The amount of rubble may sometimes be most conveniently and accurately measured by weighing it in cart or car-loads.

Methods of Laying Rubble Concrete. The forms for rubble concrete may be built as for ordinary concrete, or the faces of the work may be of cut stone or ashlar masonry.

Ordinarily, derrick buckets are the most suitable apparatus for placing the concrete, because the derrick can also be conveniently used for handling the stone.

One of the best examples of rubble concrete work which has come within the observation of the authors is the dam of the Jersey City Water Supply Company at Boonton, N. J.,* built in 1902–4 under the direction of Mr. William B. Fuller, Resident Engineer. The dam proper contains about 240 000 cubic yards of "cyclopean" or concrete rubble masonry, and the contract price at which this was let, which covered all labor and all materials excepting the cement, was $1.98 per cubic yard. Other bids ranged from $2.20 to $3.60. The rubble stones, which actually averaged in size from 1 to 2½ cubic yards each, were brought from the quarry about three miles distant over a standard gage track built for the purpose, and the stone for the concrete aggregate was also broken at the quarry, although it was not touched by hand from the time it entered the crusher until it was deposited in concrete. One of the distinctive features of the construction was the consistency of the concrete, which was mixed extremely wet, in fact, about like pea soup, so that when dumped it spread out, forming a level bed for the stone. As soon as a bucket of concrete was dumped, a large stone, which had come from the quarry on flat cars, was picked up by one of the stiff-legged derricks ranged on trestles along each face of the dam, and dropped, — with force, not gently lowered, — usually with its smoothest face down, into the mushy mass. Settling into place, it bedded itself in the concrete, and laborers joggled it with crowbars so as to bring it to a firm bearing and drive out all air bubbles. A stone lifted after placing left a bed conforming to the irregularities of the stone, and having the appearance of mortar, no stones being visible. Scraping this mortar in places showed that the stones of the concrete were covered with an exceedingly thin film of mortar.

The labor of actually placing the concrete and stone after bringing them to the dam may be estimated from the fact that each stiff-legged derrick supplied a gang of three or four laborers dumping concrete and joggling the stone, with one foreman mason, who not only looked after the depositing

* See drawing, Chap. XXVI. See also *Engineering Record*, Aug. 8, 1903, p. 152.

of the stone in the concrete, but also spent some of his time on the face stone masonry. In addition to these, there were the men mixing concrete and handling the cars of stone. Mr. Fuller stated that seven derrick gangs averaged about 700 cubic yards of concrete rubble masonry in ten hours, or about 100 cubic yards to a derrick. A maximum day's work for a derrick was about 125 cubic yards.

The concrete was proportioned 1 part Portland cement, 2¾ parts sand, 6¾ parts broken stone, the latter ranging in size from fine particles up to 3 inches in diameter. The masonry contains about 55% of rubble, the large stones being kept at least far enough apart so that the fist could be thrust between them. About 0.6 barrels of cement were used per cubic yard of concrete rubble masonry. This quantity is less than is generally used in a rubble wall built of fairly well dressed stones laid in 1:2 cement mortar; and where water-tight rubble is required and the stones are accordingly left as rough as possible, the quantity of cement is apt to average slightly more than one barrel per cubic yard.

In a dam built in eastern Connecticut in 1899 to 1901,* where methods somewhat similar to those just described were employed, the quantity of cement averaged about two-thirds barrels per cubic yard of masonry.

The masonry dry dock at the Charlestown Navy Yard, which was begun in 1900, furnishes an example of rubble laid in dry mixed concrete. The stones, which were placed about 18 inches apart in all directions, averaged about ½ cubic yard in volume, and had comparatively square faces and level beds. They occupied less than one-third of the total volume of the concrete. The concrete, mixed in proportions about 1 part Portland cement to 2 parts sand to 5 parts gravel, was deposited from buckets, and thoroughly rammed, and the stones, after washing with a hose, were placed by derrick. If a stone did not bed itself properly, the derrick picked up a heavy weight and allowed it to drop several times upon the stone to ram it into place.

DEPOSITING CONCRETE UNDER WATER

Although some engineers still specify that no concrete shall be laid under water, the many important structures which have been built of late years upon foundations of concrete deposited loose, to set and harden under water, prove that excellent work can be performed with proper selection of materials and care in laying. It is absolutely necessary, however, to lay the concrete by some means which will prevent the separation of the ingredients as they pass through the water. This has been accom-

*Described by Herbert M. Knight, *Engineering News*, June 12, 1902, p. 470.

plished, as discussed in the succeeding pages, by the following methods: (1) passing the concrete through a tube in a continuous flow, (2) lowering it in large buckets from which the concrete may be dropped in large masses, (3) confining it in bags, (4) forming the concrete into blocks on land, and after setting placing them by machinery or by floats, and (5) allowing the concrete to partially set in air and then depositing it in a "plastic" condition.

For sea water construction, the cement should be carefully tested to see that it is of standard quality.* Occasionally the water of a stream or pond may be impregnated with by-products, such as sulphuric acid from industrial plants, or with mineral impurities which prevent the concrete from setting properly.

Cofferdams, which need not be water-tight, are almost always necessary to prevent the concrete from spreading and the cement from washing away.

Laitance. "Laitance" is a French word, quite generally adopted in the United States and England for the light-colored powdery substance which is held in suspension by the water when cement or concrete is deposited below the surface. On land the same substance forms on the surface of concrete which has been mixed very wet.

The analysis of a sample of laitance† showed its composition to be as follows:

Silica (SiO_2)	16.00%
Alumina and Iron (Al_2O_3, Fe_2O_3)	8.66 "
Lime (CaO)	47.40 "
Magnesia Oxide (MgO)	2.40 "
Ignition loss	23.60 "

If calculated to a water and carbonic acid free basis the analysis becomes:

Silica (SiO_2)	20.94%
Alumina and Iron (Al_2O_3, Fe_2O_3)	11.30 "
Lime (CaO)	62.04 "
Magnesia Oxide (MgO)	3.14 "

Mr. Richardson notes that this composition corresponds with that of a normal Portland cement except that it is unusually high in alumina and iron, a fact which may be explained by the large amount of magma detected in the thin section examined. He further states:

> I have had a thin section ground, but find that it shows no structure which is characteristic. The section consists largely of amorphous material of an isotropic nature, that is to say, it does not affect polarized light. It reveals a considerable amount of a yellow substance which seems to be the undecomposed magma contained in the original cement. I have formed a material very similar to the "laitance" by shaking Portland cement with water, decanting the finer portion and allowing it to settle out and harden. This material, like your "laitance," is rather soft, and this is due to the fact that the Portland cement is much more thoroughly decomposed under these conditions than under ordinary ones, and this accounts for its character.

* Also see Chapter XV, and page 308.

†Analyzed for the authors by Mr. Clifford Richardson.

It is evident from these facts that the milky laitance which appears on concrete laid under water represents an actual loss of cement, which should be prevented by confining the mass until it reaches its position.

Depositing Concrete through Chutes. In his Treatise On Limes, Hydraulic Cements and Mortars,* Mr. Gillmore refers to a "trémie" used in laying concrete under water in Chesapeake Bay. This consisted essentially of a tube of boiler iron about 2 feet in diameter, and long enough to reach the place where the concrete is to be deposited. Similar apparatus is still employed for forming layers of concrete under water.

When building the piers of the Charlestown Bridge, Boston, a cofferdam was first constructed, and then a tube, about 14 inches in diameter at the bottom and 11 inches at the neck, with flaring top, was suspended by a differential hoist from a moving platform, as shown in Fig. 92, page 270. The tube was made in removable sections bolted together by outside flanges so that its length could be readily varied. Mr. William Jackson, Chief Engineer for the bridge, describes† the method of operation as follows:

> The foot of the chute was allowed to rest on the bottom, and was filled with concrete dumped from wheelbarrows. The chute was then raised slowly from the bottom, allowing a part of the concrete to run out in a conical heap at the foot, while the loss was made good by dumping in more concrete at the top. The truck bearing the chute was then moved from side to side of the dam, so as to leave a ridge or bank of concrete crosswise of the pier, the chute being kept always filled or nearly filled by dumping more concrete into the hopper. The height of the ridge of concrete was regulated by the height to which the foot of the chute had been raised from the bottom. When the ridge was completed across the dam, the traveller supporting the truck was moved a short distance lengthwise of the pier, and the truck was moved back again across the dam, parallel to its former course, allowing the concrete to run out over the edge of the bank first deposited, widening it on the side to which the traveler had been moved, and this process was continued until the whole area of the foundation was covered with a layer of concrete, upon which, when it was sufficiently hardened, another similar layer or course could be deposited.

*Page 236.

†Third Annual Report, Boston Transit Commission, 1897, p. 74.

The thickness of each course depended upon the height to which the foot of the chute was raised above the top of the preceding course. Courses were laid up to 6 feet in thickness, but it is thought that the best results were attained with a thickness of 2 or 2½ feet.

If the bank is made too high, or if the bottom (or the top of the preceding course) is very uneven, or if the piles interfere with the motion of the chute, or if the chute is moved along or raised too rapidly, the concrete is likely to run out so fast as to empty the chute entirely before the flow can be checked. In this event the "charge" is said to be "lost," and the chute must be lowered again to the bottom and refilled. When the charge is lost the water rises inside the chute to the same level as that outside, and into this water the concrete must be dumped until the water is wholly displaced or absorbed by the concrete. This has a tendency to wash the concrete, and to separate the cement from the sand and gravel, and as it generally takes a cubic yard or more of concrete to displace all the water in the chute, there is danger that a rather large body of badly washed concrete will be deposited whenever the charge is lost. This danger threatens not only when the charge is accidentally lost, but whenever work is begun in the morning or after the mid-day intermission; for whenever the work stops the charge must be allowed to run out lest it set in the chute.

To obviate partially the evil of washed concrete, the contractor was directed, whenever work was begun after an intermission, or whenever the charge was lost or water leaked into the chute, to throw into it, before each wheelbarrow-load of concrete, until the water was displaced, a quantity of dry cement. He was also directed to begin work after an intermission with the chute near the center line of the pier, so that any body of washed concrete resulting would be completely surrounded by sound concrete.

After the workmen and the inspector had gained experience with the chute, the accidental loss of the charge was not a frequent occurrence, and the danger of an occasional body of partly washed concrete, surrounded as it must be by good concrete, was not looked upon as a very serious matter.

A difficulty sometimes met with in using the chute is that when a sudden rush of concrete takes place, even if the charge is not entirely lost, the concrete within the chute often falls far below the level of the water outside. The outside water then, especially if there is a deficiency of sand in the concrete, is likely to force its way through the concrete remaining in the bottom of the chute, tending to separate the cement from the sand and gravel, and making the concrete too wet, and so threatening a complete loss of charge. If there are any leaks in the joints of the chute, water comes in and tends to cause loss of charge, and this leakage is especially troublesome when the concrete in the chute falls below the level of the water outside.

The chute seems to work best when the concrete is mixed not quite moist enough to be plastic. If it is mixed too wet the charge is likely to be lost; if very dry there is a tendency to choking of the chute. The working of the chute is affected also by variations in the proportions of sand and gravel. With gravel in excess the outside water too readily forces its way in at the bottom. With an excess of sand the concrete tends to clog in the chute.

Sometimes when the concrete becomes clogged in the upper part of the chute, the concrete below the clogged place continues to flow out, leaving a vacant space into which water forces itself through the concrete remaining in the bottom of the chute. When the clogged concrete above is loosened, it falls into this body of water, which, unable to find exit by the way through which it entered, is displaced by the falling concrete, and rises into the hopper, sometimes to a level considerably above that of the water outside.

In the construction of the foundations for the piers for the Cambridge, (Mass.) Bridge,* a tube was used in much the same way as that employed for the Charlestown Bridge. The concrete was dumped from derrick buckets into a hopper, below which was a tube 16 inches in diameter at the top and 22 inches in diameter at the bottom, built in 4-foot cylindrical sections, which telescoped one another, so that a length varying from 4 to 40 feet could be obtained. Each layer of concrete was 1 to 2 feet thick. The tube was suspended from a traveler running upon a pair of traveling trusses which rested at each end upon tracks laid on top of the cofferdam, so that concrete could be deposited at any point within the rectangle.

Depositing Concrete from Buckets. The opinion of engineers is divided as to whether the best method of depositing concrete under water is by a chute, as has just been described, or from a bucket. The objection to the former is the difficulty in always maintaining a continuous flow, while with the latter it is not so easy to place the layers uniformly and to prevent the formation of mounds which are more or less washed by the water. With careful superintendence, however, either of these methods is satisfactory.

The best results can be attained with buckets so constructed that the material flows out through the bottom. A mass of concrete deposited under water must be disturbed as little as possible, and in tipping a bucket the material is apt to be stirred. Various buckets with bottom doors have been devised for opening automatically when the place for depositing is reached. In one type, used in 1900 at the Charlestown Navy Yard, the slackening of the rope released latches which fastened the trap doors so that they opened as soon as the bucket commenced to ascend. Another style, designed by Mr. John F. O'Rourke, is shown in Fig. 109. The photograph shows the bucket closed. When it reaches the bottom the

*See article by Sanford E. Thompson, *Engineering News*, Oct. 17, 1901, p. 282.

handle slides down, allowing the doors to swing open and the concrete to drop out in a single mass. The bail catches when it has dropped to the bottom, so that when hoisting the bucket the doors remain open. Covers

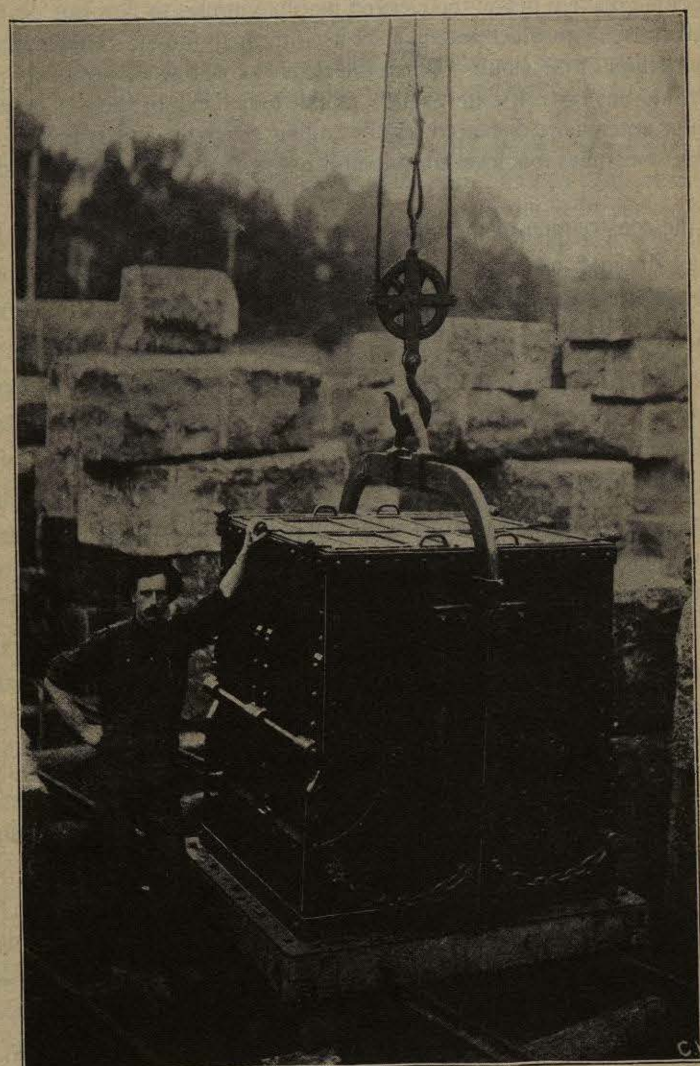

FIG. 109.—Bucket for Depositing Concrete. (*See p.* 305.)

prevent the water from rushing in at the top as the bucket is being lowered, and the V-shaped bottom lessens the disturbance of the water.

Depositing Concrete in Bags. Bags, varying from small paper or mus-

lin bags to jute sacks containing 100 tons,* have been employed in the past for holding concrete together as it passed through the water. In some cases the concrete has been placed in the bags dry.†

Mr. William Dyce Cay in building the breakwater at Aberdeen Harbor Eng., employed bags holding from 28 to 50 tons of concrete. A bag was placed in the hopper bottom of a barge filled with concrete, and sewed up as the barge was being warped to place. When the doors of the hopper were released it fell into place.

John C. Goodridge's method§ of laying concrete under water, employed in 1887, consisted in enclosing the concrete "in paper bags or other soluble envelopes, and then lodging the bags or envelopes so filled in the desired position under water, in such a manner that the bag or envelope shall not be ruptured until after or at the time it and its contents are in place."

Molded Blocks. Under some conditions, especially where it is difficult to construct a cofferdam and monolithic work is not required, blocks of concrete of any desired shapes are molded on land and placed after setting.

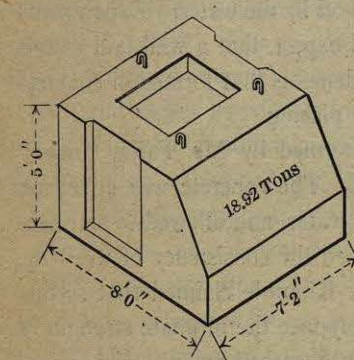

FIG. 110.—Face Blocks of Buffalo Breakwater. (*See p.* 307.)

On the Buffalo breakwater,‖ blocks weighing from 15 to 20 tons, one style of which is illustrated in Fig. 110, were employed in parts of the structure. For handling them, three iron bolts having legs bent to an angle at the ends and of unequal length,—one 24 inches long and the other 12 inches long,—so that the strain would occur in two separate planes, were sunk into the top face of each block. After placing them in position, grooves molded into their adjacent faces were filled with concrete so as to dowel them together.

In the harbor of the Welland Canal, Ontario,¶ blocks of somewhat smaller size were used just at the water level, with mass concrete placed on top of them. For handling these blocks four vertical channels, two on each side, were molded into each block, with recesses just below the central points to catch the four hooks used for moving it. As the hooks passed

* Proceedings Institution of Civil Engineers, Vol. XXXIX, p. 126, and LXXXVII, pp. 101 and 126.

†Lt. Col. J. A. Smith, *Engineering Record*, March 23, 1895.

§U. S. Patent, No. 358 853.

‖See article by Major T. W. Symonds, *Engineering News*, May 29, 1902, p. 426.

¶*Engineering News*, May 15, 1902, p. 382.

down in the channels, they projected so slightly that a block could be set close to the last one placed, and the hook removed without disturbing it.

As early as 1873, concrete blocks ranging in size from 13 to 60 tons in weight were used by the Department of Docks in New York City,* and in 1900 this method of construction was still in operation in that city.

In Belgium in 1899, for breakwater construction,† blocks about 25 feet square and 82 feet long, weighing 3 000 tons, were formed by building on the shore metal caissons of the required size, lining them with concrete, then floating to place, and removing plugs in the bottom so as to allow them to sink. The remainder of the concrete to fill the caisson was deposited in the interior.

Depositing Dry Concrete under Water. By dry concrete is meant in this case a mixture of aggregates and cement without water. This method, although occasionally practised, is undoubtedly one of the worst to employ in laying concrete under water. No matter how carefully the concrete is placed, more or less of the cement is carried off by the water. Experiments by Mr. B. B. Stoney‡ show, as one would expect, that a wall laid in this way is honeycombed, and is not nearly so dense as that formed of concrete mixed with water in the usual way before placing.

Plastic Concrete. Plastic or, as it is termed by Mr. Faija, "reset" concrete was once employed in England.§ The concrete was mixed on land with the smallest possible quantity of water, and allowed to set there about three to five hours, or until it attained the consistency of wet clay, before being deposited in the water. Mr. Kinniple claimed that setting eight hours on land before placing did not reduce the ultimate strength of the concrete, and that less of the cement was washed away.

Concrete in Sea Water. In the United States several instances have been noted where concrete has been disintegrated to the depth of 2 or 3 inches and sometimes more. The injury in all cases is limited to the space between high and low water mark, and frequently appears to be caused in part by frost action. Since other concrete close by is often intact, the chief cause for the defects seems to be in the character of the concrete. From the many cases of structures in good condition after many years, notably the docks in New York Harbor, the conclusion is drawn that concrete can be used with confidence in sea-water construction provided it is proportioned and laid with the best materials so as to form a dense impervious concrete. A still further precaution is to keep the concrete from immediate contact with sea-water by leaving the forms in place for several weeks.

*"Fabrication of Beton Blocks by Manual Labor," by Schuyler Hamilton, Transactions American Society of Civil Engineers, Vol. IV, p. 93.

†See paper by L. Vernon Harcourt in Proceedings Institution of Civil Engineers, Vol. CXII, p. 2

‡Proceedings Institution of Civil Engineers, Vol. LXXXVII, p. 230.

§W. R. Kinniple, Proceedings Institution of Civil Engineers. Vol. LXXXVII, p. 65.

CHAPTER XVI

EFFECT OF SEA WATER UPON CONCRETE AND MORTAR*

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The principal conclusions which have been reached by the author of this chapter, as discussed in the following pages, may be summarized as follows:

(1) No cement or other hydraulic product has yet been found which presents absolute security against the decomposing action of sea water. (See p. 309.)

(2) The most injurious compound of sea water is the acid of the dissolved sulphates, sulphuric acid being the principal agent in the decomposition of cement. (See p. 310.)

(3) Portland cement for sea water should be low in aluminum (see p. 312), and as low as possible in lime. (See p. 311.)

(4) Puzzolanic material is a valuable addition to cement for sea water construction. (See p. 313.)

(5) As little gypsum as possible should be added, for regulating the time of setting, to cements which are to be used in sea water. (See p. 310.)

(6) *Sand containing a large proportion of fine grains must never be used in concrete or mortar for sea water construction.* (See p. 316.)

(7) The proportions of the cement and aggregate for sea water construction must be such as will produce a dense and impervious concrete. (See p. 316.)

EXTERNAL PHENOMENA

At present there is no hydraulic product which is known to be capable of resisting absolutely the decomposing influence of sea water. It is true that some concrete masonry has remained intact for a very long time in salt water, but with our present knowledge it is impossible to say why these structures have resisted so well, and there is little doubt that the cements from which they were made might have decomposed rapidly if they had been used under different conditions. In some cases, on the other hand, similar large structures subject to the action of sea water were

*The authors are indebted to Mr. Feret for this chapter, which has been especially prepared by him for this Treatise.