as it was a cylinder or other form parallel form top to bottom.

As it would be possible, with a movable caisson under air pressure, to build the upper part of such a pier with a gradually reduced section—say, between the mud line and low-water mark—after the parallel portion had bottomed, then in such case the relation which the total weight would bear to the base area could be reduced, and so leave a margin to carry the bridge and its load. (Plate VII.) Suppose, for instance, one fourth of the height was taken off such a fully loaded foundation 185 feet high, leaving it only 139 feet, then under the foregoing conditions any given area of base would have a carrying power available for superstructure, equal to one-fourth of the weight of the whole loading permissable upon such base. The foundation in such case would require to be of such an area that $\frac{11.16}{4}$ — or 2.79 tons was the limit of superimposed weight, apart from and above the pier, per square foot on the rock bottom. In other words, if the pier itself below the 139 feet level made up three-quarters of the total load of the bridge and pier in tons, then the whole weight in tons divided by 2.79 would give the base area in square feet.

Now, in the selected design the approximate maximum weight imposed by each one of the four legs of the Northern Pylon, through its steel base plates upon the granite pier, is 7,000 tons. The drawings (See Fig. 1.), show that the granite masonry under the base plates has been designed to be carried down to 11 feet under low-water mark, while below this a conical head of concrete which caps the cylinder continues down to 33 feet below low water, or approximately to the mud line. Below this the casing must be made parallel if it is to be sunk by wet dredging, because there does not appear to be anything in past experience to warrant the assumption that it would be possible to sink a conical or tapering caisson to such a great depth as 166 feet deep—either by open dredging or under air pressure—with any prospect of keeping it truly in place. This being granted, the use of a parallel casing becomes imperative, and simple calculation shows that one so proportioned as to meet the conditions of the case under consideration, would have to be 65 feet in diameter from the mud line to the rock, as shown in Fig. I., where the contents are given as 17,907 cubic yards.

With such foundations the concrete filling for each of the casings, at current rates, would cost, say, £31,337, or over £125,000 for the four legs of the pier. This, it must be observed, is quite apart from the cost of the four steel casings, which, at 250 tons each and £30 a ton would mean £30,000 additional, or, say, a total of £155,000 for the under water legs of one Pylon.

Another difficulty presents itself in the fact that the Government borings made on the site show a very uneven bottom, and indicate that rock might be reached upon one side of these foundations many feet higher than on the opposite one. In order to cope with this difficulty, should further and more accurate borings show that the rock surface is really so very irregular, the annular caisson shown by Plate VII. was designed to enable the excavations to be continued through separate wells upon the low side after the main casing touched bottom. The cost of this scheme, however, was found to be so enormous, that several other proposals for getting the foundations in were investigated before a thoroughly approved scheme was arrived at.

In the course of these investigations, it became apparent that if it were possible to put in a foundation of profile somewhat like (Fig. 3), so that all the conditions as to pressure on the rock would be met, while the concrete would be under a practically uniform pressure throughout its entire height, without surplus material as useless load; then something less than one-third of the mass of concrete which is involved in the parallel caisson would be sufficient to meet these conditions. As such a reduction of material from 17,907 cubic yards to 5,778 yards in each leg, would mean a saving of £80,000 in concrete alone, there was at once an inducement to look for a method under which four such bell-shaped foundations—44 feet diameter at the bottom, and only 32 feet diameter at top—could be carried up truly in position from the rock under the harbour bottom at these unprecedented depths.

The enormous difficulties which attended the comparatively simple task of sinking the casings for the Hawkesbury Bridge, with only a 24 inch splay at the bottom, is well known to engineers. Some of these casings could not be kept in their position nor truly vertical, neither could they be brought back into place after they had got out of line. One of the main girder spans of the bridge was actually lengthened in consequence, and one masonry pier still, it is understood, overhangs the foundation. Such experience as this, of course, quite precluded a second thought being given to any proposal to sink in a similar way, and to a still greater depth bell-shaped casings, with the base twice the area of the upper surface. As the legs of the Pylons are over 400 feet high above water, and must be erected absolutely accurately as to centres, no modification, after thought, or lengthening of a girder as was done at the Hawkesbury, would be possible in the case of the North Shore Bridge piers.

Having for over 40 years had more or less experience in artificial refrigeration—both as patentee and as the designer of plants for the Ether, Cold Air and Ammonia systems, the author went into the question of freezing the clay and silt overlying the rock, as a substitute for coffer dams or caissons, and worked out the scheme since approved by the Advisory Board. Under this it is intended to freeze the mud under the harbour waters right down to the rock. Such a procedure would enable the foundations to be put in to any profile desired, because it would permit of an open excavation or shaft, enabling the work to be done in the full light of day. Simply as a question of comparative cost, this proposal has shown itself to be a most economical one, should the strata not be otherwise water-tight and safe for excavation.

It will be observed from the accompanying plans that the harbour has comparatively shallow water at the site of these piers, where the rock is deepest, Plate IX. illustrates the proposed method of founding them.

A very strong wharf would first be built around the positions the piers are to occupy, leaving the four open spaces for the foundation so clear as to be easily filled up to a foot or two above high water. This filling might be dredged clay or material lightered from the shore, and it would of course be a detail whether such artificial island was left to form its own natural batter under water, was enclosed by a wall of sheet piles, or confined by an iron casing. If it were left to form its own slope then the earth filling might form one large island in the harbour sufficient to embrace all the four foundations, in which case less timber wharfing would be necessary. On this island or wharf, as arranged there would be erected two or three powerful Refrigeration machines each at least equal to the melting of 150 tons of ice per day; they could be driven by their own steam engine and have their boilers alongside, or otherwise the machines could be driven by electric motors operated by generators placed on the shore. Under either arrangement there would be all the brine tanks, expansion coils, and circulating pump system, provided for the freezing medium.

Figures 4 and 5 show how a double ring or annulus of circulating tubes would be sunk around the required excavation. Similar work has already been many times successfully carried out in mine sinking, and through quicksands. In this case the double pipes would surround a cone of the overlying material right down to the rock, and the cold brine would be circulated down the outer tubes and return by the inner ones—see detail Fig. 6. The heat which the cold brine would abstract from the soil in its course through the tubes would be given up in the refrigerator, and then the brine would pass to the brine tank to be cooled, whence it would be again circulated. By this continual abstraction of heat an annulus of the strata would soon be frozen so hard that the centre or core could be excavated just as an ordinary pit or shaft; and this shaft would be open to the sky, and have walls of artificial frozen rock to keep out the water. In making calculations as to the time that would be required before excavation might be safely commenced, the crushing strength of ice, as given by authorities, has been allowed for, quite apart from the natural strength of the ground, It is evident that as the depth of the excavation increases, and the consequent pressure upon the sides of the shaft, or tendency to collapse increases also, so the thickness and strength of the frozen casing would also be increased owing to the longer continued action of the refrigerating machines.

Figure 4 shows a Piling engine erected over the right hand foundation, with a double set of "leaders" to drive independently the inner and outer rings of circulating pipes. The whole machine is mounted upon a circular railway or turntable, so that when once adjusted in position, the two sets of circulating pipes would be driven accurately in their places. The descent of the pipes would be facilitated in the usual way by a stream of water under high pressure being forced down them while being driven. From experience with similar work in the harbour, it is expected that their own weight should suffice, and it is not thought the use of a ram will as a rule be necessary to get them to the rock.

The filling above the mud on one side of the plan is shown as kept together by a timber enclosure.

The left hand foundation shows an iron casing to the filling above the mud line, and a frozen annulus from the surface down to the rock. The staging or poppet heads, for the purpose of excavation and lowering the concrete would replace the revolving pile engine after all the pipes were in position.

The most important thing to remember after what has now been said is the fact that the amount of the tender by the author's contractors, Messrs. J. Stewart and Co., for the foundations as per Figs. 3 and 4, carried to the rock at 166 feet below low water, and in an open shaft, was practically the same as that for the pyramidal pier as appendix "K" of the Advisory Board's Report (see Fig. 7.) This, like the foundations of rival designs, was to be founded on the clay with its base 90 feet below high water level, or 76 feet above the rock.

In the latter case the total pressure due to the enlarged base was 6.3 tons per square foot, or 2.5 tons additional to the natural pressure at that depth.

The tender for the foundations built in annular caissons, as in Fig. 2, was approximately £150,000 higher than that of those in the frozen ground.

As it may be thought the circulating pipes would tend to diverge greatly from their desired positions before reaching the rock bottom, it may be pointed out that the outer tubes are of comparatively large diameter, and of such strength that the guidance afforded by the lofty leaders of the machine should ensure an arrival at the bottom without any significant deviation, as the clay is washed away by the water pressure.

It is very possible that as extensive excavations would be connected with the bridge approaches, the spoil might be deposited in the harbour and form a large island to embrace the four separate foundations of the Northern Pylon, and thus render the construction of a pile wharf unnecessary. If this bank was afterwards dredged into shape and faced with ballast, it would form a permanent protection to the whole pier and save the bridge after completion from damage by collision.

In conclusion the present position of the North Shore Bridge project may be briefly summarised.

Parliament having refused permission to private syndicates to construct a bridge, the State Government advertised for competitive designs and tenders on the 4th January, 1900, and offered premiums of

£1000 and £500 respectively, "partly to recoup the trouble and expense in preparing the designs and particulars." The contract was, of course, the only goal for which genuine bridge building competitors aimed in their responses.

On the 30th September, 1900, the Government was in possession of nineteen sets of designs from America, Europe, and Australia, with all the information connected therewith, worth at a moderate estimate £30,000; for this the £1500 was paid in premiums, but no tender was accepted.

Having this thirty thousand pounds' worth of information from the bridge engineers of two Continents to guide them, the Government then prepared an entirely new set of conditions, differing widely from the original ones, and ten times as elaborate, and invited a second set of designs and tenders. This time no premiums were offered, but both Prime Minister Lyne and Secretary for Works, O'Sullivan, made statements to the effect that the Government "meant business." The great bridge engineers accepted such statements in good faith, and again responded with tens of thousands of pounds' worth more of designs and tenders, fully warranted in believing that if the conditions were fulfilled, one design and tender would be accepted.

No tender was accepted, however, even this time, although all the advertised conditions were fulfilled and the reason was that the Government requirements were again so radically altered as to demand further entirely new designs. Three competitors, as already pointed out, had their designs selected tentatively, and these were asked to again modify their tenders to the latest new requirements.

The three competitors responded, and at very great expense his colleagues sent their leading bridge engineer out from Europe to assist the author, which he did by giving any information desired to the Advisory Board. The report of the Board, as already stated, was absolutely and unanimously in favour of this last set of plans and the tender of Messrs. Stewart and Co., as sent in by the author, but it need not be again quoted here.

As one set of plans alone costing £4000 was offered to Government for £8000,* £60,000 is a very moderate estimate of the value of the whole of the sets that have been supplied to the Government in response to their invitations. Most of them have been returned to their authors as per the contract in the printed conditions; but while eight out of the ten designs sent in by the author have been returned, one set of plans in the second competition, and the accepted design and plans of the third competition have now been held by the Government for over three years, and the latter have been copied, printed, and published without one word of communication as to the Government's intentions.

The present Government has informed the author that it does not intend to build the bridge; he therefore asked that a small payment should be made for the plans retained, such amount to go towards the contract should a tender be accepted within a given period. The Hon. Chas. Lee, Minister for Public Works, has personally informed the author for himself and colleagues that as the competitors were not compelled to respond to the official invitations to compete, his Government absolutely refuses to recog-

*By the Fives Lille Campagnie of Belgium.

nise any claim, and declines to consider the question of justness, the successful competitors' position, or the honour of the State in the connection. Although the Government has appropriated the plans, it is nevertheless true, as Mr. Lee says, that competitors were not obliged to accept previous Ministers in good faith, nor forced to believe that the Government would abide by its own printed conditions, and there the matter rests for the present.