

PRELIMINARY WORK ON THE PROPOSED CONNECTION
BETWEEN SYDNEY AND NORTH SYDNEY, WITH
SOME NOTES ON LONG SPAN BRIDGES
AND SUBAQUEOUS TUNNELLING.

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*(Read before the Sydney University Engineering Society,
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The proposal to connect Sydney with North Sydney by means of a Bridge or Tunnels has been under consideration for many years. At one time, in 1882, the matter had reached such a stage that the proposal of a private Company to erect a high level bridge was agreed to by the Government, of which Sir Henry Parkes was then the head, and a sum of £5,000 was deposited as security, but owing to a change of Government negotiations fell through, and nothing further was done.

The author's connection with the project dates from 1900, when he was engaged in examining the designs submitted in connection with the first Bridge Competition. From March, 1901, until November, 1903, he acted as Secretary to the Sydney Harbour Bridge Advisory Board, whose Report was presented on the 25th November, 1903, and latterly he has been engaged upon Bridge and Tunnel Schemes for the Royal Commission on Communication between Sydney and North Sydney. Three of these Tunnel Schemes were recommended for adoption by the Commission in their Report, which was presented on 29th March, 1909. At the outset the author wishes to make it clear that the following paper is presented merely as a record of the preliminary work done in connection with the above, and that it is not intended to express any opinion as to whether a Bridge or Tunnels would form the most suitable method of connection. The description of works of a similar nature executed in other parts of the world embodies the results of studies made from time to time when engaged upon this important work, and will, it is hoped, prove of interest to members.

Before describing some of the various schemes proposed for a connection by Bridge, the following general particulars are submitted of some of the greatest of the Long Span Bridges already built, or now in course of construction elsewhere.

LONG SPAN BRIDGES.

THE FORTH BRIDGE.—This structure is so well known, and the purpose for which it was constructed is so entirely different to the requirements of the North Sydney connection, that only a very brief reference will be here given. This bridge, which crosses the Firth of Forth, was erected 1883-90, to shorten the distance for the English railway lines which converge to Edinburgh. The main structure consists of three double, symmetrical cantilevers resting on the shore at either side, and at the centre on the Island of Inchgarvie, which separates the water into two channels. Over the centre of each channel there is an interval of 350 feet, which is spanned by a pair of lattice girders, which are supported on the ends of the cantilevers. The length of the main portion is 5,330 feet, consisting of the central tower on Inchgarvie, 260 feet; the shore towers, each 145 feet; the two central connecting girders, each 350 feet; and six cantilevers each of 680 feet. Each of the two main spans is 1,710 feet between the centres of outer posts of the towers. For a length of 500 feet at the centre of each channel there is a clear headway of 151 feet above high water. The top of the towers reaches a height of 361 feet above high water.

There are also approach viaducts on either side, which bring the total length of the structure to 8,296 feet. The main structure carries an internal viaduct, consisting of a pair of lattice girders on which is supported a double line railway of 4 feet 8½ inches gauge, with a footpath about 4 feet 6 inches wide on either side.

The dead weight of one of the main spans is about 16,000 tons, the weight of steel in the cantilever portion of the bridge amounting to 51,000 tons, or at the rate of 9 tons 11 cwt. per foot run. The total cost of the work, including approach railways, Parliamentary expenses, and interest during construction, was about £3,000,000. The engineers for the structure were Sir John Fowler and Sir Benjamin Baker. Sir William Arrol was the principal contractor.

AREA AND POPULATION OF NEW YORK.—The New York bridges are those which possess the greatest interest in connection with the problem under consideration. Before proceeding to a description of these it may be well to refresh our knowledge of the geography of this great city. The City of New York embraces the following boroughs:—(See Mr. W. B. Parsons' paper, read 25th February, 1908, Proc. Inst. C.E., Vol. 173.).

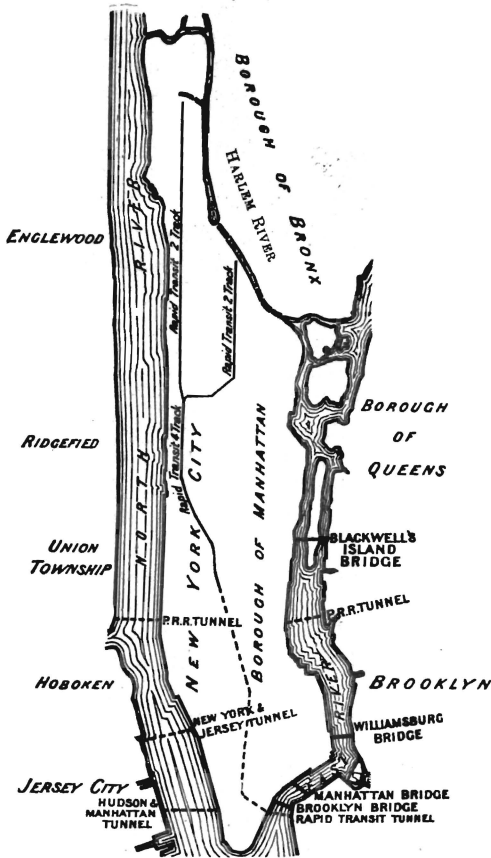


BROOKLYN BRIDGE—NEW YORK.

[Face page 68.

	Population.	Area sq. mls.	Population per square mile.
Manhattan ..	2,174,335	21.93	99,149
Bronx ..	290,097	40.65	7,134
Brooklyn ..	1,404,569	77.62	18,095
Queens ..	209,686	129.50	1,619
Richmond ..	74,173	57.19	1,297
Total ..	4,152,860	326.89	12,704

Manhattan Island, which is the great commercial section, carrying the enormous population of 155 persons to the acre, is about fourteen miles long, with an average width of $1\frac{1}{2}$ mile. It



NEW YORK BRIDGES & TUNNELS

is separated from the mainland on the west by the Hudson or North River, on the east and south by the East River, and

on the north by the Harlem River. Exclusive of the numerous ferries, of which there were in 1907 no less than 17 across the East River alone, the means of communication between Manhattan and the mainland are by various tunnels under the Hudson; by the Rapid Transit and other Tunnels under the East River and Harlem River; and by the Brooklyn, Williamsburgh and Blackwell's Island Bridges over the East River. In addition to these there is the Manhattan Bridge, in course of construction over the East River. No Bridge has yet been built over the North River, though a scheme was prepared some years since for a suspension bridge of 3,200 feet span, in which it was proposed to use nickel steel for the stiffening trusses.

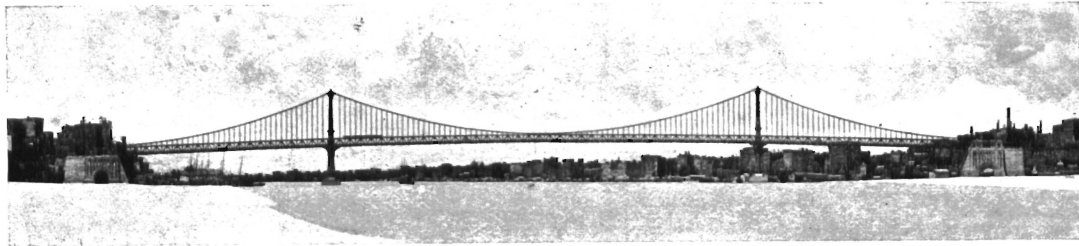
THE BROOKLYN BRIDGE.—This was opened in 1883. It is a suspension bridge with inclined stays, having a central span of 1,595 feet between centres of the masonry towers, and two side spans of 930 feet, together with several masonry arches, and embanked approaches between retaining walls. The eight cables are each $15\frac{3}{4}$ inches diameter, formed of 5,296 parallel straight wires, with a breaking strength of 12,200 tons. The function of the stays is to minimise oscillation due to wind or unsymmetrical loading, and they relieve the cables of but little stress. The stiffening trusses are of wrought iron, with a sliding joint at the centre. The bridge is 135 feet clear of water at the centre, and 85 feet wide, carrying two roadways, each 18 feet wide, and one footpath 15 feet 6 inches wide. There are two tramways along the roads, and two lines of elevated railroad at the sides. The construction of this bridge occupied thirteen years, and the cost was about £1,875,000, exclusive of £1,365,000 for land. The traffic across this bridge prior to the opening of the Williamsburgh Bridge, amounted to 120 millions of passengers carried by the tramways and elevated railroads per annum, and great congestion ensued, resulting in an accident in 1901, whereby a number of the suspension rods were crippled. It has been proposed to reconstruct the bridge superstructure at a cost of over two million dollars, but this has not so far been done.

As designed, the structure was intended to carry one pair of tracks in the centre of the bridge, with an estimated capacity of thirty million passengers per annum, and this figure was not reached for many years, although in slightly over 20 years after its construction, the traffic was four times as great as that first allowed for.

WILLIAMSBURGH BRIDGE.—The Williamsburgh Bridge opened to traffic in 1904, is situated to the north of the Brooklyn Bridge. It is a stiffened suspension bridge, with a central span of 1,600 feet between centres of steel towers. The width is 114 feet over all. There are two decks carrying two elevated railroad tracks, four street car tracks, two carriage-ways, and two



WILLIAMSBURGH BRIDGE—NEW YORK.



MANHATTAN BRIDGE—NEW YORK.

promenades. The bridge is 135 feet clear of high water mark at the centre, and is 7,200 feet long between terminals. The towers are of rivetted steel, 316 feet high above mean tide, built on caisson foundations carried down to rock.

The four main cables are each $18\frac{3}{4}$ inches nett diameter, with a breaking strength specified for at least 50,000,000 lb. (22,320 tons). They have a versed sine of 175.95 feet, and are composed each of 7,696 straight steel wires, No. 8 B.W.G. (about 3-16th inch diameter), with a breaking strength of at least 225,000 lb. (or over 100 tons) per square inch. The cables were constructed in place on temporary platforms, slung one on either side from anchorage to anchorage over the tops of the towers.

The two stiffening trusses are 40 feet deep and 67 feet apart centres, with triple intersection diagonal web members, dividing the trusses into bays of 19 feet 11 inches each. The trusses are suspended from the cables at each panel point, and extend back past the towers, giving each a cantilever arm, on the end of which is supported the shore span. The approach spans are of steel, 2,500 feet long on the Manhattan side, and 1,744 feet long on the Brooklyn side. The cost of the structure has been about \$11,000,000, exclusive of the cost of land, which was nearly as much more.

BLACKWELL'S ISLAND BRIDGE.—This bridge, opened for traffic in March, 1909, has been constructed across the East River, above the other structures, and has a total length of 7,424 feet. It is a pin connected cantilever bridge, the spans of which over the east and west channels of the river are respectively 984 feet and 1,182 feet, while the span at the centre over Blackwell's Island is 630 feet, and the anchorage spans are 459 feet and 469 feet 6 inches respectively.

The clear headway above mean high water is 135 feet.

The trusses vary in depth from 185 feet over the piers to 45 feet at the centre. They stand 60 feet apart in vertical planes, and carry a double deck 90 feet wide over all. On the lower deck is a 36 feet carriage-way, and four street car tracks; while on the upper deck are two elevated railway tracks and two promenades.

The design is remarkable for the omission of the connecting spans usually suspended from the arms of cantilever bridges, and for the use of nickel steel eyebars of very large proportions.

MANHATTAN BRIDGE.—This bridge is of the suspension type, and is being constructed across the East River between the Brooklyn Bridge and the Williamsburgh Bridge. It will have a total length of 9,900 feet including approaches. The towers will be of steel, 322 feet 6 inches high to centres of cables, carrying a suspended centre span of 1,470 feet and two shore spans of 725 feet each.

There will be four steel cables, each $20\frac{3}{4}$ inches diameter, consisting of 9,472 parallel wires of .192 inch diameter. The stiffening trusses will be of the riveted Warren type, anchored vertically to the abutments and piers by rocker arms, but having no joint at the centre. The deck will be 120 feet wide, including a carriage-way at the centre, two double-track street car lines and two footpaths on cantilevers. There is also to be an upper deck in two sections, each with two elevated railroad tracks. The total estimated weight of steel, including cables, is about 37,000 tons, of which about 20 per cent. is nickel steel.

The estimated capacity of this bridge is about 200 million passengers per year, and the cost about \$13,000,000, exclusive of land.

QUEBEC BRIDGE.—This structure was commenced across the St. Lawrence River, about eight miles above Quebec in 1904. The design provides for a cantilever bridge with a central span of 1,800 feet, consisting of two cantilever arms of 562 feet 6 inches each, and a central suspended span of 675 feet. The anchor arms are each of 500 feet span, and there are also two independent deck spans of 214 feet each.

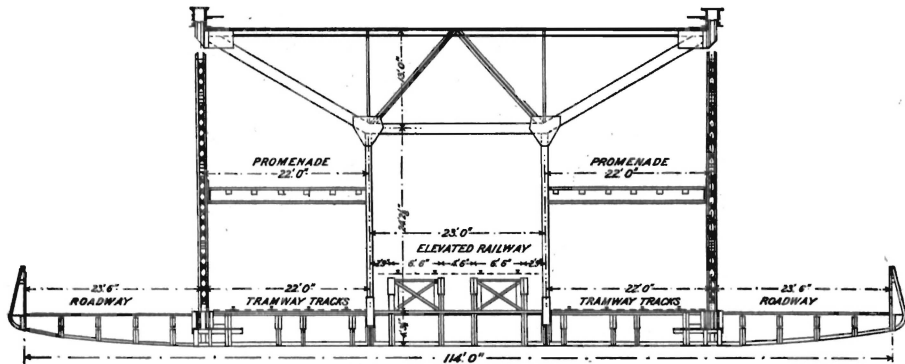
The main span consists of two steel pin connected trusses in vertical planes, 67 feet apart, and 315 feet deep over the piers, diminishing to about 97 feet deep at the ends. The suspended span has a horizontal lower chord and parabolic upper chord, the trusses being 130 feet deep at the centre. The top of the towers is about 415 feet above low water. The towers were founded on timber caissons of large dimensions sunk under air pressure. There is a clearance of 150 feet above mean high water over the central 1,200 feet of the span.

The deck is designed to include two railroad tracks, and two roadways, with tram tracks, with provision for footpaths on cantilevers in the future, making a total width of 82 feet, all on the same level.

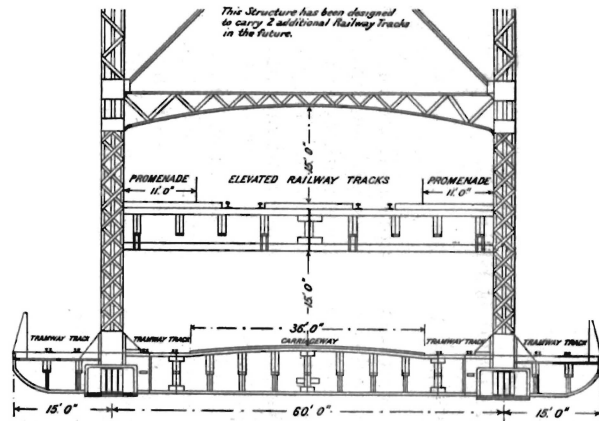
On 29th August, 1907, the whole of the cantilever span erected to that date collapsed and fell, killing 75 out of the 86 men who were at work upon it. At that date the whole of the substructure had been completed, and the whole of the southern anchor arm erected. Of the main span the southern cantilever and three of the twelve panels of the suspended span had been erected. None of the cantilever spans had been erected at the northern end. It was estimated that about 17,800 tons of steel fell, some upon the shore and some into the river, which in places is 200 feet deep. The cause of failure was subsequently investigated by a Commission, whose report has been published in the Technical Journals, but is too long to reproduce here.

We come now to the preliminary work done from 1900 to 1909 in connection with the proposed Sydney Harbour Bridge.

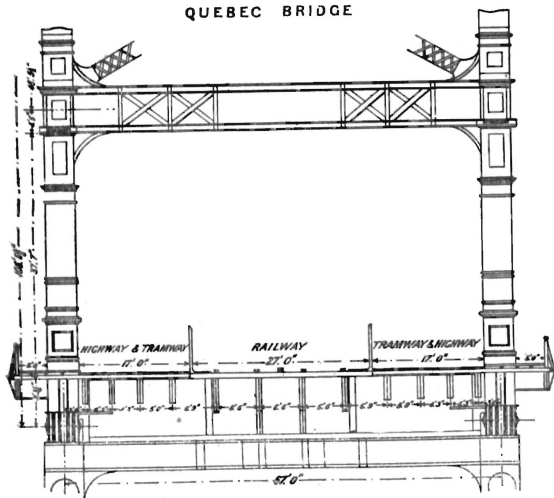
WILLIAMSBURG BRIDGE



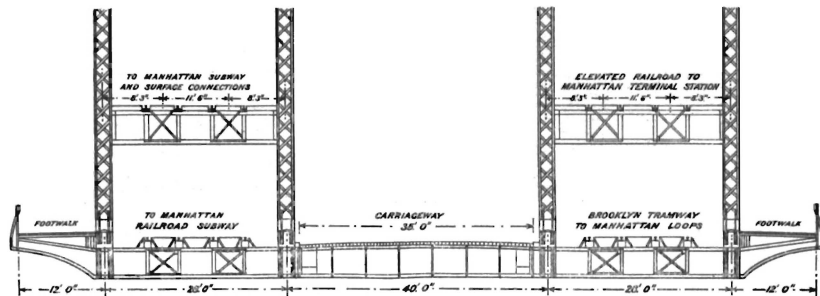
BLACKWELL'S ISLAND BRIDGE



QUEBEC BRIDGE



MANHATTAN BRIDGE



PROPOSED SYDNEY HARBOUR BRIDGE.

FIRST COMPETITION, 1900.

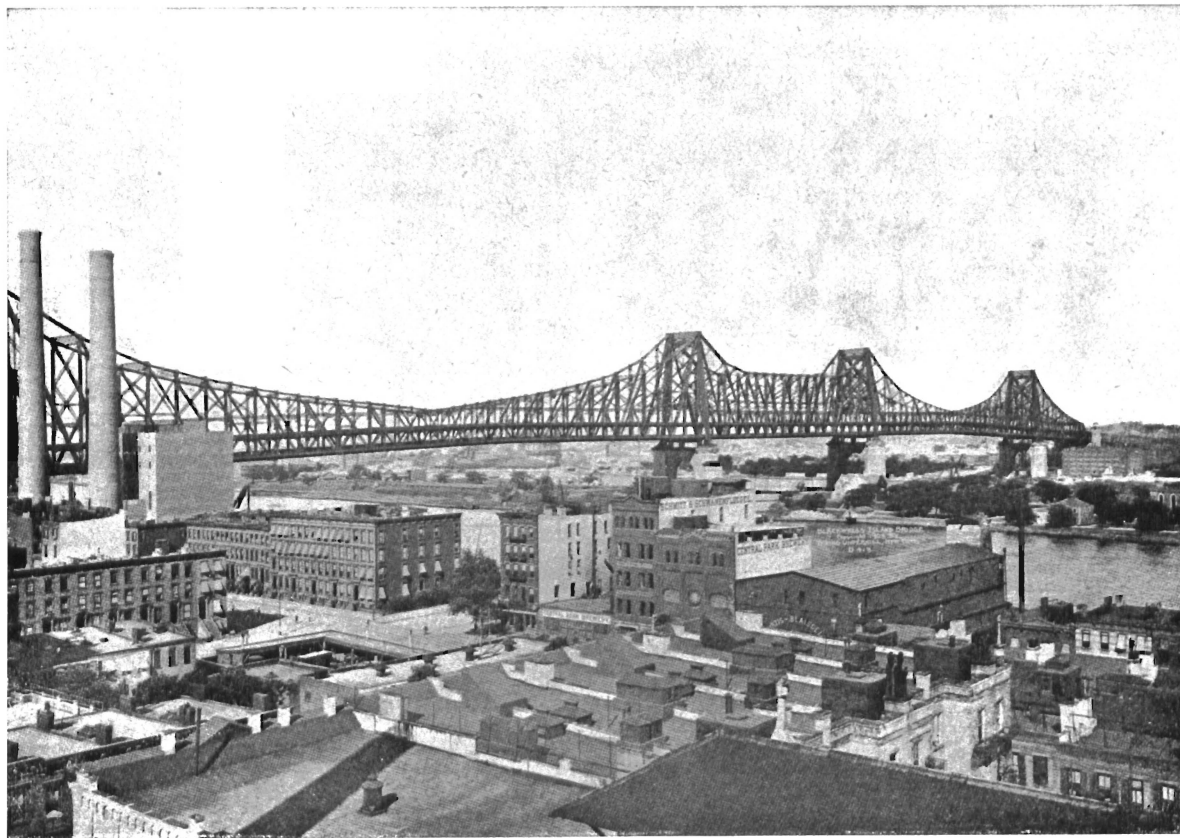
On 4th January, 1900, an advertisement appeared in the Government Gazette, calling for competitive designs and tenders for a "Bridge and Approaches connecting Sydney with North Sydney," in accordance with a printed set of conditions. These stipulated for a bridge of one span, with a clear headway of 180 feet above high water of spring tides for at least 600 feet at the centre, and with the best possible headway on either side of this; provision to be made for suitable connections with the Hornsby to Milson's Point railway; and with the streets of the City and North Sydney; the deck to include two footways each of 10 feet, and two roadways of 20 feet each, or one roadway 40 feet wide, together with a double line of railway.

The designs and tenders, 24 in number, were received on 1st September, 1900, and two months later the Board of Reference of the Public Works Department, of which Mr. R. R. P. Hickson, M. Inst. C.E. was Chairman, presented a report recommending that the first premium of £1,000 be awarded to the design submitted under the nom-de-plume of "Sablazo," and the second premium of £500 to the design bearing the nom-de-plume of "In Suspense."

This report stated: "We regret to have to report that, owing to the fact that even the best of the designs are unsatisfactory, either as regards cost, structural defects, or other features, we cannot recommend the acceptance of any tender."

The design which received the first premium was submitted by Sir William Arrol & Co., Ltd., and was for a cantilever bridge with a central span of 1,266 feet, and side spans of 618 feet each. There were two pairs of main cantilevers, each having a shore arm of 618 feet, and a harbour arm of 489 feet, while the central suspended span was 288 feet in length. The main trusses were of different strengths, owing to the arrangement of the cross section, whereby the whole of the deck was brought inside the main girders, and the railway tracks were placed adjacent to one of these instead of being situated at the centre of the bridge. The piers and abutments were of masonry, and full approaches were included in the design.

The design which received the second premium was submitted with a tender from Messrs. Stewart and Co., and was by the same authors as those referred to later in connection with the design recommended in 1903. It was for a suspension bridge of 1,800 feet central span on towers of 400 feet in height above water, with side spans finishing on brickwork anchorage towers. The main cables were 144 in number, each 3 15-16ths inches



BLACKWELL'S ISLAND BRIDGE—NEW YORK.