CHAPTER XIX

WATER-TIGHTNESS

A wall of concrete may be rendered water-tight in several ways:

(1) By accurately grading and proportioning the aggregates and the cement. (See p. 339.)

(2) By special treatment of the surface of the concrete. (See p. 341.)

(3) By the introduction of foreign ingredients into the mixture. (See p. 342.)

(4) By the application of layers of waterproof material, such as asphalt and felt. (See p. 343.)

It is often advisable to combine two or more of these methods.

In the succeeding pages directions are given for practically applying these methods, and experimental investigation is cited.

LAYING CONCRETE FOR WATER-TIGHT WORK

The manner of laying the concrete in walls or floors which are to withstand water pressure is as important as the proportioning of its ingredients. Approved methods of placing are fully described in Chapter XV.

The chief points applicable to water-tight work are briefly recapitulated as follows:

(*a*) Mix concrete of quaking or of wet consistency. (See p. 338.)

(*b*) Place concrete carefully so as to leave no visible stone pockets.

(*c*) Lay the entire structure, if possible, in one continuous operation, working night and day when necessary.

(*d*) If joints are unavoidable, clean and roughen the old surface, then wet it and coat with a layer of cement or mortar. (See p. 284.)

(*e*) Make suitable provision for contraction by special joints, or by steel reinforcement without joints. (See p. 285, also chapter xxi.)

Effect of Consistency. A series of experiments, conducted by the authors, upon several blocks of mortar mixed in the same proportions of cement, sand, and stone, but with different proportions of water, indicates that the best consistency for concrete designed to withstand water pressure is intermediate between a *quaking* and a *mushy* mixture, as defined on page 280.

Also, the general conclusion was reached that with the same dry materials the consistency producing the greatest density after setting gives the most impermeable mortar or concrete up to the point of a very wet consistency, when the excess of water affects the chemical composition of the cement, forming "laitance" (see p. 302), and thus reduces both the strength and the water-tightness of the specimen. After setting, the very wet specimens were found to have about the same density as the medium and mushy mixtures, because the cement, sand, and stone settled into place and expelled the surplus water.

PROPORTIONING WATER-TIGHT CONCRETE

The proportions* employed to resist the percolation of water usually range from 1: 1: 2 to 1: 2½: 4½, the most common mixtures being 1: 2: 4 or 1: 2½: 4½. However, with accurate grading by scientific methods, such as are described in Chapter XI, water-tight work may be obtained with proportions as lean as 1: 3: 7. (See p. 183.) Permeability, the quality of allowing water to pass through, and porosity, the property of containing pores or voids, are not synonymous terms, and the most porous material is not necessarily the most permeable, because the dimensions of the voids as well as their volume affect by capillarity the passage of water.

For maximum water-tightness a mortar or concrete may require a slightly larger proportion of fine grains in the sand than for maximum density or strength, but otherwise the general principles discussed on page 172 are applicable. A mixed aggregate (such as is shown in Fig. 61, p. 173) evidently has fewer channels through which the water can pass than an aggregate consisting of coarse stone and sand (such as is shown in Fig. 59, p. 172), provided the character and relative proportioning of the finest particles are the same in both cases. Recent tests indicate that gravel produces more water-tight concrete than broken stone under similar conditions.

Porosity of Concrete. The total voids, air plus water, in first-class concrete and mortar of various proportions are shown in column (20) of the table of Mr. William B. Fuller's experiments on pages 376 and 377. The percentage of total voids in the mortars averages about 26%, while in the concretes, of proportions commonly employed in practice, the voids range from 13% to 17%.

In neither the concrete nor the mortar do these percentages ever represent air alone. A portion of the water, an amount estimated at 8% of the weight of the cement,† corresponding to about 2½% of the volume of

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*Proportions are based on an assumed unit of 100 lb. cement per cu. ft. or the equivalent of 3.8 cu. ft. to the barrel. (See p. 217.)

†Allen Hazen in Transactions American Society of Civil Engineers, Vol. XLII, p. 128.

ordinary concrete, combines with the cement, and a still larger portion of the water remains in the pores unless dried by artificial heat.

The porosity of mortars is discussed on page 127.

Size of Stone. Authorities disagree as to the relative advantages of small stone ranging between ½ and one inch, and coarse stone, ranging from ½ inch up to, say, 2½ inches. The latter is theoretically the better, but it is sometimes claimed that the fine material can be placed more satisfactorily. This depends upon the workmanship. With proper selection of materials and care in laying, the concrete containing the coarse stone produces excellent work, as is illustrated by the constructions at Little Falls, N. J. (see Chapter XXVIII), and Boonton, N. J. (see Chapter XXVI), where carefully graded stone up to 2½ or 3-inch diameter was used.

If very fine stone, under ½-inch, and containing dust, is used for the coarser aggregate, the addition of sand may increase the porosity and the permeability, because concrete with such small stone is practically a mortar, and the finer particles of stone are really sand. A concrete in proportions 1 part cement : 2 parts sand : 4 parts unscreened stone less than ½-inch diameter, makes a porous concrete, while a mixture 1 part cement : 2 parts sand : 4 parts stone ¼-inch to 1½-inch diameter, makes a dense one. With the small stone, proportions 1:1:2 would be the leanest advisable mixture.

The method of proportioning by mechanical analysis, as described by Mr. Fuller in Chapter XI, has been found in practice to produce impermeable concrete.

THICKNESS OF CONCRETE FOR WATER-TIGHT WORK

It is impossible to specify definite thicknesses of concrete to prevent percolation under different heads of water, because of variations in proportions and methods of laying. We have known rain water under a head of 2 or 3 inches to percolate through a 4-foot wall of excellent concrete of dry consistency. On the other hand, had the same materials been mixed to a wetter consistency and placed with no joints between successive layers, concrete but a few inches thick would have withstood a high head.

The best criterions for thicknesses of walls of first-class concrete are obtained from actual examples. Instances are cited in Chapters XXVI and XXXVIII of water-tight concrete 4 inches thick sustaining a head of 4 feet, concrete 15 inches thick sustaining a head of 40 feet, and concrete 5.5 feet thick sustaining a head of 100 feet.

SPECIAL TREATMENT OF SURFACE

Various methods of treating the surface of concrete have been employed to increase the water-tightness.

Plastering. Plastering the surface of concrete with rich Portland cement mortar in proportions 1:1 or 1:1½ is the method which first occurs to one, but in temperate or cold climates it is only useful for walls below the surface of the ground and therefore not subject to atmospheric changes. In such cases it can sometimes be used as a substitute for, or in connection with, paper and asphalt.

In certain sections of the Boston Subway[*], a 6 inch wall of concrete was laid up next to the bank of earth and plastered with a layer of 1:1 mortar about ½ inch thick. After spreading the mortar with a plasterer's ordinary metal float (see Chapter XXIII.) the surface was run over with a toothed roller about 12 inches long by 4 inches in diameter, which pressed the plaster into any crevices, and left a rough surface. The main wall of concrete forming the lining of the Subway was then laid up against this plastered surface.

On the arch of the approaches to the East Boston tunnel, a layer of plaster, like that on the walls, was spread before laying the final 6-inch thickness of concrete, thus forming a water-tight joint in the interior of the arch ring.

Granolithic Finish. On horizontal or inclined surfaces, a granolithic surface of rich mortar of Portland cement and sand, or Portland cement and screenings in proportions about 1:1 may be laid and troweled, as in sidewalk construction. (See Chapter XXIII.) The surface finish must be placed at the same time as the base, and with the same, that is, Portland cement.

Troweling Surface. The water-tightness of horizontal or inclined layers of concrete can be greatly increased by troweling the concrete in the same manner that granolithic work is troweled. (See Chapter XXIII.) This brings the cement to the surface, and produces a dense, hard surface which is nearly equal to a surfacing of rich mortar. This is very effective for surfacing a structure like the inclined face of the dam shown in Chapter XXVI.

In experimenting upon the permeability of different concretes, the authors have noticed that even the very light joggling which is necessary to compact a wet concrete, and also the ramming of a stiffer mixture, increases the impermeability of the concrete. Even after chipping off the top of the specimen for a depth of ⅛ or ¼ of an inch, the flow will be several times less than when the pressure is directed upon its under surface.

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[*] In Subway construction since 1902 and in the tunnel built in 1907–9, the trench frequently was shored with 2½-inch reinforced concrete sheeting (*See* Chap. XXV), the surface evened with plaster, if necessary, and water-proofing applied.

Grout. Portland cement grout is preferable to plaster for coating the soffits of arches or for wall surfaces. It is also valuable for coating the interior of cisterns or tanks.[*] The grout should of course be applied against the surface which is to come in contact with the water, and if the wall is to be made impervious in both directions, both sides should be washed.

A specially prepared cement wash has been found effective in preventing dampness in masonry.[†]

Alum and Lye Waterproof Wash. United States Army Engineers[‡] have satisfactorily employed a wash of alum and concentrated lye mixed in proportions one pound lye, 2 to 5 pounds alum, and 2 gallons of water, which has been used with good success in several instances.

Special Coatings. A few patented compounds which have proved successful are on the market. These are generally used with neat cement or mortar. In many cases it has been found possible to waterproof the face of the wall instead of the back upon which the water presses.

INTRODUCTION OF FOREIGN INGREDIENTS

The principal advantage of introducing foreign ingredients into a mortar or concrete is to permit the use of a lean mixture, the fine particles of hydrated lime, or whatever may be used, tending to reduce the volume and the dimensions of the voids. Every case must be studied by itself, since it is frequently cheaper to obtain the required water-tightness by adding cement than by admixtures..

Lime and Puzzolan Cement. The effect of the addition of lime in small quantities is chiefly mechanical, and the quantity which should be employed depends, therefore, upon the fineness of the sand and the proportions of the mixture.

Although it is impossible to replace the water which separates the grains in neat cement paste or rich mortar with a material like lime, a series of tests[§] made by one of the authors in 1908 indicates that the introduction of a small percentage of hydrated lime into the concrete for small structures like tanks will render them more watertight, especially at early periods, and also that for large masses of concrete the addition of hydrated lime may permit the use of leaner proportions. The percentage of hydrated lime to use varies with the proportions of concrete and the character of the materials,

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[*] J. W. Schaub, Transactions American Society of Civil Engineers, Vol. LI, p. 123.

[†] Oscar Lowinson, Transactions American Society of Civil Engineers, Vol. LI, p. 125.

[‡] C. B. Hegardt in Report Chief of Engineers, U. S. A., 1902, p. 2482.

[§] "Permeability Tests of Concrete with Addition of Hydrated Lime," by Sanford E. Thompson, American Society for Testing Materials, Vol. VIII, p. 500.

permissible quantities in practice ranging from 5 to 15 per cent of the weight of the cement. Results of tests with different proportions are given in the paper mentioned.[*]

Lime paste made from a given weight of hydrated lime occupies about 2½ times the bulk of paste made from the same weight of Portland cement and is therefore very efficient in void filling.

The strength of concrete has been found in some cases to be slightly reduced by the addition of hydrated lime, but not in a sufficient degree to influence its use in a water-tight wall, where the strength is seldom a determining quality.

The effect of the addition of lime upon the strength and density of mortar is discussed on page 154d.

Unslaked lime must not be used under any circumstances. (See p. 156.)

Puzzolan cement, unlike lime, tends to increase the strength even of neat cement and rich mortars,[†] in many cases 20% by weight of total dry materials being beneficial if the Puzzolan cement is ground with the Portland. Undoubtedly the impermeability is similarly increased, since mixtures of Portland and Puzzolan cements have been found to well resist the action of sea-water.[‡]

In Japan in the Nagasaki Dock,[§] concrete blocks were made in proportions 0.25 lime; 1 Puzzolana; 1 Portland cement; 4 sand; 8 gravel:

Clay. Pure clay, finely powdered and free from any trace of vegetable matter, has been found to appreciably increase the water-tightness of concrete,[‖] especially of lean mixtures. In certain cases 5 per cent of clay to the weight of the sand has been found effective. The proportions should vary with the character of the aggregates.

Clay acting as a colloid in combination with an electrolyte such as alum sulphate has been suggested by Mr. Richard H Gaines[¶] for increasing water-tightness. Tests by him show a marked decrease in the flow of water due to these materials either added alone or in combination.

Pulverized Rock. Mortars 1 : 3 and leaner, and concrete made with these proportions of cement and sand to the stone, are increased in strength,[†] and probably in impermeability, by the addition of rock pulverized as finely as the cement and equal to it in weight, although if the natural sand is very

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[*] "Permeability Tests of Concrete with Addition of Hydrated Lime," by Sanford E. Thompson, American Society for Testing Materials, Vol. VIII, 1908, p. 500.

[†] Feret's *Chimie Appliquée*, 1897, p. 493.

[‡] See R. Feret, Chapter XVI.

[§] N. Shirrishi, Transactions American Society of Civil Engineers, Vol. LVI, 1906, p. 76.

[‖] See paper on "Waterproofing Cement Structures," by James L. Davis, Proceedings National Association of Cement Users, Vol. IV, 1908, p. 328.

[¶] Transactions American Society Civil Engineers, Vol. LIX, 1907, p. 159.

fine or contains dust, the addition of fine material is not beneficial.

Alum and Soap. A soap and alum mixture in various proportions sometimes is used to make what is called "waterproof mortar." The Sylvester Process mixture employed in New York Harbor by Major W. L. Marshall[‡] was made by "taking one part cement and 2½ parts sand and adding thereto ¾ of a pound of pulverized alum (dry) to each cubic foot of sand, all of which was first mixed dry, then the proper amount of water—in which had been dissolved about ¾ of a pound of soft soap to the gallon of water—was added, and the mixing thoroughly completed. The mixture is little inferior in strength to ordinary mortar of the same proportions and is impervious to water, and is also useful in preventing efflorescence."

The effect of alum and soap in diminishing the permeability has been experimented upon by Mr. Edward Cunningham[§] and Prof. W. K. Hatt,[§] and found useful for small structures.

LAYERS OF WATERPROOF MATERIAL

The use of cement plaster has already been described on page 419.

Layers of waterproof paper or felt cemented together with asphalt or bitumen or tar are extensively used, — and sometimes asphalt alone, — to form an impervious layer. A mixture of alum and lye has also been tried.

Paper or Felt Waterproofing. Layers of paper or felt with tar or asphalt between them are employed for a waterproof course in concrete floors, roofs, and walls of underground structures of large or long area, like tunnels and subways, which require special protection from infiltration of water. The materials range from ordinary tarred paper, laid with coal tar pitch, to asbestos or asphalted felt, laid in asphalt. Coal tar products appear to be satisfactory when made to contain a large percentage of carbon, and are being used by many in preference to asphalt.

In the New York Subway, portions of which are built below tide-water, much of the waterproofing consists of layers of felt laid in asphalt. The specifications,[**] approved by Mr. William Barclay Parsons, Chief Engineer, contain the following requirements for the materials:

> The asphalt used shall be the best grade of Bermudez, Alcatraz, or lake asphalt, of equal quality, and shall comply with the following requirements: The asphalt shall be a natural asphalt or a mixture of natural asphalts, con-

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[*] See R. Feret, Chapter X, also in Annales des Ponts et Chaussées, 1901, IV, p. 194.

[†] Feret's Chimie Appliquée, 1897, p. 477.

[‡] Report Chief of Engineers, U. S. A., 190., p. 918.

[§] Transactions American Society of Civil Engineers, Vol. LI, pp. 127 and 128.

[**] Contract No. 2, June, 1902, p. 107.

> taining in its refined state not less than ninety-five (95) per cent of natural bitumen soluble in rectified carbon bisulphide or in chloroform. The remaining ingredients shall be such as not to exert an injurious effect on the work. Not less than two-thirds (⅔) of the total bitumen shall be soluble in petroleum naphtha of seventy (70) degrees Baumé or in Acetone. The asphalt shall not lose more than four (4) per cent of its weight when maintained for ten (10) hours at a temperature of three hundred (300) degrees Fahrenheit.
>
> The use of coal tar, so-called artificial asphalts, or other products susceptible to injury from the action of water, will not be permitted on any portion of the work, or in any mixtures to be used.
>
> The felt used for waterproofing shall be dipped in asphalt and weigh not less than fifteen (15) pounds to the square of one hundred (100) feet. All felt shall be subject to the inspection and approval of the engineer.

With reference to the laying of the water-proofing the contract required:[*]

> Each layer of asphalt fluxed as directed by the engineer must completely and entirely cover the surface on which it is spread without cracks or blowholes.
>
> The felt must be rolled out into the asphalt while the latter is still hot, and pressed against it so as to insure its being completely stuck to the asphalt over its entire surface, great care being taken that all joints in the felt are well broken, and that the ends of the rolls of the bottom layer are carried up on the inside of the layers on the sides, and those of the roof down on the outside of the layers on the sides so as to secure a full lap of at least one (1) foot. Especial care must be taken with this detail.
>
> None but competent men, especially skilled in work of this kind, shall be employed to lay asphalt and felt.
>
> When the finishing layer of concrete is laid over or next to the waterproofing material, care must be taken not to break, tear, or injure in any way the outer surface of the asphalt.
>
> Any masonry that is found to leak at any time prior to the completion of this work shall be cut out and the leak stopped.

Method of Laying Paper or Felt. The waterproof layer of a floor may be laid directly upon the ground if the soil is fairly dry and firm, but is usually spread upon a layer of concrete from 4 to 8 inches thick. In the former case[†] the first layer consists of strips with a 2 to 6-inch lap cemented with asphalt, and the remaining layers are mopped on. Upon a concrete base it is customary to first spread a layer of asphalt upon the concrete, although, if the concrete is damp, the bottom layer of paper or felt may be placed dry, as described above.

The "ply" in waterproofing,—that is, the number of layers which cover all parts of the surface,—varies from 2-ply to 10-ply. It is considered better practice to "shingle" the strips than to place each ply or layer independently.

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[*] Contract No. 2, June, 1902, p. 107.

[†] This method was followed in portions of the floor in the approaches to the East Boston Tunnel.

If the surface to be waterproofed is rough it may be leveled with cement mortar. It must be dry before applying the tar or asphalt. The asphalt is heated and brought, generally in buckets, to the work. Several rolls of paper are started consecutively. Ahead of each roll, as it is unrolled, the liquid asphalt is swabbed upon the concrete with a mop, so that the paper or felt is spread directly upon the fresh hot stuff. As soon as the first roll is started the second is placed to overlap the first, a width depending upon the number of ply to be laid. For example, if the felt is 32 inches wide and is laid 3-ply, the second roll is lapped upon the first about 22 inches. As this is unrolled (in the same general direction as the first roll) the surface ahead of it is mopped with asphalt, as described above. A third roll is immediately started, lapping both of the two others, and so on for the entire width of the surface to be covered.

A waterproof course of this character always forms a distinct joint in the mass, thus destroying its cohesion upon that plane, and the strength of the concrete in bending on the two sides of the layer must be considered independently.

Asphalt Waterproofing. Asphalt is sometimes laid as a waterproof course in one or more continuous sheets, and is also used for filling contraction joints in concrete.

In the sedimentation basin for the Albany (N. Y.) Filtration Plant[*] 16 inches of clay and gravel puddle were covered with 6 inches of concrete laid in blocks 7 feet square, with ½-inch asphalt joints 3 inches deep, that is, extending halfway through the concrete. This proved to be a successful treatment.

In the Astoria (Ore.) Water Works[†] the bottom of the reservoir consisted of 6 inches of concrete in approximate proportions, one packed cement : 0.7 sand : 3.5 fine gravel : 6.5 broken stone, covered with a ⅜-inch finishing coat of 1 : 1 mortar, and upon this two layers of Alcatraz brand asphalt. The first layer was of natural liquid asphalt, and the second was the product of refining natural rock asphalt with about 20% of the liquid as a flux. Mr. Adams made the rule that no asphalt should be placed until after the concrete had set at least two weeks, and was well dried out. All dust was carefully removed from the concrete, and the asphalt was applied with twine mops. The slopes of the reservoir were lined with brick laid in asphalt upon 6 inches of concrete. Under ordinary conditions such complete measures are unnecessary.

In the construction of government fortifications by the United States

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[*] Allen Hazen in Transactions American Society of Civil Engineers, Vol. XLIII, p. 258.

[†] Arthur L. Adams in Transactions American Society of Civil Engineers, Vol. XXXVI, p. 29.

Army Engineers, numerous methods of waterproofing have been used,[*] in some cases an asphalt course being placed between two layers of concrete. Asphalt paint has been used for a protective coating where earth is to be deposited above or against it.[†]

A ¼-inch coating of asphalt applied hot with a mop upon a surface already covered with grout (see p. 339) has been satisfactorily used by Mr. J. W. Schaub[‡] for coating the interior of tanks where the head is greater than 10 feet. He considers this sufficient to withstand a water pressure of 60 feet.

Mr. Schaub[‡] also suggests the method of building the wall in two parts and filling the core or hollow space between with asphalt.

CONSTRUCTION WITHOUT WATERPROOFING

New York Subway Practice. Formerly asphalt waterproofing was required on the floors, walls and roof of the New York Subway, varying in thickness from 3 to 6-ply or else using two layers of waterproofing with one or more layers of brick dipped in asphalt. It was found, however, that the sections of subway waterproofed in this way were not so cool as other sections because the waterproofing prevented radiation of heat. Consequently, it was proposed to use the waterproofing below high water level but extending only 2 feet above it, except in special localities. The concrete was to be reinforced longitudinally, as well as laterally, using a rich mixture, well spaded. This was further protected by a blind drain composed of broken stone 6 inches thick on the top of the subway and hollow tile built against the walls.[§]

Philadelphia Subway Practice In all of the subway work it is the practice to rely on the proper placing of the concrete for waterproofing except that on the roof a layer of asphalt 1-inch thick is used. Longitudinal reinforcement, generally to the amount of 0.3 per cent., is introduced to prevent cracking of the walls.[‖]

METHODS OF TESTING PERMEABILITY

Permeability tests are somewhat difficult to make because of the many variables which must be provided for. In all cases it is advisable to measure the water which has passed through the specimen and not the water

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[*] Report Chief of Engineers, U. S. A., 1901, pp. 911 to 925, and 1902, pp. 2451 to 2484.

[†] Report Chief of Engineers, U. S. A., 1902, p. 2473.

[‡] Transactions American Society of Civil Engineers, Vol. LI, p. 123.

[§] Personal correspondence with Henry B. Seaman, Chief Engineer, 1909.

[‖] Personal correspondence with Charles M. Mills, Principal Assistant Engineer, 1909.

flowing into it. Results of permeability tests are comparable only among the specimens of each individual series. The methods which have been successfully employed may be outlined as follows:

Cementing a pipe upon the top of a block of concrete similar to the plan employed by the French Commission for mortar.*

Incasing a block on all sides except the top and bottom and forcing the water through.

Making thin discs and confining the water pressure to the center by means of gaskets.

These three methods as they have been developed are illustrated in Figs. 113, 114 and 115.

In Fig. 113, an apparatus designed by one of the authors,† the pipe is enlarged to 4 inches diameter to give a good surface of concrete and permit thoroughly chipping it, while at the same time the external pipe connections are small, so that tight joints can be made readily. The walls of the mold may be coated with neat cement as well as the bottom, if desired, the concrete being placed in any case before the neat cement has begun to stiffen.‡

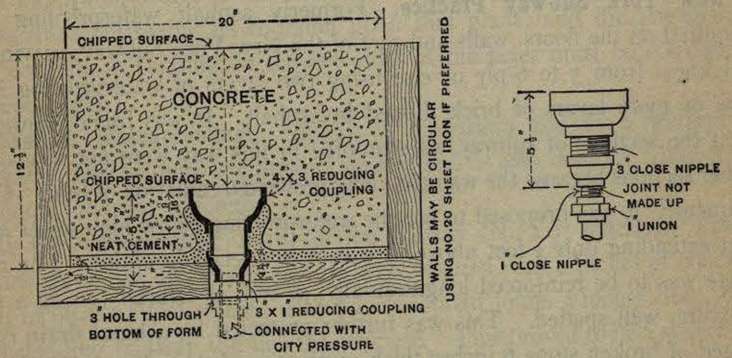

FIG. 113. Detail of Specimen for Testing Permeability.* (*See p.* 348.)

The apparatus used at Jerome Park§ is a still better although somewhat more expensive design which is capable of modification to suit the size of the specimen. The concrete specimens, which are described at length in the paper referred to, were made first and afterward coated with neat cement by placing in a mold after thoroughly roughening and wetting the surfaces. (See Fig. 114.)

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* See p. 128.

† "Permeability Tests of Concrete with Addition of Hydrated Lime," by Sanford E. Thompson, American Society for Testing Materials, Vol. VIII, p. 506.

‡ For example of the method adopted in earlier experiments, see "Consistency of Concrete," by Sanford E. Thompson, Proceedings American Society for Testing Materials, Vol. VI, 1907, p. 374.

§ See "Laws of Proportioning Concrete," by William B. Fuller and Sanford E. Thompson, Transactions American Society Civil Engineers, Vol. LIX, 1907, p. 67.

Molding concrete in iron pipe is not satisfactory because the concrete shrinks in setting and there is consequently danger of leakage.

The method used in the St. Louis Structural Materials Laboratory* is illustrated in Fig. 115. This plan requires expensive castings and great care to make a water-tight joint at the rubber washers.

In tests of permeability the apparatus must be designed so as to make all the water pass through the concrete; the surface of the specimen must be cut down to the pure interior concrete to prevent surface effects; the mix must be very uniform, the size of the specimen being proportioned to the maximum size of the aggregate; sufficient water must be used to produce uniformity, the consistency depending upon the purpose of the tests; a slight excess of sand rather than a deficiency must be used to prevent large voids; if neat cement is used as a coating, it must be molded with the concrete or else the surface of the concrete must be chipped rough and soaked with water before applying the cement paste, and it must be kept wet for some time; the specimen should be soaked for 24 hours before testing.

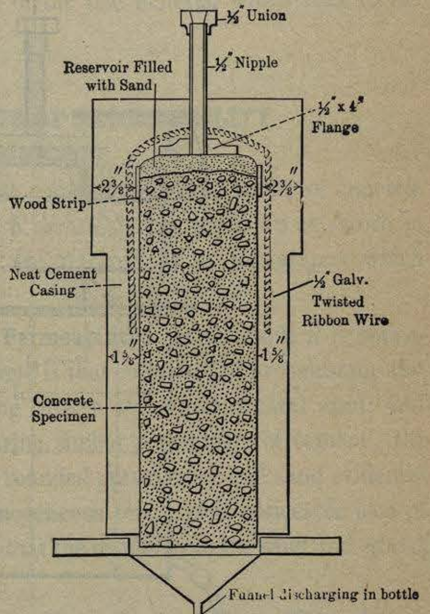

FIG. 114.
Permeability Specimen used at Jerome Park. (*See p.* 348.)

LAWS OF PERMEABILITY

The following conclusions have been reached with reference to the permeability of concrete and mortar:

(1) The permeability or flow of water through concrete is less as the percentage of cement is increased, and in very much larger inverse ratio.*

(2) The permeability is less as the maximum size of the stone is greater. Concrete with maximum size stone of 2¼-inch diameter is, in general, less

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* Bulletin No. 329, U. S. Geological Survey, 1908, by Richard L. Humphrey.