coloring stucco can also be used for tinting the finishing coat.

Gypsum Plasters—Gypsum is a sulphate of lime, and when heated so as to drive off the water of crystallization, and ground to a powder, it acquires the property of hardening on the application of water, with which it combines in the proportion of about 4 parts of gypsum to 1 of water by weight. When prepared for the use of the plasterer, gypsum is commonly called plaster or plaster of Paris. The finest gypsum is called alabaster, which is soft, pure in color and fragile, and is used for making statuary, vases, and ornaments.

Gypsum plasters produce a hard, white surface of fine texture and are used for all plastered walls and ceilings unless intended to be covered by paper. They are extensively employed in the following classes of construction:

1. For walls and ceilings, applied in two or three coats.
2. Applied as a finishing coat over Portland cement mortar.
3. Applied as a finishing coat over lime mortar.
4. As a cement for ceramic tiles, mosaics, etc.

Gypsum plasters are also of the following types:

a. Plaster or plaster of Paris.

b. Ready-mixed plasters.

c. Keene's, Parian, Martin's and other white cements.

Plaster of Paris is prepared by calcining or heating gypsum, thus driving off some of the water which it contains. When plaster is again mixed with water, they re-combine to make gypsum and the minute crystals of this substance in forming, interlace and cause the plaster to set.

Ready-mixed plasters, containing plaster of Paris, mixed with the proper proportions of sand for scratch, brown, or finishing coats, are put up by manufacturers in various parts of the United States. Among the advantages which are said to accrue from their use may be mentioned: uniformity in strength and quality, extra hardness and toughness, freedom from pitting and saving in time.

The white gypsum cements, such as Keene's, Parian, and Martin's, are employed for their hardness and strength.

The operation of *plastering with gypsum cements* and plasters is essentially similar to that which has been described for lime. From two to three coats are employed, and these are floated, scoured, scratched, and trowelled, as in the case of lime mortar. Greater care, however, is required as the plaster is generally either exposed or kalsomined and a perfect surface appearance without seams, cracks, or flaws is essential.

In using Parian or other white cement on lath-work, exceptional care must be observed that all the lath nails be galvanized or painted over, or covered with shellac to prevent rust. For first-coating and floating ceilings with this material, the proportions for best work are 1 part of cement to 2 of sharp sand, adding about the same quantity of hair as for lime plaster.

For the sake of economy or for the purpose of excluding dampness, walls are generally floated with Portland cement mortar in the proportion of 1 part of cement to 3 of sand, and finished with neat Parian or other white cement. Portland cement is much cheaper than Parian, but produces an efflorescence on the finished surface, which is inimical to successful painting if attempted before the material has had time to dry out. Gypsum cements, on the other hand, cannot resist the effects of moisture. It is, therefore, imperative that damp walls should be floated with Portland cement, where a white cement finish is desired.

Plaster of Paris is used as a finishing coat over lime mortar to improve the appearance of the surface, and is also mixed with the lime putty for the same purpose. When a harder finish is desired, Keene's cement is employed.

Keene's cement is employed as a binder for ceramic tiles and mosaics, although for exterior work, white Portland cement is now used, on account of its superiority when exposed to the weather.

By the use of white cements a great saving in time can be effected, as work can be begun and finished in one operation without waiting for the different coats to dry, as in ordinary lime plastering. For sanitary purposes they are unequalled. This, combined with their chemical properties, which enables them to be painted, papered, or kalsomined as soon as finished, renders them the most valuable of all plastering materials for interior work. They are free-working, sanitary, durable, and practically fireproof, and when properly manipulated can be worked to a porcelain-like surface.

PORTLAND CEMENT PLASTERS OR STUCCO

Portland cement mortar is now employed for external plastering or stucco work on account of its durability and resistance to moisture. It is also used as a scratch coat for interior walls and ceilings where Parian or Keene's cement is used as a finishing coat; while white Portland cement is used as a final coat for both interiors and exteriors.

Stucco is a composite coat, about 1 1/2 inches thick, placed on the outside of a building in one, two, or three coats. Stucco may be applied to wood, stone, brick, tile or concrete, either by roughening the surface or by means of wood or metal lath, supported on furring strips. Stucco may be composed of:

a. Portland cement and sand.

b. Portland cement, sand, and pebbles.

c. Portland cement and sand mixed with about 1/6 of its volume of lime paste.

Moyer also recommends the addition of 15 per cent of mineral oil to the wet mortar, after the latter has been thoroughly mixed.

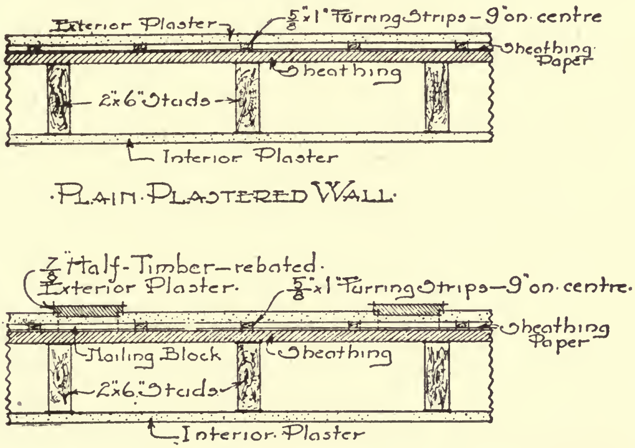

FIG. 27.—Application of Stucco to Frame Building.

Lime mortar is employed, chiefly, when the stucco is applied to stone, the object being to prevent hair cracks, retard the rate of setting and render the mortar easier to work.

Application of Stucco to Laths.—Lime mortar and gypsum plasters for interior plastering and fresco work are generally applied to wooden laths nailed to the studding. The laths are separated about 3/8 of an inch apart, so that the mortar will be forced into the interstices and serve as a key. The best laths are of split pine. Oak laths formerly used are very liable to warp. Sawn laths are cheaper than riven but are weaker because of cross-graining. The defects that are to be avoided in laths are sap, knots, crookedness, and undue smoothness.

For exterior work and for hollow-walled interiors, metal laths are employed. These consist of woven wire, expanded metal, rib-lath, and other forms of steel fabric, and may be obtained either painted or galvanized.

Specifications for Lath.—Metal lath is generally specified by gauge and it is always designated by gauge in catalogues.

All purchasers of lath should specify the gauge and weight. The weight per square yard of the lath in different gauges is given in the table below.

TABLE VII.—SIZES OF METAL LATHS.

Size of Sheet 18 × 96 Inches.	Weight per Bundle.	Yards per Bundle.	Sheets per Bundle.	Weight per Yard.	Yards in 100 Pounds.
No. 27 Gauge	27½ lbs.	12	9	2⅓ lbs.	43
No. 26 "	30 "	12	9	2½ "	40
No. 25 "	35 "	12	9	2.9 "	34¼
No. 24 "	40½ "	12	9	3.4 "	29⅔

TABLE VIII.—QUANTITIES FOR 100 SQUARE YARDS OF LATH.

Width of Furring.	Material.	Lineal Feet per Lb.	Pounds Required.	
			12 In. Ctrs.	16 In. Ctrs.
¼ inch..................	Flat wire.	20	50	37
½ "	Band iron.	20	40	34
¾ "	" "	15	67	45
1 "	" "	10	90	67

Rib-lath is made by the Trussed Concrete Steel Co., Detroit, Mich., and consists of a series of parallel ribs which are deeply corrugated or beaded. In application these ribs act as small steel beams spanning between the studs and giving the lath extraordinary stiffness and rigidity. Owing to this stiffness the studs may be placed a much greater distance apart than with the ordinary forms of lath, thus saving in the cost of studding and the labor of installation.

Rib-lath is so expanded as to provide a perfect clinch or key for the plaster. The key thoroughly anchors the plaster to the lath, allowing only a minimum amount of plaster to flow through.

By the use of rib studs and lath, hollow partitions may be built of ample strength and rigidity. Hollow exterior walls supported on metal lath also furnish a practicable and damp-resisting structure, when the construction is properly safeguarded.

A stucco finish possesses many advantages over the ordinary wood exterior—it presents a handsome appearance, it does not require painting, and it is exceedingly durable. Either metal lath or wood lath can be used, but the metal is preferable. The wood lath, if used, should be wet enough to prevent absorption of moisture from the plaster, but not wet enough to cause it to swell, because it will shrink again upon drying, and cause the plaster to crack. Green wood lath is better than dry.

The use of wooden lath should be restricted to small and unimportant work. In the case of small buildings, or such as may need patching, it offers a cheap method of obtaining a pleasing exterior, but is very apt to prove a failure. The reason is as follows: If the lath is too dry when the stucco is applied, it will absorb moisture from the plaster to the degree that the cement will not set properly and in time the stucco will fall off. On the other hand, wood made too wet will contract when it becomes dry and the same disastrous results are apt to follow. For the reasons given above it is best to employ a metal lath where the importance of the undertaking will warrant the slight additional expense imposed by its use.

Practical Considerations.—The following principles and rules should be taken into consideration when specifying the use of metal lath for plastering or stucco.

Painting adds but little weight to the lath.

Galvanizing adds from 0.75 lb. to 0.9 lb. per square yard according to the gauge of the lath.

Beware of lath cut from sheets galvanized before cutting and expanding, for only two sides of the four in each strand have any galvanizing on them, and these are badly cracked and scaled during the process of expanding.

Be sure to specify the gauge of the metal from which the lath is cut, and in addition thereto the weight per square yard, and if coated or galvanized add the weight of the protection.

Fasten the sheets horizontally, *i.e.*, the long way of the mesh being horizontal, so that the length of the sheets is across the studding instead of being placed vertically.

The dip of the strand should be inward and downward, away from the workmen, so that a perfect key can be formed.

Grounds should allow 3/8 inch over face of lath. Edges of sheets should lap about the width of one mesh and no more, simply to make the lath stiff, and the meshes should nest.

When using metal studding, the lath will be fastened in the manner provided, which differs with the studs made by different makers.

When the lath is placed on wooden studding, it is advisable to use crimped metal furring to provide a key between the lath and the studding, to maintain a uniform thickness of plaster, and also to prevent the line of studding from showing through the plaster, owing to the difference in the moisture in the plaster against the studding and that between adjacent studs.

For walls place studs 12 to 16 inches on centres. Twelve inches is best for ceiling beams, channels, or T's.

Staples should be about 5 inches apart and of sufficient length to go through lath and astride of furring strip into the wood at least one inch. When fastened to metal channels or T's, galvanized wire is used.

When plastering on walls of brick, concrete, etc., metal furring should always be used.

In building a cement stucco-finished house the usual construction is completed as far as the exterior sheathing. Precaution must be taken to make the framework as stiff as possible. Often all the exterior sheathing is placed diagonally so that no swaying will occur to crack the plaster, although metal lath reinforces the cement work considerably and prevents to a great extent any surface cracking.

SPECIFICATIONS FOR EXTERIOR LATHING AND PLASTERING

(American Association of Portland Cement Manufacturers)

"**Lathing.**—Cover all exterior walls, etc., shown for plaster with an approved galvanized woven wire lath secured to 5/8-inch by 1-inch furring strips, set 9 inches apart, with 1-inch galvanized staples every 5 inches. All lath must run at right angles to furring, and all joints are to be made where they will be covered with half timber, and joints are to be broken every course.

"**Plaster.**—All walls, etc., shown on elevation for plaster to be three-coat work on wire lath as follows: The first coat is to be composed of 2 parts rich lime-mortar and 1 part Portland cement, with a large proportion of long cow-hair. The lime-mortar is to be mixed four days before using, and the cement is not to be added until the mortar is ready to be used, and is to be mixed in small quantities as the work progresses. The face of the first coat must be well scratched to make a key for the second coat, and shall be thoroughly dry and surface cracks appear before the second coat is applied. The second coat will be the same composition as the first, except that the cow-hair is omitted. The scratch coat will be dampened before the second coat is applied. The third coat will be the same as the second, except that a coarse sand will be used and the third coat will be floated up to a rough finish. All sand used in the exterior work is to be approved by the architect. The contractor will be careful to bring his plaster work up perfectly flush with nailing grounds furnished and set by carpenter. No exterior plaster will be attempted until the building is under roof and all interior partitions are studded up and braced."

Application of Stucco to Stone.—When stucco is applied without the aid of fabrics, special care must be taken to obtain a sufficient bond. When applied to stone, the surface must be thoroughly cleaned of all loose mortar and disintegrated stone, and before the plaster is applied the surface must be thoroughly wet. The amount of wetting necessary depends upon the character of the stone of which the house is built. If it be a soft, porous stone, a great deal of water must be applied, if it be a hard, compact stone, not so much. In every case the old surface must be sufficiently saturated so that no water will be absorbed from the plaster This is an important point, and one which is often overlooked, and many failures can be traced to the fact that the surface was not thoroughly saturated with water.

There are several methods of wetting the exterior to be plastered. A large brush can be used, and in a manner similar to that employed in whitewashing a wall. In this way the whole surface can be wet, or the water can be applied with a hose. When a hose is used, the best way is to spray the water. This can be easily accomplished by compressing the end of the hose. Care must be taken to apply the plaster at once, and before the wall has had an opportunity to dry.

If the plaster is applied to a dry, porous surface, the latter will take up so much water that the cement in the plaster will not set. This causes the plaster to dry out, crack, and fall off, and is usually

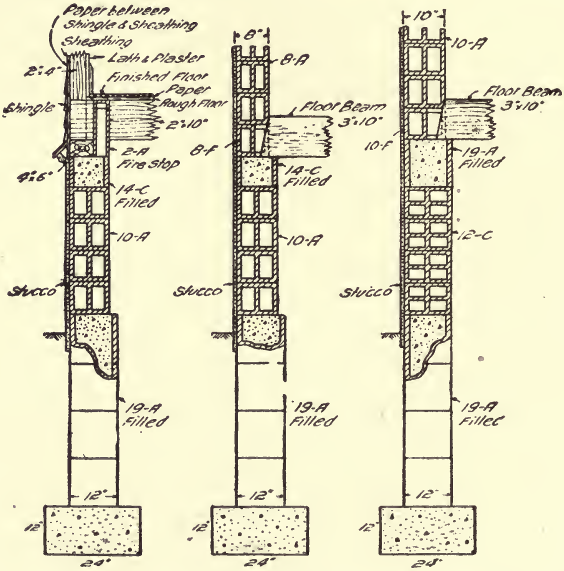

FIG. 28.—Stucco on Hollow Concrete Tile Walls.

the cause of most of the unsatisfactory results in the use of cement plaster.

Application of Stucco to Brick.—The treatment of a brick surface is very similar to that of a stone exterior. The porous nature of the brick, however, necessitates the utmost care in wetting before the first coat is applied, or the results will not be satisfactory. If the brick wall has been painted and this paint is scaling off, as it so often does, it should be thoroughly scraped and cleaned, and all loose mortar removed. If possible, the old mortar should be picked out 1/2 to 3/4 of an inch from the face of the brick-work, and when the first coat is applied it is forced into these crevices and forms an excellent bond. The comparatively smooth surface of the brick wall will require less material for the first coat than a rough surface of stone. The first coat over the brick-work must be scratched thoroughly and allowed to set until it is strong enough to support the second coat. The second coat is then applied in the same way as has been described.

The original smooth surface of the brick wall lends itself very readily to a smooth plaster finish. This is obtained by using a

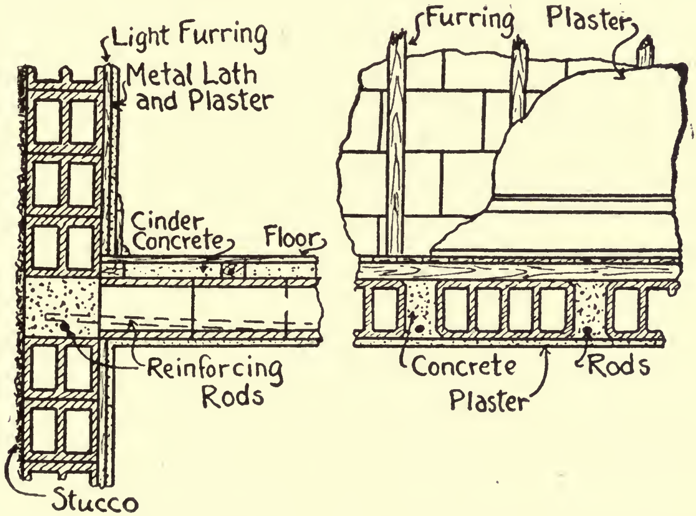

FIG. 29.—Hollow Concrete Tile and Stucco Wall and Floor Construction.

finish coat containing rather fine sand and placed with a steel trowel. When it is desired to obtain an Old English style of exterior, the smooth finish coat is necessary. Very artistic and desirable results have been secured by thus renovating brick exteriors.

Stucco on Hollow Tile.—Walls of hollow tile form an ideal framework for stucco houses, on account of their strength, indestructibility by fire and insulation against heat and cold. When properly surfaced, such blocks also furnish an excellent bond to the stucco, so that plastering can be applied directly to the tile without furring or lathing. This bond is obtained by indenting or scoring the surface of the tiles by a series of corrugations, by leaving the surfaces rough, and by the use of dovetailed grooves to receive cement, plaster, and stucco. The tile should in all cases be well wetted before applying the mortar, and if the weather is hot, it will be necessary to spray the finished wall twice a day for a period of three or four days after the completion of the work.

Application of Stucco to Concrete.—The treatment of a concrete surface that needs to be plastered depends upon whether the wall is new or old. The best results are obtained by placing the plaster immediately after the forms have been removed and while the concrete is still green. In this case very little or no preparation of the concrete is necessary to receive the plaster, which is applied

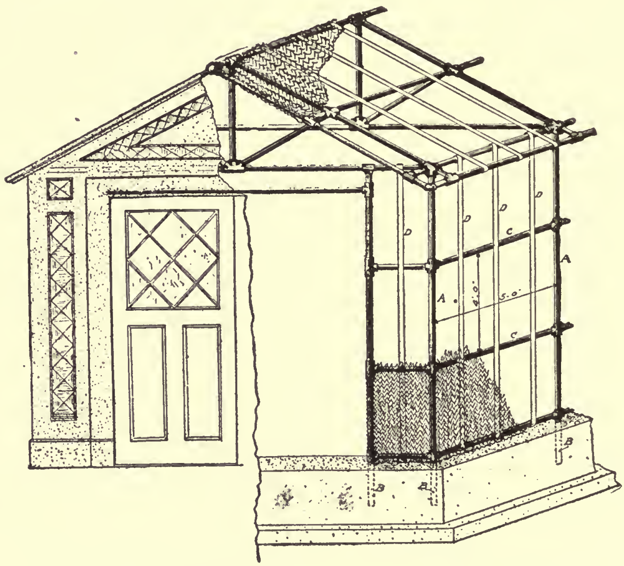

FIG. 30.—Artistic Garage. Stucco on Pipe Frame.

before the wall has dried out. A single coat is usually all that is required, and the finish desired may be secured in the same manner as with the final coat over a stone or brick exterior. If the concrete wall is old, much care must be taken in preparing it for the plaster. The excess of cement likely to have flushed to the surface must be removed and the surface thoroughly cleaned and well wet before applying the plaster, or it will crack and fall off. By the use of facing forms, new walls may be constructed in which the plaster finish and concrete wall are carried up simultaneously, resulting in a perfect bond between the two.

Renovating Frame Buildings.—Old frame buildings can be readily renovated by the use of cement stucco. The exterior is covered with lath furred out as already described and either two or three coats are applied. In such a case it is necessary to bring out the door and window trim unless the plaster is to finish flush with the old trim, or if it is desired to keep the old frames and have them project, it will be necessary to remove the old siding and staple the furring directly to the old studding. Frequently the trim is removed and the lath brought around the casing, thus getting a recessed window with no wood showing.

Quantities of Materials for Stucco.—The quantities of cement and sand required for stucco work vary with the thickness of the coat and the proportions of the ingredients. The following table shows the covering power of a barrel of cement when made into mortar for thicknesses varying from 1/2 to 1 inch, and for proportions varying from 1 : 1 to 1 : 3 mixtures of cement and sand.

TABLE IX.—AREA COVERED BY MORTAR.

Produced from One Barrel of Portland Cement Mortar (3.8 cu. ft. Cement Paste). No Lime.

Composition of Mortar.	Thickness of Coat.	Square Feet of Area Covered.
1 Cement, 1 Sand	1 inch	67
	$\frac{3}{4}$ "	90
	$\frac{1}{2}$ "	134
1 Cement, 2 Sand	1 inch	104
	$\frac{3}{4}$ "	139
	$\frac{1}{2}$ "	208
1 Cement, 3 Sand	1 inch	140
	$\frac{3}{4}$ "	187
	$\frac{1}{2}$ "	280

CHAPTER XII

THE ARTISTIC TREATMENT OF CONCRETE SURFACES

Imperfections in Concrete Surfaces.—Methods of Finishing Surfaces.—Spading.—Stucco.—Mortar Facing.—Grouting.—Scrubbing and Washing.—Etching.—Tooling.—Selected Aggregates.—Tinting and Coloring.—Panelling, Mosaics, Carving, etc.—Prevention of Cracking and Crazing.

CONCRETE is a plastic material which can be moulded and modelled at will, and as such the temptation is strong to cast it into forms strongly suggestive of some other material. "Beauty, however, in structural design is worthy the name only when, like beauty in Nature, it has character. It must not be a servile copy of the style peculiar to some other material, but in fact must express its own individuality without dissimulation." *

Imperfections in Concrete Surfaces.—Good design requires that the surface must be finished so as to produce a pleasing effect. In many concrete structures the surface is irregular, uneven in texture, and stained or discolored or of lifeless hue. Imperfections in the surface of concrete are due to one or more of the following causes:

1. Imperfectly made forms.
2. Carelessly mixed or placed concrete.
3. Use of forms with dirt or cement adhering to the boards.
4. Efflorescence and discoloration of the surface.
5. Shrinkage cracks, and crazing of surface.

In well mixed and placed concrete, the film of cement paste which flushes to the surface will take the impress of every flaw in the surface of the forms. It will even show the grain marks in well-dressed lumber.

Joint marks may be eliminated wholly or in part by pointing the joints with clay or mortar or by pasting strips of paper or cloth over them. Grain marks and surface imperfections can be reduced by oiling the lumber so as to fill the pores or by first oiling and then filling the coat of oil with fine sand blown against the boards.

* A. O. Elzner on "The Artistic Treatment of Concrete."

Imperfectly mixed and placed concrete gives irregularly colored, pitted, and honeycombed surfaces with here a patch of smooth mortar and there a patch of exposed stone. Careful mixing and placing will avoid this defect. Spading forks should be used to pull the coarse stones back and cause the mortar to flush to the surface. Surface coatings can also be used to cover up any defects.

Efflorescence is the term applied to the whitish or yellowish accumulations which often appear on concrete surfaces. Efflorescence is due to certain salts leaching out of the concrete and accumulating into thin layers after the water has evaporated. It is most troublesome at horizontal joints where new work is placed on concrete that has already set. Scrubbing the top surface with wire brushes and flushing it with a hose before the new work is started is the best preventative.

Where the efflorescence extends over the surface of the wall, it may (1) be covered up by the use of cement coatings or waterproofing compounds, (2) or removed by scraping and chipping or (3) washed away with acids. Muriatic acid is generally used for this purpose. It is diluted with 4 or 5 times its bulk of water and applied with scrubbing brushes. Water should also be played with a hose on the concrete while being cleaned to prevent penetration of the acid. The cost of scrubbing with acid is from 30 cents to 50 cents per square yard. The question of efflorescence is further discussed in Chapter XXX.

METHODS OF FINISHING SURFACES

The usual methods of finishing concrete surfaces are as follows:

1. Spading and trowelling the surface.
2. Facing with stucco.
3. Facing with mortar.
4. Grouting.
5. Scrubbing and washing.
6. Etching with acid.
7. Tooling the surface with bush-hammers or other tools.
8. Surfacing with gravel or pebbles.
9. Tinting the surface.
10. Panelling, mosaics, carving, etc.

Spading and Trowelling.—With wet concrete and ordinarily good form construction a reasonably good surface appearance may be obtained by pushing a spade down between the lagging and the fresh concrete and pulling back the stones, so that the grout can flush to the surface. Trowelling should be done while the concrete is still green. In this condition the edges of copings, etc., can be rounded by edging tools such as are used for finishing cement sidewalks.

Facing with Stucco.—When properly applied, stucco finishes are most pleasing and artistic, especially for residences. By the use of white Portland cement, white sand or crushed marble, a most beautiful effect can be produced. Cream-colored or other delicate tints can also be obtained by mixing pigments with the cement or by the use of colored sand and gravel. The most successful stucco finishes are as follows:

a. Smooth float.

b. Rough cast.

c. Slap-dash finish.

d. Pebble-dash finish.

A smooth float finish on a building is always pleasing, especially when white or delicately tinted materials are used. Such finishes are ordinarily produced with a wooden float. Floats should be made of hard, close-grained timber such as beech or birch, and should be drawn straight along the wall, without twisting or turning. Smoother finishes can be obtained by the use of steel trowels or with wooden floats covered with felt. Trowelling brings the neat cement to the surface while the float tends to bring out the grains of sand. In Germany by the use of felt-covered floats beautiful effects have been obtained, and this method is used to some extent in the United States, although the tendency in this country is in the direction of rougher finishes.

A rough cast surface is one of the most pleasing finishes and is especially appropriate for residences, rustic bridges, and suburban villas. A rough cast surface can best be put on with a broom dipped into a solution of mortar, half and half, or two of sand to one of cement, and applied by stepping back a distance of two or three feet from the wall and striking the broom with the hand in such a way as to drive the mortar against the wall, on which it collects like raindrops. The cement crystallizes and adheres firmly to the wall. By the use of white mortar, a sparkling, glistening effect is obtained.

The slap-dash finish is pleasing on account of the variety and the light-and-shade effects which are obtained. It is especially adapted to foundation courses and to suburban houses. It is applied by stepping back a distance of two or three feet from the wall and throwing the mortar against the surface with a trowel. For its successful applications, the workman must possess considerable skill and the scratch-coat to which it is attached should not have attained too great a set to prevent bond.

The pebble-dash finish is well adapted to foundation courses, rustic bridges, etc. It is obtained by embedding round half-inch pebbles in the finishing coat. Excellent effects are obtained with white quartz pebbles, and warm effects with colored stones or gravel. The pebbles should be of uniform size and tossed into the cement mortar so as to be half exposed.

Stucco finishes may by proper bonding be applied to any surface, whether of wood, stone, or concrete. They are also well adapted to the renovation of old buildings, as well as to the embellishment of new structures. Unless, however, the stucco is keyed to the underlying material by means of metal laths or fabrics, such finishes when applied to concrete are lacking in adhesive properties and one of the following methods which are especially adapted to concrete, should preferably be employed.

Facing with Mortar.—A facing mortar of cement and sand is used in thicknesses of from 1 to 2 inches when a surface finish of fine texture or of some special color or composition is desired. When this is used the mortar facing and the concrete backing should be constructed simultaneously in order to obtain a perfect bond. This is usually accomplished by the use of facing forms, which are placed temporarily the proper distance back of the lagging; after which the facing mortar is tamped into the narrow space between the two forms, the body of the wall is poured, the facing form raised, and both backing and facing thoroughly bonded by tamping them together.

Grout finishes serve only to fill the small pits and pores in the surface coating. Cavities or joint lines must first be removed by plastering or rubbing. The grout is then applied with a brush, and should have the consistency of whitewash. A 1:2 mixture of cement and sand is often used. Where a dark finish is desired, a grout is made by mixing neat cement and lampblack in equal parts.

Scrubbing and Washing.—The use of granite chips, colored stones, white pebbles, and other special aggregates, affords a successful finish for concrete structures. This consists in removing the forms while the concrete is still green, and then scrubbing the surface with wire brushes and water until the film of cement has been removed, and the clean sand and stone exposed. Warm tones can be secured by the use of crushed brick or red gravel; a dark colored stone with light sand gives a color much resembling granite; fine gravel or coarse sand gives a texture like sandstone.

There is no artistic reason for allowing only the bonding material to be displayed to the eye. On very large jobs the surface can be cleaned off by means of a sand blast, and on smaller jobs the surface may be cleaned exposing each grain of sand by means of muriatic acid in dilute solution, 1 part commercial muriatic acid, to 4 to 5 parts clear water.

Where white aggregates are used the surface may be cleaned off with a solution of sulphuric acid, 1 part acid, 4 to 5 parts clear water. The sulphuric acid leaves a white deposit and therefore should not be used excepting where the aggregates are white.

Another method is to scrub the surface while yet green, say within 24 hours, with a house scrubbing brush and clear water. This is more difficult than the others for the reason that if the stucco is allowed to remain too long before scrubbing, it will be too hard to remove the coat of neat cement from the outside of each particle of sand or other aggregates; and if scrubbed when it is too soft, the surface may be damaged and difficult to repair.

If the character of the available aggregates will not present a pleasing surface when exposed, the following surface treatment may be used as recommended by Moyer.

While the last coat is still thoroughly damp, apply a Portland cement paint composed of 1 part Portland cement, 12 per cent of the volume of the cement of well hydrated lime in pulverized form, 1 part of the volume of the cement of fine white sand. Mix with water to the consistency of cream or the ordinary cold water paint.

Stir constantly and apply by using a whisk broom, throwing this paint on with some force.

Keep this finish surface damp for at least six days or longer if economy will permit. Do not allow it to dry out in any one place during the week. If necessary protect by hanging tarpaulins and using a fine spray of water playing on several times during the day by means of a hose. This will give a pleasing light gray color of excellent texture.

In the construction of monolithic concrete masonry for bridges for the city of Philadelphia, it is the practice to use a fine concrete or granolithic face composed of 1 cement; 2 bank sand, and 3 crushed and cleaned black slaty shale, of the size commonly used for roofing,—say one-fourth to three-eighths inch. The mixture is placed against the face forms and the body concrete is poured behind and both removed together immediately. In general the washing is done on the day following that on which the concrete was deposited, and an ordinary house scrubbing brush with a free flow of water is used. When the surface is too hard for the scrubbing brush, a wire brush is first employed, then a small block of wood or a brickbat with water and sand in order to cut the film. If the surface has hardened so as to require the grinding action of the sand and block, the aggregate will not be brought into very decided relief and the face will therefore be comparatively smooth. In cold weather when crystallization proceeds slowly the forms may require to remain two days before the washing can be done with safety, and in very cold weather they have been left a whole week, and the scrubbing was successful. In general, however, the aggregate is best brought out by scrubbing as soon after the concrete has been placed as possible.

Etching with Acid.—Etching with acid is a further development of the scrubbing process, and is also employed for the purpose of removing the outer skin of cement and exposing the aggregate. It consists in first washing the surface with dilute muriatic acid, and then with an alkaline solution to remove all free acid; and finally with clean water in sufficient volume to cleanse and flush the surface thoroughly. The operation is simple and always effective. It can be done at any time after the forms have been removed, immediately or within a month or more. It requires no skilled labor—

only judgment as to how far the acid or etching process should be carried. It has been applied with equal success to trowelled surfaces, like pavements, to moulded forms, such as steps, balusters, coping, flower vases, etc., and to concrete placed in forms in the usual way. It, of course, means that in the concrete facing only such material shall be used as will not be affected by acid, such as sand or crushed granite. Limestone cannot be used, as it is disintegrated by the acid. The treated surface can be made of any desired color by selection of colored aggregates or by the addition of mineral pigments. The colors obtained by the selection of colored stone are perhaps the most agreeable and are doubtless the more durable.

Tooling.—Concrete surfaces may be bush-hammered or otherwise tool-finished like natural stone. To secure good results, however, the concrete should be at least 30 days old before it is worked. The cost runs from 3 to 12 cents per square foot, according to the character of the work.

Tooling is also done with an axe, pick, chisel, or pneumatic hammer. The tool should be light, and the blows only heavy enough to "scalp" the work, heavy tools and blows being liable to "stun" the concrete, particularly at or near the edges. This scalping partially exposes the material of the aggregate, but does not clean it. The complete exposure and cleansing will come with time and exposure to the weather if the work be outdoors; or the action of the elements can be anticipated by washing the tooled surface with a half-and-half dilution of muriatic acid, which of course must be thoroughly rinsed off.

Another method of tooling consists in removing the skin with a coarse-grained emery or carborundum wheel. The skin is cut about as quickly as the block can well be passed over the wheel. This method is well adapted to the surfacing of moulded blocks, slabs, and artificial stone.

Selected Aggregates.—An effective variation of the ordinary stone concrete surface is secured by using an aggregate of rounded pebbles of nearly uniform size, and by scrubbing or etching to remove the cement enough to leave the pebbles about half exposed to view. This gives a finish similar to that obtained in pebble-dash stucco work and is very pleasing, especially for rustic bridges and cottages.

The scrubbing is best done when the concrete is 24 hours old, at which time the outer skin is readily removed. Where the forms are required to remain in position for a longer period, as in the case of arch or girder forms, the acid treatment is required.

Tinting and Coloring.—The use of colored or tinted surfaces includes:

a. Pure white or cream-colored tints.

b. Colors produced by the use of pigments.

c. Colors obtained from the use of colored aggregates.

d. Colors produced by painting the surface.

White surfaces are readily obtained by the use of white Portland cement, mixed with either white sand, crushed white quartz, ground marble, or ground white limestone. White surfaces when scrubbed or acid-etched present a pure sparkling appearance of rare beauty when touched by sunlight, and are used extensively by architects for suburban residences. The use of white cements and aggregates also permits the use of delicate tints, which are obtained either by the use of pigments or colored aggregates.

Pigments which are unaffected by the action of lime or cement are now obtainable for the purpose of tinting concrete, facing mortar and stucco. Blue, red, green, and yellow pigments cost from 8 to 30 cents per pound, and by proper mixture the intermediate shades may be obtained. The quantity of pigment required is from 2 to 3 per cent of the mixture by weight in order to produce a well colored mortar. The following table (Table X) is recommended in the bulletins of the American Association of Portland Cement Manufacturers.

In painting concrete surfaces, the material employed should either be neutral, free from saponifying oil, or the surface to be painted should be previously neutralized with dilute sulphuric acid in order to convert the free lime into gypsum. If such precaution be neglected, the oil and free lime will react chemically and form soap which will destroy the paint.

Coloring by the use of Selected Aggregates.—Many engineers and architects prefer to color their concrete by the use of colored sand and gravels in the mortar which are exposed by scrubbing and etching. While this treatment is more expensive than the use of colored facing mortars, the colors are more permanent, and the acid etched surface exhibits more life and variety. Excellent effects are produced by mixing the cement with screenings produced by crushing a natural stone of the desired color.

Panelling.—In the construction of buildings, a simple and dignified variation in the surface treatment is obtained by the use of panels or freehand modelling. "In the case of panels it is best

TABLE X.—MATERIALS USED IN COLORING MORTARS.*

Color.	Mineral.	Pounds of Color to 100 Pounds of Cement.		Pounds Color to Barrels of Cement.
		1	2	3
Gray..........	Germantown Lamp Black	1–4	1–2	2
Black.........	Manganese Dioxide.	12		48
Black.........	Excelsior Carbon Black		2	
Blue..........	Ultramarine	5	5 to 6	20
Green..........	Ultramarine Green	6	6	24
Red	Iron Oxide	6	6 to 10	24
Bright Red.....	Pompeian or English Red	6	6	24
Sandstone.......	Red-Purple Oxide of Iron	6		24
Violet	Violet Oxide of Iron	6		24
Brown.........	Roasted Iron Oxide or Brown Ochre	6	6	24
Yellow or Buff.	Yellow Ochre	6	6 to 10	24

and simplest to adopt sunken work, as this can readily be produced by merely planting a board or block of desired shape against the inside face of form work which leaves its impress upon being removed from the concrete. Or else a reverse mould made of some artistic bit of carving for a panel or over a door or window, or a frieze, etc., may be nailed against the forms, and the resulting impress will be thoroughly effective, although a much higher artistic value would be due such work if it were modelled by hand directly in the cement mortar as it is applied and before it has had a chance to harden.

"This sort of work is being done extensively and successfully in Germany, where the modern style of 'Nouveau Art' presents abundant opportunities for endless designs. It is already finding

* Differences are due to different authorities quoted.

much favor in our own country, and ought to reach a high degree of development."

Ornamenting Surfaces with Mosaics, Carving, etc.—Mosaics, similar to those made with colored glass and lead outlines, can be made with burned clays and cement outlines. Patterns from one foot to twenty feet in diameter have been made, simply by burning slabs of clay in many colors, either glazed or unglazed, and cutting the slabs into such shapes as to show the outline of an artistic design. These parts are assembled in a bed of cement, a bead being left between the pieces of clay similar to the lead bead of glass windows. This bead shows the outline of the design, its width being proportional to the size of the figure. As it becomes increasingly wide, the figure becomes more and more conventional. These cement outlines can be colored black or red, but as a rule the best results are obtained with the natural dead gray, as it harmonizes with all the colors of the clay.

These decorative inlays or mosaics are very beautiful over mantels and fireplaces as an inside decoration, and are also used to break up wall surfaces in exterior work.

Many other substances besides clay have been used in this way, such as tiles, papier mâché, etc., with more or less success.

Another method sometimes used to ornament the surface of mouldings, cornices, etc., while concrete is green, is to press blocks of wood, cut to desired shapes, such as the classical "leaf and dart," "beads and reels," or any simple figure, into the green concrete, thus leaving a shallow imprint in the surface. These imprints can be spread at appropriate intervals along a frieze or moulding, and produce very beautiful appearances.

Templets moulded in clay or cut out of sheet iron can be used in place of the carved wood, if desired.

Concrete surfaces can also be economically decorated by carving before the concrete has set. As soon as the concrete is sufficiently hard to resist the imprint of the thumb nail, the forms are removed, and the design is carved out with sharp steel tools of proper shape very much as wood is carved. In this way, scrolls and floral designs can be accomplished with less skill and very much less time than in cut-stone work.

Prevention of Cracking and Crazing of Surfaces.—The following is quoted from Mr. Albert Moyer's article on this subject, to which he has given a great deal of study:

"It has been known for some time that a very wet mixture of concrete is more apt to craze and show these undesirable hair cracks than a medium dry mixture of concrete.

"Neat cement, or the richer mortars, are found to be much more liable to hair cracks and crazing than mortars containing a larger proportion of sand or finely crushed stone. This is particularly true in the manufacture of cement stone by the use of sand moulds in which the mixture is poured very wet. It has also been noted that, when the stone is properly seasoned by keeping the surface covered with a thick layer of very wet sand, or when the stone is immersed entirely and for some time in water, the trouble has been overcome almost entirely.

"In the past this trouble has been partially overcome by brushing off the surface of the concrete or cement stone with a stiff steel brush; or by scrubbing the surface with a cement brick and wet sand or carborundum stone, thus partially removing what might be termed a neat cement face. It has been found, however, that this does not entirely overcome the trouble, the remedy proving but temporary, the cracks appearing several months afterward. The brushing or scrubbing is merely an assistance; the real remedy lies in keeping the surface thoroughly and continuously wet as long as possible.

"It is desirable to have the surface of the concrete or cement stone as near the same texture as the body of the concrete. The exterior should then be kept wet by the application of wet sand, clean sawdust, hay, etc., sprinkled from time to time with water or hanging wet cloths over the perpendicular surfaces, keeping the exterior wet and the cloths wet by sprinkling, or by any other method which will accomplish this result *and supply similar or same conditions as when hardened under water.* By so doing not only is crazing avoided, but a stronger, tougher, and harder concrete is obtained. It is reasonable to conclude that if so treated the surface will slightly expand, but not to a greater extent than the body of the concrete which is already wet.

"Hair cracks may be avoided by the addition of mineral oil to the wet mixed concrete.

"Mineral oils added to wet mixed concrete and the concrete immediately remixed has the effect of emulsifying the oils. The proportion of oil used should be 10 to 15 per cent of oil to the weight of the cement. Oil weighs from 7 1/2 to 8 pounds per gallon.

"This oil-mixed concrete, when hard, appears to be non-evaporative, indicating that the emulsifying oils held all the excess water in the mortar or concrete, keeping the cement particles moist until the water had been taken up in crystallization and ultimate strength reached. Thus similar conditions are supplied as apply to concrete set under water."

In this chapter the readier methods that can be employed in producing artistic effects have been considered. "This humble material, so replete with possibilities, but as yet so little understood, is manifestly destined to take an important place in the construction of our buildings and must therefore strongly influence their design." Our leading architects are beginning to find in concrete a new and useful friend, and with its help will evolve a new architecture that will be full of life and character, strength and dignity and all else that goes to make up a living style."

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* "The Artistic Treatment of Concrete," by A. O. Elzner, in Proceedings of the National Association of Cement Users, 1907.

SECTION III

THE MAKING OF CONCRETE PRODUCTS IN THE SHOP

CHAPTER XIII

CONCRETE BUILDING BLOCKS

Advantages and Disadvantages of Concrete Blocks.—Materials for Concrete Blocks.—Types of Blocks.—Block Machines.—Making the Blocks.—Coloring the Blocks.—Waterproofing the Blocks.—Building Details.—Cost of Blocks.—Objections to Concrete Blocks and Remedies for Same.—Table of Concrete Block Data.—Concrete Tiles, etc.—Specifications for Concrete Blocks.

THE concrete products manufacturing industry has had a very phenomenal growth, and in fact, the growth has been too rapid for the good of the business, as it has caused a large volume of poor products to be placed upon the market and the disrepute into which much of the industry had fallen on account of this, has not yet been fully removed; the tendency now, however, is toward better products and with renewed confidence due to wider experience and the law of the survival of the fittest, we expect to see an accelerated increase in all lines of manufactured concrete.

The use of concrete blocks as a substitute for wood, brick, and stone has become very extensive. Concrete blocks, when properly made and used, form an excellent material for building construction. They commend themselves for their cheapness when compared with brick and stone, and their greater durability when compared with wood; they also possess the advantage over the latter of being fireproof.

When concrete was first applied to building construction, it was used to build monolithic walls. The idea of making a wall hollow for the sake of economy, or for prevention of moisture or frost working through the wall was a later development. At the present time practically the whole concrete-block industry aims to produce a wall made of hollow blocks, with continuous air chambers, or of blocks which, though not themselves hollow, can be laid so as to produce a hollow wall.

Advantages of Concrete Blocks.—Briefly enumerated, the following advantages are claimed for concrete blocks:

1. A properly constructed concrete-block wall is as strong or stronger than a brick wall of equal thickness.

2. The hollow form results in a saving of materials over brick walls, amounting to from 20 to 50 per cent.

3. It costs less to build a concrete-block wall than one of brick. This is due to the much larger dimensions of the concrete block.

4. The hollow chambers in the concrete walls tend to prevent moisture from penetrating to the interior face of the wall; lathing can often, therefore, be dispensed with, and the plastering done directly on the wall, particularly when the blocks or the wall has received a waterproofing treatment.

5. The hollow chambers form an air cushion that prevents sudden changes of temperature, and tends to keep the building cool in summer and easily heated in winter.

6. The fireproofing qualities of concrete blocks are superior or at least equal to those of brick.

7. Pipes and wires can be run through the hollows of the blocks, resulting in a saving of space and labor and avoiding ugly appearances.

8. Concrete blocks can be manufactured near the building site. This will save breakage, also part of the cost of transportation as compared with brick, as cement in bags requires less handling than brick.

Materials for Concrete Building Blocks.—Building blocks are made of cement, sand, and water mixed in proper proportions, in which case they are properly called "mortar" blocks; or, the above materials can be combined with either broken stone, gravel, or cinders, in which cases a concrete block is produced.

Sand and gravel will usually be found the cheapest and most available materials to employ.

Since the space for concrete in the mould is very small, the block-builder is limited to the use of gravel and stone not exceeding 1/2 to 3/4 inch in size. A 1 : 5 mixture containing such gravel or screenings will produce a block as strong and as durable as a 1 : 3 mixture with sand only.

Cement.—Only Portland cement should be used in the manufacture of concrete blocks, as, owing to its present cheapness, nothing is gained by using substitutes. Natural and slag cements are sometimes used for blocks that are supposed to remain constantly wet, but such blocks rapidly deteriorate when dry. No cement is as fully reliable as Portland cement, and only the latter should be considered for concrete blocks.

Broken Stone.—This should be small enough to pass through a 1-inch mesh screen. If there is much dust present it must be removed by means of a small mesh screen. Another way is to wash out the dust. A barrel having a wire-sieve bottom is filled with the broken stone, and water is run through the stone; the water, as it runs out, will carry with it all the dust.

Gravel.—If gravel is used it should be screened through a 1-inch screen. If it contains much clay or earth, they must be removed in the manner described for broken stone. The strength of the concrete will not be impaired if the quantity of clay and earth present does not exceed 3 per cent.

Cinders.—Cinders are sometimes used for concrete blocks with fair results. Such blocks are inferior in strength to those made with broken stone and gravel because the cinders are very porous and are easily crushed. For these reasons they should be used only where great strength is not required; for instance, in interior walls carrying light loads.

Lime is sometimes mixed with cement mortar to improve its qualities. The dry-slaked or hydrated lime is the most convenient form to use, and it is mixed in the proportion of one-quarter to one-half of the cement employed. As lime is about as expensive as Portland cement there is no saving in its use. It will, however, cause the blocks to set more rapidly, will make them lighter in color, and the concrete will be denser and will resist better the penetration of moisture.

In 1 : 4 and 1 : 5 sand mixtures at least one-third of the cement can be replaced with lime without appreciable loss of strength.

Proportion of Water.—The quality of concrete blocks will depend greatly upon the amount of water used. A dry mixture is necessary if the block is to be removed from the mould as soon as made. Too much water will cause the block to sag out of shape, should the plates be removed before the concrete has set.

Processes of Manufacture.—There are two ways of making concrete blocks, depending upon the amount of water used in the mixing. These are called the "dry" and the "wet" processes.

In the *dry* process just enough water is added to give the concrete the consistency of damp earth. When such concrete is tamped into a block machine, the mould can be removed immediately after, and the process continued.

In the *wet* process sufficient water is used to render the concrete mass semi-fluid. When poured into the moulds, the concrete must, of necessity, remain there until hardened.

The "wet" process produces a superior block both in point of strength and waterproofing qualities, but the "dry" process is by far the most extensively used.

Blocks made of too dry concrete will be weak and will crumble no matter what process of curing they are later subjected to. It is possible, however, to obtain a mixture with enough water to give the required density and hardening qualities, and still be able to remove the block at once from the mould.

It is impossible to give a fixed percentage of the amount of water required as this varies with the character of the materials, the moisture in the atmosphere, and other causes. Generally speaking, about 8 or 9 per cent of the weight of the dry mixture will be found satisfactory.

Types of Concrete Blocks.—Concrete blocks may be classed under two headings:

1. One-piece blocks in which a single block provided with one or more hollow cores makes the whole thickness of the wall.

2. Two-piece blocks in which the face and back of the wall are made up of different pieces, so lapping over each other as to give a bond and hold the wall together.

These blocks are made in various shapes and sizes, the standard size having the following dimensions:

Length 32 inches, height 9 inches, and thickness 8, 10, and 12 inches. Blocks are also made with lengths of 24, 16, and 8 inches. Because of the excessive weight of the 32-inch block, the 24-inch size is rapidly gaining in favor among architects and builders.

The simplest block made has one hollow core and a wall erected with such blocks will have a series of vertical air spaces running through the entire height of the wall.

The block which is by far the most extensively manufactured block on the market, is reinforced with a single transverse web, thus giving two hollow cores. It is favored not so much because of its good qualities as the cheapness of manufacture. This block is superior to the single-core block in point of strength. It has, however, its disadvantages. The transverse webs present so many additional paths for moisture to penetrate from the outer wall to the inner. The tamping of concrete around two cores is more difficult than around one, and a block of smaller density and uniformity is produced. Also, a block with two cores is more liable to injury in the process of removing the cores than a block with one core.

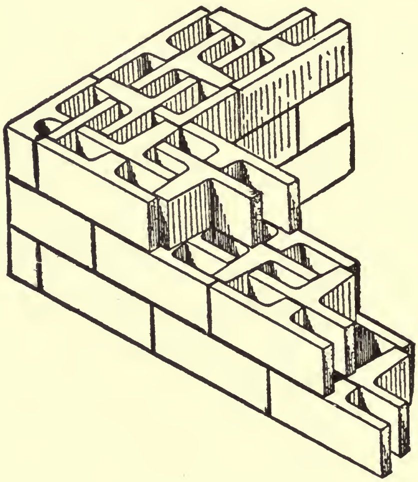

Fig. 31.—Concrete Block Having Multiple Air Space.

The penetration of moisture is the chief defect of concrete blocks, and to reduce this to a minimum various forms have been evolved. Chief among these are blocks with staggered air spaces and the two-piece block.

In the staggered air space block, known as the Miracle block, the web and air spaces are so arranged that no web extends directly from the outer to the inner wall. The air spaces register exactly so as to create two series of continuous, perpendicular air chambers throughout, all solid sections being backed by air spaces. This practically assures a block that is frost and moisture proof.

The Blakeslee block is another type of block having a width equal to the whole thickness of the wall in which there is no direct connection between the exterior and interior walls. Unlike the Miracle block, however, the continuous air chambers are horizontal.

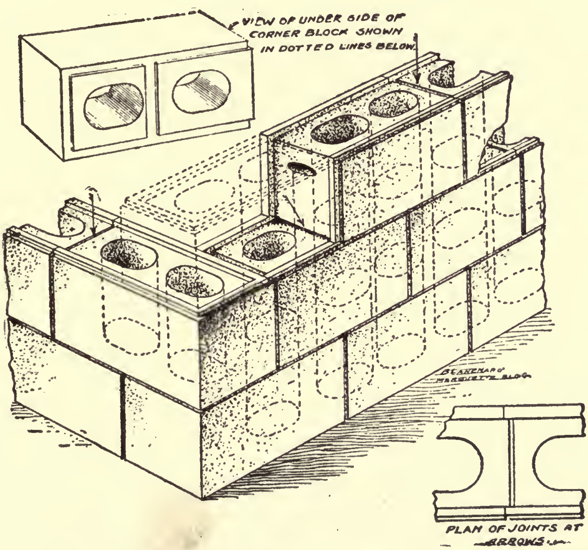

FIG. 32.—Self Lining and Interlocking Concrete Block.

In the blocks of the American Hydraulic Stone Company, each block has one long and two short arms which break joint with the corresponding arms of the adjacent courses. This system possesses many advantages over other systems since it permits a continuity of both horizontal and vertical air spaces; it produces, in effect, two walls, thus securing thorough insulation and making a concrete wall construction which is impenetrable by moisture.

Two-piece blocks are made having the two faces tied together with galvanized wire during the process of manufacture, making one whole block to handle in the field.

Concrete Block Machines.—There is a great variety of concrete block machines on the market, and these may be roughly divided into four classes:

1. Machine in which the face plate is vertical.
2. Machine in which the face plate is horizontal.
3. Machine for pouring blocks from wet concrete.
4. Machine for making blocks of the two-piece system.

Machines of the first class have removable hinged sides, and upright interior cores. There is a great variety of labor-saving

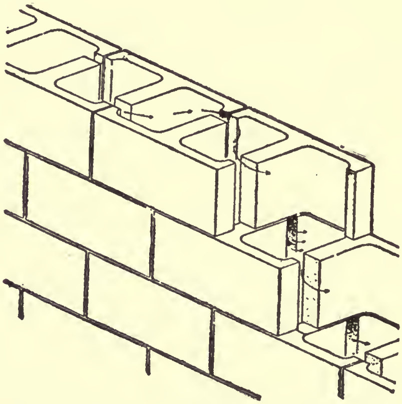

FIG. 33.—Hollow Wall of Two-piece Block.

devices to be found in the different machines, but the principle of manufacturing the blocks is essentially the same in all.

The blocks are made by tamping under the "dry" process and immediately removed on iron pallets. In some machines the labor needed to move the blocks is saved by turning the mould over and releasing the block on wood, or by making the block on a wooden board and lifting the mould bodily away from the green block. Several types of machines have contrivances for mechanically raising and lowering the cores, while in others the cores remain stationary, and the bottom and sides are adjustable.

There is some disadvantage in using vertical-face machines when it is desired to make a block with facing of richer concrete than is used in the body of the block. Such a facing is often desired to secure greater impermeability and better appearance. It is necessary then to provide a vertical parting plate, and great care must be exercised to secure an intimate bond between the two mixtures; otherwise, the facing may fall off in rough handling or with the freezing of moisture which may settle between the two mixtures.

In the second class of machines the face plate forms the bottom of the mould. The facing mixture is first deposited and tamped, after which the cores slide in laterally, and the filling and tamping continued; the mould with the block is then tipped to bring the face plate to a vertical position and the block removed.

The third class of machines for making blocks from very wet concrete consists of a large number of separable moulds made from sheet metal, and provided with interior cores. The wet concrete is poured into the moulds and allowed to harden there for 24 hours. The principal contentions of the manufacturers of these moulds are that the blocks possess excellent hardening and waterproofing qualities; that they are actual stone, and are cheaply made.

Machines of the fourth class differ radically from all other types. This is due to the fact that the shape of the "two-piece" blocks made on these machines, permits the use of mechanical and hydraulic pressure. The machines are, therefore, of heavy and complicated construction, and capable of large output. The mixture is shovelled into the mould, pressed almost instantaneously, and forthwith released. Where it is desired to have a facing differing in color and texture from the body of the block, about three-quarters of an inch of the coarse concrete is first raked out before it is pressed, the facing is applied to this loose mass, and all pressed at one time. This insures a firm bond between the face and body of the block, and as the pressure is applied directly to the face of the block, a beautiful face of great hardness and density is produced.

Making the Block.—*Dry Process.*—The concrete should be placed in the mould in layers about 3 inches thick; tamping should begin immediately upon the placing of the first shovelful, and should be continued until the mould is full. The material should be tamped with a tamper having a small face, and short, quick, sharp blows should be struck.

To insure a block of the same consistency throughout, the tamping must be very thorough and should be continued until water appears at the top. This will insure a minimum of air spaces and voids.

Wet Process.—When placing the material in the mould, the entire mould is filled with one pouring. Of late, the tamping of concrete by means of mechanical or pneumatic pressure has come into extensive use. Moulding concrete by pressure is not successful unless the pressure is applied to the face of a comparatively thin layer. If compression of thick layers is attempted, the materials arch and are not compacted at any considerable depth from the surface. Moulding blocks by pressure is therefore practical only in the two-piece system, in which the load is applied to the surface of pieces having no great thickness.

Facing.—It is customary now to use for the facing of a block a richer mixture than is employed for the body of the block. The following are the advantages of facing:

1. Saving in Cost.—The facing being not more than 1/2 inch thick, there is a considerable saving by employing a coarser material for the body of the block.

2. A dense and impervious facing is secured by using a richer mixture and selected aggregates.

3. A pleasing appearance is given to the block. This may be attained by introducing a coloring mixture; since there is some danger of the color fading, colored sand and stone may be used.

It is of the utmost importance that the facing and the rest of the block be thoroughly bonded together, otherwise there is danger of a cleavage plane being formed. The manner in which this may be accomplished is explained under the heading "Making the Block."

Concrete blocks being moulded from a plastic material, their faces are capable of endless variations. The faces most commonly used are the smooth face, panelled, corrugated, and rock faces, also special ornamental designs. In choosing a facing it should be borne in mind that a concrete block possesses ornamental and artistic properties of its own, and a far more pleasing appearance can be obtained by bringing these out than by imitating other kinds of stone.

Curing.—The curing of concrete blocks is a very important consideration. A block badly cured may lose all the good qualities imparted to it by careful manufacture.

All blocks made by the medium wet or medium dry process, should be made under cover, and should remain on the pallet at least 24 hours. They should be kept under cover for at least ten days, protected from the dry currents of air. Under no circumstances should blocks be made under the direct rays of the sun, nor should blocks be exposed either to sunshine or dry winds while curing.

The blocks should be gently sprinkled as soon as possible after making; that is, just as soon as the cement has set sufficiently so that it will not wash.

Plenty of water is absolutely necessary. The process of hardening in the concrete goes on for a great many days, and crystallization, upon which depends the strength of concrete, cannot go on without the presence of a sufficient amount of water. As soon as a block begins to turn white, it is a sure indication that water is lacking. Care should be taken to so pile the blocks that they will receive water on all sides. A block should never be allowed to dry out on the sides before the centre is thoroughly cured.

Blocks should be kept wet from ten days to two weeks, and should never be removed for the purpose of using in a building until they are from thirty to sixty days old. It is well to remember that the longer a block is cured, the harder and better it will become.

Coloring.—In using coloring matter with concrete, the color should always be mixed with the cement dry, before any sand or water is added. The mixing should be thorough, so that the mixture is uniform in color. After this mixing, the combination is treated in the same way as clear cement.

Pure white is impossible where great strength and durability are required, unless white Portland cement is employed. The following formula will make a white block which is stronger than some sandstones. One part pulverized lime, or hydrated lime, two parts white Portland cement, two parts pulverized marble, two parts fine washed silica sand, two parts coarse silica sand.

Blue-gray.—A blue-gray color is often obtained without coloring matter at all, by using a blue Portland cement. Light-colored

Portland cement may be blended to its proper color by the addition of seven pounds of Ultramarine blue to every barrel of cement.

Gray.—Add two pounds of Germantown lamp black to every barrel of cement used, when sand is of light color. Dark sand will require less. Lampblack is a protector against the elements, but reduces the strength of the product; not enough, however, to be detrimental in ordinary dwelling-house construction.

Blue.—Add from ten to fifteen pounds of Ultramarine blue to every barrel of cement. Use dark-colored cement.

Black.—From forty to fifty pounds of Peroxide of Manganese to each barrel of cement.

Red.—Twenty-five pounds of Oxide of Iron to a barrel of cement.

Bright Red.—The above amount of English Red to each barrel of cement.

Lake Superior Red Sandstone.—Twenty pounds Violet Oxide of Iron to a barrel of cement. Less with light sand.

Indiana Bedford.—Ochres, which are detrimental to the stone by reducing its strength, must be used for making buff stone. Twelve to fifteen pounds of Yellow Ochre to every barrel of cement will produce an excellent buff stone.

Waterproofing Concrete Blocks.—The waterproofing of concrete has been treated at length in another chapter; it is well, however, at this point, to enumerate and describe the various methods in so far as they are applicable for securing impermeability of concrete building blocks.

Concrete blocks, as ordinarily made, are exceedingly porous and readily absorb water; this is especially true of blocks made by the "dry" process. This tendency to absorb water gives ground to one of the chief objections to concrete blocks. Concrete blocks, however, are no more water-absorbing than ordinary bricks and it is well known that brick walls must be furred and lathed to avoid dampness; but concrete block walls can and should be sufficiently waterproof so that plastering can be done directly on the wall.

The different methods available for securing impermeability in concrete blocks are as follows:

1. Use of properly graded materials.
2. Use of rich mixtures.
3. Use of a facing.
4. Use of an impervious partition.
5. Use of waterproofing compounds.
6. Applications to surface after erecting.

All the above methods except the use of an impervious partition have been dwelt upon elsewhere in this book. Suffice it to say here that the use of a waterproofing compound will be found to be an effective and economical method, provided the compound is judiciously selected and the work done conscientiously. The following explains the method of waterproofing by securing an impervious partition. In face-down machines, it is a simple matter, after the face is tamped and cores pushed into place, to throw into each spacing a small amount of rich and rather wet mortar, spread this evenly, and then tamp the ordinary mixture until the mould is filled. A dense layer across each of the cross-walls is thus obtained, which effectually prevents moisture from passing beyond it. Recently a method was patented for accomplishing the same results with vertical-face machines. Tapered wooden blocks are inserted in the middle of the cross-walls. After tamping, the blocks are withdrawn, and the spaces filled with rich mortar.

Building Construction Details.—It is usual to employ the following thicknesses of walls in concrete block construction:

For one-story buildings	8 in. walls
For two-story buildings	10 in. walls
For three-story buildings	10 and 12 in. walls
For four-story buildings	10, 12, and 15 in. walls

the thickness, of course, varying from the foundation upward.

The mortar for laying concrete blocks should be composed of 1 part of Portland cement to 3 parts of sharp sand. It is well to add a little hydrated lime to the mortar when mixing. This will prevent it from becoming brittle.

The blocks should be wet when set in the wall, otherwise they will absorb moisture from the mortar, making it very weak. Pointing should be done the same way as in laying brick.

Joists can be fastened by cutting into the blocks. It is far preferable, however, to use hangers for this purpose; these not only facilitate construction, but possess the additional merit of distributing the load on the joists over a greater section of the wall.

Several special devices are employed to enable one to lay metal plugs in the joists; another way is to cast a wooden plug in the concrete when moulding the block.

Cost of Concrete Blocks.—The success of the hollow concrete block industry depends to a great extent on cheapness of product, since it is necessary, in order to build up a large business, to compete in price with common brick and rubble stone. At equal cost, well-made blocks are certain to be preferred, owing to their superiority in strength, convenience, accurate dimensions, and appearance. For the outside walls of handsome buildings, blocks come into competition with pressed brick and dressed stone, which are, of course, far more costly. Concrete blocks can be sold and laid up at a good profit at 25 cents per cubic foot of wall. Common red brick costs generally about 12 dollars per thousand, laid. At 24 to the cubic foot, a thousand brick are equal to 41.7 cu. ft. of wall; or, at $12, 29c. per cu. ft. Brick walls with pressed brick facing cost from 40c. to 50c. per cubic foot, and dressed stone from $1.00 to $1.50 per foot.

The factory cost of concrete blocks varies according to the cost of materials. Let us assume cement to be $1.50 per barrel of 380 lbs., and sand and gravel 25c. per ton. With a 1 to 4 mixture, 1 barrel cement will make 1,900 lbs. of solid concrete, or at 130 lbs. per cu. ft., 14.6 cubic feet. The cost of materials will then be

Cement, 380 lbs.	$1.50
Sand and gravel, 1,520 lbs.	0.19
Total	$1.69

or 11.5c. per cu. ft. solid concrete. Now, blocks 9 inches high and 32 inches long make 2 square feet of face of wall, each. Blocks of this height and length, 8 inches thick, make 1 1-3 cubic feet of wall; and blocks 12 inches thick make 2 cubic feet of wall. From these figures we may calculate the cost of materials for these blocks, with cores or openings equal to 1/3 or 1/2 the total volume, as follows:

Per cu. ft. of block, 1-3 opening	7.7 cts.
Per cu. ft. of block, 1-2 opening	5.8 "
Block 8 × 9 × 32 inches, 1-3 opening	10.3 "
Block 8 × 9 × 32 inches, 1-2 opening	7.7 "
Block 12 × 9 × 32 inches, 1-3 opening	15.4 "
Block 12 × 9 × 32 inches, 1-2 opening	11.6 "

If one-third of the cement is replaced by hydrated lime the quality of the blocks will be improved, and the cost of material reduced about 10 per cent.

The cost of labor required in manufacturing, handling, and delivering blocks will vary with the locality and the size and equipment of factory. With hand-mixing, 3 men at average of $1.75 each will easily make 75 8-inch or 50 12-inch blocks, with 1-3 openings, per day. The labor cost for these sizes of blocks will therefore be 7c. and 10 1/2c. respectively. At a factory equipped with power concrete mixer and cars for transporting blocks, in which a number of machines are kept busy, the labor cost will be considerably less. An extensive industry located in a large city is, however, subject to many expenses which are avoided in a small country plant, such as high wages, management, office rent, advertising, etc., so that the total cost of production is likely to be about the same in both cases. A fair estimate of total factory cost is as follows:

	Material.	Labor.	Total.
8 × 32 inch, $\frac{1}{3}$ space	10.3	7	17.3 cts.
8 × 32 inch, $\frac{1}{2}$ "	7.7	6	13.7 "
12 × 32 inch, $\frac{1}{3}$ "	15.4	10.5	25.9 "
12 × 32 inch, $\frac{1}{2}$ "	11.6	9	20.6 "

With fair allowance for outside expenses and profit, 8-inch blocks may be sold at 30c. and 12-inch at 40c. each. For laying 12-inch blocks in the wall, contractors generally figure about 10c. each. Adding 5c. for teaming, the blocks will cost 55c. each, erected, or 27 1/2c. per cubic foot of wall. This is less than the cost of common brick, and the above figures show that this price could be shaded somewhat, if necessary, to meet competition.

Objections to Concrete Blocks and Remedies for Same.—In spite of the admirable qualities of concrete blocks as a building material, their use has not been so extensive as their merits would seem to warrant. There is still considerable opposition from architects and builders to the use of blocks. This is not due to prejudice against the new material concrete, but rather to the manner in which this material is used. In the past few years, a great many inexperienced men have ventured into the business of block manufacture, allured by the glowing prospects of profit held out by an army of block-machine agents. As a result, everywhere are seen glaring examples of concrete-block buildings that fall far short of the standard of excellence that is claimed can be attained.

The following have been the main objections to the use of concrete blocks:

Imitation of natural stone.
Poor workmanship.
Fixed dimensions.
Similarity of blocks.
Too great weight.
Unpleasing appearance.

Anything that savors of imitation, that pretends to be what it is not, will be shunned by right-minded architects and builders. The common rock-faced block is an imitation of the cheapest form of quarry stone, and a poor imitation at that. But why imitate granite or anything else? Why not bring out in the concrete the beauty that is peculiarly its own? A very prominent architect recently said in a conversation: "These block makers come in here and say, 'Why don't you use blocks? I can make a block that ten feet away you can't tell from red sandstone or marble or what not.' No, I don't wish a concrete block that I can't tell from sandstone. I wish a concrete block that won't 'flower.' When I wish sandstone, I can get sandstone." The rebuke is just; the concrete block maker must confine his energies to making concrete blocks and not to imitating sandstone.

Poor workmanship can be eliminated with proper inspection. Blocks made from too dry mixtures will always be weak and will crumble, and can easily be detected, no matter how much they were cured. Good concrete produces a hard and dense block and emits a musical tone when struck with a hammer.

Contractors and masons often object to the size of the block. A 12 x 32 inch block weighs 180 lbs., and to hoist a number of these and properly handle them is quite a task. For this reason the use of 32-inch blocks is decreasing, except for large buildings and foundations; and the 24-inch block now meets with most favor. Such a block, having a width of 12 inches and a height of 9 inches, weighs only 97 lbs., and if properly made, possesses sufficient strength and durability to meet all requirements.

Concrete Tiles and Other Products.—There are now being manufactured on a large scale, concrete wall tiles, shingles, and

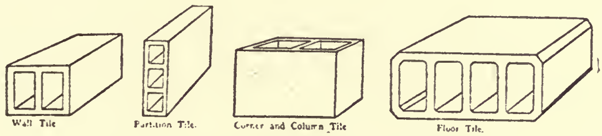

FIG. 34.—Standard Shapes of Concrete Tile.

other accessories for building construction. While the machinery employed varies with the different processes employed by different makers, the general principles as to mixing, curing, etc., are essentially the same as in ordinary block-making.

HOW TO FIGURE THE COST OF BLOCKS (SEE TABLE XI)

One barrel contains 3¾ cubic feet.

One cubic yard contains 7¼ barrels.

One yard of sand and 3⅝ bbls. of cement equals 2 to 1 mixture.

One yard of sand and gravel and 1½ bbls. of cement equals 5 to 1 mixture.

In making blocks we recommend a mixture for the facing of one part cement, 2 parts coarse sharp clean sand, and the body of the block, 1 part cement, 2 parts sand, and three parts gravel or broken stone. The gravel or broken stone to range in size from ¼″ to ¾″ in diameter.

For manufacturing 100 blocks 8 x 8 x 16 inches there is needed 2.24 barrels of cement, 0.68 cubic yards of sand, and 1.06 cubic yards of gravel or broken stone which, at the following estimated cost of materials, will amount to:

EXAMPLE

2.24 barrels of best Portland cement at $2.00 per bbl....	= $4.48
0.68 cubic yards of sand at $1.00 cu. yd..............	= .68
1.06 cubic yards of gravel or broken stone at $1.50 cu. yd.	= 1.59
Cost for labor for 100 blocks........................	= 1.75
Incidentals for safe margin per 100 blocks	= .50
Total cost for 100 blocks 8 x 8 x 16″	= $9.00

The above are approximate and conservative prices for materials and labor. These may vary, however, to a less or higher degree governed by locality.

The cost of concrete blocks in any locality will be found to be much less than that of common brick and they are also a better and more lasting material.

TABLE XI.—Concrete Block Data.*

Giving size and weight of blocks, the number one barrel of cement will make, the number to one cubic yard of material and the number per square of one hundred superficial feet.

Height. Width. Length.	Solid Blocks.			Hollow Blocks.			No. per Square of 100 Square Feet.
	Weight of Block. Pounds.	No. per Bbl. of Cement at 1 to 5.	No. per Cubic Yard.	Weight of Block. Pounds.	No. per Bbl. of Cement at 1 to 5.	No. per Cubic Yard.	
8 × 8 × 16	73	34	48	50	49	71	112
8 × 10 × 16	92	27	38	67	37	53	112
8 × 12 × 16	109	22	32	80	31	44	112
4 × 8 × 16	35	68	99	24	100	144	224
4 × 10 × 16	44	54	79	32	76	109	224
4 × 12 × 16	53	44	66	39	63	91	224
8 × 4 × 16	37	68	95	....	....	....	112
8 × 8 × 24	112	22	31	77	32	45	75
8 × 10 × 24	140	18	25	92	25	38	75
8 × 12 × 24	166	15	21	112	21	31	75
4 × 8 × 24	54	46	65	37	66	94	150
4 × 10 × 24	67	36	52	46	52	76	150
4 × 12 × 24	79	30	44	55	44	63	150
8 × 4 × 24	55	44	63	....	....	....	75

Explanation.—To find the number of blocks for a building, get the surface feet of the building by multiplying the length around the building by the height of the wall. Add to this the surface of gables, then deduct the surface feet of all the openings, thus giving the actual surface to cover.

Rule.—Multiply the number of squares to cover by the number in the last column, for the size block you are to use, which will give the number of blocks for any building.

* Published by the Ideal Concrete Machinery Company.

Concrete Building Blocks

STANDARD SPECIFICATIONS FOR CONCRETE BLOCKS

RULES AND REGULATIONS FOR BLOCKMAKERS, AS REVISED, CORRECTED, AND ADOPTED BY THE NATIONAL ASSOCIATION OF CEMENT USERS AT THEIR CONVENTION, 1908.

Concrete hollow blocks made in accordance with the following specifications, and meeting the requirements thereof, may be used in building construction, subject to the usual form of approval required of other materials of construction by the Bureau of Building Inspection:

1. *Cement.*—The cement used in making sand blocks shall be Portland cement, capable of passing the requirements as set forth in the "Standard Specifications for Cement," by the American Society for Testing Materials.

2. *Sand.*—The sand used shall be suitable silicious material, passing the one-fourth-inch mesh sieve, clean, gritting, and free from impurities.

3. *Stone or Coarse Aggregate.*—This material shall be clean broken stone, free from dust, or clean screened gravel passing the three-quarter (¾) inch, and refused by the one-quarter (¼) inch, mesh sieve.

4. *Unit of Measurement.*—The barrel of Portland cement shall weigh 380 pounds net, either in barrels or sub-divisions thereof, made up of cloth or paper bags, and a cubic foot of cement shall be called not to exceed 100 pounds or the equivalent of 3.8 cubic feet per barrel. Cement shall be gauged or measured either in the original package as received from the manufacturer, or may be weighed and so proportioned; but under no circumstances shall it be measured loose in bulk.

5. *Proportions.* For exposed exterior or bearing walls: (*a*) Concrete hollow blocks, machine-made, using semi-wet concrete or mortar, shall contain one (1) part cement, not to exceed three (3) parts sand, and not to exceed four (4) parts stone, of the character and size before stipulated. When the stone shall be omitted, the proportions of sand shall not be increased, unless it can be demonstrated that the percentage of voids and tests of absorption and strength, allow in each case of greater proportions, with equally good results. (*b*) When said blocks are made of slush concrete, in individual moulds, and allowed to harden undisturbed in same before removal, the proportions may be one (1) part cement to not exceed three (3) parts sand and five (5) parts stone, but in this case also, if the stone be omitted, the proportions of sand shall not be increased.

6. *Mixing.*—Thorough and vigorous mixing is of the utmost importance.

(*a*) Hand Mixing.—The cement and sand in correct proportions shall be first perfectly mixed dry, the water shall then be added carefully and slowly in proper proportions, and thoroughly worked into and throughout the resultant mortar; the moistened gravel or broken stone shall then be added, either by spreading same uniformly over the mortar, or spreading the mortar uniformly over the stones, and then the whole mass shall be vigorously mixed together until the coarse aggregate is thoroughly incorporated with and distributed throughout the mortar.

(*b*) Mechanical Mixing.—Preference shall be given to mechanical mixers of suitable design and adapted to the particular work required of them; the sand and cement, or sand and cement and moistened stone shall, however, be first thoroughly mixed before the addition of water, and then continued until the water is uniformly distributed or incorporated with the mortar or concrete (such as will quake or flow). This procedure may be varied with the consent of the Bureau of Building Inspection, architect, or engineer in charge.

7. *Moulding.*—Due care shall be used to secure density and uniformity in the blocks by tamping or other suitable means of compression. Tamped blocks shall not

be finished by simply striking off with a straight edge, but, after striking off, the top surfaces shall be trowelled or otherwise finished to secure density and a sharp and true arris.

8. *Curing.*—Every precaution shall be taken to prevent the drying out of the blocks during their initial set and first hardening. A sufficiency of water shall first be used in the mixing to perfect the crystallization of the cement, and, after moulding, the block shall be carefully protected from wind currents, sunlight, dry heat, or freezing, for at least five (5) days, during which time additional moisture shall be supplied by approved methods, and occasionally thereafter until ready for use.

9. *Ageing.*—Concrete hollow blocks in which the ratio of cement to sand be one-third ($\frac{1}{3}$) (one part cement to three parts sand), shall not be used in the construction of any building in the (City) of.............., (Town) of................, until they have attained the age of not less than three (3) weeks.

Concrete hollow blocks in which the ratio of cement to sand be one-half ($\frac{1}{2}$) (one part cement to two parts sand), may be used in construction at the age of two (2) weeks, with the special consent of the Bureau of Building Inspection, and the architect or engineer in charge.

Special blocks of rich composition, required for closures, may be used at the age of seven (7) days with the special consent of same authorities.

The time herein named is conditional, however, upon maintaining proper conditions of exposure during the curing period.

10. *Marking.*—All concrete blocks shall be marked for purposes of identification, showing name of manufacturer or brand, date (day, month, and year) made, and composition or proportions used; as, for example, 1:3:5, meaning one cement, three sand, and five stone.

11. *Thickness of Walls.*—The thickness of bearing walls for any building where concrete hollow blocks are used, may be ten (10) per cent less than is required by law for brick walls. For curtain walls, or partition walls, the requirements shall be the same as in the use of hollow tile, terra-cotta, or plaster blocks.

12. *Party Walls.*—Hollow concrete blocks shall not be permitted in the construction of party walls, except when filled solid.

13. *Walls, Laying Of.*—Where the face only is of hollow concrete block, and the backing is of brick, the facing of hollow block must be strongly bonded to the brick either with headers projecting four (4) inches into the brickwork, every fourth course being a heading course, or with approved ties; no brick backing to be less than eight (8) inches. Where the walls are made entirely of concrete blocks, but where said blocks have not the same width as the wall, every fifth course shall extend through the wall, forming a secure bond, when not otherwise sufficiently bonded. All walls, where blocks are used, shall be laid up with Portland cement mortar.

14. *Girders or Joists.*—Wherever girders or joists rest upon walls so that there is a concentrated load on the block of over two (2) tons, the block supporting the girder or joists must be made solid for at least eight (8) inches from the inside face. Where such concentrated load shall exceed five (5) tons, the blocks for at least three courses below, and for a distance extending at least eighteen (18) inches, each side of said girder shall be made solid for at least eight (8) inches from the inside surface. Wherever walls are decreased in thickness, the top course of the thicker wall shall afford a full solid bearing for the webs or walls of the course of blocks above.

15. *Limit of Loading.*—No wall, nor any part thereof, composed of concrete hollow blocks, shall be loaded to an excess of eight (8) tons per superficial foot of the area of such blocks, including the weight of the wall, and no blocks shall be used in bearing

walls that have an average crushing at less than 1,000 pounds per sq. in. of area, at the age of twenty-eight (28) days; no deduction to be made in figuring the area for the hollow spaces.

16. *Sills and Lintels.*—Concrete sills and lintels shall be reinforced by iron or steel rods in a manner satisfactory to the Bureau of Building Inspection, and the architect or engineer in charge, and any lintels spanning over four feet six inches shall rest on block solid for at least eight inches from the face next the opening and for at least three courses below the bottom of the lintel.

17. *Hollow Space.*—The hollow space in building blocks, used in bearing walls, shall not exceed the percentage given in the following table for different height walls, and in no case shall the walls or webs of the block be less in thickness than one-fourth their height. The figures given in the table represent the percentage of such hollow space for different height walls.

TABLE XII.—Hollow Spaces in Blocks.

Stories.	1st.	2nd.	3rd.	4th.	5th.	6th.
1 and 2.......	33	33				
3 and 4.......	25	33	33	33		
5 and 6.......	20	25	25	33	33	33

18. *Application for Use.*—Before any such material be used in buildings, an application for its use and for a test of the same must be filed with the Bureau of Building Inspection. In the absence of such a bureau the application shall be filed with the chief of any department having such matters in charge. A description of the material and a brief outline of its manufacture and proportions used must be embodied in the application. The name of the firm or corporation, and the responsible officers thereof, shall also be given, and changes in same thereafter promptly reported.

19. *Preliminary Test.*—No hollow concrete blocks shall be used in the construction of any building unless the maker of said blocks has submitted his product to the full tests required herein, and placed on file with the Bureau of Building Inspection, or other duly authorized official, a certificate from a reliable testing laboratory, showing that representative samples have been tested and successfully passed all requirements thereof, and giving in detail the results of the tests made.

No concrete blocks shall be used in the construction of any building until they have been inspected and approved, or, if required, until representative samples be tested and found satisfactory. The results of all tests made, whether satisfactory or not, shall be placed on file in the Bureau of Building Inspection. These records shall be open to inspection upon application, but need not necessarily be published.

20. *Additional Tests.*—The manufacturer and user of such hollow concrete blocks, or either of them, shall, at any and all times, have made such tests of the cement used in making such blocks, or such further tests of the completed blocks, or of each of these, at their own expense, and under the supervision of the Bureau of Building Inspection, as the chief of said bureau shall require.

In case the result of tests made under this condition should show that the standard of these regulations is not maintained, the certificate of approval issued to the manufacturer of said blocks will at once be suspended or revoked.

21. *Certificate of Approval.*—Following the application called for in clause No. 18, and upon the satisfactory conclusion of the tests called for, a certificate of approval shall be issued to the maker of the blocks by the Bureau of Building Inspection. This certificate of approval will not remain in force for more than four months, unless there be filed with the Bureau of Building Inspection, at least once every four months following, a certificate from some reliable physical testing laboratory showing that the average of at least three (3) specimens tested for transverse strength, comply with the requirements herein set forth. The said samples to be selected by a building inspector, or by the laboratory, from blocks actually going into constructing work.

22. *Test Requirements.*—Concrete hollow blocks must be subjected to the following tests: Transverse, compression, and absorption, and may be subjected to the freezing and fire tests, but the expense of conducting the freezing and fire tests will not be imposed upon the manufacturer of said blocks.

The test samples must represent the ordinary commercial product, of the regular size and shape used in construction. The samples may be tested as soon as desired by the applicant, but in no case later than sixty days after manufacture.

Transverse Test.—The modulus of rupture for concrete blocks at 28 days must average one hundred and fifty, and must not fall below one hundred in any case.

Compression Test.—The ultimate compressive strength at 28 days must average one thousand (1,000) pounds per square inch, and must not fall below seven hundred in any case.

Absorption Test.—The percentage of absorption (being the weight of water absorbed, divided by the weight of the dry sample) must not average higher than 15 per cent, and must not exceed 22 per cent in any case.

23. *Condemned Block.*—Any and all blocks, samples of which on being tested under the direction of the Bureau of Building Inspection, fail to stand at twenty-eight (28) days the tests required by this regulation, shall be marked condemned by the manufacturer or user and shall be destroyed.

24. *Cement Brick.*—Cement brick may be used as a substitute for clay brick. They shall be made of one part cement to not exceeding four parts clean sharp sand, or one part cement to not exceeding three parts clean sharp sand and three parts broken stone or gravel passing the one-half inch and refused by the one-quarter inch mesh sieve. In all other respects cement brick must conform to the requirements of the foregoing specifications.

CHAPTER XIV

THE MAKING OF ORNAMENTAL CONCRETE

Methods Employed.—Modelling.—Moulding.—Wooden, Metal, Plaster, Glue, and Sand Moulds.

Ornamental concrete, as has already been referred to in the section on Concrete Architecture (under which this chapter might also have been included), is now playing a large part, and is destined to play a still greater part in enhancing the elegance and beauty of our modern homes, gardens, and landscapes.

The development of the various methods of manufacture has given us the possibility of the highest, as well as the most enduring, architectural effects, and most of these are within the financial reach of the most modest home. Simple pottery, garden furniture, and other handsome decorative work can be made at home by the exercise of care, patience, and some study and the possible enhancement of any home in appearance by their use cannot be overestimated. The principal methods of making these products are given in the following pages.

All the precautions to be observed in ordinary concrete work are especially important in ornamental work. The sand must be clean and free from loam, or the ornament will have a dirty color, and if any color work is to be attempted either with pigments or colored stones, cleanliness of sand is absolutely necessary. Soundness of cement is important because sharp edges will crumble if the cement is not sound. The aggregate, too, must be selected to produce the desired effect. Ordinary concrete is dull and monotonous, and this must be remedied in ornamental work by using selected aggregate, either marble dust and small marble chips to produce a white effect, or selected red, brown, or blue stones for color effects. The color and sparkle of the stones must be brought out by surface treatment as explained in Chapter XII.

Methods of Manufacture.—The methods of making concrete ornaments and producing ornamental effects in concrete can be divided into two general classes: first, *modelling*, which includes all concrete work built without moulds, usually onto wire mesh foundations and modelled into shape by hand or by scraping with templets of wood or metal; and second, *moulding* which includes all concrete work made in forms.

Modelling.—The cheapest and quickest way to make simple designs where only one or two of a kind are planned is that of modelling. It is surprising how great a variety of forms can be

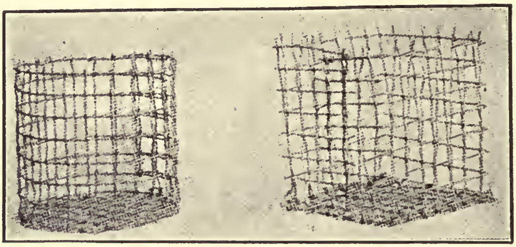

FIG. 35.—Wire-mesh Frames for Modelling Concrete Pottery.

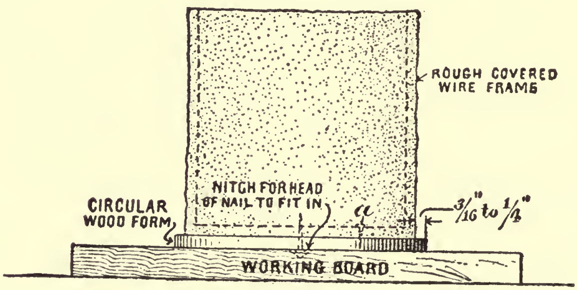

FIG. 36.—How Rough-Coated Jar is Attached to Circular Wood Form.

obtained by a little ingenuity. The fundamental principle in every case, no matter how simple or complicated, is to make a skeleton of wire mesh, or some rough material, or build up the body solid, approximately the form of the finished product, and lay onto this rough body the concrete to the proper lines. Then finish with a templet by revolving the concreted form about its centre, the templet being held still. We will describe a simple case from which the reader will be able to see the method and easily make more complicated designs.

To make a cylindrical vase by modelling, procure sufficient wire mesh, and with a compass or piece of string and chalk, describe a circle on the mesh about the size of the base of the vase to be made. With a pair of wire-cutters, cut the mesh at each point on the circle. Now cut a rectangular piece an inch and a half longer than the circumference of the circle just made, and an inch broader than the height of the vase. Roll this piece on a table or board into a cylinder the size of the vase; the extra inch and one-half will overlap. This is to hold the cylinder fast. Lay this on the table and place the bottom on top of it, and bend the wires of the sides around the bottom. This makes a firm and tight cage on which to build your ornament. Now mix up sufficient concrete for the scratch coat and with a small trowel or knife force this into the mesh, leaving the outside rough as possible so as to form a bond with the finishing coat. Cut an inch board into a circle a little larger than the frame, equal to the outside diameter of the ornament and in the centre of the board drive a nail; place the unfinished piece on this board with the projecting nail in its centre so that when the piece is revolved about this nail, every point of the frame will be an equal distance from the circumference of the board. Now make a scraping tool by attaching two pieces of inch wood together to form right angles and bevel the edge of one to form a cutting edge. Next mix your finishing coat and apply as before with a small trowel when the concrete is built out to the circular base. Take your scraping tool and hold it on a table or board so that the cutting edge is vertical and rests tight against the wooden base. Revolve the base board and concreted frame together; the tool will scrape off the projections. Fill in all holes with more concrete and continue revolving until the cutting edge touches at every point and there are no projections. Next level off the top to the right height by similar method, having the tool fixed at proper height and revolving your piece until a smooth surface is procured. The inside is built out to the desired thickness and finished by scraping and filling until its surface is parallel to the outside surface. This can best be done by using three pieces of wood formed into a U, the distance between the two vertical legs being the thickness of the piece and their lengths equal to the height of the piece. The inside should not be started until after the outer coat has set for about

6 to 12 hours; it will then be sufficiently hard so that the tool will not injure its surface. The inside bottom is finished by holding a board about as wide as the inside diameter and revolving the ornament as before.

A small amount of goats' hair added to the concrete makes it hold together and the concrete should not be mixed very wet.

No matter how complicated the form is, the method is essentially the same, a cutting edge being used to form a guide, usually of wood, on which the ornament rests and is centered. If the ornament is square or oblong, the cutting edge is moved along each side of the piece of wood until all are formed.

If the form has a spherical surface, a templet of a circular shape must be cut to scrape to the right lines.

This method of scraping is often used to form solid mouldings, copings, etc., the ornament being built in place by moulds and the top built up and scraped to the desired lines by templets formed of sheet iron backed with lumber. The templet is moved along the top edge of the form. The ornaments made in this way can be further decorated by one or other of the ways to be described later.

Moulding.—The method of making concrete ornaments most generally in use and the one most economical and satisfactory where any number of a similar form are to be made, is that of moulding. There are many different methods of moulding, and each is especially adapted to special classes of work. The simplest, perhaps, is the wooden mould, where the object to be formed is composed of straight lines such as square or oblong boxes decorated with diamonds or some such simple impression, or ornamental concrete lattice work for porches, fences, etc. When the forms become more complicated, standard plaster, sand, or glue moulds must be employed.

Standard moulds are best wherever ornaments are to be made on a commercial scale large enough to warrant their first cost, and when they can be procured of proper size and form for the purpose. As ornamental concrete work is in its infancy, the variety of standard forms on the market at present is not very large, and it is much better to make a form for yourself than to accept one that does not fill your requirements. With present progress, there is no doubt that in a very short time there will be such a variety of forms that it will be absurdly extravagant to make one for yourself, unless your need is unique.

Wooden Moulds.—In making ornaments with wooden forms or moulds, all that is necessary is to build an outside mould of such form that its inside corresponds to the outside of desired ornament; if your ornament is to be hollow or have an open bowl, make a core or inside mould, the outside of the core corresponding to the inside of the ornament. The core must be in so many parts that it can be removed without injuring the ornament after it is hard. The outside mould is placed on a board or working table bottom down. All surfaces that are to come into contact with the concrete are shellacked and oiled well. A layer of concrete is then poured into the mould, as thick as the bottom of the ornament; the core having been shellacked and oiled is then set in place on this bed of concrete. The remaining concrete is poured around the core and well tamped and the top is carefully smoothed off. After this has set about 24 hours the core and outside mould are removed and the surface of the ornament is treated in one of the many ways suggested. It is then laid aside to cure. It should be wetted once or twice a day for a week or two to prevent crumbling.

In making wooden moulds, the core must be made collapsible so as to be easily removed, and as few nails as possible must be used to avoid unnecessary hammering. Rounded or bevelled edges can be obtained in wooden forms by using picture moulding and triangular strips, blocks of wood, diamond shape, square or round can be tacked in the form, and thus produce corresponding indentations in the concrete. These indentations can be filled with colored cement, clay or tiles, producing very interesting effects. Tiles can be placed in the forms held by light strings in proper positions and the concrete carefully tamped around them. After the concrete has set, the string is cut, and the form is removed, thus leaving the tile in the finished ornament.

Metal Moulds.—Forms made of galvanized sheet iron stamped and bent to the desired lines have been used with some success as moulds for concrete work. They can usually be made by any cornice mason and with the bending machines used in cornice work. For large designs the sheet iron must be braced with wood to prevent bending.

Plaster Moulds.—In making concrete mould work with any but wooden forms, the first thing is to obtain a model. These models may be made of wood for simple designs or modelled in clay, or plaster of Paris for more complicated designs. Metal or China ornaments, vases, and jardinières can also be reproduced.

Take a simple case of making a concrete box. First, construct a box of wood of the required size, make the inside of the box taper slightly so that the material is thicker at the bottom than at the top; this will allow the model to be slipped out from the mould when the same is hard.

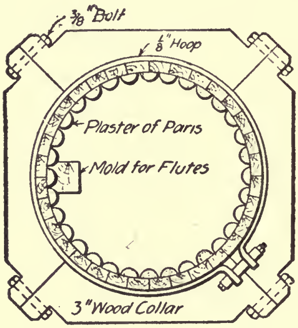

FIG. 37.—Moulds for Ornamented Column.

Now lay your wooden box upon a working board, shellac and oil all surfaces, and mix up enough plaster of Paris to make a layer about one-half inch thick around the sides of the box. By means of thumb tacks or small tacks attach a strip of paper at each of two opposite edges of the box. This paper is to separate the mould and make two halves of it. Now apply the plaster to the model, making a wall about one-half inch thick. When this is hard, remove same from the box and proceed to make the core or inside portion of mould. First shellac and oil well the inside of the box, then mix up sufficient plaster of Paris and fill the box with same. Level off the top and allow to harden about 15 minutes, then hold the box upside down over the working board and tap gently. Owing to the taper of the box, the plaster will slip out easily. This core should be smoothed off and corners rounded if desired.

All that is necessary now is to shellac and oil the parts of the mould which come in contact with the concrete as well as the working board on which they rest; properly centre the core and outside walls on the board, the two parts of the outside mould being held together by a string tied around them. As they are on the board now, the bottom of the box is up, so that the core must be placed with its largest side down. The outsides will project up above the core an amount equal to the thickness of the bottom. Now mix up your concrete and pour same into the annular layer between the core and the outer mould and over the core to the top of the mould. Carefully tamp your concrete down into he mould, preventing air holes, etc. When mould is full, scrape off the top with a straight edge and allow to stand until concrete has set. This takes about 8 hours. At the end of this time, the mould can be removed as follows:

Gently tap the working board on its edges and it will fall free from the mould, then place the mould and model together on some

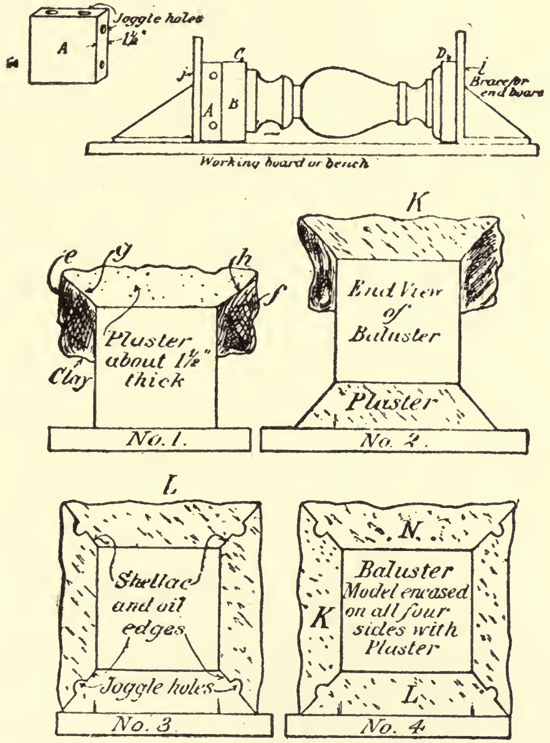

FIG. 38.—Plaster Moulds for Concrete Baluster. Sketch showing progressive steps in moulding same.

blocks of wood a few inches high on the board, supported so that the concrete ornament and the outside mould rest on the blocks and the inside core is free. Gently tap the mould until the core drops out. The outside form is next removed by similar tapping, the string that binds the two parts being severed.

To make more complicated designs in plaster moulds, all that is necessary is to procure a model, and cover same with plaster, making it in so many parts as to avoid all reentrant angles, undercuts, or overhanging corners. If a core is used, it can be cut up into small wedges so as to be easily removed. Plaster of Paris can be cut with a fine saw very nicely if kept wet.

Handles or ears to vases can be moulded separately and fitted to holes prepared in the vase and cemented in place.

Glue Moulds.—For designs in concrete which have considerable undercut, glue moulds have been used almost exclusively in the past, because they are flexible and can be strained so as to allow the finished product to be removed.

A glue mould can be reused about six times and the glue can then be boiled down and used again for other moulds, but they are not quite so good as plaster moulds, which will last indefinitely if handled carefully.

Sand moulds are displacing to some extent, the use of glue moulds, because of certain advantages, of which more will be said later.

In concrete work formed from glue moulds, as with all other mould work, a model of the piece to be formed must first be obtained or made. The model is laid on the table or working board and a pencil line is drawn around it on the board, so as to mark its position. This enables the workman to put the model back again in the precise position after it has been moved. The model is next covered with a damp newspaper, the paper being pressed into all the corners and angles of the model. A layer of damp clay about 3/4 of an inch thick is then laid over the model following its contours roughly. Next, a plaster case is moulded over the clay, filling this case about 3/4 inch thick, and is made flat on its outside so as to be able to rest on this side when in use. The outside of the case is marked on the board in the same way as the model was. When the plaster case is sufficiently hard, it is removed and the clay and paper taken from the model which is now shellacked, oiled, and replaced, in its original position, by means of the line on the board.

The plaster case has two holes bored into it, one about 3/4 inch in diameter to permit the glue to flow through it; the other, a small hole, to allow the air to pass out as the glue is poured in, is bored in the highest point in the case, thus serving to tell when the space between the model and case is full, by the glue coming out of it. The plaster case is next put into the position indicated by the line on the board, and fastened in this position by straps passing over it.

The glue should be of a good quality of white glue; it is heated in a double boiler until it is thin enough to pour. The space between the plaster case and the model is filled with the glue by slowly pouring it into the hole provided until it runs out of the air vent. It is then allowed to stand about 12 hours to congeal. The plaster case is removed, and the glue mould is taken from the model by springing its ends and sides slightly so as to allow the undercuts to slip out without injuring the model or the mould. The mould is kept in the plaster case so as to preserve its shape.

Before using the glue mould, its surface must be treated so as to make it waterproof; this is accomplished by washing it with a saturated solution of alum. Two or three coats are necessary, and each coat must be dry before the next is applied. In lieu of the foregoing, the surface can be varnished and oiled.

Sand Moulds.—Sand moulds are probably the cheapest moulds in which concrete can be cast, and at the same time they offer some advantages over all other methods of moulding. In a sand mould, it is of no account how great the undercut or how small the orifice through which the core has to be removed, for the sand after it has dried out can be crumpled into little grains and poured out of an orifice or scraped out of an undercut with great ease and without possibly injuring the ornament.

The process of making artificial stone by casting in moistened sand is described by W. P. Butler, the inventor, as follows:

"Opening Casting.—The first step in the process is to make a wooden pattern of the stone to be made. This pattern or model is made of the exact size of the stone desired, and it may be made in one or in several pieces. The size and style of the block usually determine the method to use in the casting of it.

"The most common method of casting is that of casting on the floor, or 'open-casting,' as it is commonly called. Nearly all large stones as well as small ones are cast in this way. The pattern is embedded solidly upon the compound (which for brevity we will call the sand), which is then packed solidly around it and built up until it is fully embedded in the same manner that a pattern is set in the sand in a foundry. To remove the pattern from the sand it should be lightly tapped, so as to loosen it without noticeably enlarging the mould, from which it should then be withdrawn with the greatest care so as not to break down the edges.

"If, on examination, the surfaces of the mould are not perfectly smooth, or if any edge is broken down, or if any detail is imperfect or damaged, it may be 'touched up' or repaired with the moulder's tools which it is necessary to have.

"One perfect mould having been made, as many others as are desired can be made in like manner from the same pattern. A competent moulder can make from five to fifty moulds in a day, according to the difficulty or size of each. If the pattern has no projecting parts which would prevent its being withdrawn from the sand, it may best be made in one piece, but if there are projecting details or undercuts on the pattern, then it must be made in two or more pieces so as to make it possible to withdraw it from the sand without breaking down the mould This necessitates not only good workmanship on the part of the pattern-maker, but a thorough knowledge on his part of the necessities of the moulding process.

"The removal from the sand of a pattern of two or more pieces is done in the same manner as though there was but one piece, but it requires more time and care.

"Compartment Casting.—If the block to be cast is for a cornice, belt-course, water-table, or any similar purpose where there is an ornamental or moulded face, with the other sides plain, a better and more rapid method of casting is to fasten two planks on edge, and parallel with each other, with partitions, fashioned between the planks at proper distances, forming a series of compartments in each of which is to be cast a stone. The length of the pattern or distance between the planks is made to equal the length of the block.

"The pattern in this case need be only the face of the block which is adjusted within the compartment at such a distance from the partition back of it as to give the proper width to the block. Then in the space in front of the pattern, solidly tamp the sand.

"Next loosen the pattern and draw it away from the sand, which retains the design of the face. This process is repeated in the several compartments, and the moulds are then filled. By this method a minimum of time is required and blocks are formed much more rapidly than when moulded in a bed of material on the floor.

"Casting in Open-end Flasks.—This method will prove to be the best in many cases, especially where it is desired to pack the moulding compound vertically on the face of the pattern. In this process a box or collapsible 'flask' is open at the top and bottom. Within the flask and at the proper distance from the bottom is fastened the pattern or face-plate.

"Over and upon the top of the pattern tamp the sand and then fasten over this the cover to hold the sand in position while the flask is being turned over. Next loosen and remove the pattern, leaving the mould ready for the cast, wherein the face of the block alone is in the sand. When the cement is hardened the flask is loosened and removed.

"Casting in Closed Flask.—Many pieces, such as balusters, balls, or similar turned forms, or forms which are symmetrical on all sides, must be cast in closed boxes or flasks.

"The pattern of the baluster is, in the case shown, made in two pieces which are embedded in the lower and upper halves of the flask. The patterns are then withdrawn and the two halves of the flask are carefully locked together. The cast is then made by pouring the liquid cement through the opening in the end of the flask. A great variety of the finest ornamental work is cast in this manner.

"In all cases the cement and powdered stone, in the proportions of one of cement to three of stone dust, are mixed with water until of the consistency of thick gravy, and then carefully poured into the mould, using a pouring board or pipe to guide the stream and prevent its tearing up the sand. The mass is then allowed to set and harden for about a week before it is removed from the mould. This protection of the cement in the moistened mould prevents the cracking or checking of the surface. When the stone is fully dried out, the surface is brushed off with a wire brush to remove the surplus sand, and, if a tooled appearance is desired, the surface can be gone over with tools and then the block cannot be distinguished from one carved from the natural stone."

CHAPTER XV

CONCRETE PIPES, FENCE POSTS, ETC.*

Advantages of Concrete Pipes.—Moulds, Machines, and Manufacture of Reinforced Concrete Pipes.—Concrete Tile, Data, and Costs.—Advantages of Concrete Fence Posts.—Moulds, Machines, and Manufacture.—Reinforcement for Fence Posts.—Fastening Fence to Posts.—Quantity of Materials for Fence Posts.

CONCRETE PIPES*

A LARGE amount of concrete pipe is now being manufactured and used in this country. They possess many advantages over and are far superior to any other kind of pipe for many purposes.

Advantages of Concrete Pipe.—Concrete pipe can be manufactured practically anywhere. But little equipment is required and this can readily be obtained. Of the material necessary for manufacture, the sand and stone can always be found locally. The cement may have to be shipped some distance, but the cement constitutes but a small portion of the bulk. Thus, easily obtained materials, low freight charges, and low cost of equipment all make for a low-priced pipe. It costs less to make concrete pipe than to make clay pipe, and a better, truer, and stronger pipe is the result.

Properly made concrete pipe does not, under usual conditions, deteriorate with age, but instead grows stronger. The life of the pipe is therefore indefinite. This can be said of no other form of pipe. If made impervious it is immune from injury by acids, oils, alkali, and other disintegrating influences as explained in a previous chapter.

Concrete pipe, if properly made, is perfectly shaped and is true at both ends. This uniformity greatly simplifies the laying of the pipe, as because of it all members will fit together easily and accurately.

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* The best treatise on cement pipe will be found in "Cement Pipe and Tile," by E. S. Hanson, editor of *Cement Era*, published by Cement Era Publishing Co., Chicago, Ill.

Enlarged bells are not necessary for the proper jointing of concrete pipes. The pipe therefore may be of uniform diameter throughout, which greatly facilitates bedding and aligning.

Concrete pipe is not limited to the circle in shape, but may be varied to suit the conditions. Where the flow is variable the egg shape may be desired, and again where a greater area of bed is necessary a pipe with a flattened invert may be decided upon. Such shaped pipes may be as readily made in concrete as the more generally used circular ones.

Concrete pipe may be made of any strength desired by introducing suitable reinforcement. It may, therefore, be used for pipes under pressure.

Manufactured vs. Cast-in-Place Pipe.—When compared with a concrete pipe cast in place, the following advantages are claimed for a concrete pipe, made in short lengths in some convenient place, and then laid.

The pipe may be readily inspected both during and after manufacture.

Reinforcing metal may be accurately placed and kept in place until the concrete has been poured.

The forms may be used over and over again, thereby decreasing the cost of the pipe.

Being laid in short lengths, each length may be allowed to settle firmly on its bed before closing the joints. In large pipes the back fill may even be placed before cementing the joints. This minimizes the danger of the pipe straining or cracking due to unequal settlement. Also, under these conditions, when once closed there should be little or no tendency for the joints to reopen.

The disadvantage of a pipe laid in short sections is the number of joints. These joints are of necessity the weakest part of the pipe, and are therefore the controlling element. This inherent weakness is overcome to a certain extent by various special methods, as the use of metal ties between sections, or by lapping the reinforcement of one section over that of the next.

Moulds, Machines, and Manufacture.—Various kinds of moulds and machines for the manufacture of concrete pipe have been designed and patented.

The simplest of these consists of an iron pallet, an outer hinged shell and an inner collapsible core, both of sheet steel, a cap to fit over the core and a tamper. To these may be added an attachment for forming a bell end on the pipe. The method of using is as follows:

The iron pallet is placed on the floor, the core is backed inside and the conical cap is placed over it. The outer shell is then backed in place, and the mould is ready to be filled. Concrete is shovelled in a little at a time and thoroughly tamped. The whole outfit is then removed to the curing shed where the inner core is first collapsed and removed, then the outer shell expanded and removed, leaving the finished pipe standing on the pallet.

The "Schenk Siam" tile* machine consists essentially of a pyramidal frame about 8′ high, a revolving table for carrying moulds, a revolving shaft carrying the packer head, a loot from which the moulds are filled, and a bucket elevator which delivers the concrete to the loot.

The tile are made in galvanized iron jackets, made in two parts, and provided with hinges and lock. These jackets are set on pallets carried by the revolving table, the table carrying six pallets of any size. These pallets are held by pins in the table, the change from one size to another being made by simply lifting off one set of pallets and dropping another into place.

The table is revolved and the jacket placed in a position for making tile by means of a cam at the rear of the machine. There is a ring, or rather a combination ring and a small hopper, which drops down on to the jacket after it is revolved into position, and holds the jacket solidly in position while the tile is being made.

When the jacket is in place, the packer head, which is on a sliding shaft, operated by another cam at the rear of the machine, drops down through the jacket and into and fills the bottom ring; and just at this point, where the packer fills the ring, the concrete is dumped in from the top by means of the elevator. The cup on the elevator holds just enough material to make a tile, different cups being put on for the different sizes. Thus the concrete is dumped down inside of the jacket and around the packer, and the packer

* From "Cement Pipe and Tile," by Hanson.

head revolves up through the concrete and packs, forces, and presses the material between the jacket and the packer. This packer head has concave sides and is graduated out from the size of shaft on which it revolves, to the full size of the inside of the tile at the lower end. Thus, it is in one sense the core, for it forms the inside of the tile, and revolves up out of the jacket through the top ring, and the ring rises with it and releases the jacket, and the tile is made; then the table revolves and another jacket moves into place.

As the tile are made they are removed from the machine and taken to the drying shelves where the jackets are taken off.

The machine has a square upright plane and the pallets are carried on a sliding rack which holds two pallets, so that as one finished tile is carried away, another jacket slides into place. The power head is made in two parts, the main part attached to the shaft revolving at one speed while the wings attached to the outer shaft revolve at a much higher speed, pressing the concrete outward against the walls of the jacket and trowelling it down smooth.

When the carriage is at its highest point the head fills the lower ring, or pallet; then the concrete is dumped in automatically; the head revolves continually and forms the tile. When the carriage is at its lowest point the table shifts automatically and the tile in the jacket is taken to the curing shelves, where the jacket is removed immediately and returned to the machine.

The machine is set in motion by a lever which operates a friction clutch. The lever at the left of the machine is used to start the cable. After this is put in motion, the concrete is thrown into the hopper, the buckets taking up a sufficient amount for one tile. This is dumped in just at the time the carriage is at its highest point. The head at once presses the concrete against the jacket and as the carriage is lowered, the tile is formed. The cable then shifts to one side, putting the finished tile in position to be put away and bringing another jacket into position under the tamper. The machine makes tile from 4 to 16 inches in diameter.

The Miracle Power Tile Machine consists of a base from which rises a hollow shaft carrying the operating mechanism, and around which shaft revolves the table carrying the moulds.

The tile are made by means of a peculiarly shaped revolving packer which operates inside the steel mould or casing. The circular table around the column of this machine is moved vertically by the mechanism and carries the casing with it. When the table or carriage is at its highest point the packer completely fills the ring or pallet upon which the casing rests. At this moment the machine automatically dumps the proper amount of concrete into the casing, which then goes downward with the table and the revolving packer gradually moves up inside the casing, forcing and packing the concrete against the latter and forming the tile. When the casing reaches the bottom, the packer and casing are free and the table revolves and brings the next casing into position, and the operation is repeated. In the meantime the tile are carried away in the casing to the curing shelves. The casing is then removed from the tile and returned to the machine to be used over again.

The packer head of this machine is made reversible, so that when worn out in one position by the grinding action of the sand, it can be used in another.

The manufacturers claim that 6 to 8 horse-power is ample for operating the machine.

In the manufacture of concrete pipe, the concrete used is of a sufficient consistency to permit of the immediate removal of the moulds. The mixture is therefore comparatively dry.

After the pipe is moulded it is taken to the curing shed where it remains from four to seven days, during which time it is kept constantly moist by frequent sprinkling. In some plants steam, under low pressure, is used in the curing shed. This assures an equal distribution of moisture, and under this condition it is impossible for any pipe to dry out.

After curing, the pipes are taken to the drying yard. Here they may or may not be sprinkled occasionally, depending upon atmospheric conditions. Pipe is kept in the drying yard until it is about 30 days old, when it is ready for laying.

Reinforced Concrete Pipe.—Various forms of reinforced concrete pipe have been used where the strength of the manufactured pipe is insufficient. They are reinforced either by steel rods in flats placed both circumferentially and longitudinally or by wire mesh or expanded metal. Particular attention is now being paid to the joints, the object being to make the joint equally as strong as the rest of the pipe, thus giving a truly monolithic pipe line.

The Jackson Concrete Pipe is one where particular attention has been given to the method of jointing.

This pipe is manufactured in sizes ranging from 24 to 108 inches. The forms for making this pipe are assembled by first setting up the inner wall in rolled sheet sections on the upper and inner flange of the bottom plate or ring. The lateral reinforcement, consisting of steel slabs, is inserted in pockets in this ring. The circumferential reinforcing, consisting usually of one or two cylinders of triangular mesh reinforcement is now placed, after which the outer wall is assembled on the lower or outer flange of the bottom plate. Space clips at the top of the wall hold the reinforcement in position. The mould is then filled and rammed by hand.

The longitudinal reinforcement extends beyond the sections and terminates in hooked ends which fit into the rebated space which forms an outside groove, when the two sections are placed together. The sections are then interlocked with a tie band passing completely around the pipe at the groove and through the hooked ends of the longitudinal reinforcing bars. A joint shield is then drawn up snugly around the pipe and the joint first flushed with water and then grouted.

In the latest form of this pipe, the pipe is so shaped that the lower half of the groove is on the inside and the upper half is on the outside of the pipe. In this case the lower half of the joint is interlocked and grouted from the inside and the upper half from the outside.

This pipe is usually manufactured at the trench. Local labor and material are therefore used and there are little or no freight charges. This method also leaves the pipe open for inspection at all times.

Another pipe, where the distinctive feature is the method of jointing, is the Lock Bar Pipe (Meriwether System).

This pipe is manufactured in sizes ranging from 24 to 96 inches in diameter and in either three- or four-foot lengths. The standard pipe has a circular section. The reinforcement is placed concentric with the circumference of the pipe and toward the interior of the section. Each section is cast with a bell and a spigot end. The bell, however, does not project beyond the circumference of the pipe, but is flush with it.

For unusual conditions, a pipe of special design with a flat base section is made. In pipes of this design, the reinforcement is placed toward the interior of the crown and inverted toward the exterior at the sides.

Usually in the expanded metal or American Steel & Wire Co.'s Triangular Mesh, the reinforcing metal extends throughout the length of the section and projects both into the bell end and out of the spigot end for several inches. The spigot is shorter than the bell, so that when two sections of the pipe are placed together the reinforcing metal from one section overlaps the reinforcement of the other section in an internal recess. The recess in this joint is filled with cement mortar, thus locking the section together and sealing the joint at one operation. On all pipe of 36 inches in diameter, or larger, the joints are made from the interior after the back filling has been placed by forcing grout behind a shield with a grout gun. On sizes less than 36 inches in diameter the joints are made from the outside through openings in the crown portion of the bells before the back filling is placed. By placing the back filling before the joints of the larger pipe are sealed, any settlement caused by the fill will occur before the joint is made; thus any strain on the joints that would tend to injure their efficiency is eliminated.

TABLE XIII.—CONCRETE TILE DATA AND COSTS.*

Inside Diameter of Tile in Inches.	Thickness of Walls in Inches.	No. of Tile from Bag of Cement.	Cost per Tile for Cement at $1.50 per Bbl. 2-Foot Lengths.	No. of Tile from Yard of Sand.	Cost per Tile for Sand at $1 per Yard.	Average Capacity per Day with 3 Men to do all the Work, 2-Foot Lengths.	Cost per Length for Labor $2.50 and $1.75.	Total Cost per Length.	Total Cost per Foot of Cement Tile.	Average Selling Price Clay Tile, per Foot.
6	1¼	10	$0.03	60	$0.02	90	$0.06	$0.11	$0.06	$0.15
8	1¼	6½	.06	45	.02	80	.07	.15	.08	.20
10	1⅜	5	.09	32	.03	70	.08	.20	.10	.30
12	1½	3	.12	25	.04	65	.09	.25	.13	.36
15	1⅝	2	.18	19	.05	57	.10	.33	.17	.55
18	1¾	1 9/10	.21	16	.06	50	.11	.38	.19	.80
20	2	1½	.24	14	.07	45	.12	.43	.22	1.00
24	2⅛	1 1/10	.34	9	.11	40	.14	.59	.30	1.50
30	2½	¾	.45	7	.14	35	.16	.75	.38	2.00
36	3	⅔	.60	6	.18	30	.18	.96	.48	2.50
42	3½	½	.75	5	.20	17	.35	1.30	.65	....
48	4	⅓	1.15	3½	.30	10	.65	2.10	1.05	....

* Besser Manufacturing Co.

CONCRETE FENCE POSTS

Principal Advantages.—Owing to the decreasing supply of available timber, the cost of wooden fence posts is constantly increasing. This, together with their short life, makes imperative the adoption of some other form of fence post.

The ideal fence post should be cheap, strong, and permanent.

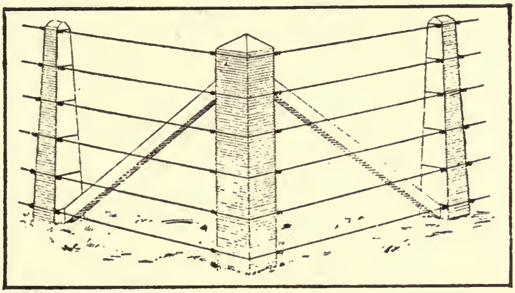


FIG. 39.—Artistic Corner Fence Post Construction.

These three qualifications are possessed only by reinforced concrete posts.

Wood posts, as before stated, are becoming expensive, and owing to their being subject to decay, and damage by fire, their life is at best short.

Steel posts have been tried, but are expensive, and unless constantly painted will soon deteriorate by rusting.

Reinforced concrete posts, however, are cheaply and easily made, may be as strong as desired, and are practically everlasting. Reinforced concrete posts may be made near their final location, of material obtained locally, necessitating very little cartage and the importation of only a comparatively small amount of cement and reinforcing steel.

The manufacture of a reinforced concrete fence post is a comparatively simple operation. A suitable mould is made or procured and the reinforcement placed in it. The mould is then filled with concrete, which is then compacted. If a dry concrete has been used, the moulds may be removed immediately; if the concrete was wet, the post should remain in the moulds about 24 hours. After being removed from the moulds the post should be cured and dried in the same manner as described for concrete pipes.

Moulds, Machines, and Manufacture.—Various moulds and machines for the manufacture of concrete fence posts have been made

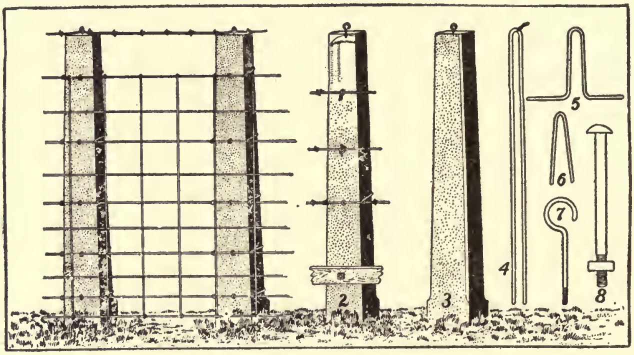


Fig. 40.—Concrete Fence Posts and Accessories.

and are on the market, all of which appear to be more or less satisfactory.

Simple moulds, such as could be made by almost any man, consist of two end pieces having notches which hold in place the longitudinal boards. Cross-pieces or hooks are provided to prevent

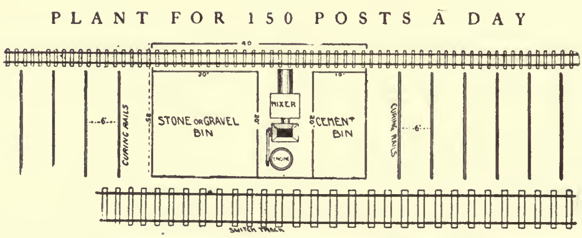


Fig. 41.—Layout of Plant for Making Concrete Fence Posts.

the longitudinal pieces from bulging. The mould is placed on a platform, oiled or soaped, after which the post may be made as described above.

The "Haas" Post Machine is 8′ 8″ long, and 28″ wide, weighs about 300 lbs., and is made of 2″ high-grade cypress lumber reinforced with steel trussed bands and bolts. The machine is treated to two coats of oil and white lead.

The "D. & A." Post Moulds are made from one piece of sheet steel about 1/16″ thick. They are U-shaped in sections with flanges bent at right angles to the body of the moulds to stiffen them. The moulds are provided with square detachable sheet steel end plates, which fasten to the moulds by means of projections which fit into slots in the flange of the mould and a clasp riveted to the bottom of the moulds at the ends. These end plates serve to hold the moulds upright as well as to hold the sides of the mould together. The post is released by removing the square end pieces. These

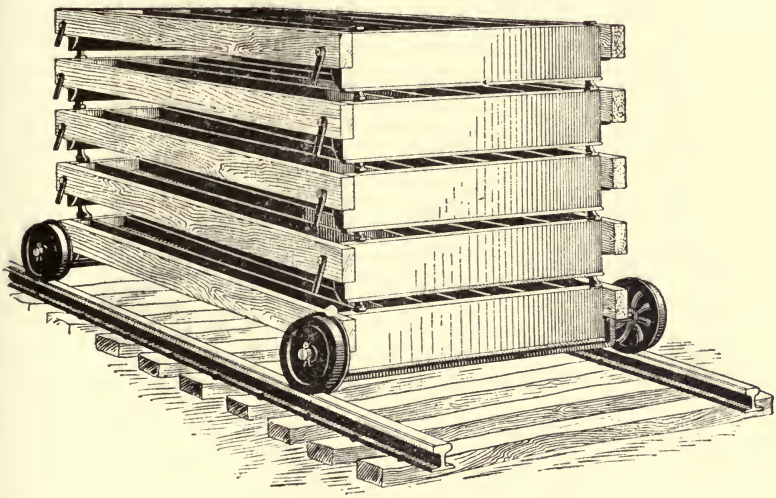


FIG. 42.—A Set of Six Post Machines, Showing Method of Piling One Machine on the Other. Can be run under the Mixer and through the Kilns or direct to curing rails.

moulds are usually set up ten at a time on a shaker, and after filling, the concrete is compacted by agitating the shaker.

The "Ohio" Post Machines consist of two strong cast-iron end frames into which are fitted six or twelve moulds of 20-gauge sheet iron. The ends fit tightly between lugs cast on the frames so that the moulds are sprung slightly together in placing, thus when removing the moulds, the sides will spring away from the posts. Two side rails hold the end moulds in position. One side rail is removed when placing or removing the moulds. To compact the concrete the frames are placed on a shaker and agitated. The finished post is T-shaped in cross-section.

The "Scott" concrete fence post mould is of galvanized iron, shaped to contain the post face up in its plastic form. The form is placed in a rack which holds four. After placing the reinforcement and concrete, and as soon as the concrete has taken its initial set, the face of the post is corrugated by a special tool for same. To remove the posts the racks are set on end with the small end of the post on top. One man then pushes the forms out of the rack while the other takes care of the posts.

In the foregoing moulds a wet mixture of concrete is usually used. The post must therefore be left in the moulds for a period of about 24 hours, thereby necessitating a number of moulds. The

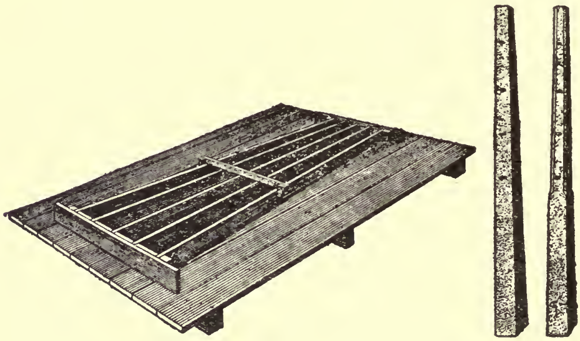


Fig. 43.—Moulds for Fence Posts, all Sides Tapering.

manufacturers of these machines claim that this loss in frames is more than offset by the increased strength of the post resulting from the use of the wet mixture.

In the following moulds a dry mixture of concrete is used, and the mould removed immediately. In this way, with but one mould, innumerable posts may be made without loss of time. Pallets of some sort are necessary with these machines.

The "Bulldog" Cement Post Machine consists of an angle iron frame to which is riveted a corrugated steel apron, thus forming the sides of the moulds and giving the post its characteristic corrugations. Hinged end gates are fitted to these sides which when interlocked, permit the sides to be spread and the post thus released.

The "Monarch" Post Machine is made entirely of steel and is composed of a double frame securely braced and bolted together.

The inside walls are hung on double hinges so that the slightest upward motion of the moulds releases the post.

The "Bailey" Post Machine is made of cast metal. The sides taper and are hinged at the top. A hinged bottom plate holds the sides together. To release the post, the hinged bottom plate is removed and the sides spread.

The "Scott" Concrete Fence Post Machine is made of steel and makes a post with a U-shaped cross-section. This machine differs from the other in that it must be turned over to release the post.

The "Luck" Cement Post Mould is made in two sections of heavy galvanized iron, held together by clamps on the flange. The

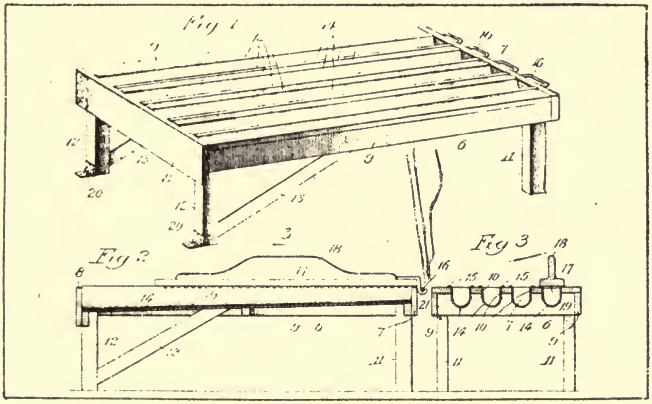


FIG. 44.—The Scott Fence Post Machine.

posts are octagonal in shape and are cast in a vertical position, using wet concrete. It is practically the only post mould in which the post is cast in a vertical position.

Methods of Reinforcement.—Various methods of reinforcing fence posts are in use and recommended by the various manufacturers. The advantages of some of these systems of reinforcement are more fanciful than real, and in some cases the reinforcement recommended would materially increase the cost of the post. For ordinary conditions, plain rods, wire, etc., may be used and entirely satisfactory results obtained. Scrap steel may frequently be used to advantage. The matter of reinforcement should depend entirely on what is most easily and economically available. For posts where a dry concrete is used, however, some sort of mechanical bond between the reinforcing and the concrete would be advisable.

TABLE XIV.—QUANTITY OF MATERIAL FOR FENCE POSTS.*

All posts are 4 × 5 inches at top; all posts are 5 × 6 inches at bottom. One-half small single load † of sand required per barrel of cement; one small single load † of screened gravel or stone required per barrel of cement. Proportion: 1 part "Atlas" Portland cement; 2 parts sand; 4 parts gravel or stone.

Length of Posts, Feet.	No. of Posts per Barrel (4 Bags) of Cement.	Weight per Post, Pounds.
5	20	130
6	17	160
7	14	180
8	12	210
9	11	234

Methods of Fastening Fence to Posts.—Various methods of fastening the fence to the post are in use at the present time, a few of which follow.

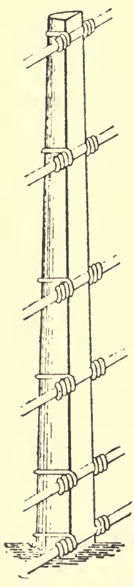


FIG. 45. — Method of Fastening Fence to Post.

Removable pins in the moulds form holes through the concrete posts, which holes receive long wire staples which clinch at the back of the post. These staples can be replaced at any time.

Another method consists of a tie wire passed around the post and then twisted tightly around the longitudinal fence wire. This method would appear to be particularly satisfactory where the face of the post is corrugated.

A variation of the above in which one continuous binding wire is used instead of a number of short pieces.

The advantage of this and the above method is that the position of the ties does not have to be determined in advance, but may be readily shifted to suit any position of the fence wires.

In another method, holes are made in the concrete into which wires are inserted. These wires

* From "Concrete Construction Around the Home and on the Farm," published by the Atlas Portland Cement Co.

† Small single load = 15 cubic feet.

are then carried to the front of the post and wrapped tightly around the fence wire.

In the "Monarch" Fasteners and Spring Steel Staples, the fastener is inserted in the post while same is being manufactured.

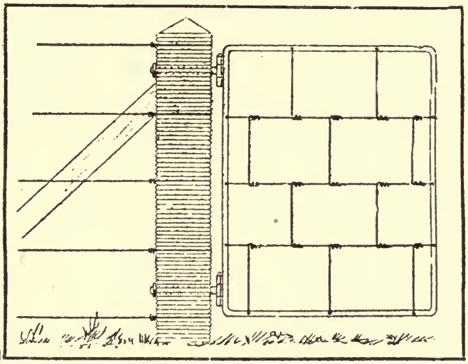


FIG. 46.—Method of Hanging Gate on Fence Post.

The staple is inserted in the fastener by means of a pair of pliers made especially for the purpose.

The "Tautwire" Fence fastener is moulded into the post when

TABLE XV.—QUANTITY OF MATERIAL FOR CORNER POSTS.*

One-half small single load † of sand required per barrel of cement; one small single load † of screened gravel or stone required per barrel of cement. Proportions: 1 part "Atlas" Portland cement to 2 parts sand to 4 parts gravel.

Size of Posts.			No. of Posts per Barrel (4 Bags) Cement.	Weight per Post, Pounds.
Length, Feet.	Top, Inches.	Bottom, Inches.		
6	12	12	2¾	900
7	12	12	2½	1,050
8	12	12	2¼	1,200
9	12	12	2	1,350
9	10	10	3	940
9	6	6	8	337
7	24	24	½	4,200

* From "Concrete Construction Around the Home and on the Farm," published by the Atlas Portland Cement Co.

† Small single load = 15 cubic feet.

same is being manufactured. To hold the fence a common wire staple is driven into the fastener.

In all wire fences considerable tension must be put on the wires if a satisfactory fence is to result. To resist this tension occasional fence posts should be braced, and in no case should this bracing be omitted at the corner posts, and the post in many cases should be made heavier than the posts in the rest of the fence.

SECTION IV

PRINCIPLE OF DESIGN AND CONSTRUCTION IN REINFORCED CONCRETE

CHAPTER XVI

ESSENTIAL FEATURES AND ADVANTAGES OF REINFORCED CONCRETE

Reinforced concrete is the term applied to that combination of concrete and steel wherein each element of the combination lends a helping hand to make up for the deficiency in strength of the other. The proverb that "In Union There is Strength," was never more exemplified than in the combination of two materials, different in so many respects yet acting together as a unit in resisting any influences that tend to disrupt the structure built therefrom.

Beginning with the building of flower pots by a French gardener 40 years ago, the business of reinforced concrete had a haphazard growth for over twenty years, owing to unfamiliarity with the nature of the materials, distrust on the part of consumers and antagonism of union labor. Through the establishment of safe, rational, and scientific methods of design, made possible by tests and studies carried on consistently by men like Melan, Hennebique, Ransome, Considère, Hyatt, Thatcher, Thompson, and others, confidence has given place to distrust and what only ten years ago was looked upon with suspicion is now hailed as a blessing. The fire at Baltimore and the earthquake and fire at San Francisco have removed the last lingering doubt, and constructors are now agreed that in point of fireproofness, and the ability to withstand severe shock and strains, reinforced concrete has no equal among structural materials.

Concrete itself is very weak in resisting tension, or pulling strains, and possesses but little elasticity, while steel, on the other hand, possesses both these qualities in a high degree. It is thus that the introduction of steel converts a practically inelastic body into one possessing a high degree of elasticity, and thus results in a material having the following inherent qualities: strength, which increases with time, lightness, rapidity of construction, and many other important advantages. So much are the resisting properties increased that reinforced concrete is bound to supplant almost entirely brick and stone masonry in most all of the forms of construction into

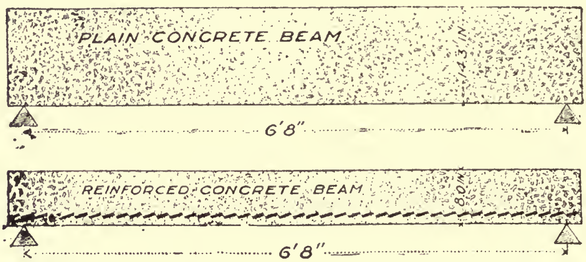


FIG. 47.—Comparative Sizes of Plain and Reinforced Concrete Beam for Same Span and Loading.

which the latter so largely enters, particularly in such structures as factories, walls, sewers, aqueducts, bridges, arches, chimneys, dams, tanks, foundations, etc.

The *economy* of reinforced concrete arises also from the fact that unskilled labor may be employed in the work, and owing to its inherent strength a great saving in material and space is made possible over ordinary brick and stone construction. There are also some disadvantages attending its use, such as the necessity for wooden forms and the difficulties which attend their use, but these are more than offset by the accompanying benefits.

Ease and rapidity of erection arise from the fact that walls can be quickly moulded and floors and roofs are moulded at the same time as the beams which support them. No dressing or dimension cutting is required and material is readily procured in all localities.

The *fireproofness* of concrete is due to the fact that it is a very poor heat conductor. It expands and contracts at the same rate as the reinforcing steel and there is no tendency of separation between them. In fact, the bond or adhesion of concrete to steel is very strong and is an important element in the design of reinforced concrete work, as it is due to this very adhesive property that strains coming upon the concrete are partly taken up by the steel, for without such adhesion they could not act as a unit.

The *bond* between the concrete and steel is due both to friction, molecular adhesion, and shrinkage of the concrete during the process of setting or hardening which causes it to take a hard, firm grip on the steel. The proportion of the strain taken by the concrete and by the steel is in direct ratio to the relative moduli of elasticity of the two materials, the ratio between them being from 10 to 18; that is, steel is 10 to 18 times as elastic as concrete, or will carry 10 to 18 times the load with the same amount of deformation. The whole secret of the successful design of reinforced concrete lies in distributing the steel in such positions and quantities as to relieve the concrete of any pull or tension as well as any excessive shearing or cutting stresses, and leave it to resist the crushing stresses which it is so well able to do.

The *rigidity* of a reinforced concrete structure arises from the fact that each part of the structure is inseparably bound to every other part by a continuous network of beams, rods, and pillars, and the structure is one whole unit and not a collection of parts. The monolithic nature of these structures reduces the vibration caused by machinery and external shocks, and has proved the best type of construction in earthquake countries, and where unequal settlement would be dangerous.

The *durability* and *permanence* of reinforced concrete arises from the very nature of the constituent materials. The concrete becomes stronger as times goes on, and the steel is protected from rusting by its concrete envelope. In fact, so great is this protection that painting of steel work is very objectionable while on the other hand a little initial rust does no harm. Abundant experience proves that such rust is removed by some little understood chemical process and in good concrete the steel will always remain bright and clean. Special advantages appertaining to individual structures will be discussed in appropriate chapters.

Materials for Reinforced Concrete.—As reinforced concrete is generally used where strength and stiffness are required, it is essential that a rich mixture of Portland cement be employed and that sand be well graded and clean.

In massive work, the coarse aggregate may run as high as 2 1/2 inches in size, as in foundations and large piers. In columns, girders, beams, and slabs, no stone or other aggregate should be used larger than what will pass a one-inch screen. In important beams and columns, especially when the reinforcing bars are closely spaced, the size should be made even smaller. Good trap rock or gravel should preferably be used.

The best proportions for the materials which enter into the concrete depend upon the size and character of the construction. With proper limits on the size of the aggregate and with coarse sand containing a percentage of fine grains, a mixture of one part of Portland cement, two parts sand, and four parts of stone or gravel is always reliable.

For reinforced concrete work, no mixture should be used that does not develop a strength of at least 2,000 lbs. per sq. in., in compression at the age of 28 days.

It is not the province of this book to go into the higher intricate details of the design of reinforced concrete as the subject is complicated at best, and the reader must be referred to the many excellent treatises on design now to be had. It is well to state, however, that the whole subject of design resolves itself into the study of a few elementary types of structure such as the beam or girder, the slab, the column, and the arch and all structures, however complicated, are either a modification or a combination of these elementary types; in fact, the slab is even a modification of the beam, being a beam supported on all sides. The amount of bending or other forces produced by external loading is computed in the same way as in any other structure, the problem in reinforced concrete being to distribute the resultant stresses in such a manner between the concrete and steel as to have the concrete take the compressive stresses and the steel take the tensile stresses, and thus require the least amount of each material. How this is done is explained in the two chapters following.

CHAPTER XVII

HOW TO DESIGN REINFORCED CONCRETE BEAMS, SLABS, AND COLUMNS

Nature of the Problem.—Kinds of Stresses.—Rules for Designing Beams.—Rules for Designing Slabs.—Tables for Designing.—Solution of Examples.—Summary of Procedure in Design.—Design of Reinforced Concrete Columns.—Examples and Solution.

Nature of the Problem.—Concrete and reinforced concrete structures when called upon to sustain loads or pressures, are thrown into a state of stress. When the loads are within the safe carrying capacity of the material, this condition of stress is shown by a slight increase or diminution in size. When the loads exceed this limit the material is no longer able to withstand the internal stress and the structure cracks, ruptures, or exhibits other signs of failure.

In order to properly design a concrete structure, it is necessary to make an investigation to determine whether or not the material is so disposed as to be able to withstand the effects of the external loads without on the one hand being stressed beyond the point of safety, or on the other hand without waste of material.

Such an investigation should comprise the following operations:

(1) Determination of the amount and position of the external loads, including the weight of the structure itself.

(2) Determination of the kind, amount, and position of the greatest internal stress produced by such loads.

(3) Determination of the resisting power of the material to withstand such an internal stress.

Kinds of Stress.—According to the position of the external loads a body may be called upon to sustain one or more of the following kinds of stress:

(1) Tension; (2) Compression; (3) Shear; (4) Bending.

A body is subjected to *tension* or is under a tensile stress when acted upon by forces which tend to tear or pull it apart, as a stretched rope.

A body is under *compression* or undergoes a compressive stress when the external forces tend to crush the material of which it is composed as a bridge abutment or pier.

A body is subjected to *shear* or is under a shearing stress when acted upon by forces which tend to cut or shear it across, as the rivets in a boiler tube, when the overlapping edges of the tube tend to slide apart under the action of the internal pressure.

A body is subjected to *bending* when used as a beam or girder to carry a load over an opening. This action is illustrated in the case of a plank. When a plank is laid flatwise and supported at the ends, a comparatively slight load at the centre will cause it to sag or bend. The effect of this bending is to compress the material in the upper surface of the plank and to stretch the material in the lower surface. Between these surfaces, there is a plane which is neither compressed nor lengthened. Such a plane is called the neutral surface.

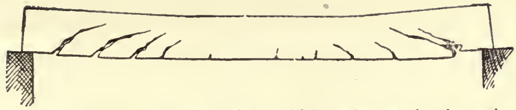
A plank laid flatwise makes a very weak beam, because of the excessive bending. When set up on edge, a plank is far stiffer and stronger. Nevertheless, such a joist tends to sag at the centre, so that the upper surface is in compression and the lower surface in tension, but the amount of sag or deflection is slight compared with what it would be were the plank turned on its broad side.

Both plain and reinforced concrete is used in columns, piers, foundations, walls, etc., where it is subjected to a compressive stress.

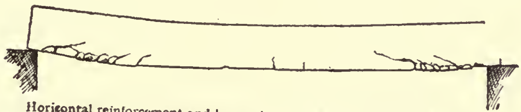
Reinforced concrete is also employed in beams, slabs, and other structures which are subjected to a bending stress, the steel being so disposed as to take care of the tension in the lower part of the beam or slab.

Concrete is never employed in direct tension for carrying a suspended load, as steel is far lighter and more economical for the purpose.

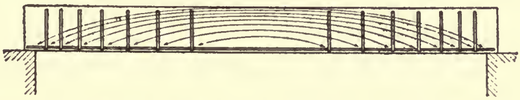
Action of Steel and Concrete in Combination.—When steel rods are embedded in concrete, the adhesion between the steel and concrete is practically equal to the bond between the ingredients (cement, sand, and stone) of which the mixture is composed. In



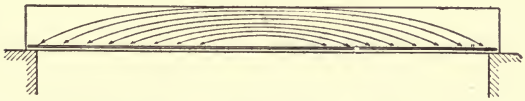
Horizontal reinforcement only. Method of failure when tested to destruction. Light load. Sudden failure caused by ends of reinforcement slipping and horizontal shear diagonal cracks in concrete.



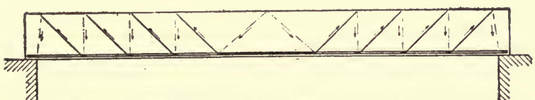
Horizontal reinforcement and loose stirrups. Method of failure when tested to destruction. Medium load. Sudden failure due to slipping of horizontal rods. Shear of concrete on horizontal plane above bars but no diagonal cracks.



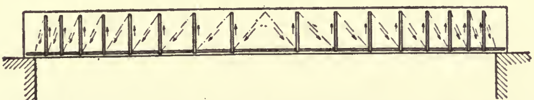
Arch action in beam with horizontal reinforcement and stirrups. Note the unbalanced horizontal stress. Stirrups slip along the horizontal reinforcement, which, therefore, cannot be developed.



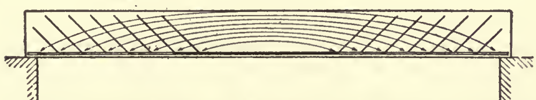
Beam with horizontal reinforcement only. Note arch action. Reinforcement furnishes no abutment for the inclined stresses, and will slip.



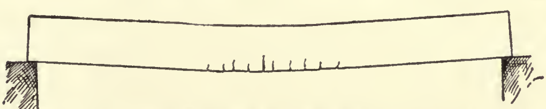
Truss action in beam reinforced with Kahn Trussed Bars. Note the action is that of a complete Pratt truss No tendency to slip or slide.



Truss action in beam with horizontal reinforcement and stirrups. Note the unbalanced horizontal component of the inclined stress and the tendency of the stirrups to slip along the horizontal reinforcement



Arch action in beam reinforced with Kahn Trussed Bars. Note the perfect abutment for the inclined stresses. Perfectly rigid and no possibility of slipping.



Kahn reinforcement. Method of failure when tested to destruction. Maximum load. Very gradual and ideal failure. Steel stretching in center.

Fig. 48.—Sketches Showing Failure of Concrete Beams Reinforced in Different Ways, When Tested to Destruction. (Kahn.)

general for ordinary round or square bars, the bond strength may be taken at from 200 to 300 lbs. per sq. in. of surface, and for indented bars, having in addition a mechanical bond, at from 300 to 500 lbs. per sq. in. These are breaking strains, and for the purpose of safe design, the bond strength is considered to be only 50 to 75 pounds per sq. in. of steel surface.

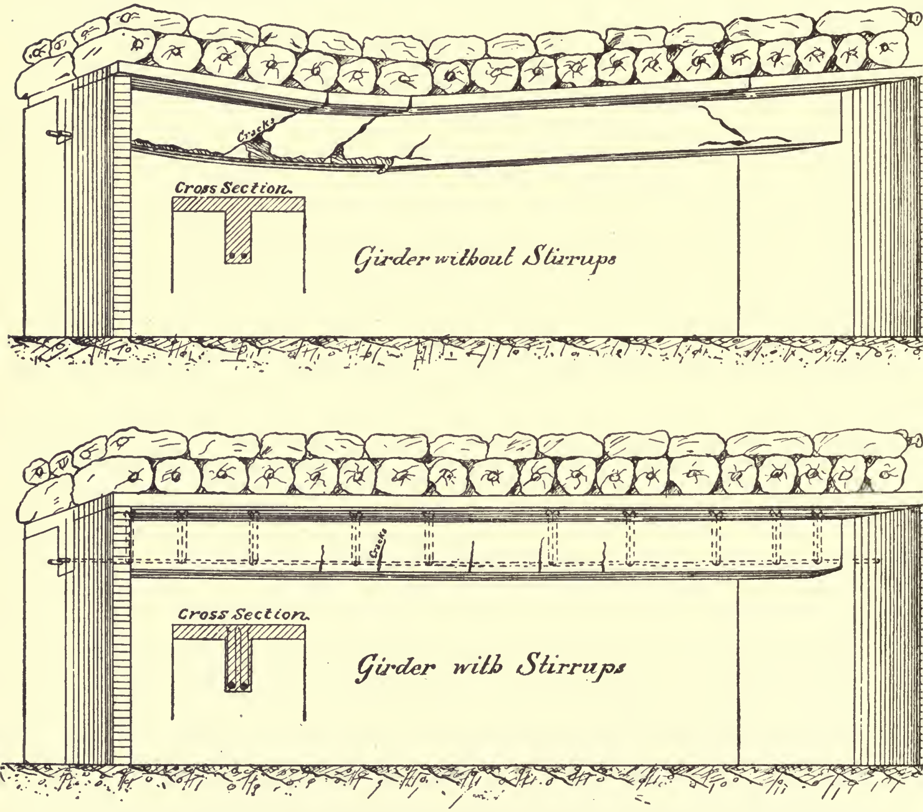


FIG. 49.—Test of Girder under Load with and without Stirrups. (Hennebique.)

Steel and concrete also expand at practically the same rate when heated, so that change of temperature does not cause any tendency for the steel to slip or separate from the concrete.

Action of Steel and Concrete in Sustaining Stress.—When a reinforced concrete member is subjected to stress, as for example, a column or post containing vertical rods, the stress will be divided between the steel and concrete in direct proportion to the ability of each to carry the load. Steel, as already stated, is said to have a modulus of elasticity from 10 to 18 times as great as that of concrete, which means that the steel rods in a column will carry from 10 to 18 times as much stress per sq. in. of cross-section as the surrounding concrete. The reason of this is that the loads on a column tend to shorten it, and from 10 to 18 times as much weight is required to shorten a steel column by a given amount as is needed to compress a concrete column having the same dimensions by an equal amount.

Effect of Spiral Wrappings.—Posts are frequently reinforced with spiral bands or hoops as well as with vertical rods. Such wrappings do not support any part of the load directly. Their object is to increase the bearing power of the concrete by preventing lateral expansion or bulging under the action of the compressive forces. Tests published by Considère in 1903 indicate that steel in the form of spiral reinforcements is 2.4 times as efficient as in the form of longitudinal rods, provided the spacing of the wire is not too great (1/4 to 1/10 of the diameter of the spiral). The chief effect of hooping is to increase the toughness or ductility of the concrete, which is desirable on account of the comparatively brittle nature of the column with longitudinal reinforcement only.

In hooped columns only that portion of the concrete which is within the spirals can be regarded as bearing any part of the load. When so regarded, and when the wrapping is circular in form and the reinforcement sufficient to insure a lateral resistance of at least 65 pounds per square inch, the hooping can be considered as increasing the bearing capacity of the concrete by 50 per cent.

DESIGN OF SIMPLE BEAMS AND SLABS CARRYING "UNIFORMLY DISTRIBUTED LOADS"

While the design of a reinforced concrete structure requires both a working knowledge of the mechanics of materials, and practical experience with the constructor's side of the art, it is nevertheless feasible for anyone with a little practice to compute the dimensions of simple beams and slabs.

Simple beams are beams which are supported at each end.

Continuous girders have one or more intermediate supports. In simple horizontal beams the steel is placed near the bottom at the centre of the span and part of the bars are bent up near the ends and anchored over the supports by bending. If the beam is continuous the bent rods stop at the top, and in addition a system of horizontal rods is placed in the upper part of the beam and these extend over the supports to the quarter points.

Stirrups are also employed in both simple and continuous girders, especially when the loads are heavy in proportion to the span. The proper placing of the steel and its anchorage at the supports are just as important as is the computation of loads and stresses. In this chapter simple practical formulas are given for determining the proper size of simple beams and the amount of steel required for their reinforcement. They can be used for continuous girders, only when proper provision is made for the placing of steel over the supports, at the top of the beams.

The *percentage of steel* required for a reinforced concrete girder is generally a little less than one per cent. Perhaps the most economical percentage is seven-tenths of one per cent. This applies to the main steel bars in the bottom of the beam. The steel employed for stirrups and the horizontal rods at the top of continuous girders are not included in this percentage.

The *load* carried by a reinforced concrete girder is generally considered to be uniformly distributed over its length. This applies to girders which support floor slabs, and to the general run of factory construction. It does not apply to a girder carrying a heavy machine at the centre of the span.

Points to be Considered in the Design.—The rational design of beams and slabs of reinforced concrete involves the study of the features enumerated below. For complete analysis of all these points reference must be had to special works on Reinforced Concrete Design. We give below in this chapter the rules and formulas for such design reduced to the simplest forms for practical use, and in the succeeding chapter the origin and explanation of these formulas are discussed for those who wish to study the theory as well as the practical applications of the formulas. The following data * are usually considered in the design:

* From "Concrete in Factory Construction," by the Atlas Portland Cement Co.

"(1) The bending moment due to the live and dead loads, this involving the selection of the proper formula for the computation.

"(2) Dimensions of beams which will prevent an excessive compression of the concrete in the top, and which will give the depth and width which is otherwise most economical.

"(3) Number and size of rods to sustain tension in the bottom of the beam.

"(4) Shear or diagonal tension in the concrete.

"(5) Value of bent-up rods to resist shear or diagonal tension.

"(6) Stirrups to supplement the bent-up rods in assisting to resist the shear or diagonal tension.

"(7) Steel over the supports to take the tension due to negative bending moments.

"(8) Concrete in compression at the bottom of the beam near the supports due to negative bending moment.

"(9) Horizontal shear under flange of slab.

"(10) Shear on vertical planes between beams and flanges.

"(11) Distance apart of rods to resist splitting.

"(12) Length of rods to prevent slipping.

"(13) End connections at wall."

Rules for Designing Beams.—In a horizontal reinforced concrete beam carrying a uniformly distributed load, the proper dimensions may be obtained from the following formula, which is based on the straight-line theory of stress as explained in the next chapter:

$$b\,d^2 = \frac{\frac{1}{8}\,l\,(W + W')}{74} \qquad (1)$$

and the sectional area of steel required in the lower portion of the beam by the formula:

$$A = .007\,b\,d \qquad (2)$$

Where b denotes the breadth of the beam in inches, d denotes the depth in inches from the top or compressive face of the beam to the plane of the steel.

l = the length of span in inches.

W = the external load on the beam in pounds and includes the weight of the floor slab which is supported by the beam.

W' = the estimated weight of the beam itself in pounds.

A = the sectional area of the steel in square inches.

p = the percentage of steel.

The above formulas are based on seven-tenths of one per cent of steel being employed for reinforcement in the bottom flange. If other proportions of steel are employed, the same formulas can be used by changing the denominator from 74 to the appropriate value as shown in the following table. This table is based on a maximum compressive stress in the concrete of 500 pounds per sq. in., a ratio of 12 between the modulus of elasticity of concrete and that of steel, and a tensile stress in the steel ranging from 15,000 to 8,000 lbs. per sq. in., according as the percentage of steel is low or high.

TABLE XVI.—DENOMINATORS FOR USE IN FORMULA I. FOR DIFFERENT PERCENTAGES OF STEEL.*

Percentage of Steel, p	.005	.006	.007	.008	.009	.010	.011	.012	.013	.014	.015
Denominator for formula (1).	66	70	74	78	81	84	86	89	91	93	95

Thus if one per cent of steel is desired, the formulas become:

$$b\,d^2 = \frac{\frac{1}{8}\,l\,(W + W')}{84} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and

$$A = .010\,b\,d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Example.—Compute the dimensions of a horizontal reinforced concrete beam, which can be used to support a uniformly distributed load of 15,000 pounds, including the weight of the floor slab, over a span of 14 feet.

Solution.—An economical value for p is .007; $W = 15{,}000$ lbs. Assume $W' = 5{,}000$ lbs., $l = 14 \times 12 = 168$ inches. Hence substituting in formula (1) we have:

$$b\,d^2 = \frac{\frac{1}{8} \times 168\,(15000 + 5000)}{74} = \frac{420000}{74} = 5676$$

Assume any practicable width for b, as $b = 13$ inches, then,

$$13\,d^2 = 5676$$
$$d^2 = 436.6$$

* The derivation of Table XVI. is given in Chap. XVIII.

and solving for d, which may be facilitated by the use of a table of squares, we have:

$$d = 21 \text{ inches}$$

$$A = .007 \times 13 \times 21 = 1.911 \text{ sq. ins.}$$

If the 1.911 sq. ins. is divided among 4 rods, the area of each will be $1.911 \div 4 = 0.478$ sq. ins.

If square rods are employed, the required dimensions will be

4–11/16 inch rods, since $11/16 \times 11/16 = 0.478$ (nearly)

$d = 21$ inches is the effective depth or depth to the plane of the steel. At least 2 inches of concrete should be placed below the steel for protection and bond. Hence the total depth of the beam must be $21 + 2 = 23$ inches.

If a heavy rock concrete weighing 144 pounds per cu. ft., including the steel, is employed, the weight of the beam 23 ins. deep, 13 ins. wide, and 14 feet long, will be

$$\frac{23}{12} \times \frac{13}{12} \times \frac{14}{1} \times \frac{144}{1} \times = 4{,}186 \text{ pounds.}$$

This is 814 pounds less than the assumed weight, and if the dimensions are again computed, using the actual weight of 4,186 pounds in place of the assumed weight of 5,000 pounds, it will be found to make a difference of half an inch in the required depth of the beam.

An inspection of the above computation for weight reveals a quick method for obtaining the weight of heavy rock concrete; viz., multiply together the total depth in inches by the breadth in inches by the length of the beam in feet.

The above method of designing a beam will probably impress the novice as faulty in that too much is assumed in advance. A very little practice will, however, enable him to estimate the probable weight very much more closely than was done in the above example, where the beam was purposely overestimated by 20 per cent in order to show that such an overestimate has very little effect on the design, and even if the first estimate should be extremely wide of the mark, two trials at the most should be all that would be required to determine the proper dimensions.

In assuming the percentage of lower flange steel in advance, the designer has two things to consider; first the most economical percentage; and second, whether he wishes to make the compression or tension half of his beam the stronger. Probably .007 is the most economical percentage, as less than this amount of steel unduly increases the volume of concrete, while more than .007 affects unfavorably the cost of the steel. Below .01 the steel will probably be weaker than the concrete at a breaking load, while above .01 the steel is likely to prove the stronger. Near this point either the steel or the concrete may be the first to fail if the beam is tested to destruction, depending chiefly on the materials and workmanship employed in mixing and placing the concrete. The designer should be sufficiently familiar with the quality of the work so that he can fix the percentage of steel at such a rate that the steel will begin to stretch before the concrete commences to crumple, thus producing deflection and giving warning in advance, in case the beam should be loaded beyond its capacity. In addition to this percentage, upper flange steel over the supports and stirrups should in general be provided.

In assuming the breadth and computing the effective depth, after the design has reached the stage where the product $b\,d^2$ = a known number, several trials may be necessary to give the best proportions for the beam. For economy a beam is made as narrow as possible, but there are practical limits to decreasing the breadth which must not be encroached upon. Thus a beam should not be narrower than 1/24 of the span. It must be wide enough to provide at least 1 1/2 diameters and preferably 2 between the reinforcing bars and between the bars and sides of the beam. Moreover, the breadth should not be less than half of the depth, excepting for very large beams. Probably the best width is between 1/2 and 3/4 of the effective depth, d.

How to Design Reinforced Concrete Slabs.—For the purpose of design, a reinforced concrete slab placed as a continuous sheet over several girders and carrying a uniformly distributed load, may be treated as though the slab was divided into narrow strips, each having a width equal to the spacing of the reinforcing bars, and a length equal to the distance between the supporting girders.

The slab can then be designed by the following formulas:

$$b\,d^2 = \frac{1/10\, l\, (W + W')}{74} \quad . \ . \ . \ . \ . \ . \quad (5)$$

$$A = .007\, b\, d \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (6)$$

Formulas (5) and (6) are identical in form with those employed for beams, and differ only in the coefficient of l, 1/10 being used instead of 1/8. The nomenclature is also the same, and if a percentage of steel different from .007, is desired, the corresponding denominator for formula (5) can be obtained from Table XVI in the same way as for beams. Such a slab requires top reinforcement extending over the girders for at least one-fourth of the span, on both sides of the girder; or if expanded metal or other fabric is employed the fabric must be placed so that in the centre of the span it will sag to near the bottom of the slab, while over the supports it will be near the top. The sectional area of lower flange steel may be obtained from formula (6), when seven-tenths per cent is used, or the coefficient .007 may be varied to suit the requirements.

Example.—Design a reinforced concrete slab supported by beams spaced 8 feet apart, which may be used to sustain a uniform load of 125 pounds per square foot, exclusive of its own weight.

Solution.—Assume a steel percentage of .007, a spacing of the reinforcing bars of 6 inches; and the weight of a strip 6 inches wide, and 8 feet long at 240 pounds.

By spacing the bars 6 inches apart, the breadth, b, becomes 6 inches, and the external load, W, at 125 pounds per sq. ft., will be:

$$W = 8 \text{ ft.} \times 6/12 \text{ ft.} \times 125 \text{ lbs. per sq. ft.} = 500 \text{ pounds}$$

while

$$l = 8 \times 12 = 96 \text{ inches.}$$

Substituting in formula (5) we have:

$$6\,d^2 = \frac{1/10 \times 96\,(500 + 240)}{74}$$

$$d^2 = 16 \text{ sq. ins.}$$

$$d = 4 \text{ ins. depth to the plane of the steel.}$$

If 1 inch of concrete is placed below the steel, the required thickness of the slab will be $4 + 1 = 5$ inches.

From (6) the area of steel will be

$$A = .007 \times 4 \times 6 = .168 \text{ sq. ins.}$$

This may be obtained from 1–1/2 inch round rod.

When fabric is employed instead of steel rods, a strip 1 foot wide is taken as the basis of the design, or $b = 12$ inches, while formula (6) will give the sectional area of fabric required for the 1-foot strip, for seven-tenths per cent of steel.

In general, a reinforced concrete slab should not be less than 3 inches thick and should have at least 3/4 inch of concrete below the steel.

In an oblong slab the steel is placed crosswise from girder to girder. In a square slab supported on four girders, equidistant from each other, the rods are placed both ways. When reinforced in this manner, the same amount of steel is used as for the oblong slab, but there is a saving in concrete, as the concrete for a square slab need only be designed for half the load.

In an oblong slab, a few rods should also be placed longitudinally to prevent temperature cracks and to serve as binders for the main tension bars which run crosswise between the supporting girders.

Tables for Use in Designing Beams and Slabs.—Such tables may be divided into two classes: (*a*) those which give the required dimensions without computation, and (*b*) those which are used to facilitate computation by saving arithmetical labor. Tables XVII, XVIII, and XIX are of the latter and Table XX of the former class.

Table XVII is a table of squares for facilitating the computation of beam depths. Table XVIII gives the weight per lineal foot of reinforced concrete beams at 144 pounds per cubic foot, and is used for estimating the weight of beams. Table XVIII also shows comparative costs of beams at $10.00 per cu. yd. This is for the purpose of comparing the cost of beams of different proportions of depth to breadth and of different percentages of steel, in order to employ those which are most economical. Table XIX gives the sectional areas of round and square bars, and their weights and cost at the rate of 2 cents per pound. This is also convenient for making a comparison of costs. The costs given in Tables XVIII and XIX do not represent the actual costs, which may be 50 per cent more or less for any given structure. They are relative costs for gauging the relative economy of different beams having equal strength or capacity.

Table XX, which is reproduced with slight modifications, by courtesy of the Atlas Portland Cement Co., from their book on the utilization of "Concrete in Factory Construction," gives the proper dimensions for beams and slabs that will carry uniformly distributed floor or roof loads of 125, 50, and 30 pounds respectively, per square foot. These beams, if checked over, by the straight line formulas (10) and (11), of Chapter XVIII, will be found to average about seven-tenths per cent of steel, to have a fibre stress in the concrete of about 500 pounds per square inch, and in the steel of between 12,000 and 15,000 pounds per square inch.

TABLE XVII.—BEAM DEPTHS AND THEIR SQUARES.

No.	Square.	No.	Square.	No.	Square.	No.	Square.	No.	Square.	No.	Square.
2.00	4.00	5.00	25.00	8.00	64.00	12.00	144.00	18.00	324.00	24.00	576.00
2.25	5.06	5.25	27.56	8.25	68.06	12.50	156.25	18.50	342.25	24.50	600.25
2.50	6.25	5.50	30.25	8.50	72.25	13.00	169.00	19.00	361.00	25.00	625.00
2.75	7.56	5.75	33.06	8.75	76.56	13.50	182.25	19.50	380.25	25.50	650.25
3.00	9.00	6.00	36.00	9.00	81.00	14.00	196.00	20.00	400.00	26.00	676.00
3.25	10.56	6.25	39.06	9.25	85.56	14.50	210.25	20.50	420.25	26.50	702.25
3.50	12.25	6.50	42.25	9.50	90.25	15.00	225.00	21.00	441.00	27.00	729.00
3.75	14.06	6.75	45.56	9.75	95.06	15.50	240.25	21.50	462.25	27.50	756.25
4.00	16.00	7.00	49.00	10.00	100.00	16.00	256.00	22.00	484.00	28.00	784.00
4.25	18.06	7.25	52.56	10.50	110.25	16.50	272.25	22.50	506.25	28.50	812.25
4.50	20.25	7.50	56.25	11.00	121.00	17.00	289.00	23.00	529.00	29.00	841.00
4.75	22.56	7.75	60.06	11.50	132.25	17.50	306.25	23.50	552.25	29.50	870.25

Example, Involving Use of Tables.—Compute the cost of beams spaced 8 feet apart, and having a span of 12 feet which will support a 6-inch slab of concrete in addition to a floor load of 140 pounds per square foot.

Solution.—Surface area, $12 \times 8 = 96$ sq. ft. Load $96 \times 140 = 13{,}440$ lbs.

Weight of slab $12 \times 8 \times \frac{6}{12} \times 144$ lbs. per cu. ft. $= 6{,}912$ lbs.

Estimated weight of beam, Table XVIII, 12 x 24 ins. $(288 \times 12) = 3{,}456$ lbs. $13{,}440 + 6{,}912 + 3{,}456 = 23{,}808$ lbs.

TABLE XVIII.

Weight of Heavy Reinforced Concrete Beams in Pounds per Lineal Foot, also Cost of the Concrete in Dollars per Lineal Foot at the Rate of $10.00 per Cubic Yard.

Total Depth in Inches.	Breadth in Inches. 4	5	6	7	8	9	10	12	14	16	18	
3	12	15	18	21	24	27	30	36	42	48	54	Weight
	.031	.039	.046	.054	.062	.070	.077	.093	.108	.124	.139	Cost
4	16	20	24	28	32	36	40	48	56	64	72	Weight
	.041	.052	.062	.072	.083	.093	.103	.124	.144	.165	.185	Cost
5	20	25	30	35	40	45	50	60	70	80	90	Weight
	.052	.065	.077	.090	.103	.116	.129	.155	.180	.206	.232	Cost
6	24	30	36	42	48	54	60	72	84	96	108	Weight
	.062	.077	.093	.108	.124	.139	.155	.185	.216	.247	.278	Cost
7	28	35	42	49	56	63	70	84	98	112	126	Weight
	.072	.090	.108	.126	.144	.162	.180	.216	.252	.288	.324	Cost
8	32	40	48	56	64	72	80	96	112	128	144	Weight
	.083	.103	.124	.144	.165	.185	.206	.247	.288	.330	.371	Cost
9	36	45	54	63	72	81	90	108	126	144	162	Weight
	.093	.116	.139	.162	.185	.208	.232	.278	.324	.371	.417	Cost
10	40	50	60	70	80	90	100	120	140	160	180	Weight
	.103	.129	.155	.180	.206	.232	.257	.309	.360	.412	.463	Cost
12		60	72	84	96	108	120	144	168	192	216	Weight
		.155	.185	.216	.247	.278	.309	.371	.433	.494	.556	Cost
14			84	98	112	126	140	168	196	224	252	Weight
			.216	.252	.288	.324	.360	.432	.504	.576	.648	Cost
16				112	128	144	160	192	224	256	288	Weight
				.288	.330	.371	.412	.494	.576	.659	.741	Cost
18					144	162	180	216	252	288	324	Weight
					.371	.417	.463	.556	.648	.741	.834	Cost
20						180	200	240	280	320	360	Weight
						.463	.515	.617	.720	.823	.926	Cost
22						198	220	264	308	352	396	Weight
						.509	.566	.679	.793	.906	1.019	Cost
24							240	288	336	384	432	Weight
							.617	.741	.864	.988	1.111	Cost
26								312	364	416	468	Weight
								.803	.936	1.070	1.204	Cost
28								336	392	448	504	Weight
								.865	1.009	1.153	1.297	Cost
30								360	420	480	540	Weight
								.926	1.081	1.235	1.389	Cost

Weight per lineal foot = Breadth in inches multiplied by total depth in inches.

Cost in dollars at $10.00 per cu. yd. = weight per lineal foot multiplied by .002572.

TABLE XIX.—PROPERTIES OF STEEL BARS.

Diameter in Inches.	Round Bars.				Square Bars.			
	Sectional Area in Square Inches.	Weight per Lineal Foot in Pounds.	Cost in Dollars per Lineal Foot at 2 Cents per Pound.	Circumference in Inches.	Sectional Area in Square Inches.	Weight per Lineal Foot in Pounds.	Cost in Dollars per Lineal Foot at 2 Cents.	Perimeter in Inches.
1/8	.0123	.042	.001	.3927	.0156	.053	.001	0.50
3/16	.0276	.094	.002	.5890	.0352	.120	.002	0.75
1/4	.0491	.167	.003	.7854	.0625	.213	.004	1.00
5/16	.0767	.261	.005	.9817	.0977	.332	.007	1.25
3/8	.1104	.376	.008	1.1781	.1406	.478	.010	1.50
7/16	.1503	.511	.010	1.3744	.1914	.651	.013	1.75
1/2	.1963	.668	.013	1.5708	.2500	.850	.017	2.00
9/16	.2485	.845	.017	1.7671	.3164	1.076	.022	2.25
5/8	.3068	1.043	.021	1.9635	.3906	1.328	.027	2.50
11/16	.3712	1.262	.025	2.1598	.4727	1.607	.032	2.75
3/4	.4418	1.502	.030	2.3562	.5625	1.913	.038	3.00
13/16	.5185	1.763	.035	2.5525	.6602	2.245	.045	3.25
7/8	.6013	2.044	.041	2.7489	.7656	2.603	.052	3.50
15/16	.6903	2.347	.047	2.9452	.8789	2.989	.060	3.75
1	.7854	2.670	.053	3.1416	1.0000	3.400	.068	4.00
1 1/16	.8866	3.014	.060	3.3379	1.1289	3.838	.077	4.25
1 1/8	.9940	3.379	.068	3.5343	1.2656	4.303	.086	4.50
1 3/16	1.1075	3.766	.075	3.7306	1.4102	4.795	.096	4.75
1 1/4	1.2272	4.173	.083	3.9270	1.5625	5.312	.106	5.00
1 5/16	1.3530	4.600	.092	4.1233	1.7227	5.857	.117	5.25
1 3/8	1.4849	5.049	.101	4.3197	1.8906	6.428	.128	5.50
1 7/16	1.6230	5.518	.110	4.5160	2.0664	7.026	.141	5.75
1 1/2	1.7671	6.008	.120	4.7124	2.2500	7.650	.153	6.00

From formula (1) with steel ratio .007.

$$b\,d^2 = \frac{\tfrac{1}{8} \times 144 \text{ in. span} \times 23808}{74} = 5{,}791 \text{ cu. ins.}$$

$$\text{If } b = 12 \text{ ins., } d^2 = \frac{5791}{12} = 483.$$

From Table XVII, $d = 22$ ins.

With 2 inches of concrete below the steel, the dimensions will be 12 x 24 ins.

From Table XVIII, the concrete will cost, at the rate of $10.00 per cu. yd.

$$.741 \times 12 = \$8.89$$

From formula (2) the steel area will be,

$$.22 \times 12 \times .007 = 1.85 \text{ sq. ins.}$$

From Table XIX, this is equal to the area of 5-5/8 inch square bars, and from the same table the cost at the rate of 2 cents per pound will be

$$5 \times 12 \times .027 = \$1.62$$

add 60 per cent for the cost of upper flange bars, stirrups, bent ends, and fabricating, and the total cost will be

Cost of steel.................................. $1.6 \times \$1.62 =$	$2.59
Cost of concrete	8.89
Total cost	$11.48

The corresponding costs with different steel ratios will be found to be as follows:

.0055 lower flange steel dimensions	12 × 25 ins., steel	5-9/16 in. sq. bars, cost	$11.37
.007 " " " "	12 × 24 " "	5-5/8 " " " "	11.48
.010 " " " "	12 × 23 " "	5-3/4 " " " "	12.17
.012 " " " "	12 × 22 " "	5-13/16 " " " "	12.47

These are relative costs based on concrete at $10.00 per cu. yd., and steel at 2 cents per pound. With concrete at $15.00 per cu. yd., the beam with .007 steel would be the cheapest in cost.

Design of Stirrups.—In a beam supporting a uniformly distributed load, stirrups are required when the total load, including the weight of the beam in pounds, divided by the sectional area in square inches, exceeds 60, or when

$$\frac{W + W'}{b\ d} \text{ exceeds } 60 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Thus in the previous example, $W + W' = 23808$, $b = 12$, and $d = 22$, and since

$$\frac{23808}{12 \times 22} = 90.2$$

stirrups should be employed.

Stirrups are, however, desirable in all beams, as they add considerably to their strength and ability to withstand shocks. Stirrups may be either vertical or inclined. They are most efficient when inclined at an angle of 45 degrees toward the end of the girder.

Ransome's Rule.—Mr. E. L. Ransome's rule is to employ four stirrups at each end of the beam, the first at 1/4 of the depth from the end, the second at 1/2 the depth from the first, while the spacing of the third is 3/4 of the depth and of the fourth, a distance equal to the depth. These stirrups are in general composed of 1/4 to 3/8 inch rods.

Stirrups should go through the beam into the floor slab, where they are bent to run parallel with the slab for about six inches. Stirrups should always be fastened to or looped around the bottom rods. In place of stirrups a sheet of expanded metal or other wire fabric may be placed in the web of the beam.

An improvement over the use of loose rods and stirrups consists in the unit system of reinforcement, where all of the members are assembled into one frame. These are illustrated in another chapter, and include the Kahn, Cummings, Unit, and Girder frames.

Design of Bond.—The steel bars may be considered safe against slipping when not called upon to sustain more than 50 pounds bond stress per square inch of surface area.

In a beam carrying a symmetrical or uniform load, this condition may be expressed by the following formula:

$$\frac{4\,(W + W')}{7\,n\,d} \text{ must not exceed } 50 \quad . \quad . \quad . \quad . \quad (8)$$

where W denotes the load on the beam in pounds.
W' denotes the weight of the beam itself.
n denotes the sum of the perimeters of the steel bars in inches.
d denotes the depth to the plane of the steel in inches.

In the previous example, $W + W' = 23{,}808$, $d = 22$ ins., and since $5 - 5/8$ inch square bars are used,

$$n = 5 \times \frac{4 \times 5}{8} = 12.5 \text{ inches}$$

and

$$\frac{4 \times 23808}{7 \times 12.5 \times 22} = 49.5 \text{ lbs. per sq. inch,}$$

which is barely within the required limit of 50. With a greater bond stress, the number of bars would need to be increased.

Summary of Method of Procedure in Design of Beams and Slabs.—The following is a brief summary of the different steps involved in the design of a beam or slab carrying a uniformly distributed load, as previously described in this chapter.

(1) Compute the total load, W, on the beam.

(2) Estimate the weight, W', of the beam itself.

(3) Compute the dimensions of the beam from the formula:

$$b\,d^2 = \frac{\frac{1}{8}\,l\,(W + W')}{D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

(4) Compute the sectional area, A, of the steel from the formula:

$$A = p\;b\;d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

b denotes the breadth of the beam in inches.

d denotes the effective depth in inches to the plane of the steel.

l denotes the length of the span in inches.

p denotes the percentage of lower flange steel.

D denotes the denominator of formula (9) and is obtained from Table XVI for the desired value of p; thus for

$p = .007$, $D = 74$; for $p = .008$, $D = 78$, etc.

(5) Employ from 7/10 to 1 per cent of steel in the lower or tension part of the beam.

(6) If girders are built in one monolithic length over three or more supports, they are called continuous girders, and should have at least four-tenths per cent of steel in the upper part of the beam, extending to the quarter-points. In continuous slabs the steel should be in the lower part of the slab at the centre and in the upper part at the supports.

(7) In large beams, employ from three to four stirrups or pair of stirrups at each end, composed of 1/4 to 3/8 inch rods, and spaced according to Ransome's rule, as described in this chapter.

In small beams use steel wire or metal fabric. Anchor all bars as previously explained, and securely wire all loose bars in such a way that they will not be displaced in concreting, and so that the concrete will cover all bars by from 1 1/2 to 2 diameters in large beams and by at least 3/4 of an inch in thin slabs. Always employ stirrups when $\frac{W + W'}{b\,d}$ exceeds 60.

(8) Test the bond between the steel and concrete by the formula:

$$\frac{4\,(W + W')}{7\,n\,d} \text{ must not exceed } 50. \quad . \quad . \quad . \qquad (11)$$

where n denotes the sum of the perimeters of the steel bars in inches.

Observe the following general rules.

(9) The best-shaped beam is one in which the breadth is from one-half to three-fourths of the effective depth.

(10) The breadth should not be less than 1/24 of the span.

(11) Stirrups must be amply provided especially when the depth is greater than 1/10 of the span.

(12) The breadth must be sufficient for the spacing of the bars. A minimum clear spacing of at least 1 1/2 diameters should be provided, with an equal distance between the outside rod and the surface of the beam.

(13) Sufficient rods should be employed; so that the diameter of each will not exceed 1/200 of the span.

(14) The length of rod on each side of the centre of the beam should be at least 80 diameters for plain and 50 diameters for deformed bars.

(15) Compare the computed weight with the estimated weight of the beam, and revise the design if the difference exceeds 10 per cent.

How to Design a Reinforced Concrete Column.—This consists in determining proper dimensions for the post or column, and the steel required for its reinforcement. The following order of computations should be observed.

(1) Compute the load, P, to be supported by the column.

(2) Estimate the weight, W', of the column itself.

(3) Determine the load per sq. in. of sectional area which the concrete can be designed to carry, also the ratio between the moduli of concrete and steel.

(4) Choose the percentage of vertical reinforcement. In general this should be between 1 and 2½ per cent.

(5) If spiral wrappings are to be used, choose the sectional area, and spacing of the bands.

(6) Compute the sectional area required for the column by the following formula, and check its weight.

$$A_e = \frac{P + W'}{C + pC\,(r-1)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$A_s = p\,A_e \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

A_c = the sectional area of the column.
A_s = the sectional area of the vertical reinforcement.
A_e = the effective area of the column.
A_h = the sectional area of the hooping.
P = the load to be supported.
W' = the estimated weight of the column itself.
C = the safe compressive stress for concrete.
p = the percentage of vertical steel reinforcement.
r = the ratio between the modulus of elasticity of steel and that of concrete in compression.

Where bands are used, the section of the column contained within the spirals may be designed to carry 50 per cent more stress than the column without bands, providing:

(*a*) The wrapping is circular in form.

(*b*) A thickness of two inches of concrete is placed outside of the bands, for protection, but not considered as taking any part of the load.

(*c*) The bands are of sufficient size so that their sectional area, A_h, divided by the pitch, s, or distance between spirals is not less than the diameter of the spiral, D, divided by 500, or

$$\frac{A_h}{s} \text{ must not be less than } \frac{D}{500} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The following practical rules should also be observed:

(7) The length of the column must not exceed more than 12 times its least lateral dimension.

(8) The vertical steel must be as straight as possible, and rest upon bed plates at the bottom. When the bars are spliced, the bars must not be lapped and wired, but the end of the upper bar must rest on the top of the lower one, and be held in place by sleeves made of pipe. The sleeves should be 24 diameters long and the joints should also be stiffened by a half-inch bar about four times as long as the sleeve, which is set alongside of but not in contact with the reinforcement.

(9) In all large columns the steel should be protected by at least two inches of concrete, and in small columns by not less than one inch.

(10) The percentage of steel which can carry the entire load when stiffened by the concrete can be found by dividing the load

to be supported in pounds by 16,000. In general this will run from 4 to 6 per cent.

(11) The load on the column must be symmetrically placed, so that the centre of the load coincides with the centre of the column. If the load bears more on one side of the column than it does on the other, it is called an eccentric load; and it requires a larger column to carry an eccentric than it does to carry a symmetrical load. An eccentrically loaded column cannot be designed by the methods explained in this chapter.

Example.—Design a square reinforced concrete post, 10 feet long, which will support a load of 20 tons without spiral wrappings.

Solution.—(1) $P = 20 \times 2{,}000 = 40{,}000$ lbs.

(2) Estimate W' at 1,500 lbs.

(3) A safe load for concrete in compression is 350 lbs. per sq. in., and a safe value of the ratio, r, is 12.

(4) Employ 1.7 per cent of vertical reinforcement.

(5) $$A_c = \frac{40{,}000 + 1500}{350 + .017 \times 350\,(12 - 1)} = \frac{41500}{415.45} = 100 \text{ sq. ins.}$$

or 10 x 10 ins.

This column will weigh about

$10/12 \times 10/12 \times 10 \times 144 = 1{,}000$ lbs., which is less than the assumed weight and therefore safe.

The area of the steel will be:

$$.017 \times 10 \times 10 = 1.70 \text{ sq. ins.}$$

If 4 square bars are used the area of each will be:

$1.70 \div 4 = .43$ sq. ins. or 4–11/16 in. square bars are required.

(6) The least lateral dimension is 10 inches.

10 inches $\times$ 12 = 10 feet.

As the length of the post is 10 feet or equal to the above value, the design is permissible.

Summarying the results of the design, we have,

External load, 20 tons.

Weight of column, 1,000 lbs.

Dimensions, 10 ins. x 10 ins. $\times$ 10 feet.

Vertical reinforcement, 4–11/16 inch square bars.

Example 2.—Design a circular reinforced concrete column with spiral wrappings 12 feet long which will support a load of 59 tons.

Solution.—(1) $P = 59 \times 2{,}000 = 118{,}000$ lbs.

(2) Estimate W' at 4,000 lbs.

(3) Take C at 350 and r at 12.

(4) Take p at 1.5 per cent.

(5) For hooping, use 5/16-inch round steel or oval bars having the same sectional area of .076 sq. ins. and let the spirals be spaced apart or have a pitch of 2 inches.

(6) $$A_e = \frac{118000 + 4000}{1.5\,[(350 + .015 \times 350\,(12 - 1)]} = \frac{122000}{611.63} = 200 \text{ sq. ins.}$$

or diameter of spirals $= \sqrt{\dfrac{200}{.7854}} = 16$ ins.

With 2 inches of concrete outside of the hooping, the diameter of the post will be $4 + 16 = 20$ inches, and will weigh

$$.7854 \times 20/12 \times 20/12 \times 12 \times 144 = 3{,}770 \text{ lbs.},$$

which is less than the estimated weight and is therefore safe. 1.5 per cent of steel is 3 sq. ins., which is equivalent to 6 – 3/4 inch square rods.

From (5) $A_h = .076$ and $s = 2$ ins., also from (6), $D = 16$ ins., and since $\frac{A_h}{s}$ must not be less than $\frac{D}{500}$, $\frac{.076}{2}$ must not be less than $\frac{16}{500}$; or since .038 is greater than .032 the hooping is in conformity with the condition.

(7) The least lateral dimension is 20 inches.

$$20 \text{ inches} \times 12 = 20 \text{ feet}.$$

As this is greater than the length of the post, the design easily satisfies the condition as to the ratio of length to least lateral dimension.

Summarizing the results of the design, we have for the circular column

External load, 59 tons.

Weight of column, 3,770 pounds.

Diameter of column, 20 inches.

Diameter within hooping, 16 inches.

Length of column, 12 feet.

Vertical reinforcement, 6 – 3/4 inch square rods.

Hooping, 5/16 inch round or oval bars with spirals spaced 2 inches apart.

TABLE XX.—Table for Designing Reinforced Concrete Beams and Slabs†

Medium Heavy Floor Loading—125 Pounds per Square Foot.

Proportions of Concrete 1:2:4. [See important footnote.]

Length or Span of Beams Feet	Distance apart of Beams Feet	Dimensions of Beams.			Reinforcement of Beams					Thickness of Slabs		Reinforcement of Slabs	
		Width Inches	Depth Inches	Depth Below Steel Inches	Number of Rods Required	Diameter of Rods Inches	Number of Stirrups at Each End	Diameter of Stirrup Rods Inches	Spacing* of Stirrups	Total Thickness Inches.	Depth Below Steel Inches	Diameter of Rods Inches	Spacing of Rods Inches
8.....	4	6	13	1½	3	½	1	5/16″	6″	3	¾	5/16	6
	6	7	15	1½	3	9/16	2	5/16″	6″	3¾	¾	⅜	6
	8	8	17	1½	3	⅝	2	⅜″	6″	5	1	½	7½
10.....	4	7	14	1½	3	½	2	5/16″	8″	3	¾	5/16	6
	6	9	17	1½	4	9/16	3	5/16″	8″	3¾	¾	⅜	6
	8	9	20	2	4	⅝	3	⅜″	8″	5	1	½	7½
12.....	4	9	16	1½	4	9/16	2	⅜″	8″	3	¾	5/16	6
	6	10	20	2	4	⅝	3	⅜″	8″	3¾	¾	⅜	6
	8	11	22	2	4	11/16	4	⅜″	8″	5	1	½	7½
14.....	4	10	18	1½	4	⅝	2	⅜″	8″	3	¾	5/16	6
	6	11	24	2	4	¾	3	⅜″	8″	3¾	¾	⅜	6
	8	13	24	2	4	13/16	4	⅜″	8″	5	1	½	7½

1. Bend, diagonally upward, one rod in three, or two rods in four from ¼ points in beam to top of beam and over supports.
2. Stirrups are made U-shaped with bent ends.
3. Slab reinforcement is placed at right angles to supporting beams. Cross reinforcement of slightly smaller rods or same rods farther apart is also placed in slabs parallel to beams.
4. Wire fabric or expanded metal mesh may be substituted for rods in the slabs, provided the area of section of metal is kept the same as the rods.
5. Cinder concrete should not be used for beams.
6. Cinder concrete may be used for roof slabs if thickness is increased one inch.
7. After setting 30 days, test two of the slabs and one beam by loading two panels with sand to depth of: 18 inches deep for heavy floor loading; 8 inches deep for light floor loading; 5 inches deep for roof loading.

† From "Concrete in Factory Construction," published by the Atlas Portland Cement Co. * Place first stirrup in every case 6 inches from support.

TABLE XX. (*Continued*).—TABLE FOR DESIGNING REINFORCED CONCRETE BEAMS AND SLABS.

Light Floor Loading—50 Pounds per Square Foot.

PROPORTIONS OF CONCRETE 1:2:4. [See important footnote.]

Length or Span of Beams Feet	Distance Apart of Beams Feet	Dimensions of Beams.			Reinforcement of Beams					Thickness of Slabs		Reinforcement of Slabs	
		Width Inches	Depth Inches	Depth Below Steel Inches	Number of Rods Required	Diameter of Rods Inches	Number of Stirrups at Each End	Diameter of Stirrup Rods Inches	Spacing of Stirrups	Total Thickness Inches	Depth Below Steel Inches	Diameter of Rods Inches	Spacing of Rods Inches
8....	4	5	10	1¼	3	⅜				3	¾	¼	5½
	6	6	13	1½	3	7/16				3½	¾	5/16	7
	8	7	13	1½	3	½				4	¾	⅜	5½
10....	4	6	12	1¼	3	⅜				3	¾	¼	5½
	6	7	15	1½	3	9/16				3½	¾	5/16	7
	8	8	16	1½	3	⅝				4	¾	⅜	5½
12....	4	7	13	1½	3	½				3	¾	¼	5½
	6	8	17	1½	3	⅝				3½	¾	5/16	7
	8	9	18	1½	4	9/16				4	¾	⅜	5½
14....	4	7	15	1½	3	9/16				3	¾	¼	5½
	6	8	19	2	3	⅝				3½	¾	5/16	7
	8	10	21	2	4	11/16				4	¾	⅜	5½

1. Bend, diagonally upward, one rod in three, or two rods in four from ¼ points in beam to top of beam and over supports.
2. Stirrups are made U-shaped with bent ends.
3. Slab reinforcement is placed at right angles to supporting beams. Cross reinforcement of slightly smaller rods or same rods farther apart is also placed in slabs parallel to beams.
4. Wire fabric or expanded metal mesh may be substituted for rods in the slabs, provided the area of section of metal is kept the same as the rods.
5. Cinder concrete should not be used for beams. 6. Cinder concrete may be used for roof slabs if thickness is increased one inch.
7. After setting 30 days, test two of the slabs and one beam by loading two panels with sand to depth of: 18 inches deep for heavy floor loading; 8 inches deep for light floor loading; 5 inches deep for roof loading.

TABLE XX. (*Continued*).—TABLE FOR DESIGNING REINFORCED CONCRETE BEAMS AND SLABS.

Roofs—30 Pounds per Square Foot.

PROPORTIONS OF CONCRETE 1:2:4. [See important footnote.]

Length or Span of Beams. Feet	Distance Apart of Beams Feet	Dimensions of Beams.			Reinforcement of Beams					Thickness of Slabs		Reinforcement of Slabs	
		Width Inches	Depth Inches	Depth Below Steel Inches	Number of Rods Required	Diameter of Rods Inches	Number of Stirrups at Each End	Diameter of Stirrup Rods Inches	Spacing of Stirrups	Total Thickness Inches	Depth Below Steel Inches	Diameter of Rods Inches	Spacing of Rods Inches
8.....	4	5	10	1¼	3	⅜				2¾	¾	3/16	6
	6	6	11	1¼	3	7/16				3	¾	¼	5½
	8	7	12	1¼	3	½				3¼	¾	⅜	7½
10.....	4	6	12	1¼	3	7/16				2¾	¾	3/16	6
	6	7	13	1½	3	½				3	¾	¼	5½
	8	8	14	1½	3	9/16				3¼	¾	⅜	7½
12.....	4	7	13	1½	3	½				2¾	¾	3/16	6
	6	7	16	1½	3	9/16				3	¾	¼	5½
	8	8	17	1½	3	⅝				3¼	¾	⅜	7½
14.....	4	7	15	1½	3	9/16				2¾	¾	3/16	6
	6	8	17	1½	3	⅝				3	¾	¼	5½
	8	9	18	1½	3	11/16				3¼	¾	⅜	7½

1. Bend, diagonally upward, one rod in three, or two rods in four from ¼ points in beam to top of beam and over supports.
2. Stirrups are made U-shaped with bent ends.
3. Slab reinforcement is placed at right angles to supporting beams. Cross reinforcement of slightly smaller rods or same rods farther apart is also placed in slabs parallel to beams.
4. Wire fabric or expanded metal mesh may be substituted for rods in the slabs, provided the area of section of metal is kept the same as the rods.
5. Cinder concrete should not be used for beams. 6. Cinder concrete may be used for roof slabs if thickness is increased one inch.
7. After setting 30 days, test two of the slabs and one beam by loading two panels with sand to depth of: 18 inches deep for heavy floor loading; 8 inches deep for light floor loading; 5 inches deep for roof loading.

CHAPTER XVIII

EXPLANATION OF THE THEORY OF THE DESIGN OF REINFORCED CONCRETE BEAMS AND SLABS

Explanation of the Theory of the Design of Reinforced Concrete Beams and Slabs, and General Specifications for Reinforced Concrete.—The Mechanics of the Beam, Stresses, and Moments.—Derivation of Formulas.

In the previous chapter the method of designing a simple beam carrying a uniformly distributed load was presented, and a number of formulas were employed. In this chapter the distribution of stress in a beam is explained, and other formulas are developed which are applicable to beams carrying concentrated as well as distributed loads, and to cantilever as well as simple beams. This chapter, while largely theoretical, will serve, perhaps, as an introduction to a more extensive study of the mechanics of materials which can then be profitably pursued. The best book for the student on reinforced concrete design is Turneaure and Maurer's "Principles of Reinforced Concrete Construction," but a study of this work should be preceded by a course in

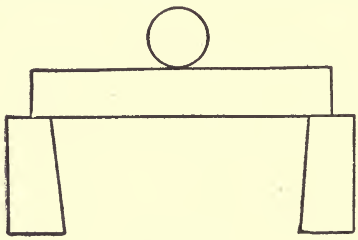


Fig. 50.

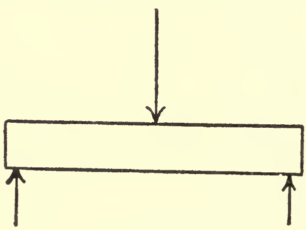


Fig. 51.

Applied Mechanics, such as is contained in Church's "Mechanics of Engineering," Merriman's "Mechanics of Materials," or other standard text books on the subject. This chapter is printed in smaller type so that it may be omitted by the reader who does not wish to go into the theory of reinforced concrete.

Design of Beams.—Before taking up the study of reinforced concrete beams, it is necessary to consider what takes place in a simple wooden beam of rectangular section when acted upon by external forces. Such a beam is shown in Fig. 50, resting on two supports and carrying a weight at the centre.

By replacing the supports and centre load by arrows representing by their lengths the forces acting on the beam, we have Fig. 51, in which the centre load is shown pressing downward while the beam is held in equilibrium by the upward pressures at the points of support.

If the load is exactly in the centre, it is evident that half of this load will be carried to each support, so that the reactions or upward pressures of the supports against the beam will be equal.

If, however, the load is nearer one end of the beam than the other, it is evident that the support which is nearest to the load will carry more than half of the weight while the further support will carry less than half.

THE MECHANICS OF THE BEAM. LOADS, REACTIONS, AND MOMENTS

The different kinds of stresses developed in beams, subjected to loading, have been described at the beginning of the previous chapter. We will now consider how the loads are carried and distributed to the supports and their effect in producing bending.

When a horizontal beam carries a single load, the reaction or upward pressure on the beam at either support due to the load is found by multiplying the load by the dis-

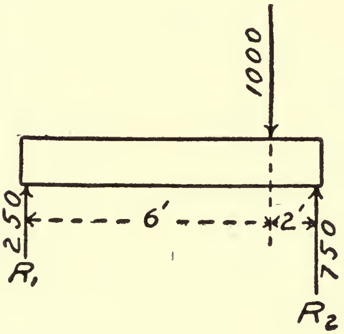


FIG. 52.

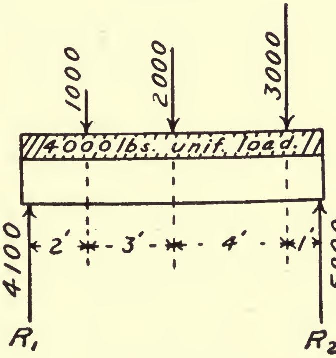


FIG. 53.

tance from the line of action of the load to the line of action of the other support, and dividing by the distance between supports.

Thus in Fig. 52, the reaction at the right support, R_2 is equal to $\frac{1{,}000 \times 6}{8} = 750$ lbs. and at the left support $R_1 = \frac{1{,}000 \times 2}{8} = 250$ lbs., neglecting the weight of the beam itself; and the sum of the reactions, $R_2 + R_1 = 750 + 250 = 1{,}000$ lbs., the total load on the beam.

If the beam carries more than one load, the reaction due to the loads at either support is found in a similar way by adding the products obtained by multiplying each load by its moment arm or distance from the line of action of the load to the line of action of the other support, and dividing by the distance between supports.

If the beam also carries a uniformly distributed load, as the weight of the beam itself, half of this load will also be carried by each support.

Thus in Fig. 53, $R_1 = \frac{4{,}000}{2} + \frac{3{,}000 \times 1}{10} + \frac{2{,}000 \times 5}{10} + \frac{1{,}000 \times 8}{10}$

or $R_1 = 2{,}000 + 300 + 1{,}000 + 800 = 4{,}100$ lbs.

and $R_2 = \frac{4.000}{2} + \frac{1{,}000 \times 2}{10} + \frac{2{,}000 \times 5}{10} + \frac{3{,}000 \times 9}{10} = 5{,}900$ lbs.

while $R_1 + R_2 = 4{,}100 + 5{,}900 = 10{,}000$ lbs., the total load on the beam.

Bending Moments and Internal Stresses.—The loads on a beam do more than exert pressure on the points of support. They also produce internal stresses in the beam itself, as is shown by the bending of a plank when carrying a load across a span.

The stresses produced in a simple horizontal beam carrying a load are compression in the upper portion, tension in the lower portion, and shear. Compression is greatest at the upper surface and decreases to zero at the neutral plane; tension is greatest at the lower surface and also decreases to zero at the neutral plane. In a wooden beam of rectangular section lying in a horizontal position, the neutral plane or plane in which the material is neither compressed nor stretched, is midway between the upper and lower surfaces.

In Fig. 54, *a h c k* represents half of a rectangular beam cut in two at the point of application of the load, P_1, b is the breadth and d the depth of the beam, R_1 is the reaction or upward pressure on the beam at the left support, and the arrows represent

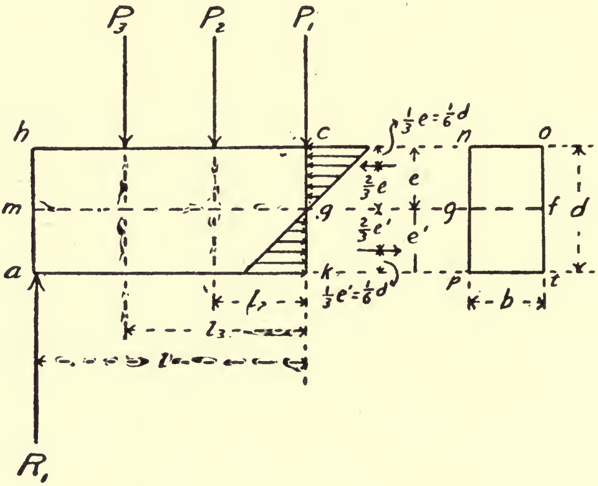


FIG. 54.

by their lengths the variation of compressive stress from the upper to the neutral surface and of tensile stress from the lower to the neutral surface. The neutral axis is the intersection of the neutral surface with any plane. In Fig. 54, the line *f g* is the neutral axis, while the lines *n o* and *p t* are called extreme fibres; *e* is the distance from the neutral axis to the extrème fibre in compression, and *e′* the distance from the neutral axis to the extreme fibre in tension. In a wooden beam of rectangular section, *e′* is equal to *e*. In a reinforced concrete beam *e′* is greater than *e*.

The internal stresses represented by the arrows hold in equilibrium the external forces on either side of the section where the beam is cut in two. These external forces R_1, P_1, P_2 and P_3, tend to produce rotation of the beam, while the internal stresses represented by the arrows, resist the tendency of the beam to rotate.

For example, in Fig. 54, the upward pressure of the reaction R_1 tends to produce clockwise rotation of the beam about the point *g*, and this is resisted in part by the downward pressures P_1, P_2, and P_3, and in part by the internal stresses represented by the arrows.

Explanation of the Theory

The effect of a force in tending to produce rotation is the product of the force by the distance between its line of application and the centre of movement. Thus the effects of the forces R_1, P_2, and P_3, in producing rotation about the point g, are $R_1\,l$, $P_2\,l_2$, and $P_3\,l_3$, and their combined effect is expressed by $R_1\,l - P_2\,l_2 - P_3\,l_3$. Each of these products is called a moment, and the algebraic sum of the moments due to

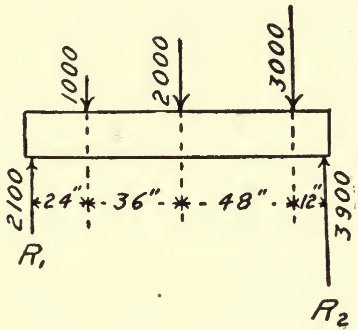


FIG. 55.

the loads and the reaction between the point of support and any section of a beam is called the *bending moment at that section.*

For example, it is required to find the bending moment at each loaded section of the beam represented in Fig. 55.

The reactions R_1 and R_2 must first be computed.

$$R_1 = \frac{(3{,}000 \times 12) + (2{,}000 \times 60) + (1{,}000 \times 96)}{120} = 2{,}100 \text{ lbs.}$$

$$R_2 = \frac{(1{,}000 \times 24) + (2{,}000 \times 60) + (3{,}000 \times 108)}{120} = 3{,}900 \text{ lbs.}$$

The bending moment under the 2,000-lb. load is therefore $(2{,}100 \times 60) - (1{,}000 \times 36) = 90{,}000$ inch-pounds.

Under the 1,000-lb. load, the bending moment is $(2{,}100 \times 24) = 50{,}400$ inch-pounds.

Under the 3,000-lb. load, the bending moment is $(3{,}900 \times 12) = 46{,}800$ inch-pounds.

Hence the position of maximum bending moment is under the 2,000-lb. load.

In a beam supported at each end and carrying a uniformly distributed load of W pounds, the maximum bending moment is at the centre of the span, and if the length of the span be represented by l,

$$\text{Max. mom.} = 1/8\,W\,l \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

If the weight of the beam itself be taken into account and represented by W',

$$\text{Max. mom.} = 1/8\,l\,(W + W') \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1')$$

In a similar beam, carrying a single concentrated load P at the centre of the span, the maximum moment due to the load is also at the centre of the span, and its value is

$$\text{Max. mom.} = 1/4\,P\,l \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

If the weight of the beam is taken into account,

$$\text{Max. mom. } 1/4\, P\, l + 1/8\, W'\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2')$$

A *cantilever beam* is supported at one end only, which is fixed or built into a wall. In such a beam the maximum moment is over the point of support. When carrying a uniformly distributed load W over a span having a length l, the maximum moment is

$$\text{Max. mom.} = 1/2\, W\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When carrying a single concentrated load P at the end of the cantilever arm, the maximum moment is

$$\text{Max. mom.} = P\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

When both ends of the beam are restrained or built into a wall, the maximum bending moment, under a uniformly distributed load W is at the wall, and its numerical value is

$$\text{Max. mom.} = 1/12\, W\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

When a beam is built continuously over three or more supports it is called a continuous girder, and the distance between each pair of supports is the span.

In a continuous girder with two equal spans, carrying a uniformly distributed load W, with supports on the same level, the maximum moment occurs over the middle support, and its numerical value is

$$\text{Max. mom.} = 1/8\, W\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In a continuous girder with three equal spans, carrying a uniformly distributed load W with supports on the same level, the maximum moment occurs over the two middle supports and its numerical value is

$$\text{Max. mom.} = 1/10\, W\, l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6')$$

In cantilever, restrained, and continuous beams, where moments occur over a support, such moments are called negative bending moments.

Where a negative bending moment occurs in a horizontal beam, the internal stresses produced by the negative bending moment are the reverse of those which take place in a simple beam. Where a negative moment occurs, the upper part of the beam is in tension and the lower part in compression. Tension is greatest in the upper and compression in the lower surface, and between the upper and lower surfaces is the neutral surface where the moment stress is zero.

In a cantilever beam, the negative bending moment occurs the whole length of the span and is greatest at the support. Hence a reinforced concrete beam, when designed to act as a cantilever, should have the main horizontal bars near the top of the beam, while the lower half must have sufficient concrete to take care of the compression. As the greatest stresses occur at the point of support, particular care must be taken to provide sufficient steel and concrete at this point.

In restrained and continuous girders positive moments occur in the centre of the span, while negative moments occur over the supports. Hence such beams should have horizontal steel bars at both top and bottom. Over the supports horizontal bars are required at the top of the beam, while in the centre of the span the reinforcement is needed at the bottom.

The length of span over which a negative moment is likely to occur depends upon the loading. Under extreme conditions this may occur entirely across the span. In general the top reinforcement should extend from 1/4 to 1/3 of the span on each side of the point of support.

Having found the amount and position of the maximum bending moment in inch-pounds at any section of a simple rectangular beam supported at each end, the corresponding internal stresses in the beam may now be computed.

In Fig. 56, let *a h c k* represent part of a horizontal beam with two end supports, cut in two along the line *c k* and loaded in any way with loads P_1, P_2, P_3, etc.

Let $S =$ the greatest internal stress in the beam. Since the internal stress in a rectangular beam decreases uniformly from the extreme fibre to the neutral axis, the average stress in the section will be $\frac{S}{2}$. This will be a compressive stress in the upper, and a tensile stress in the lower half of the beam.

Since the centre of gravity of a triangle is 1/3 of the distance from the base to the apex, the point of application of the resultant of the compressive stresses in a rec-

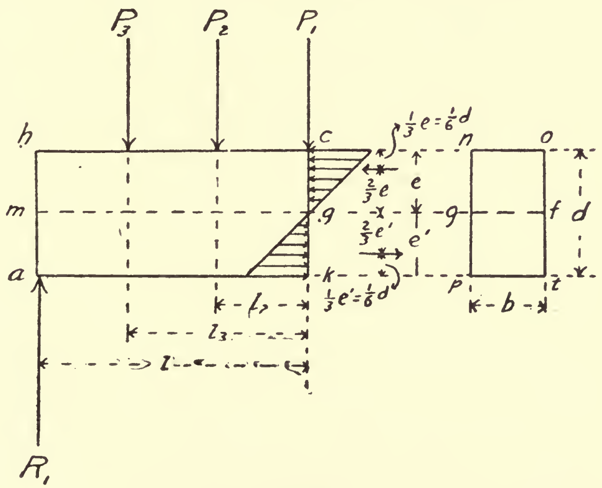


FIG. 56.

tangular beam, of homogeneous material, is 1/3 of the distance from the upper surface to the neutral axis, or (since e is equal to e'), to 1/6 of the depth of the beam, and similarly the resultant of the tensile stresses is 1/6 of the depth of the beam above the lower surface.

If b is the breadth and d the depth of the beam, the surface under compression is $1/2\, d\, b$, which is also the area of the surface under tension. The moment area of the resultant of the compressive stresses about the neutral axis will be $2/6\, d$, and similarly of the tensile stresses $2/6\, d$, while the resisting moment of the beam will be

$$\frac{S}{2}\left\{(1/2\, d\, b \times 2/6\, d) + (1/2\, d\, b \times 2/6\, d)\right\} = 1/6\, S\, b\, d^2$$

Hence for a horizontal rectangular beam of homogeneous material supported at each end and loaded in any manner,

$$M = 1/6\, S\, b\, d^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

This equation enables the dimensions of a wooden beam to be computed, which will sustain a given bending moment, M, without producing an internal stress greater than S, which can be given any safe value. It also applies to a plain concrete beam, but not to a reinforced concrete beam, since a reinforced beam is not homogeneous.

EXAMPLE.—It is required to find suitable dimensions for a wooden rectangular beam, carrying a concentrated load of 2,000 pounds at the centre of a 120-inch span, without producing an internal stress, S, in the timber greater than 1,000 lbs. per sq. in., neglecting the weight of the beam itself.

Solution.—From equation (2), $M = 1/4\, P\, l$ and from (7) $M = 1/6\, S\, b\, d^2$, hence equating:

$$1/4\, P\, l = 1/6\, S\, b\, d^2 \text{ or}$$
$$1/4 \times 2{,}000 \times 120 = 1/6 \times 1{,}000\, b\, d^2$$
$$b\, d^2 = 360 \text{ sq. ins.}$$

since l is in inches and S is in pounds per sq. in.

If $b = 4$ inches, $d^2 = \frac{360}{4} = 90$, and $d = 9.5$ ins.

Hence a beam 10 ins. deep by 4 ins. wide will carry the load with a maximum internal stress of 1,000 lbs. per sq. in. in the extreme fibre, neglecting the weight of the beam itself.

Shear at any Section of a Beam.—The loads on a beam are not directly over the supports, and this results in what are called shearing stresses. At either support, the vertical shear is equal to the upward push of the support against the beam, and at any section of the beam it is equal to the upward push of the support at either end diminished by the sum of the intervening loads. Hence the greatest shear is at the support which carries the heaviest end of the beam, and in reinforced concrete beams a portion of the steel is bent up at intervals near the supports in order to take care of this shear. When a beam carries a uniform or symmetrical load, the greatest shear is equal to half of the load.

Derivation of Straight Line Formulas for Reinforced Concrete Beams.—Reinforced concrete is most economically employed in beams, when the steel is designed to carry the entire tensile stress, as by so doing the strength of the steel may be fully brought into play. When the concrete is designed to carry a portion of this stress, the full strength of the steel is not developed, as is shown by the following considerations:

The modulus of elasticity or the ratio between the length of a rod and its elongation under a tensile force of one pound per square inch is about 30,000,000 for steel and from 2,000,000 to 3,000,000 for concrete, so that the ratio of E_s to E_c lies between 15 to 1 and 10 to 1. In practice various values of this ratio are used, depending upon the kind of concrete and the judgment of the designer. In this volume, a value of 12 to 1 is employed, as this is the ratio most frequently specified in building-codes or

$$E_s : E_c :: 12 : 1$$

According to Hooke's law, stress is proportional to strain. Hence, so long as the adhesion between steel and concrete is unimpaired, their stresses will be proportional to their moduli of elasticity or in the ratio of 12 to 1.

Again the safe working tensile stress of concrete is about 50 pounds per sq. in., and if the concrete takes its share of tension, the corresponding stress in the steel will be only 12 x 50 = 600 lbs. per sq. in.

Since steel can safely be designed to carry from 15,000 to 20,000 lbs. per sq. in. in tension, it is evident that in reinforced tension members, we must either use very low and uneconomical working stresses for steel, or else expect the concrete to be of no assistance in carrying stress.

In this discussion, the formulas, which are developed, are based on the assumption that the steel carries the entire tensional stress.

In a reinforced concrete beam the compressive stress is greatest in the outer fibre and decreases to zero at the neutral axis. Experiments indicate that the stress-strain curve approximates most closely to a parabola, but many designers for the sake of simplicity consider the stress to vary uniformly or as the ordinates to a straight line.

In this discussion the compressive stress on a vertical section is considered to vary in intensity in direct proportion to its distance from the neutral axis, or as the ordinates to a straight line, which assumption errs, if at all, on the side of safety, as it results in more concrete being employed than is the case when the parabolic theory is adopted.

The following notation is employed:

S denotes the unit fibre stress in the steel.
C denotes the unit fibre stress in the concrete in compression.
e_s denotes the unit elongation of the steel due to S.
e_c denotes the unit shortening of the concrete due to C.
E_s denotes the modulus of elasticity of the steel.
E_c denotes the modulus of elasticity of the concrete in compression.
r denotes the ratio $\frac{E_s}{E_c}$.
T denotes the total tension in the steel at a section of the beam.
P denotes the total compression in the concrete at a section of the beam.
M_s denotes the resisting moment as determined by the steel.
M_c denotes the resisting moment as determined by the concrete.
M denotes the bending or resisting moment in general.
b denotes the breadth of a rectangular beam.
d denotes the distance from the compression face to the plane of the steel.
k denotes the ratio of the depth of the neutral axis of a section below the top to d.
$k\,d$ denotes the depth of neutral axis below top of beam.
j denotes the ratio of the arm of the resisting couple to d.
$j\,d$ denotes the arm of the resisting couple.
A denotes the area of cross-section of steel.
p denotes the steel ratio $\frac{A}{bd}$.

When a beam bends under its load, it is assumed that any section, such as would be made by a vertical saw cut remains plane after bending.

It therefore follows that the unit deformations of the fibres vary as their distances from the neutral axis, or

$$\frac{e_s}{e_c} = \frac{d - k\,d}{k\,d}$$

also $$e_s = \frac{S}{E_s} \text{ and } e_c = \frac{C}{E_c}$$

hence $$\frac{\frac{S}{E_s}}{\frac{C}{E_c}} = \frac{d - k\,d}{k\,d} \text{ or } \frac{S\,E_c}{C\,E_s} = \frac{d - k\,d}{k\,d}$$

and since $$r = \frac{E_s}{E_c} \text{ we have } \frac{S}{rC} = \frac{d - k\,d}{k\,d} = \frac{1 - k}{k} \quad . \; . \; . \; . \; . \; . \quad (a)$$

In a horizontal beam, Fig. 57, with vertical loads and reactions, the total tension and compression on any section are equal, and since the average compressive stress is equal to one-half of the maximum stress, C, in the outer fibre,

$$SA \text{ (the total tension)} = 1/2\, C\, b\, k\, d \text{ (the total compression)} \quad . \quad . \quad (b)$$

Eliminating $\frac{S}{C}$ between equation (a) and (b) and introducing the abbreviation $p = \frac{A}{b\,d}$ we have, $2\,pr\,(1 - k) = k^2$, which, if solved for K, gives

$$k = \sqrt{2\,p\,r + (p\,r)^2} - p\,r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The above formula (8) shows that the neutral axes of all beams of a given concrete

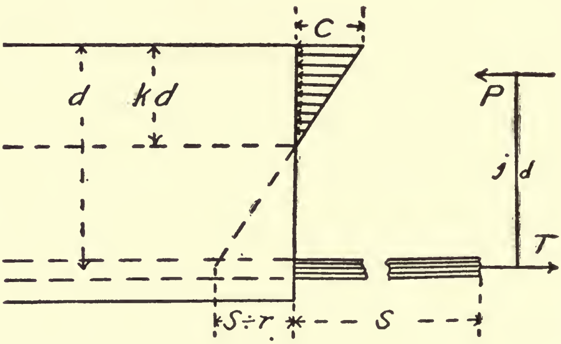


FIG. 57.

and of a given percentage of steel are at the same proportionate depth, k, for all working loads.

Since the centre of gravity of a triangle is one-third the distance from its base, the distance of the resultant of the compressive stress from the compressive face of the beam is $1/3\,k\,d$; therefore the arm of the resisting couple, $T\,P$, is given by

$$j\,d = d - 1/3\,k\,d \text{ or } j = 1 - 1/3\,k \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The resisting moment is equal to the total tension, T, or compression, P, multiplied by its moment arm, $j\,d$.

If the beam is under-reinforced, its resisting moment depends on the steel, and its value then is:

$$M_s = T\,j\,d = S\,A\,j\,d = S\,p\,b\,d\,j\,d = S\,p\,j\,b\,d^2 \quad . \quad . \quad . \quad . \quad (c)$$

If over-reinforced, the resisting moment depends on the concrete, and its value then is

$$M_c = P\,j\,d = 1/2\,C\,b\,k\,d\,j\,d = 1/2\,C\,k\,j\,b\,d^2 \quad . \quad . \quad . \quad . \quad (d)$$

The resisting moment of the beam must be equal to or exceed the bending moment due to the external loads, hence:

$$M = M_c = 1/2\ C\,k\,j\,b\,d^2 \text{ or } C = \frac{2\,M}{k\,j\,b\,d^2} \quad . \quad . \quad . \quad . \quad (10)$$

and

$$M = M_s = S\,p\,j\,b\,d^2 \text{ or } S = \frac{M}{p\,j\,b\,d^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Formulas (10) and (11) are used to find the unit stresses C and S in a rectangular beam after it has been designed. They are called check formulas because frequently employed to test a beam as to its compliance with the specifications.

Also since $M = S\,p\,j\,b\,d^2$ and M also $= 1/2\,C\,k\,j\,b\,d^2$, therefore

$$S\,p\,j\,b\,d^2 = 1/2\,C\,k\,j\,b\,d^2 \qquad (e)$$

and

$$S = \frac{C\,k}{2\,p} \qquad (12)$$

while

$$b\,d^2 = \frac{M}{S\,p\,j} \qquad (13)$$

Formula (13) is used for finding the breadth, b, and effective depth, d, of a rectangular beam, for limiting values of C, S, and r.

Steps in the Procedure for the Design.—Formulas (7–12) are readily adapted for use by proceeding in the following manner:

(1) Assume values of C and r, as for example, $C = 500$, and $r = 12$, which are the maximum values permitted in the building-code of New York City.

(2) Assume different values of p, as, for instance, $p_1 = .005$, $p_2 = .006$, $p_3 = .007$, etc., and solve for the corresponding values of k, j, and S.

k is computed from formula (8); j from (9), and S from (12).

(3) Multiply together the corresponding values of $S\,p$ and j.

(4) Tabulate the values of k, S, j, and the product $S\,p\,j$ for each assumed value of p.

(5) If other values of C or r, or both are required, prepare another table, based on such values.

For example, if $C = 500$ and $r = 12$, for $p = .007$, substituting values of p and r in equation (8), we have

$$k = \sqrt{(2 \times .007 \times 12) + (.007 \times 12)^2} - (.007 \times 12) = .334$$

$$j = 1 - 1/3\,k = (1 - .111) = .889 \text{ from (9),}$$

$$S = \frac{C\,k}{2\,p} = \frac{500 \times .334}{2 \times .007} = 11929 \text{ from (12),}$$

and the product $S\,p\,j = 11929 \times .007 \times .889 = 74.2$.

Values of k, j, S, and the product $S\,p\,j$ are tabulated for values of p, ranging from .005 to .020 in the following table. This table will be found convenient for use with check formulas (10) and (11) and beam formula (13).

p = percentage of steel reinforcement; b = breadth and d = depth of beam in inches; $j\,d$ = distance from the point of application of the resultant of the compressive stresses to the plane of the steel, and $k\,d$ the distance of the neutral axis from the extreme fibre in compression; M the maximum bending moment induced by the external loads in inch-pounds; S and C the respective unit fibre stresses in the steel and concrete in pounds per sq. inch; and r the ratio of the modulus of elasticity of steel to that of concrete; l = the span in inches, W a uniformly distributed load on the beam, and W' the weight of the beam itself.

The first and fifth columns of Table XVIA are identical with Table XVI of the preceding chapter, neglecting fractions, which for simplicity were omitted in that chapter as they do not materially affect the design.

TABLE FOR USE IN DESIGNING REINFORCED CONCRETE BEAMS OF RECTANGULAR SECTION

based on $C = 500$ lbs. per sq. in., $r = 12$, $b\,d^2 = \frac{M}{S\,p\,j}$.

TABLE XVIa.

p	k	j	S	$S\,p\,j$
.005	.291	.903	14550	65.7
.006	.314	.895	13083	70.3
.007	.334	.889	11929	74.2
.008	.353	.882	11030	77.8
.009	.369	.877	10250	80.9
.010	.384	.872	9600	83.7
.011	.399	.867	9068	86.5
.012	.412	.863	8583	88.9
.013	.424	.859	8154	91.1
.014	.436	.855	7786	93.2
.015	.446	.851	7433	94.9
.020	.493	.836	6163	103.0

In the preceding chapter, the following formula was presented for determining the dimensions of beams carrying a uniformly distributed load:

$$b\,d^2 = 1/8\,\frac{l\,(W + W')}{74} \text{ for } p = .007.$$

This formula was obtained in the following way:

From (1′) max. mom. $= M = 1/8\,l\,(W + W')$

From (13) $b\,d^2 = \frac{M}{S\,p\,j}$.

Substituting $1/8\,l\,(W + W')$ for M, we have

$$b\,d^2 = \frac{1/8\,l\,(W+W')}{S\,p\,j} \quad \dots\dots\dots \quad (14)$$

From Table XVI A, neglecting fractions, $S\,p\,j = 74$ for $p = .007$. Hence, substituting 74 for $S\,p\,j$ gives

$$b\,d^2 = \frac{1/8\,l\,(W+W')}{74} \text{ for } p = .007.$$

In a similar way, by combining formulas 2, 3, 4, 5, and 6, with formula 13, we obtain the following:

For simple beams carrying a single concentrated load, P, at the centre of the span, and weighing W' pounds, the span being l inches long:

$$b\,d^2 = \frac{1/8\,W'\,l + 1/4\,Pl}{S\,p\,j} \quad \dots\dots\dots \quad (15)$$

For simple beams carrying both a uniformly distributed load, W, and a concentrated load, P, at the centre of the span,

$$b\,d^2 = \frac{1/8\,l\,(W+W') + 1/4\,Pl}{S\,p\,j} \qquad (16)$$

For cantilever beams carrying a uniformly distributed load W,

$$b\,d^2 = \frac{1/2\,l\,(W+W')}{S\,p\,j} \qquad (17)$$

For cantilever beams carrying a single concentrated load, P, at the end of the cantilever arm,

$$b\,d^2 = \frac{1/2\,W'\,l + Pl}{S\,p\,j} \qquad (18)$$

For cantilever beams carrying both a uniformly distributed load, W, and a concentrated load, P, at the end of the cantilever arm,

$$b\,d^2 = \frac{1/2\,l\,(W+W') + Pl}{S\,p\,j} \qquad (19)$$

For beams restrained at both ends, and carrying a uniformly distributed load, W,

$$b\,d^2 = \frac{1/12\,l\,(W+W')}{S\,p\,j} \qquad (20)$$

For continuous girders of two equal spans, each carrying a uniformly distributed load, W, on each span,

$$b\,d^2 = \frac{1/8\,l\,(W+W')}{S\,p\,j} \qquad (21)$$

For continuous girders of three equal spans, each carrying a uniformly distributed load, W, on each span,

$$b\,d^2 = \frac{1/10\,l\,(W+W')}{S\,p\,j} \qquad (22)$$

The product $S\,j\,p$ may be obtained from Table XVI A for any desired percentage of steel. Thus for $p = .007$, $S\,p\,j = 74$, neglecting fractions.

Check Formulas.—Formulas (10) and (11) are convenient for testing the strength of a reinforced concrete beam to determine whether the external fibre stresses C and S, in the concrete and steel respectively, are within the limits set by the specifications.

$$C = \frac{2\,M}{k\,j\,b\,d^2} \qquad (10)$$

$$S = \frac{M}{p\,j\,b\,d^2} \qquad (11)$$

The same notation applies to these formulas as was explained under Table XVI A. Table XVI A can be used for obtaining values of k and j for any value of $C\,r$, and its use is limited to $C = 500$ only for obtaining values of S and the product $S\,p\,j$. The designer should, however, be cautioned as to the use of the effective depth, d, of the beam, which extends only to the plane of the steel and does not include the one or two inches of concrete which are placed below the steel.

EXAMPLE.—In checking a beam having a span of 10 ft., height of 20 ins., width of 9 ins., reinforced with 4–5/8 inch round rods placed 2 ins. from the bottom of the beam, and carrying a uniformly distributed load of 12,000 pounds, including its own weight, it is required to find whether the unit fibre stresses in the concrete and steel are within safe limits.

Solution.—From (1) $M = 1/8\, W\, l = 1/8 \times 12{,}000 \times 10 = 15{,}000$ ft.-lbs. $= 180{,}000$ inch-pounds.

$$d = 20 - 2 = 18 \text{ ins.} \quad b\,d = 9 \times 18 = 162 \text{ sq. ins.}$$
$$b\,d^2 = 162 \times 18 = 2{,}916 \text{ cu. ins.}$$

Area of steel reinforcement, $A = 4 \times .7854 \times (5/8)^2 = 1.227$ sq. ins
Percentage of steel $p = 1.227 \div 162 = .0075.$
From Table XVI A for $p = .0075$, $k = .345$ and $j = .886$

$$\text{From (10) } C = \frac{2 \times 180{,}000}{.345 \times .886 \times 2{,}916} = 404 \text{ lbs. per sq. in.}$$

$$\text{From (11) } S = \frac{180{,}000}{.0075 \times .886 \times 2{,}916} = 9{,}290 \text{ lbs. per sq. in.}$$

These are below the limits of 500 for concrete and 16,000 for steel and are, therefore, safe values.

Design of a Rectangular Reinforced Concrete Beam.—The dimensions of a horizontal reinforced concrete beam of rectangular section may be accurately determined by observing the following order of computations:

(1) Assume safe values for C, S, and r. Values permitted under the provisions of the New York building-code, are as follows:

$$C = 500, \; S = 16{,}000, \text{ and } r = 12.$$

(2) Prepare a table giving values of S and the product $S\,p\,j$ for different percentages of steel, p. Table XVI A of this chapter gives these values for percentages of steel ranging from .005 to .02 of the area of the section, based on $C = 500$ and $r = 12$.

(3) Determine the amount and position of the loads supported by the beam, including the estimated weight of the beam itself.

(4) Compute the amount and position of the maximum bending moment, M, at any section of the beam, as explained in the earlier part of this chapter.

(5) Assume a percentage of steel, p, and note whether the corresponding value of S, in the table, is within the specified limits. The values of p, most commonly used, are from .007 to .012.

For example, in Table XVI A for $p = .010$, the corresponding value of S is 9600, which is well below the limit of 16,000 and therefore a safe unit stress for steel according to the New York building-code.

(6) Pick out the corresponding value of the product $S\,p\,j$ from the table for use in the formula, $b\,d^2 = \dfrac{M}{S\,p\,j}$.

For example, in Table XVI A, for $p = .010$, $S\,p\,j = 83.7$.

(7) Assume a value for the breadth of the beam, b, and compute the corresponding value of the effective depth, d, using the formula $b\,d^2 = \dfrac{M}{S\,p\,j}$. If necessary try several values of b in order to obtain the best proportions of depth to breadth. The best shaped beam is one in which b lies between $1/2\,d$ and $3/4\,d$. b should not be less than $1/24$ of the span, while d should not exceed $1/8$ of the span.

(8) Compute the sectional area of the steel from the formula $A = p\,b\,d$. The area A should be distributed over several bars. Thus for $p = .0095$, the area of steel required in a beam of 12 x 20 ins. is

$A = .0095 \times 12 \times 20 = 2.28$ sq. ins. area of steel.

If 3/4 inch square bars are employed, the area of each bar will be $3/4 \times 3/4 = 9/16$ sq. ins., and the number of bars required will be $2.28 \div 9/16 = 4$.

The breadth of the beam should be sufficient for the spacing of the bars. A minimum clear spacing of at least 1 1/2 diameters should be provided with an equal distance between the outside rod and the surface of the beam.

Sufficient rods should be employed, so that the diameter of each rod will not exceed one two-hundredths of the span.

The length of rod on either side of the point of maximum bending moment should be at least eighty diameters for plain and fifty diameters for deformed bars.

(9) Check the assumed weight of the beam.

Example.—It is required to find the dimensions and reinforcement required for a reinforced concrete beam, supported at each end, which will carry a uniformly distributed weight of 15,000 pounds over a span of 14 feet, in conformity with the requirements of the New York building-code.

Solution.—(1) According to the requirements, $C = 500$; $r = 12$; and $S = 16{,}000$.

(2) Table XVI-A of this chapter may be employed in this design.

(3) Assume the weight of the beam to be 3,700 pounds; then the total load to be supported will be $15{,}000 + 3{,}700 = 18{,}700$ pounds.

(4) Since the weight is uniformly distributed, the maximum bending moment will be at the centre of the span, and its value be given by the formula:

$M = 1/8\ l\ (W + W')$ or substituting

$M = 1/8 \times 18{,}700$ lbs. $\times$ 168 ins., or

$M = 392{,}700$ inch-pounds.

(5) Assume a value of $p = .0095$ for the percentage of steel. Then from Table XVI A, S will be between the values of 10,250 and 9,600 pounds per sq. inch, which is well below the limiting value of 16,000 pounds required for safe design according to the conditions, and is therefore safe.

(6) The value of the product $S\,p\,j$, corresponding to $p = .0095$, will lie between the values 80.9 and 83.7 in Table XVI A, and for practical purposes can be taken as midway between these values or

$$S\,p\,j = 82.3.$$

(7) Assume a breadth, b, as 3/5 of the depth, or $b = 3/5\ d$, and substituting in the formula $bd^2 = \frac{M}{S\,p\,j}$, we have

$$3/5\ d \times d^2 = \frac{392{,}700}{82.3}$$

Solving for d, we have $d = 20$ ins., and since $b = 3/5\ d$, therefore $b = 3/5 \times 20$ or 12 ins.

(8) Since $p = .0095$, A the area of the steel reinforcement will be $.0095\ b\,d$ or

$$A = .0095 \times 12 \times 20, \text{ or}$$
$$A = 2.28 \text{ sq. ins.}$$

If 3/4 inch square bars are employed, the number of bars required will be $2.28 \div (3/4 \times 3/4) = 4$ plus a very small fraction which can be ignored.

(9) The beam was assumed to weigh 3,700 pounds, and if the actual design shows it to be materially heavier, a revision must be made.

The volume of the beam in cu. ft., as designed, is:

$$14 \times \frac{12 \times 22^*}{144} = 25.7 \text{ cu. ft.}$$

If the concrete is a dense mixture, weighing 144 pounds per cu. ft., its weight will be $144 \times 25.7 = 3{,}700$ pounds as assumed. Having checked the weight, the design should now be investigated to determine whether it is in conformity with the following practical considerations.

(*a*) Whether the breadth is between the limits of 1/2 and 3/4 the depth.

(*b*) Whether the breadth is greater than 1/24 of the span.

(*c*) Whether the diameter of the bars is less than 1/200 of the span.

(*d*) Whether the breadth is sufficient to provide at least 1 1/2 diameters spacing between the bars, and between the bars and the sides of the beam.

Summarizing the results of the design, we have

Total depth of beam, 22 ins.

Depth to plane of steel, 20 ins.

Breadth of beam, 12 ins.

Reinforcement 4–3/4 inch medium steel square bars.

Design of Web Reinforcement or Stirrups.—Stirrups are required when the vertical shear exceeds a safe value for concrete. The vertical shear at any section of a beam is equal to the reaction at a support diminished by the sum of the intervening loads. Thus in the preceding example, each of the end supports carries one-half of the load or 9,350 pounds, and the vertical shear at a support will also have this value.

Shearing stresses are not, however, uniformly distributed over the cross-section, and the maximum value is approximately 8/7 of the average value, while the unit stress or stress per sq. inch of cross-section, is found by dividing the maximum value by the area of the section, or

$$v = 8/7\ V/b\,d \qquad (23)$$

in which v is the unit shearing stress and V the total vertical shear produced by the loads at any section of a beam, having a breadth, b, and effective depth, d.

Concrete can safely sustain a unit shearing stress, v, of from 30 to 50 pounds per sq. inch, and if this value is exceeded, stirrups must be provided to take care of the excess. In large and important girders stirrups should, however, always be provided even if the shearing stress is low.

In the previous example, the maximum shear at either support is 9,350 pounds, and substituting in formula (23), with $b = 12$, and $d = 20$ ins., we have

$$v = \frac{8}{7} \times \frac{9{,}350}{12 \times 20} = 44.5 \text{ lbs. per sq. in.,}$$

which is large enough to necessitate the use of stirrups in a conservative design.

Design of Stirrups.—Where the unit shearing stress, v, is in excess of a safe value for concrete, say over 30 pounds per sq. in., stirrups should be provided, or the rods bent up at intervals, beginning at the point where $\frac{8}{7}\,\frac{V}{b\,d}$ exceeds 30.

Let s = the horizontal spacing of the stirrups along the beam, and let

$$V' = \frac{8}{7}\,V - 30\,b\,d \qquad (24)$$

* 20 ins. plus 2 ins. below the plane of the steel.

Call v' the average intensity of the shear over the same section, that must be carried by the stirrups, then

$$v' = \frac{V'}{b\,d} \quad \ldots\ldots\ldots\ldots \quad (25)$$

and the total tension in the stirrups will be

$$T = v'\,b\,s = \frac{V'\,s}{d} \quad \ldots\ldots\ldots\ldots \quad (26)$$

while the sectional area required for the steel will be

$$A = \frac{T}{S} \text{ or } A = \frac{V'\,s}{S\,d} \quad \ldots\ldots\ldots\ldots \quad (27)$$

If the stirrups are inclined instead of vertical, the distance, s, is the perpendicular distance between the inclined members. Where the stirrups are perpendicular to the horizontal members, s, to be effective, should not exceed 1/2 the depth of the beam, and where inclined at an angle of 45° should not exceed 3/4 of the depth. S, the unit stress in the steel, should not exceed 10,000 lbs. per sq. in.

For example, if the vertical shear at the end section of a beam, 24 ins. deep by 14 ins. wide, is 13,125 lbs., and two square rods are bent up vertically at the centre of the section, the section being 12 inches long, it is required to find the sectional area required for the steel, the unit shearing stresses being taken at 30 and 10,000 lbs. per sq. in., respectively in the concrete and steel.

From (24) $V' = \frac{8}{7} V - 30\,b\,d$ or

$$V' = \frac{8}{7} \times 13{,}125 - (30 \times 14 \times 24) = 4{,}920 \text{ lbs.}$$

From (27) $A = \frac{V'\,s}{S\,d}$ or $A = \frac{4{,}920 \times 12}{10{,}000 \times 24} = 0.246$ sq. ins.

If two square rods are employed, the area of each should be 0.123 sq. ins., or the dimensions 3/8 × 3/8 ins. In general from three to four pair of stirrups should be used at each end of the beam, according to the span.

Bond Strength Between Steel and Concrete.—For the purposes of design this should not exceed 50 pounds per sq. in. of steel area and if this amount be exceeded, the area of the steel must be increased, either by increasing the percentage of steel or the number of bars or both.

The bond between steel and concrete may be tested by the approximate formulas

$$U = \frac{8}{7}\,\frac{V}{d} \quad \ldots\ldots\ldots\ldots \quad (28)$$

and

$$u = \frac{U}{o} \quad \ldots\ldots\ldots\ldots \quad (29)$$

in which V = the maximum vertical shear produced by the loading, U the bond stress per unit length of beam, u the bond stress per unit area, say 50 lbs. per sq. in., and o the sum of the perimeters of the steel sections.

In the example worked out on page 207 the reaction at the supports was found to be 9,350 lbs., which is equal to V, while $d = 20$ ins., and the sum of the perimeters of the steel sections, o, for 4–3/4 inch square bars is 4 x 4 x 3/4 = 12 ins. Hence from (28)

$$U = \frac{8}{7} \times \frac{9{,}350}{20} = 534 \text{ lbs., and}$$

from (29), $u = 534 \div 12 = 44.5$ lbs. per sq. inch, which is below the limiting value of 50 lbs. per sq. in. Hence the design is satisfactory as regards bond.

Design of Reinforced Concrete Slabs.—For the strength of slabs, the same formulas apply as for beams. The slab may be treated as a rectangular beam of unusual width, or it may be considered as a series of beams set one alongside of another, of a width equal to the spacing of the reinforcing bars, using one rod for each beam.

In the case of square slabs, the reinforcement should be of equal amount in the two directions. It may be calculated on the assumption that one-half the load is carried by each system of reinforcement. The concrete is proportioned for one system only, or one-half the load, as the stresses due to the two systems are at right angles to each other, and the stresses in one direction do not weaken the concrete with respect to stresses in the other.

In the case of oblong slabs, the relative amount of load carried by the longitudinal system is so small that it cannot be considered in the design.

While longitudinal reinforcement is of little value in carrying loads, a small amount is nevertheless often desirable in preventing cracks and in binding the entire structure together. For this purpose 1/4 or 3/8 inch rods spaced about two feet apart, are frequently used. Metal fabrics are also commonly employed for reinforcing slabs. The successive steps to be followed in the design of a slab are explained and illustrated in the preceding chapter.

T-beams generally occur in the practice where a slab and its supporting girder are cast at the same time, as in floor construction.

The width of slab that may be taken as part of the beam is generally limited to from four to six times the width of the stem, but in any case the width of slab must not be taken as more than the distance between beams.

Where the neutral axis is not below the junction of web and flange, T-beams may be designed by the same formulas as are used for simple beams by substituting for the actual T-section the area found by multiplying the breadth of the flange by the effective depth of the beam.

Such a beam, however, must be very carefully checked for shear between the flange and web, for bond between the steel and concrete, and for negative bending moments at the supports, which, if present, would produce tension in the slab at the top of the beam and compression in the narrow stem at the bottom of the beam.

For a thorough treatment of the design of T-beams, double-reinforced beams, arches, etc., the reader is referred to Turneaure and Maurer's "Principles of Reinforced Concrete Construction," and other standard text-books on the subject. Further practical principles of design in so far as they relate to foundations, retaining walls, piers, and abutments, building construction, etc., will be found in the appropriate chapters of this book.

RECOMMENDED PRACTICE FOR DESIGNING REINFORCED CONCRETE STRUCTURES*

(1) The materials and workmanship for reinforced concrete should meet the requirements of the "Specifications for Plain and Reinforced Concrete" presented in this report of the Committee on Masonry.

The concrete recommended for general use is a mixture of one part of cement to six parts of fine and coarse aggregates. A richer mixture will be found advantageous for special conditions.

* From the report of the committee on Masonry of the American Railway Engineering and Maintenance of Way Association, presented at their annual convention in Chicago, 1910.

(2) The dead load is to include the estimated weight of the structure and all other fixed loads and forces acting upon the structure.

(3) The live load is to include all variable and moving loads or forces acting upon the structure in any direction.

(4) As the working stresses herein recommended are for static loads, the dynamic effect of moving loads is to be added to the live load stresses.

(5) The span length for beams and slabs is to be taken as the distance from centre to centre of the supports, but not to exceed the clear span plus the depth of beam or slab.

(6) The internal stresses are to be calculated upon the basis of the following assumptions:

(*a*) A plane section before bending remains plane after bending.

(*b*) The distribution of compressive stresses in members subject to bending is rectilinear.

(*c*) The ratio of the moduli of elasticity of steel and concrete is 12.*

(*d*) The tensile stresses in the concrete are neglected in calculating the moment of resistance of beams.

(*e*) The initial stress in the reinforcement due to contraction or expansion in the concrete is neglected.

(*f*) The depth of a beam is the distance from the compressive face to the centroid of the tension reinforcement.

(*g*) The effective depth of a beam at any section is the distance from the centroid of the compressive stresses to the centroid of the tension reinforcement.

(*h*) The maximum shearing unit stress in beams is the total shear at the section divided by the product of the width of the section and the effective depth at the section considered. This maximum shearing unit stress is to be used in place of the diagonal tension stress in calculations for web stresses.

(*i*) The bond unit stress is equal to the vertical shear divided by the product of the total perimeter of the reinforcement in the tension side of the beam and the effective depth at the section considered.

(*k*) In concrete columns the concrete to a depth of $1\frac{1}{2}$ in. is to be considered as a protective covering and is not to be included in the effective section.

(7) When the maximum shearing stresses exceed the value allowed for the concrete alone, web reinforcement must be provided to aid in carrying the diagonal tension stresses. This web reinforcement may consist of bent bars, or inclined or vertical members, attached to or looped about the horizontal reinforcement. Where inclined members are used, the connection to the horizontal reinforcement shall be such as to insure against slip.

"In the calculation of web reinforcement when the concrete alone is insufficient to take the diagonal tension, the concrete may be counted upon as carrying one-third of the shear. The remainder is to be provided for by means of metal reinforcement consisting of bent bars or stirrups, but preferably both. The requisite amount of such reinforcement may be estimated on the assumption that the entire shear on a section, less the amount assumed to be carried by the concrete, is carried by the reinforcement in a length of beam equal to its depth."

(8) The following recommended working stresses, in pounds per square inch of section, are for use in concrete of such quality as to be capable of developing an average

* The unit stresses as recommended in the report were higher than these values, which have been reduced in conformity with the fibre stresses employed in other portions of the chapter.

compressive strength of at least 2,000 lbs. per square inch, when tested in cylinders 8 in. in diameter and 16 in. long, and 28 days old, under laboratory conditions of manufacture and storage, the mixture being of the same consistency as is used in the field.

Structural steel in tension	14,000
High carbon steel in tension	17,000
† Steel in compression, 12 times the compressive stress in the surrounding concrete	
Concrete in bearing where the surface is at least twice the loaded area	700
† Concrete in direct compression, without reinforcement on lengths not exceeding twelve times the least width	350
† Concrete in direct compression with not less than 1 per cent, nor over 4 per cent longitudinal reinforcement on lengths not exceeding twelve times the least width	350
† Concrete in compression, on extreme fibre in cross bending	500
† Concrete in shear, where the shearing stress is used as the measure of web stress	30
NOTE.—The limit of shearing stresses in the concrete, even when thoroughly reinforced for shear and diagonal tension, should not exceed	120
† Bond for plain bars	50
† Bond for drawn wire	30
† Bond for deformed bars, depending upon form	80–120

NOTE: Chapters XVII and XVIII differ, in that, the former chapter is applicable only to the column and to the special case of the simple horizontal beam carrying a uniformly distributed load, while, in the latter chapter, the methods are general and applicable to beams loaded in any manner. The methods of design are, however, identical in both chapters, and in order to render each one complete in itself, a certain amount of matter has been repeated. It is thought that the reading of this chapter will be rendered easier by first showing the application of the theory of design to a simple case, as was done in Chapter XVII.

† The unit stresses as recommended in the report were in general higher than these values, which have been reduced in conformity with the fibre stresses employed in other portions of the chapter.

CHAPTER XIX

SYSTEMS OF REINFORCEMENT EMPLOYED

Systems of Reinforcement Employed.—Different Forms of Rods and Bars.—Special Fabrics and Types of Reinforcement.

Reinforcement is used in a variety of shapes and combinations, nearly all of them patented, and some of them forming the basis for so-called systems.

All these systems of reinforcement have been developed principally during the last decade, each one of them having its adherents and all of them giving substantial structures if intelligently employed. The selection of the type for any particular case will depend upon the nature of the structure, the local conditions, the experience of the designer, and often upon the argument of the salesman. The illustrations will serve to bring out the essential features of the different systems.

Specifications for Reinforcing Steel.—The quality of steel to be used for reinforced concrete work has received a great deal of attention from engineers and steel-makers and the rules given below represent the latest practice in this respect:

SPECIFICATIONS FOR STEEL REINFORCEMENT *

1. Steel shall be made by the open-hearth process. Rerolled material will not be accepted.

2. Plates and shapes used for reinforcement shall be of structural steel only. Bars and wire may be of structural steel or high carbon steel.

* From the report of the Committee on Masonry at the annual convention of the American Railway Engineering and Maintenance of Way Association, Chicago, March 16, 1910.

3. The chemical and physical properties shall conform to the following limits:

Elements Considered.		Structural Steel.	High Carbon Steel.
Phosphorus, max	Basic	0.04 per cent.	0.04 per cent.
	Acid	0.06 per cent.	0.06 per cent.
Sulphur, maximum		0.05 per cent.	0.05 per cent.
Ultimate tensile strength.		Desired.	Desired.
Pounds per square inch		60,000	88,000
Elong., min. per cent in 8″		25%	20%
Character of Fracture		Silky	Silky or finely granular
Cold Bends without Fracture		180° flat†	180° $d = 4t$*†

4. The yield point for bars and wire, as indicated by the drop of the beam, shall be not less than 60 per cent of the ultimate tensile strength.

5. If the ultimate strength varies more than 4,000 lbs. for structural steel or 6,000 lbs. for high carbon steel, a retest shall be made on the same gauge, which, to be acceptable, shall be within 5,000 lbs. for structural steel, or 8,000 lbs. for high carbon steel, of the desired ultimate.

6. Chemical determinations of the percentages of carbon, phosphorus, sulphur, and manganese shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector. Check analyses shall be made from finished material, if called for by the railroad company, in which case an excess of 25 per cent above the required limits will be allowed.

7. Plates, Shapes, and Bars.—Specimens for tensile and bending tests for plates and shapes shall be made by cutting coupons from the finished product, which shall have both faces rolled and both edges milled to the form of a standard test specimen; or with both edges parallel; or they may be turned to a diameter of $\frac{3}{4}$ inch with enlarged ends.

* See paragraphs 11 and 12. †"$d = 4t$" signifies "around a pin whose diameter is four times the thickness of the specimen."

8. Bars shall be tested in their finished form.

9. At least one tensile and one bending test shall be made from each melt of steel as rolled. In case steel differing 3/8 in. and more in thickness is rolled from one melt, a test shall be made from the thickest and thinnest material rolled.

10. For material less than 5/16 in. and more than 3/4 in. in thickness the following modifications will be allowed in the requirements for elongation:

(*a*) For each 1/16 in. in thickness below 5/16 in., a deduction of 2 1/2 will be allowed from the specified percentage.

(*b*) For each 1/8 in. in thickness above 3/4 in., a deduction of 1 will be allowed from the specified percentage.

11. Bending tests may be made by pressure or by blows. Shapes and bars less than one inch thick shall bend as called for in paragraph 3.

12. Test specimens one inch thick and over shall bend cold 180° around a pin, the diameter of which, for structural steel, is twice the thickness of the specimen, and for high carbon steel is six times the thickness of the specimen, without fracture on the outside of the bend.

13. Finished material shall be free from injurious seams, flaws, cracks, defective edges, or other defects, and have a smooth, uniform, and workmanlike finish.

14. Every finished piece of steel shall have the melt number and the name of the manufacturer stamped or rolled upon it, except that bar steel and other small parts may be bundled with the above marks on an attached metal tag.

15. Material, which, subsequent to the above tests at the mills, and its acceptance there, develops weak spots, brittleness, cracks or other imperfections, or is found to have injurious defects, will be rejected and shall be replaced by the manufacturer at his own cost.

16. All reinforcing steel shall be free from excessive rust, loose scale, or other coatings of any character, which would reduce or destroy the bond.

Types of Reinforcement.—The reinforcement consists of steel in one or more of the following forms:

1. Round or square rods.
2. Twisted or deformed rods.

3. Unit systems.
4. Woven wire, expanded metal, welded, or other fabrics.
5. Spiral reinforcement for columns.
6. Various patented systems.

The plain bars either depend upon the adhesion of the steel and concrete for the action of the two materials in combination, or the ends of rods are anchored in the concrete for the purpose of developing their full tensile strength.

In the deformed bars the adhesion of the concrete to the steel is supplemented by a mechanical bond due to the shape of the bar. The following bars are among the best known of this class:

1. Ransome twisted bars are made of square bars twisted cold.
2. Johnson corrugated bar in which the mechanical bond is effected by a series of corrugations on the sides of a square rod.
3. Diamond bar which is a round bar crossed by diagonals.
4. Cold twisted lug bar, which is a Ransome bar having small projections at intervals.
5. Cup bar in which the mechanical bond is effected by a series of cups.
6. DeMan undulated bar.
7. Universal type corrugated bar.
8. The Kahn and Golding bars which are provided with attached shear members.

Unit Systems, Fabrics, and Spiral Reinforcement.—In the unit systems, the reinforcement, including the tension rods and stirrups, are so tied and framed together that after being placed in the forms the possibility of shifting their positions with respect to the other surfaces of the beam, or to one another, is practically removed.

Steel fabrics are largely employed in slab and floor construction, also in conduits, tanks, foundations, etc.

Spiral wrappings for columns are employed for the purpose of permitting a higher unit stress to come upon the concrete than could safely be used without such reinforcement. The spirals have the effect of confining the concrete and preventing it from bulging or splitting.

Special Systems of Reinforcement.—The following are among the so-called special systems of construction:

Systems of Reinforcement Employed

*The Expanded Metal System.**—Expanded metal is made from mild steel, having an ultimate resistance of 48,000 pounds per square inch and an elongation of 21 per cent in a length of 8 inches. It is manufactured from flat plates of thickness varying from 1/4 to about 1/8 of an inch, and when expanded, the usual meshes are from 6 inches to 3 inches in width. The operation of making it consists in placing the sheets vertically, resting on their edges. They are then slotted and pulled out at one operation. After being slotted, they are drawn out laterally so that the width of the finished sheet is in reality produced from the height of the original plate when placed with its edge downward. The expansion effect varies from about 6 to 12 times the original width of the plate. However, no alteration is made in the length, the strands being consequently somewhat stretched. A portion is left uncut, thereby forming a strong "selvedge" edge. It has been found that the ultimate strength is increased from 48,000 to about 63,000 pounds per square inch through the operation of expanding. Expanded metal is mainly used for slab construction, although in a few instances, it has also been used in the construction of beams.

The Clinton System.—A reinforcing for concrete construction of all kinds which is being extensively used in this country is the electrically welded fabric manufactured by the Clinton Wire Cloth Company, of Clinton, Mass. The late Frank E. Kidder stated that from a theoretical standpoint at least this fabric would seem to offer the ideal reinforcement for slab construction, as the carrying wires may be varied both in size and spacing to give the necessary area for any given weight and span. The distributing or cross wires may likewise be varied in the same way. The direction of the wires coincides with the line of stress so that there is no tendency to distort the rectangle of the mesh.

As this fabric comes in 300-foot rolls it can, in a building say, for instance, 200 feet long, be secured at the front or rear and carried through the entire distance without a break. Owing to the continuous bond the reinforcing is equally strong at all points and the reinforcing members are exactly spaced 2, 3, or 4 inches apart as

* Description adapted partly from American Cement Company's publication, by Walter Muller.

the case may be. This spacing is exact; it is established by machinery and is not subject to the carelessness of employees.

The Kahn System.—This system, which is being advocated by the Trussed Concrete Steel Co., of Detroit, Mich., embodies the use of what is known as the Kahn trussed steel bar. This bar is rolled of a diamond section with projecting wings on either side. The wings are slotted off along the edge of the diamond for certain distances and are bent up to an angle of about forty-five degrees to form the reinforcements resisting the shearing stresses. They are consequently rigidly connected to the main bottom bars.

The three principal advantages claimed for the employment of this form of reinforcement are:

1. The reinforcement in the vertical plane is rigidly attached to the main horizontal member and lies in such a direction as to cross at right angles the lines of rupture.

2. The design of the diagonals economizes in the amount of metal required and enables same to be placed with a maximum amount of speed and economy.

3. Absolute fireproofness of structures is the result because this reinforcement does not depend upon the lower part of the concrete, which is affected by fire.

The Hennebique System.—This system, which is one of the best known and most extensively used in Europe, was brought out in 1892 by M. Hennebique, who was one of the first to introduce the reinforced concrete beam and is sometimes mistakenly designated as its original inventor.

The floors, according to the Hennebique system, are formed in several ways, the most commonly employed being the flat single floor with exposed beams. The floor rods are in two series, one bent up to pass over the support near the upper surface of the slab and the other set straight throughout and embedded near the lower surface.

The Hinchman-Renton System.—While plain iron rods have never been known to slide or slip in concrete yet on account of the possibility that the sliding resistance along the embedded steel will decrease in time under frequently repeated loads, American engineers have deemed it wise to use the reinforcing steel in such shape that sliding in the concrete will be impossible without tearing and crushing.

In seeking for material that would satisfactorily supply the tensile strength required by floor slabs it occurred to Mr. J. B. Hinchman of the Hinchman-Renton Company, Denver, Colorado, that ordinary barbed wire would afford the necessary reinforcement.

Roebling System.—The Roebling system is employed in connection with a structural steel frame of I-beam or girder construction.

For all flat construction of floors, the reinforcing system used consists of flat bars placed upon edge, secured at the ends to the steel beams and bridged with bar separators. The object of the edgewise position of the bars is the increased protection thus secured

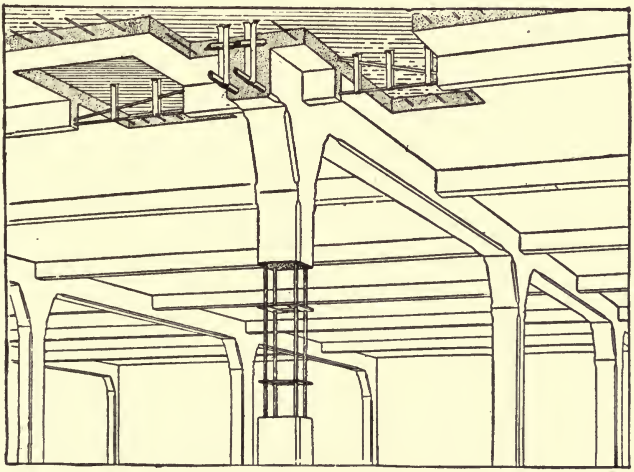


Fig. 58.—The Hennebique System of Reinforced Concrete in Building Construction.

to the reinforcing steel. With this type of floor the structural steel frame is generally completely encased with concrete.

For light roof construction where the steel work need not be protected, a continuous slab is built over the beams, reinforced with flat steel bars, 3-16 by 1 1/4 inches, placed edgewise and held in position by spacers.

For floor construction the Roebling Company also uses segmental arches of cinder concrete laid upon permanent stiffened wire lath centering, or upon wood centering which is carried on steel tees and supported by the steel I-beams of the floor system, which are generally placed about 7 feet on centres. In this system the material is placed upon the centering without puddling or tamping, in order to obtain a light porous concrete of high fire-resisting quality.

The Turner Mushroom System.—The promoter of this system, Mr. C. A. P. Turner, claims that in warehouse work it is perfectly feasible to put up a building with columns at 16-foot centres with a

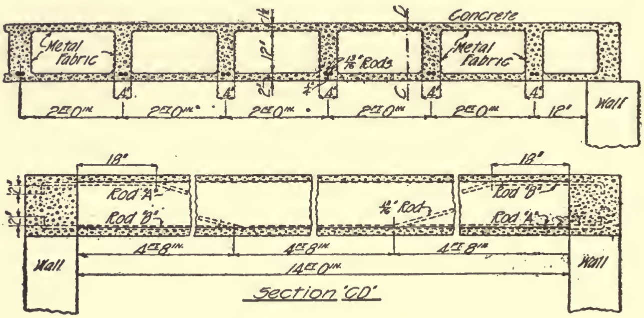


FIG. 59.—The Merrick Floor System.

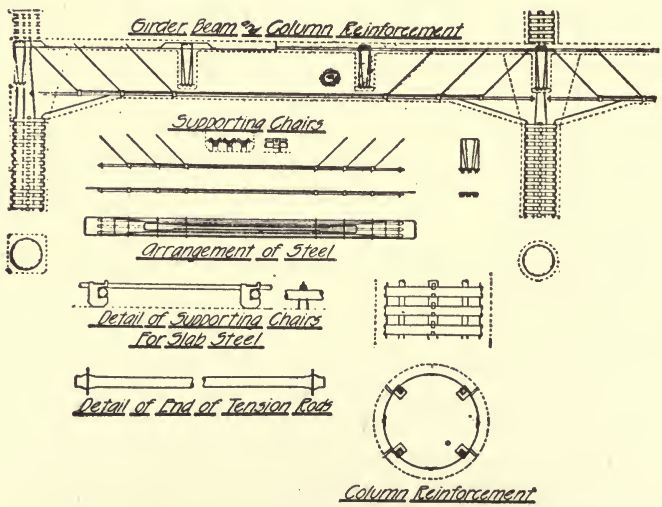


FIG. 60.—The Cummings System.

floor of 7 1/2 in. rough slabs, using no ribs at all, and test it with 800 lb. per sq. ft., without injury to the construction. Furthermore he claims that it can be put up at less cost without the ribs, and will require less metal, as the load will travel more directly to the supports, instead of around a corner, as in the case where beams are used. The method of construction which he employs is known as the mushroom system.

Merrick System.—To lighten the weight of the concrete slab, Mr. Ernest Merrick has designed a hollow floor construction,

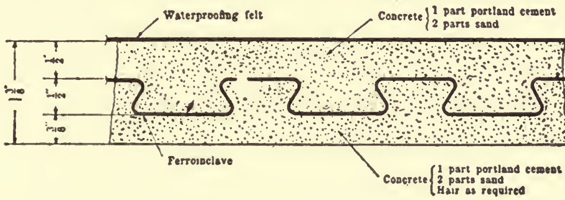


Fig. 61.

consisting of a series of reinforced concrete beams connected by a concrete plate at the top and a ceiling plate at the bottom.

Melan System.—In the Melan system of constructing bridges, steel ribs or I-beams of considerable size are employed; the steel carrying the major portion of the stress, while the concrete serves as protective covering.

The Columbian System.—This is a flat concrete system with

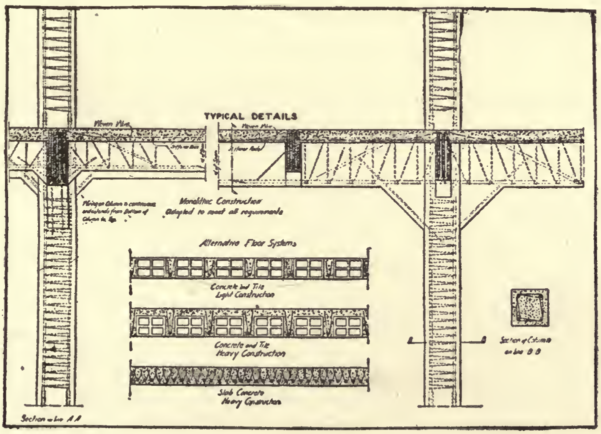


Fig. 62.—The Gabriel System of Reinforcement.

ribbed steel tension members. Rolled joists are used for beams, embedded in concrete, the double cross floor reinforcement being held in place by flat iron inverted stirrups placed over the top flanges of the joists.

The Unit System.—In the Unit System, which is controlled by the Unit Concrete Steel Frame Company of Philadelphia, all of the metallic reinforcement for each beam or girder is made into a single unit and placed as a unit in the form. This is accomplished by having both the straight and camber bars fastened together by stirrups and clamps, so that each tension and shear member is rigidly held in its proper position. This precludes the possibility of one or more members being omitted or incorrectly placed by workmen at the building, and affords opportunity for inspection prior to use.

The advantages claimed for this system are absolute accuracy in the placing of the reinforcing material; the ease with which it can be inspected and errors, if any, detected and corrected before concreting; the impossibility of omitting any tension or shear member; the additional strength secured by binding the slab concrete to the beam concrete by means of lacing of the slab reinforcement through the stirrups. The girder frames may thus be set in advance of the concrete work, and provision made for shafting or other overhead fixtures.

CHAPTER XX

REINFORCED CONCRETE IN FACTORY AND GENERAL BUILDING CONSTRUCTION

Advantages of Reinforced Concrete in Building Construction.—Practical Details of Construction. Slabs, Columns, Floors, Loads, Walls.—Roofs.—Attaching Machinery.

In the factory, where the primal considerations are serviceability, fireproofness, and cost, concrete has found one of its leading applications. When reinforced with steel, a structure is obtained which is lower in first cost than an all-steel building, which can be more quickly erected, and which is freer from vibration and more fireproof.

As compared with what is known as the "slow-burning," or "mill" type of construction, reinforced concrete is more fireproof, durable, and carries a lower rate of insurance as the mill type is a combination of brick, stone, or concrete walls with timber floors and columns.

Cost.—While all statements as to cost of reinforced concrete buildings may be somewhat unreliable, it is safe to figure that in the simple factory building where elaborate forms are not required and building material prices not excessive, the cost will be about 8 cents per cu. foot. This price will increase with elaboration of surface finish and ornamentation and other unfavorable conditions to 12 cents per cubic foot.

The volume includes the building from footing to roof and the price does not include interior work such as lighting or heating plants, machinery, plastering, plumbing, or elevators.

Fire resistance is one of the chief inducements that has led to the extensive use of concrete in factories. The materials to be employed are first-class Portland cement, quartz sand, and broken trap rock. Limestone aggregates are more easily injured by extreme heat and gravel is more readily dislodged. Cinders make a good aggregate for fire resistance, but the concrete made therefrom is not sufficiently strong for reinforced concrete work excepting for partition walls and short spans.

A reinforced concrete factory is necessarily a very stiff structure, every part being inseparably connected with every other part by continuous beams, girders, and slabs. This permits the operation of the heaviest machinery with much less vibration than equivalent steel structures.

In taking up the question of a concrete factory, the layout and arrangement of machinery should first be made and the building designed to accommodate the resulting loads.

One of the distinct advantages of a concrete factory is the large amount of window space and light thus made available which is due to the inherent strength of concrete and the thin members required to support the windows, etc. In addition to these advantages the floors of concrete may be made absolutely watertight, can readily be flushed with a hose, and are fire- and vermin-proof.

Practical Construction Details.—The essential principles governing the design of girders, columns, and slabs, have already been given in Chapters XVII and XVIII. The following data is of importance in connection with building and factory construction, and is taken from "Reinforced Concrete in Factory Construction," by Sanford E. Thompson.*

Floor Slabs.—The thickness and reinforcement of the floor slabs are determined by the distance between the beams, and by the loading which will come upon them. The most usual thicknesses are 3 1/2 inches to 5 inches, with reinforcement calculated from the bending moment produced by the loads. An economical quantity of steel is apt to be from 0.8 per cent to 1 per cent of the sectional area of the slab above the steel.

A few rods are usually placed at right angles to the main bearing rods of the slab to assist in preventing contraction cracks, and these also add to the strength of the slab.

In a factory or warehouse the most economical floor surface is generally a granolithic finish, consisting of a layer of 1 : 2 mortar about three-quarter inch thick, spread upon the surface of the con-

* Published by the Atlas Portland Cement Co.

crete slab before it has begun to set, and trowelled to a hard finish just like a concrete sidewalk.

Machines are readily bolted to the concrete by drilling small holes in the concrete at the proper points for the standards and grouting the lag screws in place, or else bolting them through the slab.

If for any reason a wood floor is required, stringers may be laid upon the top of the concrete and spaces left between them or filled with cinders or with cinder concrete.

Stirrups.—Besides the ordinary compression and pull in a beam, there are secondary stresses of shear or diagonal tension, which, if

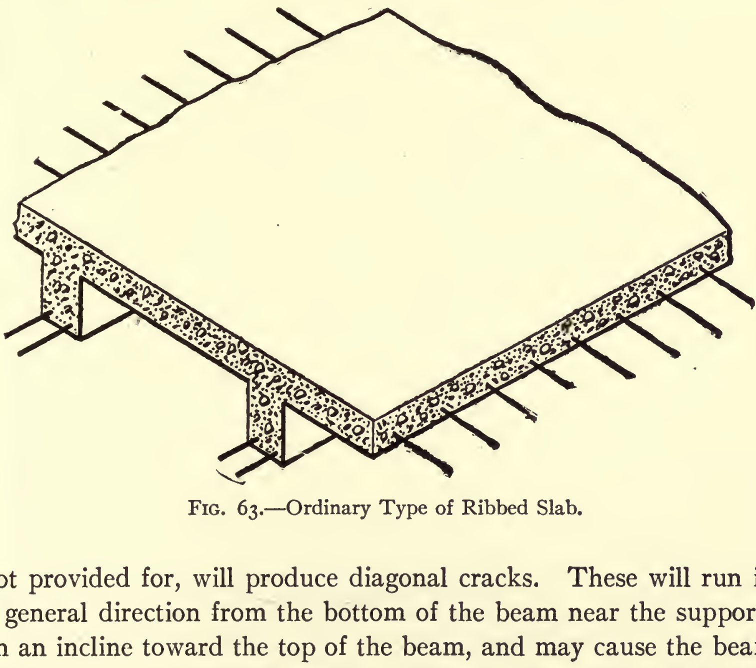


Fig. 63.—Ordinary Type of Ribbed Slab.

not provided for, will produce diagonal cracks. These will run in a general direction from the bottom of the beam near the supports on an incline toward the top of the beam, and may cause the beam to fail. To prevent this cracking, unless the beam is so wide that the concrete can take the whole of the stress without exceeding 60 pounds per square inch in shear, vertical or inclined steel bars, of sizes accurately computed, must be placed. The bent-up tension rods take care of a part of this shear, or diagonal tension, but if these are not sufficient, stirrups, which are usually made in the form of a U, must be inserted at the proper locations to take the remainder.

Columns.—The most important of all the members of the building are the columns, for if a column fails, the entire building is liable to go down.

If columns, as ordinarily built in building construction, are made of 1:2:4 proportions, it is safe in an ordinary building to allow a direct compressive strength of 450 pounds per square inch, provided the columns are at least 12 inches square. A customary manner of designing is to figure the entire compression upon the concrete to the full size of the column, but to place four or possibly six rods of 5/8 inch or 3/4 inch diameter near the corners or sides of

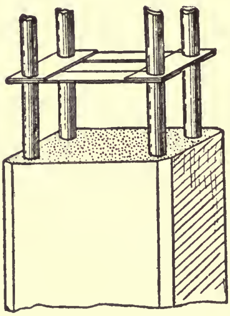


FIG. 64.—Column Reinforcement.

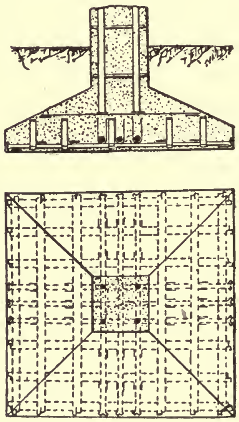


FIG. 65.—Reinforced Concrete Column Footing.

the column, with 1/4-inch wire loops around these rods at occasional intervals in the height, say, from 8 to 12 inches apart.

Vertical steel rods of larger size may be introduced when it is necessary to decrease the size of the columns. These may be computed to bear a portion of the compressive load, but they cannot be figured at their full safe value of 16,000 pounds per square inch because they have a different modulus of elasticity and compressive strength from concrete and can only shorten the same amount as the concrete. Under ordinary circumstances, therefore, they cannot be assumed to bear more than the safe compressive stress in the concrete times the ratio of elasticity of steel to concrete, or about 7,000 pounds per square inch. Because of this small amount of compression which they can bear, it is always cheaper to enlarge the column rather than to insert steel of large diameter to assist in taking the load.

Another means of increasing the strength of the column is to use a richer mixture. This is legitimate provided the same mixture is carried up through the floor system at the column so that there will be no weak places. By using proportions 1 : 1 : 3, a safe working compression in the concrete of 700 pounds per square inch may be adopted.

Hooped columns, that is, columns reinforced with bands placed near together or with spirals, are frequently adopted to reduce the size of the column. It is a serious question in the minds of conservative engineers as to whether it is good practice to assume that a large proportion of the load can be borne by such hoops. Although tests have shown that hooped columns have a high ultimate strength, these same tests prove that the concrete within the hoops is overstrained before the hoops begin to take any of the tension which must reach them before they can strengthen the columns.

Basement Floor.—The earth under a basement floor must be well drained. If necessary, drains of tile pipe or of screened gravel or stone may be placed in trenches just below the concrete, or the entire level may be covered with cinders or stone. If the basement is below tide water or ground water level, it is not safe to depend upon the concrete itself being water-tight, and waterproofing should be provided for as described in Chapter XXX.

For a basement floor in dry ground a 3-inch or 4-inch thickness of ordinary 1 : 3 : 5 concrete,—that is, concrete composed of 1 part Portland cement to 3 parts sand to 5 parts broken stone or gravel—may be laid and the surface screeded to bring it to the required level. As it sets, this concrete should be trowelled just as the wearing surface of a sidewalk is trowelled, but without the mortar or granolithic finish which is customarily laid upon a walk. If the floor is to have a great deal of wear or trucking, the usual 3/4-inch or 1-inch layer of 1 : 2 mortar may be laid upon the concrete before it has set, forming a part of the total thickness of 4 inches; but usually this is an unwarranted expense in a basement, as the plain concrete will give as good service.

It is well in any case to divide the floor into blocks, say, 8 or 10 feet square, so that any shrinkage cracks will come in the joints. This is readily accomplished by laying alternate blocks, and then filling in the intermediate ones the next day.

Design of Floor System.—*Loading.*—In designing a reinforced concrete building, the first consideration is the loading which the various floors must sustain; in other words, the strength which each floor must have to support the weights which may come upon it under all conceivable conditions. In a factory or warehouse it is frequently possible to accurately calculate the maximum weight which will come upon a given area of floor. For the very heaviest loading the problem is frequently the simplest, since the heavy weights are apt to be due to the storage of merchandise whose weight per cubic foot, and therefore per square foot of floor, can be readily calculated. Sometimes the underside of the floor must support tracks which carry certain definite weights, and the beams or girders must be calculated for these concentrated loads in addition to the uniform loads upon the floor.

In computing the strength of the floor system, the weight of the concrete itself must always be allowed for. In very long spans the concrete frequently weighs more than the load which will be placed upon it.

In many cases the loading must be assumed without actual computation. A maximum load must frequently be selected to support machinery whose weight is slight but whose vibrations require a stiff floor system.

The various conditions met with in warehouse or factory construction may thus necessitate loadings varying from 100 to 500 pounds per square foot of floor area, very wide limits and yet not more than occur in practice.

As a guide to the selection of floor loads, the following values are suggested:

Office floors	100 pounds per square foot
Light-running machinery	150 pounds per square foot
Medium heavy machinery	200 pounds per square foot
Heavy machinery	250 pounds per square foot
Storage of parts or finished products, depending upon actual calculated loads	150 to 500 pounds per square foot

When the loads are apt to occur only over a part of the floor, the slabs and beams are calculated for the full load, and when computing the girders and columns a slightly smaller load is sometimes used. For example, if the slabs and beams are figured for 200 pounds per square foot of floor area, it might be assumed that the whole of the total area supported by a girder or column would never be loaded at once, and the load per square foot actually reach-

TABLE XXI.—ALLOWABLE FLOOR LOADS IN ACCORDANCE WITH THE BUILDING LAWS OF VARIOUS CITIES.

(From Kahn's Pocketbook.)

Live Loads for Floors in Different Classes of Buildings Exclusive of the Weight of the Materials of Construction.	New York 1902.	Chicago 1902	Philadelphia 1902.	Boston 1902.	San Francisco 1906.
	Pounds per Square Foot.				
Dwellings, Apartment Houses, Hotels, Tenement Houses, or Lodging Houses	60	40	70	50	60
Office Buildings, 1st Floor	150	100	100	100	150
Office Buildings, Above 1st Floor	75	100	100	100	75
Schools or Places of Instruction	75	......	......	80	75
Stables or Carriage Houses	75	40* 100†			75
Buildings for Public Assembly	90	100	120	150	125
Buildings for Ordinary Stores, Light Manufacturing and Light Storage	120	100	120		120
Stores for Heavy Materials, Warehouses, and Factories	150		150	250	250
Roofs—Pitch less than 20 degrees	50	25	30	25‡	50
Roofs—Pitch more than 20 degrees	30	25	30	25‡	30
Sidewalks	300				300
Public Buildings Except Schools				150	

ing the girder and column at any one time would be therefore not more than 150 pounds per square foot of floor area.

Layout.—The general layout of the beams and girders and columns depends upon the loading, the uses to which the building is to be put, and the ground area. Frequently in a large building,

* Stables less than 500 square feet in area.

† Stables over 500 square feet in area.

‡ Make proper allowance for wind at 30 lbs. per square foot horizontal pressure.

it will be worth while to require the engineer to make several comparative estimates with different spacings of columns and sizes of panels, so as to determine that which is most economical consistent with the floor area required for the machinery.

Common spacings of columns in a reinforced concrete building are from 12 feet to 20 feet. Longer spans are not usually so economical, but may frequently be necessary to give the floor space required for machinery or storage.

Walls.—The walls of reinforced concrete factories are sometimes built up with the columns, but it is generally considered more economical to erect the skeleton structure and fill in the wall panels afterwards.

Slots in the columns are made by nailing a strip on the inside of the column forms. In this way the panels are mortised into the columns.

Ordinary concrete walls require light reinforcement to prevent shrinkage and give them stiffness while setting. All that is required for, say a 4-inch or 6-inch wall, are 1/4-inch rods spaced from 12 to 24 inches apart, according to the size and importance of the wall. At window and door openings a larger amount of reinforcement is, of course, necessary, and in these cases the amount of steel must be calculated just as though the lintels were reinforced concrete beams.

Roofs.—Reinforced concrete roofs are designed like floors. A roof load commonly assumed in temperate climates, to provide for roof covering, snow and wind pressure, is 40 pounds per square foot, in addition to the weight of the concrete itself.

It is not safe to assume that the concrete roof of itself will be water-tight unless special provision is made in the construction. Although tanks and walls can readily be made to hold water, a roof is under extraordinarily disadvantageous conditions because of the rays of the sun. Usually, therefore, a tar and gravel or other form of roof covering must be provided.

Methods for Attaching Shafting, etc.—The attachment of shafting, piping, etc., to the ceilings of reinforced concrete buildings presents no special difficulty, provided adequate provision is made in the design.

The following methods are employed:

1. Bolts are embedded in the concrete beams with their threaded ends hanging down. After the forms have been removed timbers are bolted to the undersides of the beams and the hangers for the

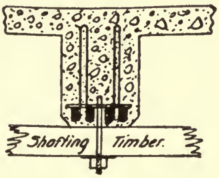


Fig. 66.

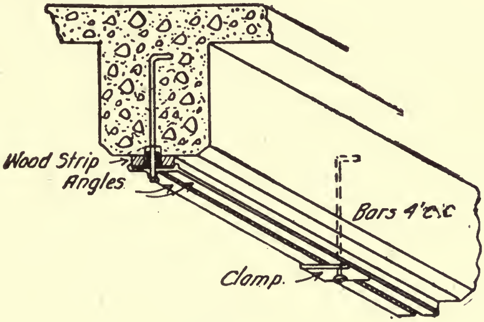


Fig. 67.

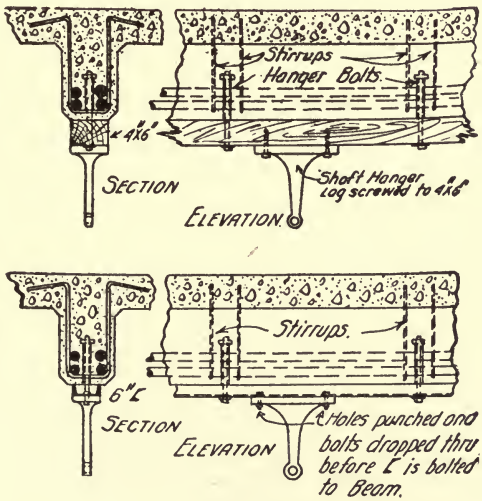


Fig. 68.

Figs. 66, 67, 68.—Showing Method of Supporting Shafting from Concrete Ceiling.

shafting are attached to the timbers in the usual way by means of lag screws.

2. Sockets into which a bolt can be threaded are fastened to the reinforcing bars. Such sockets also serve as spacers for the bars.

3. Sockets into which a bolt can be threaded are suspended by stirrups, embedded in the beam.

The suspended bolts in methods 1–3 are used to fasten either a timber or a steel channel or other shape to the bottom of the girder, from which the hangers or piping are supported.

4. A slotted pipe is suspended by stirrups and used for attaching the hangers or other fittings directly to the concrete without the interposition of a timber or metal beam. The attachment is made by means of T-bolts which are suspended from the pipe, and pass through the bolt-holes in the hangers.

5. Instead of a slotted pipe, two angles are fastened to a wooden strip and suspended from the bottom of the beam by anchor bolts, the angles being separated so as to form a slot, from which T-bolts can be suspended at any point as in 4.

6. A horizontal hole is drilled in the top of the beam, and a bolt inserted. From this a vertical rod is hung.

CHAPTER XXI

CONCRETE IN FOUNDATION WORK

Importance of Foundations.—Loads on Foundations.—Methods of Securing Good Foundations.—Essential Requirements in Construction.—Concrete in Foundations.—Reinforced Concrete Piles.—Caissons.—Cribs.

Importance of Foundations.—Every structure must depend for its security upon the integrity of its foundation and whatever its character, if the main prop be weakened, the edifice it supports is bound to suffer or fail. The importance of securing firm and stable foundations has brought to the study of the subject the ablest constructive brains of the engineering world and the difficulties which engineering genius have overcome has rendered possible the monumental engineering structures of to-day. While there is no difficulty in rearing obelisks on extensive areas of firm earth or rock beds as has been done in ancient days, the placing of enormous skyscrapers, bridge piers, carrying thousands of tons of weight, and other gigantic structures upon soft and shifting beds, or in water and quicksand, is a distinct modern development, and concrete has played no small part in this development.

Reference to the foundations of various structures such as walls, arches, sidewalks, sewers, etc., will be found in the appropriate chapters, and it is intended here to outline the general principles common to all foundations, as well as to describe the different types that are referred to.

The basic principles lying at the root of all foundation problems are:

1. That the bed upon which the structure rests, *i.e.*, the foundation bed, must not be compressed beyond certain limits which experience has established as those which they can safely stand.

2. That the material composing the foundation bed be sufficiently stable so as to prevent any displacement or tendency to displacement.

Safe Loads on Foundations.—The order of desirability in which various foundation beds arrange themselves, and the amount of unit pressure each can safely bear as determined by tests and experience, are as follows:

ALLOWABLE PRESSURES ON FOUNDATIONS.

Rock	10 to 50 tons per square foot.
Hardpan	8 " " " "
Sand	4 " " " "
Clay	1–3 " " " "
Muck	0–1 " " " "
Concrete	10 " " " "

Methods of Securing Good Foundations in Poor Soils.—The construction of foundations in ordinary soil where the load to be carried does not exceed the safe bearing value of the material is a simple matter; but when a very heavy load is to be placed on a poor soil, various methods, depending upon local conditions, must be employed to distribute the load upon a sufficiently wide area of foundation bed so that the pressure per square foot will be within safe limits. This may be done by:

1. Spreading the foundation over a sufficient area by means of footings or grillages.

2. Carrying the structure on wooden or concrete piles, piers, caissons, or cribs.

3. Consolidating and confining the materials in the foundation bed so as to increase its bearing power. This may be effected in several ways and is particularly useful when quicksand is encountered. In such cases, grout may be poured into the material which will set up and produce a rock-like mass; holes may be bored and filled with sand, or piles may be employed. During construction, quicksand is sometimes frozen by what is known as the Poetch Freezing Process and excavation carried on in frozen material.

Soft materials in foundation beds may be confined by the construction of a timber or steel cofferdam or box around the area to be confined.

Essential Requirements in Construction.—In the construction of all ordinary foundations, on earth or rock beds, a few essential requirements may be pointed out.

1. The foundation should in all cases be below the frost line at the locality in question.

2. Poor material such as vegetable or decayed matter, disintegrated rock, etc., should be removed and replaced by good sand, earth, or concrete.

3. Adequate drainage should be secured so as to remove danger of washing out of soil. Springs encountered in foundation sites must be stopped up by grouting or carried off in pipes.

4. Where walls and similar structures are to rest on sloping beds, the latter should be stepped to prevent any tendency of the superstructure to slide.

5. The loads placed on the foundation bed should be uniform over all parts of the area, as unequal loading will lead to unequal compression of the underlying material and result in unequal settlement. Evidence of the disregard of this requirement is visible in settlement cracks which may frequently be seen in new structures within a short time after their erection.

Concrete for Foundations.—Concrete, either plain or reinforced, is in all probability the most satisfactory material for foundation work that has yet been found. Being in a plastic state when laid, it easily fills all irregularities in the foundation bed and insures an even and equal bearing throughout. Concrete for foundations can be placed under water almost as readily as in air. Practically the only precautions necessary are to see that the water is at rest, and in placing the concrete, to do so with as little fall as possible through the water, so as to prevent washing out the cement.

Concrete unreinforced has, until quite recently, been used for all classes of foundation work, but the tendency at the present time in many cases is to substitute reinforced concrete. Owing to the low tensile resistance of plain concrete, the thickness is proportionately great, thus requiring a large amount of material and greatly increasing the amount of excavation necessary. In using reinforced concrete the thickness may be greatly diminished and a large saving in cost effected.

Concrete Footings.—Figs. 69, 70, 71 represent the same footing designed first in ordinary concrete, second using a steel grillage; third, in reinforced concrete.

This footing is designed to carry a load of 400,000 lbs.; bearing capacity of the soil, 6,000 lbs., per square foot.

The economy of the reinforced-concrete footing, both as regards material and excavation, is at once apparent. The plain concrete footing (Fig. 69), requires 215 cu. ft. of concrete. The steel grillage footing (Fig. 70), requires 137 cu. ft. of concrete and about 5,000 lbs. of structural steel. The reinforced-concrete footing (Fig. 71), requires 136 cu. ft. of concrete and less than 600 lbs. of

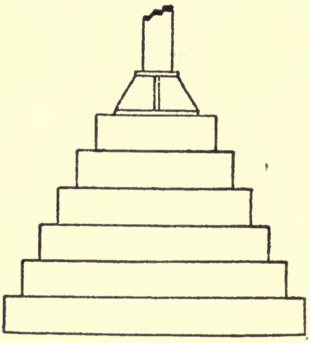


FIG. 69.—Plain Concrete Column Footing.

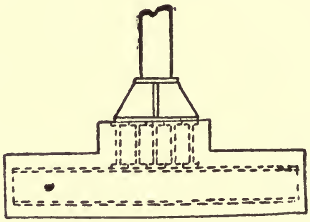


FIG. 70.—Concrete and Steel Grillage Column Footing.

steel. When excavation is taken into account a still greater economy is shown in favor of reinforced concrete.

Instead of a simple isolated footing, a combined footing supporting two or more columns at the same time may be necessary. Here

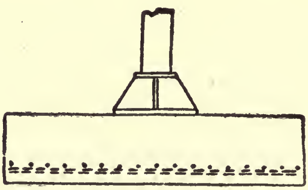


FIG. 71.—Reinforced-Concrete Column Footing.

again reinforced concrete proves more economical than inverted concrete arches or steel grillage.

Fig. 70 gives a longitudinal section and a cross-section of a combined reinforced-concrete footing. Some designers make the footing the same width from bottom to top as indicated by the dotted lines in the cross-section, in which case the amount of concrete is increased, but the cost of form work is decreased somewhat. Also, in the latter case no additional reinforcement will be necessary for shear, while some, in the form of stirrups may be necessary in the former.

A further development of the combined footing is the raft footing. In this case there are more columns, or a whole building may be supported on one footing. The footing acts as an inverted floor

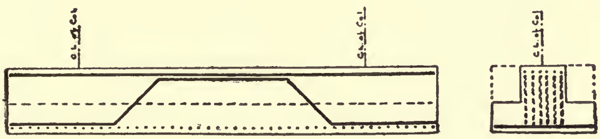


FIG. 72. Combined Reinforced-Concrete Column Footing.

carrying the upward pressure of the soil to the columns and is designed as such.

Where the foregoing types of foundations fail to develop sufficient resistance to support the loads upon them some other form of foundation must be used, such as piles or caissons.

REINFORCED CONCRETE PILES

Historical.—The first concrete piles were made in France by Mr. F. Hennebique, in 1896. These piles were cast in a convenient location and driven with a pile-driver the same as an ordinary wood pile. About the same time, A. Raymond of Chicago, conceived the idea of a pile cast in place. The Simplex pile which was patented in 1903, is also a cast-in-place pile, although the method of casting is different than in the Raymond pile. Since the introduction of the above pile, various other piles have been developed, but are really little more than modifications of the Hennebique, Raymond, and Simplex piles.

Advantages.—An ordinary wood pile will carry a load of about 15 tons; a reinforced-concrete pile may be loaded with thirty to fifty tons, depending on the nature of the ground. Wood piles, unless continually saturated with water are subject to rapid decay, and even when under water are subject to the attack of wood-borers. Reinforced-concrete piles are not subject to decay or to the attack of any destructive animal life. Reinforced-concrete piles may, therefore, be used where a wood pile would not be advisable. A concrete pile may have the lower end continually submerged, its middle portion alternately wet and dry, and the top portion always

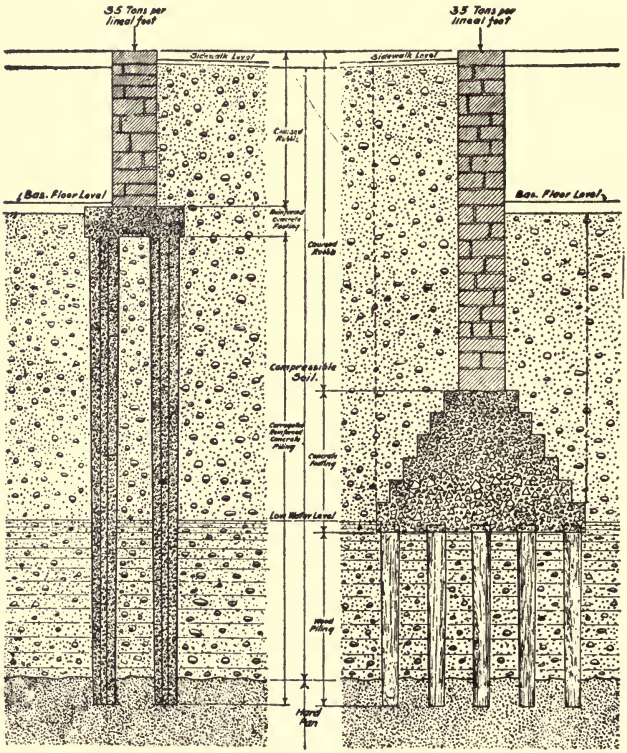


FIG. 73.—Comparative Sections. Wooden and Corrugated Reinforced-Concrete Pile Foundations.

dry, without being in any way harmful to the pile, or in any way shortening its life. A timber pile under similar conditions would last but a very short time.

Disadvantages.—The argument most frequently used against reinforced-concrete piles is their cost. While the cost per linear foot of a reinforced-concrete pile is certainly greater than that of a wood pile, still when the much greater bearing power of the reinforced-concrete pile is considered the additional cost per linear foot is discounted; in fact, the reinforced-concrete pile is likely to prove the more economical.

Types of Piles.—Reinforced-concrete piles may be divided into two classes. First, the cast-and-driven pile; second, cast-in-place pile.

The Cast-and-Driven Pile.—Piles of this type are first cast in some convenient locality, and when thoroughly seasoned are transported to the desired site and driven. Piles of this type are always reinforced both with longitudinal rods and hooping. Great care is required in handling and driving these piles. A cap, to take up the shock of the hammer and prevent shattering of the head of the pile,

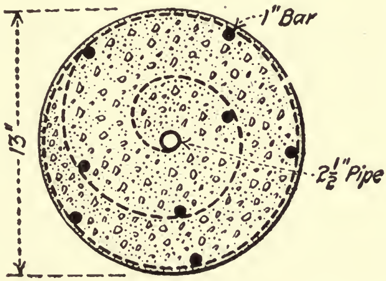


Fig. 74.—The Chenoweth Concrete Pile.

is always used, and it is on some detail of this cap that the patent for the pile is usually based. In general, the cap will consist of a cushion of confined sand, rope, or rubber hose, upon which rests a false pile. This false pile receives the shock of the hammer, the shock being distributed, by the sand, uniformly over the head of the pile. Piles of this type are frequently driven by means of a water jet, and this is advisable for all but short piles. It is also advisable to fit the pile with a metal point so as to facilitate penetration.

The principal cast-and-driven piles are the Hennebique, Gilbreth, Chenoweth, and Williams.

The "Hennebique" was the first cast-and-driven pile. It is either rectangular, triangular, or circular in cross-sections, reinforced and driven as above.

In the "Gilbreth" pile the cross-section is an octagon with corrugated side. The object of the corrugation is to allow an outlet for the water from the water jet, and to increase the skin friction.

The "Chenoweth" pile is round and is made without forms by a special machine. It is reinforced with a coiled sheet of wire netting and longitudinal steel rods placed near the surface, at equal distances apart. The apparatus for rolling the pile consists of a travelling platform and a roller between which the pile is formed. In operation the steel wire netting, with the longitudinal rods attached, is spread on the platform and covered with a layer of concrete. One edge of the netting is attached to the edge of the platform and the other to the winding pipe or mandrel. The mandrel is then rotated and the netting and its covering of concrete is wound or coiled up. At the same time and as fast as the netting and concrete are coiled, the platform moves under the roll and the roll itself rotates, thus pressing the pile into shape.

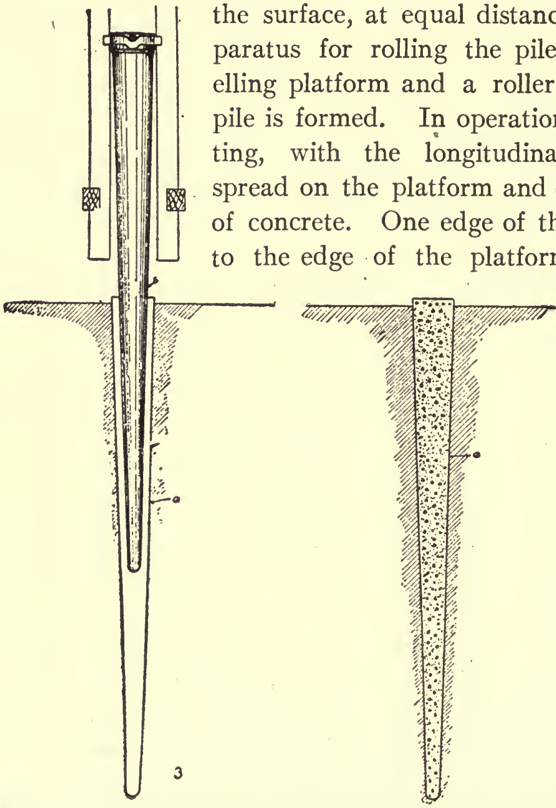


FIG. 75.—Raymond Concrete Pile Showing Partly Collapsed Core and Shell and also Finished Pile.

The "Williams" pile is reinforced by an I-beam. At the point, the web is cut away and the flanges forged to a point. The pile is further reinforced by hoops a short distance apart.

Piles Cast in Place.—Piles of this type may be divided again into two classes of which the Raymond and Simplex piles are typical.

In the "Raymond" pile, a collapsible core, the size and shape of the pile desired is enclosed in a thick, closely fitting, steel shell, and driven with a pile driver in the usual manner. After driving, the core is withdrawn, leaving the shell in the ground. This shell is then filled with concrete and should reinforcement be used, which is seldom with this pile, it is placed before the filling commences. The shell of these piles must be of sufficient strength to hold its shape after the withdrawal of the core.

The "Simplex" system consists in driving an extra heavy iron pipe into the ground with a special point to exclude the dirt; when this pipe is driven to the proper bearing, a drop-bottom bucket, filled with concrete, is lowered to the bottom of the pipe and dumped. The bucket is then removed, a heavy weight lowered into the pipe, and the pipe raised nearly to the top of the concrete, the weight being repeatedly dropped on the concrete, thus forcing it out of the end of the pipe. Another bucket of concrete is then placed in the pipe and the operation repeated until the pile is formed.

Two kinds of points are used, depending upon the character of soil through which the pipe is driven. If in soft soil, a cast-iron point closes the end of the pipe, while in stiff clay a pair of jaws are used. These jaws are attached by hinges to the bottom of the pipe, and automatically open to permit the concrete to flow through them as the pipe is raised. The pipes used are extra heavy steel, banded where necessary, and are made up in sections of varying lengths to suit the length of pile required.

Relative Advantages and Disadvantages.—The chief objection to the cast-and-driven pile is that it may possibly be injured in driving. Careful driving will, however, prevent this. The advantages of piles of this type are that the piles may be of any length, and can be thoroughly inspected during manufacture.

The chief objections to the cast-in-place pile, where a shell remains, are: First, the danger of the light shell collapsing; second, the dropping of the concrete through such a height may cause separation. The first objection is overcome by using sufficiently heavy shells and inspecting with an electric light before filling begins. As the concrete is usually a very wet mixture and deposited in very small quantities, the second objection is more fancied than real.

The disadvantage of a cast-in-place pile unprotected by a shell is the impossibility of any sort of inspection. A wet soil may carry off some of the cement, and a dry soil may absorb the water necessary for the proper setting, in either case resulting in a pile of decreased efficiency. The rough surface of a pile of this sort greatly increases its bearing capacity.

Compressed Pillar.—The compressed system, controlled by the Hennebique Co., consists of making a hole by dropping a two-ton perforator. In very soft soil, clay, cinders, and broken stone are dumped into the hole from time to time and compressed by the

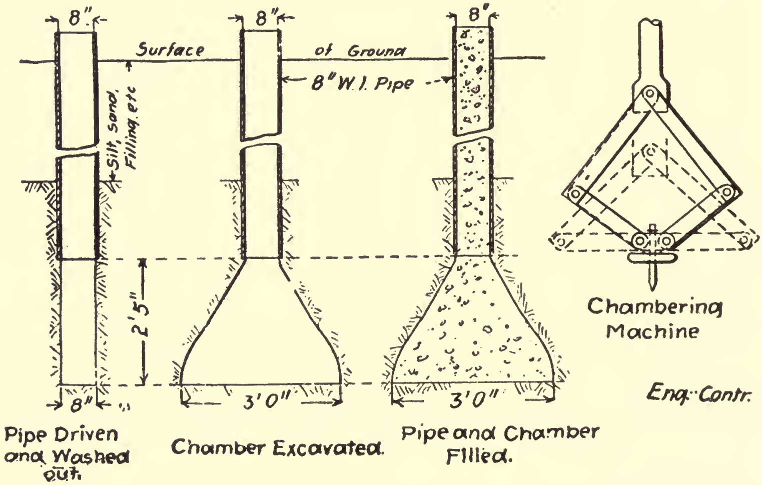


FIG. 76.—Concrete Pile with Enlarged End Showing Progressive Stages in Driving.

perforator against the sides of the hole, thus forming an almost water-tight lining. The hole is thus carried down a suitable depth, concrete is then placed in it, and is rammed with a drop tamper. This results in a pillar of large diameter, in which the concrete is forced into the surrounding soil, thus greatly increasing its bearing power. Both perforator and tamper are operated by a pile-driver.

When soft material overlies strata of firm material, the compressed system is particularly advantageous, as by its means a large pier, resting on the firm soil and extending through the soft strata, results.

Caissons.—Where all other methods of securing a satisfactory foundation fail, caissons, either open or pneumatic, carried down to bed rock or hard pan, are used.

An open caisson is a strong, water-tight, bottomless box, usually constructed of steel or timber. It is sunk by excavating the material inside of it, and if necessary by adding additional weight at its top.

Open caissons of reinforced concrete have been used in many instances, notably in the Cockle Creek Bridge, New South Wales, and in the Catskill Aqueduct, in New York State.

In the Cockle Creek Bridge, two open cylindrical reinforced concrete caissons were driven through a depth of 36 ft. of silt, sand, and gravel to hard clay. When finally seated in this clay, they were filled with concrete and used as piers for the bridge.

In the Catskill Aqueduct, three open reinforced-concrete caissons were sunk in constructing the Rondout Siphon. These caissons were sunk to rock, by excavating, under ordinary air pressure, the material within, and allowing the caissons to sink of their own weight. When the aqueduct is completed two of the caissons will serve as part of the permanent lining.

Pneumatic Caissons.—A pneumatic caisson is a strong, water-tight box, open at the bottom and closed at the top. This forms a working or air chamber. Usually the sides of the caisson are continued above the top, thus forming a second box closed at the bottom but open at the top. This is called the cofferdam. The pier is built within this cofferdam and on top of the caisson as the sinking progresses. The working chamber is supplied with compressed air which serves the double purpose of forcing out all water, and supplying the men with the necessary fresh air.

Pneumatic caissons are usually constructed of steel or timber, though a few have been made of reinforced concrete.

Reinforced concrete was recently used in the construction of the large tunnel caisson on the Jersey shore connecting the tunnels of the Hudson Co., crossing the Hudson River.

Caissons are mostly used in constructing the foundations of bridges and high buildings. When the work is under water or in water-bearing soil, the pneumatic caisson is usually used, although at times an open caisson and a bucket dredge are substituted.

Cribs.—A crib is usually a timber grillage, which instead of being built in place, is first constructed, then floated to its final resting-place and sunk in a single mass. The superstructure is then built on the crib, either in the open or in a caisson, and the function of this crib is to distribute the load carried by the superstructure over the foundation bed.

While cribs are usually constructed of timber there is no reason why reinforced concrete could not be used with economy.

CHAPTER XXII

CONCRETE RETAINING WALLS, ABUTMENTS, AND BULKHEADS

Design of Walls in General.—Methods of Failure.—Kinds of Retaining Walls.—Design of Gravity Walls.—Reinforced-Concrete Walls.—Details of Construction.—Foundations.—Abutments.—Bulkheads.—Appearance of Walls.—Tables for Design of Walls.

UNTIL the advent of concrete, retaining walls for the support of embankments and cuts as well as reservoir walls, bulkheads, etc., were constructed of rubble or ashlar masonry laid with or without mortar as the importance of the problem demanded. Concrete, especially when reinforced, has supplied a material which gives a far greater power of resistance, occupies a minimum of space and may be built at a much lower cost.

The design of concrete retaining walls follows the same general methods that are employed for ordinary masonry, the design being based upon the action of the wall when the load caused by earth, water, or other material from behind, comes upon it. Certain conditions of failure deduced from observation, experience, and mathematical reasoning are assumed to be possible and the wall so proportioned that it will be safe against any and all such possible failures. Thus it is assumed that:

Assumptions Made in Design.—A wall holding up a bank of earth, or water will be subjected to a pressure: the amount of which will depend upon the depth of the wall below the surface and upon the weight and mobility of the material pressing against it.

The question as to how much pressure is produced by banks of earth resting against walls has given rise to much discussion, and even to-day there is no general agreement among engineers as to what this pressure is. The difficulty arises from the fact that earths vary so much, their weight, consistency, and cohesive power are so constantly changing with change of the contained water, that no general pressure rule can be applied. It is thus that most computations for earth pressure assume a theoretical condition, that of perfectly dry sand, and yet this condition is but seldom found, but as it gives safe values, its assumption is justified.

When a bank of such sand has an unrestricted surface its sides will assume a natural slope of about 1 1/2 feet horizontal to 1 foot vertical. This is referred to as the "Angle of Repose," or "Angle of Friction."

If a wall is placed at the edge of a bank and the space between the back of the wall and the bank filled in, this earth or "backing" will tend to slide along the line of repose, and thus produce a pressure against the wall. The upper half of this prism is considered as producing the maximum pressure effect on the wall and its weight is employed in computing this pressure.

Effect of Earth Pressure.—Mathematical investigations have determined:

I. That the entire effect of this pressure may be considered as concentrated at a point 1/3 the height from the bottom.

II. That this pressure will tend to either slide or push the wall bodily out of place, or to rotate it about its toe and overturn, or both.

III. That since the wall is rigidly constructed and cannot yield, the effect of the external pressure is to induce strains in the material of the wall.

IV. That the material of the wall can resist safely certain specified strains per unit of area of material such as the square inch or square foot, the amount of such safe strains varying with the kind of strain and the material.

V. That the foundation material must not be subjected to unsafe strains. From these assumed conditions the dimensions of the wall are fixed so that the strain in the material will never exceed what it can safely stand. It is thus seen that the following methods of failure are possible.

Methods of Failure.—A retaining wall may fail in one or more of the following ways:

1. *By revolving about any horizontal line in the face.* This is the most frequent mode of failure, and it is due to the overturning moment, due to the earth backing being greater than the righting moment of the wall itself. A failure of this type indicates too light

a wall for the work imposed upon it or too heavy a load on the soil at the base of the wall.

A wall which shows signs of failure by this method may be strengthened by buttressing.

2. *By Sliding on any Horizontal Plane.*—This is the least frequent method of failure, and in a monolithic wall free from all horizontal joints as is the case in a wall of concrete, is practically impossible except by the sliding of the entire wall on its foundation bed. This is a rare occurrence, and when it occurs is probably the result of the wall having been founded on an unstable material, perhaps an inclined bed of moist and uncertain soil. When the foundation rests upon piles, a simple expedient is to drive piles in front of and against the edge of the foundation. When the foundation rests on rock, the resistance to sliding may be increased by leaving the surface of the bed rough, or in case the rock quarries out with smooth surfaces, the bed of the foundation may be channelled longitudinally, and the channels afterward filled with masonry. In case of the wall resting on earth, increasing the depth of the foundation below the ground level at the face of the wall, thereby increasing the area against which the face of the wall abuts, greatly increases its stability against sliding.

3. *By the Bulging of the Body of the Masonry.*—This form of failure can occur only in walls restrained at both top and bottom, as in cellar walls, some abutments, walls with land ties, etc. A failure of this type indicates too light a design.

Some of the causes of failure of retaining walls which cannot readily be taken care of in computation are: settlement of foundation, bulging due to poor drainage, formation of ice, etc. These must be looked after in the plans and construction and will be referred to later.

Types of Retaining Walls.—Concrete retaining walls are constructed in three general types, depending upon local conditions and often upon the mood of the designer. These are:

I. Gravity walls, with or without reinforcement which depend for their stability entirely upon the weight of concrete.

II. Reinforced-concrete cantilever walls of uniform thickness and wide reinforced base footing.

III. Reinforced-concrete walls having buttresses at regular intervals on the rear face of the walls.

Gravity Retaining Walls.—The gravity wall is adapted for low banks or fills as in any large work the amount of concrete necessary to give the required weight makes it very costly. In such cases the reinforced-concrete wall is always employed.

In the gravity wall the side subjected to pressure is stepped, and the exposed side slopes away from the bank to give increased stability.

It is an important principle of mechanics that the resultant of all forces acting on a wall should never pass outside of the middle third of the cross-section, and it is in order to follow this principle that the outside of the wall is stepped or sloped. By following this principle, no tensional or pulling stresses develop in the plain concrete which, by assumption, it cannot safely carry.

This principle holds true in all homogeneous masonry structures.

Design of Gravity Walls.—The design of the gravity wall is usually a rather simple matter, as it is only necessary to assume a width of base of about .4 of the height. Make it 2 feet or up, wide on the top, according to practical requirements, and then compute its weight and the pressure due to the earth backing (or water in case of a dam), and compare the effect of this pressure to produce sliding and rotation, with the power of resistance as deduced from the weight. If the latter is greater, the wall is theoretically safe.

The steps followed in the theoretical design of a gravity retaining wall are well outlined in Lewis and Kempners' Manual of Examinations, as follows:

1. The height of the wall is determined by local conditions.
2. Assume total thickness of wall.

1/5 the height at top.
2/5 the height at bottom.

3. Plot the wall to scale.
4. Compute the weight of the maximum earth prism. Also compute the thrust of same, which equals about .64 of this weight. (Earth weighs 100 lbs. per cu. ft.)
5. Compute weight of wall—concrete weighing about 140 lbs. per cu. ft. Also compute position of centre of gravity.

6. Draw to scale, the line of thrust making an angle equal to the angle of friction with the normal to the back of the wall (see Fig. 77), and passing through the centre of pressure, which is 1/3 of the height from the bottom.

7. To same scale draw line representing weight of wall through its centre of gravity.

8. Combine these as shown. The resulting pressure line should fall within the middle third of the base to insure absence of tension in the joints.

9. Compute the overturning moment due to thrust. Also compute resisting moment of the wall. The resisting moment should exceed the overturning moment by a safe margin.

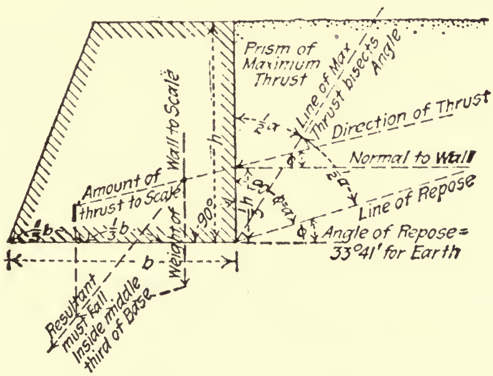


FIG. 77.—Diagram Showing Forces Acting on Gravity Retaining Wall.

10. Compute the horizontal thrust, also frictional resistance to sliding (weight × coefficient friction). The latter should be equal to or exceed 3 times the former.

11. Test security of foundation by computing unit load at the toe (total load per running foot divided by 1/2 width of base).

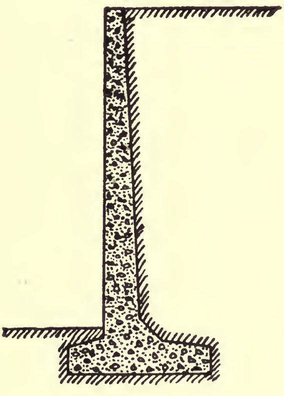
All conditions of stability must be satisfied and all unit loads should be within safe limits; if not, change dimensions and recompute.

REINFORCED-CONCRETE WALLS

Reinforced-concrete walls are designed along different lines. The external loading is the same as in the gravity wall, but the wall itself and the buttresses are considered as cantilever slabs or beams supported at the bottom only, and the stresses figured somewhat in the same way as in the beam or slab computations. The footing is also considered as an inverted cantilever beam or slab with the pressure acting upward against it, tending to rupture it at the junction and the proportions of steel and concrete must be so arranged as to prevent unsafe strains from being developed.

Reinforced-concrete walls do not depend upon the weight of the masonry alone to resist overturning, but utilize also the weight of the earth backing resting on the base of the wall.

The economy of a reinforced-concrete retaining wall is due



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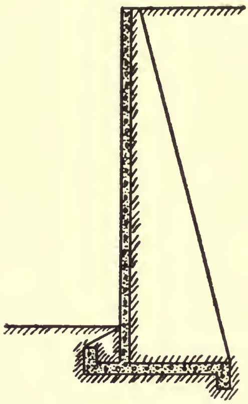

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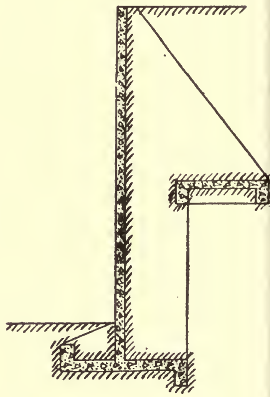

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FIG. 78.—Reinforced Concrete Retaining Wall. FIG. 79.—Reinforced Concrete Retaining Wall with Counterfort. FIG. 80.—Reinforced Concrete Retaining Wall with Counterfort and Centre Platform.

chiefly to the utilization of the downward pressure of the backing in resisting overturning.

In reinforced-concrete retaining walls as in masonry ones, provisions must be made against sliding, and the wall must have a suitable foundation.

Classes of Reinforced-Concrete Walls.—Reinforced-concrete retaining walls may be divided into three classes: 1. Walls without counterforts; 2. Walls with counterforts; 3. Walls restrained at top and bottom.

Walls without Counterforts.—This type is generally economical for walls of low or medium height. More material is used than in a wall with counterforts, but the decreased cost of form work and of placing the reinforcing and concrete will, in a wall of average height, more than offset the cost of the extra material.

These walls are simple in form, consisting of a thin reinforced vertical wall rigidly attached to a base formed by a reinforced-concrete slab. The vertical wall acts as a cantilever, with its maximum bending moment at the upper face of the base. This also is the point of maximum shear, and the vertical wall should be designed accordingly. As the bending moment and shear decrease, as the top of the wall is approached, the thickness of the wall and the amount of reinforcing may also be decreased. The base at the heel also acts as a cantilever, and must resist the weight of the earth resting upon it. The moment and shear are maximum at the rear of the vertical wall and the base should be designed accordingly. The toe of the wall also acts as a cantilever resisting the upward thrust of the earth caused by the tendency of the wall to overturn. It takes its maximum moment and shear at the face of the vertical wall.

Walls with Counterforts.—These walls consist of a broad base, a thin, vertical, curtain wall, and ribs or counterforts spaced 3 to 10 feet on centres, connecting the base with the vertical wall.

This type of wall is very economical of material, and this economy increases in proportion to the height. The cost of form work, however, is great, and except in the case of high walls, the wall without counterforts is generally more economical.

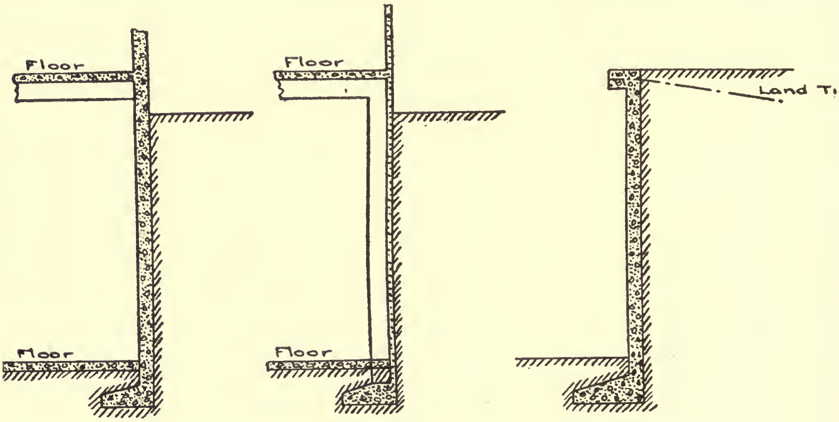
In this type of wall the bending moment produced by the earth pressure is resisted entirely by the counterforts. The vertical wall acts like a floor slab and transmits the horizontal earth pressure to the counterforts. The base at the back of the wall also acts as a floor slab, carrying the weight of the earth above it, and serving as an anchorage to the counterforts. That portion of the base in front of the vertical wall should be designed as a cantilever, fixed into the wall, and resisting the upward pressure of the earth, caused by the tendency of the wall to overturn.

The counterforts should be designed to take care of all stresses due to overturning. Sufficient horizontal and vertical reinforcing rods should be placed in the counterforts to properly tie them to the face wall and base.

In the foregoing types of walls the walls should be so proportioned that the maximum pressure at the toe does not exceed the safe bearing value of the soil.

Walls Restrained at Top and Bottom.—Cellar walls and walls with land ties are of this type. They may consist, in a cellar wall, of a slab reinforced vertically to withstand the pressure of the earth backing, and supported by the adjacent floors, or the slab may be reinforced horizontally carrying the load to vertical beams which in turn are supported by the adjacent floors.

A wall with land ties is similar with the exception that a horizontal



81 82 83

FIGS. 81, 82, 83.—Sections of Typical Types of Concrete Foundation Walls.

girder extending from tie to tie is necessary to properly deliver the load to the land tie. The resistance to sliding in a wall of this type depends on frictional resistance and the abutting power of the earth in front of the face at its toe.

Details of Construction.—In the construction of retaining walls, of both plain and reinforced concrete, the same general rules apply as to quality of material, details of form work, placing, and inspection, as are given for other structures; the difference between the plain and reinforced concrete being that in the former a much larger aggregate can be used both for the purpose of adding weight and saving cement, and it is excellent practice in the construction of large gravity walls, to employ a rubble concrete, or to embed in successive layers of concrete large blocks of stone.

The special points which must be looked for in the construction of retaining walls of any type are:

1. The preparation of a secure and satisfactory foundation below the frost line (2 to 4 feet, depending upon the climate).

2. The drainage of the foundation and removal of springs, etc., under same. Removal of poor material, stepping of rock surfaces, etc.

3. The construction of a drainage system behind and adjacent to the back of the wall, by means of gravel, channels, or other means and outlets, as weepers or pipes *through the wall* to carry off the water.

4. The compacting of the material or backing behind the wall (*except that immediately adjacent*) to reduce the pressure on same as much as possible.

5. The construction of a substantial coping along the top of the wall.

6. Expansion joints should extend through the walls either directly or by means of special connections to prevent temperature cracks. These may be 20 to 30 feet apart in plain concrete walls and 40 to 5c apart in reinforced walls, the reinforcement helping materially to avoid such cracks. Five per cent additional reinforcement will usually be sufficient for this purpose.

Foundations for Retaining Walls.—The management of the foundation of a retaining wall is an important matter, and it is generally admitted that a large majority of the failures of retaining walls are due to defects in the foundations. The nature of the soil should first be determined, and tests made to ascertain its bearing capacity, and the wall then so proportioned that no portion of the soil shall be overloaded. If necessary, the bearing capacity of the soil may be increased by: 1. deeper excavation; 2. drainage; 3. consolidating the soil; or, 4. by means of sand piles. If none of the above methods give satisfactory results, piles of either timber or reinforced concrete must be used. If the foundation is on rock it is only necessary to cut away the loose and decayed portion of the rock and to dress it to a plane as nearly perpendicular to the direction of the pressure as possible, any fissures being filled with concrete. Other methods of providing adequate foundations are described in Chapter XXI.

Drainage.—Next to faulty foundations, water behind the wall is the most frequent source of failure of retaining walls. The water not only adds to the weight of the backing material, but also softens the material and causes it to flow more readily, thus greatly increasing its lateral thrust. To guard against the possibility of the backing becoming saturated with water, holes, called weep holes, are left through the wall. The holes should be spaced generally from 1 to 3 sq. yds. of face of wall. When the backing is clean sand the weep holes will allow the water to escape; but if the backing is retentive of water, blind drains should be placed in back of the wall and lead the water to the weep holes.

Land Ties.—Retaining walls may have their stability increased by being anchored to a suitable anchorage embedded in a firm strata of earth a distance behind the wall. The amount of load taken by these rods will depend on their position in the face of the wall. If they are fastened to the wall at the top, they will take one-third of the total earth pressure. If they are fastened in the wall at one-third the height from the top, they will take one-half the total pressure.

Relieving Arches.—In extreme cases the pressure of the earth may be sustained by relieving arches. These consist of one or more rows of arches having their axes at right angles to the face of the bank of earth. Their front ends may not be closed, which then prevents the appearance of a retaining wall, although the length of the archway is such as to prevent the earth from abutting against the wall.

Concrete Abutments.—An abutment has two offices to perform: 1. to support one end of a bridge; 2. to act as a retaining wall.

There are four forms of abutments in more or less general use:

1. A straight abutment—a plain wall with or without wings.

2. Wing abutment—wing walls make an angle with the face of the abutment (usually about 30 degrees).

3. U-abutment—when the ring makes an angle of 90 degrees with the face of the abutment.

4. T-abutment—when the wings are moved to the centre of the abutment and merged into one stem.

The dimensions of an abutment are to be determined as for a retaining wall. These dimensions must be such that the abutment can safely carry the superimposed load.

The form of abutment adopted in any case will depend on the locality. If the shore is flat, and not liable to be cut away by the current, a straight abutment will be sufficient and most economical. However, this form is seldom used owing to the danger of the water flowing along immediately behind the wall.

When there is a contraction of the waterway at the bridge site, a wing abutment may be adopted, since the deflecting wing walls, above and below, slightly increase the amount of water that can pass.

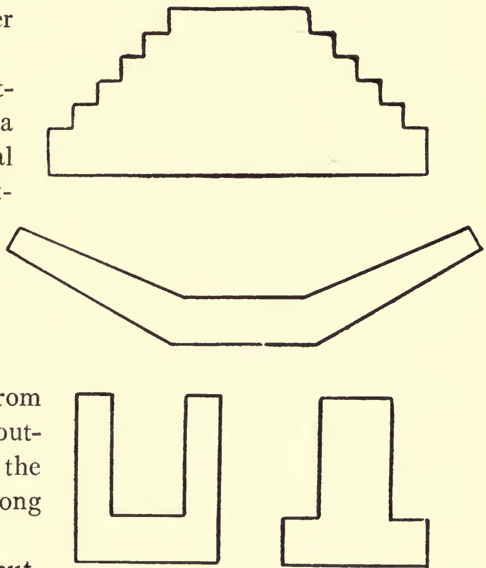


Fig. 84.—Forms of Concrete Abutments.

The use of U- and T-abutments seems to be mainly a matter of choice. To equal amounts of masonry wing abutments give better protection to the embankment than either U- or T-abutments. The latter are more stable, as the centre of gravity of the masonry is farther back from the line of the face of the abutment, about which line the abutment will turn or along which it will crash.

Reinforced - Concrete Abutments. — When reinforced concrete is used to replace masonry in abutments a considerable reduction in cost will result. The construction usually consists of a rectangular slab for a base, whose width will depend on the load to be distributed. Counterforts transmit the load from the bridge seat to the base. A face wall heavy enough to resist the earth pressure is firmly anchored to the counterforts. The face wall may continue beyond the bridge seat so as to form wing walls, which in reality are nothing more or less than retaining walls. The bridge seat consists of a heavy reinforced-concrete slab supported by the counterforts. A parapet wall at the back and ends of the bridge seat forms the mud wall. The construction and design of the reinforced-concrete abutments closely resemble the construction and design of a reinforced-concrete retaining wall, with the exception of the bridge seat and supporting counterforts. It is desirable, if possible, to place the main buttresses directly under the girders or trusses, thereby eliminating bending in the slab forming the bridge seat.

Bulkheads.—Bulkhead walls are essentially retaining walls having a large portion of their depth under water. This makes the calculation of their dimensions much more complicated than the ordinary wall, and the computations are still further complicated by the varying densities of the materials adjacent to the wall.

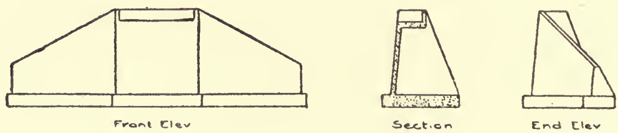


FIG. 85.—Reinforced Concrete Abutment.

In Fig. 86 is shown a typical section of a bulkhead wall extensively employed in New York City.

The forces acting for stability are:

1. The weight of the submerged portion of the wall.
2. The weight of the exposed portion of the wall.
3. The vertical pressure of the water.

The forces acting against stability are:

1. The horizontal pressure of the water.
2. The pressure of the earth filling.
3. The live load on the wall.

The amount and position of the resultant pressure of all these opposing forces must be found in order to properly proportion the wall.

The type of bulkhead wall depends upon the character of the foundation.

On rock foundations the area is dredged and the rock cleaned and stepped off when too smooth. Concrete is deposited in accordance with methods outlined in Chapter VII. Divers then smooth off the surface with mortar to receive the concrete blocks. These blocks weight about 70 tons, being 17 × 6 × 12 feet.

Upon these heavy foundation blocks, granite with concrete backing is laid, and the riprap deposited as filling.

The Hennebique Construction Company and several others have patented methods of building bulkhead walls of reinforced concrete by constructing portions on shore, floating them to place and sinking by depositing concrete in prepared chambers. While the method has been employed in Europe, it has as yet been little tried in this country.

Appearance of Retaining Walls.—While the object of the retaining walls mainly is utility, pleasing and æsthetic appearance may

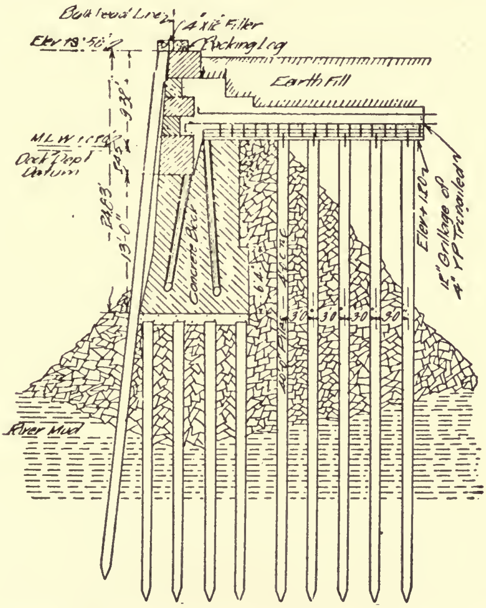


FIG. 86.—Concrete Blocks in New York City Bulkheads.

be obtained at but slight additional cost, and often at no additional cost whatever. The maintenance of a pleasing surface once obtained depends upon the construction and materials in and about the walls. We frequently see long stretches of carefully shaped and built walls disfigured by rust and smoke stains, efflorescence, checks, and cracks, and other disagreeable causes. In most cases these may be avoided by the use of a rough instead of smooth surface finish, and the avoidance of ironwork above the wall, the rust from which, carried down by water, is the cause of the rust stains. Efflorescence may largely be avoided by adding a small percentage of water-repellant compound to the cement in the concrete placed against the exposed surface forms. This will render the surface water-repellant and prevent absorption during rainstorms, which bring out the stain.

The prevention of percolation of water through walls and arches is frequently desirable and is readily effected by enveloping the structure in a 2 or more ply bituminous shield, using the membrane method as described in the chapter on waterproofing.

With this on the earth side, and the surface, water-repellant, the wall will maintain its fresh appearance if iron work above it is avoided, or proper drainage from same provided, and if a crack-free surface has been obtained.

The disfigurement by smoke and locomotive gases can be avoided only in one way: by giving the face of the wall a dark color during construction so that such staining will not be noticeable. Considering the large amount of money spent by the railroads to obtain pleasing effects in concrete work, it seems wrong to construct surfaces which particularly invite such disfigurement from the very start.

TABLE XXII.—Earth Pressures.*

Angle of Repose = θ = 33 Degrees.

Depth. in ft.	Total Inclined Press.	Total Hor. Press. per lin. ft.	Hor. Press. per Square Foot.	Depth. in ft.	Total Inclined Press.	Total Hor. Press. per lin. ft.	Hor. Press. per Square Foot.
5	335	280	112	23	7080	5935	516
6	480	405	135	24	7710	6460	538
7	655	550	157	25	8365	7015	561
8	855	720	180	26	9045	7585	583
9	1085	910	202	27	9755	8180	606
10	1340	1120	224	28	10490	8800	628
11	1620	1355	246	29	11255	9435	650
12	1930	1615	269	30	12040	10100	673
13	2260	1895	291	31	12860	10780	696
14	2625	2200	314	32	13700	11490	718
15	3010	2525	337	33	14570	12220	741
16	3425	2870	359	34	15455	12960	763
17	3865	3245	381	35	16390	13745	785
18	4335	3635	404	36	17340	14540	808
19	4830	4050	426	37	18315	15360	830
20	5350	4490	449	38	19320	16200	853
21	5900	4950	471	39	20350	17065	875
22	6475	5430	493	40	21410	17950	896

Earth Level.

Total Inclined Pressure $= \dfrac{\cos\theta\, eh^2}{2\,(1 + \sin\theta\,\sqrt{2})^2} = .1338\, eh^2$ for $\theta = 33^\circ$

Total Hor. Pressure = $11.22\, h^2$ acting at depth = $2/3\ h$.

Note.—e = 100 lbs. per cu. ft.; h = depth in feet.

TABLE XXIII.

Thicknesses of Walls and Quantities of Materials for Different Heights of Basements.

Proportions: 1 Part Portland Cement to 2½ Parts of Sand to 5 Parts of Gravel or Stone.

Height of Basement.	Depth of Foundation Below Ground Level.	Thickness of Wall at Bottom.	Thickness of Wall at Top.	Cement per 10 Feet of Length of Wall.	Sand per 10 Feet of Length of Wall.	Gravel or Stone per 10 Feet of Length of Wall.
Feet.	Feet.	Inches.	Inches.	Bags.	Cubic Feet.	Cubic Feet.
6	4	6	6	6	14½	29
8	6	10	8	12	29	58
10	8	15	10	24	57	114

* Trussed Steel Concrete Co.

TABLE XXIV.—DIMENSIONS OF GRAVITY RETAINING WALLS AND QUANTITY OF MATERIALS FOR DIFFERENT HEIGHTS OF WALLS.*

Proportions: 1 Part Portland Cement to 2½ Parts Sand to 5 Parts Gravel or Stone.

Height of Wall Above Ground.	Total Height of Wall.	Thickness at Base.		Thickness at Ground Level.		Thickness at Top.	Amount of Materials per One Foot Length of Wall.		
							Cement.	Sand.	Gravel or Stone.
Feet.	Feet.	Ft.	In.	Ft.	In.	Inches.	Bags.	Cu. Ft.	Cu. Ft.
2	6	2	2	1	6	10	1¾	4½	9
3	7	2	5	1	7½	10	2½	5½	11
4	8	2	9	1	11	12	3	7	14
5	9	3	2	2	1	12	3½	9	18
6	10	3	6	2	4½	15	4¾	11½	23
7	11	3	10	2	8	18	6	14	28
8	12	4	2	2	10	18	7	16½	33

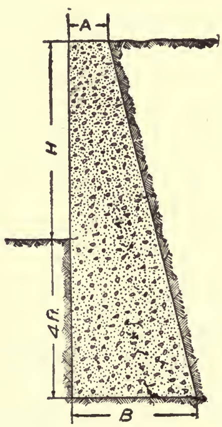


FIG. 87.—Section of Gravity Retaining Wall.

Note.—A large single load of sand or gravel is about 20 cu. ft.
A large double load of sand or gravel is about 40 cu. ft.

* From "Concrete Construction about the Home and on the Farm," published by the Atlas Portland Cement Co.

CHAPTER XXIII

CONCRETE ARCHES AND ARCHED BRIDGES

Definitions.—Parts of an Arch.—Methods of Failure.—Design of an Arch.—Abutments and Piers.—Reinforced-Concrete Arches.—Arch Bridges.—Arch Centres.—Concreting the Arch.

THE value of the arch as a structure of great beauty and economy has been known for many thousands of years, and while many elaborate arches have been constructed of the finest stones, it has remained for the present generation to see arches of masonry of such light sections and such beautiful lines as to challenge the admiration of observers. This combination of beauty, lightness, and consequent economy has been rendered possible only by combining in the arch the resisting power of steel in tension and of concrete in compression, as described in this chapter.

DEFINITIONS—PARTS OF AN ARCH

Soffit.—The inner or concave surface of the arch.

Intrados.—The line of intersection between the soffit and a vertical plane normal to the axis of the arch.

Extrados.—The line of intersection between the outer surface of the arch and a vertical plane normal to the axis of the arch.

Crown.—The highest point of the arch.

Skewback.—The inclined surface on which the end of the arch rests.

Abutment.—A skewback and the masonry which supports it.

Springing Line.—The inner edge of the skewback.

Haunch.—That part of the arch between the crown and the skewback.

Spandrel.—The space between the extrados and the roadway.

Spandrel Filling.—Material placed on top of arch between spandrel walls. It may be either earth or masonry, or a combination of both, or a system of relieving arches which carry the roadway.

Span.—The perpendicular distance between springing lines.

Rise.—The vertical distance between the highest of the intrados and the plane of the springing line.

Voussoirs.—The wedge-shaped stones of which the arch is composed—also called arch stones.

Keystone.—The centre or highest voussoir or arch stone.

Springer.—The lowest voussoir or arch stone.

Kind of Arches.—*Circular Arch.*—One in which the intrados is an arc of a circle.

Semi-circular or Full-centred Arch.—One whose intrados is a semi-circle.

Segmental Arch.—One whose intrados is an arc of a circle but less than a semi-circle.

Elliptical Arch.—One whose intrados is part of an ellipse.

Basket Handle Arch.—One whose intrados resembles a semi-ellipse, but which is composed of arcs of circles tangent to each other.

Pointed Arch.—One in which the intrados consists of two arcs of equal circles intersecting over the middle of the span.

Catenarian Arch.—One whose intrados is a catenary.

Right Arch.—Any arch terminated by two planes normal to the axis of the arch.

Skew Arch.—Any arch terminated by two planes that are not normal to the axis of the arch.

Groined and Cloistered Arches.—Those formed by the intersection of two or more arches, each having the same rise, and with axes in the same planes.

In concrete, only right arches need be considered, as any skew arch may be regarded as composed of a number of infinitely short right arches. This treatment for masonry skew arches is also quite common in this country, the arch being made of a number of short right arches or ribs, in contact with each other, but with each successive rib off centre slightly from the preceding one.

Line of Resistance.—At any joint in an arch the forces acting may be replaced by a single force, so situated as to be in every way the equivalent of the distributed forces it replaces. The line connecting the points of application of these forces is the line of resistance of the arch.

Methods of Failure.—An archway may fail in any of the four following ways:

1. *By Crushing.*—An arch will fail by crushing if the pressure on any part is greater than the crushing strength of the material used. This may be caused by too light an arch being designed or by the line of resistance passing too far from the centre line of the archway.

2. *By Sliding of One Voussoir on Another.*—An arch will fail by this method when the line of resistance makes, with the normal at any joint, an angle greater than the angle of friction for the joint. This type of failure is unlikely in a concrete arch, as, owing to its homogeneous construction, the angle of friction is very large.

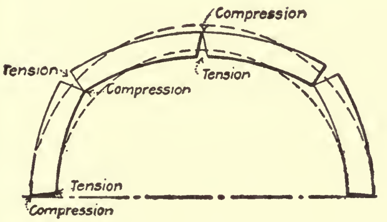


FIG. 88.—Failure of Arch by Flattening of the Crown.

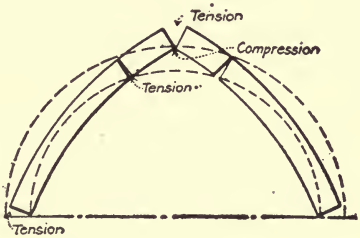


FIG. 89.—Failure of Arch by Flattening of the Haunches.

3. *By Rotation About the Edge of Some Joint.*—If the arch were incompressible, failure of this type could occur only when the line of resistance touched the intrados at two points and the extrados at one higher intermediate point, or vice versa. In a compressible arch, and all masonry arches are compressible, failure by crushing would probably occur before the conditions necessary for failure by rotation could be realized.

4. *Because of Unsatisfactory Foundations.*—More arches fail because of unsatisfactory foundations than for any other reason. Failure of this type is due either to unequal settlement, rotation, or sliding of the abutments.

Design of an Arch.—There are several theories for the design of an arch, each of which is complex and at best only an approximation. In practically all theories the stability of the arch depends on the position of the line of resistance. The position of the line of resistance is influenced greatly by the external forces acting on the arch. These external forces may be divided into three parts: 1. The moving or live load; 2. The permanent or dead load, which includes the weight of the spandrel filling and the weight of the arch itself; 3. The pressure or thrust of the spandrel filling. This pressure is more or less indeterminate. In the case of the spandrel filling being earth, it may take any value between the pressure of earth due to its own weight only, and the abutting power of the earth.

In the case of the spandrel filling being masonry, the value of the pressure may vary between the limits of zero and the working resistance to compression of either the backing or ring stones.

In the design of an arch, it is customary to limit the position of the line of resistance to the middle third of the arch ring, in which case there could be no tension in the ring, and therefore no tendency for the joint to open.

It does not follow, however, that the joint will necessarily begin to open if the line of resistance fall outside the middle third of the arch ring, or that the stability of the arch is necessarily endangered. If the greatest intensity of stress does not exceed the ultimate resistance to compression of the material, there can be no opening, except that due to the elasticity of the material, which is not considered.

Abutments and Piers.—As before stated, most arch failures are caused by the failure of the abutment due to unsatisfactory foundations. Such failure may occur in either of three ways: 1. By overturning of the abutment; 2. By sliding of the abutment; 3. By settling of the abutment.

1. Failure by overturning is usually caused by the pressure at the base of the abutment exceeding the bearing capacity of the soil. A failure of this type cannot occur when the line of resistance falls at the centre of the base, as, in order that rotation shall take place, the pressure on the soil at one side of the abutment must be larger than at the other.

2. Failure by sliding of the abutment is caused by the thrust of the arch being greater than the sum of the friction between the abutment and the soil on which it rests, and the pressure of the earth behind the abutment. In an extreme case where the abutment is very high, the pressure of the earth behind the abutment may be greater than the thrust of the arch plus friction at the base

of the abutment, in which case the abutment would fail by sliding forward. Hence, for a large arch under a light surcharge, the abutment should be proportioned to resist the thrust of the arch; but for small arches with a heavy surcharge, the abutment should be proportioned as a retaining wall.

3. Failure by settlement of the abutment implies a load on the foundation greater than its bearing capacity. This load on the foundation will be practically uniform as otherwise failure would occur by the overturning of the abutment.

As a safeguard against failure in a masonry arch, it is necessary (1) to limit the position of the line of resistance to the middle third of the arch ring, (2) not to permit the unit stress to exceed in intensity the safe crushing strength of the material employed; and (3) not to allow the pressure on the soil to exceed its safe bearing value.

REINFORCED-CONCRETE ARCHES

While concrete is a more economical material for arches than cut stone and is now replacing masonry to a great extent, a still greater economy may be realized by the use of reinforcement.

Design.—The method of designing an arch of reinforced concrete is practically the same as that employed in the design of a plain structure. The position of the line of resistance need not, however, be so rigidly fixed as in the plain arch; also the intensity of stress may exceed the crushing strength of the concrete, as by introducing sufficient steel, a resistance to crushing equal to this higher intensity may be easily obtained.

In any arch, should the line of resistance fall outside the middle third of the arch ring, tension is developed at one end of the joint and an increased compression at the other end. In a plain concrete arch the tension would tend to open cracks in the arch, as previously described. In a reinforced arch, this tension would be taken by the reinforcement placed there for that purpose, so that the opening of cracks would be impossible.

General Types of Reinforced-Concrete Arch Bridges.—There are two types of reinforced-concrete arch bridges. The first type, and the one most generally used in this country, consists of an arched slab, the full width of the bridge, extending from abutment to abutment. This arched slab supports the spandrel filling, or the system of relieving arches, which in turn carries the roadway. This type of arch is similar in all respects to the masonry arch, except that owing to the introduction of the steel reinforcement, higher unit stresses may be permitted, thus making a longer span possible.

The second type might well be called an arched-rib bridge. This type has been but little used in this country, but has been extensively employed abroad, particularly in France. A bridge of this type consists of a series of heavily reinforced arched ribs. The ribs support a series of columns, which in turn support the beams and slabs that go to form the roadway. This type of bridge is considerably lighter than the arched-slab type and is therefore more economical of material. The cost of form work, however, is higher.

A modification of the arched-slab type of bridge is the Suten Arch. The difference lies in the horizontal thrust being taken up by ties between the abutments, underneath the bed of the stream which are embedded in concrete. The usual heavy abutments, where the foundation is not of rock, are thus dispensed with. This system of tying the abutments may also be used in the arched-rib type of bridge.

Arches of the above types may be built either as continuous from abutment to abutment, or as two or three hinged arches. Either style of construction, if properly constructed, will give entire satisfaction.

The advantages of a reinforced-concrete arch may be summarized as follows:

(1) Such a structure is more economical than a masonry arch; (2) the cost of maintenance is less than that required for a steel bridge, and (3) Its life is longer than that of a metal structure. (4) Its light weight sometimes makes it possible to construct a reinforced-concrete arch where a masonry arch would be practically impossible. (5) The materials necessary are always easily obtainable, and usually in the vicinity of the work.

Another advantage of reinforced-concrete arches is their stiffness under shocks, and the small deflection under heavy loads. This has been shown repeatedly in actual practice and in special tests.

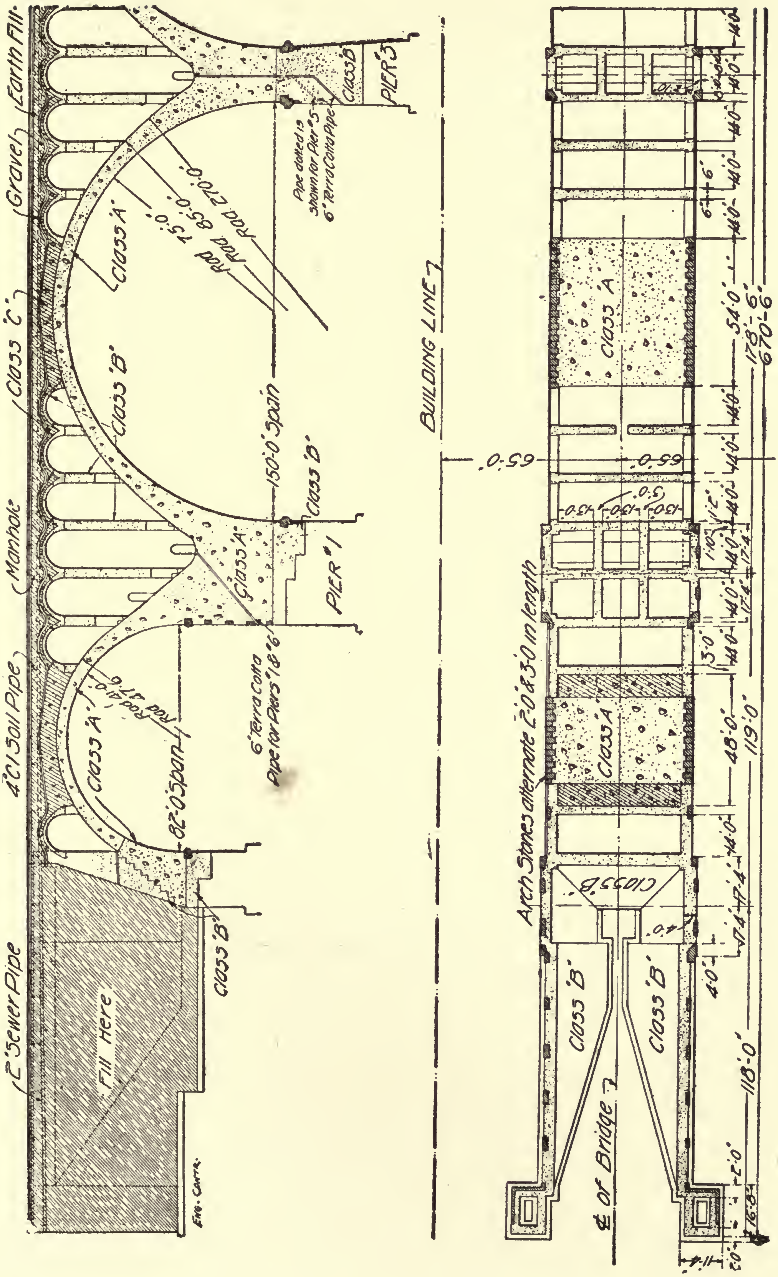


FIG. 90.—Sections Showing Construction of Connecticut Ave. Bridge, Washington, D.C.

Perhaps the most thorough tests in this line were those carried on at the bridge at Chatellnault, Vienne, France. This bridge is 443 ft. long and composed of three arches whose spans are 135, 164, and 135 ft., respectively. On the removal of the forms this bridge was subjected to the following test.

1. Each day the spans were loaded, first over their total length, then on each half, then in the middle, with sand at the rate of 165 lbs. per sq. ft., on the roadway and 123 lbs. per sq. ft. on the sidewalk. The maximum deflections under these loads were, end spans 1/4 inch or 1/7300 of the span, centre arch 13/32 inch or 1/5000 of the span.

2. One 16-ton steam roller, two 16-ton two-axled carts, six 8-ton one-axled carts, total weight, including horses, 100 tons, passed at once over the bridge, the sidewalk at the same time carrying a load of 80 lbs. per sq. ft.

3. 250 soldiers (infantry) crossed the bridge, first in regular marching step, second in double time.

The maximum deflection under these tests did not exceed 1/9000 of the span, and all vibration ceased almost immediately on the removal of the load.

Arch Centres.—A centre is a temporary structure for supporting an arch while in process of construction. It is usually made of a number of circular ribs spaced a few feet apart, and lying in a plane perpendicular to the axis of the arch. These ribs are covered with narrow planks (lagging), running parallel to the axis of the arch, upon which the arch rests while in course of construction. In concrete arches, except in those that are very flat, provision for maintaining the extradosal line of the arch must also be made.

All centres should be made as strong and as rigid as possible, as any deformation of the centre due to insufficient strength or improper bracing will cause a corresponding change in the intrados of the arch, and consequently in the line of resistance, and may endanger the whole structure.

Arch centring in general may be divided into two classes. In the first class the ribs are supported by struts braced together so as to form transverse bents. These bents are spaced at convenient distances along the axis of the arch and braced longitudinally. Where the subsoil is sufficiently firm, the struts may rest on mud sills, but in poorer soil temporary masonry or pile foundations are frequently used.

In the second form trusses are employed. These trusses may carry the lagging directly, in which case they must conform to the curve of the intrados of the arch, or they may support short braces which in turn support the ribs. Where trusses are used they should be cambered slightly so that after deflection the arch may be of the desired curvature.

The ribs are usually made of planks spiked together so as to break joints, and cut to a curve parallel to the intrados of the arch, but a sufficient distance below it so that the lagging, when applied,

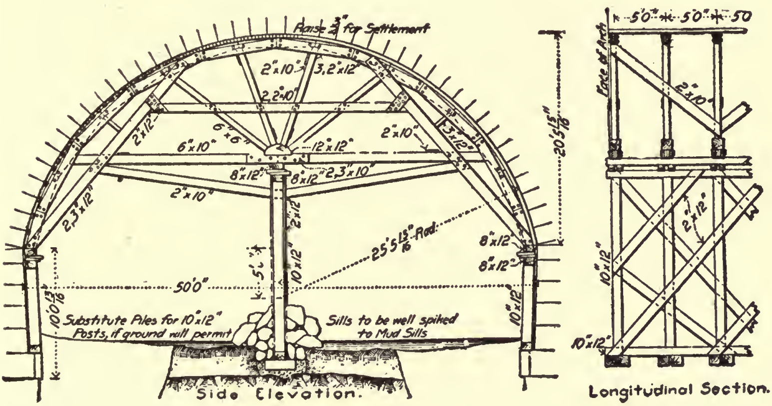


FIG. 91.—Centre for 50 ft. Arch Span (supported).

shall coincide with the intrados of the arch. Sometimes the ribs are steel shapes bent to the desired curvature.

In order that the centres may be struck, or lowered, uniformly and without shock, either sand boxes or wedges are used under all of the supports.

The wedges usually consist of a pair of folding wedges, preferably of hard wood, having a slight taper. This taper should vary with the span of the arch, the longer the span the less the taper. To lower the centres equally the wedges should be driven back uniformly. To facilitate this, compound wedges are sometimes used. By driving the wedge all work resting on the wedge will be lowered uniformly.

Sand boxes usually consist of a steel cylinder in which sand is confined. A wooden plunger rests on the sand, and on these wooden plungers is carried the centring of the arch. Near the bottom of the cylinder is a plug which may be withdrawn and replaced at pleasure, by means of which the outflow of the sand is regulated. As the sand is allowed to escape, the centres will lower and the amount of this lowering can be easily controlled by the amount of sand allowed to escape. In using sand boxes particular care should be exercised first to secure a proper sand, and second to exclude all

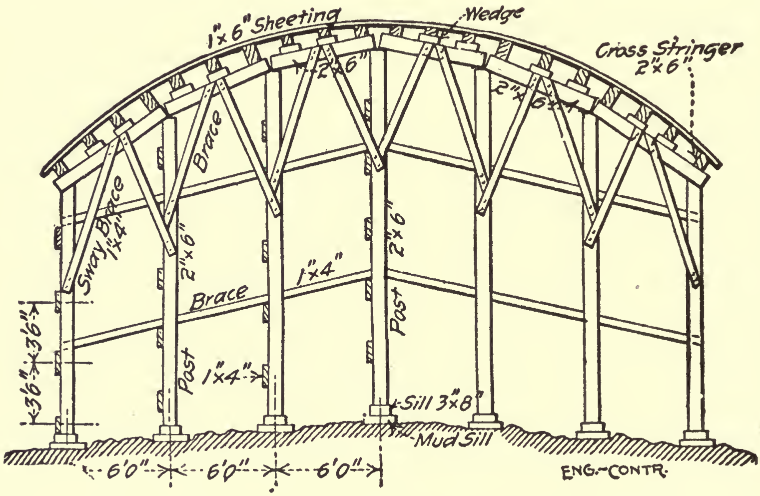


FIG. 92.—End View of Centre for Short Elliptical Arch Spans.

foreign material from the boxes, which must also be properly sealed. Where any of these precautions are lacking trouble is likely to be experienced either through the sand flowing prematurely, or its failure to flow at the proper time.

The type of centres to be used in any case will depend entirely upon local conditions. Where it is desirable to obstruct the opening as little as possible, the trussed form of centring would probably be best adapted.

In other cases where the restriction of the opening is of little or no importance, bents would probably be the most economical and satisfactory.

Concreting the Arch.—For convenience in concreting, an arch is frequently divided into a number of strips, which are practically arches in themselves. In all cases the concreting should be carried up from the springing line toward the crown, uniformly on each side of the arch. While this concreting is in progress the action of the centres should be carefully observed. Generally as the load on the haunch increases, the crown will tend to rise. If this tendency becomes excessive, it may be overcome by loading the crown with any material that is convenient, or by placing the concrete for that

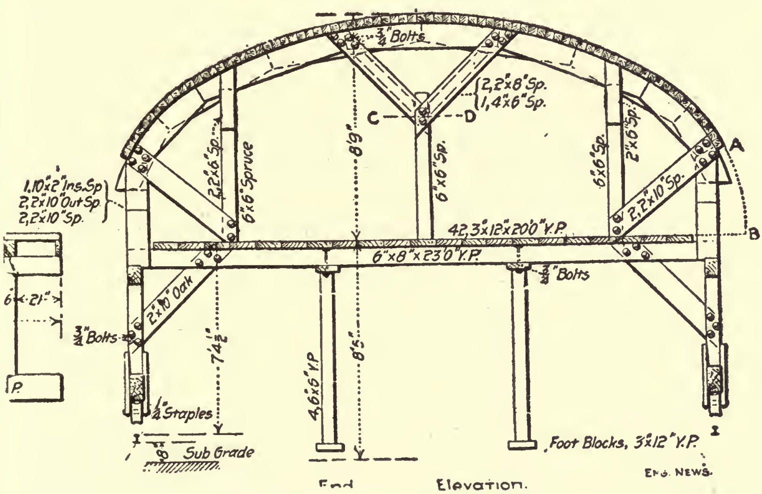


FIG. 93.—Travelling Form for Roof Arch, New York Subway Tunnels.

portion of the arch before proceeding further with the haunches. It is well, if this method of placing the concrete is used, to so divide the arch that a complete ring may be placed without intermission.

Another method is to divide the arch in strips extending the full width of the arch. The strips are first placed near the springing line, then, to overcome the tendency of the crown to rise, the strip at the crown is placed and so on until the arch is completed.

Backfilling.—Backfilling is usually begun after the arch has hardened but before the centres are struck. The reason for this is obvious. If the filling were placed after the removal of the centres, it would be necessary to place the filling uniformly over the arch, as filling a large weight on one side while the other is unloaded might so seriously deform an arch as to endanger its safety.

On the other hand, when parapet wall and railing are built before the centres are removed, the settlement of the arch may cause these to crack badly, and while this would in no way endanger the safety of the arch, still it is unsightly and therefore to be avoided. It would therefore appear that in some cases, particularly, where, instead of earth backfill, a system of relieving arches, etc., are used, that when possible the centres should be removed and the arch allowed to settle in place before that portion of the work above the arches is begun.

A properly designed and executed concrete or reinforced arch, is economical, permanent, strong, rigid, and last but not least, can easily be made a thing of beauty. Various concrete arch bridges have been built where the effect is as pleasing as the best stone arches, and at a considerable saving in cost. Also the introduction of reinforced concrete permits of a light, graceful arch being built which is not attainable in stone masonry.

CHAPTER XXIV

CONCRETE BEAM AND GIRDER BRIDGES

Advantages of Concrete Bridges.—Kinds of Girder Bridges.—Reinforced-Concrete Trusses.—Viaducts. — Concrete Floors. — Abutments.—Centring.—Depositing Concrete.—Surface Finish.

Advantages of Concrete in Bridge Work.—The use of concrete in bridges was, until quite recently, limited to the arch. This limitation was caused by the low tensile strength of concrete, and where, for any reasons, the arch was considered undesirable, the use of steel or timber became necessary. With the introduction of reinforced concrete, however, the limitation of concrete work ceased to exist, as by the proper placing of steel reinforcement, the concrete could be relieved of all tensile stresses, and at the same time its great compressive strength called into play. We, therefore, at the present time, find not only arches of reinforced concrete, but also various types of flat bridges, and in a few cases even trusses constructed of this reliable material.

Bridges, of all engineering structures, are probably the most exposed to the action of external destructive forces, and at the same time receive the severest load treatment.

In bridges of steel or wood, constant inspection, painting, and repairing are necessary if the structure is to be kept in anything like first-class condition, and even when these are carried on, almost continually, periodic renewals will be necessary. This causes the cost of maintenance to be very high, and this cost of maintenance is a large and important factor in the final cost of the bridge.

With concrete bridges this continual painting and repairing is entirely unnecessary and the cost of maintenance is therefore very small. Also as concrete increases in strength with age, and as it is in no way affected by atmospheric conditions, a well designed and constructed concrete bridge may be said to be everlasting. A concrete bridge, therefore, when once built is built for all time, and periodic renewals are entirely obviated.

The initial cost of a concrete bridge is therefore practically its final cost. It would appear, moreover, that even should the first cost of a concrete bridge be considerably higher than the initial cost of a steel or timber structure, that in view of its extremely long life and very low cost of maintenance, a concrete bridge would be the most economical in the end.

The initial cost of a concrete bridge, while somewhat greater than that of a timber structure, is frequently lower than the first cost of a steel bridge. In localities where suitable sand, gravel, and broken stone are easily available, necessitating the transportation of only a comparatively small amount of cement, and reinforcing steel, the initial cost of a concrete bridge will be considerably less than that of a steel bridge, and will approach very closely the first cost of a timber structure.

Another advantage of concrete bridges is that the major portion of the work can be readily done by local labor, and a great portion of the material can be purchased locally. Thus a large percentage of the money spent in the construction remains in the community, and the community is therefore doubly benefited.

Traffic passing over a concrete bridge makes little or no noise. The same amount of traffic passing over a steel or timber bridge would cause a noise that would be heard for a considerable distance. This is particularly true where either steam or electric cars form part of the traffic. This elimination of all noise is particularly desirable in built-up communities, such as cities and large towns.

Concrete, before it has set, is extremely plastic, and can therefore be moulded into practically any shape or form desired. Thus in building a bridge of concrete, a very pleasing and artistic design may be executed, at but a small increase of cost, resulting in an efficient and beautiful bridge. With but few exceptions steel bridges are far from being things of beauty, and at their best, can in no way compare with concrete structures.

Classes of Concrete Bridges.—Concrete bridges may be classified as either arch bridges or flat bridges. Arch bridges of both plain and reinforced concrete have been discussed in the preceding chapter. A flat bridge is one in which the load on the structure acts vertically on the supports. A flat bridge may consist of either a straight flat slab, or of a combination of beams and slabs or of a combination of beams, girders, and slabs. All flat bridges require reinforcement.

Flat-Slab Bridges.—The simplest form of a reinforced-concrete bridge is the flat slab. This consists of a sheet of concrete of uniform thickness, supported at each end. It is designed as a slab whose span is the distance between the abutments. The main reinforcement, therefore, extends from abutment to abutment, and may be of any of the numerous forms of reinforcing bars common to reinforced concrete. Structural shapes and even old railroad rails have been used in this capacity, and have given complete satisfaction.

A secondary reinforcement perpendicular to the longitudinal bars or shapes should be placed in all bridges of this type. The function of this secondary reinforcement is to aid in the distribution of stresses due to concentration, to take temperature stresses, and to prevent the formation of cracks. Generally no special provisions for shear are necessary in flat slabs. It is customary, however, to bend a portion of the main reinforcement up to the top of the slab near the point of support. Should the bridge be continuous over two or more spans, additional reinforcement should be placed at the top of the slab, over the points of support, to take the tensile stresses caused by the negative bending-moment.

Bridges of this type will generally be found economical for spans up to 15 feet. For larger spans the thickness of the slab and, hence the dead load, becomes excessive, and some other type of bridge should be used.

Beam-and-Slab Bridges.—Beam-and-slab bridges consist of two or more reinforced-concrete beams extending from abutments to abutments and supporting a slab on which the roadway is laid. These beams are in the majority of cases entirely below the slab, but in some instances are carried up above the slab to form the side rail.

The design of a beam-and-slab bridge is essentially the same as that of a slab and beam in ordinary floor construction. The slab is supported by the beams and carries the superimposed live and dead loads. The beams are supported by the abutments and carry the slab with its attendant live load. The beams must be carefully investigated for shear and where necessary for this purpose additional reinforcement should be introduced.

Where the beams are entirely below the slab they may be considered as T-beams and designed as such. In this case the slab and floor beams should be poured at the same time so as to assure a proper bonding of the slab and beam.

Bridges of this type, on account of their low cost and light weight, are particularly adapted to light highway bridges, etc., and are economical in general for spans up to 20 feet.

Girder Bridges.—Girder bridges are usually composed of two or more large reinforced-concrete girders supporting intermediate beams, which in turn carry the slab on which the roadway is laid.

In designing a girder bridge, the slabs are designed to carry the superimposed loads to the beams. The beams are designed to

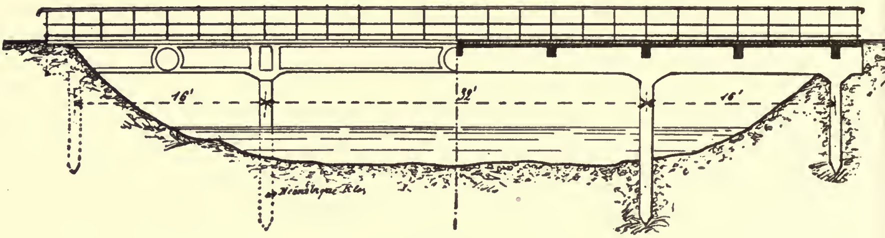


FIG. 94.—Typical Reinforced-Concrete Girder Bridge.

carry the loads to the girders, and the girders are designed to carry the loads to the abutments. Both the beams and the girders should be carefully investigated for shear and where necessary reinforcing for this purpose should be introduced. The girder should also be carefully investigated to see that sufficient compressive strength is obtained in their upper portion. Steel for temperature stresses and to prevent cracking should be placed where necessary throughout the structure.

Girder bridges have been constructed with spans as great as 100 feet. They are not, however, economical for such long spans and should be used for these only where the restriction of the waterway or poor foundations make the arch inadvisable.

In some girder bridges the girders have been designed as cantilevers at the points of supports, and carrying a simple span at the centre. In such cases the girders are deepest at the abutment, and have somewhat the appearance of an arched rib. The position of the reinforcement is, however, radically different. If some of the very flat arches had been designed thus instead of as arches, the unsightly cracks over the haunches so common to them would probably have been avoided.

Reinforced-Concrete Trusses.—A true truss of reinforced concrete was constructed by Considère in France. The compression members were of concrete reinforced by spiral hooping as in a hooped column. The tension members were of steel surrounded by concrete. This bridge was built only as a test of the strength of the hooped member and when finished was loaded until failure took place. It demonstrated, however, that bridges of this type may be built in reinforced concrete. The economy of such a bridge is doubtful, as the cost of form work must have been excessive.

Girder bridges are occasionally constructed with open webs. The girder is thus given the appearance of a truss. Beyond the saving of a little weight, this type of bridge has no advantage over a bridge with a solid girder, and as anything approaching an exact determination of the stress acting in the open girder is impossible, they should be avoided.

Concrete Floors for Steel Bridges.—In long-span highway bridges, when steel trusses are necessary, the wood planking, which until recently was the standard flooring, is now being largely replaced by reinforced-concrete slabs, supported on the steel beams. On these slabs the wearing surface of the roadway is placed. A floor of this type is more expensive in first cost than a plank floor, but it will outlast the bridge itself, while a wood floor requires renewing in from one to five years.

In steel railroad bridges, reinforced-concrete floors are now being extensively used to replace trough and open floors. These reinforced-concrete floors are practically noiseless, and may be ballasted in the same way as the rest of the roadway, thus making a uniform roadbed throughout the line.

Reinforced concrete may also be used to strengthen existing steel bridges when same have become insufficient for the present need, or so badly corroded as to be considered dangerous. In the bridge at Perigueux, France, the lattice bars of the main girders and the webs of the cross beams were so badly corroded by the gases from locomotives stopping under them that the safety of the bridge was threatened. The bridge was protected and strengthened by incasing all the old steel members in reinforced concrete, and a new reinforced-concrete floor was then built. This resulted in a new bridge, stronger and stiffer than the old one, that would not be acted upon by the gases from the locomotives. If it had been necessary, the strength of the bridge could have been still further increased by the addition of reinforcing rods parallel to and alongside of the beams and girders.

Abutments.—The abutments of a concrete bridge may be constructed in either plain or reinforced concrete. They should be designed to resist overturning due to the pressure of the earth backing, and at the same time to so distribute the load on the foundation caused by this pressure, and the load of the bridge, that in no place will the load on the soil exceed its safe bearing value. In some cases the bridge is rigidly attached to the abutments while in others it simply rests in the seat. In the first case all tendency of the bridge to expand or contract, due to temperature stresses, must be resisted by the abutments or internally by the bridge itself. In the second case the bridge slides on its seat as this expansion or shortening takes place. For long bridges the second method is preferable while for short bridges either method will give satisfactory results.

Centring.—The form work for flat reinforced-concrete bridges is essentially the same as for floor construction. Troughs are formed in the centring to receive the beams and girders when they extend below the slab, and when the girders or beams are above, the slab formwork is built up to receive them. The formwork should be as firm and unyielding as possible, so that there will be no deflection or distortion when the concrete is placed. It should also be sufficiently tight to prevent the cement and water from leaking out, thereby causing a poor porous concrete.

Depositing Concrete.—In general the concrete should be deposited as quickly as possible so as to insure a monolithic structure. Beams, girders, and slabs should, if possible, be deposited at the same time, especially where the beams have been designed as T-beams. Where the beams or girders are deep, it is sometimes inadvisable to do this, as the contraction of the beam or girder in setting may cause it to crack away from the slab. In such cases it would be well to concrete the beam or girder first, and the slab after a sufficient interval had elapsed. In this case, however, if T-action is desired, special reinforcement will be necessary to bond the beam and the slab properly together.

Finish.—In some structures, where appearance is of little importance, the concrete can be left just as it comes from the moulds, and if sufficient care has been taken in building the form work and placing the concrete, a very satisfactory finish will result. A better finish may be obtained by placing against the forms a one-inch coat-

TABLE XXV.—PRINCIPAL DIMENSIONS AND QUANTITIES OF MATERIALS FOR SLAB BRIDGES.

(From "Concrete in Highway Construction," published by Atlas Portland Cement Co.)

Clear Span in Feet.	Thickness of Slab in Inches.	Longitudinal Bars.		Abutment Walls.		Length of Side Walls. Feet.		Cu. Yds. of Concrete.		Pounds of Steel Rods.	
		Size of Square Bars. Inches.	Distance c. to c. Inches.	Thickness. Inches.	Width of Footing. Inches.	6 Ft.*	8 Ft.*	6 Ft.*	8 Ft.*	6 Ft.*	8 Ft.*
8	9	5/8	6	8	20	32.0	38.0	43	53	2715	3440
10	11	3/8	5	11	23	34.5	40.5	49	60	3195	3880
12	13	5/8	5	13	27	37.0	43.0	57	69	3420	4100
16	15	3/4	5	15	45	41.5	47.5	73	87	4375	5035

ing of cement mortar and then placing the concrete behind it. This mortar may be applied with a trowel or behind a steel plate which separates it from the concrete backing.

In the removal of forms this facing may be treated in various ways as described in Chapter XII. If the mortar is not set too hard, it may simply be brushed with a stiff wire brush and water. This will remove the outer film of cement and bring the grains of sand into prominence. If the mortar is set too hard to be acted upon by the wire brush, sand or a cement block may be used and the same effect attained. By a proper selection of the sand, various color effects may be obtained in this way.

* Distance in feet from top of footing course to bottom of slab.

If a mortar facing is not desired, the concrete itself may be rubbed, sanded, or tooled until the outer film of cement is removed and the aggregate exposed. Where proper thought has been given to the selection of the aggregate, very pleasing effects may be obtained in this manner.

If further treatment is thought advisable, the surface of the concrete may be washed with a weak solution of acid. After the acid wash it is well to again wash it with an alkaline solution to neutralize any acid that may remain in the concrete.

SECTION V

THE USES OF CONCRETE FOR SPECIAL PURPOSES

CHAPTER XXV

CONCRETE IN SEWERAGE AND DRAINAGE WORKS

Advantages of Concrete for Sewers.—Forms of Sewers.—Combined and Separate Systems.—Dimensions of Sewers.—Construction of Sewers and Conduits.—Quantity of Flow.—Culverts and Drains.—Types of Culverts.—Imperviousness of Sewers and Conduits.—Tables of Dimensions for Culverts.

Advantages of Concrete for Sewers.—In no situation perhaps are constructive materials subjected to greater destructive forces than in subsurface work, particularly where the ground is charged with corrosive chemical and electrical influences. Under such conditions, many sewers and water-carrying conduits built of iron and steel have been destroyed in the course of comparatively few years. It is therefore with reason that municipal engineers throughout the country rejoice that in concrete, both plain and reinforced, a material has been found that will not only be cheaper than brick or masonry but more enduring than steel and iron and more susceptible to use under any condition from the largest conduit to the smallest pipe.

While in Europe, factory-made cement pipe has been largely used up to 7 feet in diameter, American engineers have found it more economical up to the present time to mould all pipes and sewers exceeding 3 feet in diameter right in place. For pipes smaller than 3 feet, difficulty in securing and using adequate forms have made it advisable to manufacture them in factories specially equipped for turning them out in large quantities and standard sizes.

The economy in the manufacture of the smaller sizes arises from the fact that the specially moulded pipes have very much thinner shells, 6 inches being about the thinnest that can be moulded on the job, while the manufactured pipe runs from 1/2 to 3 1/2 inches thick. There is thus a large saving of material, but this economy disappears when sizes larger than 3 or 4 feet are reached. A well-constructed concrete pipe will give as good results as a vitrified clay pipe and be less costly than the latter.

The process of making these pipes has already been described in the chapter on concrete products.

Another advantage in the use of concrete for sewer work is the smooth surface obtainable, and smoothness of surface is very desirable to reduce the frictional resistance of the flowing sewerage.

Systems of Sewerage.—Sewers are built in circular, egg-shaped, and other forms, depending upon the relative quantity to be carried during low and high stages of flow, and upon whether the rain or storm water is to be carried in the same system as the sewerage proper. This is a very important question and is usually one of the first things to be decided upon in any extensive sewer project. When the storm water and sewage are carried in the same set of sewers, we have a "combined" system. Separate sewers for the storm water and for the sewage proper is referred to as the "separate" system.

While for a detailed discussion of the merits of each system, the reader must be referred to special works on sewerage, a few remarks on the controlling features may not be out of place.

Separate and Combined Systems.—The separate system is employed principally when the sewage must receive some purification treatment before being discharged into streams. In such cases the storm water is excluded to reduce the maintenance charge at the disposal plant. Where the sewage discharges directly into running water without preliminary treatment, the combined system is to be preferred, as the storm water acts as a cleansing agent and but little artificial flushing is required.

Forms of Sewers.—The circular sewer is built wherever conditions permit its use, as with a given external area the circular section requires less material than any other form, and is thus the most economical. Where, however, the amount of sewage fluctuates largely, the circular section offers greater frictional resistance to flow at low stages and the egg-shaped section is employed. The increased frictional resistance to flow in the circular section arises from the fact that a greater area of surface is covered for the same quantity of flow than in the case of the narrower egg-shaped section. In the latter the dimensions are so fixed that a fairly uniform rate of flow is obtained under all conditions of flow, and, as in the combined system the flow is sometimes very large, and sometimes very slight, the egg-shape is very well adapted.

Many horseshoe-shaped conduits and sewers have been constructed, this shape being usually easier to build, particularly when made of brick; but with the introduction of concrete and improvement in collapsible forms, the circular section is the predominating type. The horseshoe section is, however, employed in very large conduits for water supply where the flow is fairly uniform and the greater frictional losses and the extra material required, being counterbalanced by the greater ease of construction.

Depth of Flow.—Sewers and conduits not flowing under pressure reach their maximum capacity when flowing about 0.9 full, the flow being greater at this depth than when the whole section is filled, owing to the increased surface friction at the top and the consequent reduction in velocity.

Velocity in Sewers.—The velocity in sewers is kept within the limits of 2 1/2 to 10 feet per second and the grades so established that velocities between these limits are obtained. The lower velocity is necessary to prevent the deposit of solid matter in suspension and the higher velocity to prevent excessive wear on the material composing the surface of the conduit, as the abrasive power of water flowing at high velocities is very great. It is partly for this reason that conduits under pressure where the water moves at a high velocity are generally built of steel or iron, the further reason being that the high pressure exerted on the walls would be fatal to ordinary masonry. Reinforced concrete, however, has now come into favor even in high-pressure conduits, and many of the tunnels of this character are being designed on the new Catskill waterworks for the City of New York.

Dimensions of Sewers.—The size of the sewer or conduit is fixed by the amount of material to be carried and the grades obtainable; the smallest size consistent with the limiting velocities is usually adopted.

The size and the shape having been determined, the thickness of the top, sides, and bottom are to be fixed. There is no special method or formula for proportioning these parts as the conditions are so variable. The depth below the surface, the character of the material, the foundation, etc., must be considered. Experience has, however, fixed certain standard dimensions which may safely be employed for various sizes both in plain and reinforced-concrete

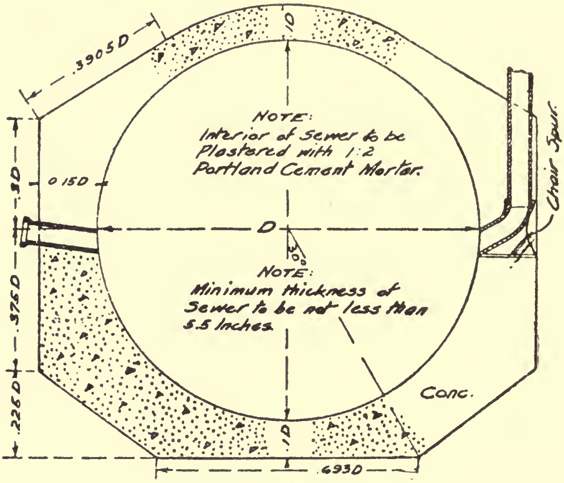


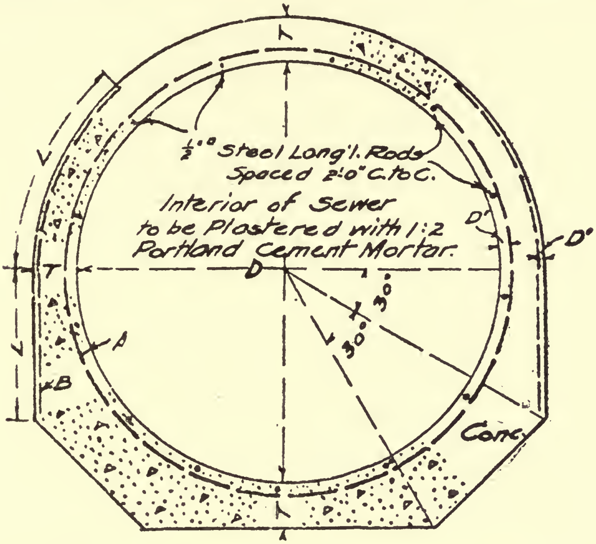
FIG. 95.—Standard Section in Plain Concrete. New York Rapid Transit System.

sewers, and these are given below. It will be noticed that these dimensions point to a very simple rule for finding the thickness at the crown of circular sewers; *i.e.*, the thickness at the crown in inches is equal to the number of feet in diameter + 1, the minimum thickness being 4 inches.

The amount of steel in reinforced-concrete sewers and conduits must be sufficient to take care of the bursting strain due to the hydrostatic pressure of the water or sewage. This quantity may be determined by the simple formula:

$$A = \frac{6\,p \times d}{f} \text{ of steel.}$$

p = Internal hydrostatic pressure in lbs. per sq. in.
d = Internal diameter in inches.
f = Allowable working stress, for steel, in lbs. per sq. in.



SECTION OF REINFORCED CONCRETE SEWERS.

SIZE		BARS A & B		D'	L	T
3'-0"	Cir.	½"ø Rods	T and C.	1"	21"	4½"
4'-0"	"	⅝" "	8" " "	1"	26"	5⅜"
5'-0"	"	¾" "	9" " "	1¼"	31"	6½"
6'-0"	"	⅞" "	11" " "	1½"	36"	7¾"
7'-0"	"	1" "	11" " "	1¾"	42"	9"
8'-0"	"	1" "	10" " "	2"	42"	9⅝"
9'-0"	"	1" "	9" " "	2"	42"	10⅞"
10'-0"	"	1" "	8" " "	2"	44"	12"
11'-0"	"	1" "	7½" " "	2"	48"	13½"
12'-0"	"	1" "	7" " "	2"	52"	14⅜"
13'-0"	"	1½" "	10" " "	2¼"	56"	15⅞"
14'-0"	"	1½" "	9" " "	2¼"	60"	16⅞"
15'-0"	"	1½" "	8½" " "	2¼"	65"	18"

FIG. 96.—Standard Sections: Reinforced Concrete Sewers. New York Rapid Transit System.

A = Area of steel required for each longitudinal foot of concrete.

Construction of Sewers.—The construction of sewers follows the general methods already described in mixing and placing concrete. The special features that accompany sewer work are:

1. The construction of the trenches to the proper depth. These should be somewhat wider than the actual width of the masonry, to allow working room, the excess being later carefully backfilled.

2. The trenches must be adequately braced so that no sliding of material will occur during the progress of the work. In shallow cuts with a firm material very little bracing is required, but in soft material heavy tongue and grooved sheet-piling is employed and interlocking steel sheet piling is now coming into extensive use for this purpose.

3. The bottom of the trench should be properly prepared; loose and poor material being removed and replaced by sand or concrete and the slope of the bottom should be made parallel to the finished slope of the sewer.

4. In case the conduit or sewer is constructed in yielding soil, special means must be taken to secure good foundations, and for this purpose piles are frequently driven and the sewer constructed on a timber platform built on these piles.

5. The excavation having been completed and the foundation prepared, the concreting begins; a mixture of 1:3:5 being suitable to the heavy portions of the work and a 1:2:4 should be employed around the reinforcement and at the crown.

6. The forms for building concrete sewers may be made of wooden lagging supported at 5- to 6-foot intervals by specially cut timbers resting on posts or sills, or one of the many forms of collapsible steel forms may be employed. These forms are especially desirable where long sections of sewers of uniform diameter are to be built, as the use and constant reuse of same results in a considerable saving in form labor.

7. In laying concrete pipe sewers having hubs, special excavations must be made under the joints of the pipes to provide room for the enlarged ends, and particular care should be taken that the pipes are properly bedded, as any unevenness in the bed may result in open joints and broken pipes.

8. After the concrete has been deposited and has hardened, the forms are removed to be used over again, and sections of the com-

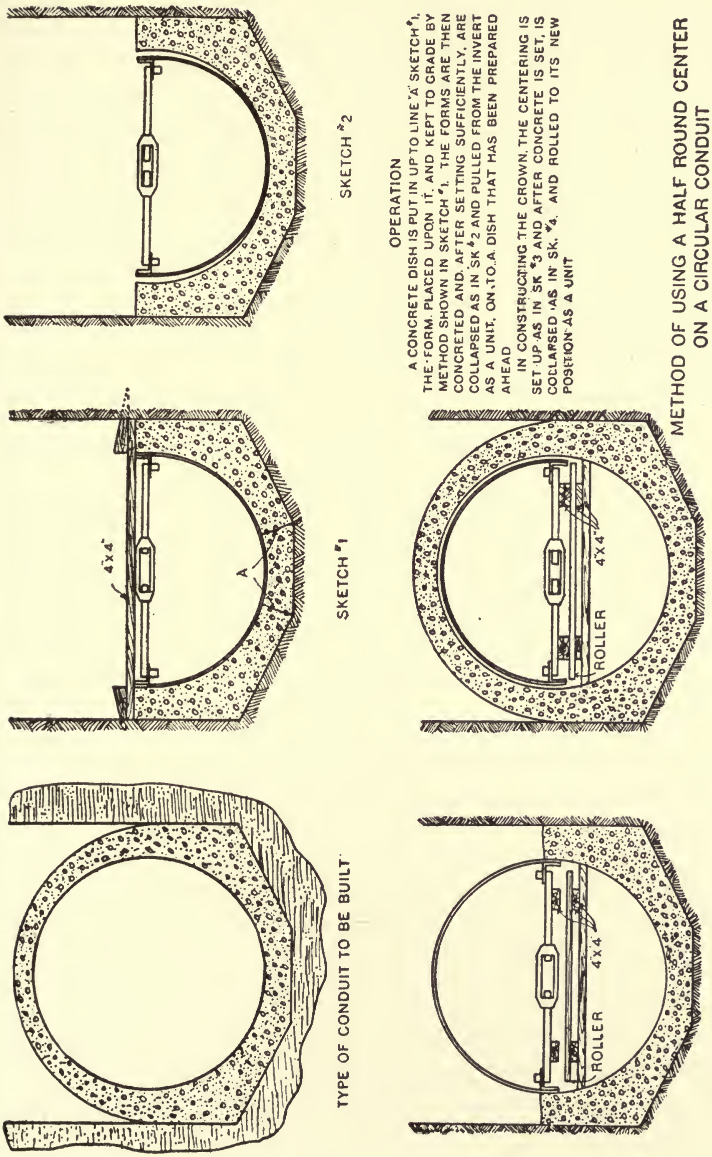


FIG. 97.—Steel Centring: Blaw System. Method of Using a Half Round Centre on a Circular Conduit.

pleted sewer are backfilled uniformly from both sides so as to eliminate eccentric strains on the roof. In placing the backfilling, care should be taken that no heavy stones are poured or rammed against the completed sewer concrete that would be likely to injure it.

Sewers and conduits are frequently constructed in tunnels where the concrete work must necessarily be done under trying conditions. The construction of tunnels is perhaps the most difficult of all engineering undertakings and the accomplishments in this field during the last twenty-five years have been marvelous in the extreme. This is particularly the case in subaqueous work where life and limb are in constant danger both from the threatening waters on the outside and the air on the inside, which is highly compressed to keep the water out.

Under the cramped and difficult conditions met with in tunnel work, the placing of the concrete is slow, and special forms of mixers and conveyors are frequently employed to accomplish it. It is, however, here that cement finds a large field of usefulness in other ways than mere concrete-placing, for after the concrete has been placed, there remain numerous crevices, and holes near the roof of the tunnel which can not be filled up in the ordinary way and here liquid concrete or grout is employed and pumped in under high pressure as described in Chapter XXXI.

Quantity of Flow in Sewers.—In the "separate" system the amount of sewage to be taken care of is equal to the water supply, as it is figured that the entire water supply sooner or later will reach the sewer. This amount in any extensive system is taken generally as 100 gallons per day per head of population tributary to the sewer. This total quantity is proportioned irregularly throughout the day, the maximum flow being possibly 10 gallons per person per hour. This is converted into its equivalent in cubic feet per second which is the unit of quantity in all calculations of flow.

The amount of water reaching the sewer from storms is a very uncertain quantity owing to the variability of the factors involved. The amount depends upon:

1. The rate or intensity of rainfall.
2. The variation in rate.
3. The length or duration of the rainfall.

4. The condition of the surface particularly as regards its power of absorption.

5. The slope of the surface.

6. The shape of the surface and its area.

7. The presence of obstructions to flow, such as vegetation.

8. The proximity to the sewer inlets.

9. The carrying capacity of the sewer.

A great many studies have been made to determine the probable amount of storm water for which the sewer should be designed, but no satisfactory rule applicable to all conditions has ever been formulated; the one most commonly employed being the formula:

$$Q = C\,y\,\sqrt[4]{S\,A^3}$$

in which

Q equals the number of cubic feet reaching the sewer per second, for which the conduit is designed.

C = a constant depending upon retentive power of surface.

3.50 = for ordinary prairie land.

5.00 = for paved, rock, or frozen surfaces.

2.00 = for wooded land.

y = rate of rainfall in inches per hour.

S = slope of receiving surface in feet per 1,000.

A = area of receiving surface in acres.

CULVERTS AND DRAINS

Culverts are employed to carry a stream or watercourse underneath an embankment constructed for highway, railroad, or other purposes. Drains are employed wherever the carrying off of surplus water is required. Siphons are employed to carry a stream of water across a hill or valley, the water in such cases flowing under pressure. In all these works, concrete, both plain and reinforced, is now extensively employed, brick work, iron, and steel being largely abandoned.

Since the purpose of culverts and drains is to carry off surplus water and thereby prevent injury to embankments or foundations, it is necessary to know approximately the maximum amount of water that may have to be taken care of during times of extreme flood.

There are several ways in which the required area of a culvert opening may be obtained.

1st. The area of the stream at narrow points along the water-course during freshet periods may be measured and the required area thus obtained.

2d. The high drift marks along the banks may be examined and the area between the bed of the stream and the high-water line determined.

3d. Culvert openings at other points along the same stream when they have been found ample, may be taken as a safe guide to proportioning the new culvert.

4th. Where none of these means for determining the area of the waterway can be employed, resort has to be made to some empirical rule or formula which has been established by comparing existing culverts with the area of land which they drain or "drainage area." Perhaps the simplest of these is Myer's formula:

$$\text{Area in square feet} = \sqrt{\text{Drainage area in acres.}}$$

Thus, for 100 acres area required is 10 sq. ft. or a 3 1/2 foot culvert.

For 900 acres, 30 sq. ft. would be required or a 5 × 6 culvert.

The carrying capacity is also, of course, affected by the grade or slope and this is usually fixed by the relative surface elevations for the entrance and exit. As steep a slope as possible should be given.

Types of Culverts.—The area of waterway having been determined, the type of culvert may be selected. There are three types in general use, depending largely on the area of waterway.

1st. The pipe culvert is available where the area of waterway does not exceed 10 sq. ft., which requires a pipe 36 inches in diameter or the maximum size of concrete pipe made. Manufactured concrete pipes below this size are economical and very satisfactory for culvert construction.

2d. Box culverts having rectangular waterways are extensively employed from the 2′ × 2′ size up to almost any size required. They are easy and cheap to build and are employed for the smaller sizes where shipment of ready-made pipe is not desired, as the box culvert can be built from materials and cements in almost any locality.

3d. The arch culvert is employed for the large openings where appearance is of more importance than the question of cost, as the construction of arches is more costly than plain rectangular work. In very large culverts, however, the arch is somewhat more economical in material for a given area of waterway.

The larger culverts, both box and arch types, may be reinforced and it is good practice and economical to do so, as it enables much lighter sections of concrete to be employed.

The concrete for culvert construction may be a 1 : 3 : 6 mix, a somewhat richer mixture, however, being employed about the reinforcement. Otherwise the construction follows the usual method

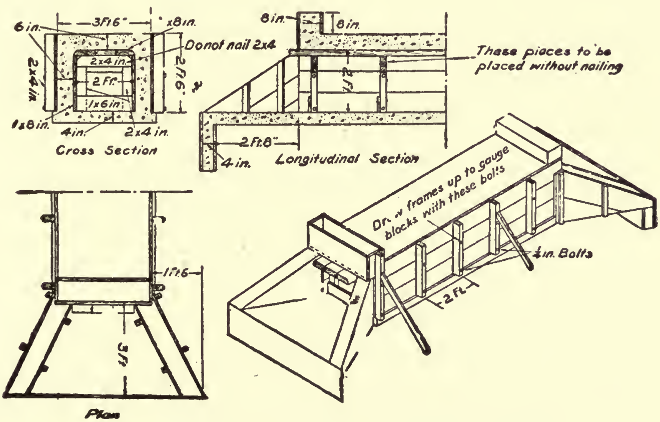


FIG. 98.—Forms for Square Concrete Culverts.

of concrete work. The particular point to be mentioned about culvert work is, the protection of the inlet to and outlet of the waterway against any scour by the flowing water. Water finding its way underneath the floor or around the ends will either undermine the culvert or erode the banks and both of these must be prevented. The method of prevention consists in a substantial stone or concrete pavement laid on the floor of the culvert to confine the water to its proper channel, and parapet walls to prevent erosion of the embankment.

The construction of culverts may become a difficult matter when a large amount of water is to be taken care of. The best method of procedure is to excavate a temporary channel or provide a temporary flume near the culvert site and divert the course of the stream through the temporary waterway. The culvert can then be constructed in the dry, and when completed, the stream diverted into the culvert, the temporary channel being removed.

Imperviousness of Sewers and Conduits.—Sewers, particularly in the separate system, should be as impervious as it is possible to make them. There are three important reasons for this, as:

1st. The necessity for excluding ground water from the sewer. The infiltration of ground water is a serious matter where the sewage must be purified before being disposed of, and records show that millions of gallons of ground water find their way into leaky

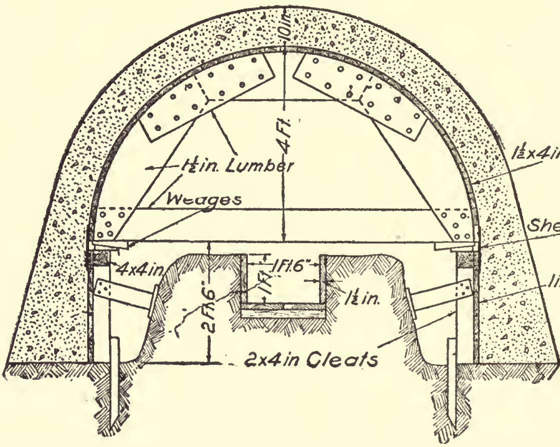


Fig. 99.—Arrangement of Forms for Arch Culverts.

and defective sewers, entailing a great burden and expense on the purification plant for which they were never designed. Furthermore, the leakage of sewage through the lining of sewers has a contaminating influence on the ground, is very unsanitary and may indirectly give rise to epidemics of disease. Another important reason for imperviousness of sewers is the protection of the concrete from possible destructive action of sewer gases which has been discussed in Chapter IV. The importance of waterproofing treatment in extensive sewer projects is beginning to be recognized and in one of the largest projects, the Bronx Valley Sewer, in New York State, the entire length has been protected by an exterior shield of 2-ply coal tar felt and pitch, following the method described in the chapter on waterproofing. A dense concrete, properly reinforced, and to which has been added a small percentage of a good waterproofing compound, or the interior surface of which has been treated to two coats of a durable and impregnating waterproof paint, will answer the purpose very well.

Water-carrying conduits likewise must be impervious, as otherwise there will be not only a large loss of water, but ground water, often polluted, may filter in and cause trouble. When expense is a secondary consideration, a coat of waterproof cement may be applied to the interior surface in accordance with the specifications for the Integral Method as given in Chapter XXX. Impervious concrete may be obtained by scientific proportioning of materials, as described in Chapter VI, but a good waterproofing treatment is usually advisable.

TABLE XXVI.—Amount of Materials for Arch Culverts.†

Materials for Culvert for 10-Foot Roadway				Extra Material for Each Additional Foot Width of Road.		
Span of Culvert. Feet.	Cement. Bags Barrels.	Sand.* Double Load.	Screened* Gravel or Stone. Double Load.	Cement. Bags. Bbls.	Sand. Double Load.*	Screened Gravel or Stone.* Double Load.
5	50 or 12½	3	6	2 or ½	⅛	¼
8	80 or 20	4¾	9½	3 or ¾	3/16	⅜
10	115 or 28¾	7	14	4 or 1	¼	½

* A double load of sand or gravel is taken as 40 cubic feet or about 1½ cubic yards.

† From "Concrete Construction About the Home and on the Farm," published by Atlas Portland Cement Co.

CHAPTER XXVI

CONCRETE TANKS, DAMS, AND RESERVOIRS

Uses of Concrete Tanks.—How to Build Tanks.—Reinforcement for Tanks.—Concrete Dams.—Small Reinforced Concrete Dams.—Concrete Reservoirs.

THE construction of waterworks has received a new impetus with the development of concrete, plain and reinforced. Its durability, adaptability to any condition, and economy have made possible the erection of any number of works which would have been impossible if more expensive and less permanent material had to be employed. Concrete has thus contributed not a little to improved sanitary conditions in water supplies.

In the collecting and storage systems, as well as with distributing systems of all modern waterworks, concrete plays an important part and will continue to do so more and more as its many advantages over other constructive materials become better known.

In the smallest of wells, springs, and watering-troughs, as well as in the largest tanks, reservoirs, dams, and conduits, concrete can be advantageously employed and a volume alone could be written on this branch of the subject. The smaller structures used about the farm are discussed in that chapter, and the question of pipes and conduits has also been discussed in other parts of the book. We must therefore confine ourselves here to the discussion of such typical structures as tanks and water towers, reservoirs, and dams.

CONCRETE TANKS*

Various Uses.—Concrete tanks have been built as receptacles for such a variety of substances that it is impossible to name them all. We naturally think first of a tank as a receptacle for water,

* For complete directions see "Concrete Tanks," published by American Association of Portland Cement Manufacturers, Land Title Building, Phila., Pa., from which this description is partly condensed.

but this is only one liquid for which a concrete tank is suitable. Manufacturers of oil, wine, milk, molasses, pulp, glue, and a variety of other materials are now using concrete in the construction of their tanks (or vats), both for the finished product and in the course of manufacture. Vegetable oils are said to have a deteriorating effect upon concrete, but through the use of the very excellent waterproofing compounds now available, concrete can be used in the construction of tanks for these oils. Very naturally, the use we will discuss most fully is that of water, as probably nine-tenths of the tanks built are for the holding of water. For other substances, where the use is a new one, careful experiments should be made to determine the chemical effect upon the concrete of the substance to be held. Concrete tanks are also extensively built to hold dry materials, such as sand, stone, coal, and grain.

Choosing the Location, Size, and Shape.—Tanks may be generally divided into two classes: viz., those above the ground surface, and those below, and in choosing the proper design the tank location must be first selected.

The next step is to decide the shape of the tank. Tanks are built in many shapes, but the convenience of use usually decides the shape selected.

How to Build the Tank—Rectangular Tanks.—*Laying Out the Ground.*—After the size has been decided upon, select a site near the water-supply if possible, and mark off the ground. In selecting the size, remember that 7 1/2 gallons make one cubic foot, and that a barrel holds from 49 to 54 gallons.

Put four nails in the ground in the shape of a rectangle, to mark the outside line of the tank walls, and stretch strings from nail to nail.

Excavate inside the space thus marked to a depth of 6 or 8 inches. If the soil is good stiff material, the bottom of the tank may be placed directly on this ground.

If the ground is soft, dig a trench just inside the strings one foot deep and one foot wide to secure additional foundations.

The ground under the proposed tank should be thoroughly tamped (beaten down), with as heavy a tamper as one or two men can handle. A block of wood, square or round, 12 or 14 inches across, with handles for lifting, makes an excellent tamper.

Amount of Reinforcement in Bottom of Tank.—The thickness of bottom will be made in all cases 6 inches; for tanks of this depth reinforcement must be placed 2 inches from the bottom of the slab, and this reinforcement must run each way.

Placing Reinforcing.—By referring to the accompanying tables, we find it necessary for a tank 6 feet deep to use in the bottom one $\frac{1}{2}$-inch round steel rod every 14 inches. If the tank is to be five feet square, these should be cut in lengths of 5 feet each. Lay them on the ground spaced properly, the rods in one direction resting on the rods in the other. Then cut the rods for the vertical reinforcement of the wall. Also we find that for a tank 6 feet deep we require $\frac{1}{2}$-inch round rods spaced 5 inches apart. Fifty-two of

TABLE XXVII.—For Spacing of Rods in Bottom of Tank.

Depth of Tank.	Spacing of $\frac{3}{8}$-inch Round Rods.	Spacing of $\frac{1}{2}$-inch Round Rods.	Spacing of $\frac{3}{4}$-inch Round Rods.
3 feet	10 inches		
4 "	8 "	16 inches	
5 "	$7\frac{1}{2}$ "	15 "	
6 "	7 "	14 "	
7 "	$6\frac{1}{2}$ "	13 "	
8 "	6 "	12 "	24 inches
9 "	5 "	10 "	20 "
10 "	4 "	8 "	16 "

these will be required. These rods should be cut 7 feet long. Make a hook at each end of these bars. This can be done by placing the end of the bar between two heavy spikes nailed in a block of wood and bending by moving the other end of the bar. The length of these bars after they have been bent should be about 6 feet 4 inches. Rods should also be bent for the horizontal reinforcing. From Table XXVIII, we see that for this sized tank $\frac{1}{2}$-inch round bars spaced 10 inches apart are required. Seven of these will be needed on a side.

The 1/2-inch rods with hooks at each end are placed in position by hooking the lower end of all the bars on one side under the rods in the bottom reinforcing, coming about 2 inches outside the line of the form which has been erected. After having placed these vertical 1/2-inch round rods in the correct positions, the next step is to place the horizontal reinforcement for the walls. This we have previously seen consists of 1/2-inch round bars spaced 10 inches apart. Where the bars lap, they should be firmly wired together.

TABLE XXVIII.—Showing Size and Spacing of Rods in Wall.

Depth of Tank.	Thickness of Wall.	Spacing of ⅜-inch Round Rods.		Spacing of ½-inch Round Rods.		Spacing of ¾-inch Round Rods.		Spacing of 1-inch Round Rods.	
		Vertical.	Horizontal.	Vertical.	Horizontal.	Vertical.	Horizontal.	Vertical.	Horizontal.
Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
3	5	5	10	10	20			..	..
4	5	4	8	8	16	16	32	..	..
5	5½	3	6	6	12	12	24	..	..
6	6½	2½	5	5	10	10	20	18	36
7	8	..	..	3	6	7	14	15	30
8	9½	..	..	2½	5	5	10	11	22
9	10½	..	..	..	..	5	10	10	20
10	12	..	..	..	..	4	8	8	16

TABLE XXIX.—Dimensions for Circular Tanks.

(1) Depth.	(2) Diameter.	(3) Thickness of Concrete in Wall.	(4) Diameter of Horizontal Rods.	(5) Spacing Horizontal Rods at Bottom.	(6) Spacing Horizontal Rods at Top.	(7) Diameter Vertical Rods.	(8) Spacing Vertical Rods.
Feet.	Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
5	5	6	¼	8	18	¼	36
5	10	6	¼	6	12	¼	30
10	10	8	⅜	6	18	⅜	36
10	15	8	⅜	4	18	⅜	36
15	10	12	⅜	4	18	⅜	30
15	15	12	½	6	20	⅜	30

We will illustrate the method of using Table XXIX in building a tank 15 feet deep and 10 feet in diameter. From the table we see that the thickness of concrete in the walls of the tank is 10 inches; that the size of reinforcement to be used is 3/8-inch rods, that is, round rods 3/8 of an inch in diameter; for the first foot these rods should be spaced 4 inches apart; and the vertical rods should be placed 30 inches apart. The table calls for the spacing of the horizontal rods 18 inches apart at the top of the tank, and the intermediate horizontal rods will therefore be spaced distances varying from 18 inches to 4 inches; thus in the second foot from the bottom the horizontal rods will be 5 inches apart; in the third foot, 6 inches apart; in the fourth foot, 7 inches apart; in the fifth foot, 8 inches apart; in the sixth foot, 9 inches apart; in the seventh foot, 10 inches apart ; in the eighth foot, 11 inches apart; in the ninth, 12 inches apart; in the tenth, 13 inches apart; in the eleventh, 14 inches apart; in the twelfth, 15 inches apart; in the thirteenth, 16 inches apart; in the fourteenth, 17 inches apart; and in the fifteenth, 18 inches apart.

CONCRETE DAMS

Concrete is now being extensively employed in the construction of dams of every conceivable shape and size. They are all, however, of three general types, the solid or gravity type, the arched type and the hollow reinforced type.

The fundamental principles in the design of gravity dams are much the same as those underlying the design of retaining walls, the main difference being that the dam must not only be strong enough to be safe against a full head of water in the reservoir, but also in the case of very high dams it must be safe against the weight of masonry in the structure itself. Furthermore the external pressure of the water can be determined with scientific exactness while the pressure of earth on walls is subject to many uncertainties. The amount of water pressure per square foot against a dam at any depth is found by the simple rule

$P = 62.5\ H.$ and against the surface one foot wide. $P = 31.25\ H^2$

$P =$ Pressure in lbs. at any depth H in feet.

Table XXX gives the pressures at different depths:

Gravity dams may be constructed of solid concrete or of concrete in which is embedded large blocks of rubble. The latter type which is called "Rubble Concrete," or "Cyclopean Masonry," is by far the most economical as the amount of cement required is reduced to a minimum.

Small Dams.—The construction of small dams under six feet high may be undertaken without special engineering advice as follows: *

"If possible, dig a temporary trench so as to carry the water around the dam while it is being built. If this cannot be done, run the water through a wooden trough in the middle of the dam, and after the wall each side of it is finished, carry the forms across the opening, and make these tight enough so that the water is quiet between them; then place the concrete.

"Dig a trench across the stream slightly wider than the width of the base of the dam, carrying it down about 18 inches or 2 feet below the bed of the brook, or if the ground is soft, deep enough to

TABLE XXX.—HYDROSTATIC PRESSURES.

Hydrostatic Head. Feet.	Lifting Pressure per Square Foot. Lbs.	Average Pressure per Square Foot on Vertical Surface. Lbs.
0.5	31.2	15.6
1.0	62.5	31.2
2.0	125.0	62.5
3.0	187.5	93.7
4.0	250.0	125.0
5.0	312.5	156.2
6.0	375.0	187.5
8.0	500.0	250.0
10.0	625.0	312.5
12.0	750.0	375.0
15.0	937.5	468.7
20.0	1250.0	625.0
25.0	1562.5	781.2
30.0	1875.0	937.5
40.0	2500.0	1250.0
60.0	3750.0	1875.0
80.0	5000.0	2500.0
100.0	6250.0	3125.0

reach good, hard bottom. In case the earth is firm enough for a foundation, but is porous either under the dam or each side of it, sheet piling consisting of 2-inch tongued-and-grooved plank can be pointed and driven with a heavy wooden mallet so as to prevent the water flowing under or around the dam. Build the forms so as to

* From "Concrete Construction About the Home and on the Farm," published by Atlas Portland Cement Co.

make the wall of the dimensions shown in the table. Wet them thoroughly, then mix and place the concrete.

"Use proportions one part Portland cement to two parts clean, coarse sand to four parts screened gravel or broken stone.

"Take special care to make the concrete water-tight by using a wet mix. If possible, lay the entire dam in one day, not allowing one layer to set before the next one is placed. If it is necessary to lay the concrete on two different days, scrape off the top surface of the old concrete in the morning, thoroughly soak it with water, and spread on a layer about 1/4 inch thick of pure cement of the consistency of thick cream, then place the fresh concrete before this cement has begun to stiffen.

"If the forms on the lower side of the dam are well braced, the forms on the upstream side may be removed in three or four days, and the pond allowed to fill. The forms on the down-stream face should be left in place well braced for two or three weeks. No finish need be given to the surface."

Reinforced-Concrete Dams.†—Reinforced concrete is particularly adapted to the construction of dams. When so used there is a

TABLE XXXI.—DIMENSIONS FOR SMALL DAMS AND QUANTITY OF MATERIALS FOR DIFFERENT HEIGHTS OF DAMS.

Proportions: 1 Part Portland Cement to 2 Parts Sand to 4 Parts Gravel or Stone

Height Above Bed of Stream.	Depth Below Bed of Stream.*	Thickness at Base.	Thickness at Top.	Amount of Materials per Foot of Length of Dam.		
				Cement.	Sand.	Gravel or Stone.
Feet. H.	Feet. G.	Feet. B.	Feet. T.	Bags.	Cu. Ft.	Cu. Ft.
1	1½	1	1	½	¾	1½
2	1½	1	1	1	1½	3
3	1½	2	1½	1¾	4	8
4	2	2	1½	2¾	5	10
5	2	2½	1½	3½	6¾	13½
6	2	3	1½	4½	8¾	17½

* Make deeper if necessary to get a good foundation.

Note.—A large single load of sand or gravel is about 20 cubic feet.
A large double load of sand or gravel is about 40 cubic feet.

† This discussion is arranged from "Concrete, Plain and Reinforced," by Homer A. Reid.

great saving in material, and on this account a reduction in cost of, in some cases, as much as 20 per cent. Again, the space under the apron may be utilized for storage or power-house purposes, as for the location of turbines, electric generators, etc. Another advantage is that of securing a practically impervious curtain face wall, without any of the dangerous leaks so troublesome to locate in some masonry structures. If sufficient number of reinforcing rods are used and run in every direction there will be little or no danger of cracking in the deck concrete.

The design of steel dams is that of a triangle with the upstream face so flatly inclined that the water pressure is made to give increased stability by its weight, and this basic principle has been the leading feature in the development of dams of reinforced concrete,

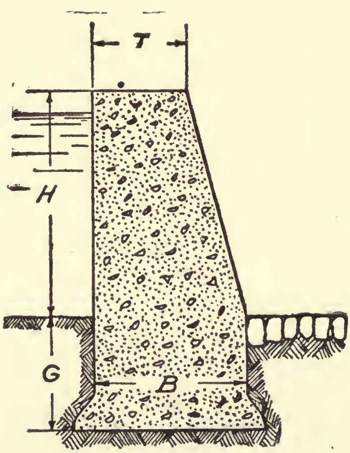


FIG. 100.—Design for Small Dam.

which were first introduced in the Eastern States about the year 1902 by the Ambursen Hydraulic Construction Company, of Boston.

About 30 dams varying in height from 10 to 80 feet, some over 1,000 feet long, have been erected during the last 8 years, many of them attracting marked attention by the engineering profession.

The design of these dams illustrates very strikingly the adaptability of reinforced concrete to new conditions. The principle followed in the design is that the vertical pressure of the water is utilized to firmly hold the dam down on its foundation.

With the usual type of gravity dams, the up-stream face is vertical or nearly so. The pressure of the water is thus exerted horizontally, tending to overturn the dam, which must therefore be made heavy enough to prevent same from occurring.

In the reinforced-concrete dam, the slope of the water face may be so fixed that the pressure on the foundation is controlled by the designer, and the safety factor is made at least five.

The usual type of reinforced-concrete dam consists of an inclined slab of reinforced concrete extending from the heel to the crest, and spanning between and supported by transverse buttresses of concrete, resting upon the foundation. Another inclined slab may or may not be used to form an apron or spill-way. The deck

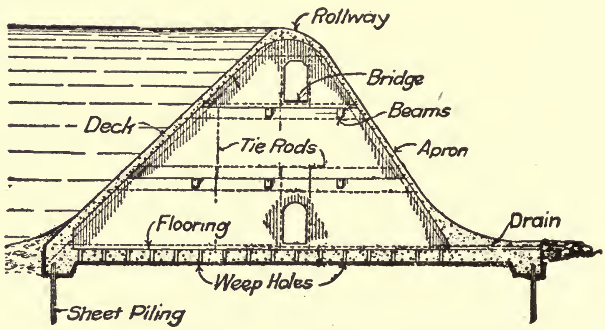


FIG. 101.—Curtain Type of Reinforced Concrete Dam.

is usually increased in thickness from the crest to the heel on account of the increase in pressure as the water deepens.

The principles governing the design of reinforced-concrete dams are the same as those used for the design of masonry dams as far as the external pressures are concerned. However, as reinforced-concrete dams are usually of triangular cross-section, they have a much wider base than masonry structures, which greatly increases their resistance to overturning. This resistance is further increased by the weight of the water above the face or deck, which usually has an inclination of from 30° to 45° with the horizontal.

An increase in the height of the water flowing over a masonry or solid dam increases the pressure thereon and causes the line of pressure to rise, thereby greatly increasing the overturning moment on the dam without in any way increasing the resisting moment to the same.

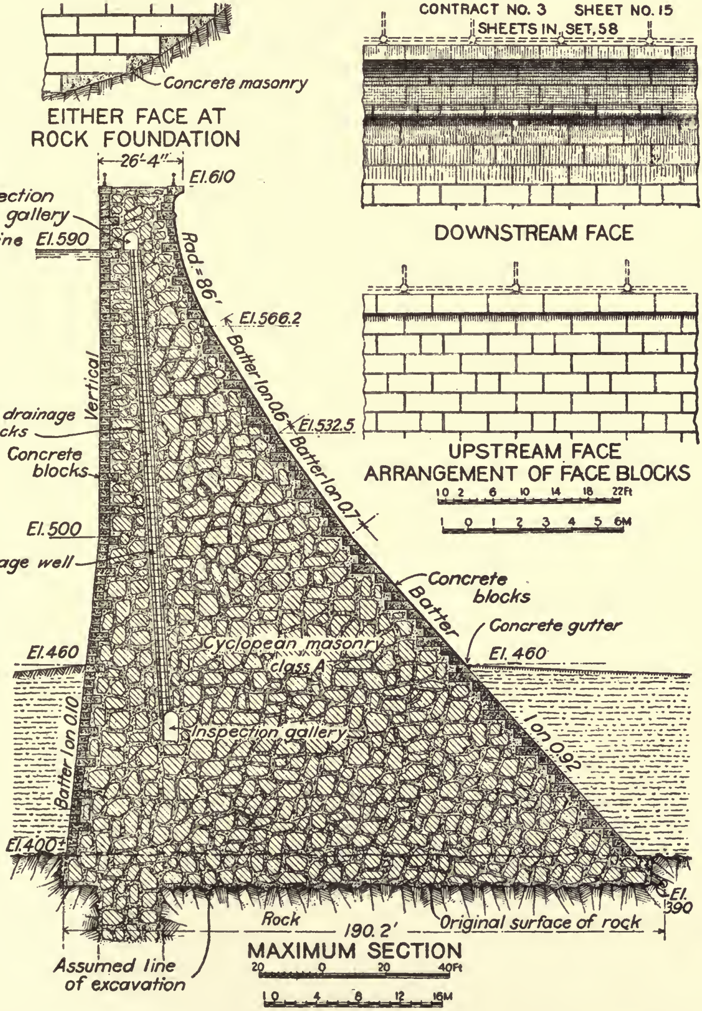


FIG. 102.—Ashokan Dam of the New Water Supply System for the City of New York. One of the Largest Dams in the World.

In a triangular dam, however, with a broad base, as in the hollow reinforced-concrete dam, when the head of water flowing over the dam is increased, the lines of pressure become more nearly vertical, the overturning moment is actually reduced, and the stability is in no way endangered. Owing to the reduction in weight it may be necessary sometimes to fill hollow dams with sand, earth, or gravel to increase its resistance to sliding.

Reinforced-concrete dams are particularly fitted to poor foundation conditions on account of the broad base and consequent low unit pressures. This will often enable a large saving in cost.

Concrete Reservoirs.—The construction of reservoirs of concrete present but few features not already discussed in the sections on walls and dams. The principal difficulty encountered is in obtaining a watertight bottom, as extensive areas of shallow concrete are subject to cracking on account of settlement, shrinkage, and expansion. The best means to avoid this cracking is by having a double lining. The under lining is laid in a continuous sheet and covered with a sheet of a good asphaltic material, and over this is placed concrete, in sections ten feet square, the joints between the sections being filled with an asphaltic material.

CHAPTER XXVII

CONCRETE SIDEWALKS, CURBS, AND PAVEMENTS

Advantages of Concrete Sidewalks.—Materials, Equipment, and Forms.—Construction of the Sidewalk.—Coloring and Protection.—Tables of Dimensions and Materials Required.—Concrete Curbs and Gutters.—Concrete Roads and Pavements.—Table of Offsets for Crowning Roads.

THE class of work in which the value and adaptability of concrete has been brought most intimately to the attention of laymen and municipal authorities is cement sidewalk construction. Being one of the oldest forms in which cement has been employed, its use in this connection has grown so rapidly that no important community is without its miles of well-paved walks; and what had formerly been a luxury employed only by large towns and cities, has now become an every-day necessity in all progressive communities. In fact, it is due to the introduction of the cement walk, that many hundreds of communities have been enabled to provide themselves with walks at all; for the cement walk possesses all the merits of the older forms of wood, brick, and stone, and few of their defects, and the low cost and maintenance charges place it within the reach of almost any up-to-date home.

The beauty, convenience, noiselessness, durability, and economy of well-constructed walks have always had a highly beneficial influence on property values wherever they have been constructed.

Concrete as a material for curbs and gutters is just as advantageous as for sidewalks, and its adaptability for the roadway of streets is now becoming quite generally recognized and will continue to be more so in the future. The question of its use as a paving material is taken up later in this chapter.

Materials for Sidewalks.—Sidewalks should be constructed only of Portland cement, as the natural and slag varieties are unfitted for constant exposure to the elements. A good sand or screenings and a clean, hard, and durable stone should be employed and the same well graded. Five per cent of clay may be allowed. The same principles should be followed in selecting these materials as have been outlined in Chapter V.

Tools and Equipment.—The tools and equipment employed by the sidewalk builder are shown in the accompanying illustration and their use is there indicated.

Forms.—Forms for the sides are made of sound wood, at least two inches thick by five inches wide, while the cross forms and protection strips may be of metal. The forms must be firmly secured by stakes driven at frequent intervals (about 2 feet) and placed upon proper lines and grades. Specially designed metal forms are economical and very desirable on any large work.

Construction.—The foundation of the sidewalk is, as in all other structures, the most important element upon which the lasting qualities of the structure depend. To assure a good foundation, the soil underneath it should be well drained by means of broken-stone trenches, tile pipes, or other suitable means depending upon the character of the soil and local drainage facilities.

The soil should be brought to the required elevation of the subgrade either by excavation or fill as the original surface may require. If in excavation, all spongy and bad spots must be removed and replaced by sand or other good material.

If in fill, the material should be wetted and tamped in layers not more than 6 or 8 inches thick. The fill should extend far enough (at least 2 feet) on either side to allow the material to assume its natural slope without danger of running from under the walk.

Preparing the Sub-Base.—The subgrade should be at least 12 inches below the finished surface and slope toward the curb at least 1/2 inch per foot for drainage. The foundation or sub-base should be at least 8 inches thick, made of hard cinders, slag, gravel, crushed stone, or broken brick, grading from 1/4 to 4 inches in size.

Concrete Base.—In placing, the under bed of concrete should be well tamped until its upper surface is at the required height, about 3/4 inch below the finished surface of the sidewalks.

At all driveway crossings, increase the thickness of sub-base 2 to 3 inches, and of the top 1/2 inch.

Do not remove cross forms until concrete is well compacted and set, and in laying adjoining sections, see that old surface is clean and free from loose mortar.

Leave expansion joints at least every 50 feet, about 1/8 inch wide. This is done by the insertion of expansion strips which are later removed and replaced by paving pitch or good sand.

No block should contain more than 36 square feet, and no dimension should be more than 6 feet.

Never leave the work with a slab partly finished, as breaks will be bound to occur at such points.

Wearing Surface.—The wearing surface should be smooth but

FIG. 103.—Principal Tools Employed in Building Cement Walks.

not slippery and of uniform dull color. Mixture 1 part cement to 1 or 1 1/2 parts crushed granite, slag, grit, or sand.

The top surface may be "tamped" or "floated." The tamping may be applied to the top 3/4 inch, which may be a specially rich mixture. The thin mortar will work to the surface which may then be trowelled smooth.

The tamping method will produce a better bond with the base and cause less delay. When the floating method is used the mortar should be mixed thin and worked to a true and smooth finish.

Special pains should be taken to obtain a good bond of top surface to base. The latter should be clean and the top surface placed as soon as possible after the base is tamped. Should the base have already hardened, it should be drenched and cleaned and prepared by a thin film of grout before the top layer is placed. The methods described to secure good bond in Chapter XXX, are likewise applicable to sidewalk work.

The wooden trowel gives a good finish and is somewhat free from the excessive smoothness and checking caused by the steel trowel. While the surface is still green a grooved roller or brush may be run over it to remove the smoothness and give a better foothold for pedestrians.

Coloring.—The coloring of sidewalks follows in a general way the coloring of other cement work, as described in Chapter XII. Certain facts have been brought out by experience, however, which it is well to state here.

The color of a walk will be affected by:

1. The consistency of the mortar and character of cement and aggregates.

2. The steel floating trowel gives a darker color than the wooden one.

3. The finishing tool.

4. Weather conditions.

5. The protection of the surface.

6. The interval of time between placing and finishing. Trowelling on partly hardened surface produces blotches.

7. Sunshine will give lighter color than shade.

It is therefore important that the work be done under as uniform conditions as possible to obtain uniform color effect.

Protecting the Walk.—The walk should be protected against:

1. Rain and sun, which will cause pitting of surface. This may be effected by a layer of sand, tar paper, canvas, or boards secured from displacement.

2. *Frost.*—The method of laying concrete in freezing weather and its protection described in Chapter VII, applies as well to sidewalk construction.

3. Against displacement by growing roots of trees. This should be done by allowing a clearance of at least six inches all around.

4. Against walking on it or other interference until thoroughly set.

TABLE XXXII.—DIMENSIONS OF CONCRETE SIDEWALKS FOR RESIDENCE DISTRICTS.

Width.	Thickness.	Length of Block.	Area of Block.
4 Feet	3½ to 4″	5 Feet	20 sq. ft.
4½ "	3½ to 4″	6 "	27 " "
5 "	4″	5 "	25 " "
6 "	4½″	5 "	30 " "
6 "	5″	6 "	36 " "

TABLE XXXIII.—MATERIALS FOR CONCRETE SIDEWALKS.*

Bags of Cement to 100 Square Feet of Surface Area of Concrete Base or of Wall.				Bags of Cement to 100 Square Feet of Mortar Surface.			
Thickness. Inches.	Proportions.			Thickness. Inches.	Proportions.		
	1:1½:3	1:2:4	1:3:6		1:1	1:1½	1:2
3	8½	6½	4¾	½	3½	2¾	2½
4	11½	8¾	6	¾	5	4	3½
5	14½	11	7½	1	7	5¼	4½
6	16¾	13¼	9½	1¼	8¼	6½	5¾
8	22¾	18	12	1½	10	8	6½
10	28¾	22¼	15½	1¾	12	9¼	7¾
12	34¾	26½	18½	2	14	11	9
No. of Square Feet of Concrete Laid with 4 Bags (1 bbl.) of Cement.				No. of Square Feet of Mortar Surface Laid with 4 Bags (1 bbl.) of Cement.			
3	47	60	83	½	114	146	178
4	36	46	66	¾	80	100	118
5	27	36	52	1	57	73	89
6	24	30	41	1¼	48	60	70
8	17	22	33	1½	40	50	59
10	14	18	26	1¾	33	43	52
12	12	15	21	2	29	36	44

* From "Concrete in Highway Construction," published by the Atlas Portland Cement Co. See also bulletins of Universal Portland Cement Co. and Vulcanite Cement Co. on Cement Sidewalk Construction.

Cost.—A gang of six men can lay about 700 sq. ft. of 6 ft. walk per day, having a 4″ base and a 3/4″ top coat, at a cost of from 10 to 14 cents per sq. foot, depending upon the local price of labor and material.

CONCRETE CURBS AND GUTTERS

Curbs are usually 6 to 8 inches wide and 12 to 14 inches deep, 6 to 7 inches of which extends above the surface of the roadway. The exposed surface of the curb is slightly inclined and corners rounded off with a 1-inch radius. As in the walk, the curb should be underlaid with an 8- or 10-inch layer of cinders. The gutter

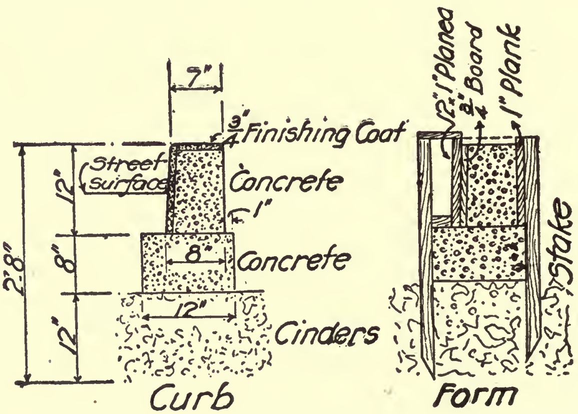


Fig. 104.—Concrete Curb and Gutter.

should be 1 1/2 to 3 feet wide, slope toward the curb and have 7 or 8 inches of concrete overlying a cinder base.

Several patented devices have been introduced for reinforcing curbs against injury by wheels of vehicles, and these have proved very efficient. The construction of curbs and gutters should follow the same principles as to excavation, fill, concreting, etc., as outlined for walks. The following detailed directions should be given careful attention:

Rules for Construction of Cement Curb and Gutter.—1. The drainage of foundations should be of the same materials as described for sidewalk paving, and similarly placed, using the methods and instructions as previously described.

2. Place in position forms to receive the concrete. These forms are held in place by stakes set by an engineer at points necessary to accurately designate the line and grade of the proposed curb and gutter.

3. For forms use 1 1/2 to 2-inch rough planks. Dimensions to be according to the height of the curb and thickness of the gutter, or special metal forms may be employed.

4. Place forms in position and deposit the concrete base.

5. Cut curb and gutter entirely through every six feet. A convenient and sure method is to use a piece of quarter-inch sheet iron the same form as the concrete base of curb and gutter. Fill in the cuts thus formed with dry sand.

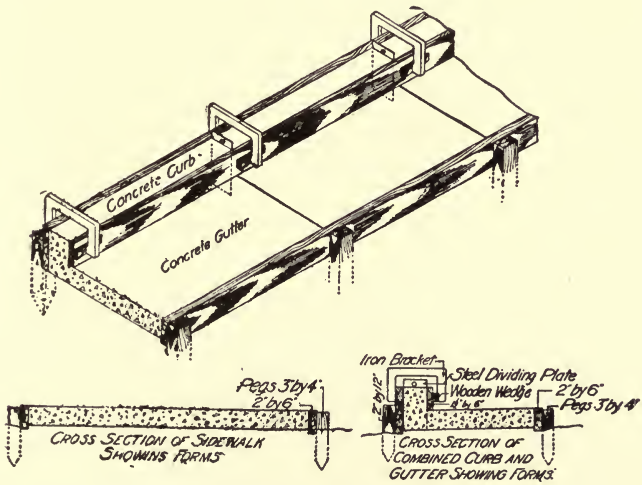


Fig. 105.—Combined Concrete Curb and Gutter.

6. After each batch of concrete is laid, it should immediately be covered with a top coat or wearing surface.

7. Slope the gutter to meet the requirements of drainage by increasing the thickness of the top coat on the side nearest the street. Work to an even surface with a straight edge laid parallel with the curb.

8. The upper face corner of curb and angle between curb and gutter should be rounded with a radius of 1 to 1 1/2 inches.

9. After getting a good surface, float with plasterer's float until

a smooth, even surface is obtained. This surface should be wet or very moist.

10. Dust this surface while it is still wet with granite dust and Portland cement mixed half and half, dusting to take place before the surface water has been absorbed. Immediately smooth down with a trowel, and do not let too great an interval elapse between floating and trowelling. Use a curved trowel for top corners of curb and angles between curb and gutter.

11. After trowelling, finish with a soft brush; an ordinary hearth brush or whitewash brush will do. If the top is too dry sprinkle with water. The brush will take out the trowel marks and give an even texture and color to the finished work.

Cut top coat directly over the cuts made in the concrete base, levelling the edges of the cuts with a jointer.

12. Protect the work as previouslv described under Sidewalks.

CONCRETE ROADS AND PAVEMENTS

The first true concrete pavement was laid in Bellefontaine, Ohio, about 1893. The base was 4-inch concrete, 1 to 4 and 2-inch wearing surface 1 to 1. The pavement was laid in 5-inch strips longitudinally starting at each curb and cut into 5-foot squares.

During the last 10 years, a great number of concrete pavements have been laid, most of which have been either the "Hassan" pavement or the Blome Grantwood Block, both of which are patented.

Mr. J. H. Chubb in an interesting paper read before the National Association of Cement Users, refers to the systems of concrete pavements in this country, and the following is quoted from his paper:

"A study of the pavements, and of the conditions under which they were laid, makes it quite evident that a first-class pavement may be constructed of concrete at a reasonable cost. Such a pavement must, however, be properly laid with suitable materials, to insure satisfactory construction.

"A concrete pavement is easily and economically cleaned, and from a sanitary and æsthetic point of view is an ideal pavement. Where properly laid, such a pavement offers a good foothold for horses, is very little, if at all, more slippery than brick or stone block, and certainly less so than asphalt or wood block. Its resistance to traction is probably less than for any other pavement, and while it is not as noiseless as asphalt or wood block, is superior to brick and stone blocks in this respect.

"Such pavements are probably not adapted to the heaviest traffic of our largest cities, but may be considered as suitable in all places where brick, wood block, or asphalt would be proper; and adapted to all conditions of traffic except those demanding stone block. Concrete is the ideal material for the paving of residence streets, of alleys, courts, and squares, and in general makes an excellent intermediate pavement, as to cost and durability, between the stone-block pavement of heavy travelled streets and the macadam of our country roads."

Concrete pavements have been laid by contract at a cost of from 99 cents to $2.92 per square yard. The former figure is undoubtedly too low for first-class construction even under the most favorable conditions, and $2.92, the cost per square yard of the New Orleans pavement, is high, owing to local conditions. Considering the cost of material and labor and the method of construction, the estimated cost of $1.95 per square yard for the pavement proper as laid in Bozeman, Montana, is probably more representative of the cost of this type of pavement; if anything, it is a little high.

The expensive part of a brick block or asphalt pavement is the wearing surface. In the construction of a concrete pavement a comparatively cheap but satisfactory material, and one that costs much less to lay, is substituted for these expensive wearing surfaces, which explains why this pavement can be constructed at a much less cost than for those now in general use. The saving in cost is in the wearing surface, for practically the same concrete base answers for each type of pavement.

GENERAL HINTS FOR BUILDING CONCRETE PAVEMENTS

Grading.—The entire width of the roadway should be graded to a depth sufficient to lay the required thickness of pavement.

The subgrade when properly compacted should be parallel to the finished surface of the street and constructed in the same general way as described for sidewalks; that is, bad spots should be removed and replaced and fills made in 6-inch layers. Heavy rollers and tampers should be employed for compacting the material. Drainage should be provided for in all cases where natural drainage does not exist.

Sub-Base.—In clayey and other water-holding soils, a 6- to 10-inch sub-base of cinders, gravel, or stone should be laid, the material ranging in size from 1/2 inch to 4 inches. This sub-base is wetted and rolled to a uniform surface, parallel to the final roadway.

Pavement Proper.—The pavement should be made of a 4- to 6-inch base and a 1/2 to 2-inch wearing surface depending upon the extent of the traffic.

A wet mixture should be used for the concrete base, but not too wet to creep under light tamping. This concrete should be deposited across the entire roadway and well tamped with 8-inch hand tampers, weighing at least 18 pounds each.

Expansion joints should be provided at the curbline 1/4 inch wide, and every 50 feet across the street 1/2 inch wide, formed by means of wooden or metal strips set in place. These are removed and replaced by paving pitch.

Wearing Surface.—The wearing surface should be placed within an hour of the base before the latter begins to harden much, and the laying follow right along after the completion of the base. A mixture sufficiently wet to allow floating without tamping should be employed. It should be finished with a wooden float and brushed with stiff brooms before completely hardened and may be cut into any desired grooves or blocks to provide good foothold for horses.

Protection.—The pavement should be protected from the weather until thoroughly set, be kept well sprinkled for 3 days at least, and not put into service in less than a week and longer if weather conditions have not been favorable to proper hardening.

Patented Pavements.—The essential features of the "*Blome Granitoid*" Pavement may be stated as follows:

1. The subgrade is prepared 7″ below the finished surface.

2. A 5 1/2 inch base of 1: 3: 5 concrete is then laid in sections extending the full width of street.

3. A 1 1/2 inch cement mortar wearing surface made of 1 cement, 3 parts clean, crushed stone is laid on the green concrete base.

6. The wearing surface is grooved into 4 × 9 inch blocks, the length of the blocks being perpendicular to the curb. The grooves have rounded edges and are about 1/4 inch deep and 1/2 inch wide.

7. Before final hardening, the wearing surface receives treatment with stiff brushes to eliminate what may otherwise be objectionable smoothness.

8. To eliminate danger from temperature changes, expansion joints are placed 50 feet apart and filled with paving pitch.

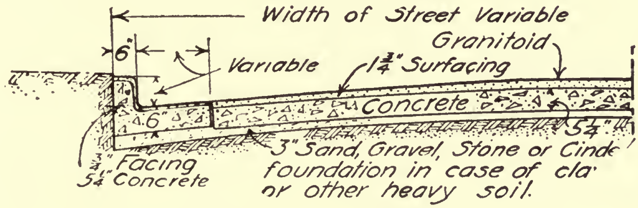


Fig. 106.—The Blome Granitoid Concrete Pavement.

The Hassan pavement is constructed as follows:

1. The street is excavated to the required depth of about 6 inches below grade line.

2. A layer of 1 1/2 to 2 1/2 inch crushed stone is then placed upon the subgrade properly prepared.

3. This is rolled until top is within 2 inches of finished surface.

TABLE XXXIV.—Offsets for Crowning Streets of Various Widths.

From "Concrete in Highway Construction," by Atlas Portland Cement Co.

Width of Roadway Between Curbs.	Crown.	Distance from Centre of Roadway.	Vertical Offset.	Distance from Centre of Roadway.	Vertical Offset.
Feet.	Inches.	Feet.	Inches.	Feet.	Inches.
24	3	4	⅓	8	1⅓
30	4	5	4/9	10	1 7/9
36	5	6	5/9	12	2 2/9
48	6	8	⅔	16	2⅔
60	8	10	8/9	20	3 5/9

4. A grout mixture of 1 part cement to 3 parts fine sand is then poured in the stones and rolling and grouting continued until an even surface is obtained and all voids filled.

5. A 2-inch wearing surface of trap rock is then laid, rolled, and grouted with a 1 to 2 grout.

6. A finishing coat of 1 cement, 1 sand and 1 pea size crushed trap rock is poured on and brushed over the surface.

7. The pavement then receives its final rolling, and is allowed to harden for a week before being open to traffic.

8. Expansion joints 1 inch wide filled with tar are provided for at the curbs and about every 100 feet longitudinally.

CHAPTER XXVIII

CONCRETE IN RAILROAD CONSTRUCTION*

Foundations and Retaining Walls.—Bridges and Trestles.—Train Sheds and Platforms.—Signal Towers.—Power Houses.—Shops and Warehouses.—Coal and Sand Pockets.—Ash Plants.—Round Houses.—Turntables, Pits, Tank Supports, and Bumping Posts.—Concrete Ties and Roadbed.—Posts and Fences.—Telegraph Poles.—Tunnels.—Docks.—Reservoirs.—Elevators.

In railroad construction perhaps more than in any other branch of engineering has concrete shown its versatility. Not only is it replacing steel in construction, but to an even greater extent it has taken the place of stone and brick masonry, not merely for foundations, but also for various railroad structures above ground.

The classes of railroad structures in which concrete is now extensively employed or in which its use is extending, are in part as follows:

(1) Foundations, retaining-walls, piers, and abutments.
(2) Bridges and culverts.
(3) Depots, signal-towers, shops, and other buildings.
(4) Coal and sand stations, roundhouses, and turntable-pits.
(5) Tank supports, bumping posts, ties, and roadbeds.
(6) Posts, fences, telegraph and power poles.
(7) Tunnels and tunnel lining.
(8) Wharves and docks.
(9) Storage reservoirs.
(10) Grain elevators.

Many of these classes of construction are described with more detail in other portions of this work. In this chapter only such mention can be made of each as will best serve to illustrate the special rôle of concrete in connection with railroad economics.

Foundations.—Concrete has been used for foundations in railroad construction for many years. It was first employed to encase

* The matter in quotations in this chapter is reproduced by courtesy of The Atlas Portland Cement Co., from "Concrete in Railroad Construction."

the tops of wooden piles and form a level platform on which to start the masonry, thus forming the foundation courses of bridge piers and abutments, buildings, etc. Within recent years reinforcement has been introduced, which distributes the stress, prevents settlement, and saves material.

Retaining Walls.—Both plain and reinforced concrete is in general use for retaining walls. As explained in a previous chapter plain concrete walls are made heavy enough to withstand the earth pressures by virtue of their weight alone while reinforced walls consist of a thin, vertical slab attached to a horizontal base, and either braced by counterforts on the back, or else designed as a cantilever anchored to the base slab which also has a front projection, the whole section being in the form of an inverted T.

Piers and Abutments.—Concrete is employed for bridge piers either as filling for ashlar or cut stone masonry, or for the entire pier, in which case it may be either plain or reinforced. When of plain concrete, the sizes and general proportions are practically the same as for stone piers. If reinforced concrete is used a great saving in cost can be effected either by reducing the size of the pier or by building it hollow with reinforced walls.

Abutments are built generally of plain concrete although reinforced abutments are also coming into use, and consist essentially of a buttressed retaining wall, supporting a heavy reinforced slab, which forms the bridge seat.

Bridges and Trestles.—One of the most important applications of concrete to railroad construction is in the building of bridges and trestles. In addition to its freedom from rust and decay the use of concrete represents a large saving in maintenance charges, since such a structure requires no paint or repairs.

A concrete bridge is free from the excessive vibrations often experienced in steel bridges and from disagreeable noise.

Track is easily maintained on such a structure, since the ordinary track ties and ballast take the place of the more cumbersome and expensive track timber of a steel structure.

In the construction of a concrete bridge there is no obstruction of traffic from swinging booms as is the case when setting stone of large dimensions in masonry bridges, nor so much difficulty in securing the necessary skilled labor during times when the building trades are active. The materials used can generally be obtained in the immediate vicinity of the bridge site, while the cost is considerably less than that of a stone structure of the same capacity.

Owing to the deteriorating influence of locomotive gases upon the under surface of bridge floors the construction of overhead highway crossings is one of the greatest problems which the railroad engineer is called upon to solve.

Steel girders when unprotected have to be painted very frequently. To do away with this expense, old structures are being encased in concrete, and new ones are being built either of reinforced concrete or of structural steel encased in concrete. Bridges thus constructed are absolutely unaffected by ordinary rust, rot, or fire, and can be designed economically along artistic lines.

Stations and Train Sheds.—"Railroads throughout the country are adopting the use of concrete in the construction of railway stations of every class, in many cases for the entire structure and in others for integral parts, such as foundations, platforms, smoke ducts, stairways, and often for architectural features, such as cornices, belt courses, and platform columns. Its permanence, fire-resisting qualities, and adaptability to architectural treatment render it a most satisfactory building material for both large and small stations.

"The train shed for the new Lackawanna passenger terminal at Hoboken, N. J., is an entirely new departure from the hitherto considered standard type of structure for this purpose. Instead of comprising a series of high arches, which in the common type of train shed are continually enveloped in a haze of smoke and gases from the locomotives, it consists essentially of a system of low-arched, short span, longitudinal sections, just high enough to clear the largest locomotives in use on the line, with smoke ducts of reinforced concrete through which the locomotive gases are discharged directly into the open air. In addition to the smoke ducts, the platforms, pedestals and footings are of concrete construction.

"**Platforms.**—While plain concrete has been used for many years in the construction of low platforms at main stations, the adoption of high platforms on rapid transit and suburban lines during the past few years has opened up a new field for reinforced concrete.

"The Brooklyn Rapid Transit Company, which operates elevated railroad lines in Brooklyn, has recently completed a number of stations in the Flatbush section. At these stations the platforms on either side of the track are about 240 feet long and 8 feet wide and are constructed of a reinforced-concrete slab carried on girders of the same material which are in turn supported by concrete piers placed at 20-foot intervals.

"Expansion joints are provided every 60 feet by separating the construction entirely with tarred paper.

"The outside edges of the platform are equipped with patent bulb nosing.

"The fences running the length of the platform and forming the guard railings on the outside and ends of the platforms are constructed of cement plaster on metal lath.

"In designing the platforms a live load of 150 pounds per square foot was assumed and the concrete was figured at 500 pounds per square inch extreme fibre stress in compression, while the steel was allowed to carry 16,000 pounds per square inch in tension.

Signal Towers.—"Railroads throughout the country are experiencing a period of architectural renaissance. Structures which have in the past been built of temporary construction, apparently regardless of outward appearance, are being replaced by permanent buildings of artistic design. This is particularly true in the case of signal towers, the old unsightly and necessarily temporary wooden structures being superseded either by entire concrete or combination concrete and brick towers of pleasing appearance and permanent construction.

"The standard signal towers of the electric zone of the N. Y. C. & H. R. R. R. are combination brick and concrete structures. In these towers, the footings and foundation walls below grade are of 1 : 4 : 7 1/2 concrete, and the walls above grade up to the first floor level are of 1 : 3 : 6 concrete. All the sills and lintels, the coping, the overhanging bay window and supporting brackets and the cornice are of 1 : 2 : 4 concrete. In this work an excellent surface finish was obtained by floating the green concrete with water and rubbing it with a mortar brick composed of 1 part cement to 2 parts sand. The roof and floor construction consists of 1:2:4 concrete slabs, reinforced with 1/2 inch round rods, supported by steel I-beams.

Power Houses.—"The electrification of railroad systems, which bids fair to be a thing of the near future, will necessitate the construction of a large number of power stations along their lines. The N. Y., N. H. & H. R. R., which has electrified its line between New York and Stamford, in the construction of a power house at Cos Cob, about three miles from Stamford, has shown what can be done with concrete in this kind of construction.

"The exterior of this power house was designed in the Spanish Mission style of architecture, with very pleasing results. The foundations, column footings, and walls up to the water table were built of monolithic concrete mixed in the proportions of 1 part Atlas Portland cement, 3 parts sand, and 5 parts 2-inch crushed granite. All exposed surfaces of the walls were given a bush-hammered finish. For the water-table, window arches, coping and window sills, monolithic blocks were used. These blocks were built in special shapes and composed of concrete having the same proportions as the other monolithic work. The facing consisted of a mixture of 1 part cement to 2 parts sand.

"The walls above the water-table were built of hollow blocks, 10-inch by 12-inch by 24-inch, composed of a mixture of 1 part cement, 3 parts sand, and 3 parts 1 1/4 inch crushed granite, faced on the exterior surface with a mixture of 1 part of cement to 2 parts of sand, and where the inner surface of the wall is exposed with a mixture of 1 part cement to 4 parts sand. All the window lintels were cast in place, and consist of 1 : 3 : 5 concrete reinforced with two 3/4-inch trussed bars.

Railroad Shops and Warehouses.—"The same advantages which reinforced concrete possesses over other materials for the construction of power houses are equally enjoyed by it as a material for shop and warehouse buildings for railway purposes."

The C. R. R. of N. J. have recently erected a mammoth seven-floor warehouse in Newark, N. J., having a length of 360 feet, a width which varies from 130 to 165 feet, and a storage capacity of about 1,200 carloads of freight. The first floor is devoted to teaming, the second to the freight tracks, and the basement and four top floors to storage.

In general the building consists of a steel frame and concrete walls, with steel columns and girders carrying floor slabs of reinforced concrete. Owing to the presence of quicksand, an exceptionally wide spread of footing was required which resulted in the engineers making the foundation one continuous plate of concrete fifteen inches thick, reinforced with extra heavy expanded metal.

The walls, which are embellished with rustications, mouldings, dentils and cornices, are twenty inches thick to the second story, sixteen inches thick to the third story, and twelve inches thick from there up to the top. The reinforcement for the walls consists of expanded metal and 3/4-inch rods laid horizontally about four feet apart.

Reinforced concrete is peculiarly adapted to the construction of structures which are to be used for the storage of coal on account of its fire-resisting qualities, permanence, and strength.

Coal and Sand Pockets.—The combination coal and sand station built for the N. & W. Ry. in 1907, consists of an elevated coal pocket, having a capacity of 260 tons of coal, and a wet sand storage house on the ground with an elevated dry sand bin. The coal is dumped through a 10 × 12 foot track hopper into a reciprocating feeder which delivers it into a steel bucket elevator, discharging into a conveyor trough above for distribution into the pocket. The coal is fed to the engine tenders through hinged gates and over counterweighted coaling chutes. The wet sand passes into a dryer, emptying into a sand pit underneath, where it is scooped up and carried by a sand elevator which dumps it from above into the dry sand bin. From this bin it is fed to the engines through two telescopic sand spouts.

In the construction of the building, concrete mixed in the proportion of one part Atlas Portland cement to 2 parts sand to 4 parts broken stone was used. The side walls were designed on the basis of the computed lateral pressure exerted by bituminous coal weighing forty-seven pounds per cubic foot. This gave a maximum lateral pressure of two hundred and forty-eight pounds at the bottom of the pocket; and a vertical pressure on the bottom slab of nearly one thousand pounds per square foot.

Ash-handling Plants.—Inasmuch as wood burns and steel corrodes, it has long been a problem as to how to build ash-handling plants capable of withstanding the destructive effect of ashes quenched with water. The advent of reinforced concrete into the field of railroad construction has successfully solved this problem. At the present time most of the plants being built throughout the country consist of a steel framework which support bins constructed of reinforced concrete.

Roundhouses.—The adaptability of concrete to roundhouse construction is clearly demonstrated in the report submitted on that subject by the Committee on Buildings of the American Railway Engineering and Maintenance of Way Association, before the annual convention of that society held in Chicago, March, 1908.

For the purpose of discussion, the roundhouse was considered divided into Foundations and Pits, Roof, Supporting Columns, and Outer Walls; and excerpts from the report are given below in order named.

Foundations and Pits.—"While in some cases local conditions may favor the use of stone or brick for foundations and pits, it may be stated, as a general proposition, that good practice in roundhouse construction now requires the use of concrete for these parts of the structure. When a solid foundation cannot be obtained within a few feet below the floor level of the building a considerable saving may be effected by the use of reinforcement."

Roof.—"In economy of first cost, durability and fire-resisting qualities, there is no other fireproof roof construction which is equal to reinforced concrete. Steel except as a reinforcement for concrete, is not a satisfactory material for engine house roof construction."

Supporting Columns.—"If the roof is of reinforced concrete, it should be supported by columns of the same material in the outer and end walls, as well as in the interior of the building. These columns should be concreted with the roof, the concrete being run into the forms from above. The columns on the inner circle to which the doors are attached should be of some other material than concrete, preferably steel or cast iron."

Outer Walls.—"For a structure roofed with reinforced concrete, the curtain walls may be of brick, plain concrete, reinforced concrete, or plaster. Concrete will, if properly made, give good service and local costs of materials and labor would ordinarily determine which of the first three styles of curtain walls named above should be built. The plaster curtain wall may be used where it is desirable or necessary to reduce the first cost to a minimum.

"To build such a wall Portland cement is mixed with enough lime so that it can be worked with a trowel and is plastered on expanded metal. The latter is stiffened with rods and channel irons, which are used to support the window frames. A wall of this character can be built more quickly than a concrete wall, is efficient and should be durable. If damaged by a locomotive or otherwise, it is easily repaired, and alterations can be readily made. Used with concrete columns, it should not crack, and its first cost is but about half that of a brick wall."

Cost.—"The cost of concrete construction in roundhouses depends largely upon the number of times the forms can be used. If follows, therefore, that where the structure is large and the forms for each unit or stall can be used many times in the same roundhouse, the cost per stall is much less than in a small building. Consequently reinforced-concrete construction is more economical in large than in small roundhouses, when compared with brick or frame construction."

Turntable Pits, Tank Supports, and Bumping Posts.—"In connection with roundhouse construction the subject of turntable pits is of special interest. The facility and cheapness with which concrete pits can be built is so generally recognized that practically all turntable pits constructed to-day are built of concrete.

"Owing to its strength, rigidity, and resistance to fire and decay, reinforced concrete is well suited for the construction of water-tank supports."

Such supports are octagonal in form and consist of reinforced-concrete columns, strongly braced, and supporting a platform from 20 to 40 feet high. The columns may be reinforced with old rails or with the usual bar and hoop reinforcement. The platform should be about 9 inches thick, and strongly reinforced to sustain the weight of the tank.

"A bumping post, to insure safety against rotating or breaking down under constant buffing, should be constructed so as to be anchored in the earth direct rather than attached to the track itself, as is the case with practically all of the patented posts now in use on railways in this country. By the use of concrete, bumping posts can be constructed economically so as to meet the conditions of stability and permanence."

Concrete Ties and Roadbeds.—One of the most serious and perplexing questions which confront the railroad engineer of to-day is the tie problem. As an evidence of this, during the year 1907, the railroads of the United States used approximately 118,000,000 ties, a very large percentage of which were renewals.

This vast inroad upon the limited and rapidly decreasing supply of timber has caused wooden ties to become poor in quality and high in price, with the result that railroad engineers are beginning to realize the necessity of procuring a substitute. Many roads have been experimenting with concrete ties of various designs during the past few years. While none of these have been tested long

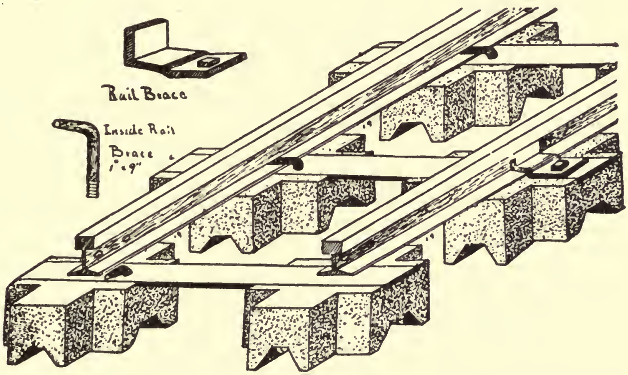


Fig. 107.—The Kneedler. One of Many Forms of Concrete Ties.

enough under heavy and high speed traffic to warrant the selection of any one as a proper substitute for wooden ties under all conditions the success of some of the ties tested thus far has been great enough to convince railroad engineers who have given the most study to the subject that a properly reinforced concrete tie with proper fastenings, is both practical and economical, especially for tracks where the speed is low and where conditions are adverse to the life of wood or metal. Without question concrete ties are entirely suitable and economical for use in yards and sidings and for this purpose alone there is an enormous field for their installation and use.

Concrete ties possess certain natural advantages over either timber or steel inasmuch as dampness, drawn fires, and insects have absolutely no effect upon them. In addition, they are practically independent of the steel and timber market, and can be made along the line of the railroad, and, as compared with the chemically treated timber or the steel tie, at a reasonable cost.

Concrete ties have been for about ten years in successful use in Indo-China, where a very peculiar species of ant destroys wooden ties in a few months. At the present time it is estimated that there are over 1,000,000 of these ties in service. They are of an inverted T-section, the flange of which is laid on the ground, the stem being vertical. The rails are fastened by bolts which are embedded in an enlargement of the stem where the rails pass. In Italy concrete ties have been tried with such success that the Italian government has recently placed an order with various manufacturers in Italy for 300,000 concrete ties.

In the design of a successful tie there are a number of important functions that seem to be more or less overlooked in many of the ties thus far built.

Cushion blocks, if used, should be removable, and the fastenings should be of such a nature that they will not tend to shake loose. They should also be easily accessible, so that they can be renewed when injured.

Inasmuch as automatic block signalling is being extended very rapidly upon practically all of the railroads, it is important that the rails should be insulated, and therefore it is necessary to place sufficient concrete between the metal in contact with the rails and the longitudinal reinforcement.

Many long ties have failed from the fact that they were not designed to act as cantilever beams, thus being unable to withstand the severe shocks coupled with the sinking of the tie under passing loads on centre bound track. The difficulty experienced with tie blocks has been in keeping them in longitudinal position and maintaining them so that the vertical deflection of one rail will not greatly exceed that of the other, thereby causing rolling and pounding of the equipment.

Finally, ties should be of sufficient strength to support derailed cars and engines until they are off the ends of the ties and actually into the ditch; otherwise, an ordinary derailment may become a serious wreck.

Solid Concrete Roadbeds.—While the original cost of a solid concrete roadbed is greater than the ordinary cross-tie construction, it is undoubtedly more economical in the end for tunnels and subways; especially if the space be cramped, traffic heavy, and a track cannot be temporarily abandoned; also where the running rails, guard rails, and third rails are attached to long ties (as in the case of electrified lines), it is extremely difficult and very expensive to maintain and tamp up track to surface and make tie renewals.

A solid roadbed can also be used to great advantage and economy in rock and earth cuts where there is always a large maintenance expense to keep ditches open and track in good surface.

In addition to the question of ultimate economy, the solid concrete roadbed is especially commendable for tunnel and subway

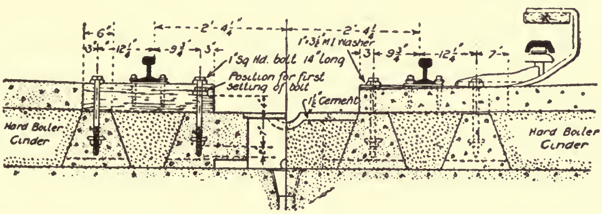


FIG. 108.—Concrete in Trackwork: Hudson Terminal Station, New York.

construction from a hygienic standpoint; for in most tunnels and subways ventilation is difficult and the accumulation of grease, dirt, and débris, which is readily held by the ballast of the cross-tie track construction, is a serious menace to the health of the passengers. This danger can be eliminated in the solid concrete construction, as the entire roadbed can be flushed with water and kept in a neat, clean, and sanitary condition.

Posts and Fences.—The growing scarcity and the increasing cost of suitable timber for posts has brought concrete into quite general use. Concrete posts possess the advantage over wooden ones not only of unlimited life, greater strength, and resistance to action of fire and decay, but also they present a more pleasing appearance.

It would seem that the concrete post is particularly adapted to railroad use. Most of the post machines are cheap and portable and the materials employed are in daily use on all roads using concrete. The materials are cheap and easily obtained.

The Lake Shore and Michigan Southern Railway use concrete whistle posts, made in moulds like blocks, which are 3 1/2 inches thick, 12 inches wide, and are set about 5 1/2 feet above the ground. The letters and signs are cast right in the post and are painted black.

In places where a substantial fence is required, ultimate economy, strength, durability, and a pleasing appearance can be attained by the use of reinforced concrete. Two types of concrete fences have been tried with success, viz., solid reinforced concrete and cement plaster on metal lath.

The solid type of fence generally consists of a vertical slab of reinforced concrete about 3 inches thick with a rounded moulding like a hand rail on the upper horizontal edge.

Telegraph Poles.—Owing to the increasing scarcity and inferior quality of wood, which has heretofore been used exclusively for telegraph and trolley poles, engineers have been experimenting with reinforced concrete for a number of years with the result that poles have been designed which are meeting the requirements in every way.

Among the advantages of the reinforced-concrete pole, the following are worthy of special mention: (1) Lines thus equipped have practically no trouble from lightning, the reinforcing rods apparently acting as conductors of electricity; (2) the poles require no preservative or paint to protect them from the ravages of the weather, as is the case with wood or steel; and (3) the material is elastic enough to withstand all ordinary shocks.

Tunnels and Tunnel Lining.—One of the most common uses of both plain and reinforced concrete is in the construction of tunnels and subways. The term tunnel, as generally understood by railroad engineers, is applied to construction under cover, in which the tunnel bore is advanced by drifting, the surface of the ground above the work not being disturbed. The term subway is applied to open cut construction. A tunnel for heavy and fast railroad traffic should be built with a concrete lining, and for still greater economy the roadbed should also be constructed of this material. The old Bergen Hill tunnel on the Lackawanna Railroad is lined with brick for a portion of its length, yet fourteen men are at work every night in the year inspecting the lining and repairing the track. This expensive and dangerous maintenance work, which costs annually about $6,000, is practically eliminated in the new tunnel described below, which is built with the entire lining and roadbed of concrete.

This tunnel is 30 feet wide in the clear, 23 feet 5 inches high from the base of the rail to the crown of the roof arch, and has a concrete lining of a minimum thickness of two feet. The length of the tunnel is 4,280 feet and at two points located at about one-third the length of the tunnel from each portal it is connected to the old tunnel, which is immediately alongside the new, by an open cut extending across the four tracks, 100 feet long and 80 feet wide.

At about the centre of the sections, into which these open cuts divide the tunnel, shafts 10 feet long and 30 feet wide were sunk to the new tunnel. These shafts and open cuts were used to good advantage in moving the waste material from the headings and they also greatly facilitated the work of placing the concrete lining.

Docks.—Inasmuch as practically every railroad system in the country owns valuable water front the question of dock construction is a most important one. The recent terrible fires with their attendant devastation along the water fronts of Hoboken and of Boston, have demonstrated only too clearly the absolute necessity of positive fire protection in structures of this nature. The new piers which the Delaware, Lackawanna and Western Railroad have designed to replace those burned down in the Hoboken fire of 1904 are to be built entirely of concrete construction from the cut-off of the piles.

In the tropics where the waters are infested with the teredo and limnoria terebrans, either of which will destroy a wooden pile in a few years, and where the very atmosphere itself eats away unprotected wooden and steel structures, reinforced concrete is especially adapted to the construction of wharves and warehouses. Practically all the docks of any magnitude now being constructed in South and Central America and the Philippines are designed as entire concrete structures.

Storage Reservoirs.—The advent of power construction into the field of railroad engineering incidentally introduces another problem for railroad engineers in the subject of storage reservoirs for supplying these plants with water.

Reinforced concrete has been used extensively in the construction of reservoirs, and when properly designed and constructed is a most suitable material on account of its durability and adaptability to lighter design than common masonry. For large or small tanks it is usually cheaper than steel and requires no repairs.

Reservoirs are built most economically of circular form, and all the tensile stresses must be taken by the steel hoops.

In building water tanks, the materials for the concrete must be very carefully proportioned so as to give a watertight wall, and the stone should be of such size that a good surface can be easily obtained. The proportions used to resist the percolation of water usually range from 1 : 2 : 2 to 1 : 2 1/4 : 4, the most common mixture being 1 : 2 : 4.

The concrete should be mixed so that it will entirely cover the reinforcing metal and flow against the form. It is absolutely essential that the concreting for the entire tank should be done in one operation, or else that the surface be specially prepared and treated to make water-tight joints.

Grain Elevators.—Reinforced concrete is especially adapted to the construction of grain elevators or other structures to be used for the storage of grain on account of its being absolutely proof against fire, water, or dampness, dust and vermin; which are all important and essential qualities of the ideal grain elevator.

Grain elevators may be grouped into two classes according to the arrangement of the bins and elevating machinery; viz., elevators which are self-contained, with all the storage bins in the main elevator or working house; and elevators consisting of a working house which contains the elevating machinery and storage bins connected with the working house by conveyors. Reinforced-concrete elevators are commonly built of the latter type, with a working house that is generally rectangular in shape with either square or circular bins connected with the independent storage bins, which are usually circular.

Concrete is being used in enormous quantities at the present time by all of the leading railroads in the United States. Prominent among these may be mentioned:

The New York Central and Hudson River Railroad in the construction of its new passenger terminal in New York.

The Pennsylvania Railroad in the construction of its new depot in New York, the tunnels under the North and East Rivers, and the yards at Long Island City.

The Chicago, Burlington and Quincy Railroad in connection with its track elevation work in Chicago, and in its work of replacing wooden with reinforced concrete trestles throughout its system.

CHAPTER XXIX

THE UTILITY OF CONCRETE ON THE FARM*

Advantages of Concrete for the Farmer.—Concrete Types Found on the Farm.—Posts.—Troughs.—Tanks.—Farm Drainage.—Cisterns.—Cess Pools.—Stalls.—Silos.—Miscellaneous.—Useful Hints for the Farmer.

Advantages of Concrete for the Farmer.—Concrete, both plain and reinforced, has provided the farmer with an entirely new building material. Indestructible, economical, and fireproof, it offers, under most conditions, features of advantage over every other type of construction. Concrete has long been recognized as the ideal building material for heavy construction and is now looked upon with equal regard for the purpose of the lighter forms of construction found necessary on the progressive and up-to-date farm.

During the past few years the price of lumber has advanced to almost prohibitive figures, and therefore it is natural that a substitute material which is both cheap and durable, sanitary and beautiful, should gain the recognition which it deserves.

The cost of concrete work is variable with the conditions under which the work is performed. It is generally cheap for the farm structure, because the work can be done by the farmer at odd times, with comparatively cheap help, as it is unnecessary to employ masons or carpenters.

The lumber for the forms is expensive, but it can be used again, generally, for other purposes. Contractors in concrete construction figure to save 30 per cent of the form lumber for subsequent use.

If the farmer hires carpenters and laborers to do the work, his concrete structure will have a larger first cost than wood construction, but it will neither decay nor burn and will be the cheapest in the end.

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* Partly condensed from "Concrete about the Home and on the Farm," published by Atlas Portland Cement Co. See also bulletins on Concrete Tanks and Concrete Silos published by American Association of Portland Cement Manufacturers.

The Utility of Concrete on the Farm

Concrete Types Found on the Farm.—A competent engineer or architect should always be employed or consulted in the preparation of plans for houses, barns, or other structures of any magnitude; but by carefully following authentic rules and specifications, the inexperienced farmer can safely undertake reinforced-concrete construction of simple structures.

Concrete is found on the farm in the following forms: Posts of all kinds, troughs and tanks for various purposes, walls of all descriptions, blocks of all styles, steps and stairs, side-walls, curbs, and gutters, drains, floors, stalls, and pens, silos, corn cribs and grain elevators, houses, barns, and cellars, and in many miscellaneous forms too numerous to mention.

Fence Posts.—Concrete fence posts may be considered as typical of post construction. They are generally made with a square or rectangular cross-section, the length depending upon the height desired above ground. The amount to be placed underground depends upon the depth of the frost line which is sometimes 3 or 4 feet. It is customary to make them slightly larger than the wooden posts which would be used for the same purposes, the average cross-section being about 25 square inches. The making of fence posts has already been described in Chapter XV.

Hitching Posts, Clothes Posts, Horse Blocks.—Hitching posts and clothes posts may be made in a similar manner, round if desired, and reinforced with 3/8″ iron rods if more than 7 feet long.

Horse blocks are so heavy that they are generally cast in place. An ordinary box form will serve the purpose. It is best not to plaster the top or sides, for it is apt to crack or peel off. Trowel the surface when the concrete is first laid. Care should be used in the preparation of a foundation to prevent unequal settlement.

Concrete Watering-Troughs.—A concrete watering-trough is one of the easiest and simplest tanks that can be made of concrete, and will never rot. They are frequently built not only in the barnyard or near the house, but, where large numbers of stock are pastured, they are built in the fields, to hold water from a small spring which would not otherwise be available.

Watering-troughs may be made with or without reinforcement, the difference being that between a 5- and 8-inch wall. Typical dimensions are 10 ft. long, 2 ft. wide, 2 ft. deep, 5 in. thick, which may be varied at will.

The reinforcement may be done by placing a 2 1/2 inch layer of concrete in the form, and immediately after placing and before the concrete has set, place a sheet of woven fence wire or some other wire fabric over the concrete, bending it up so that it will come to within one inch of the top of the forms at the sides and ends. Place 2 1/2 inches more of the concrete in the bottom and ram lightly to bring the mortar to the surface and smooth it off evenly. Have the inner form all ready and as soon as the base is laid and before it has begun to stiffen set it, taking care to keep it at equal distances

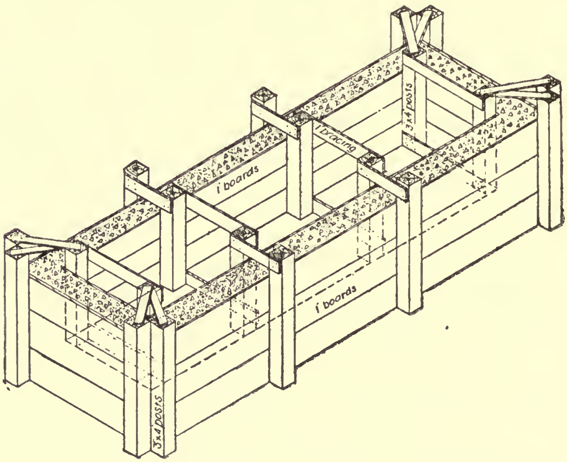

FIG. 109.—Watering-trough, Forms, and Bracing.

from the sides, and then immediately fill in the concrete between the outer and inner forms to the required height.

Small troughs have been built at as low a cost as $5.00.

Dipping Tanks, Hog Troughs, Slop Tanks, Fertilizing Tanks.—Dipping tanks for disinfection, hog troughs for feeding, slop tanks for heating food in cold weather, fertilizing tanks for containing fertilizing fluids, have all been made of concrete and have given satisfaction. Methods of procedure in such construction will readily suggest themselves.

Barn and cellar floors may be made after the manner of side-walks, the barn floor requiring a porous sub-base from 6 to 12 inches thick while the cellar floor can be laid directly on the earth which should be evened off and tamped hard. Waterproofing is sometimes desirable. Feeding floors of concrete have been found advantageous for the spreading of fodder.

Farm Drainage.—Farm drainage is an important problem and concrete its most practical solution. Drains may be made in place by digging a trench with sufficient grade to flush well, and setting forms of the shape of the inside of the drain, so that the concrete will be from 3 to 4 inches thick. If a tile drain is preferred, they may be made from concrete in the following manner: Use 1 part

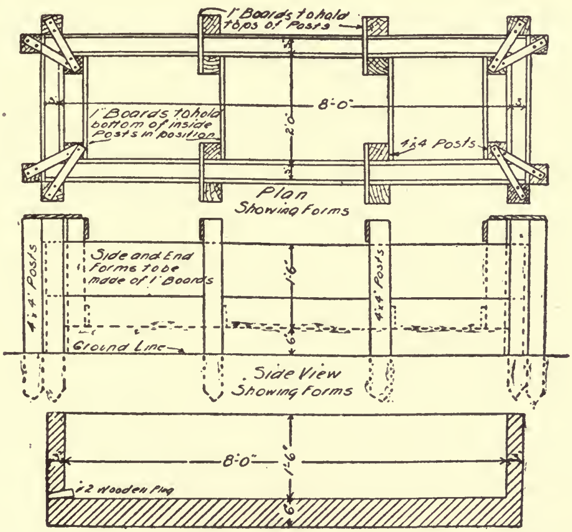

FIG. 110.—Forms for Watering-trough. Section through Centre.

of cement to 3 of clean sand. "One or two sets of forms with four or six tile each may be made so that they can be filled every morning, and in this way enough tiles can soon be on hand to drain a large acreage of land. The concrete tile should be made with a circular bore, and may be either circular, or square on the outside."

"Use ordinary stove pipe of the required diameter for the inside mould; this should project far enough above the top of the wood form so that a good grip can be had on it in order to remove it from the concrete. If desired, holes can be punched through the stove-pipe near the top and a rod placed through these holes in order to more easily withdraw the pipes. To keep the pipes in place when pouring the concrete for each tile, drive four nails in the floor or platform on which the tile are to be cast, leaving them projecting so as to locate the end of the pipe and keep it from getting out of position but yet not hindering its removal. The stove pipes must be thoroughly cleaned and greased each time they are used, and must not be dented or have any irregularities on them to make them catch."

"The time to remove the stove pipe core varies with the wetness of the mix and the temperature, but it should be pulled as soon as

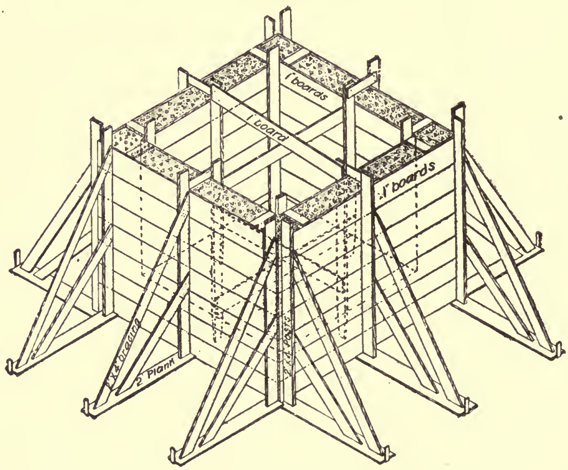

Fig. 111.—Forms for Square Trough.

the top of the concrete begins to harden, which generally is from one-half to one hour; if left too long it is very hard to get them out. The outside forms can usually be removed after two or three hours, or may be left until the next morning. To remove the wood forms, pull the protruding nails with a claw hammer, and carefully turn the whole tier on the side. Next draw out the other side with the partitions attached. If any of the forms stick, they can generally be started by tapping them lightly with a hammer; this applies as well to the stove pipe cores. Scrape the form carefully, re-oil, attach the long side and they are ready for a second filling."

Cisterns, Cess-Pools.—Concrete cisterns and cess-pools are of similar construction. "Make a circular excavation 16 inches wider than the desired diameter of the cistern, or allow for a wall two-thirds the thickness of a brick wall that would be used for the same purpose, and from 14 to 16 feet deep. Make a cylindrical inner form the outside diameter of which shall be the diameter of the cistern. The form should be about 9 feet long for a 14-foot hole, and 11 feet long for one 16 feet deep. Saw the form lengthwise into equal parts for convenience in handling. Lower the sections into the cistern and there unite them to form a circle, blocking up at intervals six inches above the bottom of excavation. (Withdraw blocking after filling in spaces between with concrete and then fill holes left by blocking with rich mortar.) Make concrete of one part Portland cement, two parts clean, coarse sand, and four parts broken stone or gravel. Mix just soft enough to pour. Fill in space between the form and the earth with concrete, and puddle it to prevent the formation of stone pockets, using a long scantling for the purpose and also a long-handled paddle for working between the concrete and the form. To construct the dome without using an expensive form, proceed as follows: Across top of the form build a floor, leaving a hole in the centre two feet square. Brace the floor well with wooden posts resting on the bottom of the cistern. Around the edges of hole, and resting on the floor described, construct a vertical form extending up to the level of the ground.

"Build a cone-shaped mould of very fine wet sand from the outer edge of the flooring to the top of the form around the square hole and smooth with wooden float. Place a layer of concrete four inches thick over the sand so that the edge will rest on the side wall.

"Let the concrete set for a week, then remove one of the floor boards and let the sand fall gradually to the bottom of the cistern. When all boards and forms are removed they can be easily passed through the two-foot aperture and the sand taken out of the cistern by means of a pail lowered with a rope. This does away with all expensive forms and is perfectly feasible. The bottom of the cistern should be built at the same time as the side walls and should be of the same mixture, six inches thick."

Box Stalls.—Box stalls of concrete are found to be warmer in winter and cooler in summer and so are held in high favor. Concrete barns with hollow walls are readily ventilated by utilizing the air spaces for that purpose.

Dairy.—The sanitary features of concrete make it an especially appropriate material for use in dairy construction. Being a non-conductor of heat concrete can be used to advantage when it is desired to build an ice box as a part of the building itself.

Concrete Silos.—During the past decade silos have come into universal use upon the American farm. A good silo must be air-tight, water-tight, smooth on the inside, and maintain an even temperature. A concrete silo meets all these requirements with the additional advantage of being vermin-proof and indestructible. There are three kinds of concrete silos, Solid Wall Monolithic, Hollow Wall Monolithic, and Concrete Block. The first type requires the least material, the second prevents freezing of silage in

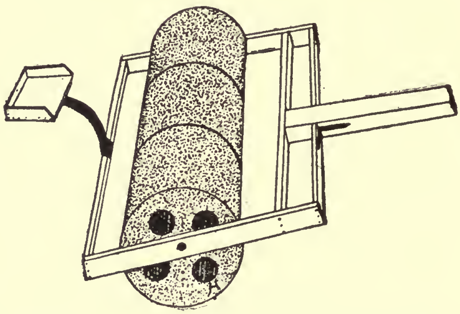

FIG. 112.—Handy Road Roller of Concrete.

cold climates, the third requires no forms to build. The relative cost will depend largely upon local conditions. Having selected the type of silo to build, the size is next considered.

The diameter of the silo depends upon the number of cattle to be fed daily, the height upon the number of days for which a supply of fodder is required. Ten head of cattle will consume thirty-six tons of silage in 180 days, requiring a silo of 10 feet in diameter and a height of 25 feet.

Seventy head will consume 252 tons in the same time and require a silo 19 feet in diameter and 40 feet high. Intermediate dimensions may be estimated proportionally. These figures provide for 40 lbs. per cow per day, at least two inches in depth of silage being consumed daily. The diameter of a silo should never exceed 20 feet, and is better too small than too large.

"The concrete-block silo is built of circular hollow blocks laid in cement mortar, and reinforced with steel hoops which fit in between every second or third course. When finished the silo is usually painted both inside and out with a cement mortar to insure air tightness. The block silo, like the hollow silo, has a dead air space in the walls which tends to prevent freezing. The principal advantage of the concrete-block silo lies in the ease with which it can be constructed.

"The hollow wall monolithic concrete silo is constructed much the same as the solid wall except that two walls are built instead of

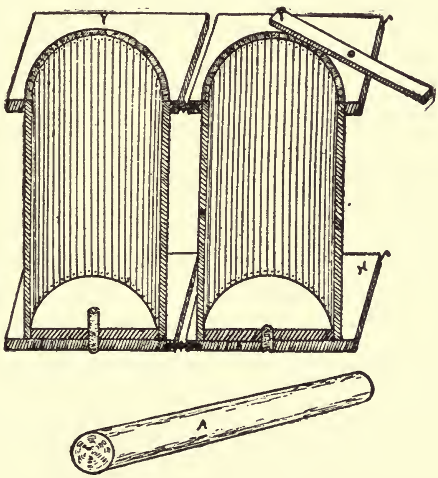

FIG. 113.—Wooden Form for Concrete Roller.

one with an air space of 4″ between them. The inner wall is reinforced." The only reason for the outer wall is to form the air space which prevents the silage from freezing.

The solid-wall silo is cheap and easily built and fulfills all the requirements of a perfect silo. This type is the one most frequently adopted. Its cost is about 25 per cent less than hollow-wall construction.

The average dimensions of a silo are 10 feet inside diameter and 25 feet in height. It is built in the following manner: Excavate to a depth of 4 or 5 feet and dig a circular trench one foot deeper for the foundation walls. Fill the trench with a 1:3:6 mixture and spread 4 inches more over the entire foundation. The earth under the footing should be dry and firm and the excavation well drained. If the foundation is poor the concrete base should be reinforced in the same manner as the walls. After the foundation and floor are complete, the remaining operations take the following order:

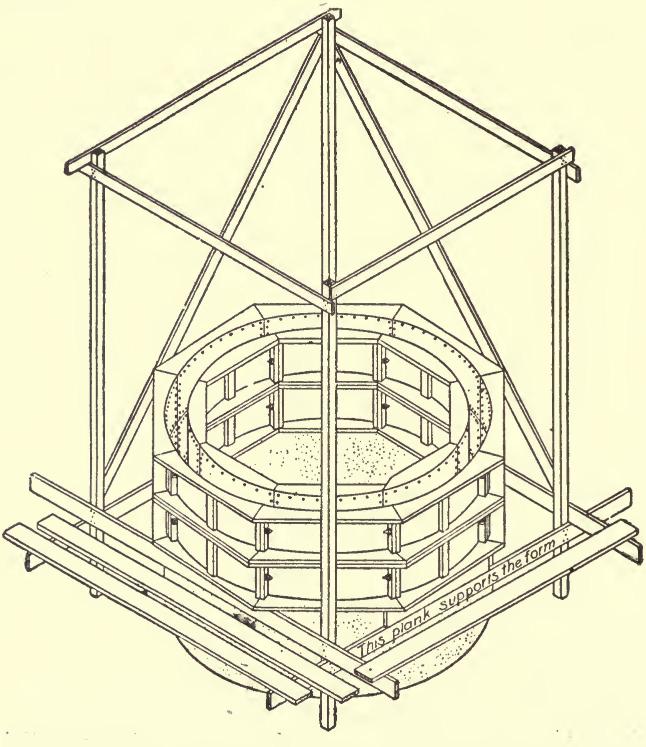

FIG. 114.—Forms and Staging for Concrete Silos.

1. The building and setting of forms.
2. The placing of the reinforcement.
3. The mixing and placing of concrete.
4. The removal, hoisting, and resetting of the forms.

The wall forms are circular and are placed six inches apart to give the proper thickness to the wall. Their height is generally three feet, which enables three feet of silo to be built without shifting the forms. After each three-foot section is complete the forms are loosened by means of adjusting bolts, raised by levers and reset by the bolts, this operation being repeated until the structure is complete. The forms consist of 2″ × 6″ plank cut circular and held together by 1″ × 4″ cleats, forming 2 complete circles held apart by 1″ × 4″ studding. The inside surface is then covered with sheet steel, No. 24 gauge or with 1″ tongued and grooved boards. Both outside and inside forms are constructed in the same manner. Screw bolts are used to pull together and separate the forms.

Reinforcement for Silos.—"The concrete reinforcing of the silo walls with small steel bars or steel wire must be done with accuracy and care, as the strength of the silo depends on the correct use of steel in the walls. The silo walls are reinforced in two directions; vertically, to prevent failure due to wind pressures, and horizontally to prevent failure due to the pressure of the silage. Silage is a heavy material and is estimated by the various State experimental stations to exert a side pressure of 110 lbs. per square foot for every foot in depth.

" Since the pressure in a silo increases with the depth, it is necessary to make the walls much stronger at the bottom than at the top.

"In no case should the horizontal wires or bars be placed over 18″ apart or the vertical more than 36″ apart. The horizontal reinforcement should be cut in one length, if wire, and the ends looped together and twisted back. If bars are used, the ends should be bent around each other at each lap. The extreme ends of the vertical reinforcement should be tied by bending around four extra strands of the largest wire used, two wires being placed 2″ below the top of the silo wall, and the other two in the centre of the silo footings.

"The vertical rods should be placed in short lengths, as it is very hard to handle the forms with rods running the entire height of the silo. These short lengths can be twisted or spliced together, as the wall is built up.

"In starting the vertical reinforcement in the footing use only 2′ 6″ or 3′ 0″ lengths, taking six inches to twist around the two horizontal tie rods or wires placed in the centre of the footings. This will leave 1′ 6″ to 2′ 0″ to stick above the finished footings.

"The next section of vertical reinforcement is tied to these short lengths, and they will not interfere with the setting of the concrete forms."

A roof should be made of 2″ × 6″ rafters set at a good pitch, and covered with 1″ sheeting; this in turn may be covered with galvanized iron, tin, or shingles. A hollow-wall silo is constructed in the same way, except that the forms are placed one foot apart and circular boxes used to form the air space as the concrete is placed.

TABLE XXXV.—DATA FOR REINFORCED-CONCRETE SILOS.
(Including 6-inch Floor.)

Height.	Inside Diameter.	Thickness of Wall.	Horizontal Reinforcement.		Cement, 1 Part.	Sand, 2 Parts.	Stone or Gravel, 4 Parts.
			Size.	Spacing C. to C.			
Feet.	Feet.	Inches.	Inches.	Inches.	Bbl.	Cu. Yd.	Cu. Yd.
10	5	6	¼	12	6½	2	4
10	10	6	¼	12	15½	4	8
15	5	6	¼	12	9½	3	6
15	8	6	⅜	12	15½	4	8
15	12	6	⅜	12	24	6½	13
20	8	6	⅜	12	19½	5	10
20	12	6	⅜	12	29½	8	16
20	15	6	½	12	38	10	20
25	10	6	½	12	27½	7½	15
25	15	6	½	12	45	12	24
25	20	6	½	12	62	16½	33
30	10	7	½	12	37	10	20
30	15	7	½	12	58	15½	31
30	20	7	⅝	12	80	22½	45
40	15	8	½	12	80	22½	45
40	20	8	⅝	12	114	30½	61
40	25	8	¾	12	147	38½	77

Place vertical rods same size as horizontal, 2½ feet apart.
A cubic yard is about 1½ single load or ¾ of a double load.

Concrete is also found in many other useful forms upon the farm, such as: well curbs, ice-houses, root and mushroom cellars, hen houses, green houses, flower boxes, cold frames, wind mill foundations, lawn rollers, porch steps and lattice, and chimney caps. Convenient uses for concrete in such domestic construction will occur to the builder's mind as necessity arises.

Useful Hints for the Farmer.—1. Always use the best Portland Cement obtainable.

2. Store your supply of cement in a dry place until ready to use.

3. Use sand that is both clean and well-graded. A large proportion of the grains should measure from 1/32 to 1/4 of an inch in diameter. If fine sand must be used, increase the amount of cement; that is, use a richer mixture.

4. If the sand is dirty, wash it.

5. If the gravel is dirty, wash it.

6. Before using the product of a gravel bank, screen through a 1/4-inch sieve and remix, using about twice as much stone as sand.

7. Use gravel or broken stone up to 2 1/2 inches in diameter for foundations and thick walls but limit the size to 3/4 inch diameter when reinforcement is to be used.

8. Avoid the use of soft stones in the aggregate.

9. Use clean water, free from alkalis.

10. Use enough water to give the concrete the consistency of heavy cream.

11. For ordinary work use a 1 : 2 : 4 mix.

12. For forms, use white pine, fir, yellow pine, or spruce and green timber if possible.

13. Grease the inside of the forms with soap, linseed oil, lard, and kerosene, or petroleum.

14. Omit the greasing if the surface of the concrete is to be plastered, in which case, wet the forms just before placing the concrete.

15. Lay sheathing or form boards horizontally. Place studs 2 ft. apart for 1 in. sheathing and 5 ft. apart for 2 in. sheathing.

16. Brace the forms securely.

17. Do not drive the nails all the way home, but let the heads project so that they may easily be withdrawn.

18. Keep forms from bulging or separating by the use of bolts or wire.

19. Place concrete in forms in layers from 6 to 12 inches thick. Spade and tamp.

20. After removing the forms, concrete which is exposed to the sun should be soaked with water each day for a couple of weeks.

21. In laying the concrete in hot or freezing weather, use the precautions outlined in Chapter VII.

SECTION VI

IMPORTANT MISCELLANEOUS DATA ON CONCRETE CONSTRUCTION

CHAPTER XXX

THE WATERPROOFING OF CONCRETE STRUCTURES

The Necessity for Waterproofing.—Modern Methods of Waterproofing.—General Conditions of the Work.—Principles to be Followed.—The Membrane Method in Detail.—The Integral Method in Detail.—Waterproofing by Means of Surface Coatings.—Tabular Outline of Modern Waterproofing Processes.

The Necessity for Waterproofing.—In many of the forms of construction work to which concrete is so admirably adapted, its use brings with it one inherent fault—a fault for which remedies have long been sought, but which, until recent years, have not been found in a practical form suited to all the varied needs of modern construction. This striking fault of concrete work is its great thirst for water, a fault which varies in its gravity according to the proportioning and mixing of materials and to the nature of the structure, it frequently being the cause of extremely serious difficulty. Of all the opposing forces which constructors have had to combat from time immemorial, none has exceeded in its power for evil the unwelcome intrusion of water, and building materials which in their nature favor such intrusion must suffer in value to the extent of their permeability or absorptive power.

The fact that in practice, concrete is frequently found to be porous and permeable has been one of the leading checks in its rapid development. Volumes have been written on how the ingredients might be mixed to produce a watertight concrete, but we might as well seek to solve the problem of perpetual motion as to try to mix cement, sand, and stone so as not to *absorb* water.

The Waterproofing of Concrete Structures

If we could examine a section of concrete under a powerful microscope, it would appear to us like an immense sieve through which fine particles of water flow with more or less freedom.

We have seen water rise up through concrete walls for many feet, and it will rise until the weight of the water absorbed is equal to the capillary attracting force.

As already stated in Chapter VII, if concrete is mixed rich and mixed wet, a high degree of impermeability can be secured. Mixing rich imposes greater barriers to the passage of water; mixing wet minimizes the formation of blowholes by displacing much of the extrained air, but neither mixing rich nor mixing wet destroys the "capillary positive" property of the concrete mass. Its absorptive capacity has been largely decreased, but its attraction for moisture has, however, not been eliminated; thus the water-tightness secured by rich and wet mixtures, however theoretically correct the proportions might be, is one of degree only, a degree sometimes approaching ideal but never reaching it. We cannot expect that a mixture made of cement and stone, each of which is in itself "capillary positive," or water-attracting, can become absolutely proof against the *absorption* of water by the mere act of mixing, unless, indeed, the operation had produced some phenomenal change in the very nature of the constituent materials. By care and diligence, a mixture may be produced which is sufficiently close-grained to prevent the free transmission of water, prevent it sufficiently, in fact, to be all that is required in many forms of construction work. But where water *absorption*, besides water *penetration*, is to be absolutely prevented, no degree of mixing, no richness of mixture, will altogether answer the purpose; and yet in many of the forms in which concrete enters our modern buildings, it is resistance to water *absorption* that is required. Not merely water-tightness in the ordinary sense of the word, but resistance to the ceaseless endeavors of atmospheric moisture to find its way by capillarity through porous bodies. Some counteracting influence to this tendency of ordinary concrete to take up water by capillarity, is, therefore what is required when *dampness* is to be eliminated.

It is true that concrete exposed to the free passage of water becomes after a time so clogged up by fine silt present in the water that the permeability is greatly reduced; and Hagloch states that concrete-block buildings exposed to the weather become water-tight in from three to twelve years, a fact which we must likewise ascribe to the clogging of the surface of the blocks by atmospheric dust deposited by rain, and which remains after evaporation.

Modern engineering or architectural practice should certainly not sanction a practice of waiting for the erratic and uncertain hand of time where it is essential to secure water-tightness and damp-proofness in concrete structures, and in the meantime to incur the annoying consequences that always accompany damp and leaky structures; and yet this is precisely what is being done in numberless instances by those who refuse to realize the importance of water-tightness in concrete work, or while realizing it, are willing through motives of false economy, to gamble with the future—nearly always at their loss.

The number of mistakes made by inadequate provision for waterproofing, and their costly consequences, running into thousands of dollars, should serve as object-lessons to those who have the design of concrete work in hand and the same degree of attention and study should be given the subject of water-tightness as that given to other details of construction.

The importance of the subject and the scarcity of literature concerning it has induced the author to cover the subject in greater detail than would otherwise be necessary.*

Method of Conducting the Work.—*Work Under Contract.*—Waterproofing work should be done, if possible, under contract by a specially skilled waterproofer, or by the concern making or supplying the material.

In a large proportion of cases, the actual construction is left largely to a contractor, sometimes under a more or less loose guarantee; often under no guarantee at all, and frequently without the least supervision being exercised on the part of the owner. In case of trouble after the completion of the work, the owner may consider himself fortunate if he happens to have a guarantee from a responsible contractor who values his reputation for good work as much as he does the cost of remedying the trouble. It is usually not a difficult

* Much of this chapter has already appeared under authorship of Myron H. Lewis in *Cement Era* for 1909–1910, at whose special request the material was prepared and is here rearranged with their permission.

matter for a contractor to disclaim responsibility and endeavor to shift the burden, particularly where the cause of the difficulty cannot readily be ascertained, and where several independent contractors were at work on various parts of the job at the same time. Any interference or injury to the waterproofing by any but his own men, and without his knowledge, will naturally tend to absolve the waterproofer from direct responsibility.

Any deviation from the plans and specifications forming the basis of the contract, failure to lay protecting masonry when required, necessary openings made for pipe passages through walls without the knowledge of the waterproofer, will likewise relieve the latter from his contract in case of future trouble. This division of responsibility has often been the cause of endless annoyance, delays, and expensive litigation. A competent inspector who would look after all the details of the waterproofing from the time preparation of the surfaces begin until final completion of the work, would avoid a great deal of such trouble. If a record is kept of all the work as it progresses, the responsibility for any future trouble may then be traced with some degree of certainty. Without such record, which is more often omitted than kept, establishment of direct responsibility is a difficult matter.

Work Not Under Contract.—A great deal of waterproofing and dampproofing work must of necessity be done, not by contract, but by the purchase of materials and using same according to directions. Where the work to be done is not large, and where the services of an experienced waterproofer are not available, this method must be employed, although, as a rule, it is not so advisable as having the work done by contract, owing to the unfamiliarity of the purchaser with the material and method of application.

In all waterproofing work a great deal of judgment and patience must be exercised if good results are to be obtained, and where materials are not applied by the manufacturer or by one specially familiar with same, the purchaser or owner should see that the material purchased is delivered, and that it be used in accordance with full and explicit directions furnished by the manufacturer or dealer. Conditions on different jobs of waterproofing vary so much that the trade literature accompanying materials cannot be expected to give sufficient information to cover all conditions, and consequently the purchaser in ordering material should describe to the dealer in detail the character of the waterproofing work he has in hand, and request that material and directions be sent specially adapted to that particular work. The usual vagueness and indefiniteness of such descriptions always gives rise to unnecessary delays, errors in shipments, and often in failure of the work.

Importance of Adequate Inspection.—Thorough inspection is particularly essential in the bituminous shield or membrane method, where the waterproofing is to be covered or backed up by protecting masonry or other material, and thus cannot be readily reached for repairs. In dampproofing exposed walls of buildings by application of an asphaltic coating on the interior surface of the walls, inspection should also be particularly rigid as failure means the removal of the plaster covering. Furthermore, the difficulty in tracing sources of leakage when the waterproofing is covered up makes the repair work more uncertain and costly.

On large works particularly, materials specified for waterproofing purposes should be subject to the same degree of inspection and tests as other construction materials. There is nothing easier than the substitution of poor materials for good ones by irresponsible contractors or dealers, particularly when the price is much below the standard price for like materials. So many of the coal tar and asphaltic preparations look alike, that the quality of the material delivered can be ascertained only by subjecting them to specified tests, fixed according to the character of the work in hand. Waterproofing felts and other fabrics should also be examined for defects, and powders and other materials to be introduced as a part of concrete work should be tested and compared with samples obtained, to see that the material ordered is actually delivered.

So many instances of failures due to various causes have occurred that it might be well before proceeding to the detailed consideration of various systems of waterproofing, to review briefly the important points to be considered in general to obtain permanency and efficiency.

The following general principles, if carefully followed, will result in an economical, durable, and efficient work:

The Waterproofing of Concrete Structures

GENERAL PRINCIPLES TO BE FOLLOWED IN ALL WATERPROOFING

1st. In deciding upon a system of waterproofing for any particular structure, study the individual conditions of the problem in hand. Consider the location, climate, service, nature of soil, foundation, and all other pertinent data and adopt a plan best suited for the necessities of the case. The "Tabular Outline" at the end of this chapter will materially assist in deciding on the method to employ under given conditions.

2nd. The portions of the structure to be treated must be so designed and prepared that the waterproofing may be properly applied thereon; allowing sufficient working room for securing good surfaces and providing for adequate drainage where water pressure is to be taken care of during construction.

3rd. Complete, unbroken continuity of the waterproofing stratum must be obtained, being allowed for in the design and insisted upon in the construction. Any breaks in the continuity of the work will surely be disclosed in time by leaks.

4th. The material as well as the design should be suited to the individual conditions of the work, and the delivery of the material ordered should be proved by tests and comparison with samples previously submitted.

5th. Where the designer or owner is not familiar with this class of work, alternative plans and estimates may be called for from several responsible concerns and submitted to an impartial architect or engineer qualified to pass judgment on same.

6th. Where work is to be done by the immediate purchaser of materials, complete and explicit instructions should be obtained from the dealer upon written request and in conformity with the conditions outlined by the purchaser, and these instructions should be rigidly followed.

7th. The labor employed in all waterproofing work should be intelligent and careful and wherever possible experienced. The most satisfactory way is to have materials applied by a representative of the manufacturer under a guarantee and under supervision of a competent inspector.

8th. On all large jobs a competent inspector should be present from the inception of the work to its completion, and nothing should be done, and no tampering or interference allowed without his knowledge.

MODERN METHODS OF WATERPROOFING

Numerous methods and materials are now available to keep water and dampness out of almost any structure, and under the most trying conditions, and failure to secure water-tightness at this date must be looked upon as a mistake on the part of some one; either the designer, constructor, or inspector.

All the methods may, however, be embraced in three general classes, as follows:

1. The "Membrane" or "Elastic" method; a term introduced by E. W. DeKnight. (See page 350.)

2. The "Integral" or Rigid, a term introduced by Myron H. Lewis, in 1907, while editing the *Waterproofing Magazine.* Both of these terms have since been widely accepted by leading writers on the subject. (See p. 359.)

3. Surface Coating. (See p. 366.)

These methods are defined in detail in the treatment which follows:

THE MEMBRANE METHOD OF WATERPROOFING

The term "membrane method," as employed by De Knight, refers to an elastic, continuous, bituminous, impervious sheet or membrane which completely surrounds the structure to be waterproofed. This method is adapted principally to waterproofing structures in course of erection, particularly those portions below ground, such as subways, tunnels, building-foundations, retaining-walls, arches, reservoirs, etc. It is not so well adapted to waterproofing structures already erected, or to remedy leaky conditions in same, or to damp-proofing exposed walls of superstructures. Other methods must be adopted for these conditions and these will be considered later.

Materials.—The materials employed in the membrane method of waterproofing are:

1. Coal tar pitch (applied hot).
2. Commercial asphalts (applied hot).
3. Specially prepared asphalts and compounds sold under various trade names (applied cold).
4. Asphalt mastic (applied hot).

When merely dampness is to be excluded, any of the first three

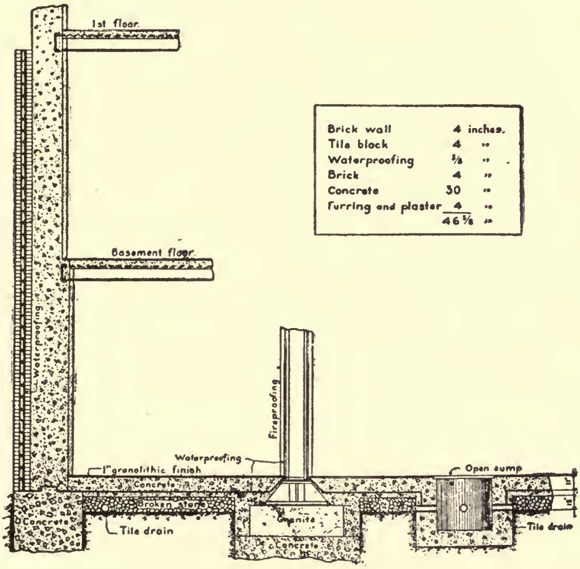

FIG. 115.—Section of Building Substructure, showing the "Membrane" Method of Waterproofing. (The Waterproofing Co.)

named materials may be employed, two or more coats being put on to insure thoroughly covering the surfaces.

When water is to be excluded, these three materials are employed as cement or binders in conjunction with either of the following fabrics:

(*a*) Tarred felt.
(*b*) Asphalted felt.
(*c*) Burlap (ordinary).
(*d*) Burlap (saturated with asphalt).
(*e*) Combinations of felt and burlap.

The cement or binder acts as the waterproofing agent, and the fabric acts as a reinforcement, in addition to its water-resisting properties (when the fabric is a saturated material).

The binding material and fabrics are applied in alternate layers, one layer of fabric coated on both sides with the binder or cement, forming one "ply." The number of ply to be used depends upon the local conditions and the head of water to be resisted. The following table gives approximately the number of ply required for various heads of water, using the material stated:

TABLE XXXVI.—Giving Number of Ply of Waterproofing Required for Varying Heads of Water.

Head of Water.	Material.			
	Coal Tar and Felt.	Commercial Asphalt and Felt.	Special Felts and Compounds.	Asphalt Mastic.
0	2	2	1	¼ in. thick
1	3	3	2	⅝ " "
2	4	4	3	⅝ " "
6	5	5	4	⅝ " "
8	6	6	5	¾ " "
10	7	7	6	¾ " "
15	8	8	7	¾ " "
20	9	9	8	¾ " "

For bridges, 4- to 7-ply, depending upon character of traffic; or a mastic about 1 inch thick; or part mastic and part felt and cement.

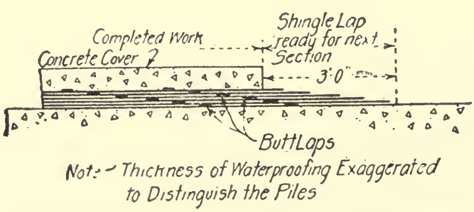

Fig. 116.—Showing Arrangement of Laps in 6-Ply Waterproofing. "Membrane Method."

The inspector should be careful to observe that the number of ply or thickness called for in the plans and specifications is actually put into place.

Quality of Material.—Both the cementing materials and the fabrics, in order to be serviceable for waterproofing operations, must be elastic and durable and retain these properties through the range of temperature to which they may possibly be subjected after being placed in the work.

In order that materials of the desired quality be obtained, certain requirements are usually outlined in the specifications, and it is incumbent on the inspector to see that these requirements are fulfilled as far as it is within his power to do so. Laboratory tests should be made on the material delivered on the work to determine whether the physical and chemical requirements are satisfied.

Typical Specifications for Bituminous Materials.—The following examples illustrate some of the requirements on important work. The New York Rapid Transit Subway has this specification:

Coal Tar Pitch.—Shall be straight run pitch which will soften at 70° F., and melt at 100° F. The distillate oils, distilled from the required grade of pitch, shall have a specific gravity of 1.105.

The requirements for coal tar pitch on the Pennsylvania-Long Island Railroad are similar:

Asphalt.—(*a*) Must be best grade of Bermudez, Alcatraz, or Lake of equal quality.

(*b*) It must be either a natural asphalt or a mixture of natural asphalts.

(*c*) Must contain in the refined state not less than 95 per cent natural bitumen soluble in rectified carbon bisulphide or in chloroform.

(*d*) Not less than two-thirds of the total bitumen shall be soluble in petroleum naphtha of 70° Baumé, or in acetone.

(*e*) The asphalt shall not lose more than 4 per cent of its weight at a temperature of 300° F., when maintained for ten hours.

(*f*) No injurious ingredients shall be present.

An excellent set of requirements for obtaining a good asphalt is found in the specifications of the Chicago and Northwestern Railroad. These are as follows:

1. The asphalt must be free from coal tar or any of its products.

2. Must not volatilize more than one-half of one per cent under a temperature of 300° F., maintained for ten hours.

3. Must not be affected by:

A 20-per-cent solution of ammonia.

A 25-per-cent solution of sulphuric acid.

A 35-per-cent solution of muriatic acid.

A saturated solution of sodium chloride.

4. Must not show any hydrolitic decomposition when subjected, for a period of ten hours, to hourly immersions in water with alternate rapid drying by warm air currents.

5. Range of temperature:

(*a*) For metallic structure exposed to direct rays of sun.

Flow point not less than 212° F.

Brittleness—Must not become brittle at 0° F., when spread on thin glass.

(*b*) For underground structure such as masonry arches, abutments, retaining walls, building foundations, etc.

Flow point, 185° F.

Brittle point, 0° F.

(*c*) Mastic made from (*a*) or (*b*) must be pliable at 0° F.

Must not perceptibly indent under load of 20 pounds per square inch when at temperature of 130° F.

6. Preparation of the asphalt.

(*a*) Care should be taken that the asphalt is not "pitched." This will take place if heated above 450° F. The inspector can tell when this point is reached by the change in color of paper from a bluish tinge to a yellowish tinge.

(*b*) The inspector can further test for the sufficiency of the cooking by putting in and withdrawing a stick of wood. The asphalt should cling to it.

(*c*) Should pitching occur, fresh material should at once be added to reduce the temperature.

(*d*) When delays occur in the work and pitching is to be prevented, the fire should be banked or drawn and fresh material added to reduce the temperature.

The weight is also a distinguishing feature between the various materials and will aid the inspector in his work. They are approximately as follows:

Coal tar, 63 pounds per cubic foot.

Coal tar pitch, 75 pounds per cubic foot.

Trinidad asphalt (natural), 80 pounds per cubic foot.

Trinidad asphalt (refined), 93 pounds per cubic foot.

A good coal tar pitch for waterproofing should weigh 70 to 80 pounds, and a good asphalt 90 to 95 pounds per cubic foot.

The relatively low melting-point will readily distinguish whether a coal tar is being substituted, when asphalt is specified, and in addition to the weight and flowing-points the characteristic odor of the tar will detect substitution.

Adulteration of the asphalts with cheaper petroleum products and substitution of domestic asphalts for the Trinidad or other foreign brand usually specified, will also make itself known in the lower flowing-point and lower flaming-point, the petroleum oils decreasing these points in accordance with the amount present.

When bituminous products are specified and delivered under trade names and are to be applied cold, the flowing-point cannot be used as a factor so readily, but such material should also be tested for brittleness under low temperature, and stability at high temperature and acid tests should be made to determine their immunity from ready attack by acid present in the ground water.

Specification for Asphaltic Felt.—The felt must be saturated and coated with asphaltic products and must conform to the following requirements:

(*a*) The weight per 100 sq. ft. shall be from 12 to 14 lbs., saturated, and from 5 to 6 lbs. unsaturated.

(*b*) The weight of the saturation and coating shall be from 1.25 to 1.75 times the weight of the unsaturated felt if coated on both sides, and from 1 to 1.5 times the weight of the unsaturated felt if coated on one side.

(*c*) The saturation shall be complete.

(*d*) The ash from the unsaturated felt shall not exceed 5 per cent by weight.

(*e*) The wool in the unsaturated felt shall not be less than 25 per cent by weight.

(*f*) Soapstone or other substances in the surface of the felt to prevent adhesion shall not exceed .5 lb. per 100 sq. ft. of felt.

(*g*) The saturating and coating materials shall remain plastic after being heated to 250 degrees Fahr. during 10 hrs. The coating not to crack when the felt is bent double at ordinary temperature.

(*h*) The felt shall be soft, pliable, and tough when received from the factory and until placed in the work.

(*i*) The quotient obtained by dividing the tensile strength in pounds of a strip 1 in. wide, cut lengthwise, by the weight in pounds of 100 sq. ft. shall not be less than 7.

(*j*) The quotient obtained by dividing the tensile strength in pounds of a strip 1 in. wide, cut crosswise, by the weight in pounds of 100 sq. ft. shall not be less than 3.5.

(*k*) The strength saturated shall be at least 25 per cent more than the strength unsaturated, taken lengthwise.

The inspector should see that all the material delivered arrives in unbroken packages and contains the proper label of the manufacturer as specified.

Application of Materials in the Membrane Method.—In the application of the materials, certain fundamental requirements must be fulfilled upon which the final success of the work will largely depend, and it is the duty of the inspector to see that such requirements are fulfilled. These requirements may be conveniently classed under three headings, thus:

1. Preparation of surface.
2. Continuity of work.
3. Protection of waterproofing.

Preparation of Surface.—It is difficult to make a bituminous sheet adhere to a surface that is either too rough, too wet, covered with dirt or foreign matter or possessing too fine a glaze due to richness of cement surface. It is, therefore, necessary to see that:

(*a*) All dirt and foreign matter are removed before waterproofing is applied.

(*b*) That an adequate drainage system is installed and maintained, and that the wall is dry when the waterproofing is applied.

(*c*) In case complete dryness cannot be secured, a layer of felt in addition to those called for in the specifications is first laid against the surface.

Some specifications require that asphalt cut with naphtha shall first be applied cold.

(*d*) The surface should be smoothed off with a trowel, if too rough.

(*e*) In case wall is of concrete, that the concrete be thoroughly set.

(*f*) In case wall is covered with a fine skin of cement, see that it is roughened up to insure sticking of material.

(*g*) Sharp projections on the masonry should be removed or they will puncture the waterproofing.

(*h*) Metal surfaces should be dry and clean, free from rust, loose scale, and dirt. If previously coated with oil, same should be removed with benzine or other suitable means. Warming may be accomplished by heated sand, which is removed as material is applied.

FIG. 117.—Method of Waterproofing Retaining Wall.

Continuity of Work.—Lack of continuity will be fatal to any waterproofing work, as water is sure to find its way through any breaks, however small. In order to secure proper continuity, see that:

(*a*) The waterproof sheet is applied continuously over the whole surface to be treated as shown on the plans; thus in building substructures it should be applied over all footings, walls, cellar bottoms and on the outer face of all foundation walls.

(*b*) That all joints are broken properly at least 4 inches on cross joints and 12 inches on longitudinal, and at least 12 inches lap left at corners to form good connections with adjoining sections.

(*c*) Where it is necessary to stop work, laps of at least 12 inches should be provided for joining on new work.

(*d*) Each layer of pitch, asphalt, or other cementing material must completely cover the surface on which it is spread, without cracks or blowholes or other imperfections.

(*e*) The fabric must be rolled out smoothly and pressed over the cementing material, so as to insure its sticking thoroughly and evenly over the entire surface.

(*f*) In connecting side wall with floor work, the layers of the fabric on the sides should be carried down on the outside of the ends of the floor layer and lap at least 24 inches.

(*g*) In connecting side wall and roof work, the layers of fabric of the roof should be carried on the outside of the sidewall layers with at least a 24-inch lap.

(*h*) Before new work is added to old, the inspector should be careful to see that the old surface is cleaned of all foreign matter, such as cement, mortar, or other substance which finds its way thereon. After cleaning the laps, they must be well covered with fresh cementing material before new layer of fabric is placed against it, and the new fabric should be made to stick smoothly and evenly over entire joint area.

Protection.—After the waterproofing has been put into place,

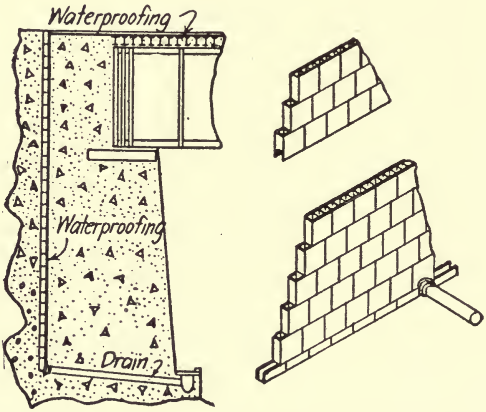

FIG. 118.—Draining and Waterproofing Tunnel Wall.

it must be properly protected against injury from any cause whatever. Such injury is liable to occur by puncturing when:

(*a*) Backfilling with earth.

(*b*) Depositing concrete against same.

(*c*) Laying brickwork or rubble against same.

Lack of protection may also cause:

(*d*) Bulging of waterproofing from wall.

(*e*) Cracking of same due to bulging.

(*f*) Running of material due to heat.

(*g*) Injury due to frost particularly when materials, brittle at low temperatures, are used.

Injury from any of the above causes may be avoided by placing against the waterproofing a protecting layer of cement mortar mixed in the proportions of 1 part cement to 2 1/2 parts sand.

This safety coat should be placed as soon as possible after the laying of the waterproofing, not exceeding 12 to 24 hours. Failure to place such protection, if called for in specifications, will be sufficient cause for relieving the waterproofer of responsibility, if under a guarantee.

When this safety coat is omitted, and backing of earth or concrete, brick or stone masonry is to be laid immediately against the waterproofing, the greatest care must be exercised that the sheet is not punctured by sharp corners of stones or bricks.

When brick work is placed against waterproofing on vertical walls, a slight space may be left for slushing in with mortar to avoid puncturing. The bricks should not be rammed up against the waterproofing sheet.

Injury to the waterproofing might also occur when the hydrostatic pressure is very large, and insufficient weight has been placed upon same to secure it against displacement by such pressure.

Protection of the waterproofing should not stop with placing the backfilling on same. Tampering with it should be absolutely forbidden. When openings or incisions in the sheet are necessary, the inspector should be notified, and he must see that such places are repaired in the most thorough manner. All pipe passages should be pocketed and connections thoroughly made. Such places should not be covered up until the work has been examined by the inspector and found properly executed.

THE INTEGRAL METHOD OF WATERPROOFING

The term "Integral" refers to those methods wherein the waterproofing material becomes an integral part of the structure treated. It includes:

I. The various methods employed in making concrete and masonry impermeable per se:

By properly grading the materials and

(*a*) The addition of special materials to the water used in tempering the cement, or

(*b*) The addition of special materials, dry, to the cement, or (*c*) The use of a cement waterproofed in the process of manufacture.

II. The application of materials thus prepared as a plaster or coating to the surfaces to be treated, such coating becoming an integral part of the structure.

The Integral method is distinguished from purely surface applications, in that the latter are applied as a paint, and while some of the materials penetrate to a considerable extent, periodic renewal is required when exposed to the elements, although, with some of the materials, renewals may not be required for many years.

Adaptability of the Integral Method.—The "Integral" method of waterproofing as above outlined, is adapted to treatment of numerous conditions. In the form of the coating, it is particularly adapted to remedying leaky conditions in substructures already erected, where excavations would be too costly and inconvenient.

Although the logical place to apply waterproof cement coatings is on surfaces exposed to the water, yet owing to the inaccessibility of the outer surfaces for examination and repairs, the coatings are applied to the inner surfaces as shown in Fig. 117. It will withstand any ordinary water pressure in this position, if the work is properly executed.

In mass concrete work, imperviousness may be secured, as already stated, by the simple expedient of carefully grading the materials, proper mixing, and the rational use of reinforcement and expansion joints to prevent the development of cracks. For many conditions, no further treatment is necessary. Where, however, capillary absorption is to be prevented, and where even dampness or slight leakage is objectionable, the introduction of special materials in the work is advisable.

In many cases, either the Membrane or Integral methods may be employed with equally good results, and the selection of type must be made by the designer, after comparing their cost.

Addition of Waterproofing Material to the Concrete.—Concrete, even when mixed according to the most rigid rules and under the most competent supervision, often falls short of its purpose in resisting water penetrations. This condition, and the inherent attraction of concrete for water, has resulted in the appearance on the market of a large number of compounds having the express purpose of obviating these objections. The compounds are of a proprietary nature, and the composition is kept secret by the makers. The designer not familiar with them should make his selection of material only after carefully investigating their merits.

These compounds may be grouped in four classes:

1. *Powders.*—Added dry to cement before mixing. These are usually of white, floury consistency, extremely fine, and are water-repellant. The water-repellant properties are imparted by the introduction of a metallic stearate, such as lime soap, which is of a fatty nature. Being so extremely fine, they have a distinct void-filling property, and their uniform distribution in the cement must give a denser mixture. In addition to the metallic stearates, they contain varying proportions of alum and hydrated lime. The latter materials are themselves extensively used to densify and waterproof concrete work.

2. Cements are now manufactured under several patents, where by the addition of special materials and special treatment a water repellant cement is obtained.

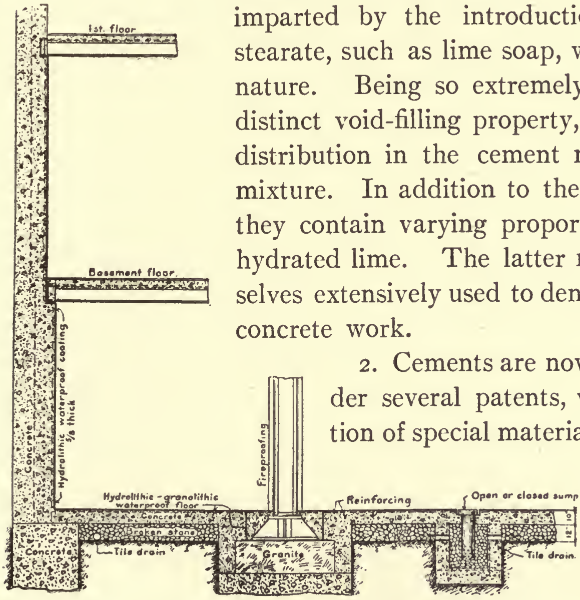

FIG. 119.—Section of Building Substructure showing the "Integral" Method of Waterproofing.

3. *Liquids.* — Added to water employed in tempering the cement. These are various forms of metallic salts, such as chloride of lime and oil emulsions. Soap solutions are also employed for this purpose. In the case of the liquids, the waterproofing property is imparted by the formation of gelatinous coatings about the minute particles of the concrete. Lime soaps, suspended in the water, are also employed.

4. Combinations of liquids and powders. The most frequent form is the addition of alum dry to the cement, and the mixture of soap solution to the water employed in tempering the cement. This is usually referred to as the "Sylvester" mixture. In this case

waterproofness is imparted by the precipitation of insoluble compounds in the voids.

Where any expensive work is to be undertaken, and the employment of any of these compounds is contemplated, tests should be carried on to determine:

1. The effect on the strength of the concrete.

2. Their behavior when subjected to extreme ranges of temperature.

3. Their immunity to decomposition by various acids, etc., liable to reach the concrete.

4. The effect of admixture of the materials to steel, embedded in concrete.

These materials being usually purchased under trade names, and their composition being secret, there is little that the inspector is capable of doing in regard to them. He should, however, satisfy himself that the material specified is being used on the work, by identifying the packages, and noting that they are unbroken, and contain the proper trade-marks.

He should have the directions furnished by the manufacturer, see that they are explicitly followed, and allow variations only in case unforeseen conditions are encountered, and where special instructions to cover them are not at hand.

When the work is being done by the manufacturer or his representative under a guarantee to secure water-tightness, the inspector should give the latter free rein to follow his own methods, providing they are in conformity with the general contract. He should, however, keep a complete and reliable record of the progress of the work for future reference.

Workmanship.—As previously stated, the treatment may consist of adding waterproofing material in the body of the concrete, or in a coating or plaster applied to the surfaces to be protected.

In either case the essential requirements for good work are:

1. Homogeneity of mixture.

2. Continuity of work.

3. Soundness or freedom from cracks, etc.

When applied as a coating a further requirement is:

4. *Bond.*—A uniform and efficient bond of coating to concrete or masonry surface must be secured.

Homogeneity.—The inspector should see that the waterproofing material is uniformly distributed throughout the work. Irregular distribution will result in weak spots, which should be avoided as much as possible.

Continuity.—He must see that all portions called for on the

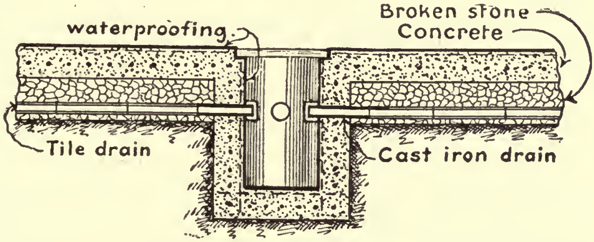

FIG. 120.—Details of Sump Employed in the Integral Method of Waterproofing. Sump may be Sealed or Open as Required.

plans receive waterproofing treatment. Any omissions will break the continuity of the work and will nullify the object which the designer had endeavored to attain.

Soundness, Freedom from Cracks, Etc.—These are essential requirements in successful waterproofing work by the Integral

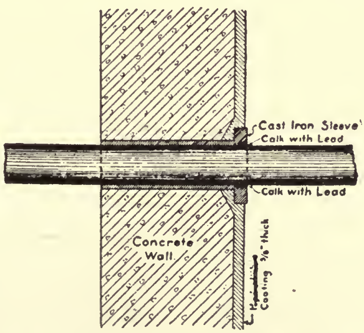

FIG. 121.—Passing Pipe Through Concrete Wall. Method of Making Water-tight Joint.

method, and they should be minimized by the use of expansion joints and reinforcements. The inspector should be particularly careful that the plans are properly carried out in this respect.

Bond.—As already stated, the bond is an important matter where the waterproofing is done by the application of a coating of specially prepared cement mortar to the concrete or masonry surface. The coating should be homogeneous, continuous, sound, and uniform. A good bond will require:

1. Correct mixture of the coating materials.
2. Proper condition of surface to receive the coating.
3. Thoroughness in application.
4. Careful connection of one day's work to preceding.

INSTRUCTIONS FOR APPLYING WATERPROOF CEMENT COATINGS

In order to carry out the above provisions the following directions are added: A powdered material is here taken as an example, although most of the directions apply equally as well whatever character of compound is to be employed. This method of procedure is followed by some of the leading contractors doing this class of work, and if intelligently carried out, a durable and watertight job will be secured.

1. **Preparation of Coating.**

(*a*) To each bag of cement add dry the waterproof compound called for in specifications in percentage directed by manufacturer. Manipulate until the appearance and color indicate that a uniform mixture has been obtained.

(*b*) Mix the cement thus waterproofed with sand in proportion of 1 cement to 2 sand. Sand to be absolutely clean and well graded from coarse to fine. Sand need not be sharp. Sand is to be moistened, waterproof cement spread over it, and the whole manipulated until a homogeneous waterproof coating mortar is obtained.

2. **Preparation of Surface.**

(*a*) The old concrete surface should be thoroughly chipped not more than two days prior to application of the coating. The chipping may be greatly facilitated by a previous application of muriatic acid or a bonding compound, the strength of the solution depending upon the age of the wall; or the use of the bonding material may be deferred until the chipping has been completed.

(*b*) In case acid or bonding powders have been employed, all unspent acid should be removed by rigid application of the hose, immediately after the acid treatment has reached a satisfactory stage.

(*c*) The dust, dirt, and loosened material must be completely removed, either by patient scrubbing with stiff brushes, water nozzle, steam jet, or other suitable means. An absolutely clean surface should be obtained, not more than twenty-four hours ahead of the application of the coating.

(*d*) All holes should be filled up, large holes with the waterproof concrete, and small holes with waterproofed mortar. Before filling the holes, the old surfaces should be drenched and slush coating applied, as described below.

(*e*) Just before the main cement coating is to be applied, the entire wall should be drenched and soaked to its full absorbing capacity.

3. Application of Coating.

(*a*) Before the wall shows marked signs of drying a slush coating should be applied quickly and uniformly with a palmetto. This slush coating should be made by a thorough mixing of waterproofed cement in water, to the consistency of cream.

(*b*) Before the slush coating has dried, the first application should be applied as a scratch coat, one-fourth to three-eighth inch thick, and pressure brought on the trowel to push the coating on, to form a uniform bearing. The scratch coating should be made by mixing one part of waterproofed cement to two parts of clean, well graded moist sand, and enough water to obtain proper consistency.

(*c*) The scratch coat should be trowelled to a fairly good surface and scratched before hardening.

(*d*) Upon the scratch coat, before its final setting, the finishing coat of sufficient thickness to obtain a total thickness of five-eighths inch should be applied. This should be pushed on hard and uniformly trowelled and floated to a true surface, free from pin holes, projections, or other defects. The composition of the finished coating shall be one part waterproofed cement to two parts sand, well graded and previously moistened.

(*e*) If not feasible to apply finishing coat until after the scratch coat has already set, the latter must be thoroughly rinsed and slush-coated before finishing coat is applied.

(*f*) The floating of the finished surface shall be done from the bottom of the wall up.

(*g*) When the work has been completed all bad and defective work shall be cut out and replaced in the same manner as above described.

(*h*) When the work has thoroughly hardened, sounding with a light hammer over the wall should be resorted to, to discover any loose or hollow portions, and same must be cut out and replaced.

(*i*) In leaving a portion of work for the day, the section being finished should be left with straight edges. When the new work is to be started the old edges are to be roughened up by chipping and roughing with the trowel and the same rinsed and slush-coated, as already described.

WATERPROOFING BY MEANS OF SURFACE COATINGS

The third or "Surface Coating" method remains to be considered. In this method, the materials are applied as a paint to the surface to be treated, and are presumed, upon completion, to form a barrier to the passage of water.

Applicability.—Owing to the comparatively low cost and ease of application, this method of waterproofing has been widely adopted and often, unfortunately, under conditions where it had no right to be employed.

It should *not* be employed to keep water out of basements or substructures of buildings, particularly when subject to water pressure; its function in building work being to *damp* proof more than to *water* proof. Its use under ground can be justified only where no permanent water is present and ground dampness merely is to be kept out. Its principal uses are:

1. To keep water and dampness out of *superstructure* of buildings.

2. To preserve building materials and structures from decay due to absorption of water and other atmospheric impurities, and avoid staining of stone and efflorescence.

3. To avoid and remedy leaky conditions in tanks, conduits, and other water-containing structures.

Materials.—A large variety of materials is on the market for waterproofing by this method, but they may be all conveniently included in five distinct classes. A large proportion of them are made on secret formulas and sold under trade names and substitution of inferior materials is often tempting, owing to the wide variations in price.

The materials employed as surface coatings may be grouped in the following classes:

1. Soap and alum mixtures applied in alternate coats, popularly known as the "Sylvester" process.

2. Paraffine and other mineral bases, applied cold (in solution), or paraffine in melted condition.

3. Specially prepared bituminous products.

4. Cement grout, with or without the addition of water repellants.

5. Miscellaneous materials of unknown composition.

All of the above, except class 3 (bituminous products), are applied to the surfaces directly exposed to the action of water. In the case of class 3, the application is made to the *inner* surface of exposed building walls, its function in this position being not only to dampproof, but to serve as an insulating film against rapid changes of temperature; and also to replace furring and lathing, as plaster may be directly applied thereon. This is particularly so in the case of brick walls. Furthermore, the material being protected from the elements, a long life is assured.

The Sylvester Process.—This process has been principally employed and is mainly adapted to coating the surfaces of tanks, conduits, and other water-carrying structures, to render them tight. It has also been employed for treating concrete roofs and walls with varying success. The process consists of alternate applications of solutions, the first, third, etc., coats of soap, and the second, fourth, etc., of alum.

Proportions.—For soap solution—3/4 lb. castile soap to 1 gallon of water. For alum solution—1 lb. alum to 8 gallons of water.

The following precautions should be observed:

1. The soap and alum should each be perfectly dissolved before using.

2. The surfaces should be clean and dry.

3. The soap solution should be applied first.

4. The soap solution should be boiling hot.

5. A flat brush should be used.

6. Care should be taken to avoid frothing.

7. The first coat to remain on 24 hours, or until it is dry and hard.

8. Temperature of air to be not less than 50° F. at time of application.

9. Alum solution to be about 60° to 70° F.

10. Alum solution, second coat to be applied thoroughly over the first coat.

11. Second coat allowed to remain 24 hours before third coat (soap solution) is put on.

12. Two or more coats of each should be employed, depending upon exposure, pressure, and other local conditions.

The Sylvester process imparts waterproofness by the formation of insoluble compounds due to chemical action between the soap and alum solutions, the compounds filling the pores.

Paraffine.—*Cold Process.*—Applicable to all classes of masonry above ground, whether old or new; adapted to protecting against decay, and preventing either leakage or absorption of water. Material is paraffine specially treated and dissolved in volatile carrier, in saturated solution. A translucent liquid leaving the surface to which it is applied the same in appearance as before. Efficient, easily applied, and inexpensive; covering capacity about 125 square feet to the gallon on first coat, and about 175 feet to gallon on second coat; two coats required. Materials best obtained from manufacturers all ready for use. Has a high penetrating capacity into masonry surfaces, and after application volatile carrier evaporates, leaving paraffine in the pores.

Precautions to be employed on the work:

1. See that the material specified is being used.

2. Obtain explicit directions from manufacturer and follow them.

3. Surface to be treated should be smooth and freed from all projections. Holes to be filled up.

4. Surface to be clean and thoroughly dry, not only on surface but all the way in.

5. Material to be applied thoroughly; well rubbed in, filling all corners, recesses, etc.

6. At least two coats to be applied.

7. In severely exposed locations three coats are advisable.

8. Fire should be kept away from the material during application.

Paraffine.—*Hot Process.*—In this process, the walls are first treated with artificial heat and when sufficiently warm, melted, hot paraffine wax is thoroughly rubbed in. This is one of the most durable of all the waterproofing methods for work exposed to the weather and for the preservation of building stones. It must necessarily be applied by those specially equipped for and experienced in the work.

Bituminous Process.—Employed for dampproofing exposed building walls of superstructures by application to the interior surface of such walls; for underground work to prevent absorption of ground dampness, and also for coating the covered faces of building stones to prevent staining and discoloration due to leaching of salts from masonry backing.

Materials must possess a high degree of elasticity and durability, and when used on walls, must have a gripping power so that plaster can be directly applied thereon.

Materials specially prepared for these purposes obtained ready for use under various trade names.

Precautions to be observed on the work:

1. See that the material specified is employed.

2. Obtain directions of manufacturers and follow them.

3. Surface to be clean and dry.

4. Two coats to be applied.

5. First coat to be allowed to set up before second is applied.

6. Work to be well rubbed in in corners and recesses and continuous throughout.

7. When plaster is to be applied directly on waterproof film, wall surface should be left rough to obtain good bond.

8. Work to be kept exposed as little time as possible after completion.

9. In applying plaster upon film see that latter is not in any way injured.

Cement Grouting Processes.—Plain cement grout has often been employed for a waterproof coating, but owing to the fact that such coatings will absorb water by capillarity and also on account of the difficulty of making such coatings adhere without peeling, they are not to be highly recommended. Several excellent prepared cement grouts are on the market which have been treated with water repellants, and, having high penetrating qualities, they assist the bonding to the masonry surfaces. They are sold under trade names and are employed to impart a flat finish in various colors to concrete surfaces, as well as to dampproof.

Miscellaneous Materials.—Numerous other materials are on the market for the purpose of waterproofing superstructures. The composition is secret and when they are employed the inspector should follow the directions of the maker. He should, however, see that in any case at least two coats of any material are applied. It is almost impossible to obtain a surface free from pinholes and other defects, on the first application.

Workmanship.—Whatever method is employed the inspector should always see that the surface is properly prepared and that the application is continuous throughout. Any omissions at corners, cornices, around windows and other points easily accessible may prove fatal to the final success of the work.

As for the preparation of surfaces, they should always be clean and free from foreign matter. Where cement coatings are employed and the waterproofing depends upon the setting of the cement, the surfaces should be *damp* or *wet*, so that the water necessary for the setting will not be absorbed by the masonry. Where the waterproofing depends upon the penetration of the material into the pores, the surface should be *dry* to increase the penetration as much as possible.

Surfaces should generally be smooth, holes filled up and projections removed. Projections are likely to be injured by scaffolding and to admit water at such points. Not only does a smooth surface make the application easier and more certain, it is also more economical in material.

In the bituminous process, however, where the material is applied on the inner surface of exposed walls and plaster is to be applied directly on the waterproof film, the surface should be rough. This is necessary in order that the plaster may properly bond to the treated surface. Joints in brickwork form excellent keys for such bonding and have been taken advantage of. A large number of brick buildings have been treated by this process.

HOW TO USE THE TABLE

The accompanying table has been prepared with a view of condensing into small space the principal features of modern water-

TABLE XXXVII.—Outline of Modern Waterproofing Processes.

METHODS AVAILABLE FOR VARIOUS STRUCTURES.

	Nature of Structure.	During Construction. (New Work.)	Remarks.	After Construction. (Old Work).	Remarks.
Buildings.	Exposed Walls	D	For Damp Proofing Only		
		B, C	For Damp Proofing and Preservation of Stone.	B, C	D { Principally for Brick and Stone Walls, Not Advisable on Smooth Concrete Walls
	Superstructural Floors	I,K,J,G,M	For Bath Rooms and Floors Liable to be Wet	G, M	
	Foundation Pits	I, J	For Resisting Dampness Only	G	For Dampness Only or Pressure Work
	Foundation Trenches	I, J	For Resisting Dampness Only	G	
	Foundation Footings, Walls, and Floors	I, J	For Resisting Dampness Only	G	
	Walls, Reinforced	G,K,L,M	For Resisting Water Pressure	G, M	For Resisting Water Pressure.
	Walls, Not Reinforced	K,L,M	For Resisting Water Pressure	G	For Resisting Water Pressure.
	Floors, Reinforced	G,K,L,M	For Resisting Water Pressure	G	For Resisting Water Pressure
	Floors, Not Reinforced	K,L,M	For Resisting Water Pressure	G, M	For Resisting Water Pressure.
	Column Footings Heavily Loaded.	O			
	Concrete Block, etc.	G,B,C		B, C	
	Preservation of Stone	B,C	Also for Preventing Efflorescence	B, C	
Railroads.	Subways and Tunnels	K,L,M,G		G, H	
	Bridges	N,K,L,M		G, M	
	Culverts	E, F		G, A, B	
	Retaining Walls, Arches	E,F,K,L		G,A,B,H	
		E,F,K,L,M		G,A,B,H	
Water Supply and Sewerage.	Reservoir Banks	K,L,M		K, L, M	
	Dams	E,F,H			
	Conduits	E,F,G,		A, B	
	Tanks	G, F, B		B, A	
	Chambers	G, F, B, A		G, B, A	
	Sewers	E, F, K			
	Manholes	F, G		G, H	
1	2	3	4	5	6

TABLE XXXVII. (*Continued.*)—INDEX AND DESCRIPTION OF METHODS.

Method	Classification.	Material Employed	Manner of Application.	Position in Structure.	Thickness, Etc.	Remarks.
A	Surface Coating	Solutions of Alum and Soap (Sylvester Process)	As a Paint	On Exterior Surface.	4 to 7 Coats	Applicable to New or Old Work; Not to Underground Work.
B	Surface Coating	Paraffine in Saturated Solution.	As a Paint	On Exterior Surface.	2 to 3 Coats	" " " Also a Preservative for Building Stone
C	Surface Coating	Melted Paraffine Wax Applied Hot	As a Paint	On Exterior Surfaces (Surfaces Previously Heated)	Penetrates $\frac{1}{4}$ to $\frac{1}{2}$ inch.	Also a Preservative for Building Stone
D	Surface Coating	Proprietary Bituminous Compounds, Applied Cold	As a Paint	On Interior Surface	2 Coats	Used also as a Substitute for Furring and Lathing
E	Integral or Rigid	Masonry or Concrete Correctly Proportioned				Available Only During Construction
F	Integral or Rigid	Masonry or Concrete Correctly Proportioned with Cement Water-Proofing Compound	In the Body of the Work			Available Only During Construction.
G	Integral or Rigid	Cement Mortar with Compound	As a Plaster or Stucco	On Interior Surface	1″ to 2″ on Floors $\frac{1}{4}$″ to $\frac{5}{8}$″ on Walls	For New Work or Remedying Defective Work.
H	Integral or Rigid	Cement Mortar or Bituminous Grout	Pumped under Pressure	In Interior of Mass.		Employed Principally to Fill Voids Otherwise Inaccessible
I	Membrane or Elastic	Asphalt or Coal Tar Pitch with Felt or Burlap	In Alternate Layers	On Surfaces Exposed to Water	1 to 3 Ply	Applicable Only During Construction for Subsurface Work. To Resist Dampness Increase Thickness According to Pressure.
J	Membrane or Elastic	Proprietary Bituminous Compounds, Applied Cold with Felt or Burlap	In Alternate Layers	On Surfaces Exposed to Water.	1 to 3 Ply	
K	Membrane or Elastic	Coal Tar Pitch Applied Hot with Felt	In Alternate Layers	On Surfaces Exposed to Water	2 to 10 Ply	For Water Pressure Work.
L	Membrane or Elastic	Asphalt Applied Hot with Felt or Special Fabrics	In Alternate Layers	On Surfaces Exposed to Water	2 to 8 Ply	Asphalt Not to be Used in Ground Polluted by Gas Drip, etc.
M	Membrane or Elastic	Asphalt Mastic or	As Plaster or Coating	On Surfaces Exposed to Water	$\frac{1}{4}$ Inch to 1 Inch	
N	Membrane or Elastic	Asphalt Mastic Alternating with Saturated Felt Layers		On Surfaces Exposed to Water	$\frac{1}{4}$″ to 1″ Mastic 2 to 5 Ply Felt	Useful Particularly for Bridge Waterproofing Subject to Vibration.
O		Sheet Lead or Copper		Under Column Footings		Used as Substitute for Felt When Column Loads Are Very Heavy.
7	8	9	10	11	12	13

proofing processes as applied to varying conditions, and to enable one having a waterproofing problem to solve, and not familiar with the subject, to pick out the method most suitable without having to read up the whole subject.

As previously stated, the method must be suited to the conditions of the problem if good results are to be had. In numerous cases more than one method may be employed with good results and in such cases the methods have been given in order of their desirability. Local conditions, however, may make the order of preference different.

Use of the Table.—The table is divided into 13 columns as numbered on bottom.

Columns 3 and 5 give the methods of waterproofing for the different structures listed in columns 1 and 2. These methods are listed by key letters as *A*, *B*, *C*, etc., the essential features of which are described in columns 7 to 13.

Column 3 gives the method of waterproofing that may be provided for in plans and specifications for new structures or which may be employed before the construction work has advanced too far.

Column 5 gives the methods available for the structures already erected and for remedying leaky conditions in such structures. The fact that a method is not listed in column 5 means that it is not advisable to use it for old structures.

As a practical example in using the table, suppose it is desired to dampproof the walls of a new brick building which is to be erected and also to waterproof the foundation, which is in wet ground.

To Find the Method from the Tables.—Look up columns 1 and 2 for exposed walls; methods given are *D*, *B*, and *C*, in order of desirability. Now look in column No. 7 and those following for description of the methods *D*, *B*, and *C*.

For the foundation to resist water pressure under walls, *G*, *K*, *L*, *M*, are given in order of desirability, but *G* is omitted if walls are not reinforced. The remarks point out some special features such as for *L* and *M*, "Asphalt not to be used in ground polluted by gas drip, oils, etc., that injuriously affects it. This is an important precaution."

It is not claimed that the arrangement of methods will in all cases be decisive or that some methods not listed may not be employed; but the use of the table will prevent such glaring but frequent mistakes as using a surface coating for sub-surface work or using a wash on the inside of cellar walls, to waterproof against pressure and in other ways prevent the use of wholly unfit methods.

APPROXIMATE COST OF WATERPROOFING

The following table gives approximate cost of different classes of waterproofing which may be used as a basis for comparing relative economy of the methods selected from the table:

A.—Sylvester process, 1/2 cent to 4 cents per square foot.

B, D.—Dampproofing masonry walls, 2 coats applied in place, 2 cents to 4 cents per square foot.

C.—Melted paraffine, 5 cents to 8 cents per square foot.

F.—Adds about 10 per cent to the cost of untreated mass concrete.

G.—Cement coatings with waterproofing compounds; 1 in. on floors, 1/2 in. to 3/4 in. on walls, 8 cents to 30 cents per square foot, depending upon conditions.

I.—Hot coal tar, pitch, and felt. Horizontal surfaces: first ply, $2 to $4 per square (100 sq. ft.); additional plys, $1.50 to $2.50 per square; vertical surfaces add 10 per cent to 25 per cent.

J.—Cold process, felt or burlap, same as commercial asphalt.

K.—Pressure work, 1 ply, $4 to $5 per square.

L.—Commercial asphalt and asphalt felt, add 15 per cent to 60 per cent per ply, depending upon conditions.

L.—Special asphalts and felts, add 30 per cent to 50 per cent per ply.

M.—Asphalt mastic, 1 in., 15 cents per square foot.

CHAPTER XXXI

GROUT, OR "LIQUID CONCRETE," AND ITS USES

Preparing and Mixing Grout.—Mixing Machines.—Various Uses of Grout.

Uses of Grout.—Grout, or "Liquid Concrete," as it is sometimes called, is a thin, watery mortar, composed either of neat cement or of cement and sand mixed in different proportions. Its principal uses are as follows:

1. As a mortar for cementing the joints in masonry, after the stones have been laid.

2. For consolidating loose stones, rocks, or riprap.

3. For depositing concrete under water.

4. For waterproofing tunnels by injection behind the lining.

5. For stopping springs and leaks.

6. As a paint for coating concrete walls, either for surfacing or for dampproofing.

7. As a surface coating in thicknesses of from 3/4 to 1 inch for beams, walls, slabs, etc.

8. As a wearing coat for sidewalks, curbs, cellars, etc.

9. For bonding new to old concrete.

10. For levelling up the bedplates of engines and other machinery.

11. As a filler for paving blocks.

12. As a protective coating for iron and steel.

13. For surfacing pipes and conduits to decrease their resistance to the flow of water.

14. For cementing anchor bolts into their sockets.

Preparing and Mixing Grout.—Grout as ordinarily employed is composed either of neat cement or of cement and sand in proportions of 1 : 1 or 1 : 2. The best method of mixing grout by hand is first to mix the cement or cement and sand to the consistency of stiff paste on an ordinary mixing-board; then place in a tub or bucket and add water in small quantities until the paste is reduced to the consistency required. To facilitate the mixing, the paste should be well stirred while the water is being added. To prevent the grout from becoming stiff through partial set and thus becoming sluggish as well as weak, the material should be poured as soon as possible after the mixing. When poured from any height, it is desirable to employ neat cement or rich mixtures, as there is a

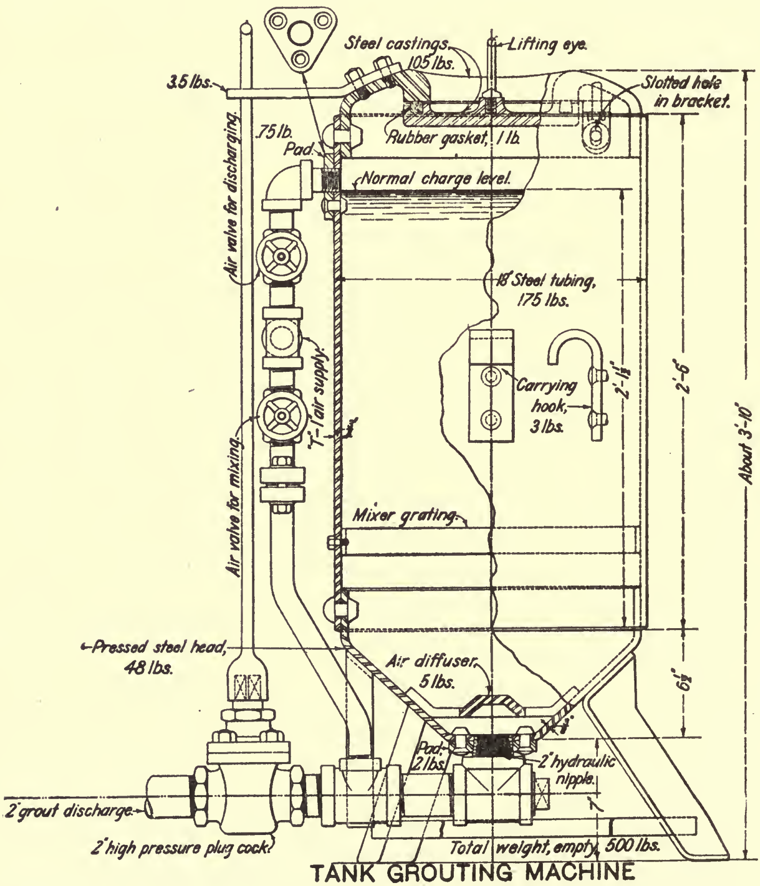

FIG. 122.—Grouting Machine Used by Board of Water Supply, New York.

tendency for the cement and sand to separate and form separate layers.

The quantity of water required for grout depends upon the class of work in which it is employed. Where the interstices through which it is to be poured are small, it must be made thin and watery, otherwise it cannot be forced beneath the upper layers of rock. When the interstices are large or the grout is applied under pressure, a thicker mixture can be used. It is always desirable to employ as thick a grout as can be forced into the cavity which it is intended to fill, since a thin grout becomes weak and porous after the water has evaporated.

Where grout is used in large quantities, machines are employed for mixing, and the grout is forced through pipes under pressure.

Grout Mixing Machines.—Grout mixing machines are of two general types: (*a*) tank mixers and (*b*) paddle mixers.

In the tank machine, grout is mixed by blowing in air at the bottom of the tank, and the material is ejected by turning the air in at the top and forcing the grout through a hole in the base. In this type, there are no stuffing-boxes or shafts carrying revolving paddles to wear out by the grinding action of the cement.

The so-called paddle-mixing machines consist in general of a closed steel box of cylindrical shape, about two feet in diameter. Through the axis of the cylinder a shaft is fitted. The shaft makes about 30 revolutions per minute and carries about six double paddles which thoroughly mix the ingredients. The time of mixing occupies about three minutes. After mixing, air pressure is admitted to the cylinder and the grout is discharged by means of a flexible hose connected with the cylinder. In grouting the dry stone packing between the tunnel and rock of the East River Tunnel for the Rapid Transit Subway between Brooklyn and New York, a pressure of 90 pounds per square inch was employed, the high pressure being required to force the grout against the hydrostatic pressure due to the depth of the working.

Cementing Joints.—Grout is employed to some extent for cementing the joints in rubble masonry, but for this purpose its use is not recommended. When so employed the interior of the wall is laid up dry. The grout is poured on top of the wall and is expected to find its way downward and fill all voids. The difficulty with this method is twofold. If the grout is made thin, it becomes porous and weak, and if made thick, it fills only the upper portions of the wall. Better results are obtained by inserting pipes into the body of the wall at several points and forcing in the grout under pressure.

Grout was formerly employed in this way in the construction of bridge piers, where it was customary after laying the large backing stones in place to fill the vacant spaces with broken stone of various size and then pour in as much grout as would work its way into the voids. Such methods are, however, no longer in vogue for first-class structures, where each stone is thoroughly bedded in cement mortar before the next course is laid.

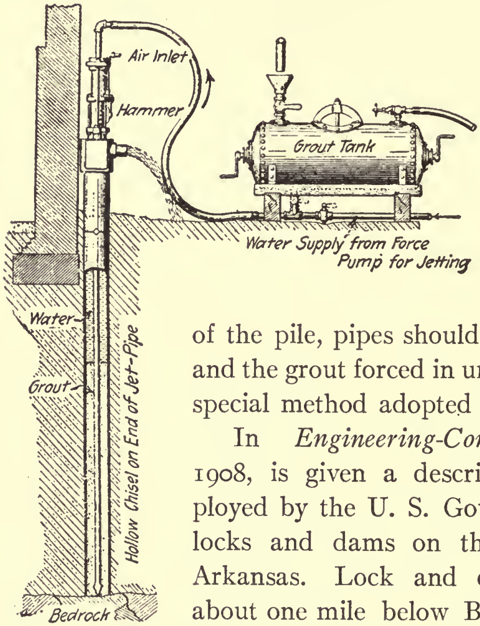

FIG. 123. — The Clark Steel Pile Filled with Grout. Showing Arrangement of Apparatus for Driving.

Consolidating Riprap.—Grout is legitimately employed for the purpose of consolidating loose stone or riprap. In order that the liquid mortar may properly fill the voids in the bottom of the pile, pipes should be inserted into the mass and the grout forced in under pressure, or else some special method adopted for obtaining this result.

In *Engineering-Contracting*, for May 6, 1908, is given a description of the methods employed by the U. S. Government in constructing locks and dams on the upper White River in Arkansas. Lock and dam No. 1 were located about one mile below Batesville, Ark. The locks were of concrete masonry while the dam was a timber crib structure weighted down with stone, and provided with a concrete apron. The lock was at one end of the dam, and a concrete T-shaped abutment was built at the other end to protect the shore end of the structure from erosion.

The foundation for this abutment consisted of a timber crib, formed of 10 × 10 in. squared timbers, with interior pens varying in size from 5 × 10 ft. to 10 × 12 ft. These pens were filled with "one-man" stones to weight down the structure, the filling averaging 11 ft. in depth. The stones were then consolidated by filling the interstices with Portland cement grout.

The method of applying the grout was as follows:

Before the filling was commenced, open-ended square boxes, 8 × 8 ins. inside dimensions, were perforated with 1 1/2 in. holes and placed on end about 10 ft. apart. These were the distribution boxes for the grout. Inside of the distribution boxes, smaller open-ended square boxes made of 1-in. boards were placed. These boxes, which were not perforated, measured 3 × 3 ins. on the inside and were at first just long enough to reach from the bottom to the top of the outside boxes. As the grout rose in the rubble, the inside boxes were raised and shortened to compensate for the depth filled. By feeding the grout through these smaller boxes, which delivered

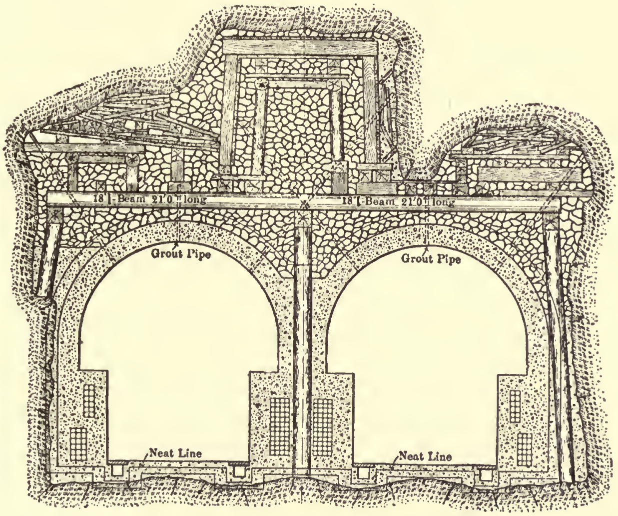

FIG. 124.—Arrangement of Pipes for Grouting Rock over Tunnel Roof.

it almost intact at the bottom of the large perforated ones, it had to enter the rubble from below upward: and being twice as heavy as water, the filling of all the voids was practically assured. The grout was a 1 : 2 mixture of Portland cement and sand, and the cost of grouting was at the rate of $3.65 per cu. yd. of stone composing the fill.

Depositing Concrete Under Water.—The standard methods of depositing concrete under water are by means of a tremie or trough, by depositing in closed buckets, and by depositing in cloth or paper bags.

An older method which, however, is not recommended for first-class work, is to deposit loose stone or riprap, and to fill the interstices by forcing liquid grout into the mass by means of a pipe reaching into the interior.

The objections to this method are the impossibility of filling the voids on account of the washing away of a large part of the grout, and to the impracticability of forcing it into all of the interstices between the stones. For use in consolidating blocks employed as paving for reservoir slopes, the use of grout is, however, economical and amply sufficient for the purpose.

Grout in Tunnel Linings.—One of the most useful applications

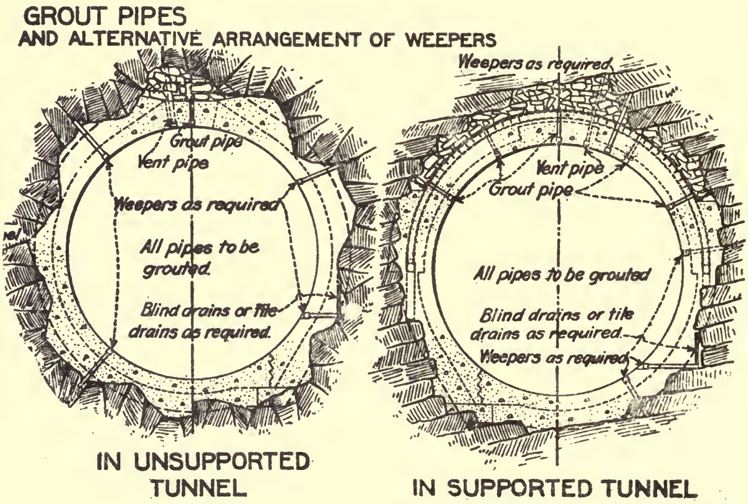

Fig. 125.—Showing Arrangement of Grout Pipes on Catskill Water Works, New York.

of grout is for the purpose of waterproofing and increasing the strength of tunnel linings.

In tunnelling through rock, the section removed by blasting is in excess of the requirements. When lined with iron rings or concrete, a space is left over the lining which, if left unfilled, would permit the accumulation of water, causing dampness or leaks in the tunnel, and in the case of unstable rock, producing unequal pressures, or endangering the roof lining from possible slides. It is, therefore, desirable to pack the space above the lining with stone, and in submarine tunnels the stone packing is consolidated and rendered impervious by forcing in grout to fill the interstices between the stones.

In the construction of the East River Tunnel for the Rapid Transit R. R. or Subway between New York and Brooklyn, an iron lining was employed, and the space between the lining and the rock was packed with stone. In each segment of the lining, holes were left and closed by screw plugs. Through these holes Portland

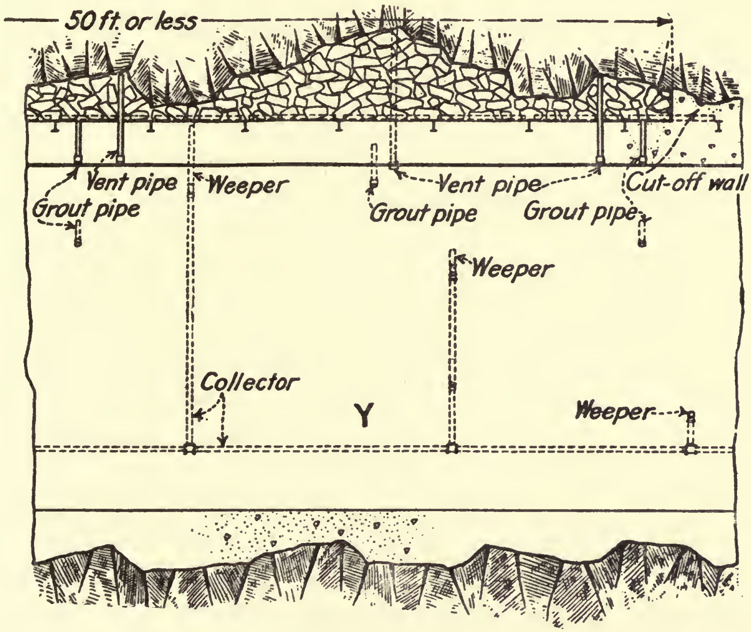

Fig. 126.—Arrangement of Grout Pipes in Tunnels of Catskill Water Works, New York.

cement grout was injected after a section of the lining had been placed.

The grout was a 1 : 1 mixture of Portland cement and crusher dust and was injected under an air pressure of 90 pounds per sq. in. through a flexible hose, which was connected with the 1/4-inch holes in the tunnel shell.

The grout was mixed by means of a paddle machine. The mixer consisted of a steel cylinder, 21 in. in diameter by 22 in. long and the mixing was done by means of a shaft carrying six double paddles, which were revolved at the rate of 30 revolutions per minute.

The mixing was done in batches. Each batch contained three bags of Giant Portland cement and three bags of crusher dust. The time occupied in mixing was 1 1/2 minutes, and it required about five minutes for the complete operation of charging, mixing, injecting the grout, and preparing the machine for the next batch.

As to the success of this method of grouting, Mr. Robert Ridgway, who was Division Engineer in charge of the tunnel section, reported that the filling of the interstices in the stone packing with grout was excellent where the tunnel was in rock. Where the tunnel was in sand, grout was forced up through the ground and was found filling minute crevices in the earth all the way to the surface.

Stopping Leaks and Seams.—Grout has long been employed for filling the seams in rocks and for stopping springs and leaks.

In excavating for the purpose of obtaining suitable foundations for bridge piers, dams, buildings or other important structures, and in sinking shafts and tunnelling, seamy rock and water-bearing strata are frequently encountered. In the case of dams, the seams must all be filled before the foundation courses can safely be started, since otherwise the leakage beneath the dam would tend to float the masonry, and thus endanger the stability of the structure. Hence it is customary to excavate until sound rock is encountered, and then to inject grout under pressure into any seams or faults that may present themselves.

In the case of ordinary foundations, the chief danger from springs or flowing water is the washing away of the cement which is used in the masonry. It is therefore necessary to take care of any incoming water until the fresh mortar or concrete employed in the construction has had time to set. This is ordinarily done by carrying the water away in pipes. Where the pressure is high the pipes are carried up and the water permitted to flow away while the lower courses are being laid. With a low pressure or hydrostatic head, the downward pressure of the water in the pipe may be sufficient when carried up to prevent any flow.

After the masonry has been carried up a sufficient height, the stoppage of the leak is effected by forcing grout into the pipe. When there is no flow from the pipe, the leak can be controlled by filling the pipe with grout, which will then displace the water and on hardening form an effective plug. Where the spring flows from the pipe, it is necessary to force in the grout under pressure and to maintain the pressure until the cement has hardened, since otherwise the flow would wash away the grout. Where practicable, it is desirable to apply sufficient pressure to the grout to cause it to flow into the seams or porous strata as well as to fill the pipe and fill the interstices between the pipe and the masonry.

Grout as a Paint.—Grout, when used as a paint, is one of the surface finishes applied to mass concrete. When so employed it should be applied while the wall is still green, since after hardening the grout has a tendency to flake off in patches. Grout is also employed as a dampproofing paint, but when so used it should be applied to the water side of the wall, as it is far more effective in keeping the moisture from entering the wall than it is in preventing the egress of moisture that has already entered the mass. Where pressure is encountered, however, the layer of grout is too thin to offer effective resistance to the passage of moisture and under such conditions, the wall should either be made impervious in itself or else surrounded by a bituminous shield or mastic of sufficient mass to be able to withstand the pressure.

Surface Finish.—Grout is more effectively employed as a surface finish when it is applied in such a way as to become perfectly incorporated with the mass of the wall. This is ordinarily done by using a wet concrete mixture for filling the forms and causing the grout to flush to the surface by pulling back the coarse aggregate from the face of the wall with a spade or fork. This forms the ordinary finish for beams, retaining walls, and mass constructions. Some waterproof grouts are now on the market which make excellent surface finishes for concrete and which are made in all colors.

Grout for Walks, Etc.—Grout or mortar forms the ordinary wearing surface for sidewalks, curbs, cellar-floors, etc. In such constructions, the foundation consists of a layer, from 3 to 6 inches thick, composed of cement, sand, and 1/2-inch broken stone, while the surface coat consists of cement and sand, which is usually 3/4 of an inch thick. To improve the appearance and wearing properties of this coat, granite chips are also frequently mixed in with the mortar or grout. To be satisfactory for this purpose, the chips must be hard and tough, and should be trowelled in such a way as to bring the flat portions of their surfaces uppermost, thus providing a good wearing surface, and affording protection to the cement.

Bonding New and Old Concrete.—Grout is generally employed in bonding new concrete to old. The surface of the old concrete is first scrubbed with a steel brush and a stream of water, or a jet of steam, or compressed air to remove all dirt and grease; and where a good bond is desired, it should also be scratched, etched with acid or tooled so as to produce indentations that will serve as a key. After preparing the surface, a grout composed of neat cement is rubbed in with a broom. While this is still soft it is covered with a layer of the regular concrete mixture, and the ordinary work of concreting is commenced.

Grout in the Machine Shop.—In setting up the bedplates of engines and stationary machines, lathes, planers, drillpresses, and other heavy tools, it is customary first to block up the framework to the required height with wooden blocks and wedges and then to bed the framework to the floor or piers forming the foundation by pumping in a rich mixture of Portland cement grout. When used for this purpose, the grout should be mixed as thick as practicable. so that on drying, a strong, durable mortar will be formed, which will easily support the weight and vibration of the machinery without crumbling or settling out of level.

Grout as a Paving Filler.—One of the most common uses for grout is as a filler for paving blocks. When used for brick or stone pavements, the blocks are laid dry and the interstices between the stones or bricks are filled by pouring in grout to serve as a cement.

The materials commonly employed for fillers are asphalt, tar and its compounds, cement, grout, and sand. The principal advantages of grout for this purpose are as follows: (1) cheapness; (2) adequate protection to the edges of the blocks; (3) prevents the blocks from loosening; (4) is watertight; (5) is durable; (6) permits the blocks to be laid close together; (7) is easy to keep clean; and (8) wears uniformly.

The disadvantages of grout fillers are: (1) its tendency to crack; (2) to become slippery; (3) affords a poor foothold on grades; (4) is difficult to remove without breaking the blocks; and (5) causes objectionable noise.

These objections apply chiefly to brick pavements. Where stone is employed the irregularities of the blocks are generally sufficiently pronounced to prevent them from becoming slippery and to enable the horses to obtain a foothold on grades. Stone blocks are also less subject to injury when removed.

Miscellaneous Uses.—In addition to the uses which have thus far been briefly enumerated in this chapter, grout is employed as a protective coating for iron and steel, for surfacing pipes and conduits to decrease their resistance to the flow of water and for many other purposes. The distinction between mortar and grout is but one of degree. While the excess of water contained in grout tends to increase its porosity over that of cement mortar, yet for many purposes its use is not only legitimate but unexcelled.

Grout is not a safe substitute for mortar in laying up masonry or in important constructions under water. It can, however, be forced into cracks and crevices which thick mortar is unable to penetrate, and thus for stopping springs and leaks, filling voids between the lining and roof of tunnels, filling the crevices in foundations for dams and other structures, and for numerous other purposes, grout is extensively employed in engineering works; while its minor uses such as surfacing, painting iron, steel and concrete, filling between paving blocks, dampproofing, and levelling of foundation areas have extended the employment of this material to many kinds of construction, although other considerations both theoretical and practical have tended to circumscribe its use.

CHAPTER XXXII

INSPECTION OF CONCRETE WORK—A SUMMARY OF ESSENTIAL RULES AND PRINCIPLES OF CONSTRUCTION, FOR SECURING GOOD CONCRETE WORK

The Work of the Inspector.—Inspection of the Cement, Sand, and Aggregates.—Proportioning and Mixing.—Inspection of Forms, Reinforcement and Placing Concrete.—Rules for Removing Forms.—Rules for Surface Finish.—Rules for Blocks, Piles, and Castings.

Careful inspection is essential in all concrete work. The best design will come to naught unless it be carried out with the aid of careful and skilful workmanship and the use of good materials. Good construction can be assured only when the work is under the control of competent and conscientious inspectors.

The Work of the Inspector.—The work of the inspector may be divided into the following parts:

1. Inspection of the cement, sand, and aggregate; *a.* quality; *b.* storage.
2. Proportioning, measuring, and mixing of the ingredients.
3. Inspection of forms, arch-centres, column moulds, etc.
4. Placing of the reinforcement.
5. Placing of the concrete.
   (*a*) General rules.
   (*b*) In reinforced work.
   (*c*) In hot weather.
   (*d*) In freezing weather.
6. Bonding new to old work.
7. Removal of the forms.
8. Surface finish.
9. Moulded blocks, piles, ornamental castings, etc.

Inspection of the Cement.—Cements are subjected to laboratory tests to determine their:

(*a*) Fineness.
(*b*) Time of set.

(*c*) Soundness.

(*d*) Specific gravity.

(*e*) Strength.

(*a*) Fineness is determined by passing the cement through sieves of various meshes and noting the percentages retained.

(*b*) Time of set is found by making pats of the cement and noting the time required to resist the penetration of wires of specified weight.

(*c*) Soundness is tested by noting the condition of the edges of the pats; also by subjecting pats to a steam bath and observing whether they blow, swell, or crack.

(*d*) Specific gravity is determined by weighing a given volume in air and noting the loss of weight when immersed in a liquid of known specific gravity, such as alcohol, which does not act on the cement.

(*e*) Strength is determined by moulding briquettes of 1 sq. in. sectional area, permitting them to remain in air and under water for specified periods, and then breaking in testing machines, and noting the breaking loads.

Cement should be stored in its original package, until ready for use. It should also be kept in a clean, dry place. If stored in a damp place, the cement will partially set and become valueless for construction purposes.

Inspection of Sand and Aggregates.—Sand for impervious concrete should be silicious in character, of graduated size, and with coarse, rounded grains. Sand should also be clean, but excessive cleanliness is not essential as an admixture of clay in amounts up to 10 per cent results in no material reduction in the strength of mortars. A small percentage of clay also tends to increase the imperviousness of the concrete.

When specifications call for sharp sand, the grains should be angular. Sharp sand was until quite recently always required by engineers, on account of its binding properties. Recent experiments, however, indicate that sand with rounded grains is less liable to fracture; and when graduated, so that the smaller grains fit between the larger ones without wedging them apart, is far more impervious when used in mortar or concrete.

The best aggregates for concrete are trap rock and gravel.

Hard limestones and granite are also good. Soft limestones, sandstones and schists are less durable, while slate, shale, and cinders are poor materials to use. The size of the aggregate is of importance. In massive work, the stone should pass through a 2 1/2 inch ring, in reinforced concrete beams, the diameter should not exceed 3/4 of an inch.

Rules for Proportioning, Measuring, and Mixing.—American engineers proportion concrete mixtures by measure, thus: a 1:2:3 concrete is one composed of 1 volume of cement, 3 volumes of sand, and 6 volumes of aggregate.

The duty of the inspector is to make certain that the specified proportions are accurately and uniformly adhered to. This requires:

(*a*) That definite measuring units be employed.

(*b*) That the accuracy of the measure boxes, hoppers, etc., be verified.

(*c*) That the filling of the measuring boxes, hoppers, etc., be exact.

(*d*) That when two or more boxes or hoppers, filled with sand or stone, go to make up a batch, the exact number be employed for each and every batch.

Cement differs in volume when measured loose, and when packed in the barrel; cement barrels also vary in capacity. Hence the engineer, contractor, and inspector should reach an agreement as to:

(*a*) Whether the cement is to be measured loose or packed.

(*b*) What the cubic contents of a barrel or bag of cement shall be called.

The measures used should be tested to make sure that each holds the amount intended. This can be very simply done by using a known measure to fill the measuring box employed, or the volume of the box can be mathematically computed.

When automatic measuring devices are used to proportion the cement, the inspector should see:

(*a*) That they are regulated to give the proper proportions.

(*b*) That the materials do not clog, choke, or arch in the feed hoppers.

(*c*) That the feed hoppers are kept amply supplied with materials.

Concrete is mixed by: 1. Hand turning with shovels and hoes; 2. Machine mixing.

Rules for Hand Mixing.—Rule 1. The batches should be of such size that they can be proportioned without using fractions of measures.

Rule 2. Mix the cement and sand dry with hoes or shovels.

Rule 3. Over the dry sand and cement mixture spread the broken stone which has been previously wetted and on top of the stone apply water evenly.

Rule 4. Finally turn the whole the specified number of times with shovels.

Rule 5. The quantity of concrete in each batch should be not greater than can be mixed and deposited before the cement begins to set.

Rules for Machine Mixing.—Concrete mixers are of three types:

(*a*) Batch mixers.

(*b*) Continuous mixers.

(*c*) Gravity mixers.

In batch mixers the materials are charged, mixed, and discharged in batch units; in continuous mixers the materials are discharged in a continuous stream; and in gravity mixers the materials are caused to mingle by falling through specially constructed troughs, tubes, or hoppers.

Rule 1. The mixer should be of an approved type, and operated in such a manner as to mix the materials uniformly and efficiently.

Rule 2. If a batch mixer is used, the batch should be (*a*) composed of the proper proportions, (*b*) thoroughly mixed, and (*c*) completely dumped out as a unit.

Rule 3. When a continuous mixer is used, the materials must be (*a*) fed evenly into the mixer in the proper proportions; (*b*) the automatic measuring devices must work accurately, and (*c*) the material must not "bridge" or "choke," and so cease to feed into the mixer drum.

Rule 4. The mixer must be given the requisite number of turns for each batch, as determined by trial.

Rule 5. The concrete in discharging from the mixer should not drop any considerable distance.

Rule 6. The mixer should be cleaned of all adhering mortar or concrete when work is discontinued, as such cakes are liable to break or jar loose and be discharged as an inert body into the next batch.

Inspection of Forms.—Forms are the moulds in which concrete is shaped, and it is the duty of the inspector to see that they are of ample strength, efficiently braced and in proper alignment. The following rules should also be observed:

Rule 1. The lumber should be of such quality, size, and finish as to promise absolute stability and reasonably perfect work under the conditions.

Rule 2. Forms should be oiled or wetted just before the concrete is deposited to prevent sticking. Oil should be used where a smooth surface is desired. It should not be used where the concrete is to be plastered or whitewashed, as the grease will discolor the work and weaken the bond.

Rule 3. White pine, yellow pine, spruce, Oregon pine, and redwood are suitable for forms; hemlock is unreliable.

Rule 4. Forms should be thoroughly cleaned of shavings, chips, sawdust, dirt, or other accumulations just before the concrete is placed.

Rule 5. The construction of the forms should be such that they can be removed without injury to the concrete.

Rule 6. All forms must be erected in exact alignment, both vertically and horizontally; column and wall forms should be plumb; girder boxes and wall forms without winds or twists; arch and slab centres level: the alignment must be watched during the placing of the concrete, as the loading may distort the forms.

Rule 7. Forms should be (*a*) of ample strength; (*b*) of sufficient rigidity not to deflect unduly under load, and (*c*) horizontal forms should be given a camber to prevent them from deflecting below the horizontal. A common camber is 1/2 inch for every 10 feet of span.

Rule 8. The carpenter work should be accurate, the lines true and square, the joints close and the finish neat. All forms must be planed where required to produce a smooth surface finish.

Rule 9. All joints in forms should be tight enough to prevent leakage of the grout from the liquid mass.

Rule 10. Column moulds must be accurately spaced in all directions and set square with the lines laid down on the plans.

Rule 11. Column moulds should be cleaned with scrupulous care, as they are liable to get the sweepings from girder boxes and other débris. To facilitate cleaning the bottom of the mould should be left open on one side until just before pouring the concrete.

Rule 12. The wire ties for wall forms must be in place and drawn taut so as to pull the sides close against the spacers. The spacers must be removed from the forms as soon as they are reached by the concreting.

Rule 13. Bolts which can be withdrawn should be used instead of wire as ties for forms where the surface is left exposed, as a rust spot invariably forms on the face of the wall where a wire is cut.

Rule 14. Where bolts are used as ties, the bolts must be withdrawn and the holes filled with mortar after the forms have been removed. To facilitate withdrawing, the bolts must be greased.

Rule 15. Forms for retaining walls with battered sides, pyramidal forms for column footings, etc., should be firmly anchored down to resist the up-thrust or floating effect of the semi-liquid concrete.

Rule 16. Arch centres must be framed, assembled, and erected in a workmanlike manner. Substantial foundations are required; also suitable means for striking or lowering the centre gradually and without shock or jar to the concrete. Allowance should also be made for settlement under load and for permanent camber. The lagging should be of even thickness and planed smooth in order to give a good surface to the soffit of the arch.

Placing of the Reinforcement.—Concrete is weak in tension but strong in compression. Reinforcement is placed on the tension sides of beams to make up for the weakness of the concrete. The number, size, and spacing of the bars must be in exact conformity with the engineer's plans, otherwise the structure may be materially weakened. The position of the bars in the form is of no less importance than their proper number and size, as they are designed to be in the position where they will most add to the strength of the construction.

The following rules should also be observed:

Rule 1. Where the steel is received, it should be checked, assorted, and stored in such a way as to be reasonably protected from rust, dirt, oil, and paint.

Rule 2. In the assembling of the reinforcement, the exact number, size, form, spacing, and location of bars, stirrups, ties, spacers, etc., called for by the plans must be strictly adhered to.

Rule 3. The steel should be free from paint, scale, dirt, and excessive rust. Concrete which has lodged on the steel and hardened during previous work must also be removed before the reinforcement is finally concreted in.

Rule 4. Bars should be bent in such a manner that they do not break or crack at the bend. The bending force should be applied gradually and not with a jerk. Cold bending is always preferable; if hot bending is allowed, it must be done in such a way that the bar is not burned or weakened.

Rule 5. Splicing of bars, lapping, wiring, use of sleeves and set screws, etc., must be carried out as directed by the engineer.

Rule 6. Protruding ends of bars which are left for splicing should be coated with cement paint to diminish rusting, and guarded against being bent or loosened.

Rule 7. All reinforcement must be securely fastened to preserve spacing, location, alignment, etc.

Rule 8. The wiring of reinforcement at intersections should be done carefully and strongly, using No. 16 or No. 18 B. and S. gauge soft black wire.

Rule 9. In column reinforcement, the reinforcing frame should be concentric with that of the column below, the bars vertical, all ties in place and taut, and all splices made according to specifications. No part of the steel should touch the walls of the form and the space between the steel and form should be uniform.

Rule 10. Templets should be used especially at bottom and top of column to insure accurate spacing of bars.

Rule 11. Column bars should be spliced as follows:

In a butt joint the ends should be square, the bearing uniform, and the joint be held true to line by sleeves or splice bars.

If lap joints are allowed, the wire wrappings, cable splices, etc., must be made taut and secure.

Rule 12. Beam reinforcement should be placed symmetrically with the axis of the beam, the bottom bars kept at the required height above the bottom of the beam, the proper space maintained between the reinforcement and the sides of the beam, and the required connections made at the ends of the beam with the column bars or the reinforcement of abutting beams or walls. All planes and lines should be true and all parts of the reinforcement wired together or otherwise held firmly in position.

Placing of the Concrete.—Before the practice of reinforcing concrete came into general use, specifications called for dry mixtures, thorough tamping, and depositing in uniform horizontal layers. In reinforced work, dry mixtures do not flow readily around the bars, while tamping is liable to throw them out of position. Hence in such work wet mixtures are used and puddling or slicing takes the place of tamping. This consists in churning and cutting the wet mixtures with rods or slice bars to work out air bubbles, close up pockets, and settle the materials.

The following rules should also be observed:

Rule 1. Buckets should just clear the work when discharged, as when the materials are allowed to drop, they are liable to jar the forms and displace the reinforcement and at the same time produce separation of the stone from the mortar.

Rule 2. In depositing through chutes, care must be taken to detect any separation of the stone from the mortar.

Rule 3. Pouring should be done at several points over the area to be filled so as to reduce flowing and spreading to a minimum.

Rule 4. The concrete must be poured before it has begun to set.

Rule 5. Dry mixtures, when specified, should be deposited in even layers not exceeding 6 to 8 ins. in thickness and thoroughly tamped with rams heavy enough to thoroughly compact the concrete and bring a film of water to the surface.

Rule 6. Wet mixtures should be well puddled, so as to work out air bubbles and pockets and bring the concrete into close contact with the reinforcement at every point.

Rule 7. In making slabs, the full thickness should be poured in one continuous operation. If possible slab and beam should be made monolithic.

Rule 8. Beams should be poured in one continuous operation from bottom to top, the concrete worked closely around the reinforcement by puddling, and the stone worked back from the sides by spading.

Rule 9. When beam and slab are designed to act together as a T-beam, both must be poured in one operation.

Rule 10. Columns must be poured well ahead of the beams. The operation should be continuous from the base to the underside of supported beam or girder, and the concrete well puddled by bars long enough to go easily between the outside of the reinforcement and the inside of the form.

Rule 11. In concreting arches, the arch ring should be divided into sections of such size that the pouring of each can be made a continuous operation. In longitudinal sections, the concrete should be begun simultaneously at both skewbacks and continued uniformly and continuously to the crown. Where the sections are transverse or across the arch, the better practice is to concrete the crown section first and work towards both skewbacks a pair of sections, one on each side, at a time.

Rule 12. In depositing under water, the concrete should be kept as free as possible from wash which will float off the fine cement from the mixture. The concrete should never be allowed to drop through any considerable depth of water. The standard methods of depositing under water are in bags, in closed buckets, and through tremies.

Rule 13. In hot weather, great care must be exercised to prevent the concrete from drying out before it has set. The aggregate should be thoroughly wetted, more water used in the mixing, and if necessary, the work should be covered with planks or tarpaulins.

Rule 14. In freezing weather concreting should be stopped at the temperature required by the specifications. When salt is added to prevent freezing, the amount should not exceed 10 per cent of the weight of the water. Other methods of protection are heating the materials, housing in the work, covering with tarpaulins, using artificial heaters, and adding calcium chloride in amounts equal to about 2 per cent of the volume of the mortar.

Bonding New to Old Work.—The surface of concrete which has hardened has a skin or coating to which fresh concrete will not adhere. This skin must be removed and the surface prepared for the new material. The methods employed are, to

(*a*) Prepare the surface by scrubbing, washing, and grouting.

(*b*) Etch the surface with an acid wash, and thoroughly remove the acid by washing.

(*c*) Break the surface with steam, air blast or water under pressure.

In stopping work over night, the following rules should also be observed:

Rule 1. In slabs, the concrete should be stopped in a vertical plane at right angles to the span either (*a*) at midspan, or (*b*) over the centre of the supporting beam or girder.

Rule 2. In beams or girders, the concrete should be stopped in a vertical place at right angles to the length of the beam either (*a*) at midspan, or (*b*) over the centre of the supporting column.

Rule 3. Columns should be stopped at the level of the bottom of the beam or girder which they support.

Rule 4. Walls should be stopped in vertical planes across the wall; if practicable the stoppage should occur where an expansion joint is to come.

Removal of the Forms.—All forms must be taken down without straining or jarring the freshly placed concrete. The greatest care must be exercised to prevent workmen, who are taking down forms, from dropping a single piece of lumber on the floor.

Shores for floors or arches must never be removed in less than two weeks after the concrete is placed. In damp or cold weather, they should remain in place at least four weeks. Centres for long-span arches should remain in place from one to three months. Before removing shores on extra long spans, it is advisable to put horizontal saw cuts completely through the shores. If weakness then develops, it will simply close up the saw cuts and the shores will continue to do their duty.

Rule 1. Moulds for ornamental or indented castings must be so constructed that they can be removed piece by piece without injury to the concrete.

Rule 2. Forms should not be removed until the concrete has hardened sufficiently to carry its load. Forms should remain longer under beams and arches than around columns and walls, and longer under arches of long than of short span. Forms should not be removed until the concrete is hard enough to ring clearly when struck with a hammer.

Rule 3. Under average conditions, forms should remain in place for the following periods:

Walls in mass work from 1 to 3 days.

Thin walls and columns from 2 to 5 days, according to weather conditions as noted above.

Slabs up to 6 feet span, from 1 to 2 weeks.

Beams and girders, from 2 to 4 weeks.

Small arches, from 1 to 3 weeks; large arches from 1 to 2 months.

Rule 4. Forms should be removed gently without chipping or jarring the concrete. Prying with bars or striking with a sledge should be prohibited.

Rule 5. Column forms should be so constructed as to permit of their removal without disturbing the beam or slab forms.

Rule 6. Beam forms should be so constructed as to permit of the removal of the sides before the bottom is disturbed in order that the condition of the concrete can be examined.

Rule 7. Beams should be supported by shores for a considerable time after the forms have been removed, or until the concrete has become thoroughly cured.

Rule 8. Arch centres must be removed without shock or jar to the arch ring. Centres should be lowered evenly and gradually, so that the ring can settle uniformly.

Rules for Surface Finish.—Surface finishes are of two kinds:

(*a*) Those in which the moulded surface is treated after the forms are removed.

(*b*) Those in which the moulding is so done that the finish is a part of the moulding process.

The following rules should be observed for class (*a*):

Rule 1. If the surface is to be grouted all holes and joint marks must be filled or smoothed down before the grout is applied.

Rule 2. When the surface is to be tooled, from 30 to 60 days must elapse before the concrete is hard enough to give a good, clean tool cut.

Rule 3. When scrubbed, the scrubbing should be continued just long enough to remove the surface cement and to partially expose the aggregate without loosening it.

Rule 4. When etched with acid, the acid must not be allowed to remain too long, and all excess acid must be removed by washing.

Spaded or mortar finishes are used for class (*b*). The following rules should be observed:

Rule 1. Spading is best done with a special flat-bladed spade, having the blade perforated with holes or slots, which will screen back the stones and allow the mortar to pass.

Rule 2. In a mortar finish, the facing mortar and concrete backing are placed at the same time and are tamped together. The tamping should not be so hard as to force pieces of stone through the facing, but hard enough to bond thoroughly the facing mortar and backing.

Rule 3. The preferable method of construction is to use a facing form between the lagging and the backing. Fill between the facing form and the lagging with mortar, then fill behind the facing form with the backing, and finally withdraw the facing form and tamp backing and facing together.

Moulded Blocks, Piles, Ornamental Castings, Etc.—Three general processes are employed for moulding cast concrete work:

(*a*) A dry mixture is heavily tamped into a mould and the block is immediately released and set aside for curing.

(*b*) A liquid mixture is poured into moulds where the blocks remain until hard.

(*c*) A medium wet mixture is compressed into moulds by hydraulic presses or other means of securing great pressure.

The following rules should be observed for Dry Mixture Blocks.—

Rule 1. For dry mixtures the mixing and tamping must be thorough and the water uniformly distributed. Tamping should begin with the first shovelful and should be continued until the mould is filled.

Rule 2. Dry mixtures should have a consistency such that the block will part from the mould without sticking, sloughing, sagging, or loss of form. Dryness in excess of these requirements should not be allowed.

Rule 3. Moulds must be rigid and adequately clamped. The construction should be such that the green blocks are not injured when removed.

Rule 4. After removal, the dry mixture blocks must be stacked in a horizontal position on immovable supports and freely sprinkled with water. A dry mixture block does not have enough mixing water to enable the cement to set and harden perfectly, and this deficiency must be supplied by sprinkling. The sprinkling should begin within an hour after moulding and should continue for at least ten days. While the block is soft, the sprinkling should consist of a gentle spray, that will not wash the concrete.

Rule 5. Blocks should be cured for at least 30 days before they are removed from the storage yards for use in construction.

The following rules apply to wet mixtures: Rule 1. The mixture must be thoroughly stirred and churned to eliminate air voids, prevent arching and fill corners and edges of moulds.

Rule 2. The mould must not be removed until the concrete has thoroughly set and is hard enough to do without its support.

Rule 3. The block must be true to shape and exact in dimensions, with faces true to plane, and edges true to line. Mouldings and other ornamentations must be perfect. A moulded block should be equal in perfection to cut stone in all particulars of shape and dimensions.

Rules for Concrete Piles.—Concrete piles are driven (*a*) by punching a hole in the ground by means of a metal mould and filling with concrete; (*b*) by casting the piles in moulds and driving by aid of a water jet.

The following rules should be observed for concrete piles in place:

Rule 1. In driving the shell for new piles, care must be taken that adjacent piles in which the concrete is still green are not jarred and injured.

Rule 2. In concreting piles in place, the concrete must be lowered in small buckets or in such a way that the cement is not separated from the stone.

Rule 3. The reinforcement must be set parallel to and concentric with the axis of the pile. The best practice is to assemble the reinforcement into a unit frame, and to place it as a unit.

The following should be observed for cast piles:

1. Cast piles should be straight, the metal points, when used, firmly attached and the pile should be without cracks or chipping. None of the reinforcing metal should be exposed. If cored for sinking by water jet, the cores must be open and unobstructed. If fluted on the sides to provide passages for the rise of

water used in jetting, the flutes or corrugations must not be obstructed.

2. Moulds should be straight and kept true to line and level.

3. The reinforcement must be kept parallel to and concentric with the axis of the mould.

4. The concrete should be poured at several points along the mould to prevent flowing and segregation.

5. The driving should be done in such a way that the pile is not fractured in the body. The head should be protected by a cushion cap to take the direct blow of the hammer. If the driving is done by a water jet, the pile should settle to a firm bearing.

6. Cast piles should not be dragged along the ground or otherwise roughly handled.

Ornamental Castings.—In ornamental castings, great care must be taken in the moulding, handling, and setting in place to preserve the true lines, flutings, and other ornamentations. When white cements, stainless mortars, or other special materials are required, the inspector should take particular pains to insure the use of the proper ingredients. The general rules for cast blocks and piles apply with additional force to all ornamental work.

CHAPTER XXXIII

COST OF CONCRETE WORK

General Cost of Main Classes of Work.—Elements of Cost.—Cost of Materials.—Cost of Mixing.—Cost of Placing.—General Expenses.—Summary of Costs.—Cost of Mortar.—Actual Examples of Cost.—Building Blocks.—Paving.—Removing Efflorescence.—Stucco.—Forms.—Cost of Buildings in Terms of Cubical Contents.—Cost of Residences.—Cost of Sewers.—Concrete Pipes.—Bridge Piers and Bridges.—Piles.—Trestles, Sidewalks, Curbs, and Gutters.—Fence Posts.—Poles.—Roofs.—Tunnel Lining.—Waterproofing.—Cost of Concrete Dams.

THE cost of concrete construction is made up of the combined cost of materials and labor. The cost of materials for any given class of work is readily determined from the dimensions of the structure and the market prices of cement, sand, broken stone, timber, steel, etc.; the labor cost, however, is dependent not only upon the prevailing rate of wages, but also upon the efficiency of the men employed, the amount of form work, and the character of the construction.

The cheapest construction is obtained when the concrete is deposited in large masses and when the transportation, mixing, and depositing in place is performed by machinery. When laid in thin sections, as in tunnel linings, small arches, thin walls, etc., the use of forms and of hand labor per cubic yard of concrete is very largely increased, which greatly augments the unit cost of the construction.

General Cost of Main Classes of Work.—Where Portland cement can be obtained at $1.50 per barrel, sand at 80 cents per cubic yard, and broken stone at $1.50 per cubic yard delivered on the work; and where the cost of form timber does not exceed $25.00 per M; while the rate of wages for carpenters is $3.50, laborers, $1.75, and teams $3.75 per ten-hour day, the cost of concreting, including interest and depreciation on plant, but with no allowance for profits, will run about as follows:

Heavy mass constructions, as large dams, reservoir walls, pavements, heavy foundations, abutments, rubble concrete, etc.	$3.50 to $5.00 per cu. yd.

Foundation footings and difficult mass construction.	6.00 to 8.00 per cu. yd.
Thin rough walls, sewers, and culverts............	8.00 to 10.00 per cu. yd.
Thin tooled or reinforced walls and heavy buildings and bridges, difficult pneumatic and submarine constructions which are subject to delays, reinforced-concrete retaining walls, etc.	10.00 to 15.00 per cu. yd.
Light reinforced-concrete buildings having thin walls, slabs, and columns, light reinforced-concrete bridges, arches, etc.	15.00 to 20.00 per cu. yd.

Elements of Cost.—The various elements which enter into the cost of plain and reinforced concrete may be summarized as follows:

1. Cost of cement, aggregate, and reinforcement at the work.

2. Cost of loading the materials into barrows, buckets, or cars, and of their transportation to the mixer and dumping.

3. Cost of mixing: (*a*) Hand-mixing; (*b*) Machine-mixing.

4. Cost of loading the concrete into barrows, buckets, or cars, and of its transportation to the work.

5. Cost of bending, placing, and wiring the reinforcement into position.

6. Cost of dumping, spreading, slicing, spading, and ramming.

7. Cost of forms: (*a*) Timber, nails, wire, and other materials; (*b*) Carpenter's labor.

8. Cost of plant, storage house, runways, etc.

9. Cost of engineering, inspection, time-keeping, and general expenses.

10. Interest on the investment, repairs, depreciation of plant, etc.

11. Profits.

Cost of Cement.—The cost of cement depends upon the class, brand, quantity, kind of package, freight-rates by rail or water, and cartage.

At New York, the prices in large lots delivered alongside of the docks are at the time of publication as follows for large lots:

Natural cement	$0.80 per barrel
Portland	1.43 " "
Imported	2.42 " "

At the mill Portland cement can be obtained in bulk at $1.00 per barrel.

On many of the irrigation projects in the West, where the haul from the nearest railroad is considerable, the cost of cement varies from $2.50 to $3.00 per barrel delivered; at a dam recently completed at Hume, Cal., the cement cost a little over $5.00 per barrel,* the high cost being due to the location of the work, which necessitated a great deal of hauling and handling.

Cement when ordered in wooden barrels costs 10 cents more per barrel than in bulk ; when ordered in cloth sacks, a charge of 10 cents per sack is made, but on return of the sacks, a credit of 8 to 10 cents per sack is allowed; when ordered in paper bags the cost is 5 cents more per barrel than in bulk.

Hence a barrel of cement, costing $1.40 in bulk and containing four bags to the barrel, will command the following prices, depending upon the package in which it is sent:

1. In wooden barrels.	$1.40 + .10 = $1.50
2. In cloth sacks	1.40 + .40 = 1.80
3. In paper sacks	1.40 + .05 = 1.45
4. In cloth sacks, which are returned	$1.40 to $1.48.

Cost of Sand.—The cost of sand varies from 20 cents to $1.00 per cu. yd., depending upon the need of washing and the length of haul. Standard grades of Long Island washed sand are quoted at 35 cents alongside the docks at New York; white quartz sand at 60 cents; and white quartz grit at 75 cents per cu. yd. for full cargo lots of 500 cu. yd.

Cost of Gravel.—The cost of gravel varies from 50 cents to $1.50 per cu. yd. Washed gravel alongside of dock at New York sells at 75 cents in cargo lots and white quartz roofing gravel at $1.30 per net ton.

Cost of Broken Stone.—The cost of broken stone varies from 60 cents to $1.50 per cu. yd. Alongside of the dock at New York the prices are 90 cents to $1.00 for 1-1/2-in. stone; $1.00 to $1.10 for 3/4-in. stone, and 90 to 95 cents for screenings. The contract for furnishing the Department of Docks, City of New York, with 15,000 cu. yds. of stone was awarded recently at $1.04 to $1.06 per cu. yd., including the services of men to load the buckets and empty them on the dock, the city furnishing the power.

Cost of Steel for Reinforcement.—At the mill plain bars 3/4

* *Engineering Record*, Jan. 15, 1910.

inch and larger vary in price from $1.25 to $1.80 per cwt., and smaller bars from $1.50 to $2.30 per cwt. Twisted bars are held at an advance of from 10 to 25 cents per cwt. over plain bars, while the prices of other deformed bars vary according to the shape, but are in general higher than those of twisted bars. Expanded metal varies in price from 2.80 to 8.30 cents per sq. ft. at New York, according to the mesh and weight; triangular mesh, from .67 to 2.55 cents per sq. ft. in carload lots; expanded lath from 11 1/2 to 14 cents per sq. yd., at mill for black, and from 18 1/2 to 21 cents per sq. yd. for galvanized, and diamond lath from 14 to 20 cents per sq. yd. at New York for black.

Total Cost of Materials.—This varies according to the proportions of cement, sand, and stone or gravel, and the price of each ingredient. With cement at $1.50 per bbl., sand at 80 cents, and broken stone at $1.20 per cu. yd., the quantity of materials and their cost for different mixtures would be as follows:

Plain Concrete, Cost of Materials per cubic yards, with

Cement at $1.50 per barrel.
Sand " .80 per cubic yard.
Stone " 1.20 " " "

1:2:4 Mixture.		1:2½:5 Mixture.		1:3:5 Mixture.	
Cement 1.46 bbl. at $1.50 ...	$2.19	1.20 at $1.50	$1.80	1.13 at $1.50......	$1.70
Sand .41 cu. yd. at .80....	.33	.42 at $. 80......	.34	.48 at .80.....	.39
Stone .82 cu. yd. at 1.20....	.98	.84 at 1.20......	1.01	.80 at 1.20.....	.96
Cost of materials per cu. yd.	$3.50	Cost............	$3.15	Cost...........	$3.05

Cost of Loading into Barrows, Buckets, Etc.—Under average conditions, one man should be able to load 17.5 cu. yds. of aggregate into a barrow in 10 hours. With wages at $1.75 per day, the cost per cu. yd. of materials handled would be 10 cents. For the 1:2 1/2:5 mixture the cost of loading per cu. yd. of concrete would be:

Sand .42 cu. yd. at 10 cents........	4.20
Stone .84 cu. yd. at 10 cents........	8.40
Cement .17 cu. yd. at 10 cents	1.70
Total for 1 cubic yard	14.30

Cost of Transportation and Dumping.—This depends upon the grade and length of haul and will vary from 5 to 10 cents per cu. yd. of concrete. Mr. H. P. Gillette, in his "Handbook of Cost Data," gives the following rules for the cost of transportation of materials to the mixing board:

1. With barrows: "To a fixed cost of 4 cents (for lost time), add 1 cent for every 20 ft. of distance from stock pile to mixing board if there is a steep rise in the runway, but if the runway is level add 1 cent for every 30 ft. distance of haul."

2. With a horse and cart: "To a fixed cost of 5 cents (for lost time at both ends of haul), add 1 cent for every 100 ft. of distance from stock pile to mixing board."

Cost of Hand Mixing.—This will vary from 25 to 40 cents per cu. yd., according to the efficiency of the labor and the number of times the materials are turned over with shovels. With wages at 17.5 cents per hour, and men turning over mortar and concrete at the rate of 3 cu. yds. per hour, the cost per cu. yd. would be 5.8 cents for each turn. The cement and sand for each cu. yd. of concrete will measure about .45 cu. yds. If 6 turns are given to this mixture, the cost of turning the mortar will be $.45 \times 6 \times 5.8$ cts. = 15.7 cents. If the stone and mortar are turned 3 times, the cost of mixture will be $3 \times 5.8 = 17.4$ cents. Hence the total cost of turning is $15.7 + 17.4 = 33.1$ cents per cu. yd. of concrete.

Cost of Machine Mixing.—The labor cost of mixing will vary from 2 to 8 cents per cu. yd., and the cost and maintenance of the mixer from 6 to 15 cents, according to the size and kind of mixer and the percentage of time which the machinery is idle.

If a 3/4 yd. batch mixer is employed, 200 cu. yds. are readily mixed in one day with three men to attend to the machinery. The cost of oil, fuel, and labor per day will total about $7.00; or 3.5 cents per cu. yd. of concrete.

In the *Engineering Record* of May 21, 1910, is given the actual maintenance cost of four mixers owned by the Aberthaw Construction Co., of Boston, who run a ledger account for each mixer. In this article, it is shown that the highest maintenance cost was 13.95 cents per cu. yd., the lowest 5.4 cents, and the average of the four mixers 8.94 cents.

Taking an average cost of maintenance at 9 cents, and the cost of mixing at 3.5 cents, the combined cost or the cost of machine mixing will total 9 + 3.5 = 12.5 cents per cu. yd. for a batch mixer of average size in steady use.

Cost of Loading and Transporting to Place.—When loaded by hand into barrows, the cost is less than that of loading the raw materials, since the volume of the concrete is less than that of the unmixed ingredients and should average about 12 cents per cu. yd. When mixed by machinery, the concrete is dumped directly into barrows or cars without cost of handling.

The cost of transportation by barrows or carts will be about the same as that for hauling the raw material, or from 5 to 10 cents per cu. yd. When conveyed by means of a hoist or cableway, the expenses for power, labor, and maintenance will total from 3 to 8 cents per cu. yd.

Cost of Dumping, Spreading, Ramming, Slicing, Spading, Etc.—These will vary with the character of the work and the consistency of the mixture. In mass work with a wet mixture the cost will average 15 cents per cu. yd. If a dry mixture is used, the expense of tamping may increase this amount to 30 or 40 cents. In building construction the cost of slicing to cause the material to flow around the reinforcing bars and of spading to pull back the coarse aggregate from the surface will total from 25 to 35 cents per cu. yd.

Cost of Forms.—White pine, yellow pine, spruce, and Oregon pine are used for surface forms. Hemlock, although unsatisfactory, is used in rough constructions.

Prices of timber in sizes and grades suitable for form construction are as follows at New York at the time of publication.

Spruce boards, 1 in. thick in car lots	$25.00 per M ft. B. M.
Spruce studding, 2 in. thick in car lots	25.00 to $30.00 per M ft. B. M.
Hemlock boards 1 in. thick	18.00 per M ft. B. M.
Hemlock studdings, 2 in. thick	20.00 per M ft. B. M.
North Carolina Pine, 2 in. thick, ...	20.00 per M ft. B. M.
Long Leaf Yellow Pine, dimension sizes ..	30.00 to $40.00 per M ft. B. M.

The labor cost of framing, erecting, and removing forms will run from $5.00 to $20.00 per 1,000 ft. B. M., and the cost of form work per cu. yd. of concrete in place will depend upon:

(1) The size of the walls, slabs, arches, etc., since a thin wall

requires more form work per cu. yd. of concrete in place than one of massive construction.

(2) The number of times each form can be used in the course of the construction.

(3) The salvage value of the material after the work is completed.

In ordinary walls, arches, piers, etc., which can be erected without elaborate false work, the cost of form work will run from 20 cents to $1.00 per cu. yd. of concrete in place. In reinforced-concrete buildings, forms will cost in place from 5 to 20 cents per sq. ft. of surface in contact with concrete, or in general from $2.50 to $10.00 per cu. yd. of concrete in place.

Cost of Reinforcement in Place.—In ordinary beams, slabs, columns, retaining walls, etc., from 0.70 to 1.25 per cent of reinforcement is used. Where 1 per cent of steel is employed, the volume of steel per cu. yd. of concrete will be 0.27 cu. ft., and the weight $.27 \times 490 = 132$ pounds.

The cost of handling, bending, and assembling steel reinforcing bars will run from $5.00 to $15.00 per ton, or from 1/4 to 3/4 cents per pound. Where plain bars are used at a cost of 1 1/2 cents per lb., at the mill, the cost of freight and wagon haul to the work 1/4 cent per lb., and the cost of handling and wiring in place, 1/2 ct. per lb., the total cost of 1 per cent of reinforcement in place would be $1\ 1/2 + 1/4 + 1/2 = 2\ 1/4$ cents per lb., or $2\ 1/4 \times 132 =$ $2.97 per cu. yd. of concrete.

General Expenses.—These include: (*a*) cost of plant, storage buildings, runways, etc.; (*b*) engineering, inspection, time-keeping, and (*c*) interest on the investment, repairs, depreciation of plant, etc.

In a well-equipped organization the general expenses, after deducting the salvage value of the plant should not exceed 15 per cent of the cost of materials and labor.

When work is done by contract, and the preliminary surveys, plans, and specifications are so complete and fair as to reduce the chances of loss to a minimum, a reasonable profit to the contractor would be 15 per cent of the cost in addition to the interest on his investment. When, however, there is much uncertainty as to the probable cost for materials or labor, or where the specifications are unduly severe, the contractor will be likely to raise his bid to an amount 20 or even 30 per cent above the estimated cost of the work.

Summary of Cost.—The cost of mixing and placing concrete where no expense for forms is incurred, as in a street-paving job, may be estimated as follows:

	Hand Mixing.	Machine Mixing.
Cost of loading cement and aggregate	.14	.14
Wheeling 60 ft. in barrows (4 + 3 cts.)	.07	.07
Mixing	.33	.12
Loading concrete into barrows	.12	.12
Wheeling 60 ft. in barrows (4 + 3 cts.)	.07	.07
Spreading and ramming	.15	.15
	$0.88	$0.67
General expenses, 15 per cent	.13	.10
Total cost of labor	$1.01	$0.77
Cost of materials for a 1 : 2 1/2 : 5 mixture with { Cement at $1.50 per bbl. / Sand " .80 per cu. yd. / Stone " 1.20 per cu. yd. }	$3.15	$3.15
Net cost per cu. yd.	$4.16	$3.92

When the work is done by contract, add from 15 to 30 per cent for profit.

Where forms are required, add per cu. yd. concrete in place.	For mass work from $0.20 to $1.00. For building construction, from $2.50 to $10.00.
Where reinforcement is used, add for each 1 per cent of steel per cu. yd. of concrete in place.	For mass work, $2.00 to $4.00. For building construction, $2.25 to $4.25.

In building construction, tunnel-lining, thin walls, arches, etc., where much spading and slicing is required; also where very dry mixtures are used, necessitating much ramming, the cost of spreading and ramming will be increased to from $.20 to .50 per cu. yd.

In difficult, pneumatic, submarine, and other work subject to delays in transporting and placing, the cost of mixing and placing concrete will be increased from 25 to 100 per cent.

In general, heavy mass work will cost from $4.00 to $7.00; heavy arches from $7.00 to $10.00, heavy building construction from $10.00 to $15.00 and light reinforced buildings from $15.00 to $20.00 per cu. yd. for concrete in place.

Cost of Mortar.—This depends upon the proportions of cement and sand and the cost of each ingredient. With sand containing 45 per cent of voids, and a barrel of cement holding 3.8 cu. ft. the quantities of each per cu. yd. of mortar would be as follows, according to Gillette: *

Proportions of Cement to Sand.	1 to 1	1 to 1½	1 to 2	1 to 2½	1 to 3	1 to 4
No. of bbls. of Portland cement	4.32	3.61	3.10	2.72	2.16	1.62
No. of cu. yds. of sand	0.60	0.80	0.90	1.00	1.00	1.00

With cement at $1.50 per bbl., and sand at $0.80 per cu. yd., the cost of 1 cu. yd. of 1 to 2 mortar would be as follows:

For materials—	
3.10 × $1.50 =	$4.65
.90 × 0.80 =	.72
	$5.37
Labor, transportation, and mixing	1.00
Total cost	$6.37

To the above must be added the cost of placing, whether for plastering, grouting, laying up masonry, etc.

SOME ACTUAL EXAMPLES OF COST OF CONCRETE WORK

In the remaining pages of this chapter, the actual costs of placing concrete in recently erected structures of different types are presented. In each instance the authority is stated and a brief description is given, including, wherever possible, a summary of the elements entering into the cost.

Cost of Grouting.—In *Engineering-Contracting* for May 6, 1908, the cost of grouting a rock-fill dam recently constructed on the Upper White River, in Arkansas, is given at $3.65 per cu. yd. of loose rock in place.

Cost of Concrete Building Blocks.—In a paper read before the Iowa Cement Users' Association in 1905, Mr. L. L. Bingham states that the average cost of materials and labor for mixing, moulding, and curing concrete blocks in Iowa with average wages at $1.83 per day, is 10 1/3 cts. per sq. ft. of face of wall for 10-inch walls. This is made up of 2 cts. for sand, 4 1/2 cts. for cement at $1.60 per

* Gillette's "Hand Book of Cost Data."

bbl., and 3 4/5 cts. for labor. General expenses, including interest, depreciation of plant, and profits combine to double this amount, so that the selling price is about 21 cts. per sq. ft. of wall.

Cost of Concrete Paving Blocks.—In a paper read before the National Association of Cement Users, in 1910, Mr. Geo. C. Wright * gives the following data as to the cost of 2-inch cubes made of Portland cement, sand, and 1/2-inch gravel, as used for a roadway pavement by the New York State Highway Commission on 1,600 ft. of experimental roadway near Rochester, N. Y.

"The cost per square yard of the cubes laid was as follows: Cement, 0.088 bbl., $0.121; cost of factory, $0.107; labor of manufacture, $0.161; gravel at 50 cts. per cu. yd., $0.024; carting, $0.027; laying, $0.072; total cost per sq. yd. laid, $0.512. There were placed on shoulders 219 cu. yds. of gravel covering 1,800 sq. yds., and costing $2.12 per cu. yd. rolled in place, or 26 cts. per sq. yd."

Cost of Surfacing.—According to Ransome, Gillette, and Neher, a concrete face can be bush-hammered by an ordinary laborer at a cost of from 1 1/2 to 2 1/2 cts. per sq. ft., wages of common laborers being 15 cts. per hour.

In *Engineering-Contracting,* Dec. 9, 1908, Mr. Linn White, Engineer South Park Commission, states that the cost of etching 3,466 ft. of 25-ft. cement walk in Chicago was at the rate of 1 2/3 cts. per sq. ft. This produced an excellent finish.

Cost of Removing Efflorescence with Acid.—Mr. H. P. Gillette † states that the cost of removing efflorescence on a concrete bridge at Washington, D. C., by scrubbing with a solution of 1 part hydrochloric acid and 5 parts of water was at the rate of 20 cts. per sq. yd. for plain walls, and 60 cts. per sq. yd. for the entire bridge, including the balustrades.

Cost of Tooling Surface.—In *Engineering News*, Jan. 14, 1909, Mr. L. C. Wason gives the actual cost of tooling the concrete surface of a mill at Attleboro, Mass., as at the rate of 5.6 cts. per sq. ft. of area.

In a paper presented to the National Association of Cement Users, at their annual convention in 1907, Mr. Henry H. Quimby, M.Am.S.C.E., states that the cost of tooling concrete surfaces by

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* *Engineering Record,* March 5, 1910, p. 277. † "Hand Book of Cost Data."

means of a bush hammer or axe, operated by hand or pneumatic power, without subsequent cleaning with acid, was found to be from 3 to 12 cents per sq. ft., according to the character and extent of the work and the equipment. Mr. Quimby also states that the cost of scrubbing with wire brushes is trifling if done at the right time. A laborer may wash, say, 100 sq. ft. in an hour if the material is green, or the same area, if it has been permitted to get hard, may take two men a whole day to rub into shape.

Cost of Applying Stucco.—The cost of applying Portland cement stucco to frame houses by the use of expanded metal, or similar fabric nailed to the studding strips, will run from $1.10 to $1.40 per sq. yd.

Cost of Reinforced-Concrete Building Construction.—Mr. Leonard C. Wason,* M.Am.Soc.C.E., in a valuable paper presented to the Fifth Annual Convention of the National Association of Cement Users in 1909, gave the following actual costs of forms and concrete in place as compiled by the Aberthaw Construction Co., Boston, Mass., from their office records: † [See Table on page 412.]

		Cost per Ton.
Cost of bending, fabricating, and placing of steel in dollars per ton, omitting the first cost of the material.	Highest........	$16.47
	Lowest	2 54
	Average of 21...	8.52

Deductions from Table.—The following deductions from Mr. Wason's figures by the authors, while not scientifically exact, are nevertheless sufficiently accurate to roughly approximate the average cost of constructing reinforced-concrete buildings in terms of the number of cubic yards of concrete employed.

Averaging the mean costs for each class of construction, gives the following unit costs:

Forms $.111 per sq. ft. of area, or assuming that each sq. ft. of area corresponds to 1/54 of a cubic yard of concrete, the cost would be per cu. yd. of concrete in place, $.111 × 54, or	$6.00
Concrete per cu. yd., $3.04 × 27, or	8.21
If 1 per cent of steel is used, the weight of steel per cu. yd. of concrete in place will be 132 pounds. At a cost of 1 3/4 cts. per lb. delivered at the work, the cost of the reinforcement per cu. yd. of concrete would be $.175 × 132, or	2.31
	16.52

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* President Aberthaw Construction Co., Boston, Mass. † *Engineering News*, Jan. 14, 1909, page 43.

Brought forward from previous page	$16.52
At a mean cost of $8.52 per ton, the cost of placing this reinforcement would be $.00426 per lb., or $.00426 × 132 per cu. yd. of concrete, or	0.56
Average cost of concrete work in buildings containing 1 per cent of steel per cu. yd. of concrete in place	$17.08

Cost of Buildings in Terms of their Cubical Contents.—At the annual meeting of the Association of Cement Users in 1907, Mr. Emile G. Perrot, in a paper on "Comparative Cost of Reinforced Concrete Buildings," gave the following costs for concrete buildings built by his firm in terms of their cubical contents:

Warehouses and factories	8–11 cts. per cu. ft.
Stores and loft buildings	11–17 cts. per cu. ft.
Miscellaneous, such as schools and hospitals	15–20 cts. per cu. ft.

These costs include the building complete, omitting power, heat, light, elevators, and decorations or furnishings.

In "Reinforced Concrete in Factory Construction," published in 1907, by the Atlas Portland Cement Co., it is stated that the cost of reinforced-concrete factories finished complete with heating, lighting, plumbing, and elevators, but without machinery, may run under actual conditions from 8 to 12 cents per cubic foot of total volume, measured from footings to roof. The former price may apply where the building is erected simply for factory purposes with uniform floor loading, symmetrical design, which permits the forms to be used over and over again, and with materials at moderate prices. The higher price will usually cover buildings located in restricted districts, where the appearance both of the exterior and interior must be pleasing. The cost does not, however, in either case include interior plastering or partitions.

Cost of Concrete Residences.—The following comparative building costs of different systems of buildings are based upon an average frame dwelling costing $10,000 complete, located in the vicinity of New York:

(*a*) $10,000 Frame.
(*b*) $11,000 Brick outside walls, wooden inside.
(*c*) $10,250 Stucco on expanded metal, wooden inside.
(*d*) $10,500 Hollow terra cotta blocks stuccoed, wooden inside.
(*e*) $12,000 Hollow blocks stuccoed: fireproof throughout except roof.
(*f*) $14,000 Hollow terra cotta block walls faced with brick, fireproof floors and roof.
(*g*) $15,000 Brick walls, fireproof floors and roof.

TABLE XXXVIII.—COST OF FORMS IN DOLLARS PER SQUARE FOOT OF CONTACT AREA AND OF CONCRETE IN DOLLARS PER CUBIC FOOT.

		Forms per Square Foot.				Concrete per Cubic Foot.						
		Carpenter Labor.	Lumber.	Nails and Wire.	Total.	Concrete Labor.	General Labor.	Cement.	Aggregate.	Teams and Miscellaneous.	Plant.	Total.
Plain Concrete Columns	Highest	$.133	$.082	$.002	$.181	$.166	$.056	$.109	.084	$.041	$.034	$.340
	Lowest	.057	.013	.001	.075	.064	.003	.062	.027	.008	.013	.271
	Average of 9	.082	.036	.001	.130	.096	.027	.085	.049	.021	.023	.301
Reinforced Concrete Beam Floors	Highest	.165	.107	.004	.275	.186	.035	.194	.101	.052	.055	.470
	Lowest	.037	.027	.001	.067	.047	.004	.071	.037	.007	.010	.202
	Average of 18	.070	.045	.002	.116	.111	.020	.106	.063	.025	.024	.354
Flat Slab Floors	Highest	.078	.039	.003	.118	.146	.017	.109	.084	.026	.039	.374
	Lowest	.067	.037	.001	.106	.043	.004	.087	.053	.012	.010	.252
	Average of 3	.071	.038	.002	.111	.097	.009	.096	.070	.019	.024	.315
Reinforced Concrete Slabs between Steel Beams	Highest	.110	.071	.003	.184	.144	.048	.208	.080	.064	.046	.428
	Lowest	.028	.012	.001	.049	.073	.005	.076	.026	.004	.010	.272
	Average of 13	.061	.032	.002	.095	.102	.019	.128	.068	.024	.017	.359
Building Walls Above Grade	Highest	.136	.073	.005	.176	.146	.052	.105	.187	.077	.055	.446
	Lowest	.046	.016	.001	.079	.042	.004	.034	.043	.007	.005	.174
	Average of 17	.085	.036	.002	.128	.090	.016	.073	.076	.025	.019	.301
Foundation Walls	Highest	.134	.048	.004	.193	.213	.037	.203	.116	.057	.040	.599
	Lowest	.032	.009	.001	.056	.040	.002	.038	.027	.003	.010	.148
	Average of 14	.068	.033	.002	.103	.076	.015	.080	.062	.019	.017	.269
Footings and Mass Foundations	Highest	.119	.077	.003	.198	.081	.020	.098	.099	.013	.049	.275
	Lowest	.016	.006	.001	.018	.025	.001	.047	.043	.003	.010	.181
	Average of 10	.057	.034	.002	.093	.045	.007	.071	.077	.007	.021	.229

The above figures are based on an average taken from two architects and two builders, who have had experience with the methods of construction designated and have been compiled by The National Fireproofing Co.

Cost of Constructing Concrete Sewers.—In *Engineering News*, for Feb. 3, 1910, Mr. Frederick R. Charles, City Engineer, Richmond, Ind., gives the following table, showing the costs per lineal-foot for materials and labor employed in placing the concrete for sewers ranging from 42 to 54 ins. in diameter, which were recently constructed in Richmond, Indiana:

Cost per Linear Foot of Concrete Sewers at Richmond, Indiana.

Diameter of sewer	54 ins.	48 ins.	42 ins.
Thickness of shell	5 ins.	5 ins.	4 ins.
Total cost, exclusive of machinery, and superintendence	$1.349	$1.083	$0.911

In *Engineering Record* for April 4, 1908, the cost of building a 53 × 54 in. arch sewer with cement at $1.53 per bbl., sand at $0.50 and broken stone at $1.10 per cu. yd., is stated to be at the rate of $2.97 per lineal foot or $8.02 per cu. yd. of concrete.

Data on Cost of Concrete Pipe.—The following figures are given in the March Bulletin of the U. S. Reclamation Service for 1908, and relate to the cost per lin. ft. of constructing concrete pipe.

Cost of cement, $3.05 per bbl.; of sand, $1.40 per cu. yd.; and of labor, $5.00 per day for foremen; $3.00 per day each for two men; and $2.75 per day each for two men. The concrete was made of 1 part cement and 3 parts sand. The unit costs were as follows:

Diameter of Pipe. Inches.	Thickness. Inches.	Weight per Linear Foot. Lbs.	Number of Feet Made.	Cost per Foot.
12	1 ½	56	144	$0.25
18	1 ¾	94	248	.37
24	2	143	56	.57
36	3	366	54	1.15

Cost of Large Concrete Pipes.—In the *Reclamation Record* for June, 1908, the cost of constructing 63 1/2 in. concrete pipe at Ballantine, Montana, is given at $6.90 per lin. ft., and the unit cost at $11.64 per cu. yd.

Cost of Reinforced-Concrete Culverts.—In *Engineering-Contracting* for July 1, 1908, the cost of constructing a 7-foot reinforced-concrete box culvert with flat roof slabs at Huntley, Montana, is given at $17.41 per cu. yd.; while the cost of the steel was $0.0327 per pound in place.

Cost of Concrete in Bridge Piers.—The following costs for materials and labor used in placing concrete used to construct the piers and abutments of the Chattahoochee River Viaduct near Atlanta, Ga., in 1907, were given by Mr. John W. Ash in the *Engineering Record*, for Aug. 29, 1908. These costs do not include excavation or cofferdam construction:

Total cost of materials	$20,555.83	
Total cost of labor	4,515.39	
5,024 cu. yd.	$25071.22	= $4.99 per cu. yd.

The total cost of the work, including excavation, cofferdams, pile driving, etc., was about $45,000.

Cost of Reinforced-Concrete Bridges.—The approximate total cost of reinforced-concrete highway bridges, including excavation, falsework, and all other charges, is from $2.50 to $10.00 per sq. ft. of roadway area.

The following are actual costs of recently built structures:

Mulbury Street reinforced-concrete viaduct, Harrisburg, Pa., which is 1,841 ft. long and consists of 19 arches, varying in span from 36 to 93 ft. in the clear, cost $2.60 per sq. ft. of roadway area. This bridge is fully described in *Engineering News*, Jan. 13, 1910.

Two-span highway bridge near Carlisle, Pa., consisting of two 62 ft. 9 in. arches, was built in 1909 at a cost of $2.35 per sq. ft. of bridge floor. This structure is described in *Engineering Record* for Feb. 19, 1910.

In his paper on "Cost of Concrete Bridges," presented to the National Association of Cement Users in 1907, Mr. Henry H. Quimby, Engineer of Bridges of Philadelphia, said in part:

"Of 18 concrete arch bridges recently built in Philadelphia, the concrete price spread upon the span area—the clear span by the width—varies from $3.11 to $9.74 per sq. ft. The average of the lot was $6.25 per sq. ft. of span area, most of them being single-span bridges with long wings, and all being highway bridges designed to carry loads of 40 tons on two axles 20 ft. apart. All have ornamental concrete balustrades and washed granolithic surfaces and paved decks, with electrical conduits and manholes, and water pipe and sewer well-holes, and some have pretty deep foundations. If the whole contract price be set against the yardage of the concrete in the structure, the unit costs vary from $8.50 to $11.25 per cu. yd., averaging $9.75."

Mr. Quimby also states that in several instances where opportunities for fair comparison occurred, steel plate-girder bridges would have cost 25 per cent. more than the reinforced-concrete bridges, which were constructed. A real money value also attaches to the superior beauty and attractiveness of a decorative arch over that of a purely utilitarian structure.

Cost of Constructing Piers on Concrete Piles.—Two piers built at Brunswick, Ga., in 1906, one 500 ft. long and 140 ft. wide; the other 900 ft. long and 140 ft. wide, both constructed on concrete piles, cost $1.40 per sq. ft. The piers are described in *Engineering News*, May 20, 1909. In a similar pier built at Charleston, S. C., described in the same issue, the cost was $2.60 per sq. ft.

Cost of Concrete Piles.—In a dike recently constructed on the Missouri River at St. Joseph, Mo., and described in *Engineering News*, Feb. 18, 1909, Cap. Edw. H. Schulz, Corps of Engineers, U. S. A., gave the following data:

Total piles driven, 36; total lin. ft., 1,457; length of piles, 32 to 50 ft.; penetration, average, 21 ft. Total cost, $1977.21 or $1.36 per lin. ft. of pile.

Cost of Concrete Trestles.—The average cost of concrete trestles, used to replace similar timber structures on the Chicago, Burlington and Quincy Railroad, is given by Mr. C. H. Cartlidge, bridge engineer for the railroad, in *Engineering Record*, April 23, 1910.

These trestles vary in length from 100 to over 1,000 ft. The bents are spaced from 14 to 16 ft. c. to c. Each bent consists of six 16-in. rolled piles spaced 2 ft. 4 in. on centres. The cap is 2 1/2 ft. wide, 3 ft. 3 in. deep, and 14 ft. long. The floor is 14 ft. wide, made up of two solid reinforced-concrete slabs each 7 ft. wide and 1 ft. 11 in. in minimum thickness for a slab of 16-ft. span. Parapets 6 in. high are cast on the slab to retain the ballast.

The cost of the trestles is said by Mr. Cartlidge to vary from

$20.00 to $45.00 per lineal foot. For estimating purposes a cost of $30.00 plus a constant of $300.00 was ample for any design.

Cost of Reinforced-Concrete Poles.—In *Engineering-Contracting* for Feb. 26, 1908, the cost of constructing reinforced-concrete poles 30 ft. long, and 6 × 6 ins. in sectional area at the top, and 10 × 10 ins. at the base, is stated to be $7.45.

The cost of erecting a pole of this size is said to be $1.00 when proper equipment is provided.

In the March 11, 1908, issue, of the same journal the following cost data for reinforced-concrete poles, erected at Richmond, Ind., is given:

Length. Feet.	Top. Inches.	Bottom. Inches.	Cost.
25	6	10	$6.71
30	6	11	8.63
35	6	12	11.45
40	7	15	17.05
45	7	16	21.78
50	7	17	25.50
55	7	18	31.93
60	7	19	36.60

Cost of Constructing Concrete Sidewalks.—The following data relates to the cost of laying cement sidewalks in Chicago, and is condensed from a paper by Mr. N. E. Murray, Superintendent of Sidewalks, for Chicago, Ill., which was printed in *Engineering News*, Feb. 17, 1910.

The ordinary concrete sidewalk gang in Chicago is usually composed of six men, paid as follows (for 8 hours): 1 finisher at 65 cts., $5.20; 1 helper at 47 1/2 cts., $3.80; 4 laborers at 37 1/2 cts., $12.00; total $21.00. Such a gang will lay on the average 600 sq. ft. per day of 5-inch cement walk.

The cost per day for materials and labor, including the cost of filling and grading, is as follows:

Cinders (allow for 20 per cent shrinkage), 20.83 cu. yds. at 50 cts.		
Base, 4 ¼ ins. (1: 2 ½: 5)		$10.42
Cement, 9.77 bbls. at $1.20	$11.72	
Sand, 3.47 cu. yds. at 1.75	6.07	
Gravel, 6.85 cu. yds. at 1.50	10.28	
		$28.07
		$38.49

Brought forward from previous page		$38.49
Wearing coat, ¾ ins. (2:3):		
Cement, 5.56 bbls. at $1.20	$6.67	
Sand, 1.17 cu. yds. at $1.75	2.04	
		8.71
Water, at 1 mill per sq. ft.		.60
Labor, one gang per day		21.00
Use of tools, waste of materials, etc., at 2 per cent		1.37
Supt. and office expenses at 5 per cent		3.51
Profit at 10 per cent		7.36
Total cost per day		$81.04
Average cost 13.51 cts. per sq. ft.		

Cost of Concrete Curb and Gutter.—The cost of building concrete curb and gutter is about 40 cts. per lineal foot, including excavation, for a gutter slab 24 ins. wide, and a curb 12 ins. high, both curb and gutter being laid monolithic in 7-foot alternate sections, with a 3/4 in. surface coat of cement and sand.

Cost of Concrete Boundary Monuments.—The cost of building 103 concrete monuments in post holes five feet deep, the average sectional area being 8 × 8 ins., is stated by Mr. Leonard Metcalf in *Engineering Record*, for Jan. 1, 1910, as averaging $4.30 for each monument.

Cost of Constructing Concrete Silos.—Data taken from *Hoard's Dairyman*, for June 19, 1908, and described in *Engineering-Contracting* for Sept. 9, 1908.

Cost of concrete silo 10 ft. in diameter, and 31 ft. deep—15 ft. in ground and 16 ft. above.

Materials, $75.00; labor, $97.00. Total, $172.00.

Cost of Constructing Concrete Roofs for Filters and Reservoir.—This should approximate $6.00 per cu. yd. In *Engineering News* for April 7, 1910, Mr. Thomas H. Wiggin, Assoc. M.Am. Soc. C.E., gives data on the design, construction, and cost of 44 different filters and reservoirs. In these structures, the cost of constructing the groined arch roofs varied from $0.182 to $0.61 cts. per sq. ft., depending upon the span, thickness, and other conditions.

Mr. Wiggins estimates the comparative cost of plain concrete groined roofs as $0.25 and reinforced-concrete slab roofs as $0.54 per sq. ft.

Cost of Concrete Tunnel Lining.—The Gunnison Tunnel, recently completed by the Reclamation Service near Montrose, Colo., is the largest work of its character and purpose. This tunnel has a width of about 11 ft., a height of 12 ft., and a length of 31,000 ft. The following data as to the cost of lining about 984 lin. ft. of arch and side walls with plain concrete was compiled by Mr. F. W. Hanna, engineer U. S. Reclamation Service and published in *Engineering Record*, May 30, 1908.

The rate of wages was for foremen, $5.00 per day; and for laborers, $3.04. The mixture was in the proportion of 1 : 2 1/2 : 5.

TABLE SHOWING COST OF CONCRETE TUNNEL LINING IN THE GUNNISON TUNNEL

Distribution of Cost.	Total Cost.	Cost per Linear Foot.	Cost per Cubic Yard.
Superintendence	187.50	$0.203	$0.212
Placing steel forms	275.12	0.336	0.351
Tearing down forms	288.80	0.307	0.321
Mixing concrete	305.52	0.331	0.345
Placing concrete	583.68	0.632	0.659
Hauling concrete	218.02	0.236	0.246
Sand and gravel at $0.637 per cu. yd.	793.70	0.859	0.897
Cement delivered at $3.00 per barrel	3319.15	3.592	3.750
	$5971.49	$6.496	$6.781

During the period in question, 818 linear feet of forms were put into place and 940 linear feet were taken down.

Cost of Waterproofing.—Hot coal-tar and felt. Horizontal 1st ply—$2.00 to $4.00 per square (100 sq. ft.). Additional—$1.50 to $2.50 per square.

Vertical, add 10 per cent to 25 per cent.

Pressure work, 1 ply $4.00 to $5.00 per square. Commercial asphalt and asphalt felt, add 15 per cent to 60 per cent per ply; special asphalts and felts, add 30 per cent to 50 per cent per ply; cold process—felt or burlap, same as commercial asphalt; asphalt mastic, 1 in., 15 cts. per sq. ft.

Cement waterproofing compounds.—1 in. on floors, ½ in. to ¾ in. on walls, 8 to 30 cts. per sq. ft.

Dampproofing masonry walls.—2 coats applied in place, 2 to 4 cts. per sq. ft.

In a paper presented to the National Association of Cement

Users in 1907, Mr. H. Weiderhold, Mgr. Vulcanite Paving Co., Philadelphia, Pa., states that the cost of asphalt mastic for waterproofing in the vicinity of New York, when laid in 1-inch layers, will range from 15 to 25 cts. per sq. ft.

In *Engineering Record* for Oct. 31, 1908, is given the following cost data for waterproofing concrete-covered bridge floors with felt cemented together with Hydrex compound, as used by the Central R. R. of New Jersey, on their through girder bridges.

"The work per square of 100 sq. ft. required 1.66 hours of time for a foreman, 11.71 hours water-proofers' time, and 7.75 hours of laborers' time. The best record was 750 sq. ft. in one day of 10 hrs., while the average time was 40 per cent longer. The materials cost 20¾ cents, and the labor 10¾ cents per sq. ft. for a five-ply covering.

Cost of Reinforced Concrete in Dam Construction.—The Corbett Diversion Dam of the Shoshone Irrigation Project, near Cody, Wyoming, is of the reinforced-concrete buttressed type, having a deck 30 in. thick on the upper side with a slope of 1 to 1. This deck rests on buttresses two feet thick, spaced 14 ft. on centres. The following data as to the unit cost of concrete placed in the structure is condensed from the *Reclamation Record* of August, 1907.

Materials and engineering, $5.00 per cu. yd.

Contractors' labor and plant charges, $10.00 per cu. yd.

Placing steel, $.035 per lb.

Cost of Rubble Concrete.—In *Engineering-Contracting* for Oct. 7, 1908, is given the following cost data for placing 30,000 cu. yds. of concrete in a rubble-concrete dam near Chicago:

	Cost per Cubic Yard Concrete in Place.
Stone	$1.26
Sand	0.46
Cement	2.31
Forms	0.62
Mixing	0.58
Placing	0.69
Total	$5.92

In the canvass of bids opened Aug. 6, 1907, by the Board of Water Supply of New York City, for the construction of the Main Dams of the Ashokan Reservoir, the bid submitted by Messrs.

McArthur Bros. and Winston, who received the contract, was as follows for concrete construction:

Description.	Unit.	Quantity.	Price.
Portland Cement	Barrels	1,100,000	$1.50
Concrete Masonry	Cubic Yards	280,000	4.90
Cyclopean Masonry, Class A	" "	475,000	3.40
Cyclopean Masonry, Class B	" "	55,000	3.90
Concrete Blocks	" "	64,000	11.50
Grout of Portland Cement	" Feet	5,000	0.50

The total bid on all of the estimated quantities for this work, of which concrete represents a large percentage, amounted to $12,669,-775.00. The actual unit costs to the contractor for concrete may be approximated by deducting 15 per cent from each item. This represents his probable profits for the work.

HEAVY TRIANGULAR POSTS.

Materials.	Cost.	Number of Posts.	Cost per Post.
1 yard of rock or gravel	$1.00	29	$.03 ½
1 yard of sand	1.00	58	.01 ¾
1 barrel of cement	1.50	18	.08 ½
3 two-ply No. 12 wire cables (weight 1 ¾ lbs.)	.025 per lb.	1	.04 ¼
2 men for one hour at 20 cents per hour	.40 }	5	.11
1 boy for one hour at 15 cents per hour	.15 }		
Total Cost			.29

STRAIGHT SQUARE POSTS.

1 yard of rock or gravel	$1.00	25	$.04
1 yard of sand	1.00	50	.02
1 barrel of cement	1.50	16	.09 ½
4 two-ply No. 12 wire cables (weight 2 ¼ lbs.)	.025 per lb	1	.05 ¾
2 men for one hour at 20 cents per hour	.40 }	5	.11
1 boy for one hour at 15 cents per hour	.15 }		
Total cost			.32 ¼

Cost of Reinforced-Concrete Fence Posts.—The above data relative to the cost of constructing 7-foot reinforced-concrete fence posts was published in Bulletin 403 of the U. S. Dept. of Agriculture, issued May 21, 1910. The mixture consists of 1 part of cement, 2 parts of sand, and 4 parts of crushed rock or screened gravel; a reinforcement consisting of two No. 12 smooth fencing wires twisted into a cable and cut to the necessary length at the factory; concrete mixed by hand; all material delivered at the work, and all labor of men and teams paid for.

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