This paper has been prepared more with a view to suggesting points for discussion and comment than as a formal treatise on the subject. Its preparation has, of necessity, been hurried, and no doubt there are many very important points in connection with cement concrete construction that it will not treat of at all, my aim at present being to promote informal and social meetings among our members as much as possible rather than the presentation of ambitious papers.

From the title I have chosen, it will be gathered that I do not propose that the discussion should be confined to Portland cement concrete, though, as probably 95 per cent. of all the concrete used here is of that class I shall give only a passing notice of the cheaper types of concrete.

In my opinion, the most important ingredient in cement concrete is the sand, and not, as is generally assumed, the cement. My experience is, that if the engineer in charge have sufficient skill and patience to investigate the treatment best suited to the brand of cement supplied him, he could get good results with almost any brand of Portland cement, at any rate with any which I have ever been offered during more than 20 years continuous work. I do not, for one moment, mean to infer that all cements are alike good, or that the pains taken by engineers to keep the cement supply up to the highest standard for quality should be in any way relaxed, though I do think that, in many cases in these States, engineers most extravagantly use only the best and most expensive quality cements, where a very much cheaper article would be amply sufficient.

On the question of sand, however, we are met with an altogether different state of affairs. With a well worn and rounded sand, no matter how clean it may be washed, from all impurities, and almost no matter how rich the mortar is made, you cannot get strong work. It is therefore of the greatest importance to procure sharp sand if the mortar is to be good. As to the proportions of sand to be used to cement, this will depend, to some extent, on the sand itself. It is commonly thought that a sharp sand is much more hungry than a fine one, that is to say, that it will take a larger proportion of cement to fill interstices; this view is not however, entirely true. An investigation of the mathemati-
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Cal facts will show that the proportion of spaces or voids in any sand of uniform size is entirely independent of what the grade of that size may be. To give a clear idea of what I mean, let us suppose that every particle of sand is a sphere, and every sphere is an inch in diameter, then the amount of voids will be exactly .5236 cubic inches per cubic inch of space, and if, instead of the cubic inch, you use any other unit, foot, or decimetre, the measurement of voids will be exactly the same in feet or decimetres. So by this arithmetical means, without troubling to put an algebraic equation on the blackboard, you will see that the ratio of voids to the bulk of sand does not necessarily vary with variations in the size of the grains. The result of an actual measurement of three sands, which I recently made, was as follows:

Coarse sand, supplied by the Frankston Sand Pits Company—(Sample herewith) voids, 39.75 per cent. Fine sand—(Unscreened) voids, 39.5 per cent. Mixture of coarse and fine sand, taken from Port Melbourne Beach—Voids, 38.75 per cent.

Obviously, the mixture of coarse and fine gives a smaller proportion of voids than the uniform sized sand.

These measurements were all made by accurately measuring the proportion of the water which the sand displaced.

Judging from these, the best cement proportion would be between 2½ parts sand to one (1) cement, and 3 parts sand to one (1) cement, probably about the former. With poorer proportions, it will be obvious that there will be a larger number of voids formed in the concrete, which will consequently be porous, and if not proportionately weaker on this account, will certainly be very much inferior for use with impure or sea water; the most scientific investigators now attributing to this cause (poverty of cement) most of the failures of Portland cement concrete in sea-walls and in sewers.

Personally, I always prefer a coarse sand to a fine, though I have seen many excellent results got with very fine sand indeed, and I would require a considerable proportion of fine sand in mortar for marine or sewerage work.

Probably the preference to coarse sand is due to the fact that from the circumstances of its formation, the coarse sand is more likely to be sharp and sound. This point of soundness of the sand is one which I think is generally overlooked. The more nearly the sand approaches to pure quartzite the sounder do we count it. Where any large proportion of other material, e.g., granitic detritus, ferspars, micas, and ironstone occurs, the sand will be found to make a mortar of less strength, though externally it may present an even harder surface. The reason for this is not very obvious. Something no doubt is due to the adhesion of the cement to the
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surface of the sand, but a great deal more is, I think, due to the actual strength of the particles of the sand themselves. The rock, from which the sand has been broken down in the process of breaking and attrition, will have been fractured throughout, and every small particle will contain minute fractures, hardly discernible under the most powerful microscope, but nevertheless present to a sufficient extent to destroy the strength of any substance built up with such material. Obviously, the more brittle the quartzite from which the sand is formed, the less will the small particles be damaged by such fracture. This is one of the reasons why sharper sands give very much stronger concrete. There are other reasons, however, and more obvious. The most familiarly instanced of these reasons is that the cement forms a network of pure cement inside the concrete, and binds the sand together much as the roots of a tree growing in gravel will hold the gravel, or as fish will be caught in a net, and the sharper the sand the more angles are presented for the grip of the cement strings. No doubt, where there is a larger proportion of cement than is sufficient to just fill the voids in the sand, this is the principal factor which determines the strength of the concrete. But we find that sharp sands in very much poorer mortars also give a far better result than rounded sands, though in these poor mortars the principal factor of strength is the adhesion of the cement to the surface of the sand. My explanation of this phenomenon is that the sharp sand presents a large number of points for the formation of the crystals. In the science of crystallography it is a well-known fact that in a supersaturated solution the crystals will form rapidly round sharp points, and much more slowly on rounded surfaces. Consequently, mortars made with sharp sand are found to harden much sooner than similar mortars made with a rounder sand. And for a somewhat similar reason, namely, that rapid crystallisation generally produces an altogether different arrangement of crystals than slow crystallisation, it is probable that the mortar made with rounded sand will never reach as great a strength at later dates, as that made with sharper sand, but that the initial difference in favour of the sharp sand will be maintained during the whole life of the structure.

It is needless to emphasise the necessity for obtaining sand free from foreign matter. Should there be mineral impurities, such as sulphates or arsenites, present, it is better not to use the sand at all, unless the circumstances would justify the expense of roasting it. But most impurities can be sufficiently removed by a thorough washing. In washing sand, the appliance should be so designed that the water will travel upwards through the sand, since the objectionable impurities
are almost invariably lighter than sand, consequently, unless the water boils up through the sand, the impurities cannot be separated from it.

The readiest sand washer is a flat box, with waterpipes introduced into the bottom of the box at various points. The sand is thrown into this box and the water allowed to rise through the sand and flow away over a side of the box. It is usual to arrange a second compartment through which the water passes after it has left the box, as otherwise a considerable portion of the finer sand will be lost. The sand caught in this second compartment, is, of course, thrown back and washed with the rest of the sand in the washing box. The general result is that washing sand costs rather more than 1s. a yard, and loses from 5 per cent. to 10 per cent. of its bulk.

PORTLAND CEMENT.

A few words on Portland Cement would, perhaps, not be out of place. I therefore read you a portion of the specification adopted by the experts for the new Sydney Harbour Bridge, as being one of the most satisfactory cement specifications used in any of these States.* I have omitted a portion about gauging and sampling cement, as being too local in its character for general use.

I would call attention to the fact also that this specification is for slow-setting cement. It specifies the cement “must set in a damp atmosphere in from 1½ to 12 hours.” Of course so slow-setting a cement would not be suitable for all classes of work, and on this subject of the time of cement setting, I will have something to say further on, when dealing with the question of water.

This specification will be observed to be one of a highly technical character, and such, that to give full effect to, would require the assistance of a fully equipped laboratory. For every day purposes, I would make some omissions to this specification, to bring it more in touch with the practical requirements and facilities at the disposal of resident engineers engaged on works in the country.

The clauses dealing with fineness, setting, test pats, and strength when neat, would of course stand, with the exception of the Deval Hot Bath, which can be excised; and I would alter the sand testing, specifying the use of sand taken from the works absolutely untreated by sieving or drying. I may mention that with good cement and sand this stipulation would not mean any decrease in the test requirements; for instance, I have with the coarse Frankston sand (mentioned above) got much better results than these (up to 300 lbs. at 7 days), and when mixed 2½ to 1 by volume, as used in the
work, I have obtained up to 350 lbs. at 7 days with this sand, and Colonial Cement (Emu Brand).

Where the cement is being purchased by the contractor, I consider the sand test used in this manner is the proper one, as it tests the whole of the material. I would, of course, delete a clause like the following—Notwithstanding that the cement may have set within the limit of time specified above, such cement may be rejected, if the nature of the work on which it is proposed to be used requires a cement setting either slower or faster, as the case may be—since I think specifications should not be written like weather prophecies, but should, before every consideration, be clear and definite. Ample powers are always retained by the engineer to deal with unforeseen contingencies.

If a cheaper class of cement is desirable, rather than have a cement setting more quickly I would adopt the old-fashioned style of accepting a coarsely-ground cement with a lower breaking strain, as being a safer material for general concrete work than the ordinary finely-ground and consequently quick-setting cement. As to the broken stone or gravel, which is always used in cement concrete, what has been said above about sand, to a great extent applies to the larger materials. Logically it would seem that there is no difference in the two beyond the difference of size, but there undoubtedly is, and if we investigate this question more closely than our limited time this evening will allow, we will find that this is one of those cases where Nature gives a hint of her limitations, showing that facts are different from the dreamings of philosophers and scientists. Though there is nothing in this investigation, directly proving that the often assumed statement that there is no limit to the infinitely small, is false, it yet shows how the properties of matter, as existing on this globe, fix a practical limit on the size of the particles of matter in any aggregate. Several investigators give the strength of concrete made with gravel as being from 80 to 85 per cent. of similar concrete made with local stone in substitution of the gravel.

The very potent question arises as to what the ordinary proportions of concrete should be. Taking as a basis that good sand, to give the best results, requires 40 per cent. of its volume of cement, and on a similar basis, that the broken stone will require 40 per cent. of its volume of mortar, it will be seen that a concrete made of such broken stone, sand and cement, would consist of 6½ parts broken stone, 2½ parts sand, 1 part cement. In hand-broken stone, however, the voids are more than 40 per cent., and it will be found in most cases, the best proportions are about 5½, 2½ and 1 respectively. Machine-broken metal will give a larger proportion of metal, but the concrete with machine-broken metal is
never so strong, from the fact that the metal is considerably damaged by the crushing, and this for a similar reason to that explained above, in connection with quartz sand, viz.: that the stone is full of small minute fissures, and is seriously damaged in texture. Of course, the more flinty varieties of stone will not suffer so much in this way from going through the stone crusher as the bluestones, and metamorphic sand stones.

It would no doubt be necessary, if the very best results were desired, to increase the amount of cement from the amount thus theoretically arrived at, since a consideration of the surface to be covered is a factor where the stone material is introduced into the aggregate. A good proportion for hand-broken metal is 5, 2, and 1; this material will be found to give, with ordinary cements, a compressive strength of about 30 cwt. to the square inch at 4 or 5 weeks of age.

THE QUESTION OF THE ADDITION OF WATER.

A considerable amount of difference of opinion exists as to whether cement concrete should be made with a superabundance of water, or with only a small percentage (1 or 2) above what is actually required theoretically to give the best results. Roughly speaking, about 10 per cent. by weight of water, i.e., 25 per cent. by volume, say, 40 gallons per cubic yard, will give the strongest concrete; but two very important considerations operate in favour of adding a slightly larger percentage of water. These are, first, that with the dry cement it is necessary to ram the concrete well, after it has been deposited in its place. Unless a very slow setting cement is used, there is grave danger of this ramming damaging the concrete severely, and rendering it unsafe. This danger is the more appreciable the hotter the temperature at the time the concrete is mixed; while a slight increase of water so as to make the aggregate so plastic that it will, with light tapping from spades instead of rammers, fall into its proper shape in the work, not only prevents this danger of breaking the cement during setting, but also makes the cement much slower setting. And, second, though it is a well-known fact that at early dates concrete made in this way is considerably weaker than concrete made by the dry method, and rammed, assuming of course, that in the latter case a sufficiently slow-setting cement has been used, yet the fact is lost sight of that such concrete on maturing, invariably shrinks, and shows cracks throughout the whole mass, thus reducing the strength to something indefinitely weak. A familiar instance of how this occurs is that in platforms and footpaths laid down in cement concrete unless a dry joint is left at a distance of not more than 8 feet or 10 feet, the con-
crete will itself crack at these distances. When made wet the shrinkage observed in this way will be so much less that if it cracks the fissures will be at least twice as far apart, and if the concrete is sufficiently strong and more than 6 inches deep, there will be no cracking at all.

On the Manchester Waterworks, Thirlmere Scheme, when examined continuously for months after construction, I did not find more than one crack in every 3 miles, though the sections were laid in lengths of 100 feet. There the thickness of the concrete in the floor was generally 6 inches, in the sides 9 inches, and in the arch 15 inches. The concrete was 5 to 1, and put in in the condition of a slurry. The mould boards were of Yellow Pine and so well planed there was no necessity for plastering.

There are several other questions in connection with concrete which I wish to add, but, owing to the lateness of the evening I would propose, with your permission, to postpone the discussion till some other evening later on, thus leaving time at present for a discussion on some of the points I have so far mentioned.

APPENDIX.

Extract from specification for North Shore Bridge, Sydney, N.S.W.

CEMENT.

The cement must be the best Portland cement, of approved brand, delivered in thoroughly sound condition, fit for immediate use, packed in strongly-made casks. Any damage to the packing, or any symptoms of staleness or of moisture having effected the cement, such as caking or partial setting, will cause the rejection of the casks in which such damage or symptoms are found.

Weight.—Each cask shall contain not less than 374 lb. weight of cement, exclusive of packing, otherwise the deficiency must be made up in quantity. The specific gravity to be not less than 3.00.

Fineness.—The cement must be ground so fine that the residue on the sieve, of 14,400 meshes per square inch, without rubbing, shall not exceed 15 per cent., and on a sieve of 32,400 meshes, not more than 30 per cent.

Hydraulicity.—The cement, when gauged with water to a stiff paste, must set in a damp atmosphere in from one and a half to twelve hours. Neat cement of the consistency abovementioned will be made into pats, kept in moist air until set, and then placed in water at a temperature of between 65 degrees and 75 degrees F., and also in Deval's hot bath at a temperature of 180 degrees F. These test pats
will be examined from day to day, and should they show symptoms of blowing, or any alteration or variation in form or volume, or imperfect setting capacity, the whole parcel from which the cement was taken may be rejected.

Notwithstanding that the cement may have set within the limit of time specified above, such cement may be rejected, if the nature of the work on which it is proposed to be used, requires a cement setting either slower or faster, as the case may be.

Tensile Strength.—For this test the cement will be gauged with three times its weight of standard sand (viz., sand from Nepean River, washed, dried and sifted through a sieve of 400, and retained upon one of 900 meshes to the square inch), mixed with clean water, and made into briquettes formed in moulds of one inch sectional area at the smallest part. Such briquettes to be kept thoroughly damp, and put into water twenty-four hours after they have been made, and remain in water at a temperature of between 65 degrees and 75 degrees F. until their tensile strength is tested. These briquettes must bear a tensile stress of not less than 130 lb. per square inch seven days after gauging, and 200 lb. per square inch twenty-eight days after gauging. Cement when tested neat under the same conditions must bear a tensile stress of not less than 350 lb. per square inch three days after gauging, 450 lb. seven days after gauging, and 550 lb. twenty-eight days after gauging. Briquettes shall also, after being kept thoroughly damp for twenty-four hours, be kept in water at a temperature of 180 degrees F. for seven days, when the tensile strength must be equal to that specified for twenty-eight days at normal temperature. The tensile strength will be ascertained with the load increasing at the rate of 200 lb. per minute, and the average breaking weight of six briquettes will be taken for each test.

Free Lime.—Any cement which absorbs in proportion more than (2) milligrams of carbonic acid to three (3) grammes of cement, shall be taken as containing more than the permissible quantity of free lime.

Should the sample fail in any or all of these tests, or not show a proper progressive increase in strength with age of briquette, then the whole parcel from which the sample was taken will be rejected, and must be at once removed from the Bridge site, and all expenses and loss, in freight, storing, handling and removing such rejected cement must be borne by the tenderer.
ADDITIONAL NOTES ON
ORDINARY CEMENT CONCRETE CONSTRUCTION.

Read by the President, J. T. Noble Anderson, 7th May, 1902.

MANIPULATION.

On the question of the best method of mixing the concrete and depositing it in place, there are very widely different views. On one point, however, to get the best result, sound practice admits of no variation, viz., that the material should be mixed as thoroughly as possible before being wetted, and after wetting, the only object of further turning the material is to get the water as evenly and uniformly distributed throughout the mass as possible. There are, however, very wide differences of practice on such points, as to whether the sand should not be damped before being mixed with the cement, whether all the ingredients should be mixed simultaneously, whether the cement after being mixed and wetted should be consolidated by being tipped from a specified height and merely levelled over in situ, and gently deposited and spread in thin layers and then well rammed. Good concrete can be got by all these methods, if proper precautions are taken, but what I am going to describe will give the manipulation, which, with medium setting cement, seems to me to offer the least danger.

All gauge boxes should be rectangular in section, open at top and bottom, and as deep as is practicable.

The concrete should be gauged by placing the broken stone in a gauge box placed direct on the mixing board, which should be carefully levelled and be sufficiently long to admit of all the operations of gauging, mixing, wetting and filling into barrows to go entirely on it. The sand, or sand and gravel, gauge box should be laid resting on the sides of the broken stone gauge box, and be designed of such dimensions that it will practically strike the surface of the broken stone, and so enable it to be truly gauged with little trouble. The cement should be placed over the sand and the whole mass mixed by throwing the heavy material up from the sides on top of the cement, by having men placed in rows on each side, each one turning the heap up from below, and throwing it over to his neighbour; the incorporation will go uniformly. After the third mixing, the watering takes place, a break of say five feet being left in the row of mixers, then two more mixers will turn the material over once to mingle the water
through it, and it will be filled and wheeled by the barrow men to place. Eight (8) mixers, three (3) gaugers, and one waterer should gauge and mix from six to seven yards of material in the hour in this manner. Consequently it will be seen that this part of the operation alone will cost about 2s. per cubic yard.

When it is desirable that more than this rate of work should be maintained, it will be far preferable to have a simple mechanical mixer, since it is awkward and perhaps somewhat difficult to arrange for good uniform results with a larger gauging than about 1 1/2 cubic yards per gauging.

In my work I have employed a very simple type of mechanical mixer with most successful results. This consisted of a semicircular trough of No. 10 or No. 12 steel, closed at one end, firmly stiffened by angle iron hoops bent to fit the outer circumference, and braced across the diameter by stout angle iron, carrying brackets. In these brackets a shaft is placed concentric with the semicircular trough. A number of dasher blades were attached to this shaft by collars, and flats were cut on the shaft spirally, so that these blades would be arranged along a helix to give two revolutions in the length of the trough, and about 12 blades in all. For mixing about 10 yards an hour, a convenient size mixer is 2 feet 3 inches in diameter, and 16 feet long. Such a mixer would be driven by a small portable engine. A 4 inch belt would suffice to connect to shaft, and as the mixer can be placed on wheels the apparatus can be moved from place to place.

It is desirable that the trough should be placed about 2 feet from the ground with a slight inclination towards the discharge end, though this inclination is not necessary, as the spiral direction of the blades will work the concrete from one end to the other. The concrete gauging board would be placed on the feeding end, at an elevation of about 3 feet, so that the material can be shovelled into the mixer by one single man. By having two gauge boards, one on each side, four or five men gauging on one side, and one or two shovelling into the mixer on the other side, the concreting work can be absolutely continuous. The water for the concrete is manipulated by a perforated pipe, placed at a convenient height, say 2 feet above the top of the trough, and regulated by one of the men. To obtain good results it is necessary that there should be a fair pressure, at least 10lbs. per square inch, on this pipe, and that the perforations should be very small, so that the water will fall in the shape of spray. Incidentally, I may mention that the difficulty of getting good water pressure is one of the most troublesome problems in carrying out concrete work on a small scale, or where the concrete, as in the case of water channels, is spread over a large area of country.
Generally speaking, the concrete if mixed in a proper mechanical mixer, is not only cheaper, but considerably more reliable, and the very best results can be obtained with the proportions I have given above when mechanically mixed. That is to say, 5, 2, and 1.

To return to the question of the general manipulation of concrete, the most important point to be observed is that the concrete be deposited in place as soon as possible after being wetted. Tipping from a short distance, up to 10 feet or 12 feet, from barrels, will thoroughly consolidate the material, and the view held by some engineers that this tends to separate the broken stone from the mortar is not borne out by fact. It is, however, most undesirable to tip down a chute, as in this case there is a distinct tendency for separation in the aggregate.

When deposited in place, if the concrete is intended to be in mass, there can be no objection to the use of a large proportion of sound displacers. The more irregularly shaped these displacers are, provided they can be properly bedded in the concrete, the more reliable will be the resultant masonry. Care should be taken that all the displacer stones are properly cleaned and wetted before being put in place, and it is usual to specify a minimum width between the displacers, sufficient to prevent any cavities occurring in the work.

I have mentioned above that the quantity of water to be added should be at least 40 gallons per cubic yard of mortar in the concrete. A good rough rule is to ensure that every broken stone in the aggregate shall be sufficiently wetted to carry cement material with it, when taken in the fingers, out of the work. If by any chance the stones should be so dry that, when taken from the aggregate they do not show a coating of cement and sand, it will at once be known that the concrete is going in far too dry for good results.

In general practice it will be found that the stones absorb a good deal of water. In the case of concrete, where bricks are substituted for stones (since an ordinary hand-made brick absorbs 15 per cent. of its own weight of water), it is important that the bricks should be steeped for 24 hours before being mixed with the concrete, and in this case the mortar should be gauged and mixed dry in itself before being mixed with the bricks, as otherwise the wettings of the bricks will interfere with the proper mixing of the mortar. When wetted bricks, or an impervious stone is being used, it will be found that from 30 to 35 gallons of water will be amply sufficient for a yard of material measured in the finished work. In the case of ordinary materials the average is about 40 gallons, and owing to the necessity for wetting laggings and so on, it is always well to provide for a margin
of 40 per cent. to 50 per cent. of water. Water should also be provided for wetting the concrete for two to five days after its construction, according to the time of year; two days being ample in winter, but five days being required in really hot weather.

A usual way of wetting is to cover the concrete with wetted bags and sprinkle these bags when starting in the morning, and before knocking off in the evening.

Structures in cement concrete should be designed so as to avoid sharp angles and square arrises. A little pains will enable the centres to be designed so as to obtain rounded or bevelled edges, and the small extra cost will be more than compensated by the ease with which centres can be drawn and laggings removed when there are no sharp corners to be pinched off or otherwise damaged. It is not, however, on account of appearance and the preservation of the exterior from the necessity for plastering over that this feature, rounded corners, are desirable, but from the fact that in any crystalline structure a sharp edge is a source of danger. I need not elaborate this point as I am sure you are all aware of it from your previous experience with cast-iron work.

GENERAL REMARKS.

It will be remembered that in the early part of this paper I spoke of using an excess of water in the concrete, and stated that one reason why I favoured the wet method of mixing and working concrete was due to the greater danger of shrinkage in the mass of concrete made on the dry method. Where concrete is used in great masses, as in large masonry dams, or breakwaters and piers, it is hardly possible to devise any method even with the wettest aggregates whereby this fracturing from shrinkage or variations of size can be satisfactorily eliminated. The usual method is to build up the structure in huge monoliths of say 20 feet side, or say thirty cubic yards capacity; and when these have set in place grout in the spaces between them, making what is practically a masonry structure built up of huge concrete blocks in place of stones.

I am not aware of any exhaustive experiments which authentically demonstrate what the variations in form of ordinary concretes is due to. Of course it is well known that concretes have a definite and regular coefficient of expansion with heat; the most recent experiments give this for seven to one concrete, such as I have recommended above, made of the best materials as 0.000,005.5 per degree Fahr. Apart from this regularly and well known variation in bulk there is another important variation, which so far as I know, is indeterminate—namely, the change which occurs in setting. I have noticed a shrinkage from this cause as
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generally less than .000,05 though occasionally it has been more. On this account a limit must be set on the speed with which concrete structures can be erected. It is usual in the case of concrete weirs to stipulate that the concrete must be deposited in continuous horizontal layers throughout, of not more than some specified thickness (usually less than eighteen inches) and this ensures that the mass will not be so rapidly erected so as to cause trouble from initial shrinkage, which generally reaches its maximum before the concrete is more than 48 hours old. I have made many experiments on this question, but the most satisfactory was at the Laanecoorie Weir, on the Loddon River. There, as the structure was carried out in the manner I have just mentioned, the shrinkage caused no trouble, but the diurnal variations were considerable, and so much so as to cause a misunderstanding between myself and the Chief Inspector of Works, who refused to believe that such variations were possible. At a height of 37 feet above the foundation, the diurnal difference observed, from a reliable B.M., on a part of the structure kept cool with water from our tanks, and the centre of the structure where the sun heat played on the face of the dam, was about .0075 feet, or more than one-twelfth of an inch, and the maximum difference exceeded .01 feet or one-eighth of an inch. So far as I know, that structure, though some 340 feet long and 50 feet high by 47 feet wide, and put in place practically as one huge monolith, has not shown any fissures such as might be expected, and this in spite of the fact that absolutely no displacers were permitted in its construction. The concrete was mixed in accordance with what I have called the best method, and the proportions were 1 cement, 2 sand, and 4 of broken stones and gravel. Owing to the methods adopted in gauging, however, the proportion approximated to those I have given above, namely, 1, 2, and 5. The broken stone was of a quartzite, and so was the sand and gravel, so an excellent concrete was obtained.

I made a considerable effort to obtain permission to put displacers in the aggregate, pointing out that the danger of shrinkage and fissuring would thereby be considerably reduced, and my representations were so far effective that the contractor was asked to state what remission of price he was prepared to accept. He refused any reasonable remission, contending that the only saving to him was a small saving in cement, which would be practically absorbed by the labour of properly placing the displacers. This point suggests the question of what is the actual saving in price due to using displacers. The first factor in this consideration is, of course, the proportion of the whole mass which the displacers occupy. I have made several experiments by means of the water displacement of displacers taken from actual
work, and find that with the class of displacers which are most usually provided, namely, spawls such as are readily handled and carted, weighing on the average between 30 and 40 lbs. each, it is practically impossible to obtain so much as 30 per cent. of displacers without making the spawls actually touch each other in the walls. Mr. Mansergh, Past President Inst. C.E., last year stated in a discussion published in the proceedings of that body, that in the Birmingham Water Works he aimed at getting a displacement of at least half of the whole mass of the masonry. To achieve any such result it would be necessary to adopt special precautions in the quarry, and to place the stones in the structure by means of cranes or other lifting and travelling mechanisms. Undoubtedly, apart from the economical aspect of the case, the best and safest practice demands the use of large and skilfully placed displacers in the mass. Some engineers have contended that it is practically impossible in large masonry dams to secure absolutely water-tight conditions in Portland cement construction, and consequently advocate the safe but very slow method of using hydraulic limes in such constructions. While I advocate strongly the use of these limes where they can be used with economy, I would point out that in many cases the delay in waiting on them maturing before utilising the structure entirely changes the economical balance against the cheaper article (lime). In this State there are several slightly hydraulic limes. I have found, however, that their use is but little understood by most masons and inspectors, and consequently they have fallen into disfavour owing to the marked variation in quality of the limes taken from the same district, and sometimes even from the same quarry. It is not sufficient to take such well-known precautions as to slightly slake the lime a day or two before using it, and to run it several hours before, but also to make frequent practical tests of each consignment several days before any of the consignment is to be put into the works. In many districts such as the Northern Mallee, including Mildura, this should certainly be done, and as the saving in cost of lime concrete as compared with Portland cement concrete is very considerable, the trouble will be amply repaid.

The above is a brief review of some of the broader practical points in connection with ordinary concrete construction. It must not, however, be taken as in any way exhaustive, since it has been put forward merely to bring out a discussion on a question of great interest and importance.
Discussion, 2nd July, 1902.

Mr. Gordon (by correspondence) said he agreed with Mr. Anderson when he says that there is a great extravagance prevalent in the country, in the use of very expensive Portland cement concrete, when often a much less expensive material could be used—and he thought even lime mortar in many cases. Using blocks in concrete when the latter is in a considerable mass effects a material saving. When the Bridgewater Weir was being built he suggested to the Engineer that blocks to the extent of one-third the bulk should be used. The contractor agreed to a deduction of 10 per cent. on the contract price, which was 60s. per cubic yard. The writer estimated the cost at contract prices to be as follows:—Two-thirds cubic yard concrete, 40s.; one-third cubic yard bluestone blocks, 5s.; equal 45s. per cubic yard, thus saving 15s. per cubic yard, of which the Trust benefited to the extent of 6s., and the contractor’s profits were increased by perhaps 3s. In 1872, Mr. E. Dobson used the following proportions in the lower wall of the E. Brywash at Malmesbury—1 cement, \( \frac{4}{3} \) sand, 4 metal, and 2 rubble blocks. The contract price was £1 16s. 10\frac{1}{4}d. per cubic yard. As to voids in the material for concrete, Mr. Anderson’s remarks on the second page of his paper, refer to the voids in the mortar of the concrete, not in the whole mass. It was evident that the voids in a cube composed of spheres, as Mr. Anderson assumed in the case of sand, will be the same whether the spheres be large or small, provided they are all of the same size; but if they are of different sizes they will not be the same. Neither is sharp sand composed of spheres, so that different samples may have a different proportion of voids. For this reason he thought that the only safe way to determine the proportions of the cementing material to the metal or gravel of the concrete is to measure the voids in the metal or ballast, by filling a cubical box (say of 1 yard) with it, and filling it up with water. The quantity of water it will take represents the aggregate of the voids to be filled by the mortar. A very little more should be used so that no two pieces of the metal should touch each other. He thought it is very important in mixing concrete for hydraulic works that are subject to pressure, and required to be watertight, that the cement and sand should first be mixed into mortar, because he thought there must always be a risk in dry mixing that the sand and cement grains may get separated by wind or water in the course of mixing. He always specifies that the mortar shall be made first, and then if there are two classes of material to be used, such as metal and gravel, that the finer shall be added first and the larger last, just after being washed.
and while still wet. Of course, the relative bulks of the sand and cement, separately, and mixed, must be ascertained after experiment, and after testing the mortar, not the neat cement. Thus the quantity of cement required for each cubic yard of ballast would be determined and measured accordingly. Some cement put in by Mr. E. Dobson at the East Bywash, Malmsbury, in 1872, was specified as 1 cement, 1\(\frac{1}{2}\) sand, and 4 of 3-inch metal. The finished work was to the gross measurement of the materials, as 100 to 126. At the same time and place, with lime concrete, of 1 lime, 2 sand, and 4\(\frac{3}{4}\) metal, the finished work to the bulk of raw material, was as 100 to 130. In both cases the voids in the metal were more than filled up. The first cost (actual cost), £1 14s. 2d.; the second, 14s. 1\(\frac{1}{4}\)d. per cubic yard. The cost of gauging, wheeling, mixing, and placing, was 2s. 6d. and 2s. 8d. per cubic yard, of the completed work respectively.

He proved by trial that 4 cubic feet of metal, 3 of gravel, 2 of sand, and 1 of cement, equals 10 cubic feet in all—measured when mixed, 6.33 cubic feet, the voids being thus 36.3 per cent.

Also, Taradale gravel, unscreened, had 28\(\frac{1}{2}\) per cent voids. Bluestone, “screenings and toppings,” mixed as delivered, had 50 per cent. voids. Bluestone, delivered separately, washed and mixed, 45\(\frac{1}{2}\) per cent. voids. Bluestone, two toppings and one of screenings, washed and mixed, 47 \(\frac{1}{5}\) per cent. voids. Washed gravel, screened, 1-inch and 2-inch, 59 per cent. One and a half sand and 1 cement lost in bulk; when mixed, 33 per cent. He thought that to get good watertight concrete the most important things are good mixing and placing, and the testing of the mortar, and not neat cement.

The Chairman (Mr. G. A. Turner): Mr. Higgins had brought forward a very important point in the comparison of hand-broken and machine-broken metal. There could be no doubt that hand-broken metal was better than machine-broken metal, but the cost might be a very important consideration. In examining machine-broken metal it could be seen that the sharp corners were broken off, and more or less rounded, and that must tend to decrease the strength of the concrete.

Prof. Kernot had intended drawing attention to the error on page 2 of Mr. Anderson’s paper re the space taken up by voids, to which Mr. Gordon had drawn attention. Otherwise what Mr. Anderson had said in his paper was very reasonable, and was based upon a large amount of valuable experience. With reference to the question which was started by Mr. Higgins about hand-broken and machine-broken metal, he was hoping to have found some information on the subject, but he had
not done so. He quoted some curious figures from a paper by Professor Warren, read before the Royal Society of N.S.W., on some experiments made by him, which showed that the strength of cement and concrete went up and down. It sometimes went up to a considerable height and then down again, and then, as time passed, it seemed to increase again. For example; there was one concrete which ran up to a maximum strength at 27 days, and then went steadily down until at 80 days it had lost about 20 per cent. of its strength; and there was a different preparation of the same materials which went up rapidly for 10 days, and then went down slowly until a little over 80 days, when the experiment terminated. All that he could say was that concrete was very curious stuff, and the more one studied it the less one knew about it.

Mr. Geo. Higgins said Mr. Anderson’s paper was very admirable indeed. He had brought forth a great many points for discussion, and he had said his object was to create discussion. There were a few points which Mr. Anderson had not dealt with, which he (Mr. Higgins) thought were especially worth while having some discussion upon. When this Institute visited the cement factory at Burnley, he was delighted to see the pains they took to secure uniformity. A cement was wanted that would always give the same result if possible. He was pleased to see that the process and method of mixing were conducted so as to conduce to this desirable result. Mr. Anderson dealt with the sand, and made a good many suggestions, but he did not give results of any experiments performed on crushed sand. In the neighbourhood of Melbourne we have no good coarse sand. There have been a few patches of it, but Melbourne was pretty devoid of sharp sand. He would like to know if any records have been kept of the results of experiments in mortars or concretes made with rounded sand, and with crushed sand. It seemed to be rather an important matter. In crushing you got a mixture of the coarser and finer particles of sand. Whether the sand would be damaged in crushing is another point, and experiments would probably show this.

Prof. Bernot said they had made a number of experiments, which showed that bluestone toppings acted very successfully, and had a decided advantage over the sand.

Mr. Higgins: In New South Wales he had seen concrete made with the ordinary Hawkesbury sandstone, and it was found that a certain class of the sandstone, if broken by hand, would yield enough sand to make the concrete. If broken small it gave almost too much sand. Of course that was a weak stone, and it could not be expected that stone such as that would give such good results as the basaltic stones here.
Prof. Kernot: Mr. Anderson has said very rightly, that it was not desirable to touch concrete until it had properly set. Experiments had also been made showing the effect of the different kinds of water used in making concrete. He had very early experiments in concrete to show the superiority of fresh water over salt water, but members were no doubt familiar with those experiments. In building a bridge we examined the material available, ascertained whether the stone would stand any pressure, and tried its hardness and durability. If the contractor could be got to say, "This block of concrete was made so many years ago, and I can guarantee to supply that kind of material," it did not matter how he got the result as long as the material would stand blows, such as from a pickaxe. Some day we might reach that stage where we could go by the finished product, when the contractor will have samples and will agree to supply material accordingly. Mr. Higgins has suggested that a number of experiments be made. If he would have the samples or cubes made he (Prof. Kernot) would have them tested.

The Chairman (Mr. G. A. Turner) bore out what Mr. Higgins said about Sydney sandstone. Pyrmont sandstone, when cut out fresh from the cliff, could be crushed with the fingers. He was, however, assured that it became very much stronger when exposed. He would like to know if any other members had experience on this point.

Mr. Hill said that in putting in some concrete recently, he had used the Frankston Sandpits Company sand, and had worked according to the proportions recommended by Mr. J. T. N. Anderson. He had to fight against the prejudice of the overseer and contractors. It was not rammed; it was simply thrown into the trench and flattened with the shovel. Failure was predicted; but a solid mass of concrete resulted. The effect has been that, in future, where he had specified five to one and ramming, he would leave that out and not ram it at all.

The Chairman (Mr. G. A. Turner) moved that further discussion be postponed until next meeting. The notes of the present discussion would be forwarded to Mr. J. T. Noble Anderson as early as possible.

Mr. J. T. N. Anderson, in reply:—It has given me very great satisfaction indeed to read this discussion. I feel that the paper hardly deserves so generous an appreciation as it has received. There are many points which I have treated on in a cursory and sketchy manner which deserved accurate and careful treatment. Foremost among these is the point which has been raised by Mr. Gordon, on the amount of the interstices in a space filled with spheres. The statement, as I made it, is merely put forward in a popular manner. The
minimum amount of interstices which could be obtained is considerably less than the amount I stated, that amount being the maximum space for interstices which can be obtained when all the spheres are touching, and, from my experiments, I think this may be taken as fairly accurately giving the mean result of all the conditions which would occur with loosely distributed materials of fairly uniform size. The results which Mr. Gordon gives as having been obtained with gravel, bluestone and screenings all seem to me to agree fairly well with my own experiments, excepting that of washed gravel, viz.: "Washed gravel, screened, 1\(\frac{1}{4}\) inch and 2 inch (spaces) 59 per cent." I would like to know if this statement has not been misquoted. Another point in Mr. Gordon’s communication which calls for reply is, I think, his preference to the method of mixing sand and cement and wetting it before adding broken stones. While entirely agreeing with him that the method of mixing all the materials dry has a great disadvantage, especially in windy weather, I, generally speaking, object to the method he proposes, preferring to adopt precautions such as erecting a screen on the windward side of the mixing board, and sometimes even putting an awning over the board, rather than adopt a method which, with ordinary cement, I have found to cause trouble. If the cement is at all quick setting, the trouble arises from the tendency to add just enough water to slake the mortar in the first instance, because if the full quantity of water is then added at that stage, the subsequent turning with the stones and gravel renders the concrete too wet. Now, with a quick-setting cement, the danger of a too rapid initial set is very much aggravated by such treatment; consequently, in my own practice, I would only allow this method to be adopted when dealing with cement which could be relied on, as being uniformly of a slow-setting character. Contractors generally prefer the method mentioned by Mr. Gordon, since the wetting of the sand enables the sand particles to come together much closer, and causes a shrinkage in that material of about 10 per cent. They generally manage to so manipulate matters that they use this moist sand in the gauging, and as a result, unless very carefully inspected, the mortar has only 90 per cent. of the strength which it should have. With reference to the use of bluestone toppings, which has been mentioned by Professor Kernot, the practice of using bluestone is deprecated by some of the highest authorities on concrete work, owing to the amount of trass, or puzzuolana-like ingredients, of the bluestone—which, however they may tend to increase the strength of the concrete—are regarded with suspicion as likely to introduce dangers from expansion and rendering the treatment of the concrete more difficult. Personally, I have not had experience of sufficient extent of top-
pings in concrete to speak authoritatively on this question, but I was much struck with a statement made by Mr. J. B. McKenzie, M. Inst. C.E., in a discussion on a former paper of mine before this Institution, where he spoke of the unsatisfactory result of using bluestone toppings, I think, at Cockatoo Island Works, New South Wales. At the same time it is very probable that bluestone toppings can, when properly understood, be used to advantage in concrete for many purposes. This is one of those cases where most perplexing results, such as those which Professor Kernot mentions, occur, and which often impel engineers to take the view which Professor Kernot takes in his statement that "All that he could say was that concrete was very curious stuff, and the more one studied it the less one knew about it." Mr. Higgins, I notice, dwells on the advantage of using crushed sand. I think that crushed sand does not suffer from the damage due to crushing to the same extent as broken stone. In the Manchester Water Works, which I mentioned in my paper, I used crushed millstone gritt, and all the sand required was obtained by crushing that material. I have never worked with better mortar than was made from this sand. It has given me much pleasure to read of Mr. Hill's practical application of the principles I have advocated. I am satisfied from this, as well as from my own experience, that these methods are, if possible, more suitable for use in a warm climate—such as this—than in the cold climate of the North of England.
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