Bearing hand driven
rivets .. Nickel steel . 24,000 do. do. do.
do. .. Carbon steel . 21,000 do. do. do.
Bending in pins ...... Nickel steel . 40,000lbs. per sq. in. in outer fibre
do. ...... Carbon steel . 26,000 do. do. do. do.
Bearing on pins ...... Nickel steel . 30,000 do. do. do. on diameter of pins.
do. ...... Carbon steel . 26,000 do. do. do. do.
Shear on pins ...... Nickel steel . 16,000 do. do. do.
do. ...... Carbon steel . 14,000 do. do. do.

Members Not Subject to Combined Loads (Class II.).—In determining the sectional areas the unit stresses set forth below are to be adopted for the following members:—

(a) The web members of cross girders and all other bridge members, which do not depend on a combination of live loadings to produce the maximum possible stress.

(b) Wind laterals, wind and sway bracing.

Tension .... Nickel steel . 25,000lbs. per sq. in. on net area
do. .... Carbon steel . 17,000 do. do. do.
Compression .... Nickel steel . 24,000 — 80 L ÷ r with a max. of 20,000lbs per sq. in. on gross area.
do. .... Carbon steel . 17,000 — 70 L ÷ r with a max. of 12,500lbs. per sq. in. on gross area.
Flange stress ...... Tension on flanges of plate girders, stringers, &c., and extreme fibre stress on tension side of rolled beams, troughs, &c., 16,000lbs. per sq. inch.
Web shear .... Plate girders or beams 7,500lbs. per sq. in. on gross area.
Shear machine driven
rivets .. Nickel steel . 14,000lbs. per sq. in.
do. .. Carbon steel . 12,000 do. do. do.
Shear hand driven
rivets. .. Nickel steel . 11,200 do. do. do.
do. .. Carbon steel . 9,600 do. do. do.
Bearing machine driven
rivets .. Nickel steel . 25,000 do. do. do.
do. .. Carbon steel . 21,500 do. do. do.
Bearing hand driven
rivets .. Nickel steel . 20,000 do. do. do.
do. .. Carbon steel . 17,000 do. do. do.
Bending in pins ...... Nickel steel . 30,000 do. do do. in outer fibre
do. ...... Carbon steel . 22,000 do. do. do. do.
Bearing on pins ...... Nickel steel . 25,000 do. do. do. on diameter of pins
do. ...... Carbon steel . 21,500 do. do. do. do.
Shear on pins ...... Nickel steel . 14,000 do. do. do.
do. ......Carbon steel . 12,000 do. do. do.

It will be noted that unit stresses 6 per cent. less than for eyebars are specified for built tension members. This is considered advisable, owing to the lesser strength of built members, as proved by test, the wide thin plates having a tendency to tear when heavily stressed.

It was considered desirable that compression members acting as columns should be well within the limits of bending under axial load for ideal conditions, viz., the material to be homogeneous and the line of stress to be coincident with the neutral axis of the member. Any theory which considers the bending stresses involved by axial load is inapplicable, and to keep the struts well within the limits of rigidity, either the working stress of long struts must be low or a definite limit placed on the value of $L \div r$. This limit was fixed at 100.

During the inquiry by the Advisory Board in 1902-3, the question was raised that Euler's formula should be used in designing the compression members. The author does not think this formula should be used. Euler's formula (for pinned columns) is:

$$P = \frac{\pi^2 E I}{L^2} \quad \text{where}$$

P = least axial load necessary to cause a small lateral deflection in column.
E = modulus of elasticity.
I = moment of inertia.
L = length of column.

It is evident that the Euler formula cannot differentiate between nickel and carbon steel since both of these have about the same co-efficient of elasticity.

The following table shows the comparison of the bending strength of columns, as given by Euler's formula, and the working stresses adopted for the Sydney Harbour bridge.

TABLE No. 12.

Bending Strength from Ruler's Formula and Working Stresses.

$\frac{L}{r}$	Ruler's Formula	Sydney Harbour Bridge Nickel Steel		Sydney Harbour Bridge Carbon Steel	
		Class 1	Class 2	Class 1	Class 2
	lbs. per sq. in.	lbs. per sq, in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
40	185,055	24,000	20,000	15,000	12,500
60	82,247	22,600	19,200	15,000	12,500
80	46,264	20,800	17,600	13,600	11,400
100	29,609	19,000	16,000	12 000	10,000
120	20,562	17,200	14,400	10,400	8,600

Taking the maximum value of unit stress allowed in the design of columns, when $L/r = 100$, the least load causing bending by Euler's formula is 29,609lbs. per square inch, whereas the working stress adopted for nickel steel is 19.000lbs. per square inch, so the ratio of congested load stress to the least load causing bending is never more than 1 : 1.55.

As no question of general bending due to direct stress is involved, where columns are straight and have no external influence causing bending, it is clear that failure under test would be due to local buckling, weakness of details, or irregularities of manufacture. Nickel steel is better able to resist these secondary stresses, and in this way nickel steel columns have a greater strength than columns of carbon steel.

The properties of carbon steel are well known, but nickel steel, as a commercial product, is of comparatively recent origin, and few examples of its use for bridge construction can be quoted, although it has been largely used in the construction of ships for His Majesty's Navy.

The most important bridges built either partly or wholly of nickel steel are:—

Queensboro Bridge. Plan No. 22. The eyebars are constructed of nickel steel.

Manhattan Bridge. Plan No. 21. The stiffening trusses are constructed of nickel steel.

Bridge over the Mississippi River at St. Louis. Plan No. 23. The main trusses are constructed of nickel steel.

Table No. 13 shows a comparison of the unit stresses for nickel steel bridges already erected—Waddell's specification for nickel steel bridges and the Sydney Harbour bridge specification.

TABLE No. 13.

	*Waddell	Queensboro	Manhattan	† St. Louis	Sydney Harbour
Tension Eye bars	30,000	39,000	...	32,000 Dead 16,000 Live	30,000
Tension Built Members	28,000		40,000	26,000 Live 13,000 Dead	28,000
Compression in Chords	30,000— 120 L÷r			Dead 34,000—110 L ÷ r Live 17,000— 55 L ÷ r 30,000 Dead } Max. 15,000 Live }	
Compression other Struts with fixed ends	27,000— 120 L÷r	Carbon Steel.	40,000— 150 L÷r	......	28,000— 90 L÷r Max. 24,000
Compressi'n Struts with pinned ends	27,000— 160 L÷r			Dead 28,000—90 L ÷ r 14,000—45 L ÷ r Live	
Shear Rivets—Shop or Machine Driven	14,000		...	14,000	16,000
Shear Field or Hand Driven Rivets	11,200		20,000	11,200	12,800

* "Nickel Steel for Bridges," Proc. Am. Soc C. E., Vol. 63, June, 1909.

† Municipal Bridge, St. Louis, Boller & Hodge, Engineers.

TABLE No. 13—CONTINUED.

	*Waddell	Queensboro	Manhattan	† St. Louis	Sydney Harbour
Shear Pins ...	25,000	24,000	...	14,000	16,000
Bending Pins ...	50,000	48,000	...	36,000	40 000
Bearing Rivets—Shop or Machine Driven	30,000	...	...	22,000	30,000
Bearing Rivets—Field or Hand Driven	24,000	...	35,000	17,600	24,000
Bearing Pins ...	38,000	48,000	...	...	30,000

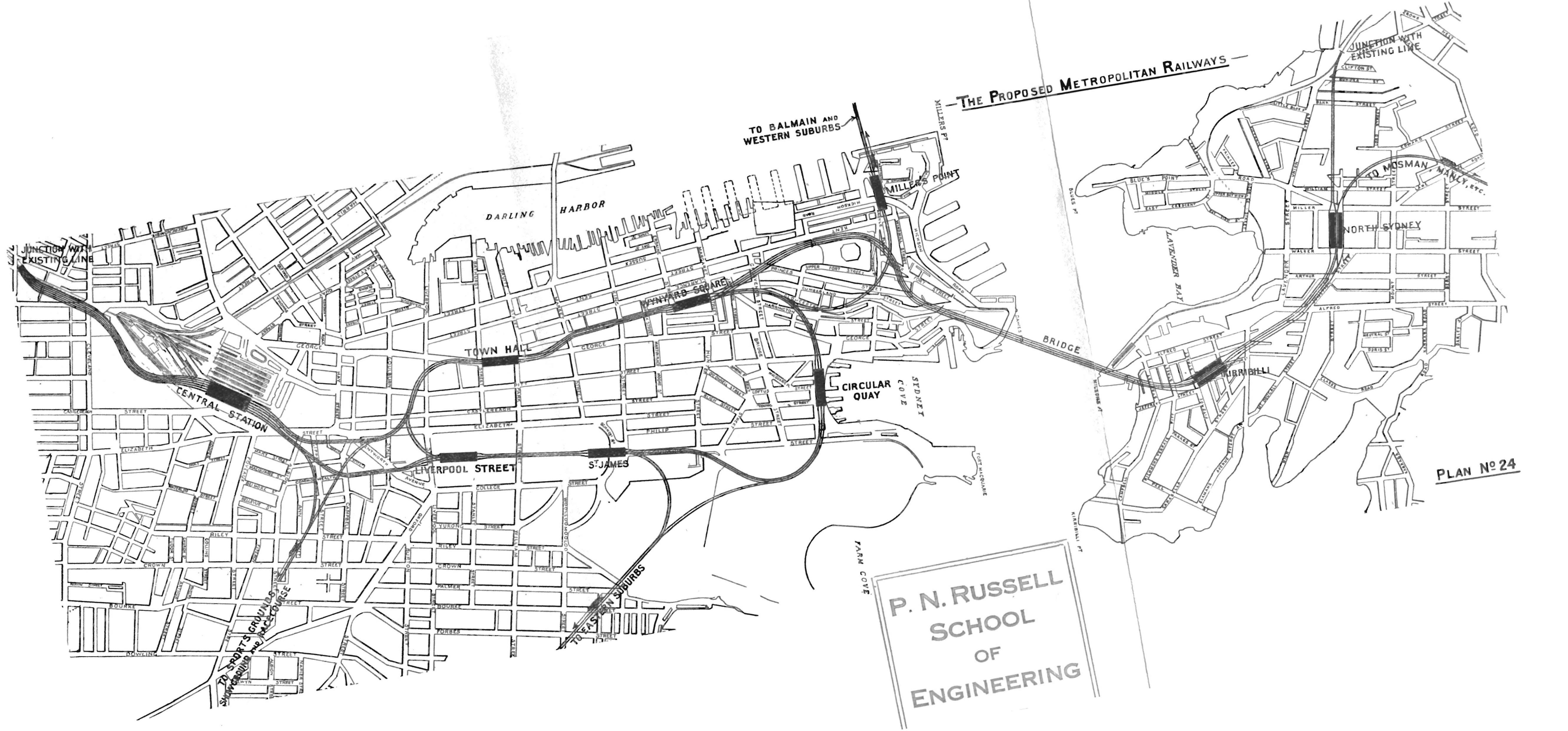
Stresses as high as were used in the Manhattan Bridge would not be satisfactory for a cantilever bridge. A failure of the stiffening trusses of a suspension bridge would not necessarily entail the collapse of the structure. On the other hand the failure or buckling of one main member of a cantilever bridge could cause a complete wreck of a large part of the structure.

It is very doubtful if the high stresses for rivets used in the Manhattan Bridge will ever be repeated for any structure, being above the limit at which initial slip of the joint will take place.

The stresses for tension members and columns would also be too high for a cantilever bridge from the points of view of safety first longevity second.

From Plan No. 22 it will be seen that there are a greater number of lines of traffic over the Queensboro' Bridge than are proposed for the Sydney Harbour bridge, and in consequence there is more likelihood of the calculated stresses being realised in the Sydney Harbour bridge. From this point of view there is some justification for somewhat lower stresses in the latter, or vice versa, assuming either to be correct. It is to be noted, however, that the question of safe working stress is largely a practical consideration. The unit stresses adopted for small span bridges are derived almost entirely from the results that practice has proved good and sufficient to cover all the deficiencies of design and manufacture where these are as good as are generally obtained. Where both are good, much higher unit stresses than are allowed could undoubtedly be used without the least risk of failure of the structure.

The ratio between the ultimate strength of the main members as a whole, and ordinary heavy working load, viz., one-half the maximum theoretical load will be about 3 : 1 for struts and 4 : 1 for tension members. The lower factor is considered satisfactory for struts, because questions of stability rather


The Proposed Metropolitan Railways
Junction with Existing Line
To Balmain and Western Suburbs
Millers Pt
Miller's Point
Darling Harbor
Wynyard Square
Town Hall
Central Station
Circular Quay
Sydney Cove
Liverpool Street
St. James
Bridge
Milsons Pt
Kirribilli
North Sydney
To Mosman, Manly, etc.
Lavender Bay
Junction with Existing Line
To Eastern Suburbs
To Sports Grounds, Showground and Racecourse
Fort Macquarie
Farm Cove
Plan No 24

than fatigue are the leading considerations—the elastic limit for struts bearing a higher ratio to the crushing strength than is the case in tension members.

A comparson may be made of the specification for the St. Louis Bridge with Sydney Harbour Bridge. Consider a typical chord member of the suspended span of Sydney Harbour Bridge.

The stresses estimated are:—

Dead Load	....	1,945 tons
Live Load	....	1,440 ,,
Impact	....	143 ,,
Total	....	3,528 tons

Bending stresses involve a fibre stress of 1,100lbs. per square inch. The quantity L ÷ r is about 40, thus the unit stress allowed is 24,000lbs. per square inch, less 1,100 for bending stress = 22,900lbs. per square inch.

Area required = 345 square inches.

Using Roller and Hodge's specification for the St. Louis Bridge:—

Area required for dead load = 145 sq. ins.

Area required for live load = 215 ,,

360 sq. ins.

This is an increase of about 4.5 per cent. over that demanded from Sydney Harbour Bridge specification, but the maximum calculated stresses for St. Louis Bridge would approach much nearer those that would be realised under the specified loadings than in the case of Sydney Harbour Bridge, with its greater number of lines of traffic, and thus the slight discrepancy in the sections demanded by the specifications would not be without justification.

In conclusion the Author desires to express his thanks to the Director General of Public Works for permission to read the paper; to Messrs. L. M. Roberts and R. Y. Smith, for assistance in preparing the same, and to the P.W.D. Professional Officers' Association for obtaining the Lantern Slides for illustrating it.