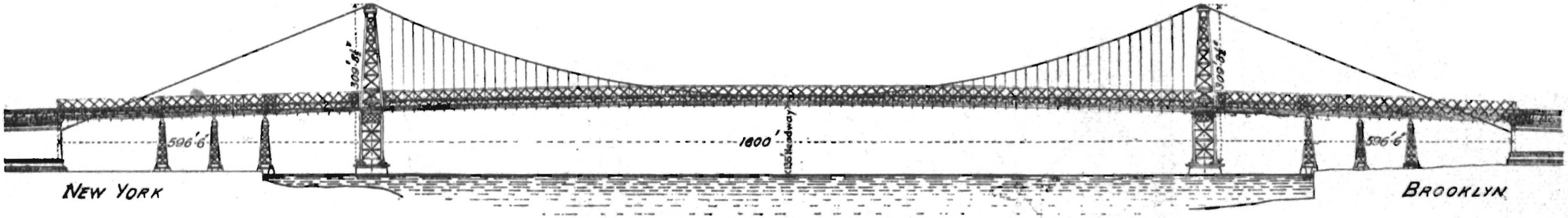
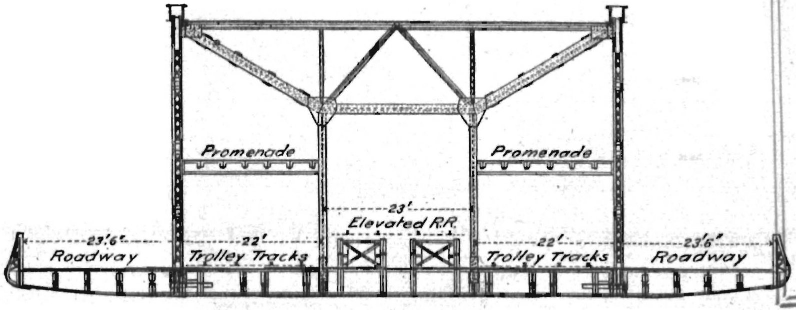
PLAN No. 19.

WILLIAMSBURG BRIDGE—EAST RIVER, NEW YORK.

OPENED DECEMBER, 1903.



ELEVATION.



CROSS SECTION.

Another bridge is now under construction; when completed, it will have the longest clear span in the world, viz., 1,800 feet centres of piers. Clear headway for shipping, 150 feet for a length of 640 feet. The bridge has been designed for a double line of railway, to carry 5,000lbs. per foot of track; the total weight of traffic to be carried is 10,000lbs. per lineal foot of bridge.

(3) Cantilever bridge over the Firth of Forth. Plan No. 18.

This bridge, the most important yet constructed, was completed on 4th March, 1890, at a cost of over £3,000,000. Span, centre to centre of towers, 1,912ft. 6in.; clear span, 1,700ft.; clear headway for shipping, 150ft. for a length of 500ft. The bridge has been designed for a double line of railway, to carry 1 ton per foot of track; total weight of traffic to be carried is 4,480lbs. per foot of bridge.

(4) Suspension Bridge over the East River, at New York. Williamsburgh Bridge. Plan No. 19.

This bridge was completed in six years, of which the cables took one year to construct. It was opened for traffic in 1903. Clear span, 1,600 feet, centres of towers; headway for shipping, 135 feet. The bridge has been designed for a double line of railway, four lines of tramway, two roadways, and two footways, including cycle tracks.

(5) Suspension Bridge over the East River, New York. Brooklyn Bridge. Plan No. 20.

This bridge was completed in 1884, and took 14 years to construct, of which the cable occupied 2 years.

Clear span, 1,595ft. 6in., centres of towers; headway for shipping, 135ft. The bridge has been designed for a double line of railway, a double line of tramway, two roadways and one footway.

(6) Suspension Bridge over the East River, New York. Manhattan Bridge. Plan No. 21.

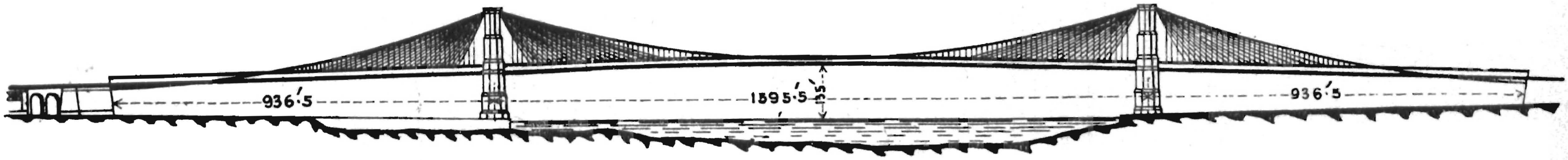
This bridge was opened for traffic on December 31st, 1909. On account of improved methods, the cables took only 4 months to construct, as against 2 years for the cables of the Brooklyn Bridge and 1 year for those of the Williamsburgh Bridge. Clear span, 1,470 feet, centres of towers; headway for shipping, 135 feet. The bridge has been designed for four lines of railway, four lines of tramway, one roadway and two footways.

(7) Cantilever Bridge over the East River, New York. Blackwells Island or Queensboro Bridge. Plan No. 22.

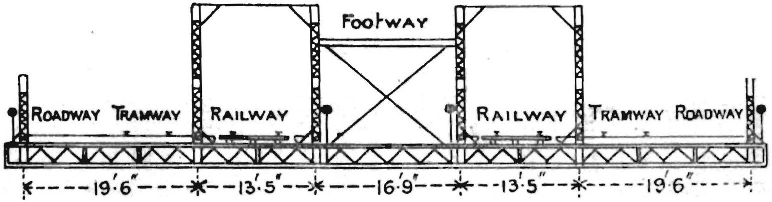
Plan No. 20.

BROOKLYN BRIDGE—EAST RIVER, NEW YORK.

Completed 1884.



Elevation.

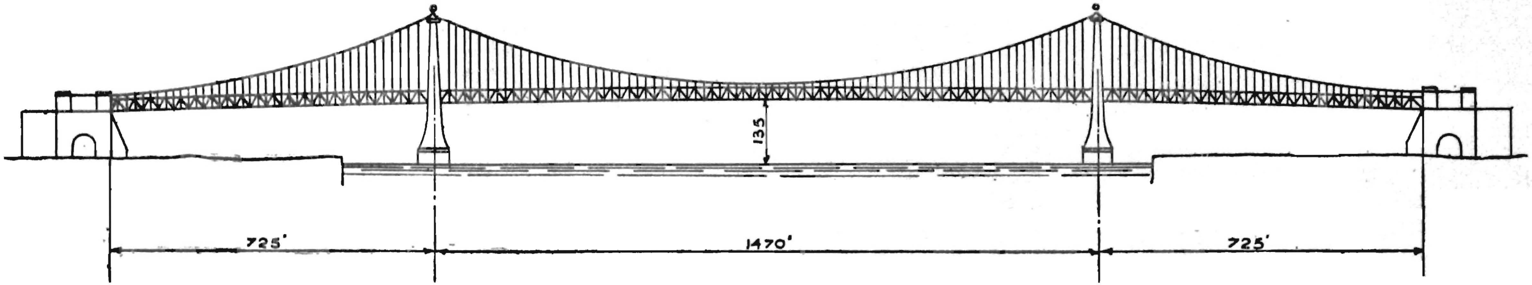


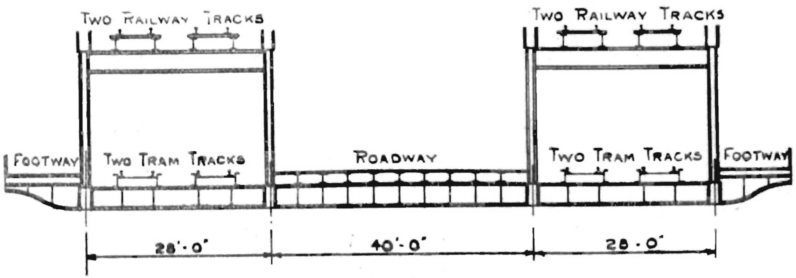
Cross Section.

Plan No. 21.

MANHATTAN BRIDGE, EAST RIVER, NEW YORK

Opened December 31st, 1909.



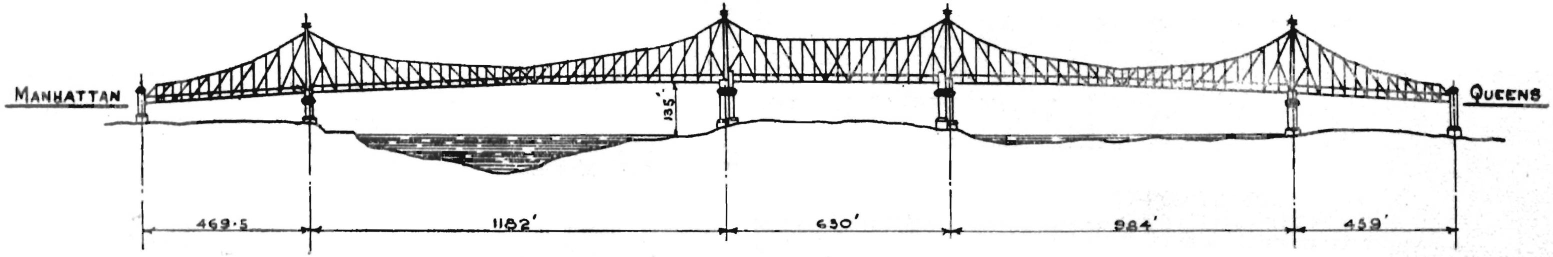


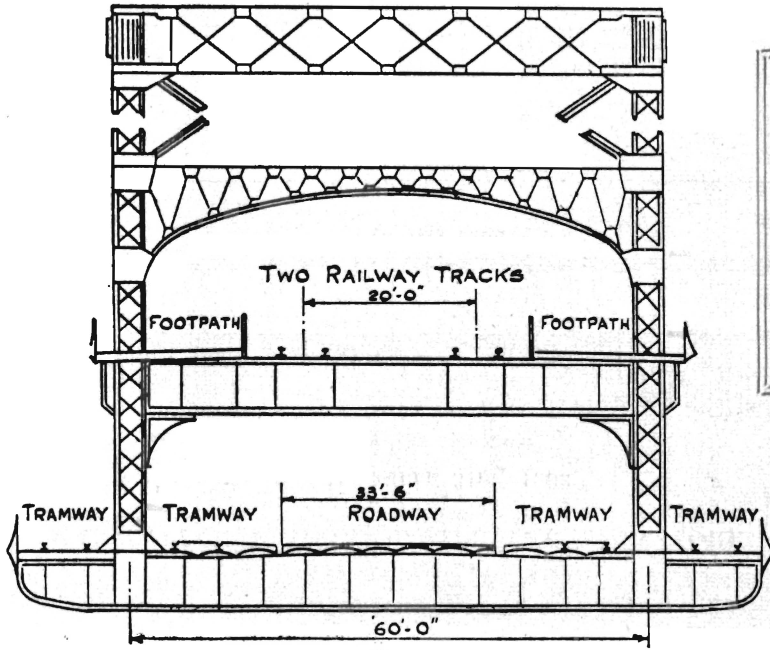
Cross Section.

PLAN NO. 22.

QUEENSBORO BRIDGE, EAST RIVER, NEW YORK.

COMPLETED, 1909.

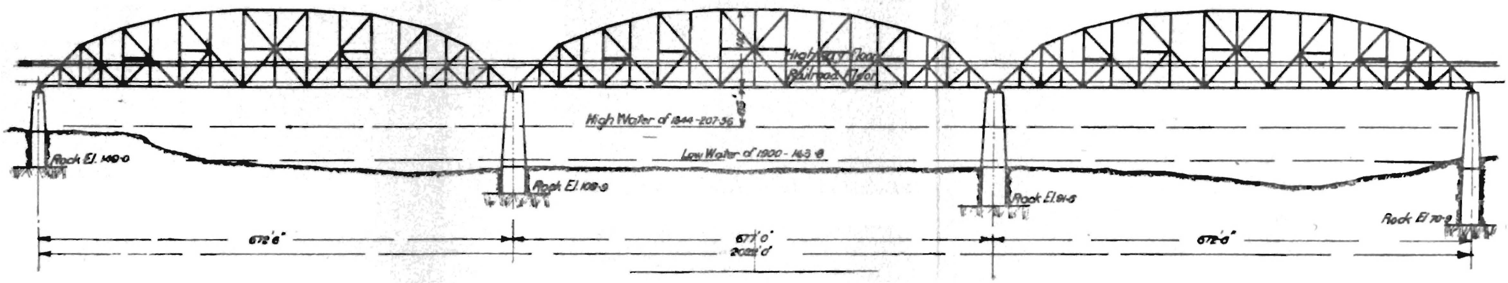


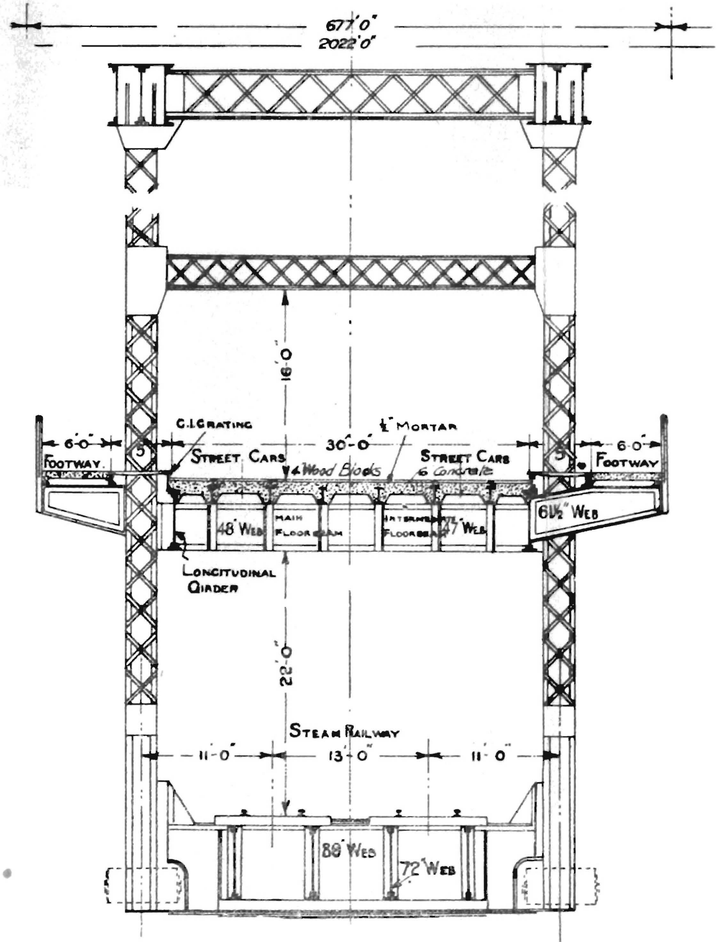


Plan No. 23.

MUNICIPAL BRIDGE,

Crossing Missisippi River, St. Louis, U.S.A.





Cross Section.

This bridge was opened for traffic in 1909. The largest clear span is 1,182 feet, centres of piers; headway for shipping, 135 feet. The bridge has been designed for a double line of railway, four tramway tracks, a roadway and two footways. The bridge was intended to carry traffic aggregating 16,000lbs. per lineal foot, but the safe load is estimated by Professor Burr to be 8,442lbs. per lineal foot.

(8) Truss Bridge over the Mississippi River at St. Louis. Plan No. 23.

This bridge—668 feet span—though much shorter in span than any of the foregoing, has been included, as it is the longest truss span bridge yet erected. The bridge carries on the lower deck a double line of steam railway, and on its upper deck a roadway 30 feet wide and two 6ft. footpaths. Provision is made on the roadway for a double line of tramway.

For length of span, the proposed Sydney Harbour bridge, Plan No. 12, would rank third in the world, viz.: Quebec Bridge, 1,800 feet; Forth Bridge, 1,700 feet; Sydney Harbour Bridge, 1,600 feet; Williamsburgh Bridge, 1,600 feet. For headway for shipping the Sydney Harbour Bridge would rank first, viz.: 170 feet headway, as against 150 feet headway for the Quebec and Forth Bridges, whilst it is to be designed to carry traffic aggregating 14,600lbs. per lineal foot of bridge, as against 10,000lbs. per lineal foot for the Quebec Bridge, and 4,480lbs. per lineal foot for the Forth Bridge.

The Sydney Harbour Bridge would be the first long span bridge, the main girders of which would be constructed entirely of nickel steel.

A truss bridge from Dawes' Point to Milson's Point similar to the St. Louis Municipal Bridge, shown on Plan No. 23, providing for the same traffic as the cantilever design recommended, with railway connections from Bay Road to Wynyard Square, could be constructed for £2,000,000, but it would be objectionable in that there would be one pier in the centre of the fairway. To keep the fairway unobstructed will cost quite £750,000, but in view of the recent unprecedented growth in the length and tonnage of shipping, this expenditure is warranted, as in equity the water-borne traffic should receive the first consideration.

UNIT STRESSES.

It is the usual practice to adopt higher working stresses for long span bridges than obtain for bridges of shorter span. The main factors justifying this practice are as follows:—

(1) For bridges of long span, the maximum live load stress will in general not exceed about 45 per cent. of the total stress, whilst for bridges of shorter span it may, and often will, exceed 80 per cent. of the total stress.

For Sydney Harbour Bridge, Plan No. 12, typical members of the suspended span show ratios of live load stress, including impact to total stress of 45 per cent. for the truss adjacent to the railways, and of 38 per cent. for the truss adjacent to the roadway, whilst for the main members of cantilever arms, the live load stress will not exceed $\frac{1}{3}$ of the total stress.

For the St. Louis Municipal Bridge, Plan No. 23, in the main compression chord members the ratio of live load to total stress is 46 per cent. exclusive of impact.

For the Queensboro' Bridge, Plan No. 22, in the main compression chord members the ratio of live load to total stress is 45 per cent., exclusive of impact.

For the original Quebec Bridge the estimated stresses for the main chord member were: Dead, 11,249 tons; live, 4,000 tons. The ratio live load to total stress was 26 per cent. exclusive of impact. This was a cantilever railway bridge of 1,800ft. span, which collapsed during construction in 1907, and is now being erected on a new design.

For short span bridges the ratio of live stress, including impact to total stress is much greater. Typical chord members of a 200ft. span Pratt truss single track railway bridge as erected in New South Wales give a ratio of 78 per cent.; the corresponding ratios for 157ft. and 120ft. truss spans are 79 per cent. and 81 per cent. respectively, and for the standard 66ft. single track plate web girder bridge the ratio of live load including impact to total stress is 84 per cent.

In deriving these figures, impact is based on the formula:

$$I = S \left(\frac{300}{L + 300} \right) \text{ where}$$

I = impact stress to be added to the live load stress S,
& L = loaded length of bridge in feet, which produces the maximum live load stress in member.

These examples show that the ratio of live load stress to total stress for long span bridges is much less than for bridges of shorter span.

The dead load exerts a constant stress, the live load exerts a continually varying stress—the smaller the range in the value of this stress, the less likely is the steel to become fatigued and develop brittleness, consequently where the range of stress is smaller a higher workirng stress can safely be adopted.

(2) In the case of long span bridges carrying mixed traffic, the maximum live stress possible will seldom, if ever, be realised, unless the bridge carries traffic heavier than that for which it was designed, as it is only remotely possible that the traffic will at any time be disposed as is assumed in the calculations for maxima live stresses.

On the other hand, the members of short span bridges, also the cross girders and stringers of long span bridges may frequently receive the maximum stresses for which they are designed.

To give the calculated maxima stresses in members of the Sydney Harbour bridge, trains of the maximum weight adopted would have to be in definite positions on all four tracks, the main roadway fully or partially loaded to 100lbs. per square foot, according to the position of the member under consideration, whilst the pathway and motor roadway would similarly have to be fully or partially loaded to 80lbs. per square foot at the same instant. Whilst such combinations of loading are possible, they are also improbable, and a unit stress can be used in conjunction with the total calculated stress, higher than if the total stress could originally be realised in practice.

The working stresses proposed by the various authorities for nickel steel are derived from the results of practice in the use of carbon steel, combined with the relative strength of the two materials when tested. The general practice is to allow for nickel steel a 50 per cent. increase over the stresses proved satisfactory for carbon steel, the apparent reason being that nickel steel is about 50 per cent. stronger than carbon steel. This practice has been in general followed for Sydney Harbour bridge, except in the matter of bearing stresses and shear on rivets. The soft nickel steel rivets would give results about 16 per cent. better than carbon steel rivets, as proved by tests, so approximately this increase in unit stress has been allowed for in stresses on rivets. The results of tests carried out in America in connection with the Manhattan, Blackwells Island and Quebec bridges show that nickel steel plates, shapes and eyebars can be manufactured with an ultimate tensile strength ranging from 85,000 to 100,000lbs. per square inch, with an elastic limit of 50,000lbs. per square inch for plates and shapes, and 48,000lbs. for full-sized eyebars.

A working stress of 30.000lbs. per $\frac{3}{5}$ square inch, i.e., of the elastic limit has been adopted on the net area. This will allow a factor of safety of about 3 on the ultimate tensile strength, and a factor of safety of $1\frac{2}{3}$ on the elastic limit.

The tests of $\frac{1}{4}$ full-sized model columns of the Quebec Bridge compression members and of $\frac{1}{2}$ full-size model columns of the St. Louis Municipal Bridge indicate that full-sized nickel steel compression members can be constructed to develop an elastic limit of 40,000lbs. per square inch. and an ultimate strength of quite 60.000lbs. per square inch. The maximum working stress to be adopted for nickel steel in compression is 24,000lbs. per square inch, i.e., $\frac{3}{5}$ of the elastic limit of full-sized columns. This will allow a factor of safety of $2\frac{1}{2}$ on the ultimate strength of full-sized members and $1\frac{2}{3}$ on the elastic limit.

To accurately estimate the stresses to which the members are subjected under normal conditions of loading is impossible.

In the design of the Blackwells Island Bridge (Queensboro) the normal live load was estimated to be 50 per cent. of the maximum live load possible, and two sets of calculations were necessary, one for normal or regular loading, and the other for the maximum possible, i.e., the congested loading. With the normal loading unit stresses applicable to small span bridges were adopted; for congested loading a higher unit stress, approaching $\frac{4}{5}$ of the elastic limit of the material was adopted.

In the calculations for the Sydney Harbour bridge, the method adopted is to calculate the maxima possible stresses due to all conditions of loading, and with these maxima stresses to use a working stress higher than would be used for short span bridges.

Different unit stresses have been adopted for members, subject to a combination of loads, and for members not subject to a combination of loads.

Throughout the bridge combined stresses from bending due to a member's own weight; additional bending moments set up in columns due to deflection, also deflectional stresses in all members and other secondary stresses must be added to direct stresses and any total fibre stress kept within the limits stated.

Members Subject to a Combination of Loads (Class I.).—In determining the sectional areas, the unit stresses set forth below are to be used in conjunction with:

(a) The maximum possible stress from the combined railways, roadway, motor roadway and footway, together with dead load stress and impact.

(b) Dead load combined with wind stresses.

Tension eyebars	Nickel steel .	30,000lbs per sq. in. on net area
Tension built members ..	Nickel steel .	28,000 do. do. do.
do. do. do. ..	Carbon steel .	20,000 do. do. do.
Compression	Nickel steel .	28,000 — 90 L ÷ r with a max. of 24,000lbs. per sq. in. on the gross area.
do.	Carbon steel .	20,000 — 80 L ÷ r with a max. of 15,000lbs. per sq. in. on the gross area.
Shear machine driven rivets. .	Nickel steel .	16,000lbs. per sq. in.
do. ..	Carbon steel .	14,000 do. do. do.
Shear hand driven rivets ..	Nickel steel .	12,800 do. do. do.
do. ..	Carbon stee .	11,200 do. do. do.
Bearing machine driven rivets. ..	Nickel steel .	30,000 do. do. do.
do. ..	Carbon steel .	26,000 do. do. do.