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PERMEABILITY OF CONCRETE BY WATER.

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The wide application of concrete for construction purposes has rendered it necessary to pay careful attention to the adoption of suitable means for rendering it watertight. Some time ago the present authors became interested in this matter, when asked to investigate the properties of a material for which waterproofing qualities were claimed. A considerable number of preliminary tests had been made when the report of an extensive research carried out by Wig and Bates at the Bureau of Standards came into our hands. The methods adopted in that work afforded a solution of many of the difficulties which we had encountered, but in our opinion, although their work is of an exhaustive character, it leaves important matters of a practical nature still undecided. We therefore determined to go on with our own tests, and apply the apparatus as devised by the Bureau of Standards.

Having been asked to bring forward a paper on this subject, however, it is necessary to make it perfectly clear that our own work has only reached a preliminary stage, and our remarks will therefore be based to a large extent on the results of Wig and Bates, at the same time indicating the direction in which our own investigations have proceeded.

At the outset it may be as well to define clearly what is meant by the terms **permeability** and **porosity**, which we find are frequently confused with one another. **Per-**

meability is the quality of allowing water to pass through, while **porosity** is the property of containing **pores** or voids, which take up water when the material is immersed. A porous material may not be permeable owing to the fact that the pressure required to drive water through the fine capillaries is so great as to exceed all practical limits.

Before coming to consider tests of permeability, it will be of advantage to consider the question from first principles, and to endeavour to form a clear idea as to what we mean when we say that a concrete aggregate is watertight. In the first place, we may assume that practically all the larger aggregate used will in itself be impermeable to water. When such material forms part of a concrete, the water which passes through finds its way around the aggregate through the spaces which are filled with mortar. Hence it follows that the problem of rendering a concrete watertight really consists in sealing the voids of stone by means of an impervious mortar.

The success with which this is carried out will be affected by the following considerations:—

1. The efficiency of the mortar as a watertight seal.
2. The quantity of voids to be sealed.
3. The thoroughness with which the mortar is placed in position.

Thus the mortar may be absolutely impervious, but may not fill the voids, or adhere completely to the metal. With a more or less permeable mortar, a much larger quantity of water will pass where the voids are large because of the greater area which has to be closed by the mortar.

From these considerations and the experience we have gained, we have formed the opinion that in order to deal with this subject effectively it is necessary to confine oneself in the first place to a study of mortars, and the effect of varying conditions on their properties.

The earlier work carried out on this subject was principally due to Thompson, who has set forth the following conclusions:—

1. The permeability is less as the proportion of cement is increased.
2. The permeability is less as the maximum size of the stone is greater.
3. Rounded aggregates like gravel require less cement than sharp aggregates like broken stone. The same remark applies to sand.
4. As the concrete gets older its permeability decreases.
5. With increased water pressure the permeability increases uniformly.
6. The thicker the layer of concrete the less the permeability.
7. Medium and wet consistencies produce concrete much more watertight than dry consistencies, and slightly more watertight than very wet consistencies.
8. The surface as moulded is much more watertight than the bottom of a specimen, owing to the fine material which rises to the top.

In addition to the above general conclusions, a certain amount of data had been published, but the figures are very largely disconnected, and in many cases insufficien information is furnished to enable practical use to b made of the results.

To have a practical value it is necessary that our knowledge should be definite, and that we should be able to answer practical questions of an engineering character.

Thus it should be possible to furnish answers to the questions:—

1. What quantity of water will flow through a concrete of given composition, thickness and area under varying pressures?

2. How will the rate fall off as the water continues to flow?

As a preliminary step to planning a series of tests with the object of gaining information on this subject, it was decided to set up an apparatus and carry out a series of tests on sandstone concrete. After this work had been commenced the Report from the Bureau of Standards came to hand, as a result of which we decided to alter our methods, and instal an apparatus similar to that described in their report.

We will describe our preliminary tests as briefly as possible, since they are of interest in showing some of the difficulties of this work, and then pass on to consider the improved apparatus, with the results obtained at the Bureau of Standards, and our own work. Since the Report from the Bureau of Standards also deals with special ingredients for waterproofing which we have not yet examined ourselves, we propose to treat that as a separate subject, and deal with it at the end of our remarks.

Preliminary Tests.

The preliminary series of tests was carried out on Sandstone Concrete, which was made to the following composition:— 4:2:1
& 6:3:1

The metal used was broken to a maximum size of 2 inches graded to ⅛-inch, and the sand was obtained from the Nepean River without special treatment.

The blocks of concrete required for the permeability tests were cast in 12in. earthenware pipes. These were first prepared by soaking in water, and were then well grouted with neat cement. They were placed on oiled iron plates, and concrete was filled in to a depth of 11 inches, the consistency being such that it could readily be placed in position without ramming, working with a trowel being sufficient. The layer of concrete is shown at H in fig. 1.

The moulded blocks were kept covered with wet blankets for seven days, after which they were allowed to dry out. A small quantity of pitch was then run round the edges of the surface of the concrete (G), where it came in contact with the pipe. This was done to avoid the

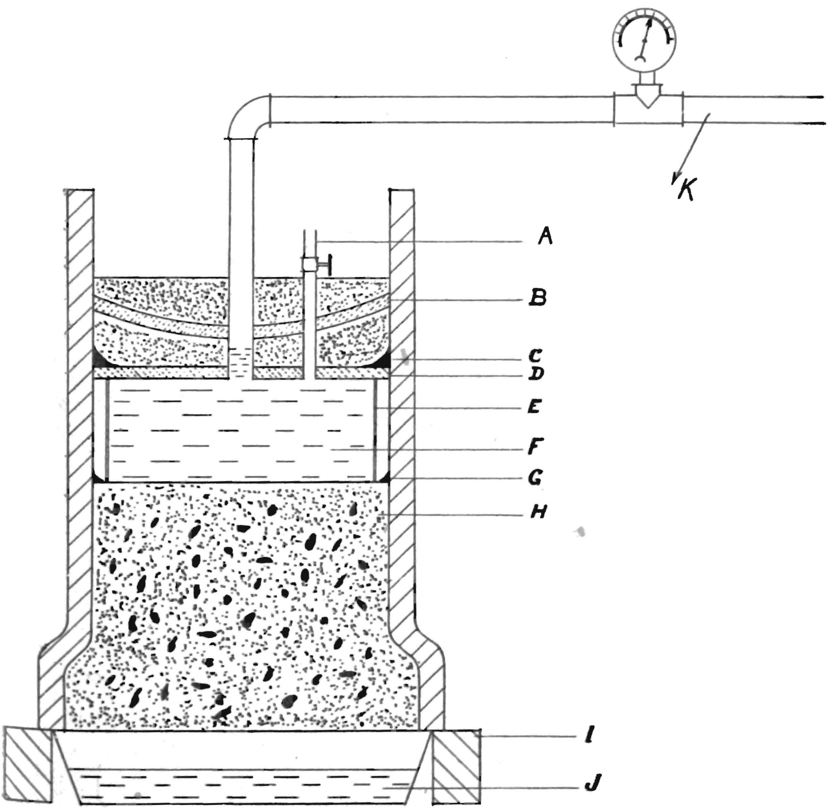

Fig. 1

possibility of any water finding its way between the concrete and the walls of the pipe. A cover plate D, to which the water connections were attached, rested on a cylinder of galvanised iron E four inches deep, a water chamber F thus being formed above the concrete.

The cover plate was luted down with a layer of bitumen and pitch (C). Since with the pressures used there was a tendency for the cover plate to rise, it was necessary to adopt means to hold it firmly in position, and for this purpose two pieces of curved steel pipe B were jammed tightly down the inside of the earthenware pipe at right angles to each other. 2:1 cement compo. was filled in on top of the cover plate, completely surrounding the pieces of steel piping.

From previous experience it was found necessary to interpose a filter between the apparatus and the water main. Some trials were made with filter candles, but they were found to choke up so rapidly that frequent renewal was essential. Accordingly in the tests here described a filter was constructed consisting of a fine wire gauze filled with charcoal, and this gave very satisfactory results.

Considerable trouble was, however, experienced on account of variations in the water pressure, and for this reason the whole apparatus was subsequently dismantled and reconstructed.

The test blocks were connected up to the water main under a pressure of 10lbs. per square inch, and the quantity of water passing through was measured periodically. It will be seen that at the beginning the blocks allowed water to pass freely through them, but that the flow rapidly decreased and finally fell to a more or less constant value.

The results obtained are given below, and are shown in the curves in figure 2.

It should be pointed out that in making the 6:3:1 mixture it was necessary to use a wetter consistency owing to the lean mixture. The consistency of the 4:2:1

mixture would be described as "wet," but it is possible that the lower permeability of the 6:3:1 mixture is due to the use of a larger quantity of water.

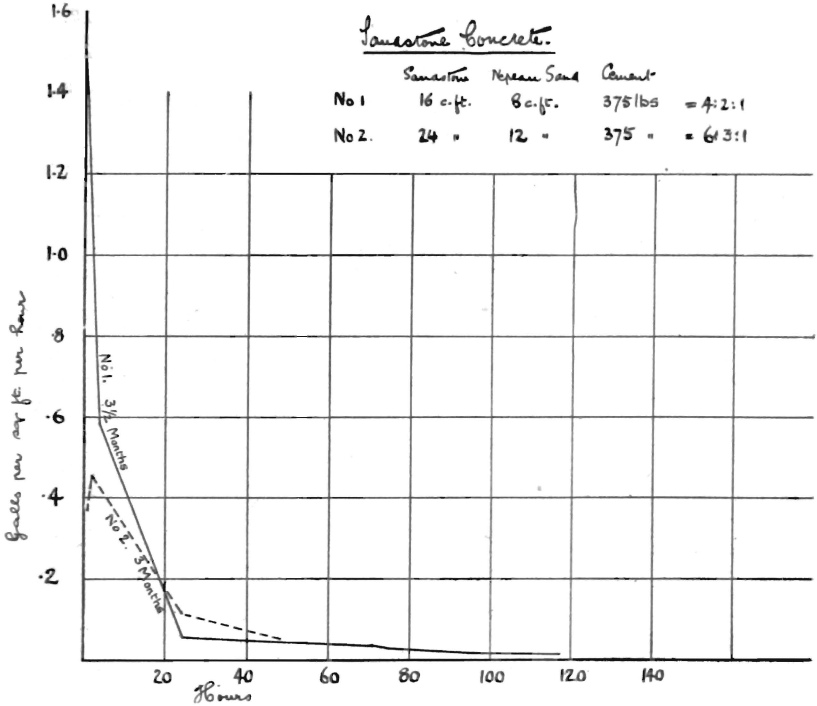

Fig. 2

Hours from Commencement.	Rate of Flow—Gallons per sq. foot per hour	
	4 : 2 : 1.	6 : 3 : 1.
Commencement	1·52	·375
2	—	·450
4	·58	—
24	·057	·117
48	—	·047
71	·032	—*
75	·027	—*
95	·018	—*
117	·012	—*
216	—	·022

*Readings missed owing to a leak.

Standard Apparatus for Measuring Permeability.

The improved apparatus as constructed from the description given in the report of the Bureau of Standards is shown in the photograph (fig. 5), and in detail in figs. 3 and 4. The methods of preparing the test pieces are those adopted in our own work, and differ slightly from that adopted by Wig and Bates.

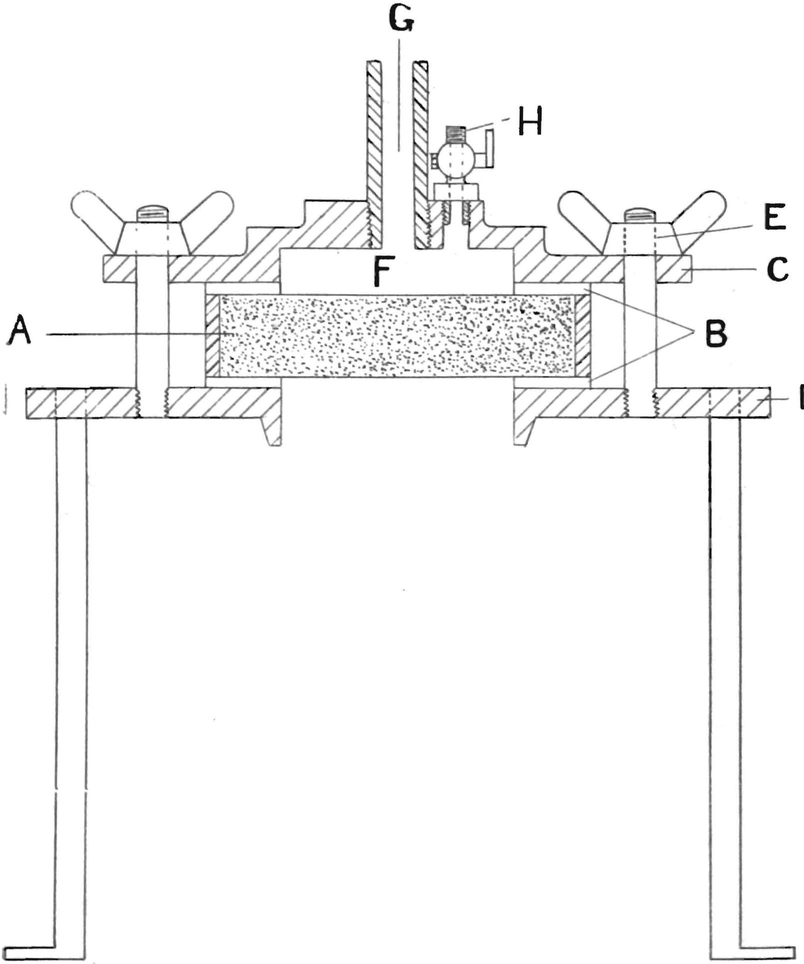

Fig. 3

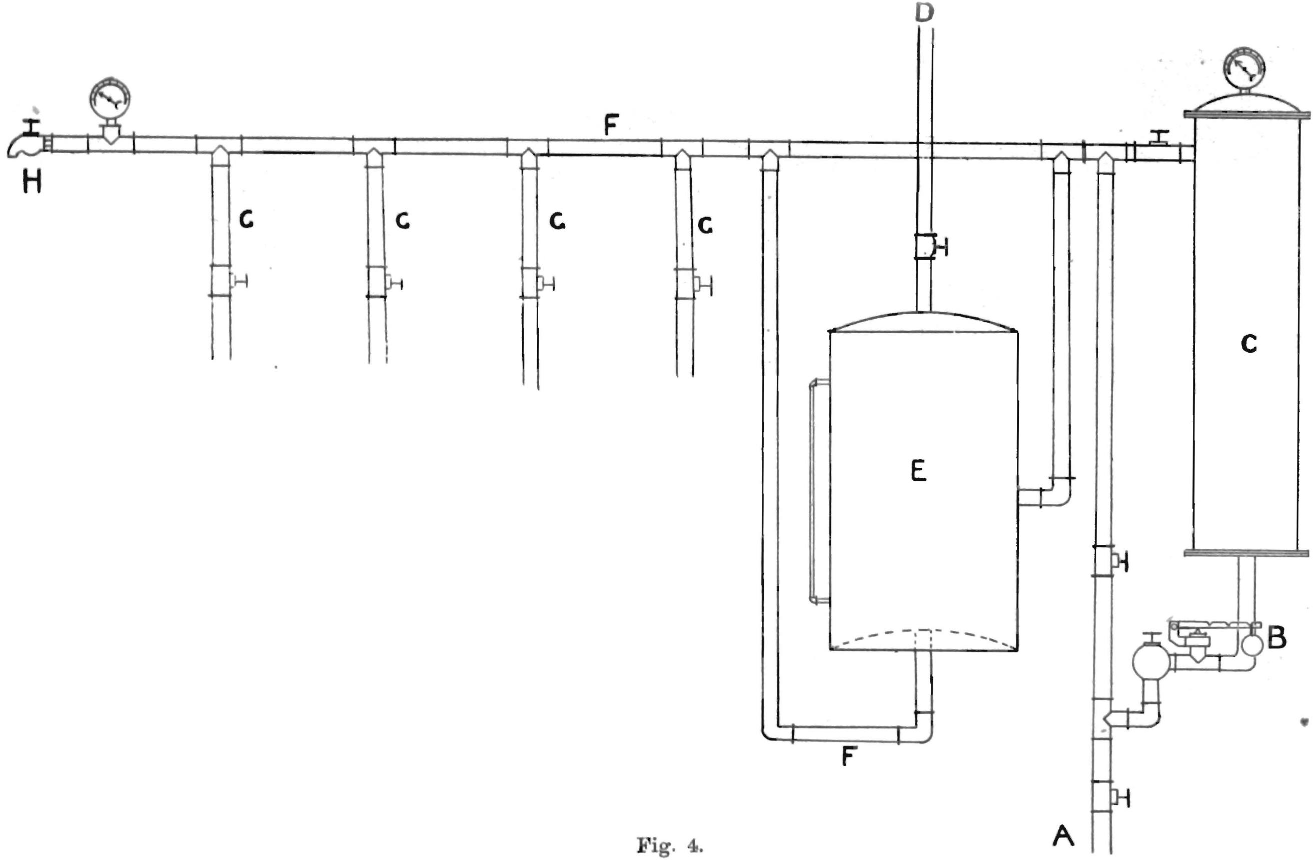

Fig. 4.

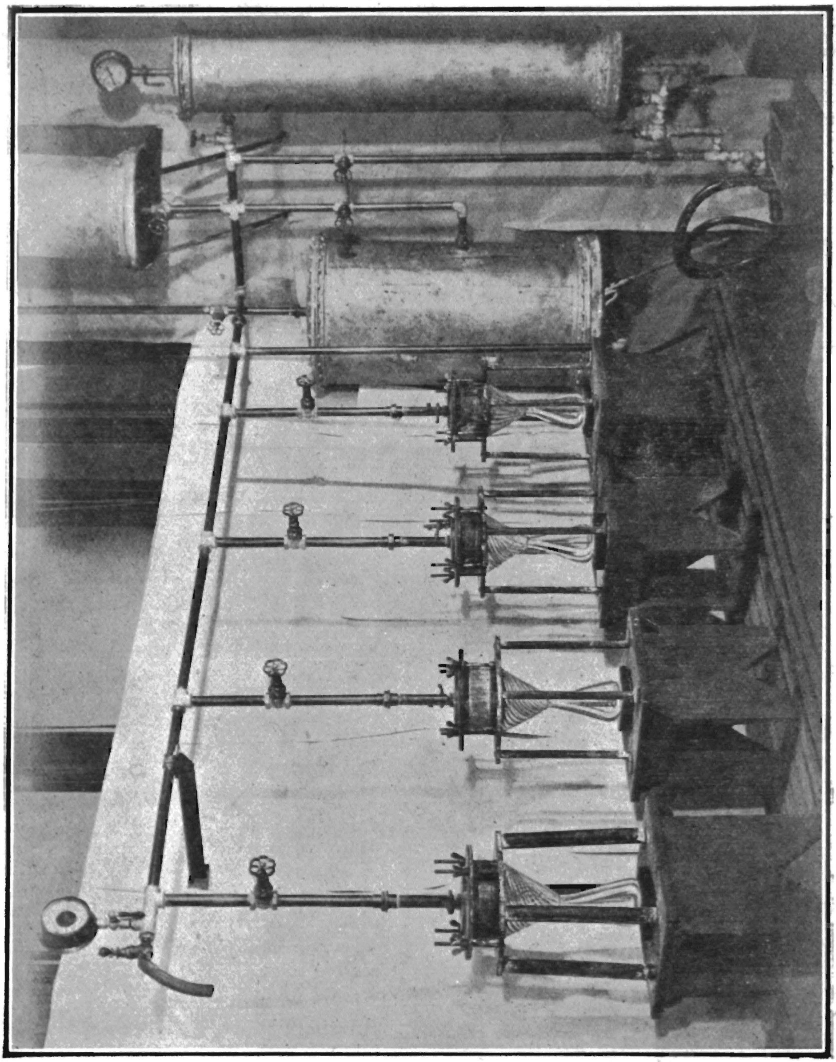

Fig. 5.

In carrying out tests of mortars, the test block A (fig. 3) is placed between rubber rings B, held in position between the cover plate C and the annular bedplate D by means of bolts with wing nuts E. Above the test piece is a space F, the air in which can be displaced with water by means of the inlet pipe G and the pet cock H.

The water supply is arranged as in figure 4 in such a manner as to deliver filtered water at constant pressure, connection being made to the pipes G-G.

A charcoal filter is placed in the cylinder C, which is connected to the main by means of a blow-off valve B. Water is first allowed to flow through the whole apparatus until it reaches a certain level in the drum E determined by trial. Compressed air is then forced into E through the pipe D until the requisite pressure is obtained. This serves to form a cushion, and to prevent sudden changes of pressure due to outside causes.

Cylindrical test blocks are moulded in short lengths of 6-inch steel casing, which have previously been thoroughly washed and grouted with neat cement on the inside. The blocks may be made in any required thickness, the sizes adopted being mainly 1 inch and 2 inches.

When moulding, the rings of casing are placed on steel plates which have been slightly greased, the top surface of the compo being levelled off with a trowel. The blocks are allowed to remain in the moulds until tested, and may be stored dry or wet as required. Blocks made to be stored dry are kept moist between blankets for seven days, whilst those stored in water are first maintained between wet blankets for 24 hours.

In some cases the outside skin was removed from the top and bottom surfaces 24 hours after the blocks were moulded.

For test on concrete the same apparatus may be used, larger moulds being provided so the area under test may be sufficiently great compared with the size of the stone. The test blocks, which may be conveniently 18in. in diameter, are attached to the water supply in a similar manner to that above described.

Results of Tests Made at the Bureau of Standards.

Before coming to consider the actual results of the tests made at the Bureau of Standards, it is necessary to make a few observations regarding the conditions under which the tests were carried out.

In proportioning the mortars and concretes the weight of 1 cub. ft. of cement is taken as 100lbs. Although this is quite correct, it is our experience that in actual practice it is customary to take 3 bags of cement as 4 cub. ft. For this reason we prefer to make all our tests on the basis of 93.7lbs. per cub. ft., so as to avoid getting mixtures richer than those in ordinary use.

The test blocks were made by hand of two consistencies, "damp" and "quaking." A mortar of "damp" consistency is described as one containing only sufficient water to hold the particles together when made into a ball in the hands, and the ball held between thumb and finger. A mortar of "quaking" consistency contained all the water it would hold, and permitted of moulding a ball in the hands and holding between thumb and finger. The results show a great difference between such consistencies, and it may here be remarked that the practical value of tests of mortars made to a "damp" consistency is small. In practice the tendency will often be to make use of mixtures wetter than that described as "quaking," owing to the advantage of placing such mortars in position.

The test blocks were kept in a moist place for one day, then placed on shelves in a damp room and sprayed with water three times every 24 hours. This practice is in our opinion very open to criticism, since the intermittent spraying and drying will cause changes in the surface of the blocks by which pores will be closed and the surfaces will become less permeable.

Just prior to testing, the blocks were brushed with a stiff wire brush in an attempt to remove any "skin" of cement drawn to the surface in moulding. This was accomplished only with difficulty in some cases. In our view it is desirable that this skin should be removed, and we have treated the test blocks with the wire brush immediately setting is complete, our experience being that if deferred until a later stage hardening has proceeded too far to allow this to be done with success.

The work carried out by the Bureau is of a very voluminous character, and we find it a little difficult to follow the details in places. It is not possible to present the mass of curves and tables in this paper, but we shall be content with a review of the principal points to be noted.

When mortars and concrete are exposed to water under pressure, the quantity of water which passes through may not be measurable, and from some points of view the mortar may be regarded as impermeable. At the same time it may be wet, and thus from other points of view it may be decidedly objectionable. In the remarks which follow we shall discriminate between these conditions by referring to the surfaces as "wet" and "dry."

From the tables given by Wig and Bates we have summarised the following conclusions:—

1. The test blocks made to a "damp" consistency allowed large quantities of water to pass under a pressure of 20lbs., the best showing as high as 18 gallons per square foot per hour. For this reason we shall only refer to "quaking" consistencies in the paragraphs which follow.
2. Test blocks 2 inches thick from 4:1 mixture at an age of 1 month do not allow measurable quantities of water to pass through them under 20lbs. pressure. 6:1 mortar reaches this stage in two months; whilst 8:1 mortars cannot be relied upon even after 6 months' storage.
3. Similar test blocks of mortar 1:1 remain dry under 80lbs. at an age of one week. Mortar of 2:1 pro-

portion takes 12 weeks to reach this condition; whilst in 24 weeks 4:1 mortar was dry, whilst 6:1 mortar became moist.

4. Well graded sand containing a considerable quantity of graded fine material assists in rendering the mortars more impermeable.
5. The permeability is diminished by trowelling the surface of the mortars.
6. Test blocks of concrete 6 inches thick made with a graded limestone (2½in.), of which 20 per cent. passed the ¼in. sieve, all showed marked permeability under 20lbs. pressure, with the exception of a mixture 5½:½:1, which when made with one variety of sand (30 per cent. through 50 mesh sieve) withstood a pressure of 60lbs. after 13 weeks.

The mechanical analysis of the limestone and sand in this mixture was as follows:—

Sieve	100	80	50	40	30	20	10	¼	½	¾	1	1¼	1½	1¾	2	2½
Sand	1.50	10.0	31.5	46.5	62.0	72.0	86.0	100								
L'stn.	1.9	3.4	4.34	4.9	5.35	7.0	10.0	19.0	30.5	57.0	59.0	81.0	89.0	96.5	98.0	100

7. It appears from the above that the grading of the stone is very important as regards the proportion of fines. Of all the other concretes examined, a mixture 4:2:1 (stone graded to 1¼in. with a somewhat coarser sand than the above) came nearest to being impermeable.

General Remarks.

Taking the results as a whole, it would appear from a practical point of view that, in order to secure concrete impermeable to water, it is necessary, firstly, to pay particular attention to the thorough mixing of sand and cement, and to use enough water to ensure that the whole mixture has reached at least a "quaking" consistency.

Rich mortars are not necessary, but with lean mortars there is a greater chance that, on account of irregular mixing, patches may occur which are not watertight.