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.

The greater number of modern structures require the use of a large or small amount of waterproof concrete. Marine works in concrete must resist the action of sea water upon them. Tanks, reservoirs and dams must hold the water contained in them without leakage. Basements and underground walls must be damp-proof if the buildings are to be healthy for human habitation, and if the goods stored in them are to be preserved without damage. Tunnels and subways must be free from drips and soakage. The walls and floors in hospitals must be non-absorbent to be sanitary. Concrete pipes and sewers must resist the action of the fluids flowing through them, and silos must be damp-proof to protect the wheat which they contain.

Decay in nearly every substance is greatly hastened by damp. Damp conditions encourage germ growth, and permit or induce chemical action which would never occur in a dry state. Wheat sealed by ancient Egyptians in air-tight vessels is found to-day still in perfect condition. Water in every form is a medium of the conditions which lead to decay.

The need of waterproof concrete is now recognised by engineers, architects and owners alike. The great question is, how to secure the desired results permanently at a minimum of expense.

When it is remembered that the voids in ordinary concrete are commonly as high as 2 per cent. of its total volume, it will be seen that the problem of rendering the mass impervious is no easy one. If we accept the authors' statement that the larger aggregate used in the concrete is itself impervious (which, by the way, is *not* the case with sandstone concrete, tests of which are described early in the paper), then, as the authors state, the problem resolves itself into one of mortars.

It might be inferred from this that it is unnecessary to test actual concrete, and sufficient to test mortars only; but this is not so, since, for mechanical reasons, voids may occur in the making and placing of concrete which would not occur with the smoother working mortar.

Referring to the tests of sandstone concrete referred to on page 2 (of the paper), the results obtained are very remarkable, as they show that a concrete made with non-impervious material when subjected to continuous water pressure soon became practically watertight. These results would not have been remarkable had not the water used in the pressure tests been filtered; but under the circumstances one would imagine the watertight condition to be a temporary one only, the concrete again becoming permeable on drying out. Further reference to this point by the authors would be appreciated.

It is stated that on making some of the tests the top skin of the specimens was removed. This point brings up the use of wet and sloppy concretes, with the consequent formation of "laitance" at the top of each successive layer of concrete deposited. Dry mixed concretes have their disadvantages, but the very sloppy mixed concretes are very undesirable in any work required to resist a pressure of water, such as dams, tanks or reservoirs. The white streaks, caused through absorption and passage of water through the concrete, so commonly seen on the outer face of works of this kind, are usually due entirely to this "laitance."

The authors recognise the value of the use of well graded sand. Unfortunately in Sydney there are usually only two sands to be had—Sydney sand and Nepean sand—the one fine and the other coarse—but both fairly uniform of their kind, and not graded.

In equally important city buildings within two miles of this room, reinforced concrete construction is in full swing. In one no sand but Nepean is allowed to be used, in a seccnd none but Sydney sand, whilst in a third a mixture of equal parts of Nepean and Sydney sands was condemned.

As those responsible in each case believe that they are using the best material to obtain the strongest, densest concrete obtainable, and as the practise is so varying, a recommendation from the authors would be interesting.

I have known concrete pipes moulded on specially constructed "shaking" machines to withstand without leakage, under test, a pressure equal to 200 feet head of water. These pipes were not specially waterproofed in any way; but I agree with the conclusion to be inferred from the paper that the cheapest and best ordinary method of waterproofing is to apply a special coating to the general body of the work, as the cost of obtaining waterproof concrete by the means above referred to make its general application impossible. This is not to say, however, that all possible care should not be taken in the grading and mixing of ordinary concrete.

I have come to the conclusion that most waterproofing compounds are worth very little. Although some of them are good, some of them are positively dangerous, I am sure. I would like to ask the authors' opinion of any cement waterproofing compound having calcium chloride as its base.

The authors recommend the use of hydrated lime to obtain impervious work; but I submit to them that such material in this country is hard, or impossible, to obtain. It costs as much as Portland cement, and it reduces the strength of concrete into which it is incorporated, and it is in every way inferior to an equal bulk of cement, whose use would result in concrete of greater strength and impermeability than can be obtained by any other method.

I have very much pleasure in again moving the vote of thanks to the authors for their very able and practical paper.

MR. OAKDEN: It has been a great pleasure to me to hear the paper which has been read this evening, but to fully appreciate it a careful study of the diagrams is necessary.

I would like to state that it appears to me that the mixtures set forth in diagrams 6 and 7 cannot be compared, owing to the difference in their strength. The authors have acted properly in presenting the results obtained by the Bureau of Standards in America to us this evening. A technical journal states in a recent issue, that, although the most careful research has been made with regard to sea water concrete, great deterioration still takes place owing to the permeability of concrete to water.

Mr. Hart has said that specially constructed concrete pipes have been known to withstand without leakage a pressure equal to 200 feet head of water, and we know that this can be done. In the case of piles and massed concrete the steps that must be taken are to carefully test and investigate to find a means of making concrete impervious to water; otherwise I fear that its use will not be a success. I hope the authors will be able to carry on these tests, and that they will let us know what results they arrive at. Hydrate of lime and other mixtures will only last a comparatively short time.

Mr. Wm. Poole: The subject which Messrs. Smart and Morrison have brought before the Association is one of great value in the use of concrete, and of vital importance in the employment of reinforced concrete under some conditions.

Messrs. W. J. Wig and W. R. Ferguson have recently carefully examined many concrete structures on the coast and tidal waters of the United States. They have almost universally found that there has been a more or less serious disintegration, fritting or abrasion of the concrete from low water mark to some distance above high tide mark—the action being most marked in the latter neighbourhood.

Chlorine and oxygen in each other's presence form very active corroding agents. Permeation of concrete by salt water near the water level of sea water assists in the chemical disintegration of the material owing to the freezing of the contained water, causing prior physical cracking of the material. The cracking of the concrete in sea water always starts above the high water line, although it may extend below this point as corrosion develops. Infiltration causes steel to rust, which in turn causes the concrete to crack or split, thus facilitating the action to spread. This has been found to be the case not only with poor concrete, but also with that of excellent quality. Steel embedded in first-class concrete to a depth of one to two inches, in accordance with existing theory and practice, is not perfectly protected against corrosion by sea water action. Not even three inches of concrete cover will ensure the embedded steel from corrosion. Action has been observed under conditions where it cannot in any way be due to electrolysis or shattering in erection, etc.

Well made concrete may be gauged with sea water, and the material lasts as well as that made with fresh water, but good workmanship is requisite. In practice it is very difficult to avoid some faulty workmanship, e.g., the daily joints which it is difficult to always make watertight under pressure.

It has long been known that the surface of concrete is both harder and more watertight than the material of the interior. For a similar reason the water side face of concrete dams have been brushed, cleaned and washed with neat cement to make them more watertight. A wash of lime, fat and salt has long been used both to whiten and waterproof brick walls.

The experiments of Messrs. Smart and Morrison show that the rate flow of water through their blocks decreases with time. It would be interesting to know if this decreasing rate is due to chemical, mechanical or biological action, or a combination of them. It would also be interesting to know what would be the effect of thoroughly drying out the blocks after a test, and then re-subjecting them to the same test.

Mr. Parke (N.Z.): First of all I would like to thank you for your invitation to this meeting to-night. There is nothing more pleasant than to come to such a gathering and see so many engineers together for the purpose of discussing matters in which we are all so interested. Very often the strength of an association is undermined through members being lax in attending meetings. The meeting of members, and the expression of different opinions on subjects of importance in the engineering world is the best way to render an association of the greatest benefit to the community.

I do not feel disposed to discuss the paper at great length. In the first place, the most vital part is in the mixture of concrete, and the contractor is very often to be blamed because of the fact that he recognises the mixer of concrete only at the same value as a laborer; whereas a man must be an expert to mix concrete properly, and must be paid accordingly; that is one of the greatest troubles about getting waterproof concrete. In New Zealand it is very different from this country. There are a great many springs in the former. One instance which came under my notice about three years ago was as follows:—We had a large furnace which had been in operation for some years; there was a pit under it, and suddenly a spring broke out, and the consequence was that the water came through, and draughts affected it, so that we could not get the proper heat, and had to close down. After pumps had been going for 48 hours the water gave up. We then filled up the weak spot with carefully prepared concrete, and in three years' time we have not seen a damp spot. By careful attention when putting in concrete there is a big chance of making it waterproof.

In the furnace pit just referred to the heat was such that around the sides you could just put your hand in. Concrete, with proper watching in the mixing, can be made waterproof. On the question of waterproofing there is great diversity of opinion. It is difficult to get a perfect mixture with light sand. The sandstone here I would not use at all. I have used bluemetal. In New Zealand we have very good sandstone, and a great thing in concrete is the absolute cleanliness of the mixtures used. Sometimes the engineer is at fault in not allowing time for proper expansion and contraction. The chief trouble is not the question of the concrete itself, but the question of proper jointing, which eliminates the concrete cracks. I would like to assure you, gentlemen, that if any of you would care to have a look over the premises on which I am engaged at present at Botany I shall be only too glad to see you. On behalf of the N.Z. Institute I extend to any of you who may visit N.Z., and especially Auckland, a very warm welcome. I have a copy of the Building Regulations of the City of Auckland which I hope to have the pleasure of showing you.

MR. J. J. C. BRADFIELD: I desire to thank the Council of the Association for their courtesy in inviting me to be present to hear the paper on "The Permeability of Concrete by Water," contributed by Messrs. Smart and Morrison. These gentlemen are to be complimented upon their paper, which serves to illustrate the beneficial results which may be achieved by scientific investigation.

The authors have given a very clear explanation of the action which takes place in a concrete aggregate when it is rendered impermeable, and the results obtained from the experiments made are interesting.

The authors suggest that the results shown in Fig. 2, giving a higher permeability for a 4:2:1 concrete than for a 6:3:1, may be due to the greater proportion of water necessary in mixing the poorer concrete. This assumption would agree perhaps with Thompson's conclusion (7) that "medium and wet consistencies produce concrete much more watertight than dry consistencies, and slightly more watertight than very wet consistencies," but this may only be part of the reason.

In Fuller and Thompson's experiments, made at the Jerome Park Reservoir, it was established that in practical construction the densest and strongest mixture is attained when using "as small a proportion of sand and as large a proportion of stone as is possible without producing visible voids in the concrete."

The authors used 4:2:1 and 6:3:1 mixtures, which apparently give the same percentage of sand to the stone, which had a maximum size of 2 inches graded to ⅛ inch.

	4 to 1.	6 to 1.
Stone	16 cub. ft.	16 cub. ft.
Sand	8 ,,	8 ,,
Cement	4 ,,	2.67 ,,

The difference in the two mixtures is in the quantity of cement. It is often found in practice that 8 cub. ft. of sand has less than 4 cub. ft. of voids, and the cement in the 4 to 1 concrete is more than sufficient to fill the voids. In other words, with the 4 to 1 concrete it cannot always be shown that the largest possible proportion of stone is obtained in the mixture.

In Thompson's Tables the volume of mortar in terms of percentage of volume of stone is given thus:—

	Proportion by parts.	Proportion by volume.	Volume of mortar.
(a)	1 : 2 : 4	4 : 8 :16	56%
(b)	1 : 3 : 6	4 :12 :24	50%

This agrees with experience, which shows that a 4:2:1 mixture will yield a concrete containing less stone per cub. ft. than a 6:3:1 mixture. The stone per cub. ft. of concrete would range about:—

4:2:1 = .81 to .93
6:3:1 = .84 to .97

With broken stone ranging from 2in. to ⅛in. the voids would not exceed 50 per cent., and would be probably less, so it will be obvious that the 4:2:1 mixture was not proportioned to give the maximum density.

Mechanical analysis curves of the aggregate used in the authors' experiments would have been useful, but the authors have pointed out that their investigations have only reached a preliminary stage, and doubtless when further results are published they will cover experiments to determine as far as possible the most suitable mixture of various aggregates to yield the maximum density in concrete with a minimum of voids.

The other element to be considered would be the relative permeability of the 2:1 as against the 3:1 mortar. In the authors' experiments the permeability of 3:1 mortar, aged 30 days, shews at 20 hours, under 10 lbs. pressure, a maximum permeability of .08 gallons per sq. ft. per hour, for specimens 1 inch thick; whereas the 6:3:1 concrete at 20 hours, under 10 lbs. pressure, gives .2 gallons per sq. ft. per hour on a thickness of 11 inches. As the permeability decreases rapidly with the thickness, it seems reasonable to suppose therefore that the richness of the mortar is not a predominating influence in the permeability of concrete, provided that the cement is sufficient to fill the voids in the stone.

That it is impossible in practice to fill the voids in concrete is well exemplified by the following experiments carried out by me some years ago in connection with the erection of the reinforced concrete road bridge across the Hawkesbury at Richmond.

HAWKESBURY RIVER AT RICHMOND—CONCRETE TESTS.

Voids in Materials.

Item.	Quantity Tested Cub. ft	Water required to fill Voids. Gallons.	Cubic feet.	Voids per cent.
1. Sand (slightly damp)	10.0	25	4.0115	40.115
2. Stone, Basalt screened through 1¼in. ring, caught on ¼in. mesh	10.0	30	4.8138	48.138
3. Gravel, Screened through a 2½in. ring and caught on ¼in. mesh	10.0	22	3.53012	35.3012

The above tests were made in a square tank. 62.321 gallons of water were measured into the tank to determine exactly the capacity of 10 c. ft. The surface of the water was marked, and the above materials measured thereby.

Concrete Tests.

Ordinary Concrete—Test 4.

20 c. ft. gravel screened through a 2½in. ring and caught on ¼in. mesh; 8 c. ft. sand; 4 c. ft. cement.

The cement used was Goodlet & Smith's "Rock Brand," a slow-setting cement. The gravel was passed through a 2½in. square screen, and at least 10 per cent. was over gauge; 21 gallons of water were used in mixing. The resulting concrete block measured 5.01 ft. x 3.51 ft. x 1.25 in. = 22 cubic feet.

Voids in 8ft. of sand= 8 x 40.115 ÷100=3.21 c. ft.

Voids in 20ft. of gravel=20 x 35.3012÷100=7.06 c. ft.

Mortar: 8 sand+4 cement=12—3.21=8.79 c. ft.

Concrete: 20 stone+8.79 mortar—7.06 voids
=21.73 c. ft. concrete, as against 22 c. ft. actually made by the above.

This shows that the mortar does not fill the voids in the stone as completely as the water—some .27 c. ft. out of the 7.06 c. ft. of voids above not being filled, i.e., 3.8 per cent. will be air spaces.

Test 5—Ordinary Concrete with 1¼*in. Gauge Stone.*

20 c. ft. of stone (1¼in. basalt) screened through a ring 1¼in. diameter, caught on ¼in. mesh; 8 c. ft. of sand; 4 c. ft. of cement. 21 gallons of water were used in mixing, and the resulting concrete block measured 5ft. x 3.51ft. x 1.15in.=20.2 c. ft.

The upper surface of the block was "hungry," and it was evident that there was insufficient mortar to properly fill the voids.

Voids in sand=8ft.×40.115÷100=3.21 c. ft.

Voids in stone=20×48.138÷100=9.63 c. ft.

Mortar—8 sand+4 cement—3.21 voids=8.79 c. ft.

Concrete—20 stone+8.79 mortar—9.63 voids=19.16 c. ft.

This test was made at the contractor's request to convince him that the finer the gauge of stone the less concrete it made.

Test 6—Fine Concrete as Specified.

14 c. ft. stone (basalt), screened through a ring 1¼in. diameter caught on ¼in. mesh; 6 sand; 4 cement. 17 gallons of water were used in mixing concrete. Concrete block measured 4.51ft. x 3.02ft. x 1.134in.=15.44 c. ft.

Voids in sand=6×40.115÷100=2.407 c. ft.

Voids in stone=14×48.138÷100=6.74 c. ft.

Mortar—6 sand+4 cement—2.41 voids=7.59 c. ft.

Concrete—14 stone+7.59 mortar—6.74 voids=14.85 c. ft.