From the results given it appears that concrete can be made to withstand high pressures of water, and show no visible signs of permeability, but unless care is taken any ordinary concrete would show a moist surface. It is possible, then, even where the surface remains quite dry, this is only due to the evaporation of the small quantity of water which is passing, and the interior may be sufficiently moist to be objectionable from other points of view, especially as regards the protection of reinforcement.

Results of Our Experiments.

First Series.

In order to obtain experience with the modified apparatus, it was decided to make test blocks in the first place of any mixtures which happened to be under test for other purposes. Some comparisons were being made between Nepean sand and a crushed sandstone (consistency, wet), and test blocks were prepared from these materials as follows:—

Nepean Sand	$2\frac{1}{2}$:1	(41 days in air)
	3 :1	(41 days in air)
	4 :1	(66 days in air)
Crushed Sandstone	$2\frac{1}{2}$:1	(40 days in air)
	3 :1	(40 days in air)
	4 :1	(63 days in air)

The surface skin was removed from both sides 24 hours after gauging.

These test pieces were 1 inch and 2 inches in thickness. The test blocks were placed in the testing apparatus, and left under pressure, the quantity of water passing through during periods of 3-7 hours being measured at intervals. The results are shown graphically in figs. 6 and 7, and are only regarded as preliminary in character. They show that the mortar rapidly becomes less permeable as water passes through, but in no case did the flow fall to zero.

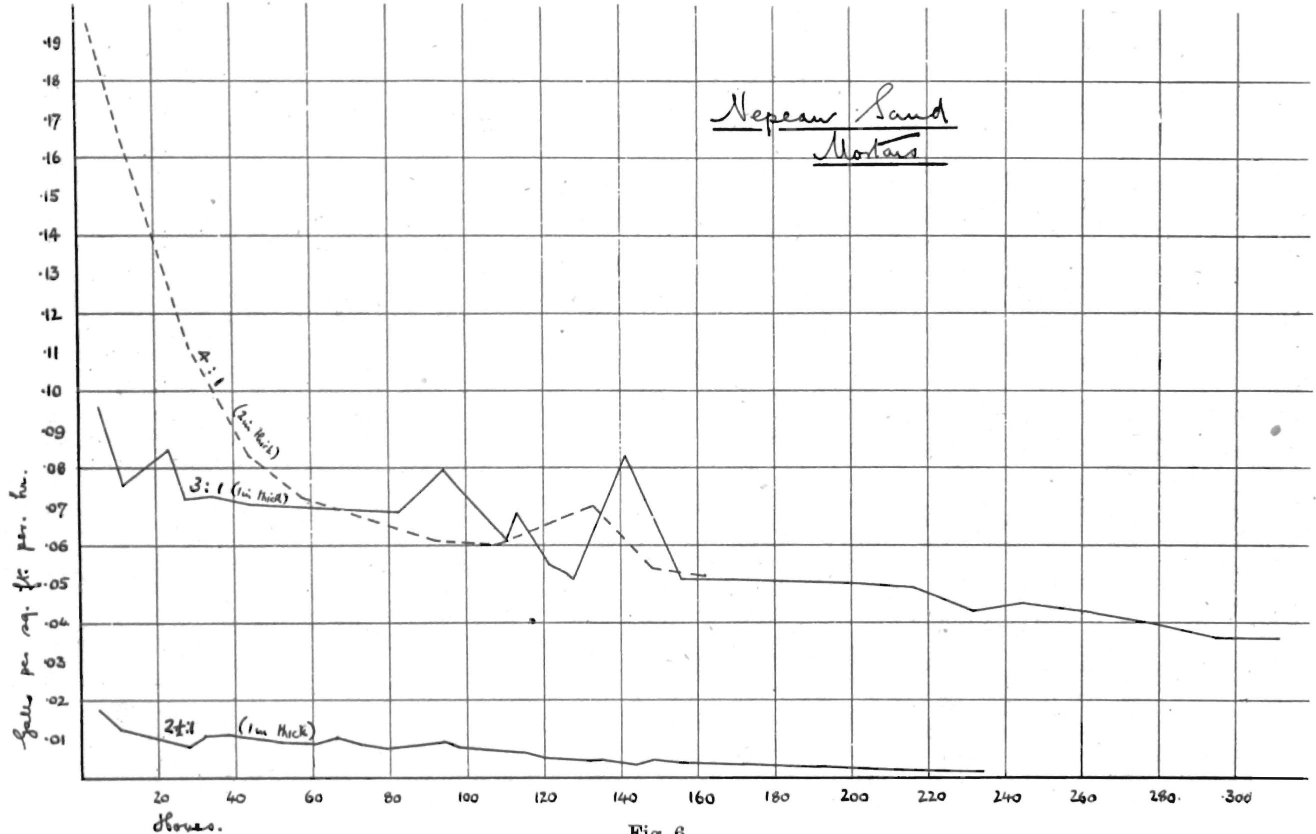
Nepean Sand
Mortars
4 : 1 (2in thick)
3 : 1 (1in thick)
2½:1 (1in thick)
Galls per sq. ft. per. hr.
·19
·18
·17
·16
·15
·14
·13
·12
·11
·10
·09
·08
·07
·06
·05
·04
·03
·02
·01
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Hours.

Fig. 6.

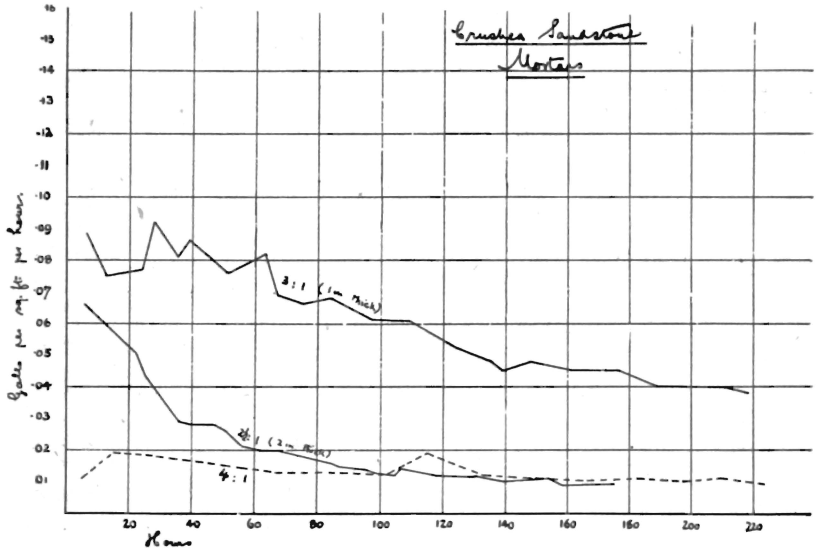

Fig. 7.

Second Series.

The second series was planned as follows:—

No. 1 Nepean Sand.—2:1, 2½:1, and 3:1.

Consistency.—Wet i.e., slightly more water than would correspond to the "quaking" consistency before mentioned, mixtures readily placed into moulds.

Thickness.—1 inch and 2 inches.

Conditions.—Series to be kept in air are placed under damp blankets for 7 days, then 21 days in air. Series to be kept in water are placed under damp blankets for 24 hours, then transferred to tank for 27 days. Series with surface skin removed at the end of 24 hours, and also not removed.

Age.—28 days.

Pressures.—7 hours under 10lbs., followed by 7 hours 20lbs. pressure.

For grading of sand see fig. 8.

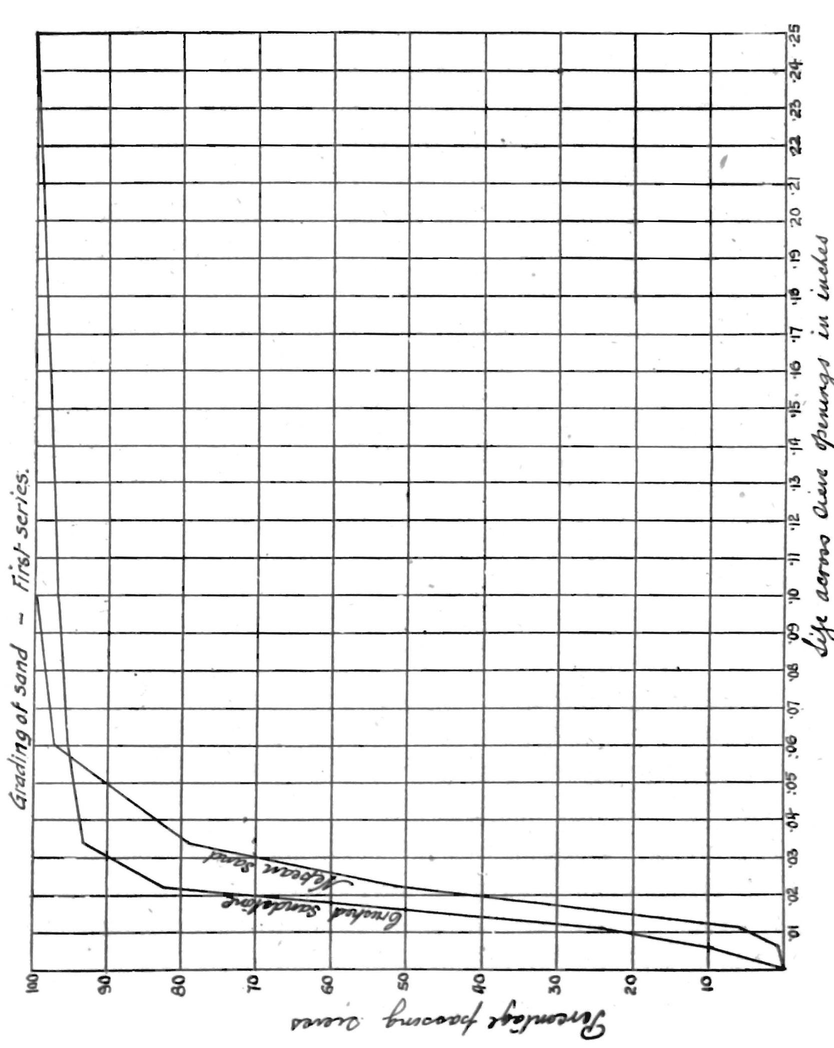
Grading of sand - First series.
Size across sieve openings in inches
Percentage passing sieves
Nepean Sand
Crushed Sandstone
·01 ·02 ·03 ·04 ·05 ·06 ·07 ·08 ·09 ·10 ·11 ·12 ·13 ·14 ·15 ·16 ·17 ·18 ·19 ·20 ·21 ·22 ·23 ·24 ·25
10 20 30 40 50 60 70 80 90 100

Fig. 8

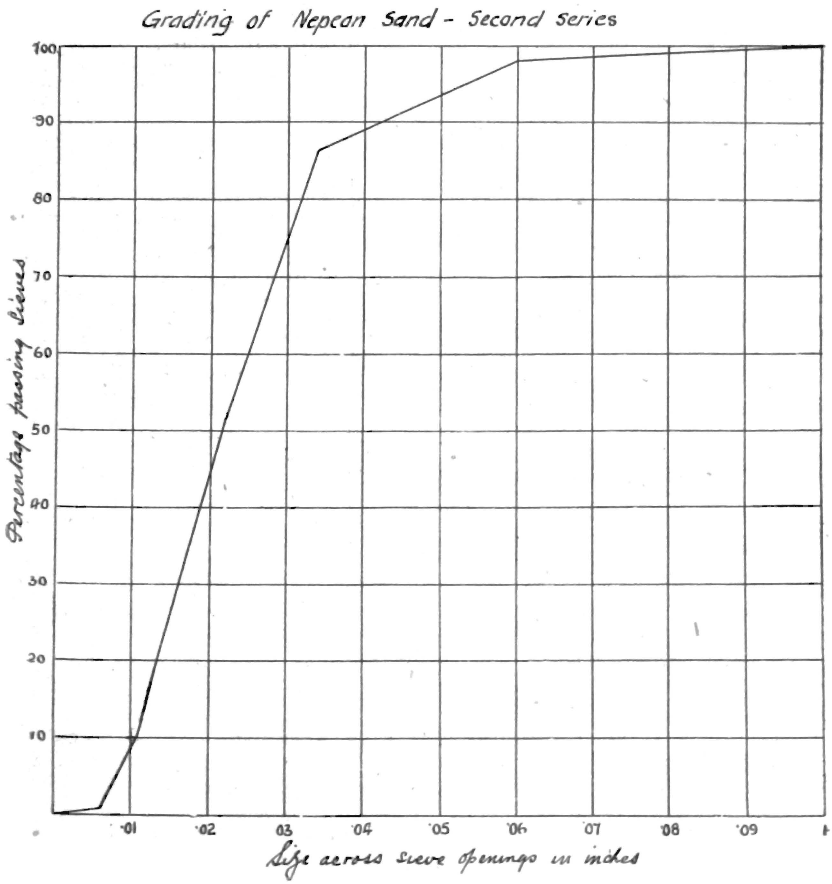
Grading of Nepean Sand - Second series
100
90
80
70
60
50
40
30
20
10
Percentage passing Sieves
·01
·02
·03
·04
·05
·06
·07
·08
·09
·1
Size across sieve openings in inches

Fig. 9.

The results are shown in the following table:—

2 : 1 MIXTURES AT 28 DAYS UNDER 10lbs.

Thickness in inches.	Vol'm. of Water passing. Galls. per sq. ft. per hour.	Condition	Stored in	Remarks.
2	0	Skin removed	Air	Slightly damp on under surface in 3 hours.
1	·0015	,,	,,	Slightly damp on under surface in 1 hour.
2	0	,,	Water	
1	0	,,	,,	
2	0	Skin left on	Air	Signs of dampness on under surface in 1 hour.
1	0	,,	,,	Signs of dampness on under surface in 2 hours.
2	0	,,	Water	Dried out underneath.
1	0	,,	,,	,,
		The same under 20lbs.		
2	0	Skin removed	Air	
1	·005	,,	,,	
2	0	,,	Water	
1	0	,,	,,	
2	0	Skin left on	Air	Surface dried out
1	0	,,	,,	,,
2	0	,,	Water	,,
1	0	,,	,,	,,
		2½ : 1 MIXTURES AT 28 DAYS UNDER 10lbs.		
2	·005	Skin removed	Air	Damp on under surface in 1¼ hours.
1	·014	,,	,,	Damp on under surface in 35 minutes.
2	0	,,	Water	Drying out in 7 hours.
1	0	,,	,,	,,
2	·0001	Skin left on	Air	Damp on under surface in 4 hours.
1	·01	,,	,,	Damp on under surface in 35 minutes
2	0	,,	Water	Dried out on under surface
1	0	,,	,,	,, ,, ,,

The same under 20lbs.

Thickness in inches	Vol'm. of Water passing Galls. per sq ft. per hour.	Conditions	Stored in	Remarks.
2	·006	Skin removed	Air	
1	·022	„	„	
2	0	„	Water	Dried out on under surface.
1	0	„	„	„ „ „ „
2	0	Skin left on	Air	Damp on under surface
1	·022	„	„	
2	0	„	Water	Dried out on under surface.
1	0	„	„	„ „ „ „

3:1 Mixture at 28 days under 10lbs.

2	·011	Skin removed	Air	
1	·091	„	„	
2	0	„	Water	Damp on under surface
1	0	„	„	„ „ „
2	—	Skin left on	Air	
1	·023	„	„	
2	0	„	Water	Drying out on under surface
1	0	„	„	„ „ „ „

The same under 20lbs.

2	·029	Skin removed	Air	
1	·177	„	„	
2	0	„	Water	Damp on under surface
1	0	„	„	„ „ „
2	—	Skin left on	Air	
1	·025	„	„	
2	0	„	Water	Slightly moist on under surf.
1	0	„	„	„ „ „ „

The following programme has been drawn up for further work:—

To determine uniformity of methods of testing:—

1. Make a series of 8 test pieces from one mixing ($2\frac{1}{2}$:1), and store 4 in air and 4 in water. At the end of 28 days place under test for 7 hours. Repeat at 6 weeks and 2 months. Test pieces to be 2 inches thick. Consistency, wet. Surface skin removed.

2. Carry out the same series with 8 separate mixings.

3. Determine quantitatively the water required to give "quaking" and "wet" consistencies, and carry out a series similar to the above, but with varying quantities of water, one at least being slightly less "wet" than "quaking."

4. Prepare a similar series, and study the effect of increasing pressure as the mortars age. Make 8 blocks. Store in water, and commence testing at 28 days. Blot off the wet surface and apply the pressure, gradually increasing by 5lbs. per hour, measuring the water passing (if any) for each hour, or recording whether surface wet or dry, as the case may be.

Further additions to the programme will be made when the above results are ready, as some special arrangements may need to be made in the light of these results.

It is intended to extend these tests to a complete study of the properties of local materials used as mortars and as concretes, with various gradings of each material as obtained commercially.

Special Materials for Waterproofing Concrete:—

A number of materials are on the market which are claimed to render concrete watertight. These substances are of two kinds, firstly, integral compounds which are added to the cement and incorporated with the concrete; secondly, coatings to be applied to the work to render the surface impervious to water.

Integral Compounds.

Substances which are ordinarily in use for this purpose fall into one or other of the following classifications:

(a) Inert fillers, such as clay, sand, feldspar, hydrated lime, which serve to fill the voids or increase the density of the concrete.

(b) Active fillers, composed principally of china clay with hydrated lime and resinate of potash. Such compounds form insoluble lime resinate when mixed with concrete.

(c) Water repelling compounds which contain stearates of lime or of soda in variable quantities. As a rule these compounds contain far more lime than is necessary to combine with the stearic acid, and this merely serves as a void filler.

(d) Waterproofing cements, which are composed of Portland Cement with the addition of about 0.5 per cent. of stearate.

(e) Various liquid fillers have been used, such as tar oil. Another contains oil, together with waterglass and soap. A third contains calcium chloride solution with a little resin-shellac added.

Tests were carried out by the Bureau of Standards on 4:1 mortar, the admixtures being made in accordance with directions given with each proprietary material, but the materials are not described by name. This mortar became wet when subjected to 20lbs. pressure, until it reached the age of 13 weeks, and under 40lbs. it required 26 weeks.

It was found that the addition to the cement of 5 per cent. of a compound made up of china clay and hydrated lime, with 15 per cent. of kauri resin, very soon became impervious, and at six weeks resisted 40lbs. pressure.

The best results were obtained with addition to the cement of 10 per cent. of hydrated lime of the following chemical composition:—

Lime	46.9	per cent.
Magnesia	32.2	„
Silica	1.3	„
Co_2	4.0	„
Water	15.0	„

This substance fills the voids and causes the mortar to be impervious in 5-6 weeks.

The following mixtures gave results of some value:—

1. A mixture containing 44 per cent. of lime, 3 per cent. of alkalis, and 8 per cent. of fat (stearic) acid, used in proportion of 2 per cent. of the weight of the cement.
2. A mixture containing 30 per cent. of lime, 20 per cent. of magnesia, and 37 per cent. of fat (stearic) acid, used in proportion of 2 per cent. of the weight of the cement.
3. The addition to the mixing water of 10 per cent. of its volume of a solution containing 27 per cent. of calcium chloride and 0.15 per cent. of resin-shellac.

In general the use of such materials is not regarded by the Bureau of Standards to have much practical advantage. It may be mentioned here that Grittner (Inter. Congress Testing Materials, 1912) claimed that the use of an 8 per cent. solution of potash soap instead of the mixing water gave surprising results. The work of the Bureau was afterwards criticised by the "Engineering News" (May 2nd, 1912), which argues that in practice it is impossible to avoid faulty workmanship, and therefore it is useless pointing out that it is possible to make watertight concrete by this means. On the whole, there is room for some more clearing-up work to decide what advantage is likely to accrue from the use of these special additions.

Waterproofing Coatings.

It is obvious that if sufficient care is taken, a waterproof coating can be applied to concrete and cement mortar. Thus for small work we have frequently used a mixture of pitch and bitumen (1:3), which is applied hot. Whether such a material would serve for all purposes would depend largely on the cost of its application on a large scale.

Substances ordinarily used for this purpose may be classified as follows:—

(a) Linseed Oil Paints and Varnishes.

(b) Bitumen (asphaltums, mixtures of various bitumens, mixtures of bitumen with wood tar and linseed oil).

(c) Liquid hydrocarbons.

(d) Soaps.

(e) Cements.

(f) Miscellaneous compounds.

The tests made by the Bureau of Standards on these compounds are only put forward as preliminary in character. Mortars, 4:1, were coated with the substances as directed, and the coated surfaces were exposed to water. The presence of water on the opposite surface was detected by means of papers impregnated with alcoholic solution of phenolphthalein. By this test every one of the waterproof coatings failed. In rendering the results Wig and Bates point out that the mortar used gave a very coarse and absorbtive surface.

The various coating compounds used are described as follows:—

(a) *Linseed Oil Paints, Varnishes, etc.*—The compound in this class differ in nowise from the ordinary enamel paints, which are usually characterised by hardness and brittleness, due to the comparatively large amount of hard resins and the small amount of linseed oil. This causes such coatings to be very inelastic, but, at the same time, would apparently increase the life of the coating, since the hard resins are more inert than the linseed oil. Linseed oil is constantly undergoing changes due to oxidation, and in the saponification which takes place in the presence of the latter.

(b) *Bituminous Coatings.*—This class includes asphalt, petroleum residuum, and coal tar pitches. They are usually characterised by great inelasticity, and are therefore recommended to be used with alternating layers of felt, and being solid at ordinary temperatures, are applied while hot. As they are all soluble in benzine and coal tar naphtha, they are frequently put on the market in this latter form.

Owing to their wide distribution, their cheapness, the ever-increasing quantities which are appearing on the market, and their supposed inertness, their application is worth further study.

(c) *Liquid Hydrocarbons.*—In this class are two kinds of compounds which act largely to fill the pores, and at the same time repel water. Both are of such a nature that they do not penetrate the mass very far, and are only very superficial. Like all coatings, they are rendered worthless by a minute crack in the concrete.

(d) *Soaps.*—The use of a solution of soaps cannot bring enduring results. It is quite likely that very much more of the soap is dissolved and washed off the surface than ever reacts to form insoluble compounds of the nature of lime soap. Unless such reaction takes place, this class is worthless.

(e) *Cements.*—There are a number of cements on the market to which have been added a very small quantity of water-repellent substances. Their suitability very largely depends on the quantity made use of.

General Conclusions.

There is no doubt that where good materials are used and good workmanship is carried out, concrete can be made watertight; but there is a little doubt as to whether such work can be done economically. It seems to us that where watertight concrete is a necessity it should be quite practicable to take every care to mix the materials properly.

It would be desirable that in all cases dry sand should be used, and the cement thoroughly incorporated with it before the metal is introduced. In the absence of dry sand the cement should be incorporated with ordinary damp sand rapidly, before mixing with the metal.

The materials should be selected and graded so as to yield a dense concrete with a minimum of voids. Should it be desired to add some filler to assist in filling up the voids, the most suitable ingredient to use would appear to be hydrated lime. In general, high lime cements are reputed to decompose more rapidly in sea water, but it is doubtful whether admixed lime is open to the same objection.

Finally, the quantity of water used for gauging should be carefully under control, mixing being so carried out that the water is equally distributed throughout the whole mass of the concrete.

Discussion.

Mr. Hart: Mr. President and gentlemen, I have very great pleasure in moving a hearty vote of thanks to the authors of the very interesting paper which has been placed before us to-night. An investigatory and experimental paper of this kind is the crystallisation of a great amount of work which the ordinary engineer has no opportunity of carrying out, and when, as in the present instance, the subject has such an important bearing on everyday work, one feels almost under a personal debt to those who so generously make public the result of their investigations.