

To convert values of pounds per square inch to tons (2,000 lb.) per square foot, divide the former by 14 (more exactly 13.89).

To convert Centigrade to Fahrenheit temperatures, multiply the former by 1.8 and add  $32^{\circ}$  to the product.

To convert Fahrenheit to Centigrade temperature, deduct  $32^{\circ}$  from the former and divide by 1.8.

One millimeter = 0.0394 inch

One centimeter = 0.3937 "

One meter = 39.37 inches or 3.281 feet

One square centimeter = 0.155 square inch

One " meter = 10.764 square feet or 1.196 square yards

One cubic centimeter = 0.061 cubic inch

One " meter = 35.31 cubic feet, or 1.308 cubic yards

One liter = 61.02 cubic inches or 0.0353 cubic foot, or 1.057 U. S. liquid quarts or 0.2642 U. S. liquid gallon

One gram = 0.0353 avoirdupois ounce

500 grams = 1.1 pounds avoirdupois

One kilogram = 2.2046 pounds avoirdupois

One tonne or metric ton = 2204.62 pounds or 1.1023 tons (of 2,000 lb.)

One English penny = \$0.0203

One " shilling = \$0.2433

One " pound = \$4.8665

One French franc = \$0.193

One German mark = \$0.238

## CHAPTER II

## ELEMENTARY OUTLINE OF THE PROCESS OF CONCRETING

This chapter is not written for experienced civil engineers and contractors, nor for those who desire to make a scientific study of methods and principles. On the contrary, it is merely an elementary outline, indicating to the inexperienced the various steps which must be taken with this class of masonry. In subsequent chapters the various divisions of the subject are treated in detail.

The question as to whether concrete is preferable to some other form of masonry may often resolve itself into a question of cost. The cost, in turn, is dependent upon the character of the structure, the rate of labor and the price of the various materials entering into the work. Portland cement concrete has been laid in large masses at as low a price as \$3 per cubic yard, while for thin walls built under disadvantageous conditions the cost of constructing molds may cause it to run as high as \$30 per cubic yard, and in the case of ornamental work even above this. Before estimating the cost in any case, the materials must be chosen and the relative proportions of the ingredients determined from a consideration of the design of the structure.

## WHERE CONCRETE MAY BE USED

By far the largest proportion of Portland cement concrete is laid in heavy foundation work and in other structures, such as tunnels and subways, below the surface of the ground. It is peculiarly adapted for foundations of engines or machinery, heavy walls, piers, etc. In the former the concrete is often carried all the way up to the base of the engine or machine, instead of being topped with brick or stone. It is widely used for sidewalks or floors upon the ground level, and for suspended floors. When suitably reinforced with steel, it furnishes probably the most economical and effective material for fire-proof construction. Its use for walls of buildings is largely increasing, but on account of the very indefinite time required in the building and moving of forms the cost may largely exceed the original estimate unless the builder is experienced in this class of work. Under favorable conditions, however, a 6-inch wall of concrete will cost no more, and usually less, than a 12-inch wall of brick work, and will be



stronger, more durable, and fire-proof. The strength of concrete columns and beams is readily calculated by means of formulas.

Concrete is destined to be used to a large extent in the construction of tanks and vats for holding various liquids which attack wood and iron. Their construction is comparatively simple, but the work must be carefully performed if the result is to be permanent and satisfactory. Concrete is especially suitable for all kinds of arches, because the stresses therein are chiefly compressive. Other classes of work for which concrete is largely employed are dams, retaining walls, penstocks, bridges, abutments, sewer and water conduits, and reservoirs. For ornamental work developments are constantly being made, and it is noteworthy that concrete or mortar can be cast in molds in a somewhat similar manner to that in which plaster of Paris is run for interior decoration.

### SELECTION OF MATERIALS

Concrete is ordinarily composed of cement, sand, gravel or crushed stone, or both, and water. The selection of each of these materials is largely dependent upon local conditions, and no unalterable rule can be laid down in regard to it, but certain general conditions may serve as a guide to the inexperienced.

**Cement.** It is a wise rule to use Portland cement for nearly all classes of concrete, and the remarks in this chapter are based entirely upon this material. Portland cement is more uniform and therefore more reliable, while its strength is so much higher than Natural cement that by mixing it with larger proportions of sand and stone, properly graded, it will usually yield better results at less cost than Natural cement.

If the job is small and unimportant, it is generally safe to select in the market a brand of Portland cement of American manufacture which has a first-class reputation, and to use it without testing. As a precaution, however, it is usually advisable that samples from a few of the packages of every shipment be tested for soundness. This can be done after a little practice with scarcely any apparatus. (See p. 79.) For very important concrete construction complete specifications should be prepared before purchasing the cement, and a small laboratory established for conducting tests to determine whether it is fulfilling the requirements. (See p. 28.)

**Aggregate.** The sand and broken stone or gravel are termed the aggregate. The sand should be clean. One may obtain some idea of its cleanliness by placing it in the palm of one hand and rubbing it with the fingers of the other. If the sand is dirty, it will badly discolor the palm.

If the use of dirty sand is unavoidable, its effect upon the strength of the mortar should be investigated. Preference should be given to sand containing a mixture of coarse and fine grains. Extremely fine sand can be used alone, but it makes a weaker mortar than either coarse sand alone or a mixture of coarse and fine sand.

Either crushed stone or clean gravel, or both, is suitable for the coarse material of the aggregate. It is chiefly a question of which can be delivered upon the work at the least cost. If the gravel is chosen greater uniformity is attained by screening it over, say a  $\frac{3}{8}$ -inch mesh screen, and then re-mixing the sand which falls through the screen with the coarser gravel in definite proportions, than by taking the run of the bank. If the gravel is dirty or clayey it should be washed with a hose, a little at a time, before it is shoveled on to the mixing platform.

Broken stone, if selected, may be used unscreened as it comes from the crusher, although it is preferable to screen out the dust and to use the latter as a portion of the sand. The maximum size is usually limited to  $2\frac{1}{2}$  inches. A smaller size than this, say one inch, will give, with less care, a finer surface. In a thick wall large sound stones may be placed by hand or derrick without detriment to the work, providing the consistency of the concrete is thin enough to properly imbed them.

### PROPORTIONS

Accurate methods of proportioning the cement and aggregate in concrete are discussed in chapter XI, page 183, and if a large or very important mass is under consideration, or if the work must be water-tight, the correct proportioning requires more careful consideration than can be given it in this chapter. The method often adopted of pouring water into the coarser material to determine the percentage of voids, and thus finding the quantity of sand to use for filling them, is apt to be misleading, because so much depends upon the compactness of the stone, due to the method of handling it — that is, whether placed quietly, dropped, thrown, or shaken down — and because in the majority of cases the sand contains many grains so large that they will not enter the smaller voids of the coarser material. In a small job it is sufficiently accurate to select the proportion of cement to sand which will give the required strength to the concrete, and then use twice as much gravel or broken stone as sand. In figuring the capacities of the measures for the sand and stone it must be remembered that a barrel of Portland cement weighs 376 pounds, not including the barrel, and a bag of Portland cement 94 pounds, and we may assume for convenience



that a cement barrel holds 3.8 cubic feet. This is a fair average measurement of a heaped barrel, or a barrel with both heads removed—a convenient measure for sand.

As a rough guide to the selection of materials for various classes of work, we may take four proportions which differ from each other simply in the relative quantity of cement:

- (a) **A Rich Mixture** for columns and other structural parts subjected to high stresses or requiring exceptional water-tightness: Proportions 1 : 1½ : 3; that is, one barrel (4 bags) packed Portland cement to 1½ barrels (5.7 cubic feet) loose sand to 3 barrels (11.4 cubic feet) loose gravel or broken stone.
- (b) **A Standard Mixture** for reinforced floors, beams and columns, for arches, for reinforced engine or machine foundations subject to vibrations, for tanks, sewers, conduits, and other water-tight work: Proportions 1 : 2 : 4; that is, one barrel (4 bags) packed Portland cement to 2 bags (7.6 cu. ft.) loose sand to 4 barrels (15.2 cu. ft.) loose gravel or broken stone.
- (c) **A Medium Mixture** for ordinary machine foundations, retaining walls, abutments, piers, thin foundation walls, building walls, ordinary floors, sidewalks, and sewers with heavy walls: Proportions 1 : 2½ : 5; that is, one barrel (4 bags) packed Portland cement to 2½ barrels (9.5 cu. ft.) loose sand to 5 barrels (19 cu. ft.) loose gravel or broken stone.
- (d) **A Lean Mixture** for unimportant work in masses, for heavy walls, for large foundations supporting a stationary load, and for backing for stone masonry: Proportions 1 : 3 : 6; that is, one barrel (4 bags) packed Portland cement to 3 barrels (11.4 cu. ft.) loose sand to 6 barrels (22.8 cu. ft.) loose gravel or broken stone.
- The above specifications are based upon fair average practice. If the aggregate is carefully graded and the proportions are scientifically fixed, smaller proportions of cement may be used for each class of work.

### QUANTITIES OF MATERIAL

Inexperienced contractors have often lost money by assuming that the quantity of gravel plus the quantity of sand required will be equivalent to the volume of the finished concrete—that is, that 7½ cubic yards of concrete in the proportions of 1 : 2½ : 5 will require 2½ cubic yards of sand and 5 cubic yards of gravel. This is absolutely wrong, since the grains of sand fill, to a certain extent, the spaces between the larger pebbles. It is incorrect, on the other hand, to figure a quantity of gravel equal to the total

volume of the concrete, because the introduction of the mortar, which is always in excess of the actual voids, swells the bulk.

If gravel or stone having particles of uniform size is used it must be recognized that the work will cost from 5 to 10 per cent. more, on account of the additional quantity of material required to make a given volume of concrete. In measuring the gravel or stone before mixing there will be less solid matter in a measure, and consequently more sand and cement will be necessary to fill the spaces between the stones. This fact, which is often overlooked even by experienced men, is illustrated in a somewhat exaggerated fashion in Figs. 1 and 2. Here Fig. 1 illustrates

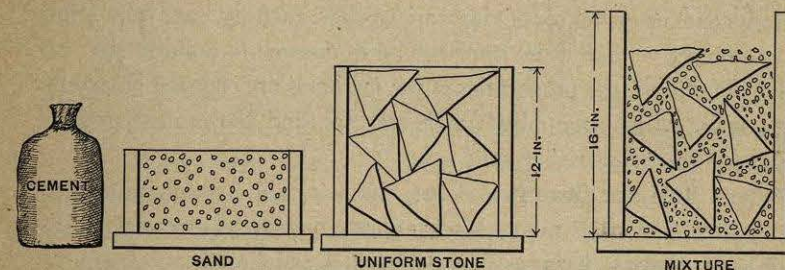


FIG. 1.—Diagram illustrating measurement of Dry Materials and the Mixture when Broken Stone is of uniform size. (See p. 15.)

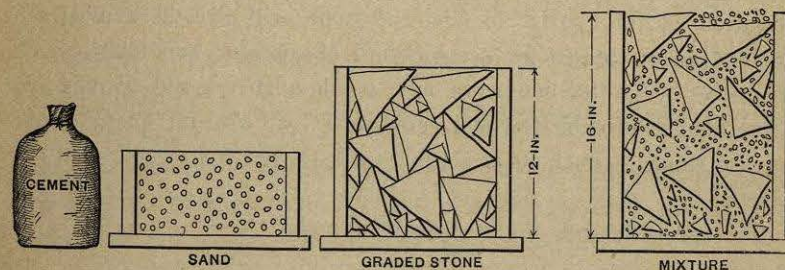


FIG. 2.—Dry Materials and Mixture when the Stone is of varying sizes. (See p. 15.)

the measurement of the dry materials and the mixture produced therefrom when the stone has been screened to one uniform size, while Fig. 2 shows the dry materials and the mixture when the stone is what is termed "crusher-run"—that is, of varying sizes as it comes from the crusher.

It is obvious at a glance that the uniform stone measured in Fig. 1 contains less solid stone than the graded stone measured in Fig. 2. The spaces between the stones in the first case are very nearly equal to the volume of



the solid particles, and as the measure of the sand is one-half that of the stone, and the particles of cement fill the voids in the sand, this sand and cement mixes in between the stones, filling the spaces or voids, and resulting in a mixture but very slightly greater in volume than the stone alone. In the second case, Fig. 2, the spaces between the large stones in the stone measure are filled with graded smaller stones, so that there is a much smaller volume of spaces or voids. Hence, when the sand and cement, which are identical with that in Fig. 1, are mixed with it the volume of mixture becomes considerably larger than the original bulk of the stone. Consequently, if we start with definite proportions of materials, more concrete will be made with graded stone — such as “crusher run” broken stone, or gravel containing various sizes, ranging, say, from  $\frac{1}{4}$  inch up to 2 inches — than if the stone has been screened to uniform size. If, on the other hand, the proportions of the materials are changed on account of the fewer voids in the mixed stone, and less sand and cement are used, a saving in these materials results.

**Fuller's Rule For Quantities**—The simplest rule for determining the quantities of materials for a cubic yard of concrete is one devised by William B. Fuller. Expressed in words, it is as follows:

Divide 11 by the sum of the parts of all the ingredients, and the quotient will be the number of barrels of Portland cement required for 1 cubic yard of concrete. The number of barrels of cement thus found, multiplied respectively by the “parts” of sand and stone, will give the number of barrels of each required for 1 cubic yard of concrete, and multiplying these values by 3.8 (the number of cubic feet in a barrel), and dividing by 27 (the number of cubic feet in a cubic yard), will give the quantities of sand and stone, in fractions of a cubic yard, needed for 1 cubic yard of concrete.

To express this rule in the shape of formulas:

Let

$c$  = number of parts cement;

$s$  = number of parts sand;

$g$  = number of parts gravel or broken stone.

Then

$$\frac{11}{c+s+g} = P = \text{number of barrels Portland cement required for one cubic yard of concrete.}$$

$$P \times s \times \frac{3.8}{27} = \text{number of cubic yards of sand required for one cubic yard of concrete.}$$

$$P \times g \times \frac{3.8}{27} = \text{number of cubic yards of stone or gravel required for one cubic yard of concrete.}$$

The following table is made up from Fuller's rule and represents fair averages of all classes of material. The first figure in each proportion represents the unit, or one barrel (4 bags), of packed Portland cement (weighing 376 pounds), the second figure, the number of barrels loose sand (3.8 cubic feet each) per barrel of cement, and the third figure, the number of barrels loose gravel or stone (of 3.8 cubic feet each) per barrel of cement:

*Materials for One Cubic Yard of Concrete.*

Proportions.	Cement, Barrels.	Sand, Cubic yards.	Gravel or stone, Cubic yards.
1: 2: 4	1.57	0.44	0.88
1: 2½: 5	1.29	0.45	0.91
1: 3: 6	1.10	0.46	0.93
1: 4: 8	0.85	0.48	0.96

If the coarse material is broken stone screened to uniform size it will, as is stated above, contain less solid matter in a given volume than an average stone, and about 5 per cent. must be added to the quantities of *all* the materials. If the coarse material contains a large variety of sizes so as to be quite dense, about 5 per cent. may be deducted from all of the quantities.

*Example.*—What materials will be required for six machine foundations, each 5 feet square at the bottom, 4 feet square at the top, and 8 feet high?

*Answer.*—Each pier contains 163 cubic feet, and the six piers therefore contain  $\frac{6 \times 163}{27} = 36.2$  cubic yards. If we select proportions 1: 2½: 5, we find, multiplying the total volume by the quantities given in the table, that there will be required, in round numbers, 47 barrels packed cement, 16½ cubic yards loose sand, 33 cubic yards loose gravel.

#### TOOLS AND APPARATUS REQUIRED FOR CONCRETE WORK

The quantity of tools will, of course, vary with the size of the gang. The following schedule is based upon a small gang of eight or ten men, making concrete by hand:

Eight square pointed shovels, size No. 3, and such as illustrated in Fig. 3, page 18. (If a very wet mixture is used substitute small coal scoops.)

Three iron wheelbarrows, Fig. 4, page 18.

Two rammers, Figs. 99, 100, or 101, pages 281 and 282.



One mixing platform, about 15 feet square, built so substantially that it can be moved without coming to pieces, and having a 2 by 3-inch strip around the edge to prevent waste of materials and water. On a small job this may be of 1-inch stuff, resting on joists about 3 feet apart, provided it is stiffened by being tongued and grooved.



Fig. 3.—Square Pointed Shovel. (See p. 17.)

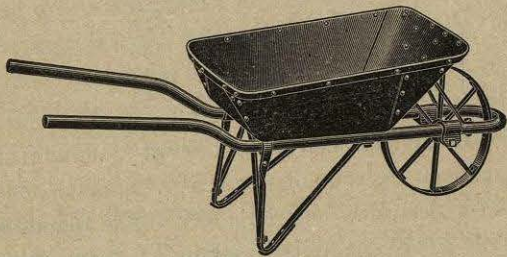


Fig. 4.—Concrete Wheelbarrow. (See p. 17.)

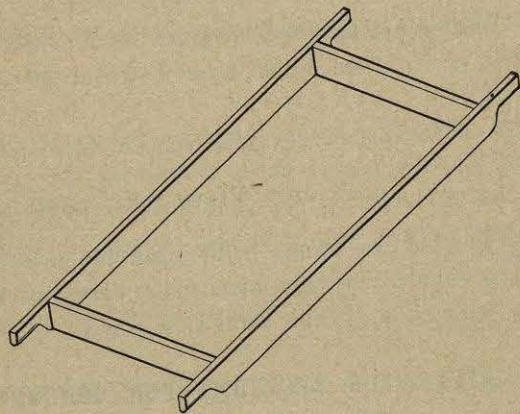


Fig. 5.—Measuring Box for Gravel. (See p. 18.)

One measuring box or barrel for sand, of a capacity for one batch of concrete. A convenient measure is a cement barrel, either whole or sawed in two, with both heads removed. It is filled and then lifted in such a manner as to spread the sand.

One measuring box for gravel (see Fig. 5) of a capacity for one batch of concrete.

Lumber for making and bracing forms.

Nails and, for some kinds of work, bolts, for forms.

### CONSTRUCTION OF FORMS

Green spruce or fir lumber is suitable for forms. If a smooth face is required the surface of the boards or plank next to the concrete must be dressed and the edges tongued and grooved or beveled. The forms must be nearly water-tight. The sheeting, which is usually laid horizontal, may be 1 inch, 1½ inch or 2 inches thick, the distance apart of the studding being governed by the thickness selected. The studs must be placed not more than 2 feet apart for 1-inch sheeting nor more than 5 feet apart for 2-inch sheeting. They must be securely braced so as to withstand the pressure of the soft concrete and of the puddling or ramming.

The lower portion of a foundation wall in a trench excavated in earth so stiff as to stand nearly vertical may sometimes be laid with no form at all, and then narrowed in at the top to the required thickness, but if the sides of the trench are sloping it is generally cheaper to save concrete material by carrying the forms to the bottom. A thin wall may be

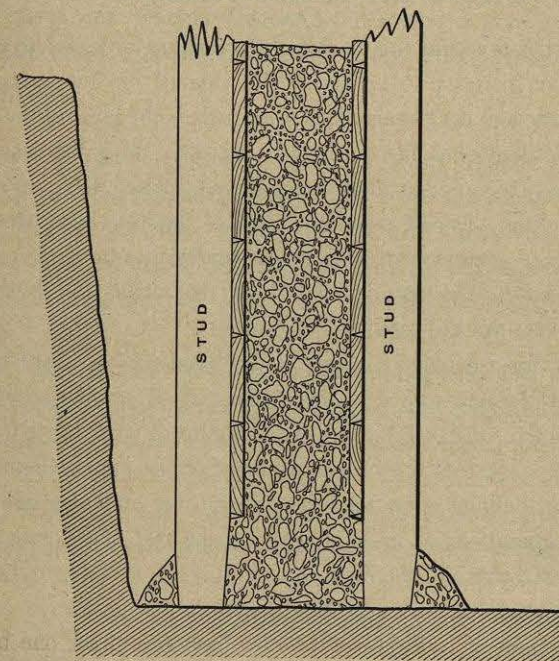


FIG. 6.—Construction of Form when Base of Wall is Spread. (See p. 19.)



greatly strengthened by spreading the base, which is readily accomplished by starting the boards or plank 6 or 8 inches above the bottom of the excavation and allowing the soft concrete to flow out under them on both sides of the wall so as to make footings, as shown in Fig. 6. The studs may run to the bottom, as indicated by the dotted lines, but should be tapered and greased so that they may be withdrawn without injury to the concrete.

For all walls under 9 or 10 inches in thickness, small steel rods  $\frac{1}{4}$  or  $\frac{3}{8}$  inch in diameter, spaced about 18 inches apart, will greatly increase the stiffness and add to the safety of the structure, especially while the concrete is hardening.

Forms must be left in place for three or four weeks if there is earth or water pressure against the wall. If, on the other hand, there is no strain upon it, 24 hours setting, or until the concrete will stand the pressure of the thumb without indentation, is sufficient.

Further descriptions of form construction and methods of facing are given in Chapter XV. Forms for special structures are described and illustrated in subsequent chapters treating of concrete design.

### MIXING AND LAYING CONCRETE

The advisability of employing machinery for mixing the concrete depends chiefly upon the quantity to be laid. On a small job the first cost of mixing machinery and the running expenses, such as the labor of the engineer, which continue when the machine is idle, may bring the cost of machine-mixed concrete higher than hand-mixed. The decision may be based entirely upon the cost per cubic yard of concrete laid, provided a first-class machine is employed, since good concrete can be made either by machine or by hand. The various types of concrete mixers and the methods of employing them are discussed in Chapter XIV.

The foreman for a gang of concrete mixers need not be of great intelligence, but must be one who will obey orders strictly, and know how to keep all of his men constantly busy. The amount of work turned out will depend to quite an extent on the arrangement of the gang, whether each man has certain definite operations to perform over and over again, and whether these operations fit into the work of the rest of the gang so that none of the men have idle moments.

A gang of at least 6 men besides the foreman is required even on small work, while as many as 23 men may be effectively employed. In addition to these, an inspector is generally necessary to watch the placing of the

concrete and see that the mixture is uniform and of proper consistency. Cheap laborers, as for instance Italians, make good men for mixing and transporting the concrete.

The materials for the concrete ought, of course, to be deposited as near the work as possible. The cement, whether it comes in bags or barrels, must be sheltered from the rain. Covering with plank is insufficient. Bags should be protected from moist atmosphere; a cellar is likely to be too damp. To keep the sand and stone as near the mixing platform as possible, it may be advantageous to haul the materials as they are required from day to day. If the sand or stone pile is at any time farther from the measuring boxes than a man can profitably throw with shovels without walking, say more than 8 or 10 feet, do not hesitate to have it loaded into wheelbarrows and dumped into the measuring boxes. Materials can be wheeled in barrows to a distance of 10 to 25 feet from the platform at about the same cost that they can be shoveled direct with a long throw.

There are many methods of mixing concrete by hand, as discussed in Chapter XIV, all of which with care produce good work. For the convenience of the inexperienced the following directions for the work of a small gang of six men with foremen may be useful. They are given merely for illustration, and must be more or less varied to suit local circumstances.

**Directions for Mixing Concrete.** Assume a gang of four men to wheel and mix the concrete, with two other men to look after the placing and ramming.

When starting a batch, two mixers shovel or wheel sand into the measuring box or barrel — which should have no bottom or top — level it and lift off the measure, leveling the sand still further if necessary. They then empty the cement on top of the sand, level it to a layer of even thickness, and turn the dry sand and cement with shovels three times, as described below, after which the mixture should be of uniform color.

While these two men are mixing sand and cement, the other two fill the gravel measure about half full, then the two sand men take hold with them, and complete filling it. The gravel measure is lifted, the gravel hollowed out slightly in the center, and the mixture of sand and cement shoveled on top in a layer of nearly even thickness.\* A definite number of pails are filled with water, and poured directly on the top of these layers, greater uniformity being thus attained than by adding the water directly from a hose. After soaking in slightly the mass is ready for turning.

\*Some engineers prefer to spread the stone on top of the sand and cement, while others prefer to mix the water with the sand and cement before adding them to the stone.



The method illustrated in Fig. 7 of turning with shovels materials which have already been spread in layers is as follows:

Two men, *a* and *b*, with square pointed shovels, stand facing each other at one end of the pile to be turned, one working right-handed and the other left-handed. Each man pushes his shovel along the platform under the pile, lifts the shovelful, turns with it, and then, turning the shovel completely over, and with a spreading motion drawing the shovel toward himself, deposits the material about 2 feet from its original position. Repetitions of this operation will form a flat ridge of the material, on a line with the pile as it originally lay, and flat enough so that the stones will not roll. As soon as, but not before, a single ridge is complete, two other men, *c* and *d*, should start upon this ridge, turning the materials for the second time, as shown in the illustration, and forming as before a flat ridge and finally a level pile which gradually replaces the last. A third mixing is accomplished in a similar way.

Fig. 7 gives the position of the piles as the concrete is being turned.

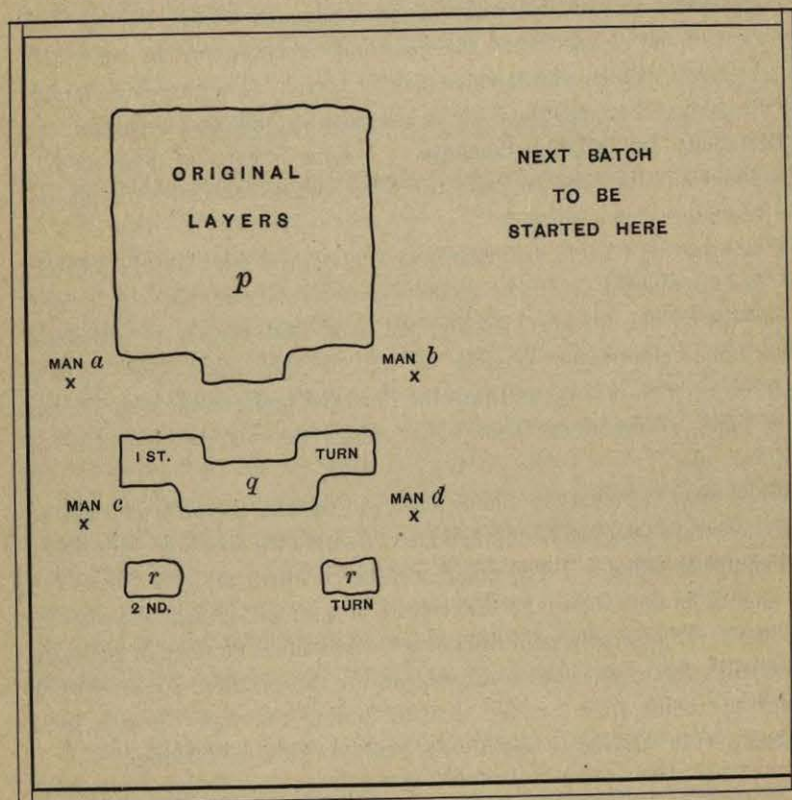


FIG. 7.—Position of Men and Concrete on Platform while Turning. (See p. 22.)

A portion of the original layers is shown at *p*, the ridge formed by men *a* and *b* shoveling from pile *p* is shown at *q*, and the beginning of the ridge formed by men *c* and *d* is shown at *rr*. The third turning is not shown.

The quantity of water used must be varied according to the moisture in the materials and the consistency required in the concrete. While the opinions of engineers regarding the proper consistency vary widely, it is advisable, the authors believe, for an inexperienced gang to use an excess of water. The rule may be made in hand mixing to use as much water as can be thoroughly incorporated with the materials. Concrete thus made will be so soft or "mushy" that it will fall off the shovel unless handled quickly.

After the material has been turned twice, as described, and as soon as the third turning has been commenced, two of the mixers who have finished turning may load the concrete into barrows and wheel to place. They should fill their own barrows, and after the mass has been completely turned for the third time by the other two men the latter should start filling the gravel measure for the next batch.

If the concrete is not wheeled over 50 feet, four experienced men ought to mix and wheel on the average about  $10\frac{1}{2}$  batches in ten hours. This figure is based on proportions 1:  $2\frac{1}{2}$ : 5, and assumes that a batch consists of one barrel (four bags) Portland cement with 9.5 cubic feet of sand and 19 cubic feet of gravel or stone.

Assuming, as given on page 17, that 1.29 barrels of cement are required for 1 cubic yard of concrete, one barrel of cement — that is, one batch — will make 0.78 cubic yard of concrete; hence  $10\frac{1}{2}$  batches mixed and wheeled by four men in ten hours are equivalent to  $8\frac{1}{4}$  cubic yards of concrete. This is for the very simplest kind of concreting and makes no allowance for the labor of supplying materials to the mixing platform or for building forms.

**Placing Concrete.** The concrete may be transported and handled by any means which will not cause the materials to separate. If mixed wet it may be dropped directly from shovels or barrows to place, or it may be run down an inclined pipe or chute. The layers should be about 6 inches thick. For a dry or a jelly-like mixture common square ended rammers are employed and the mass must be rammed until the mortar flushes to the surface. Wet concrete must be merely puddled or "joggled" to expel the air and surplus water. Before placing a fresh layer upon work which has set, the surface must be cleaned of dirt and scum, and thoroughly wet.



The placing of concrete and the kinds of rammers for different classes of work are discussed more at length in Chapter XV.

### APPROXIMATE COST OF CONCRETE

The cost of concrete depends more upon the character of the construction and the conditions which govern it than upon the first cost of the materials. In a very general way, we may say that when laid in large masses or in a very heavy wall, so that the construction of the forms is relatively a small item, the cost per cubic yard in place is likely to range from \$4 to \$7. The lower figure represents contract work under favorable conditions with low prices for materials, and the higher figure small jobs and inexperienced men. Similarly, we may say that for sewers and arches, where centering is required, the price may range from \$7 to \$14 per cubic yard. Thin building walls under eight inches thick may cost from \$10 to \$20 per cubic yard, according to the character of construction and the finish which is given to the surface.

These ranges in price seem enormous for a material which is ordinarily supposed to be handled by unskilled labor, but it must be borne in mind that skilled workmen are required for constructing forms and centers, and often the labor upon these may be several times that of mixing and placing the concrete. As a rule, unless the job is a very small one or under the personal supervision of a competent engineer, it is cheaper and more satisfactory to employ an experienced contractor than day labor. Green men under an inexperienced foreman may not be counted upon to mix and lay over one-half the amount of concrete that will be handled by a skilled gang under expert superintendence.

A close estimate of cost may be reached, in cases where the conditions are known in advance, by taking up in detail and then combining the various units of the material and labor as outlined below.

**Cost of Cement.** As the price of Portland cement varies largely with the demand, it is necessary to obtain quotations from dealers for every purchase. It is such heavy stuff that the freight usually enters largely into the cost, and quotations should therefore be made f.o.b. the nearest point of delivery to the work. The cost of hauling by wagon may be readily estimated by assuming that a barrel of cement weighs 400 pounds (gross), and that a pair of horses will haul over an average country road a load of, say, 5 000 pounds, traveling in all a distance of 20 to 25 miles in a day, that is, 10 to 12½ miles with load. This assumes, of course, that the teams are good and properly handled.

Having found the cost of the cement per barrel, delivered, the approximate cost per cubic yard is at once obtained from the table on page 17. If, for example, the cost is \$2 per barrel and proportions 1:2½:5 are selected, the cost of the cement per cubic yard of concrete will be  $1.29 \times \$2.00 = \$2.58$ .

**Cost of Sand.** The cost of sand depends chiefly upon the distance hauled. With labor at 15 cents per hour, the cost of loading (including the cost of the cart waiting at pit) may be estimated, if handled in large quantities, at 18 cents per cubic yard, or on a small job at 27 cents per cubic yard. For hauling add one cent for each 100 feet of distance from the pit. The additional cost of screening, if required, will vary with the coarseness of the material, but 15 cents per cubic yard may be called an average price for this, unless the sand is obtained by screening the gravel, when no allowance need be made. After finding the cost of one cubic yard of sand, the cost of the sand per cubic yard of concrete is readily figured from the table referred to. If, for example, the cost of sand screened, loaded and hauled 1 000 feet is 52 cents per cubic yard, the cost per cubic yard of concrete for proportions 1:2½:5 will be  $0.45 \times \$0.52 = \$0.23\frac{1}{2}$ .

**Cost of Gravel or Broken Stone.** If broken stone is used upon a small job for the coarse aggregate, it is usually purchased by the ton or cubic yard. A 2000-lb. ton of broken stone may be considered as averaging approximately 0.9 cubic yards, although differences in specific gravity cause considerable variation. A two-horse load is generally considered 1½ to 2 yards, the latter quantity requiring very high sideboards. The cost of screening gravel, if this is necessary, while a very variable item, may be estimated at 35 cents per cubic yard. The cost of loading gravel into double carts, with labor at 15 cents per hour, may be estimated on a small job at 38 cents per cubic yard. If handled in large quantities, 25 cents is an average cost. The cost of loading includes loosening and also the cost of the cart waiting at the pit. Hauling costs about one cent per cubic yard additional for each 100 feet of distance hauled under load. If, to illustrate, the cost of gravel picked, screened, loaded and hauled 1 000 feet is 83 cents per cubic yard, the cost of the gravel per cubic yard of concrete for proportions 1:2½:5 will be  $0.91 \times \$0.83 = \$0.75\frac{1}{2}$ .

For distances up to 300 feet both sand and gravel can be hauled more economically by wheelbarrows than by teams. The cost of loading wheelbarrows is about half the cost of loading carts, while the cost of hauling with barrows per 100 feet is about four times greater.

**Cost of Labor.** With an experienced gang working at the rate of 15



cents per hour, the cost of mixing and laying concrete, if shoveled directly to place from the mixing platform, will average about 80 cents per cubic yard, in addition to the work on forms. If, as is usually the case, the concrete is wheeled in barrows, 9 cents per cubic yard must be added to the above price for the first 25 feet that the barrows are wheeled under load, and  $1\frac{1}{4}$  cents for each additional 25 feet wheeled. With other rates of wages, the cost may be considered as proportional. With a green gang, the cost will be nearly double the above figures, but as the men become worked in and the organization perfected, the cost should approximate more nearly the prices given.

In building construction where the material is mixed by machinery and hoisted to place, there are numerous incidental expenses and delays, so that it is not safe to figure the cost of labor for simply mixing and laying the concrete under ordinarily good conditions at less than \$1.50 to \$2.00 per cubic yard. The cost of materials must be added to this, so that the cost of the concrete itself laid in place but *not* including forms nor reinforcement is apt to be about \$7.50 per cubic yard. Approximate costs per cubic foot of finished concrete are given in Chapter XXIV.

**Cost of Forms.** The labor on forms is not included in the above. This is an extremely variable item. The cost of rough plank forms, including labor and lumber for both sides of a 3-foot wall, may be as low as 50 cents per cubic yard of concrete, with other thicknesses of wall in inverse proportion. On elaborate work the price, which is really dependent upon the face area, will reach several dollars per cubic yard of concrete, the cost of the form work, in fact, usually exceeding the cost of the concrete. In building construction, such as a factory six stories in height of symmetrical design, the cost of materials and labor on forms may be estimated at from 9 to 12 cents per square foot of surface of forms. If forms are to be used only once, or if conditions are disadvantageous, these values may be doubled. The costs vary with the price of lumber, the design of the structure, the design of the forms, the character of the supervision, and the skill of the workmen.

**Cost of Steel.** The cost of bending and placing steel for reinforced concrete is apt to vary from  $\frac{1}{2}$  to  $1\frac{1}{2}$  ¢ per pound. If, therefore, the cost of the steel is about \$40.00 per ton or 2¢ per pound, the cost in place may be estimated at 3¢ per pound.

#### THE STRENGTH OF CONCRETE

The strength of concrete varies (1) with the quality of the materials; (2) with the quantity of cement contained in a cubic yard of the concrete; and (3) with the density of the mixture.

We may say that the strongest and most economical mixture consists of an aggregate comprising a large variety of sizes of particles, so graded that they fit into each other with the smallest possible volume of spaces or voids, and enough cement to slightly more than fill all of these spaces or voids between the solids of the aggregate. It is obvious that with the same aggregate the strongest cement will make the strongest concrete.

On important construction the various materials to be used should be carefully tested, and specimens of the mixture selected made up in advance and subjected to test. As a guide to the loads which concrete will stand in compression, that is, under vertical loading where the height of the column or mass is not over, say, 12 times the least horizontal dimension, we may give the following approximate figures as safe strengths, after the concrete has set at least one month, for the proportions which have previously been selected in this article as typical mixtures.

The figures, compared with the results of recent experiments on long columns, allow with first-class construction a factor of safety of at least four at the age of one month, or about five and one-half at the age of six months, and are based on conservative practice. The relative strengths of the different mixtures are calculated from original investigations of the authors discussed in Chapter XX.

#### Safe Strength of Portland Cement Concrete in Direct Compression.

Proportions,	Pounds per square inch.	Tons per square foot.
1 : $1\frac{1}{2}$ : 3	500	36
1 : 2 : 4	450	32
1 : $2\frac{1}{2}$ : 5	400	29
1 : 3 : 6	360	26
1 : 4 : 8	290	21

With a large mass foundation, take values one-third greater.

With a vibrating or pounding load, take one-half these values.

The tensile strength of concrete is very much less than the compressive strength. Experiments made by the authors, with mixtures of average proportions, give the ultimate fiber stress in beams not reinforced as about one-eighth the breaking strength in compression. For this reason it is not safe to use concrete for beams unless reinforced with steel.