estimates were required, and there was no obligation to deposit money as security; yet premiums of £700, £300 and £200 respectively were offered. Consequently when Mr. O'Sullivan's conditions for the infinitely more important work stated that the small premiums then offered were only "Partly to recoup competitors for their trouble" there were grounds for believing the Government meant what it said. Therefore the bridge builders of the world (who were then asked to supply much more information as well as tenders for the mighty structure intended to cross the main harbour, and to back up their offer by the deposit if required of £10,000) had solid grounds for believing that the Author of the Accepted design would be fully "recouped" by the acceptance of his tender. Otherwise there was no justification whatever for responsible people entering the competition.

During the years 1884 and 1885 the Author was travelling in Europe and America when he visited a number of the most notable bridges then in existence. In the year 1890 he prepared the "Notes" for Sir Henry Parkes under which the Royal Commission of enquiry on the City Railway and the North Shore Bridge was instructed; and later on he submitted a proposal for a Double Cantilever Bridge to that body. Subsequently he prepared a design for a Three Arched Bridge to connect Sydney and North Sydney which had a double deck after the manner of the St. Louis Bridge. Consequently when the Government of the State called for designs and tenders he was to a large extent prepared, and decided to take an active part in the Competition as a matter of business.

As a result of his investigations he had become convinced that while America was the place for a rough and ready bridge quickly built, or a highly

elaborate structure regardless of cost; and while England could be relied upon for a substantial work regardless of appearance; yet Germany was the home of the scientific Bridge Builder where the fullest consideration would be given to strength and durability, and where also economy would be combined with an effective outline in full harmony with the surroundings.

He then corresponded with a Great German Engineering Company that had works in Nurnburg, Augsburg and Gustavsburg, where about ten thousand men are employed, and ascertained that they had already built some fourteen hundred bridges. Further enquiry so satisfied the Author of the high and eminent position held by this concern, The Maschinenbaugesellschaft of Nurnberg, that he made arrangements—since fully carried out—to act conjointly with them in the Competition.

II.

THE GREAT SYDNEY BRIDGE.

(FIRST COMPETITION)

In the first Competition, opened 1st. September, 1900, out of 24 designs sent in three of them were submitted by the Author on behalf of himself and Colleagues. they were:—

1. The Author's Three Arched Bridge, Motto "United Sydney." This was a non-competitive design because the routes of the incoming and outgoing shipping were separated by a pier, instead of being under one span as required by the conditions.
2. A Suspension Bridge of 1800 feet span, Motto

"In Suspense". This received the 2nd Premium of £500.

3. A Five Linked Arch 1640 feet span. Motto "Funfgelenkbogen".

The Bridge which received first prize of £1000 was on the Cantilever principle, Motto "Sablazo", designed by Mr. Crutwell, Memb. Inst. C.E. and tendered for by Sir William Arroll and Co.

Other prominent designs were two American Bridges one on the "Suspension" the other on the "Cantilever" principal. These had cheap and perishable decks of soft pine, instead of steel and concrete as in other designs; but they received great attention, partly owing to the comparatively low price at which they were tendered for.

Other designs were most interesting and some possessed remarkable features, particularly one for a single Arch of 2000 feet span.

Although one or two valueless proposals were contributed, information worth at least £30,000 was obtained by Government from the Great Engineers of the World, in return for the £1500 paid in premiums. When, however, this information was laid before the Advisory Board the anomalies and defects of the original conditions became so apparent, that although there was no fault on the part of the Bona-fide Competitors, for being guided by such conditions, the Board could not recommend the acceptance of any tender. An entirely new set of conditions was therefore prepared in the light of the knowledge thus obtained, and a second competition was instituted by the Government. As no premiums were offered on this occasion this second invitation to bridge builders could of course only bear the one interpretation, that it was the settled intention of the Government to proceed with the erec-

tion of the bridge. Otherwise, what other object could possibly induce Ministers to put respectable firms to the further expense of tens of thousands of pounds after it was in possession of such a number of designs and tenders.

THE SECOND COMPETITION.

The Specification and Conditions for the Second competition were about sixteen times as voluminous as those for the First one, but even then they did not express a preference for, or an objection to, any particular type of bridge, as the Advisory Board did later on when the designs were in. Therefore in order to meet any possible views or prejudices of the Government's Representatives, as to type, the Author and his Colleagues sent in this time six different designs, all with their Specifications, Schedules and Tenders complete, out of the total number of twelve submitted. After full investigation into these designs by the Board, when all the arch designs were summarily rejected, further most important and radical modifications were again made with regard to the views and requirements of the Government, and thus again although conditions were fulfilled no tender was accepted; but three of the designs were selected tentatively as the basis for a Third Competition under the further modified conditions. The Advisory Board then wrote to the Author and the Representatives of the other two designs ask- for fresh Tenders, and forwarded a list of such entirely altered conditions as meant the preparation of an altogether new bridge. The Board also had a number of interviews with the Author and the Agents of the other competitors to discuss the new requirements.

The three conditionally approved designs were (a) An American Suspension Bridge (Modification of one submitted in first competition). (b) An English Can-

tilever Bridge (similar to the first premium design in the First Competition). And (c) The No. 1 Design, Cantilever Type—sent in by the Author and his Colleagues in the second competition. After the correspondence and interviews with the Advisory Board before referred to, the Author prepared sketch plans for an entirely new design, to embody the Board's latest views as to the superstructure, and sent them to Europe. While these were being worked out in detail (and it must be remembered the calculations alone for such a bridge might take one mathematician about twelve months), and the plans were being made for the superstructure, the author devoted himself to the substructure, and devised ten separate methods for founding the Great Northern Piers on the solid rock at 166 feet below the water line.

Under the conditions of the third competition, as supplied by the Advisory Board on the 18th August, 1902, it was made imperative that all the foundations should reach the rock, which had been found at 166 feet below low water level, where there is only 33 feet of water, thus leaving 133 feet of silt and clay overlying the rock.

In the course of his private practice the author has driven the longest piles of which he has any record, at three separate jetties very near to the site of this bridge; some of these piles—made of two trees—were 140 feet long, and some single trees ran up to 108 feet. As the bottom was pierced right down to the rock before these piles were driven, a very fair idea had been gained of the consistency of the strata overlying the rock in this neighbourhood. It was found to be very stiff, but still so yielding to continued pressure that the piles were all put down to the rock, being easily driven with a 3-ton ram.

Thus (although it was not imperative) the foundations in all the six designs submitted by him in the Second Competition were carried to the rock at 166 feet, while those from America, England, and the Continent of Europe mostly trusted to a bearing on the clay at from 60 to 90 feet.

Towards the end of their labours the Advisory Board had a test cylinder sunk on the site of the Northern Pier, this cylinder was then loaded, and its rate of sinking recorded. The result was such as to fully justify the action of the Board, and its anticipation by the author; a full account of the same being given in the report.

With regard to the actual tenders, it is well known to members of this Association that the author has never traded, or ever held an agency for machinery; therefore, as a purely professional man, entering this Bridge Competition with designs as advertised for, he sought a responsible local contractor of means prepared to contract for such great works. In Messrs. J. Stewart & Co. he is pleased to say he found colleagues who accepted the position, and put a price to all his local quantities, and who supplied him with tenders for ten bridges, upon the schedules with which he supplied them. These tenders the author forwarded to the Government with his plans, specifications, and descriptions.

The result of the Third Competition was made known to Parliament on the 25th November, 1903, and as probably there was never a more flattering and unanimous report signed by a board of adjudicators in connection with a competition of this magnitude, a few paragraphs from the same may be appropriately quoted here.

"Of the tenders submitted, we have no hesitation in recommending for selection that of Messrs. J. Stewart & Co. This is in our opinion the most satisfactory design received in this or the previous competition, not only as regards its compliance with the conditions of tendering, and provisions of the specification, but also in respect of the scientific design of the details of the superstructure, the substantial nature of the substructure, and its elegant appearance as a whole"

"In the design recommended the constructional lines are correct, the outline is graceful, and the bridge will harmonise with its surroundings, and not detract from the natural features of the Harbour."

It may be here mentioned that the tender for the bridge complete, 3,000 feet long, was £1,365,050, and that the report is dated November 25th, 1903. After this date other plans and documents were returned to the author and other competitors, but all those connected with the adopted design were retained, and then, without the slightest reference to him or his colleagues, they were copied and printed at the Government Printing Office. They were then issued with the report as a Parliamentary document, and made public property. Subsequently (as copies of this report seem to have been sent abroad), the principal plans, together with an abstract of the report, were reproduced and published in the pages of the "Engineer," on August 4th, 1904.

Now, by the printed conditions of the First and Second Competitions the Government clearly and unmistakably undertook to return "all designs not awarded premiums," and "all designs, tenders for which are not accepted," but, notwithstanding this contract, two sets of the author's plans have been retained, and

the approved set has been copied, without a premium or the acceptance of a tender. The Hon. Minister for Public Works, Mr. C. Lee, has, moreover, so far absolutely repudiated all responsibility on the part of the Government in the matter, on the ground apparently that the competitors were not compelled to believe the statements of his predecessors, or to respond to the invitation which a previous Government so widely advertised.

III.

THE DEEP PIERS AND FOUNDATIONS OF THE APPROVED DESIGN FOR THE NORTH SHORE BRIDGE.

Up to the time of the competition for the Great Sydney Bridge, there were practically only three systems in use under which the piers of bridges were founded below water level, although each of these systems admitted of many modifications in details. They may be classed under the respective heads of the coffer dam, the open dredged caisson, and the Pneumatic Process which includes the diving bell.

In the older method, which has been recently adopted in Sydney for founding the main pier under the swing bridge at Glebe Island, the area to be laid open and kept dry is first enclosed by a wall of piles driven into the bed below the water, and when this enclosure is water-tight it is pumped dry. It is evident that the depth below water attainable in this way is limited by several factors; at Glebe Island other piles were driven from the bottom of the excavated enclosure down to the rock, and on their heads and the surrounding clay the concrete pier was built.

Under the second system a much greater depth is attainable, because the water is not removed, and the excavation is made by wet dredging. At the time the Hawkesbury Bridge was built, the record for depth of such piers was broken, the deepest casing there reaching 162 feet below high water Spring tides. The Hawkesbury casings are 48 feet long by 20 feet wide, with rounded ends and the bottom 12 feet length is splayed out 24 inches all round to the cutting edge. Each caisson has three dredging wells 8 feet in diameter (also splayed out to the cutting edge), for the removal of the excavated material.

The third, or Pneumatic system, is an adaptation of the diving bell, so much in use in former years. The casings or caissons are here enclosed on the top and made air-tight, the water being kept out by air pressure equivalent to that of the water at the same depth. The excavation is thus carried out in a closed chamber and air locks are provided for the ingress and egress of both men and material.

This system of movable caissons was first proposed in Australia by the author, to a Select Committee of the New South Wales Parliament, on the 24th June, 1874, in connection with the construction of new sea walls for the improvement of the Circular Quay. It has since been adopted at the Antwerp Quays, and all over the world. With permanent caissons or cylinders it was used for the foundations of the great Forth Bridge, and in numerous smaller works in New South Wales.

The greatest depth below water level to which men can carry down air-locked caisson is that which gives a pressure equal to about four atmospheres, say, 100 feet, and only then at great risk of life. Several men

were lost by caisson fever when the Five Dock Bridges were in hand, and one man died as a result of working in the trial cylinder on the site of the Northern great pier for the North Shore Bridge, at lesser depths.

These facts must be kept in mind when considering the problem that was presented by the requirements of the northern piers of the Great Sydney Bridge. In the first place it is imperative that they should be most accurately in position; and, secondly, they have to be carried down to the solid rock at least 166 feet below low water; and, thirdly, under the following terms of specification:—

1. The pressure upon the foundations (that is, upon the rock bottom), due to the weight of the structure and its loads, without any allowance for friction, or for water or other material at present overlying the rock, must not exceed 25,000 lb. upon the square foot. Say, 11.16 tons.

2. The limiting load on the concrete is 200lb. per square inch. Say, 12.857 tons upon the square foot.

3. The weight of the concrete itself is to be taken at 135lb. per cubic foot—equal to, say, 16.59 cubic feet to the ton.

Under these conditions it will be found that whether we multiply 16.59 by 11.16, or divide 25,000lb. by 135lb., we obtain the same result, namely, 185 feet, as the maximum height of a column of concrete that the conditions would allow to be carried upon the rock bottom. Such a column would, of course, have no margin of supporting power whatever left to carry the bridge or its loads, or even the metal casing in which the concrete column is enclosed. It is also clear that under such conditions no increase whatever in the dimensions of such a pier would help matters so long