11TH JULY, 1918.

BRIDGE CONSTRUCTION IN NEW SOUTH WALES

BY W. F. BURROW

Open Caissons and Pneumatic Foundations.

The large amount of Bridge Construction work carried out in his State during the last quarter of a century cannot be described adequately in one short paper, and it is proposed therefore to confine these notes to Substructure Practice, with special reference to open-caisson work and pneumatic foundations.

Very extensive operations of this character will be necessary in connection with the sub-aqueous foundations for the proposed Circular Quay Station on the City Railway Inner Loop, and also for the Sydney Harbour Bridge, which may be the cause perhaps of making these notes of special interest at the present time.

The route of the City Railway, and the position of the City Stations, is shown by Plate No. 1.

The proposed open-air station at Circular Quay will be erected on the site of the existing ferry buildings shown by Plate No. 2.

A view of the new station building is given by Plate No. 3, which also indicates the arch-bridge construction connecting this station with the tunnel entrances at Macquarie-street and Harrington-street respectively.

A sketch showing the general arrangement of this station in cross-section is given by Plate No. 4, which also indicates roughly the nature of the soil to be met with in sinking the caissons or cylinders. The difficulties likely to be encountered in passing through formation of this character will be referred to later.

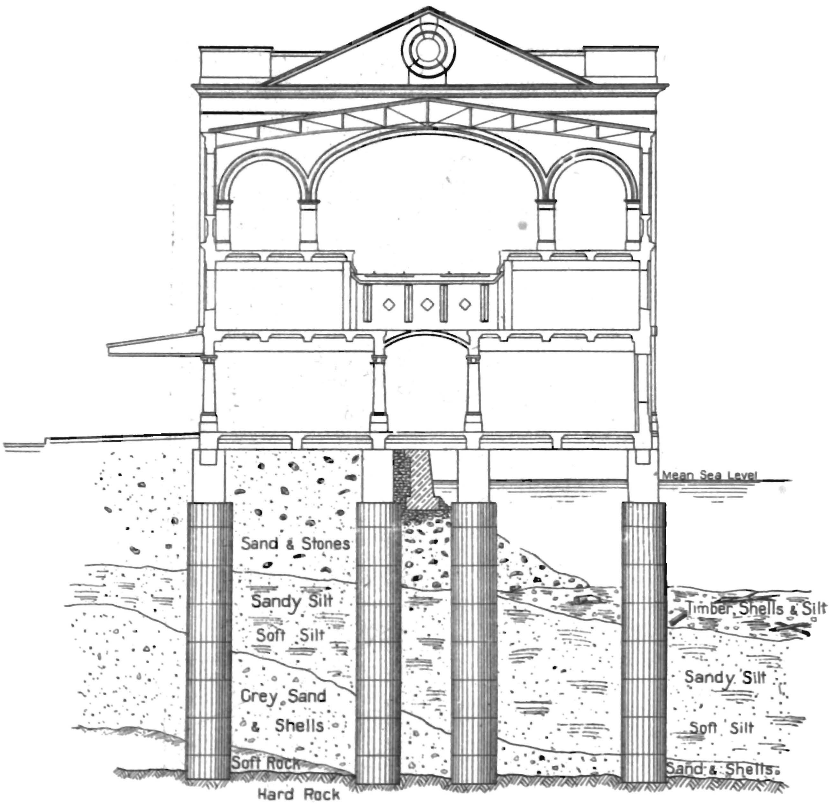
THE CITY RAILWAY

Plate No. 1.

Plate No. 3

CITY RAILWAY

TENTATIVE ARRANGEMENT OF CAISSONS IN FOUNDATION OF PROPOSED CIRCULAR QUAY STATION



GENERAL SECTION
Plate No. 4.

Plate No. 5 is a sketch plan indicating the approximate positions of the large number of caissons required. It will be seen that some of the caissons will be located just inside the sea wall, and pass through the existing footpath and roadway at Circular Quay; others will come on the sites of existing ferry wharves, whilst others will come in the deep water outside the sea-wall.

All the foundations will come under the heading of subaqueous work, and the excavation to rock will doubtless provide many problems of interest for the sub-structure engineers. One provision that will certainly be insisted upon is that the new station must be completely erected without interference with the ferry and other traffic at Circular Quay.

CITY RAILWAY

Tentative Arrangement of CAISSONS in Foundation of Proposed CIRCULAR QUAY Station

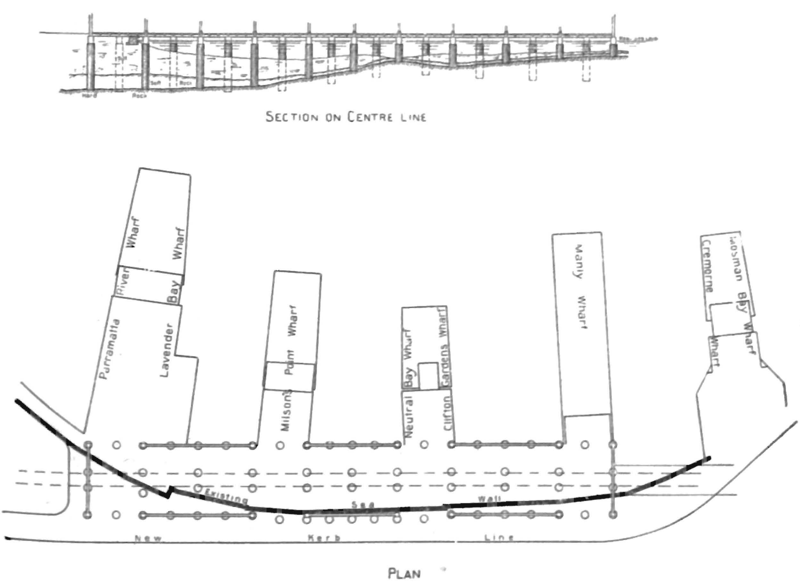


Plate No. 5.

In addition to the Circular Quay Station, there will be a very large amount of foundation work connected with the many bridges required for the City and Suburban Electric Railways approved by Parliament.

In passing, it may be of interest to show the extent of this electrification scheme by means of Plate No. 6, which indicates by red lines the new electric railways approved by Parliament for the City of Sydney. Probable future extensions are shown in yellow, whilst the existing railways, which must be electrified to enable trains to operate on the City Railway, viz.: Sydney to Bankstown, Sydney to Oatley or Sutherland, Sydney to Parramatta and Hornsby, and the Milson's Point to Hornsby Railway are shown blue.

Later, as required, the electrified zone will be extended to the Hawkesbury River, Penrith, Campbelltown, and Waterfall, so as to include the whole of the suburban area, extending about 34 miles from Sydney.

The Bulletin of the National City Bank, U.S.A., for November, 1917, dealing with the existing economic conditions of America, referred to the probable much greater use of electrical energy after the declaration of peace to make good the loss of capital and labor caused by the war. It quoted the fact that the development of the steam engine enabled England to withstand the cost of the wars with Napoleon, and speedily enjoy a more widespread prosperity than the country had ever known before, and considered there is good reason to believe that electricity can do now for America what steam did for England in the past.

In this country, as in America, we have ready to hand the important task of equipping our railways, and other industries where practicable, to operate by electric power. The change over from steam to electric traction means an immediate reduction in the cost of railway working, which experience has shown to be at least 17 per cent.; generally it is much greater. In these days when the interest and working expenses of steam railways are keeping pace, and at times getting ahead of the total earnings, most progressive countries have found it imperative to discard the steam locomotive for the modern power station, which is the most efficient type of plant yet devised for generating power by the combustion of coal.

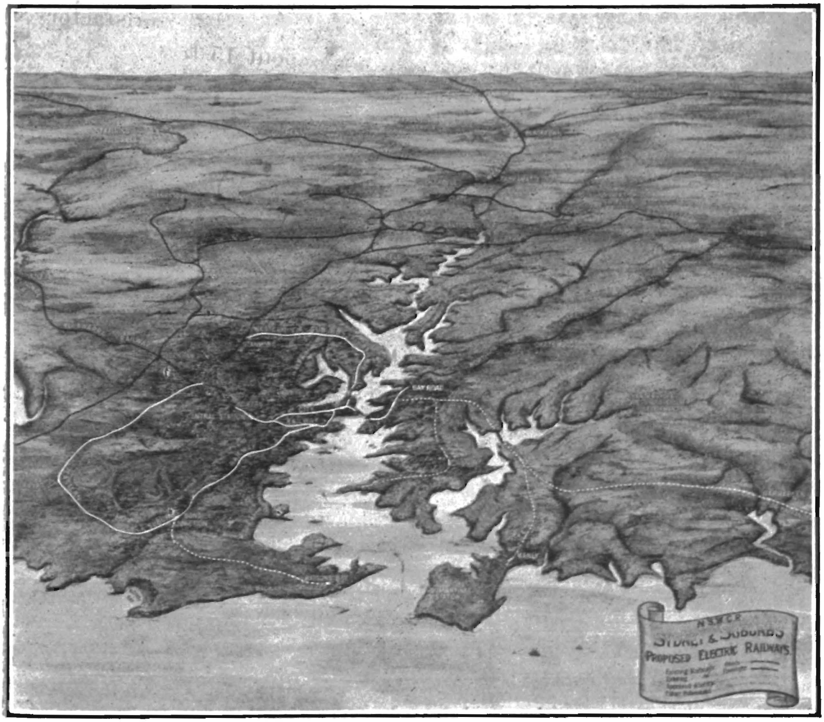


Plate No. 7.

Plate No. 7 gives a bird's-eye view of the metropolis, showing the City Railway and Harbour Bridges included in the Sydney Transit Scheme designed by Mr. J. J. C. Bradfield, Chief Engineer for Metropolitan Railway Construction, and approved by Parliament for construction.

Plate No. 8 shows a general elevation of Mr. Bradfield's design for the Sydney Harbour Bridge, which was approved by Parliament on the recommendation of the Parliamentary Standing Committee on Public Works. The main piers supporting the nickel-steel cantilevers are placed 1,600 feet apart centre to centre. The total length of the steelwork is 2,600 feet. There will be a headway of 170 feet above H.W.M. under the central span.

The sites for the main piers of this bridge have been well chosen, the bores taken showing that a satisfactory rock foundation can be secured at about 15 feet below mean sea level. At this shallow depth few engineering difficulties need be anticipated. Possibly coffer-dams, or open caissons, will be adopted. Had the designer put in a central pier, however, the foundations on rock would be a most difficult and costly undertaking. At the mid-harbor site there is a depth of about 70 feet of water, and borings show that rock is reached about 152 feet below mean sea level, which is slightly less than the deepest foundations of the Hawkesbury Bridge (160-185 feet below H.W.M.).

Plate No. 9 gives the depths of foundations for some of the largest bridges in England and America, and also some deep foundations for bridges in Australia. This plate will be referred to later, but it will be apparent that pneumatic caissons for a central pier for the Sydney Harbour Bridge would be out of the question. Open caissons, sunk by divers, could not be adopted on account of the great depth. The ordinary maximum for a strong diver is about 150 feet, but the maximum depth at which divers can do effective excavation is about 70 to 80 feet. At 150 feet a diver can remain down only about a quarter of an hour at a time, and must have lengthy intervals between dives.

For the depth of 152 feet required for a central pier in Sydney Harbour, the method of dredging through open wells, similar to the method adopted for the Hawkesbury Bridge piers, would have to be chosen. The caissons for this bridge were of elliptical iron section, 48 feet by 20 feet at the cutting edge, and were founded on a hard bed of gravel, after passing through layers of mud and sand. The sinking was accomplished by dredging through three open wells of 8 feet diameter, terminating in bell-mouth extension which met the cutting edge.

The spaces between the wells and the outer shell were filled with gravel as sinking progressed. The wells were filled with concrete to low-water mark, and the pier carried up above that with stone masonry.

The splayed bottom, adopted for the purpose of reducing friction, was found to be a mistake, as it seriously increased the difficulty of guiding the caisson during sinking.

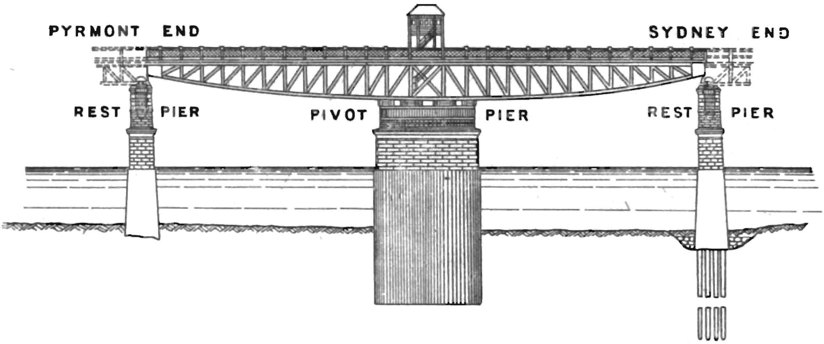
For moderate depths the excavation in open-caissons can be carried out by divers and dredging conjointly, and the mud pump can often be used to advantage.

Strong objection is frequently made to the open-caisson on account of the difficulty of inspection, and the uncertainty of the bearing and character of the submerged work. Substructure engineers can generally, with a little practice, gain sufficient experience in a diving-suit as will enable them to make a personal examination of foundations at depths of 60 or 70 feet. The writer has found no difficulty in making a long inspection in 15 fathoms, but beyond that depth a thorough inspection is practically impossible.

The open-caisson method was adopted for the pivot pier of Pyrmont Bridge, which was opened for traffic in 1902. Plate No. 10.

The caisson, which formed a part of the pivot pier as well as a coffer-dam, was a double wrought-iron shell, with an exterior diameter of 42 feet, an internal diameter of 32 feet, and a height of 53 feet, the shells being concentric, and brought together at the bottom to form a cutting-edge at the line of the outer diameter.

THE PYRMONT BRIDGE
SYDNEY, N.S.W



BASE OF PIVOT PIER

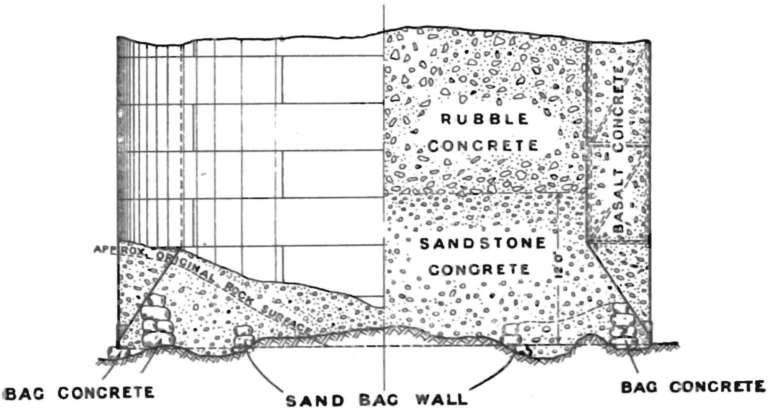


Plate No. 10

The caisson was sunk to the harbour bed, then loaded with concrete, and, while the interior was being dredged out, the caisson was sunk to bed rock.

The water was then pumped out, but no doubt owing to the rigid iron shell founding on an irregular rock bed, a blow-out occurred, which necessitated the excavation for the levelling off of the irregular rock surface by the aid of divers, with the caisson, of course, full of water. Some of the concrete in the base around the outer margin of the caisson was placed by divers, as indicated by the plate. After this was set, no trouble was experienced in pumping out the caisson, and placing the remaining concrete in the open. The time occupied in sinking this caisson was nine months.

This bridge was designed and constructed under the direction of Mr. Percy Allan, of the Public Works Department.

Pneumatic Caissons and Cylinders for Bridge Piers.

The earliest account of the use of compressed-air in bridge foundations was in 1778, when a timber diving-bell was used in the construction of the Hexham Bridge, but the first use of compressed-air in caissons was in 1841, when the pneumatic process was used in the coal mines of Chalons, France. Since that date the process has been widely used in bridge caissons, and has been found of much value, giving the engineer great control during the work of sinking, perfect certainty as to the bearing and character of the submerged work, and has the great advantage of permitting the inspection of the concrete filling, deposited under air in the working chamber.

As first used, the pneumatic caisson was of a very simple character, the caisson consisting of a cast-iron cylinder, sometimes called a pneumatic pile, which formed both the working chamber and a section of the bridge pier. This type of metal cylinder construction has several advantages over masonry: the cylinders are easily erected in place, they give a high degree of water-tightness, and, compared with other materials, there is considerably less skin-friction developed in sinking.

In New South Wales during the last 30 years these pneumatic cylinders of cast iron, ranging in diameters from 4 feet 6 inches to 12 feet, have been very largely used in the constructions of bridge piers. In most cases the diameter has been 6 feet, with at times splayed footing-rings, with the bottom sections of larger diameter to provide the necessary bearing area.

Until quite recent years these cylinders were sunk, often to considerable depths, with air-compressing plant and lighting arrangement of the most primitive character, and it is rather astonishing that the the excavation, other than rock, was in many cases taken out at a schedule price of from 15/- to 30/- per cubic yard. This is remarkable when it is considered that the excavated material had to be hoisted in small buckets to the air-lock chamber, the air discharged for the air-lock, the top door unscrewed, and the buckets lifted out, emptied, and returned, after which the air-lock had to be again put under pressure before further material could be lifted.

No laws such as are in force in America for regulating work carried out under air-pressure exist in this State, and but scanty attention was paid to ventilation. No means of cooling the air entering the locks were provided, and, as common candles were used for lighting, the atmosphere within a six-foot cylinder was not as clear as it might be. When constantly engaged under air pressure in a candle-lit cylinder, the writer adopted a scheme for mounting a small piece of sponge on the end of a stick, and used it for removing the collection of candle-soot which completely filled the nostrils; a small water-jet was found a very useful auxiliary addition to this nose-cleaning plant.

The Australian is, however, an adaptable gentleman, and the men soon acquired a knack of obtaining an occasional "blow-out" under the cutting-edge of the caisson, which means, of course, a reduction of pressure owing to the escape of air, accompanied by a consequent condensation, which, although causing a fog, was a nice cool fog, which soon lifted, and left a freshly aired chamber.

Grumblers are seldom or never found in an air-lock. Jacoby and Davis, in their book on "Foundations for Bridges and Buildings," placed a question mark against the word "whistle" in a quotation by one of the workmen in the Blackwall Tunnel, who stated that he would "Get up in the morning feeling very dour and queer, and go into the workings and then whistle (?) and sing all day long."

The English workman might not be able to whistle against the contained air-pressure, but the writer can vouch for the fact that many Australian workmen acquired the knack of whistling by sucking in air—pursing the lips in fact—and letting compressed air do the rest.

One of the earliest air-locks designed in New South Wales is illustrated on Plate No. 11. The lock-chamber consists of one of the cast-iron bridge cylinders. To overcome skin-friction during sinking it is generally necessary to load the cylinder-piers, usually with bags of sand or gravel. A cast-iron cylinder with flanges stiffened with the usual internal webs is therefore a convenient piece of plant to withstand compression. First of all a top wrought-iron or steel lock-plate is made, and fitted with a man-hole opening and door opening inwards. Holes are marked off to correspond with the holes already cored in the bridge "intermediate" cylinder. This plate is screwed down to the cylinder with the bolts used for connecting the sections of bridge cylinders together. Leaded-hemp grummets are placed over the bolt ends, with the washers above, and the nuts screwed hard down to give air-tight joints all round. The door is made air-tight with rubber packing. The bottom plate is made in a similar way, with a door opening inwards. Holes are usually drilled in the top and bottom plates for the air-supply pipe, and in the top plate for the air-discharge valve.

It will be understood that when the lock has to be lifted off for the purpose of adding cylinders during sinking operations, all the air connections through the bottom plate must be broken and remade.

BRIDGE CYLINDER USED FOR AIR-LOCK WITH SPECIAL CASTING FOR AIR-PIPE CONNECTIONS

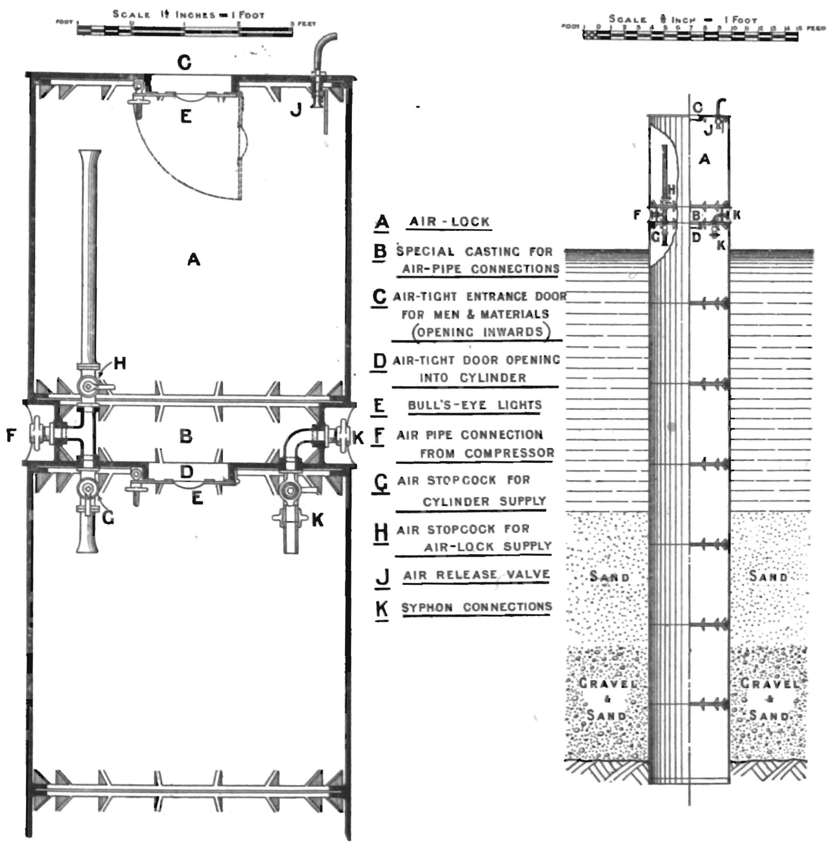


Plate No. 11.

The designer of the lock illustrated has provided a special casting for the air-connections and syphon. It is doubtful, however, if such an arrangement of syphon would be of any practical use for a dry "blow-out," viz.: the utilisation of the compressed-air for ejecting the excavated material. This process will be referred to later.

The writer has never seen a lock of this class with the refinements of bell-mouth air pipes, and bull's-eye lights in the doors. With 50 tons or so of dunnage on the top plate, and the whole outfit smothered in mud, with a dense candle fog in the interior, there would not be much daylight through the bull's-eyes. He has certainly never seen a bottom door which can only be screwed up by a man left in the workings underneath. At shift change, when all the men go out, this arrangement would be troublesome.

Within the limits of a short paper, it is impossible to do more than outline the subject of sub-aqueous foundation work, and it is therefore proposed to illustrate briefly the methods adopted in the construction of the piers for several large highway bridges erected in New South Wales.

An elevation of the highway bridge over the Macleay River at Kempsey is given on Plate No. 12.

The main waterway structure of this bridge consists of four truss spans of 154 feet, centre to centre, supported on five cast-iron cylinder piers, 6 feet diameter, of the usual pattern adopted by the Public Works Department in rivers liable to heavy floods.

Some of these piers were sunk by the pneumatic process to the great depth of 84 feet below L.W.M., and, as will be seen from Plate No. 9, rank with some of the deepest foundations in the world carried out under air pressure.

The Brooklyn Bridge piers reached 78 feet; the Forth Bridge piers went down to 89 feet; and at the St. Louis Bridge, in the United States, a depth of 110 feet was necessary.

In all the cases given the sinking was unfortunately attended by loss of life, or much illness. At the St. Louis Bridge, for example, there were 119 cases of illness, of which 14 resulted fatally, and two ended in the men being crippled for life. In New South Wales there has been some experience of the same kind. The piers of the Iron Cove Bridge at Five Dock were sunk to a depth of 90 feet by the pneumatic process, and the sinking caused the death of one man and the injury of several others.

The larger bridges of England and America mentioned on the plate had caissons of much larger size than obtained at Kempsey Bridge, thus admitting of far better ventilation and lighting.

EXAMPLES OF DEEP FOUNDATIONS FOR LARGE BRIDGES

	Depth below water level.	Theoretical gauge pressure lbs per sq. inch	Foundations	
Brooklyn Bridge U S A.	78ft.	34	Pneumatic Caissons	Loss of life and injury to workmen occurred in each case
Forth Bridge U K.	89 ,,	38		
Manhattan Bdge U S.A.	92 ,,	40		
Williamsburg Bdge. ,,	88 ,,	38		
St. Louis Bdge. U S.A ..	110 ,,	48	Pneumatic Caissons	Note: 14 men died 2 crippled for life ; 119 cases of illness
Omaha Bdge. Missouri	120 ,,		Open Caissons—Dredging.	
Kempsey Bdge., N.S.W.	84 ,, Below L.W.M.	36 to 38	Pneumatic Cylinders	No loss of life or permanent injury.
Iron Cove Bdge., Sydney	90ft.	39	Pneumatic Cylinders	1 man killed and several injured.
Victoria Bdge., Brisbane	97 ,,	42	Pneumatic Cylinders.	
Hawkesb'ry Bdg. N.S.W.	160 ,,		Open Caissons—Dredging.	

Sydney Harbour Bridge with a central pier would require foundations on rock 152 feet below mean sea level.

New York Regulations governing caisson work for Bridge Cylinders:

Gauge Pressure in Pounds ..	10	15	20	25	30	36	40	50
Time of Decompression in minutes ..	1	2	5	10	12	15	20	25

Periods of work in caissons:—

	lbs.	lbs	lbs.	lbs.	lbs.	lbs.
Gauge Pressure	0-21	20-30	31-35	36-40	41-45	45-50
Time per day in Caissons ..	8 hrs.	6 hrs.	4 hrs.	3 hrs	2 hrs.	1½ hrs.
Number of shifts	2(min.)	2	2	2 (min)	2 (min)	2
Length of shift		3 hrs.	2 hrs.	1½ hrs. (max)	1 hr (max.)	¾ hr.
Maximum time betw'n shifts	30 consec'tive mi'ntes	1 hr.	2 hrs	3 hrs.	4 hrs.	5 hrs.