June 13th, 1907.

DISCUSSION

ON

PROFESSOR W. H. WARREN'S PAPER

ON

RE-INFORCED CONCRETE CONSTRUCTION*.

Mr. W. H. German in opening the discussion said that his experience of ferro-concrete was too limited to admit of a criticism from a scientific, or mathematical point of view, but, as the Colonial Sugar Refining Coy. had done a little in this class of construction, a few comments upon items that had come under his notice might be offered for members' attention.

In Fiji, in particular, where building timber had practically all to be imported, where the climate was most severe on timber structures, and where, in the salt water estuaries, the ravages of the toredo were most destructive, ferro-concrete work was obviously a suitable substitute, so, for some years, it had been satisfactorily adopted by the Company, mostly for bridge piles, but also for abutments, tanks, bins, culverts, troughs, etc.

In Australia the reasonable price of our excellent hardwoods prevented, and probably would prevent for many years, an extensive use of ferro-concrete, except in exceptional cases, and, amongst the latter, piles for salt water stood out prominently. On several occasions projects for works for the Company for wharves and bridges had been considered and summed up as follows :—

All Timber.—Low initial cost; maintenance of sub-structure expensive and difficult; maintenance superstructure moderate.

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All Ferro-concrete—Initial cost too great, but maintenance very low.

Ferro-concrete substructure with Timber superstructure—Medium initial cost: maintenance substructure very low; maintenance superstructure moderate and easy.

In consequence of the above, the Company had done but little in ferro-concrete girders, joists or decking, so the following remarks would be practically confined to pile work :—

It might be said that hardwood piles from 30 to 60ft. in length, shipped to Fiji, or Northern Queensland, and sheathed with Muntz metal ready for driving, cost about 7/6 per foot; turpentine piles with the bark on would not stand in these tropical waters, repeated trials having shown that they were quickly riddled by cobra, and, as the Muntz metal now obtainable was often found quite perished in four or five years, something more durable was necessary. Ferro-concrete appeared to meet the case, and although the cost fluctuated considerably, according to conditions, especially transport charges, the cost ready for driving should not exceed 6/- per foot, if there were any number to be made.

From carefully kept records of a number of 30ft piles made at Lautoka, Fiji, Mr. Hillhouse found they cost 4/2 per foot. They were 14ins square, well chamfered at corners, and weighed 212lbs per lineal foot.

Plate XIII is typical of the kind of pier adopted for the Company's 2ft tramway bridges; it would be seen that timber was only used for planking and handrails. The proportion (by measurement) of ingredients used was as follows:—

Cement.	Sand.	Shivers.	(Max. size $\frac{3}{4}$)
1	1	2	

The sand in Fiji was mostly very fine, so a liberal quantity of cement was necessary. The custom was to mix five times, viz., twice turned over dry, three turns wet.

Piles should, preferably, be constructed in vertical moulds, but except in works of considerale magnitude, it was seldom convenient to do so, especially when long lengths had to be dealt with, the advantage of vertically moulded piles being that the cement was not worked to any one side in particular, a fault that horizontal piles were liable to. Satisfactory piles could, however, be made in horizontal moulds if great care be taken, especially in the pinning or ramming.

Plate XIV, Fig. 1, illustrated the section of horizontal moulds being used by Mr. Park for the Colonial Sugar Refining Co., for piles for the Lucinda Jetty (Plate XIV), near the Herbert River, North Queensland. In this case the principal difficulties that have been experienced were those of transporting and handling the piles, for they were made some fourteen miles from the wharf site and taken there on trucks. Some of the piles were 60ft long (section 15ins x 15ins) so unless handled most carefully, cracks occurred.

Plate XIV, Fig. 2, illustrated the method adopted for stiffening them to allow of transport and lifting. It seemed difficult to prevent hair cracks in the setting and it thus became most necessary to keep the concrete damp for a considerable period ; the trough shown on the top of the moulds had proved fairly effective in this respect, but nevertheless cracks have appeared during handling which could scarcely be described as hair cracks, so a neat cement grout allowed to set well before driving was used, otherwise there was a risk of the salt water penetrating to the steel rods. No difficulty or damage had resulted in driving, steel caps or sleeves being used with sawdust packing as usual, the last foot of driving taking about fourteen blows of a 2½cwt monkey, falling 4ft.

Referring to beams of reinforced concrete and to Table XIX of Professor Warren's paper, it seemed that the central breaking load for a 10in x 10in beam of reinforced 1·8%, 10ft span, was 9·6 tons, which he calculated corresponded closely to the theoretical breaking load.

The breaking weight of an ironbark beam similarly loaded and of the same size and span was 33 tons by the formula :—

$$\frac{B \cdot D^2 \times 700}{L \text{ in Ft.}} = \text{Central Breaking Load.}$$

That was to say, compared size to size, the ironbark beam was $3\frac{1}{2}$ times stronger than the ferro-concrete beam alluded to.

Three years ago the Colonial Sugar Refining Co. had ten ferro-concrete beams made and tested to destruction, size 9in x 6in. x 10ft. (8ft. span), 1% reinforcement. They all failed before centrally loaded to three tons, whereas the breaking load of the same sized ironbark beam was about 20 tons or nearly seven times as strong. When one considered instances such as these, it was not to be expected that for ordinary purposes ferro-concrete beams would in Australia readily displace ironbark, or even ordinary hardwood. It should be explained that the tests referred to were made principally with the object of determining the value of stirrups and diagonal bars for resisting horizontal shear, but the deflection measurements and the breaking loads showed little, if any, advantage derivable therefrom, though the tests were not regarded as conclusive, there not being sufficient of them.

Personally he was sceptical as to the necessity for such members. To lucidly explain the object of their use, it might be said that that they were supposed to give the difference in value to a beam that existed between say, twelve 1in planks laid on top of each other, as compared with one 12in. solid beam, the latter of course, being twelve times stronger than the former, but he had not seen authoritative statements as to what extent the particles of a concrete beam were in less intimate contact with each other than in a solid timber beam, and until this could be plainly shown, the claims for stirrups or similar members for resting horizontal shear would be regarded by many with suspicion.

Mr. J. M. Smail (visitor), said that he favored reinforced concrete construction, and had adopted it in many works under his control. One of the most essential features for its successful application, was that the concrete should have the proper plastic consistency.

He described various works that he had carried out, among others the lining of the canal from Prospect to Pipe Head Basin

Mr. J. Shirra said he rose with some diffidence to speak on this subject, as he could not claim experience in the use of this method of building, but as an engineer, he was, like all of them, intensely interested in the combination of metallic and calcareous building material. The application of armoured concrete was having an immense vogue in modern practice, and the record of Professor Warren's researches would doubtless prove a classic work of reference on the subject. What appeared to him as most interesting was the proof of the complete adhesion between the cement and the metal when properly applied, a point of much interest in iron ship construction. In the cementing of ship's bottoms various methods had been tried to insure this adhesion, such as acidifying the cement with sour beer, which both rusted and roughened slightly the surface of the iron and neutralised any free alkaline lime in the cement that otherwise might cause blows and blisters. But if properly made cement was used, and it was applied wet enough, this seemed to be unnecessary.

The author stated that the first application of metal to reinforce cement or mortar appeared to be due to Monier in 1868. But was not the application of hoop-iron bond in brickwork, the first application of its use with mortar? He thought it was that great engineer, Sir Isambard K. Brunel who first introduced this about 1830. He showed how a brick arch could be constructed on the cantilever principle, building out from the pier without centreing, by the use of bands of hoop-iron about 1½ins. by 1-12in. inlaid in the joints of the brick courses, along with rods of rough fir about 1½ins. square with their edges notched. He actually built such an experimental semi-arch 60 feet in half span, with a radius of curvature of 177 feet, and rise or versed sine of 5ft. only, which stood for some years, and only fell owing to cracks having developed through disturbance of the pier foundations, and the freezing of water in these cracks brought down the structure during a heavy frost. There was at least the germ of armoured concrete in this idea, though the bricks were laid in lime mortar only. It was about this time that he designed and built the Maidenhead Bridge on the Great Western Railway, of ordinary bricks in blue lias lime mortar; a structure which exercised much the minds of engineers of that day, many of whom predicted that it could not stand; but it was so carefully built that it carried all the heavy traffic of the main line for over half a century, and carries the half of it still, having been duplicated in 1892; the new bridge being a fac-simile of the old, but of pressed bricks in cement. built alongside of it so as to form a roadway of double the width. He (the speaker), did not know if hoop-iron bond was used in the original construction, but he thought the success of the bridge showed that faithful workmanship was the first requisite in any permanent structure; and it appeared to him that the use of ferro-concrete or concrete in mass lent itself very easily to scamped or careless work, being laid by unskilled labour, and consequently requiring rigorous supervision. No matter what laboratory tests might show, if the work was rushed as was too often the modern practice, we could not have entire confidence in it.

The use of amoured concrete had been boomed of late, in America especially, and disasters from bad workmanship had been too common. He would refer to two collapses of ferro-concrete chimney stacks, as reported in "Engineering," of February 22nd and November 23rd, last, where the upper parts of the stacks came down by the run, one had been completed for three weeks and the other for two years. Regarding the latter incident, the article said:—"It looks as though the accident was caused by the breaking of the bond between the concrete and the steel, the reinforcing bars in the wreckage being about as free from concrete as when they left the rolling mill. From the evidence we are inclined to think this is only another case of bad workmanship, and probably the concrete was, for one thing, laid much too dry. Portions of it were found after the accident to be so soft that they could be disintegrated by rubbing with the hand." In the other case, there had been some trouble in setting the form for the concrete at the part which gave way, and the batch of concrete that had been mixed in readiness in the morning was not put into place until the afternoon. There was a want of continuity in both structures at the part that failed first, so the design may not have been wholly blameless either, but as the article of November 23rd concludes—"It is to be hoped that this failure may be taken to heart as indicating that in the construction of reinforced concrete, it is necessary above all things that unceasing watchfulness should be exercised during its construction, if it is to gain the lasting popularity that it deserves."

The height of the first chimney was 232 feet from the foundations, it was 11 feet inside diameter, the wall being only 8 inches thick in the outer shell for 92 feet up, with an inner heat-resisting lining 4 inches thick for this height, detached from the outer shell by a 4 inch air space. Above this the single shell was only 6 inches thick, so that the stack was 12 feet diameter for the top 140 feet, and 13 feet 8 inches for the lower part, the two parts being connected by a splayed out part 3 feet high where the failures first occurred. The dimensions seemed remarkably slender, but those of the other chimney were still more so, yet it stood two years. Its height was 176 feet from the ground, outside diameter at bottom, 7 feet only, consisting of two concentric shells of 5 inches thickness separated by a 5 inch air space, for 70 feet up, above this being one 5 inch shell only, with an outside diameter of 5 feet 4 inches. Many such stacks had been erected and were still standing.

Contrast these with the new lighthouse built in 1905 of reinforced concrete, at Le Coubre, at the mouth of the Gironde, in France, which was described in "The Engineer," of April 5th last. It was nearly the same height as the stacks, namely, 203½ feet above foundation, and about the same internal diameter as the larger one, 11 feet 6 inches, but the thickness of the wall at the top was 27½ inches, increasing with a uniform batter to 70 inches at 47 feet from base, below which level the section swelled out in a curve until it was 11 feet 6 inches thick at the ground, the outside diameter there being 36 feet. This lighthouse was, no doubt, in a more exposed situation than most chimney stacks, though it was not exposed to the action of the waves, but either its margin of safety was absurdly high (the maximum compressive stress with wind pressure of 56 lbs. per square foot was said to be 8·7 tons per square foot), or that of the chimney stacks was recklessly low.

Armoured concrete seemed an ideal construction for lighthouses that were not exposed to the wash of the sea during erection, and the elegant little minaret at Bradley's Head, that was built at Darling Island, was an interesting example of its use. It was not the only instance of such work by our Harbour Trust, although we did not hear much about them.

To return to the paper under consideration, it was interesting to see how the Marten's extensometers showed the shifting position of the neutral axis when the beam was strained. The ordinary formula for beams, which implied the permanence of the position of the neutral layer and the retaining of a plain contour by plain cross sections when strained, was always unsatisfactory for beams of massive section, though for double "T" sections where the flanges did nearly all the work, it was fairly reliable. With it we had to use a modulus of rupture which was neither the extreme tensile nor compressive strength of the material in determining the breaking load, but this modulus varied both with the material and the character of the section and must be determined experimentally. But we were not so anxious as engineers used to be to determine what load would break a beam. We remembered that absence of vibration or deflection were vitally important in most structures, and we were more concerned to build a bridge or a boiler that would be safe under all possible conditions with a given load than one that would break or burst at say five times as much. The two conditions were not necessarily identical.

He hoped that from experiments like those of Professor Warren some formulæ would yet evolve for using some fractional power of "I" the Moment of Inertia of a section, the exponent varying in some regular way with the material and stress that would enable as to calculate what a beam would bear safely even after the elastic limit of the extreme surfaces of the section of greatest bending moment was exceeded.

Mr. Walsh (visitor), said he would like to give a brief description of some uses of the ferro-concrete work that they (The Harbour Trust) had been doing in Sydney Harbour. Before doing so, he might mention he was greatly interested in the method adopted by Mr. German for lifting piles. He had always considered in the construction of wharf work that the lifting of long piles was a very serious item in the construction of wharfs. He considered the smallest crack in the piles before driving crippled them because every vibration from ships or anything striking afterwards would open the fracture. Being under water it would not be detected until the pile was destroyed. It would be interesting to see how this wharf tested by Mr. German would be affected by the corrosion in a few year's time. His opinion was that a wharf built of reinforced concrete construction should not be built under the old design of timber wharf. He noticed that in Auckland where they are building a large monier wharf, they considered that they would be able to overcome that difficulty by building it 250 feet wide. It was practically a rigid body. Large ships would not cause vibration, that was a point that had to be proved. His opinion was that the proper system would be to abandon the ordinary piles and adopt cylindrical work. Of course a serious question was whether iron would last in salt water for any long time. He had, for the information of the members, exhibited a sample of concrete plate that had been in the salt water for four years. He had it taken out yesterday. It would be seen that the adhesion was absolutely perfect, and showed that a properly made plate with properly rammed concrete was an absolute protection against rats.

He considered it was a very interesting and very satisfactory result to contemplate after four years in the water. Of course with regard to the works that the Harbour Trust had been doing in Sydney Harbour, they had all heard of the famous wall that was to be built round Darling Harbour when the plague broke out. Few engineers knew what it meant to build a wall in Darling Harbour, where there was as much as 60 feet of mud. It came to his lot to design something that could be done at a reasonable cost. He decided to put in turpentine piles and face that with monier slabs 2ft. wide, 9 to 12 feet long, according to the height of the wharf. Up to to-day they had put in 1750 of these plates. The plates were fastened to the piles with whalings, had a bull-nose on top, tongued and groved on sides and dropped between the whalings so that they could be lifted at any future time. In places they were fastened with galvanised iron bolts. They had completed 3,500ft. of harbour sheathing which cost about £20,000, or roughly at a cost of £5 per foot. A wall in other material, under similar circumstances, would probably have cost twice as much. But in some places where a rock occurred at moderate depths of 25 to 27 feet from the surface of the wharf, they had designed monier piles which were driven two feet into the rock. The cost was about the same for that depth, as turpentine piles with monier plates. Mention had been made of the lighthouse at Bradley's Head, it was an exceptionally cheap structure. The difficulty there was a strong current. There being 18 to 19 feet of sand overlying the rock, it was decided to drive cluster piles down to the rock. The lighthouse was made in four sections, dropped down over the piles into the sand, which was then filled with concrete, the three upper sections being fastened on top.

Mr. H. E. Ross (visitor), said that he considered the author's contribution to the important subject of reinforced concrete was one of those basic studies which must precede all correct engineering practice, and as a plain statement of experimental facts, it was to a great extent outside the limits of discussion. Professor Warren was to be congratulated on this one of many instances of the valuable use made of the testing appliances he had available. Similar investigation on the behaviour of reinforced concrete were being made in other engineering laborotaries, and reliable formulæ were being thus established for all the more useful forms of construction, so that the engineer might dispose of his material to the best advantage. Certainly some expensive failures had already occurred in reinforced concrete construction, and although they afforded useful lessons, the failure was better confined to the testing machine than the constructed building. Much evidently remained to be done in this direction, and no doubt Professor Warren would have valuable information to afford later.

He (the speaker), first made use of reinforced concrete eighteen years ago in forming some cisterns, the tensile element being galvanised wire netting; and had since been attracted by the beauty of this class of construction for many purposes. The introduction of concrete and metal was attributed to Monier, who appeared to have had the necessary enthusiasm to bring his ideas into use and begin a new era, but it was interesting to note that the ancients used straw and other grass fibres with their sun-baked clay bricks for the same purpose, and one could imagine the first civil engineer in this respect, taking his idea from the grass-entangled hoof pad of some wild beast, and applying the suggestion to his mud, brick or clay hut.

He did not propose to discuss the academic details of reinforced concrete as the subject was too extensive, but might be permitted to explain some closely related constructions adopted in his own experience. The use of wire mesh in ordinary ceiling plaster for instance. He introduced this some ten years ago, the ordinary wooden lathes being covered with a lapped layer of 1in. mesh wire netting stapled at intervals to the joists. The cost was considerably less than that of the more modern metallic lathing and the result more rigid. In no case had any sign of cracking or instability appeared. In this age of concrete steel, one should not lose sight of the ancient brick. There was a tendency to use concrete steel where brick steel would do equally well at less cost and greater strength. Concrete well made, might be taken from Professor Warren's tests at a mean crushing strength of 100 tons per square foot at 100 days, brickwork in cement under same conditions 150 tons. The principle of re-inforcing brickwork appeared to have received little consideration. The cost of a first-class concrete could be taken including mould board and casing at £1 10s. per cubic yard, and the cost of first-class brick in cement was the same per cubic yard. It was well-known that the use of bond iron in brick-work was very old, but no consideration appeared to have been given to its proper disposition. The wall should be regarded as a girder and where the length was great in proportion to the height, practically the whole of the metal should be in the second, third and fourth courses from the top and the bottom of the wall. The present practice of inserting bond iron throughout the wall was merely a waste and misplacement of valuable material. His experience was that bond steel should not be galvanised, and should be of a thicknes of not less than 1-10 of an inch by 2ins. wide, when used with judgment and proportion it could be relied on to prevent cracks on precarious foundations of clay and other different bottoms. It was contended that where horizontal tensile elements were desired, the use of reinforced brickwork might be preferable to concrete. The ends of the bond should be hooked into one another at the joints, and where cross walls met main walls, a bonding in the central portion would assist the stability of the walls against bulging.

The use of re-inforced concrete had come into favour for the erecting of large chimney stacks, but despite the fact that the material used was a minimum (a stack 260feet high and 12feet diameter having only a thickness of 6ins. at the base), these chimneys were expensive to construct. Their great strength, smoothness and absence of cracks was the principal commendation, but for chimneys of moderate height, the lesser cost of