	Span.	Span.	Span.
L = total river span = $2m+l$	1,000 ft.	1,500 ft.	2,000 ft.
l = suspended span	500	650	800
m = cantilever arm	250	425	600
n = anchor arm	400	600	800
w = width C to C of trusses	50	60	80
d = depth of suspended trusses	50 – 85	75 – 110	100 – 135
h = depth at towers... ...	150	225	300

Load $L\ L$ = 18,000 lbs per lineal foot.

Wind = 30 lbs per square foot.

Working stresses for main members	Tension.	Compression.
Structural Steel	20,000	$\dfrac{20,000}{1 + \dfrac{l^2}{8000r^2}}$
Nickel Steel	30,000	$\dfrac{30,000}{1 + \dfrac{l^2}{8000r^2}}$

COMPARISON BETWEEN CANTILEVER AND SUSPENSION BRIDGES.

A great deal of controversy had raged over the respective merits of cantilever and suspension bridges. In the main, a cantilever was far more rigid, the stresses could be fully determined, and it was more suitable for heavy traffic, being rigid and only deflected to a small extent. A suspension bridge, on the other hand, was more graceful, cheaper to build for light traffic, and could be constructed in a shorter time, and, if suitably stiffened, would carry all moderately heavy traffic. As regards limiting spans for both types, a table was given below for comparison. The theoretical limiting span was that length of span when the dead-load ratio to live-load became infinitely great, and the bridge was only just self-supporting. The practical maximum span was the greatest length of span which it would be practicable to build in order to carry traffic. The maximum economic span marked the limiting span as regards cost and earning power, beyond which the bridge would very probably be a financial failure, although constructed successfully.

	Suspension.	Cantilever.
Theoretical limiting span	14,700	5,600
Practical maximum span	4,900	3,060
Maximum economic span	3,170	2,700
Span of equal cost	1,670	1,670

The suspension bridge was calculated for ample rigidity for railway traffic, in order to eliminate the advantage claimed for the cantilever (Steinman).

DECK SYSTEMS.

In order to calculate and design the decking, the amount and kind of traffic must be known in order to get the maximum possible loadings. Generally, railways and vehicular traffic were the only things to consider. In the case of railway loading, due provision should be made for traffic expansion and increased locomotive and train weights, and as there was a probability that electric locos. will come into more general use, the weights and wheel bases should be considered, and a typical wheel base diagram showing axle loads drawn out. From this and the weight of heaviest train per foot run, the loading would be adopted. Then the rail troughing system was worked out, this being carried on cross beams resting on floor stringers, which in their turn were carried by the main cross girders. This seemed to be the best system of carrying the live and dead loads to the main trusses. The advantage of the railway troughing was that in case of a derail the wheels would run along the longitudinal sleepers inside the troughing, and no great damage would be done. The roadway decking could be worked on similar lines to the railway, care being taken to place the traffic in each case in such positions as would give the worst possible maximum stress.

For girders of short spans ordinary medium steel was used, but long spans call for a stronger and high-class steel such as high grade carbon, nickel, nickel chrome, and vanadium steels, etc. Nickel steel had only been recently used to any extent. and it would be preferable to construct the cantilever trusses, suspended and stiffening trusses of this material. Carbon steel, however, was more suitable for decking owing to cheapness and to lesser secondary stresses induced on account of smaller deflections than if nickel steel were used.

A rough or trial estimate was required, first of all in order to get some idea of weights, and cost, then a second, or even a third, estimate might prove necessary to get a suitable design. One of the foremost bridge engineers in the United States, Ralph Modjeski, stated, "While it is easy to draw a diagram and a few of the principal details, it takes months of study of retracing one's steps, of tests and calculations, to make a complete design, and to learn that the preliminary diagram and sketch details must often be changed entirely to make a practicable and efficient structure."

The methods of erection of a cantilever bridge were very simple. The anchor was, first of all, built out on falsework from the anchor pier to main pier. Then the harbour, or cantilever, arm was built out, cantilever fashion, without the necessity for further falsework and consequent blocking to shipping. Cranes could be run out on arm already built, and by hoisting the various members into place and rivetting up, the structure grew until the arm was completed. The Suspension Span could then be erected by building out from both ends of cantilevers and joining up in the middle, or the span could be erected on large pontoons and floated on to the site. The former way was, perhaps, preferable, especially where the height above the water was considerable.

Before erection of any part of bridge erection stresses were carefully calculated, and where working stresses might be exceeded, temporary members were put in to take the added load. When completed all these temporary members were removed. When finally completed, with all the decking in place, a test load was generally placed in certain fixed positions, and by means of extensometers the actual deflections were noted in various members and compared with those calculated.

EXAMPLES OF DIFFERENT BRIDGES.

(1) Suspension Bridge over the Hudson River at New York (proposed)—Fig. 4. The Inter-State Commission recommended a stiffened cable suspension bridge with eyebar cables. The distance, centre to centre of towers, would be 2880 feet, and clear height over fairway for navigation of 170 feet. The traffic service to be carried consisted of four lines of railway, four lines of tramway, two roadways, and two footways, the total maximum loading amounted to 20,000lbs. per lineal foot of bridge. This bridge was estimated to cost £8,400,000, and would be the largest bridge, by far, if constructed.

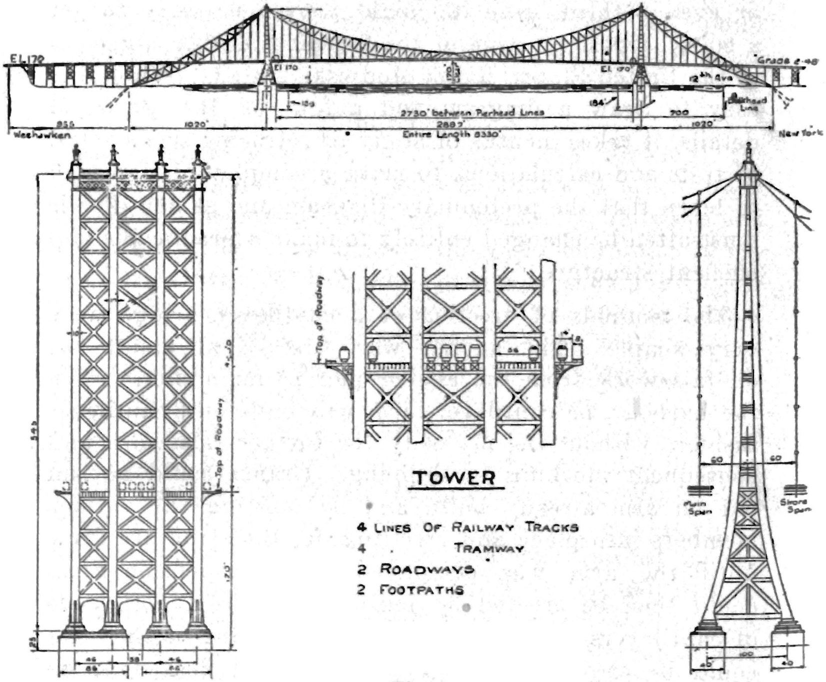
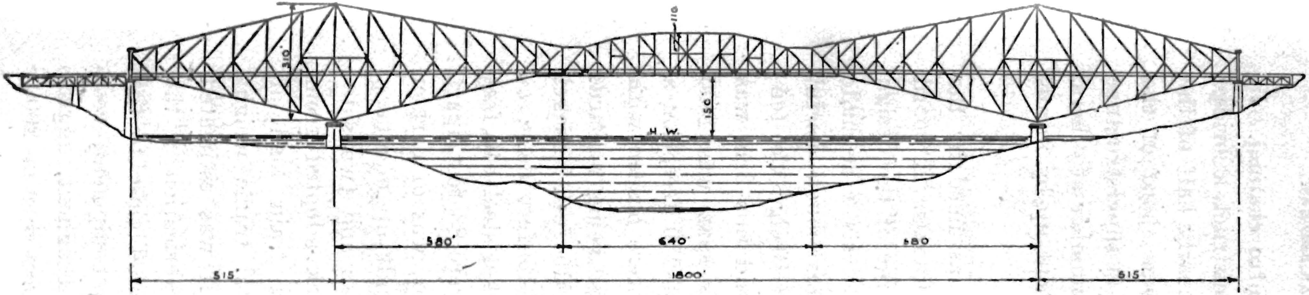
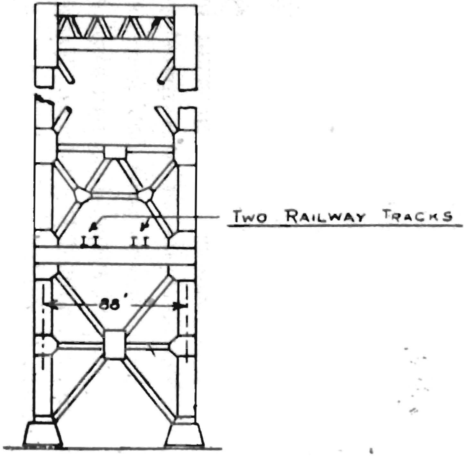


Fig. 4

(2) Cantilever Bridge over the St. Lawrence River at Quebec—Fig. 5. This bridge was located eight miles west of Quebec. The river, at this part, was about 1800



Plan 17—New Quebec Bridge.



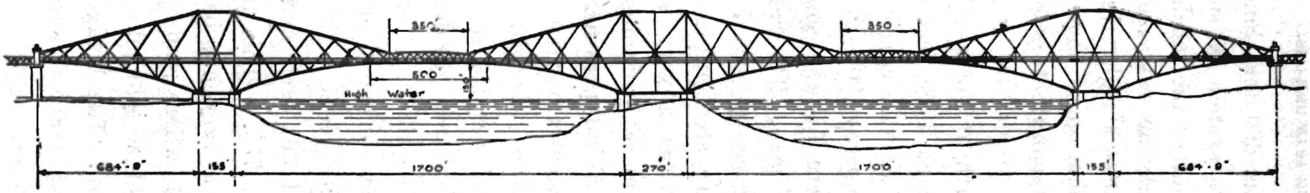
Plan 17.—Section at Pier.

Fig. 5

feet wide and 200 feet deep in the centre channel. In 1907, when the original attempt to construct a bridge was made, the south anchor arm and nearly half of the main span were erected, when the lower chord of the anchor arm truss failed and 17,000 tons of superstructure fell, killing 75 workmen and injuring a number of others. This was, later, regarded as scrap and cut up by means of acetylene blowpipes.

The building of the new bridge was assumed by the Canadian Department of Railways and Canals. A board of engineers was appointed to take charge of the design and construction. Several ¼-size model tests were made of the compression members, and thus much useful information gained. The St. Lawrence Bridge Co. tendered a design, which was accepted, and this firm was now building the structure. The clear span was 1800 feet, with a headway for shipping of 150 feet, for a length of 640 feet. The main trusses were braced with the "K" system, the top wind laterals being omitted. Carbon steel anchor arm spans were 515 feet. Nickel steel, cantilever arms 580 feet long, 310 feet deep, at towers, and suspended span also of nickel steel 640 feet long, a modified Pratt truss. Trusses were 88 feet apart centre to centre. The decking, however, was of carbon steel. The tension top chords were built up members. The service carried was two rail tracks and two sidewalks. Railway loadings on each track adopted from two E 60 locomotives, follwed by a train load of 5000 lbs. per lineal foot, and the total traffic weight was 10,000 per foot run of bridge. It was estimated to cost £2,400,000. To facilitate the fabrication of the bridge members, a workshop was erected close to the site, which, including land, shop, and equipment, cost £200,000. Electric power was used throughout, aggregating 1000 h.p., and the output expected was 2000 tons per month. The main shop was 660 feet long, by 160 feet wide, with a comprehensive system of surface tracks and crane runways. The layout of the machinery was so systematically arranged that the raw material entered the shop at one end and passed right through in successive stages. This description gave some idea of the large plant necessary in the manufacture of big bridges.

(3) Cantilever Bridge over the Firth of Forth—Fig. 6. This bridge contained two spans, each 1700 feet clear, the length over all being 8295 feet. Service carried was a double line of railway, and two footways, these latter, not being opened to the public, were for the sole use of railway officials and maintenance men. The ratio of depth of trusses at pier to depth at centre was 7 to 1. The main compression members were steel tubes ranging up to 12 feet diameter. This was a very strong construction, and reduced the amount of stiffening and secondary bracing to a minimum. Wind pressure was provided for in the calculations in exposed positions, and was taken at 56lbs. per square foot over twice the whole area of girder exposed. The rail level was 157 feet, and clear headway 151 feet above high water. Under full loading of two trains the deflection calculated at the centre was 3½ inches. Each tower consisted of four columns built up on circular granite piers. The central tower had an extreme height of 361 feet, and had an inward batter at the top of 1 in 7½. This tower, situated on Inchgarvie Island, had a very big base to counteract the overturning moment when loads were placed unsymmetrically. The total weight of traffic allowed for was 4480lbs. per foot run. The bridge was completed in 1890 at a cost of over £3,000,000, and was the most important yet constructed.


Elevation.

Forth Bridge.

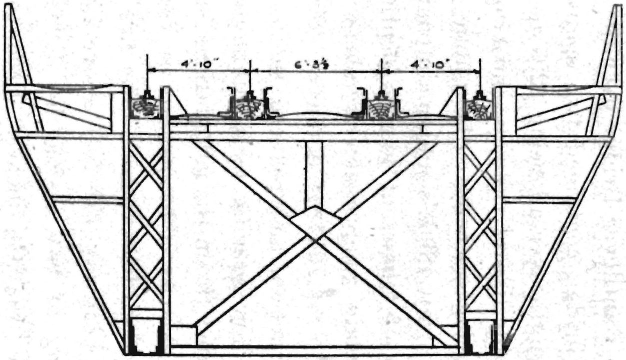


Fig. 6

(4) Williamsburg Suspension Bridge over the East River at New York—Fig. 7. Six years were taken in the completion of this bridge, the cables taking twelve months to manufacture. It was thrown open to traffic in 1903. Centre to centre of towers measured 1600 feet. and clear headway of 135 feet. Traffic served was a double line of railway, four lines of tramway, two roadways, and two footways, including cycle track.

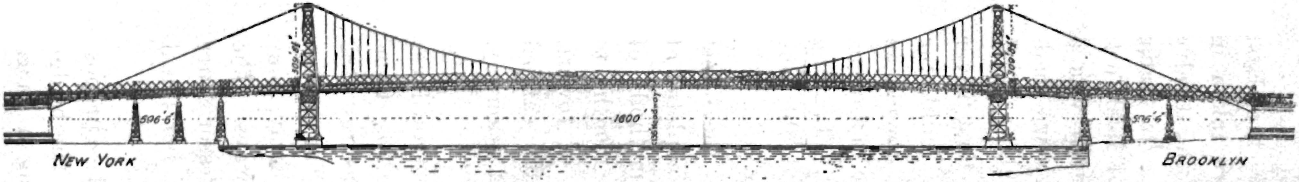
(5) Brooklyn Suspension Bridge over the East River at New York. This took fourteen years to build, the cables occupied two years, and traffic was opened in 1884. Clear span, 1595 feet 6 inches to centre of towers. and clear height for navigation of 135 feet. Loading was derived from a double line of railway, a double line of tramway, two roadways, and one footway.

(6) Manhattan Suspension Bridge over the East River, New York—Fig. 8. This bridge was completed at the end of 1909, and owing to improved methods of manufacture, the cables only occupied four months to manufacture. Clear span 1470 feet centres of towers, headway for shipping 135 feet. The traffic carried includes four lines of railway, four lines of tramway, one roadway, and two footways.

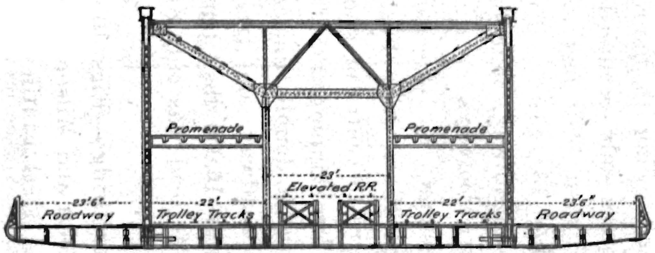
(7) Blackwell's Island, or Queensboro' Cantilever Bridge over the East River, New York—Fig. 9. Completed in 1909. Centre to centre of piers measures 1182 feet, and headway for shipping 135 feet. The bridge was designed to carry a double line of railway, four lines of tramway, a roadway, and two footways. The calculated loading was 16,000 lbs., but Professor Burr estimated that the safe load was only 8442lbs. per lineal foot.

(8) Sydney Harbour Bridge—Figs. 10 and 11—(proposed) between Dawes Point and Milson's Point. The bridge will consist of nickel steel cantilevers, having a shore

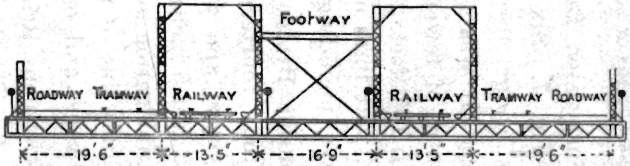
Elevation.



Plan .19—Williamsburg Bridge.

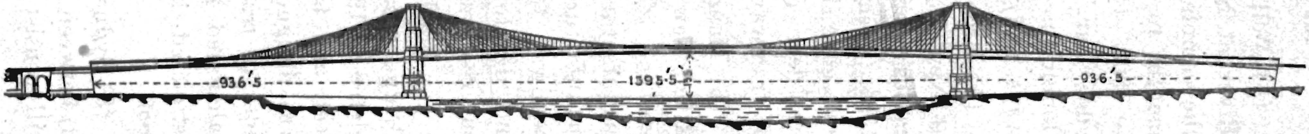


Plan 19.—Cross Section.



Plan 20.—Cross Section.

Elevation.



Plan 20—Brooklyn Bridge.

Fig. 7.

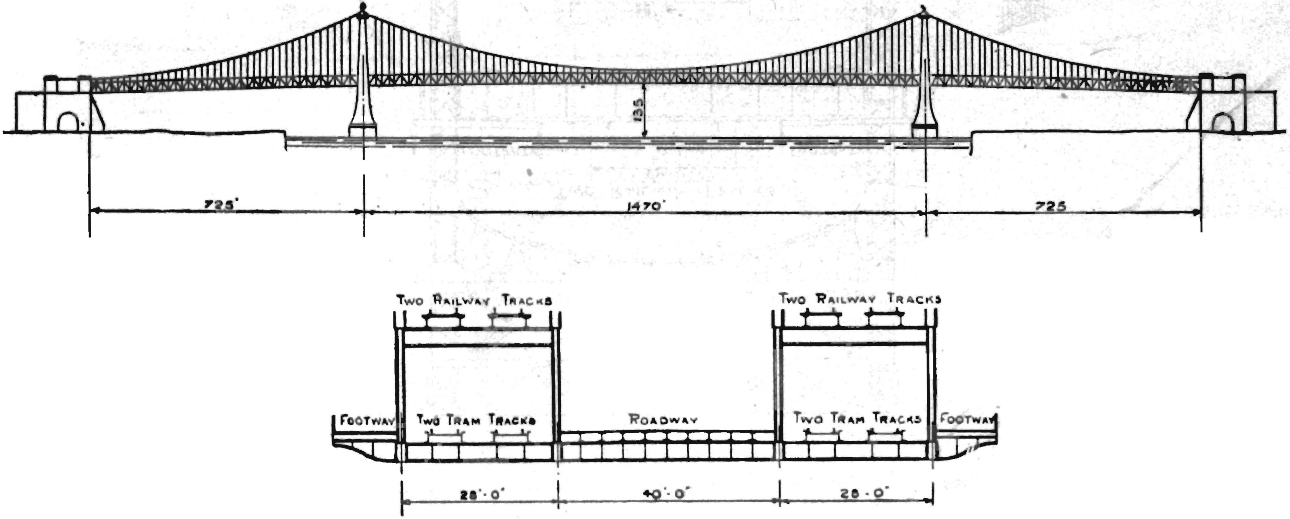

135
725'
1470'
725
Two Railway Tracks
Two Railway Tracks
Footway
Two Tram Tracks
Roadway
Two Tram Tracks
Footway
28'-0"
40'-0"
28-0"

Fig 8.

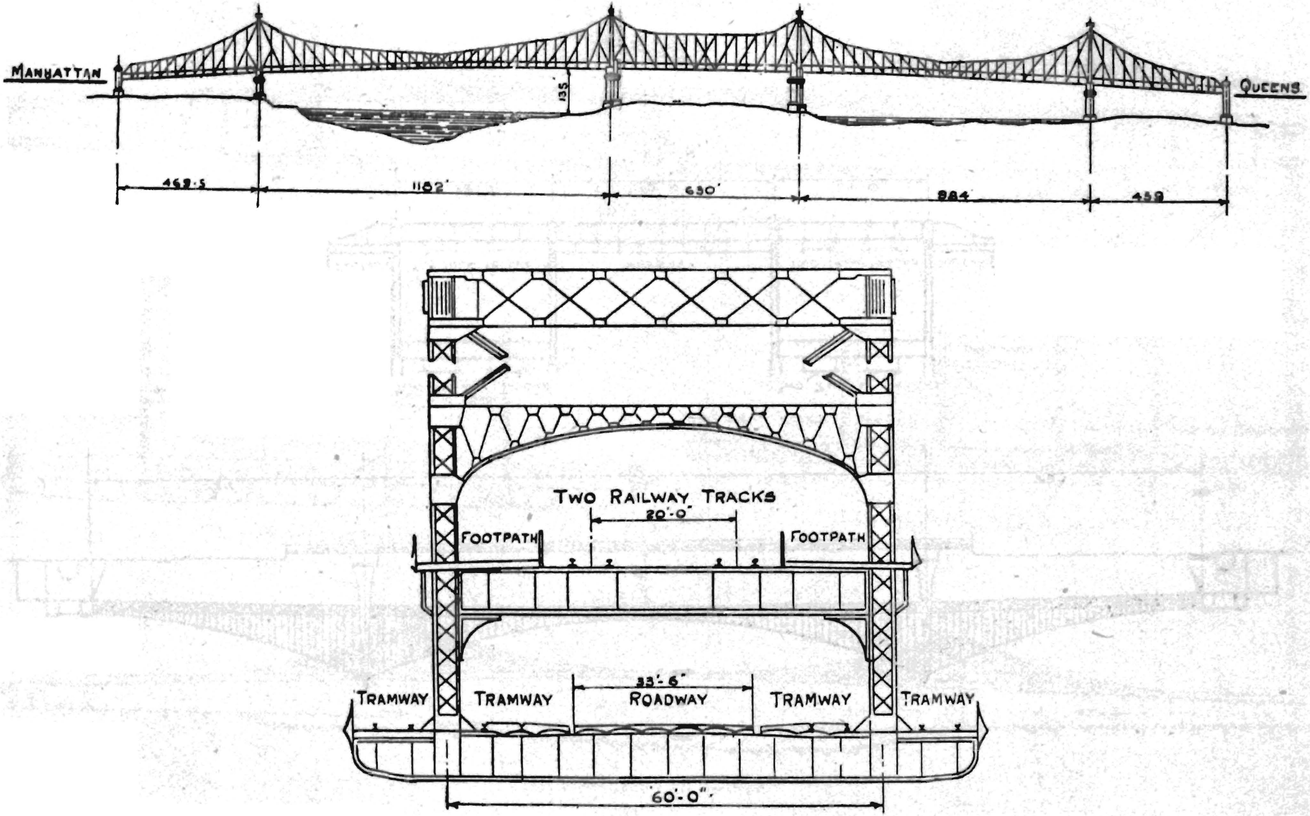
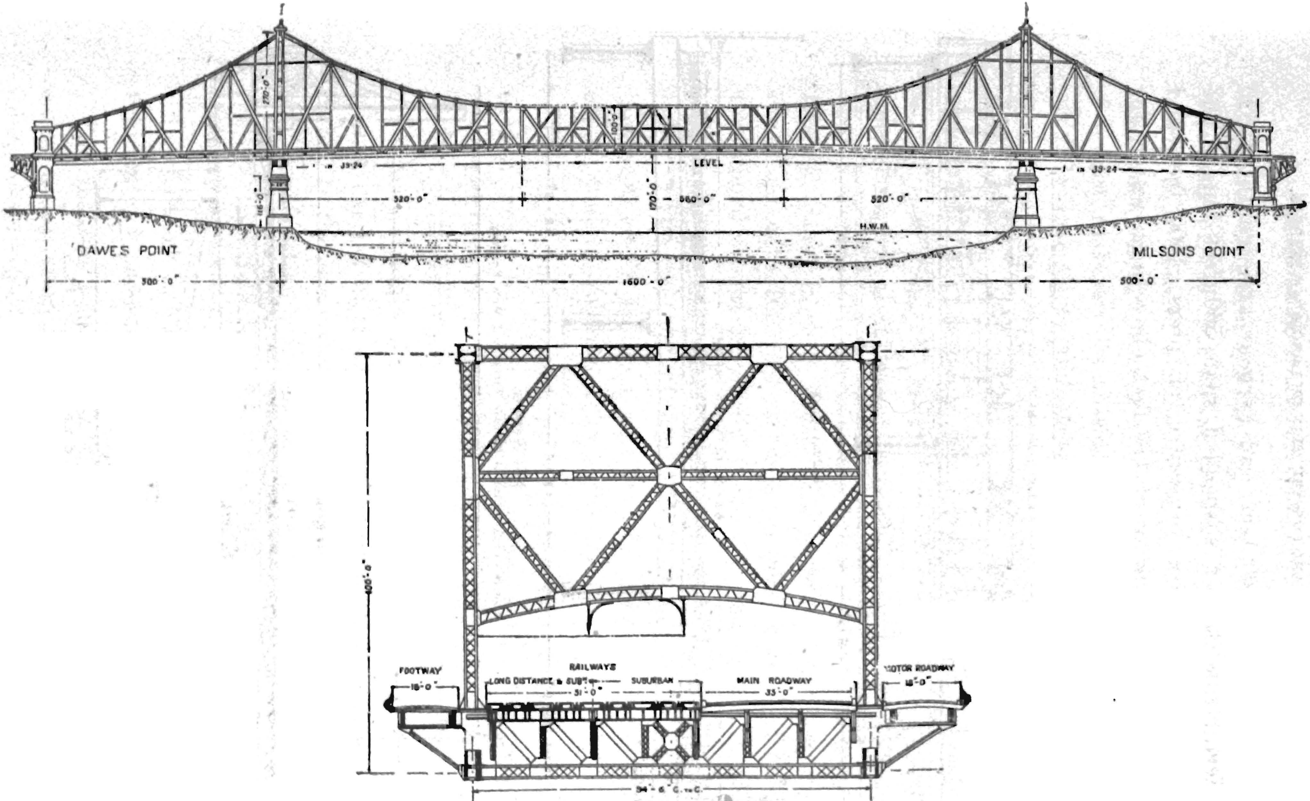

MANHATTAN
QUEENS
135'
469.5
1182'
630'
984
459
TWO RAILWAY TRACKS
20'-0"
FOOTPATH
FOOTPATH
TRAMWAY
TRAMWAY
33'-6"
ROADWAY
TRAMWAY
TRAMWAY
60'-0"

Fig. 9

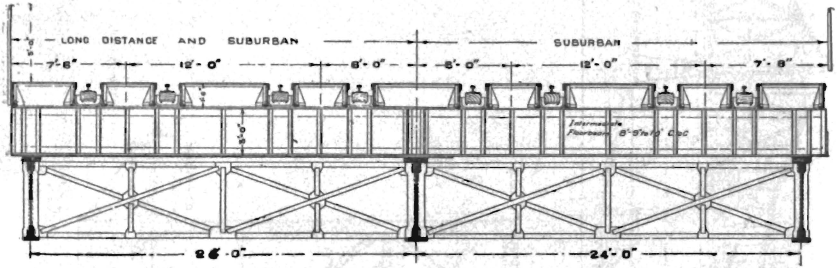


CROSS SECTION AT CENTRE

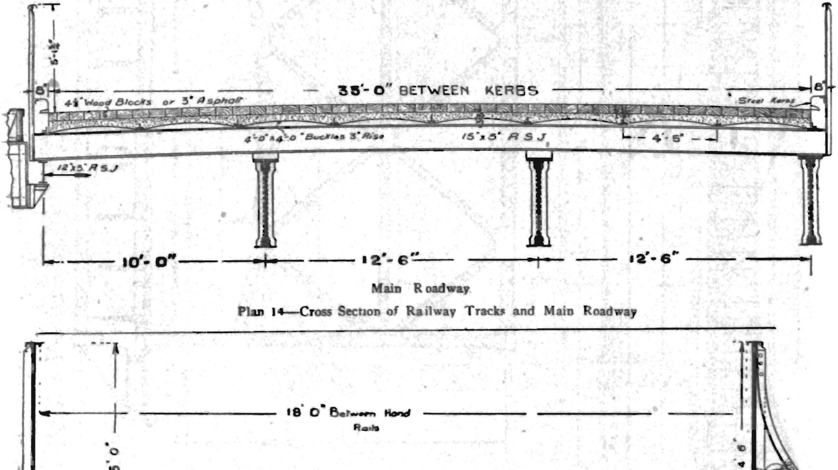
Plan 12.—Cross Section.

Fig. 10

arm length of 500 feet, and harbour arm length of 520 feet, supporting a suspended span 560 feet long. The clear span, centre to centre of piers, 1600 feet, and headway for shipping of 170 feet above high water, for

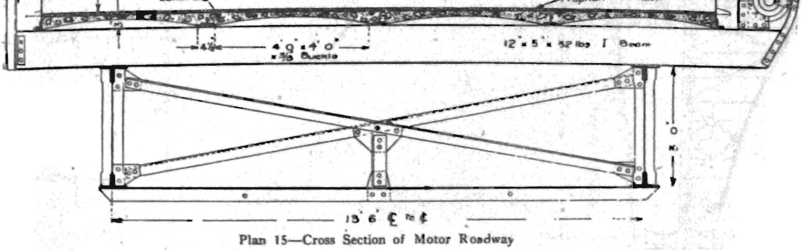


Railway Tracks



Main Roadway

Plan 14—Cross Section of Railway Tracks and Main Roadway



Plan 15—Cross Section of Motor Roadway

Fig. 11

a central 600 feet of bridge; diminishing down to a headway of 156 feet at the towers. It was designed to carry four lines of electric railway, and a 35 feet roadway between the trusses which would be spaced 94 feet 6 inches apart, whilst outside would be carried a motorway 18 feet wide, and footway 15 feet wide on cantilever brackets. The main trusses at the towers would be seated on cast steel bearings, which distribute the reactions evenly, through rolled steel joists and concrete to the tops of piers. Sway bracing would be provided between vertical members, and both top and bottom chords would be braced to take wind loads. The main trusses would have a depth of 270 feet at the towers, diminishing to 100 feet at the suspended span; the bottom chord would be straight up, but top chord (composed of two tiers of eyebars) would describe a parabola. The contour of top booms in the shore arms, however, would be a circular arc, the tangent to which, at extremity, would not be horizontal.

The floor systems, with the exception of the main cross girder, would be constructed of carbon steel. The rails for truck would be fixed on longitudinal wooden sleepers set in troughing, very similar to the construction on the Forth Bridge. This troughing would rest on crossbeams, carried in their turn on longitudinal stringers attached to the cross girders. Roadway, motorway, and footway construction was similar, there being a top wearing surface of asphalt over concrete, carried on buckle plates attached to crossbeams.

Latticework handrails were provided for the safety of vehicles and pedestrians.

The loading adopted on the two western tracks, to carry heavy traffic, was a conventional train, 615 feet long, consisting of an electric loco., 65 feet long, weighing 160 tons, and cars for length of 550 feet, weighing 2000lbs. per foot. The suburban railway tracks were to carry a train 500 feet long, weighing 2240 lbs. per foot.

Concentrated loading for main roadway and motorway could be derived from conventional traffic loading. The footway loading adopted was 100lbs. per square foot for deck system, reduced to 80lb. per square foot for cantilevers and suspended span.

For length of span the proposed Sydney Harbour Bridge ranked third in the world, viz., (1) Quebec Bridge 1800 feet, Forth Bridge 1700 feet, Sydney Harbour Bridge 1600 feet, Williamsburg Bridge 1600 feet, whilst for amount of headway it would rank first, viz., (1) Sydney Harbour Bridge 170 feet, as against 150 feet headway for Quebec and Forth Bridges, whilst the traffic it was designed to carry aggregated 14,600lbs. per lineal foot, as against 10,000lbs. per lineal foot for Quebec Bridge, and 4,480lbs. for Forth Bridge.

In conclusion the author wished to state that all information and illustrations of the Sydney Harbour Bridge, and other examples of long span bridges, were extracted from the paper prepared by J. J. C. Bradfield, M.E., M.Inst. C.E., on "Linking Sydney with North Sydney," and read before the Sydney University, Engineering Society, in November, 1913.

Discussion.

MR. TOURNAY-HINDE said he desired to propose a very hearty vote of thanks to Mr. Fry for his interesting and descriptive paper, to which he was sure everyone present at the reading thereof had listened with the keenest pleasure.

It was not his intention to attempt anything in the way of criticism upon the various matters embraced by the paper, but only to secure, if possible, a little more in-