Second. Cement mortars hardening in water increase in like manner but to a less degree.

Third. The contractions and expansions are greatest in neat cement mortars.

Among further conclusions of the committee given in this report it is stated that experiments show the contraction of neat cement in air at the end of twelve weeks to be from 0.14 to 0.32%, and of 1:1 mortar, 0.08 to 0.17%. Although these values are corroborated by Bauschinger's* experiments on Portland cement mortars, the results of which also indicate nearly the same contraction for leaner mortars as for 1:1, further data upon the action of concrete made of modern Portland cement is required before accepting the figures as applicable to this. Considère† gives 0.03% to 0.05% shrinkage for lean mortars corresponding to a contraction of about ½ inch in a wall 100 feet long. These various conclusions show that cracks in a newly laid concrete wall are due in part to contraction in setting. In fact, it has been noticed that joints open up in new concrete before it has been affected by external temperature.

It must be borne in mind that this action during hardening has nothing to do with the temperature of the atmosphere, and does not vary with it, but is in addition to the effects of temperature changes. It is possible, however, as suggested on page 285, that the shrinkage may be due in part to the cooling down from the heat evolved when the cement sets.

FACING CONCRETE WALLS

Exposed concrete walls had best not be plastered. It is a needless expense, and the results in variable climates are unsatisfactory. It is difficult to apply cement mortar uniformly to the face of hardened concrete, and it is apt to crack off and discolor, especially if the concrete behind it is porous enough for the water to penetrate it. For waterproofing walls not exposed to the atmosphere, cement plaster is sometimes serviceable, as described on page 341.

Mortar for patching irregularities and pockets, which will occasionally occur in the best work, and for filling holes, must contain the same proportions of cement and sand as the concrete, or it will set a different color.

The treatment of the face of concrete is determined by the character of the structure. A fair surface, suitable for work which is not exposed to view, and even for sheds or other buildings where the appearance need not be regarded, has been obtained by the authors on 4-inch and 6-inch walls

*Transactions American Society of Civil Engineers, Vol. XV, p. 722.

†Considère's Reinforced Concrete, 1903, p. 87.

by using merely a very wet mixture of cement, sand and gravel, with care in placing and puddling so that none of the stones, many of which were 2 inches in diameter, collected in pockets against the forms. Such treatment will result in a sandy finish, showing the joints in the forms less than a smoother one.

FIG. 103.—Face Cutter. (See p. 289.)

To produce a smooth mortar surface, a thin tool like a spade or an ice cutter, shown in Fig. 103, may be thrust down next to the molds as the concrete is placed, so as to force the stones back from the face and allow the mortar to cover every stone, care being taken not to pry the molds.

One of the best methods of finishing for a large smooth surface is to spade or cut the faces as described, and then after the forms are removed to pick them with a hand tool, shown in Fig. 104, or a pneumatic tool adapted for the purpose. The Harvard University Stadium, illustrated in our frontispiece, is finished in this way, and the photograph in Fig. 105 shows a near view of the surface. On the left is the concrete showing the impressions of the plank forms, and on the right is the finished surface. If this picking is performed by hand, it is done by a common laborer. The surface he will cover per day depends upon the hardness of the concrete. It must not be too green or the tool will loosen the stones, while if set very hard the labor is unnecessarily great. On the average, a man may be expected to cover about 50 square feet per day of ten hours. The picks require frequent, at least daily, sharpening. For the best appearance, the size of stone in the concrete should be limited to about ¾ inch to one inch. This method of picking was employed by Mr. E. L. Ransome in the construction of the Pacific Borax Works in New Jersey. A pneumatic tool suitable for this work is made with a circular end containing a number of points, using which a man should cover 400 to 500 square feet per day.

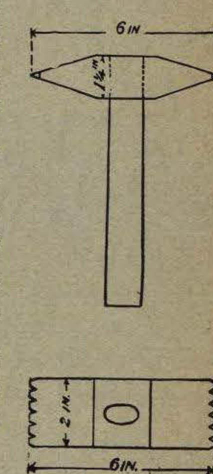

FIG. 104.—Pick for Facing Concrete. (See p. 289.)

Mr. C. R. Neher* states that with labor at $1.50 per day bush-hammering will cost less than 1½ cents per square foot.

A surface of washed concrete is shown in the photograph, Fig. 106,

*Journal Association of Engineering Societies, Jan., 1902, p. 41.

Surface left by forms is shown on left and picked surface on right.
FIG. 105.—Surface of "Picked" Concrete. (*See p.* 289.)

FIG. 106.—Surface of Washed Concrete. (*See p.* 289.)

p. 290. This finish, used by Mr. Henry H. Quimby* for surfacing concrete bridges in Philadelphia, is obtained by hand or with a hose. Hand methods are usually preferable because of the difficulty of applying the hose at exactly the right stage of hardening. In either case the forms must be removed as soon as the concrete is sufficiently hard,—a period varying from 6 hours to 2 or 3 days, according to the character of the cement and the weather,— and the washing done immediately. For washing by hand, a plasterer's float, or a small board 1 by 3 by 6 inches, is used and the cutting is done by sand rolled between the board and the wall, with plenty of water. The concrete face after this process may sometimes be too green for rinsing clean, when the final cleaning is deferred for a few hours. Mr. Quimby states that a laborer should wash and clean 100 square feet of surface in less than one hour. If the concrete has become too hard before washing, a comparatively smooth finish is obtained in a similar manner or by vigorously rubbing the surface with a rough brick. A green surface may be treated with a common scrubbing-brush and water.

A fine sandy finish may be obtained after concrete has set by rubbing with a block of carborundum about 3 by 4 by $1\frac{1}{2}$ inches.

Another plan for removing the skin of cement is the acid process.†

Mr. H. P. Gillette‡ mentions a method employed in one case on the New York Central R. R. of chiseling sloping grooves, about $\frac{3}{4}$ inch deep and 2 inches apart, upon an old discolored concrete surface.

For a very smooth mortar surface, such as may be required for moldings, curved surfaces or carving, the interior surface of the mold may be plastered about $\frac{3}{4}$-inch thick, by hand or trowel, just in advance of the laying of the concrete, so that the concrete and mortar set up as one mass.

The advocates of dry mixed concrete often require a piece of board, corresponding in width to the thickness of the layer of concrete, to be placed on edge close to the form, the concrete rammed against it, and then the board removed and the space filled with mortar mixed in proportions 1 : 2 or 1 : 3. Another method, which can be used with mortar of a wetter consistency, is to place a thin board or a strip of sheet iron at the required distance from the form, usually about 2 inches, then to fill in the mortar between it and the mold, and the concrete on the other side of it, when it may be removed. In the best modern practice, facing mortar is omitted altogether, and the concrete is made wet enough to present a good surface.§

Marking the surface to resemble masonry is considered unnecessary from an architectural point of view, for the work is actually a monolith and

* Personal correspondence. See also *Engineering News*, Dec. 20, 1906, p. 656.
† See paper by Linn White, *Engineering Record*, Feb. 2, 1907, p. 126.
‡ *Engineering News*, July 24, 1902, p. 66.
§ Other methods of facing are described in the Report of the Association of Railway Superintendents of Bridges and Buildings, 1900.

should have that appearance, but if it is desired, triangular pieces may be nailed to the forms, or if tongued-and-grooved plank are used, the horizontal molding may be formed by a strip of wood gotten out to the preferred shape, and planed with a tongue and groove so as to fit between two planks, as shown in Chapter XXIV.

The size of molding depends upon the class of masonry which is to be imitated. Mr. Edwin Thacher* specifies triangular moldings 2 inches wide by 1 inch deep.

To give a uniform color, in England† it is customary to use a rather stiff mortar in proportions 1 : 3 applied with a plasterer's hand float and worked in so thoroughly as to leave no body on the surface. In the United States a 1 : 2 grout is sometimes put on with a whitewash brush or small whisk broom. This, however, is liable to check.

A pumice-stone paint used by Mr. H. I. Moyer has given satisfaction in practice. It consists of ground pumice-stone and Portland cement mixed in equal parts to the consistency of thick paint. After removing the board-marks with a block of carborundum, the surface is wet and the paint applied with a brush. When this first coat is hard, it is wet and the second coat applied.

Plastering. When plastering on external surfaces must be resorted to, special means must be taken to make it adhere and to prevent its checking. The forms must be wet instead of oiled; irregularities must be removed by chipping or rubbing; the entire surface should be roughened; and the coat of plaster should be as thin as possible, preferably not over $\frac{1}{16}$ or $\frac{1}{8}$-inch.

By throwing on plaster with considerable force, it bonds better than by spreading it. If the first coat is thrown on the second is more apt to adhere. A spatter-dash or a pebble dash finish is made by throwing on a mortar to leave it regular but rough.

Lafarge cement finish has been satisfactorily used for house walls by Mr. Benjamin A. Howes. The process is illustrated in a photograph shown in Fig. 107, page 293. The surface, which must be very true, is wet, and a neat solution of Lafarge cement is spread on with a whitewash brush. Before this has dried, a second coat in proportions about 1 : 3 of Lafarge cement and fine sea sand is spread with a steel trowel, floated with a wood float, then immediately wet down with a whitewash brush. The total thickness of the plaster should not be over $\frac{1}{16}$ inch.

If a thick plaster is necessary, the surface must be carefully roughened, wet, and coated with a neat cement grout, preferably spread on very thin with a wire brush, and then plastered immediately before it hardens. A plaster which has been found satisfactory is made using one-sixth to one-

* *Cement*, May, 1903, p. 107.
† Sutcliffe's *Concrete*, 1893, p. 324.

third part of lime putty to one part of cement by bulk, with enough sand to make it work sandy. For 3-coat work the second coat may have about as much hair as is used in brown coat work in interior plastering.

FORMS FOR MASS CONCRETE*

The forms for structures, such as buildings and sewers, are illustrated in the chapters treating upon these subjects.

The best lumber for forms or molds for concrete is white pine because it is easily worked and retains its shape after exposure to the weather. Except, however, where a very fine face is required, motives of economy

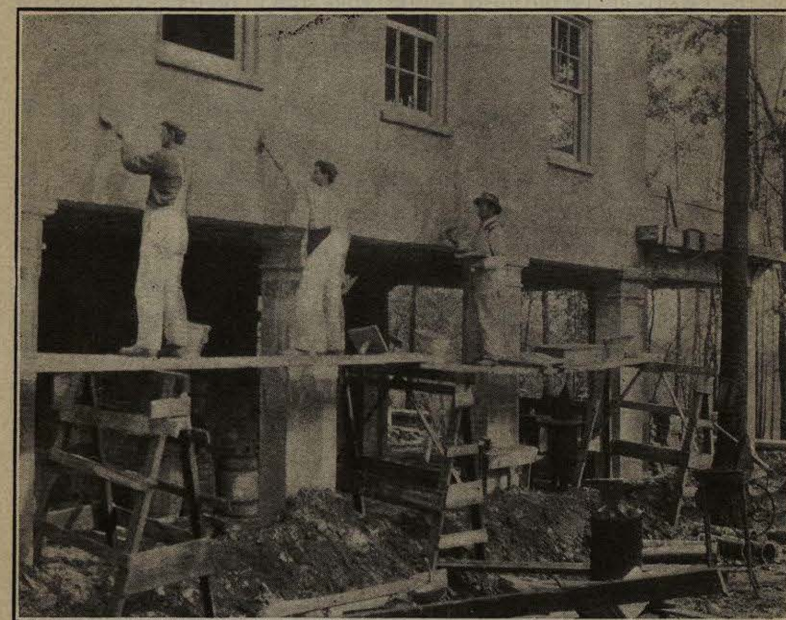

FIG. 107. Surfacing Wall with Mortar. (*See p.* 292.)

usually prompt the use of cheaper material, such as spruce or fir, or, for very rough work, even hemlock. Green lumber is preferable to dry because it is less affected by the water in the concrete.

If the planks or boards are thoroughly oiled and are not exposed too long a time to the hot sun and dry air, which tend to warp them, they may be used over and over again. Long exposure, however, will throw the surface out of true, and open up the joints. In some instances the same lumber can be employed in different places. For example, in the con-

* See also paper by Sanford E. Thompson on "Forms for Concrete Construction," Transactions National Association Cement Users, 1907, reprinted as Bulletin No. 13, Association of American Portland Cement Manufacturers.

struction of a factory building, Mr. Thompson specified 2-inch tongued-and-grooved roof plank of green spruce for the forms, and after using at least four times, no difficulty was found in laying it on the roof. The planks were merely slightly gritty and discolored by the oil employed to prevent adhesion of cement.

Lumber which is planed one side is essential to a smooth face, and where the forms must be removed within 24 or 48 hours it is sometimes advantageously employed for rough work because the concrete adheres less to planed lumber and that which does stick is easily scraped off, thus effecting a saving of labor which more than balances the cost of planing. Many concrete experts advise the use of beveled edge stuff in preference to tongued and grooved. The edges crush as the board or plank swells, and this prevents buckling.

Square corners and thin projections should be avoided when possible A beveled strip in an external corner will give it a finished appearance.

Either 1-inch boards or 2-inch plank are suitable for forms. The spacing of the studs depends in part upon the consistency of the concrete and the thickness of the walls. If the concrete is laid quite wet and the mass is large, there may be considerable pressure exerted before the cement sets. On the other hand, there is less liability of the boards being forced out of place by ramming than when a drier mixture is used. The authors have found that in comparatively thin walls laid with a wet mixture the stringers may be spaced 5 feet apart for 2-inch plank and 2 feet apart for 1-inch boards. This represents about the limit if an absolutely straight face is desired, and even with this spacing the lumber will spring slightly in places where very short lengths of it are used.

The size of the studding depends upon the height of the wall and the amount of bracing which it is convenient to use. For a low form of 1-inch stuff 2 by 4 inch studs may be satisfactory. If this size is used for a higher wall, horizontal timbers must be placed and carefully braced at distances about 5 feet apart to prevent the studs from springing. For 2-inch plank, as the studding is spaced farther apart, it must be heavier. Common sizes are 4 by 6 inches, 2 by 10 inches, and 4 by 10 inches, depending upon the character of the work and the material at hand. The toes of the diagonal braces which run from the studding down to the ground must rest securely against stout posts or other immovable supports. The use of these diagonals may be avoided in many cases or their number reduced by connecting opposite studs with through bolts or wire. An inexpensive method of connection is shown in Fig. 108, page 295. The wires are wound around opposite studs and then twisted with a stick, as a turn-buckle,

until the studs are the proper distance apart. To remove the forms the wires are cut and then trimmed off close to the concrete.

If in placing the concrete the forms commence to buckle, they must remain in their warped position unless trueness of face is of sufficient importance to warrant tearing down the concrete and replacing it. A carpenter is so accustomed to truing up his lumber after it is in place that it is

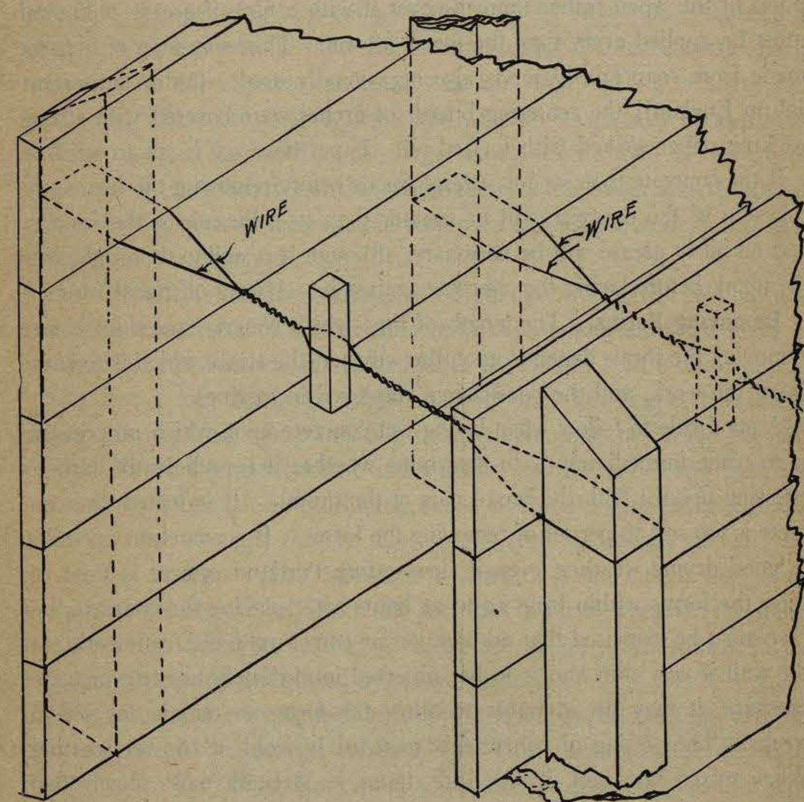

FIG. 108.—Method of Connecting Forms. (See p. 294.)

difficult for him to realize that a thin wall of concrete cannot be straightened in the same way. The fact that a crack once made in concrete which is set is almost impossible to repair cannot be too strongly impressed upon the woodworkers.

Concrete forms should be nearly water-tight but need not be absolutely so. Cracks of noticeable width which cannot be closed by wetting and swelling the lumber may be battened, and vertical joints between the ends of planks may be stopped in the same way. Hard soap has also been used for this purpose.*

In a large structure such as a dam, cement bags filled with sand† may be piled to form the temporary end of a layer or series of layers of concrete.

Greasing Forms. Crude oil is an excellent and inexpensive material for greasing forms. This is a petroleum product sufficiently liquid to be readily applied with a large whitewash brush. The object is to fill the pores of the wood rather than to cover it with a film of grease. The oil must be applied every time the forms are set. Thin soft soap or a paste made from soap and water is also occasionally used. On an important job in England‡ the centering boards of arches were covered with strong packing paper soaked with linseed oil. Paper however is apt to wrinkle.

If the concrete is to set for several weeks before removing the forms, the cohesion of the concrete will be greater than its adhesion to the lumber, and no oil or grease will be necessary, although it is well to thoroughly wet the plank before laying the concrete against it. Always oil metal forms.

Removing Forms. The length of time which concrete must set before removing the forms depends upon the weather, the strain which is to come upon the work, and the consistency employed in mixing.

A good rule to follow when laying wet concrete upon which no pressure is to come immediately is to determine whether it is sufficiently hard by pressing upon it with the broad part of the thumb. If indented, the concrete is too soft to permit of removing the forms. It is sometimes possible in good drying weather, even if slow-setting Portland cement is used, to raise the forms within from 10 to 24 hours after placing the concrete, but care must be exercised that no blow or jar comes upon the fresh work. If the wall is very thin and is to be subjected immediately to earth or water pressure, it may be advisable to allow the forms to remain for several weeks. The setting of concrete is retarded by cold or by wet weather. When mixed very wet, it sets and attains its strength more slowly than when mixed with a small amount of water.

RUBBLE CONCRETE

Rubble concrete includes all classes of concrete in which large stones are placed by hand or by machinery. The term concrete rubble has been applied when the mass consists essentially of large stone laid in joints of concrete instead of mortar.

*George W. Lee, *Engineering News*, Mar. 19, 1903, p. 246.

†*Engineering News*, Aug. 27, 1903, p. 185.

‡K. Leibbrand in Proceedings Institution of Civil Engineers, Vol. CXIX, p. 227.

Rubble concrete comes in competition with pure concrete on the one hand, and with rubble masonry, — that is, stonework laid in cement mortar, — on the other hand. Its cost in large masses is usually less than that of pure concrete, because the expense of crushing the stones used as rubble is saved, and each large stone replaces a mass of mixed cement and aggregate, thereby saving a portion of the cement. As stone is always heavier than concrete made from the crushed material, because of the pores in the concrete, the replacing of portions of the latter by large stone increases its weight, and therefore its value for certain classes of construction. Large masses of rubble concrete can usually be laid cheaper than ordinary concrete, but where the mass is small and separate machinery or apparatus will be required for handling the large stones, its use may not be advantageous. It is especially suitable where the concrete materials are handled with derricks, because these may be employed to hook the stone or transport it in trays.

In comparison with large masses of rubble masonry laid in cement mortar, rubble concrete of similar quality is almost invariably found to be cheaper because scarcely any skilled labor is required. In a thin wall, not more than 3 feet thick, the rubble masonry may be cheaper because no forms are required. In estimating comparative costs of rubble masonry laid in Natural cement mortar and rubble concrete made with Portland cement, the fact must be considered that a wall of Portland cement rubble concrete may be made thinner than one of Natural cement masonry because it is stronger. The difference in strength is not merely due to the class of cement employed, but to the fact that in rubble concrete the stones are perfectly imbedded instead of being set up on small spawls in the manner customarily employed by stone masons.

The amount of cement used in rubble concrete varies not only with the proportions of the concrete mixture, but with the percentage of rubble introduced. Very much less cement is required in concrete than in a similar quantity of mortar of like strength, but concrete joints must be thicker than mortar joints, so that the result is often more cement is required per cubic yard for concrete than for rubble masonry. However, by employing a large percentage of stone, as was done at Boonton,* the quantity of cement may be brought below that for rubble masonry.

The strength of rubble concrete can be compared only theoretically to that of concrete or rubble masonry, because there are no testing machines in existence of sufficient capacity to break a mass of Portland cement masonry containing large stones. It is generally considered less than that

*See description, page 300.

of plain concrete, but, the authors believe, with insufficient ground. Less cement is contained in a cubic yard, which tends to lessen the strength, but, on the other hand, as stated above, the large stones add density which is a source of strength.

In concrete subjected to tension or bending the introduction of large stones might possibly be a source of weakness by forming planes of adhesion. On the other hand, the stones tooth into the mass and into each other, forming an irregularity of breaking surface which would tend to increase the strength. On long-time tests, too, the strength of the large pieces of stone, which is naturally greater per square inch than the strength of small pieces of broken stone, would naturally come into play. In compression this extra strength of the large stones, especially in their resistance to shearing, has a still greater influence upon the strength of the mass, and besides this they must necessarily bond and wedge with each other.

COMPARATIVE QUANTITIES OF MATERIALS FOR PLAIN AND RUBBLE CONCRETE

The cement and aggregate are often expressed as percentages of the total mass of plain concrete or of rubble concrete. This is confusing because there are various ways of expressing percentages, and, as suggested below, it is therefore clearer in ordinary cases to employ, instead, commercial measurements, such as cubic feet, cubic yards, or pounds.

Before the concrete is mixed, the volumes of materials may be compared by percentages, thus, proportions 1:3:6 have 10% cement, 30% sand, and 60% broken stone; but this is apt to be misleading, since loose volumes, — because of the different voids, — and weights, — because of different specific gravities, — do not exactly correspond to absolute or solid volumes in the finished concrete. By absolute volumes,* for example, a cubic foot of 1:3:6 concrete† may contain 0.079 cu. ft. of solid cement grain, 0.278 cu. ft. of solid sand grains, and 0.491 cu. ft. of solid stone particles, and may be said to have 7.9% cement, 27.8% sand and 49.1% stone. This is an exact method, but such percentages cannot be determined without very complete data.

For comparing costs of different concrete it is therefore best to discard the term percentages, and instead to express the quantity of each material as weights or loose volumes required for a unit volume, — say a cubic yard, — of compacted concrete. By this method a cubic yard of average 1:3:6 concrete (from the table on page 231) contains 1.11 bbl. cement.

*See example, p. 139.

†See item (23), p. 377.

0.47 cu. yd. loose sand, and 0.94 cu. yd. loose broken stone. If, now, rubble concrete is used and if on the average every cubic yard of this rubble concrete after being laid contains large rubble stone to the amount of 0.3 cubic yards (measured net, as solid stone), we may say that the rubble concrete contains 30% rubble, and each of the other materials are reduced by 30%, thus giving $1.11 \times 0.70 = 0.78$ bbl. cement, $0.47 \times 0.70 = 0.33$ cu. yd. sand, and $0.94 \times 0.70 = 0.66$ cu. yd. broken stone per cubic yard of concrete. From such data, the relative costs of materials for plain and rubble concrete may be readily compared.†

Proportion of Rubble in the Mass. The proportion of large stones which can be placed depends upon the size of these stones and upon their distance apart. In a heavy wall or dam the size may be limited simply by the strength of the machinery employed to handle them, whereas in a comparatively thin wall subjected to water pressure, it is evident that the stones should not be large enough to run nearly through the wall and might be limited to one-half or one-third of its width. Larger stones can be used with a wet than with a dry mixture since they bed more readily.

The distance between the stones varies in different specifications from 3 to 18 inches. If the concrete is mixed of dry consistency there must be space enough between the stones to ram the concrete thoroughly and force it into all the recesses, while with a wet mixture the spaces need be regulated merely by the dimensions of the stones in the concrete aggregate, care being exercised that they do not bridge or arch across between the large stones.

The quantity of rubble is usually expressed as a percentage of the total mass of the finished concrete. The percentage may vary from 20% to 64%, both of these quantities being mentioned by Mr. John W. Steven* as used in different places in Scotland. Nearly as much space must be left between two small stones as between two large ones, so that the percentage increases with the size. Into one of the Boonton dikes (4 feet 8 inches thick) of the Jersey City Water Supply Company, — where the stones were hoisted in derrick trays and unloaded by one or two men, — 20% of stone was introduced, and this may be taken as a fair average quantity for concrete containing "one-man" or "two-men" stone. In another Boonton dike, of the same thickness and similar in other respects, the stones were large enough to handle by derricks, and the quantity was increased to 33%, while in the large dam described below, 55% was the average quantity.

*Proceedings Institution of Civil Engineers, Vol. CXIII.

† See tables of Quantities of Materials, pp. 236, 237.