This shows that the mortar does not fill the voids in the stone as completely as the water, some .59 c. ft. out of 6.74 c. ft. not being filled, i.e., 8.7 per cent. will be air spaces.

On the question of waterproofing coatings, the authors quote Wig and Bates as regarding 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 some reaction takes place, this class is worthless."

The well-known Sylvester process for repelling moisture from external walls, described in Baker's Masonry Construction, as used on the surface of the Crotin Reservoir, N.Y., in 1863, would seem not to merit the condemnation expressed by Wig and Bates. I have found this process give satisfactory results as applied to a brick dwelling. The method was slightly modified, thus: The soap ($\frac{3}{4}$ pound) was carefully shredded into a pint of methylated spirit, and was dissolved by warming the mixture over a flame; the solution was then poured into one gallon of boiling water, and the mixture applied at once with a flat brush. This was allowed to dry for a few hours, and the alum wash, mixed in the proportions of half a pound of alum to four gallons of water, was then applied. It was found that the soap solution was very easy of application, whereas the application of alum solution required much more exertion, showing that the alum was combining with the previous coating of soap. Over brick two coats of each mixture was applied, and over the lime mortar joints four coats. This particular job was done 15 years ago, and the walls treated have been satisfactory since. The action which takes place is the formation in the superficial interstices of the brick or mortar of aluminium stearate.

A soap and alum mixture, in various proportions, is sometimes used to make what is called "waterproof mortar." The Sylvester process mixture, employed in New York Harbour by Major W. L. Marshall, was made by "taking one part cement and 2½ parts sand, and adding thereto ¾ of a pound of pulverised 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."

Mr. Orams: Permeability has always been a source of trouble, especially in elevated concrete storage tanks and reservoirs, and an investigation of these structures leads one to the same conclusion as the authors—that concrete can be made watertight by using good material and workmanship. A case in point: A number of storage tanks were built in Michigan with 1:2:4 mixture, and all had to be treated after completion on inside with rich cement plaster. In building another 300,000 gallon tank a mixture 1:1:2 was used. The additional expense was justified owing to the previous trouble. In this mixture 10 per cent. by volume of hydrated lime was used, and the whole was mixed by hand, and care taken to get an even mixture. After this tank was completed it was given three coats of plaster inside, mixed in the proportions: 1 part cement, 1½ part sand (average), ¼ part rough sand. First coat was ¼in. thick, 2nd coat was ⅛in. thick, 3rd coat was brush coat.

For the first week it sweated, and in one place it gathered and flowed, but evaporated before it was 3ft. below where it first appeared. No attempt was made to prevent sweating, only fill and re-fill in two days. After ten days all trace of sweating had disappeared. The conclusion arrived at is: The plaster is also an effective waterproofing aid, although how large a part of the good results obtained were due to the plaster and the 1:1:2 mixture is doubtful; but results secured by plastering other large tanks of 1:2:4 mixture would seem to indicate that the mixture was more important than the plaster.

The cement gun has been used quite successfully in waterproofing reinforced concrete structures in California. The partition wall dividing Twin Peaks reservoir has a height of 27 feet, and when first built it was found that there was considerable leakage, and it was decided to use the cement gun. A mixture of three parts graded sand to 1 cement was used, and to this was added a small quantity of hydrated lime. The concrete wall was kept wet before gunite was put on, and was kept very wet for several days after. The coating put on varied from ¼in. at top to ½in. at the bottom. When finished the reservoir was filled, and at the end of 24 hours a slight seepage appeared. This disappeared at the end of 48 hours, and the coating is apparently a success.

The Victorian Railways build a rather novel type of tank. It is an inverted frustum of a cone of reinforced concrete. These funnel-shaped structures are 25ft. 6in. dia. at the top, 8ft. 6in. dia. at the bottom, and 12ft. deep. The capacity is 20,000 gallons, and while it is an odd looking structure, it has the advantage of giving a maximum of water for the maximum head, and thereby materially reducing the weight of the structure.

The concrete in these structures is 5 to 1: 1 part cement, 2 parts blue stone screening (to pass through ¾in. ring), 3 parts blue metal toppings.

Concrete is a good wet mixture. After the forms are removed the inside surface of the tank is roughened, and a ¾in. thickness of cement rendering is put on. The mixture is a 2 to 1 cement mortar. These structures have proved to be watertight, and no doubt the good workmanship put in, and rigid inspection while building, has helped considerably to make the concrete impervious.

It is not clear why the authors removed the skin formed on the test blocks. In ordinary work when the fresh concrete is placed in the forms, the lime of the cement at and near the surface combines readily with carbon dioxide in the atmosphere, and there is formed on the surface a layer of lime carbonate (limestone), which is practically insoluble in water, and acts as a waterproofing, as well as a protection to the uncarbonated cement in the interior.

It is assumed by most writers that when concrete is deposited in water and excluded from air, there is sufficient carbon dioxide in the water to carbonate the lime at the surface, and the same result obtained as in air. If this assumption is correct, why does not the lime of the cement under the skin carbonate in a similar manner when exposed due to abrasion of the surface?

The fact that the lime of the cement does not carbonate when the cement is abraded is demonstrated in the marine concrete structures inspected by Wig and Ferguson, and the reason they give is: Cement hydrates over a period of months in the interior of the mass of concrete when not exposed to carbon dioxide, the lime which is freed as the cement ages is changing from the amorphous to the large crystalline form. On account of its relative slower rate of solution in water than amorphous lime, this crystalline form, which is an hydrate, does not react appreciably with the limited amount of CO_2 present. When sea water comes in contact with the lime in its crystalline form, the lime is dissolved, and passes into solution largely as calcium sulphate, $CaSO_4$, the magnesium salts of the sea water being precipitated as magnesium hydrate, Mg HO_2, which is practically insoluble. The dissolving of the uncarbonated lime will continue until the cement is completely disintegrated.

Now calcium sulphate, in the hydrated condition, is slightly soluble in water, the solubility reaching a maximum at 35 deg., when 1 part of the compound requires 432 parts of water for its solution. Magnesia hydroxide slowly absorbs $C.O_2$, forming the carbonate. Owing to this fact, and to the property it possesses of re-hydrating, magnesia that has been prepared by calcination at a low temperature can be employed as a cement. Thus, if calcined magnesite be made into paste with water, the mixture is found to harden after some hours, and to become as hard as Portland cement.

Now the question that arises is: Why does not the precipitated magnesium hydroxide form a hard crust over the abraded part of the surface, and act as a further protection to the concrete?

Wig and Ferguson wrote in their report on concrete structures: "It is an interesting fact that reinforced concrete is subject to most rapid attack in localities where plain concrete is but slowly affected, and when concrete itself is most rapidly disintegrating the corrosion of the reinforcement proceeds more slowly."

Mr. McEwin: I have listened with very great pleasure to the paper which has been read this evening, and I would like to add my thanks to those already expressed. I trust that we may have the pleasure later on of hearing of the further progress of these experiments. I have also been glad to hear the remarks of Mr. Bradfield, who has contributed valuable matter to the evening's proceedings. Simple methods of ascertaining voids in the stone and sand were suggested by Mr. Bradfield. It is probably a matter of astonishment to some that the percentage of voids should be so very great, and the problem is how to fill these voids. Microscopical examination of concrete will help to ascertain what the voids consist of, and whether they are globules of moisture or dry capillary pores filled with air or gases. I have not looked into the chemistry of the subject, but take it that certain gases may be formed during the setting of concrete. If this is so, is it possible to get rid of them altogether? This point seems to have an important bearing on the subject.

The engineer in designing concrete structures has always to remember that the cement is not merely a filler. The word "cement" is a continual reminder that the substance should not be used as a filler only, but as a cementing medium.

There is a great deal of significance in the experiments which show the 6:2:1 mixture as being more impervious than the richer sample. As regards consistency, a correspondent of the Concrete Institute has made an excellent concrete with a mixture of 4 parts of stone, ½ part sand, and ¼ part cement. This result was achieved by means of carefully proportioning the ingredients so as to secure a maximum density, or, in other words, a minimum of voids. By this means no cement was wasted in filling, but was used as an adherent only. By taking greater trouble in grading the aggregate much expense could be saved, strength would be gained, and the attaining of a greater density in the concrete would make it more impermeable to water.

Concrete set under pressure develops physical properties that are very much superior to those of concrete set in the ordinary way. It is probable that it is more impervious to water also, and it would be worth while to experiment with it with a view to settling this point.

We are very much indebted to the gentlemen who have brought the very interesting results of their experiments before us.

MR. MILLAR: Thomson states: "Permeability is less as proportion of cement is increased." It has been found recently that the gain secured by adding cement becomes rapidly less after the ratio by weight of cement to aggregate exceeds 0.11.

It has also been found that, if the concrete is carefully stored for four or five weeks, the age does not affect the permeability. This has been deduced from experiments on specimens up to a year old.

There is some doubt as to the effect of thickness of specimens, but recent tests seem to indicate that the flow of water is independent of the thickness.

Proper grading of materials improves matters. Flow decreases as the density is increased. By grading to secure maximum density, it has been found possible to make a practically watertight concrete of 1 to 9, provided the pressure does not exceed 40 lbs. per square inch. To secure such results requires great care and keen supervision in mixing, determination of correct consistency, in moulding and drying out of specimens.

The use of the proper amount of water necessary to produce a medium consistency is most important in securing an impervious concrete. Weaker mixes, like 1 to 9, require special attention here. Too little water makes moulding difficult, and compact concrete is not secured. It has been established experimentally that a slight excess of water does not greatly affect rich mixes in regard to impermeability, but with the like of a 1 to 9 mix the flow is greatly increased by using even a slight excess of water.

Time of mixing does not seem to affect the richer mixtures, but with the weaker mixes experiments show that mixing for a longer period than is usual in practice helps, more so in the cases where wet sand is used.

In regard to the treatment between moulding and testing, the weaker mixes should be kept damp for not less than four weeks, while the richer mixes should be treated for not less than two weeks.

The President said that the permeability of concrete was a question of the very greatest interest to engineers at the present time, because of the trouble that was being experienced universally with regard to the rusting of reinforcement in marine works, with consequent cracking and spalling off of the concrete.

Several of the speakers to-night had referred to the recent investigation by the two American engineers, Messrs. Wig and Ferguson, and during which it appeared they inspected practically all of the more important marine concrete structures in America. They seem to have made out a very clear case that the rusting of the reinforcing material was due to the accumulation of salts in the pores of the concrete above the water line, by capillarity and evaporation, and the absorption by the concrete of air carrying very minute particles of sea water. It was, of course, generally known that chlorine and oxygen together formed a very active corroding agent, but what has not been generally appreciated was the fact that the salt air could permeate concrete to anything like the depth it apparently does. The investigators above referred to seem to show clearly that the trouble is not due to the several causes discussed in various directions during the last ten years, such as electrolysis, shattering by driving, and the use of salt water in mixing. The instance they quote of the beacons in a large river emptying into the Atlantic Ocean provided a most unique opportunity for, and evidence in support of, their contention, those in the upper reaches being unimpaired, those nearer the salt water partly damaged, and those in the salt water badly corroded.

The fact that cracking occurs only high up on the piles, and invariably above high water mark, is another very tangible reason for their conclusion.

The authors' paper comes at a most opportune time, and I do hope that, as suggested by several speakers to-night, they will carry their experiments further, and that we in this Association may have the benefit of a description of such when they are complete.

The C.S.R. Co. have, in common with other concerns, been large users of ferro-concrete piles, and lately evidence has accumulated to show that, when many of the piles were made, the danger from salt-laden air was not clearly foreseen. We are at the present time about to repair a number of piles which have cracked above water, and it is proposed to strip the reinforcement, clean it thoroughly, and replace it with most carefully-mixed concrete, not too wet and not too dry, and to increase the covering of the concrete outside the rods by perhaps 100 per cent.

Although there seems to be a fairly general opinion that waterproofing compounds have not been effective, there appears to be a leaning in many other directions in favour of the use of such. I have no doubt that in the course of time this point will be more clearly demonstrated.

It has been an extremely interesting paper and discussion, and I think the authors will acknowledge from the way in which their paper has been received that there is little more that I can add to emphasise the fact that it has been very keenly appreciated. I have pleasure in conveying to them the vote of thanks which has been moved.

Mr. Smart, in reply: The discussion which has arisen on this paper is very gratifying. When the Hon. Secretary approached me, I must confess I was diffident, because the work which we had commenced was hardly in a condition in which we felt justified in bringing it before this Association. But, nevertheless, it has given us an opportunity of getting expressions of opinion which will be of service to us in our future experiments. Coming to some of the points which have been raised: Proper workmanship in mixing concrete is certainly of great value, and it would appear to be worth while to take every step necessary to secure this object. The possibility of completely filling the voids when good work is carried out was referred to by Mr. Bradfield. It occurs to me that, to some extent, the shrinkage which he observed may have been due to the change in volume of the cement during setting. Chemical changes which take place may account for that percentage of difference in voids to which Mr. Bradfield referred. This statement is made with some reserve, and I hope to look further into the matter at some future time, and carry out some tests. Whilst on the question of workmanship, I want to emphasise the importance of the grading of materials. In this connection one may remark that very little is heard, as a rule, about the proportioning curve which has been referred to some time ago. I have started a series of tests for the purpose of determining what sort of grading curve is most suitable to obtain the maximum strength with a concrete composed of crushed blue metal and gravel. By proportioning these according to Taylor and Thomson's curve a very thin mix was obtained, which did not make a good looking concrete, but when we came to test these blocks better results were found than with concrete from other mixtures.

With regard to permeability, a noteworthy feature is the value of the surface skin which forms on top of the moulds. The formation of this skin may be due to the fact that in the process of setting a certain proportion of the cement goes into solution in water, forming a colloidal solution, which dries on the surface as a skin of hydrated silicate of lime. This skin undoubtedly prevents the flow of water through the concrete, and it appears likely something may be learned by a study of its formation. If we removed the very finest particles from a cement, it is possible that we should find that they set extremely rapidly under conditions which favour the formation of a colloidal silicate. This idea is one which rather appeals to me as likely to be worthy of further research. With regard to the point raised as to the taking up as water flows through concretes, there is no doubt that in the case of concrete which has been subjected to water pressure for a considerable time the flow becomes less and less. I do not think it would be different if the test blocks were allowed to dry out intermittently. The process is most probably not due to carbonation, but to the action of water on the cement causing the formation of a colloidal silicate, which chokes the pores of the concrete and renders it impermeable. Tests show that increased thickness makes for a diminished flow. Thus in 3:2:1 mixtures, one inch blocks show 8 times as much as two inch blocks.

Referring once more to the question of good workmanship, in actual practice a great deal depends on connecting one day's work up with the next, and this is a point which should call for the attention of engineers. Where a fairly wet mixture has been used, and it is found that the finer material floats on the surface, a large amount of this should be removed before the application of the next layer. There is no doubt that hydrate of lime may be regarded as an addition which has waterproofing properties. Since this, and also other waterproofing materials, find buyers, it must be considered as evidence that they have some practical value. From the facts available, however, I think that the use of hydrate of lime will lead to a weakening of the structure. This matter will receive our attention later on. If only a filler is required, then it is possible that a convenient material to use would be blue metal dust.

With regard to corrosion due to the action of sea water, I am inclined to think that piles crack above sea water because of the presence of oxygen. Some means should be devised to prevent the free circulation of air round the piles. For instance, if the piles could be treated with a linseed oil composition which would form a skin over the whole, the free access of air to the iron could probably be prevented.