Compression Members.

Straight line formula have been adopted for compression members, as being equally as satisfactory as those based on Enler's theory, and, at the same time, much simpler in operation.

Alternating Stresses.

Members subjected to alternating stresses are the only portions of the structure where no addition is to be made for impact. It was found more satisfactory in the case of these members to suitably increase the section by a $\frac{\text{min.}}{\text{max.}}$ formula covering the great variety of cases likely to occur.

In the great stiffening trusses of a suspension bridge, which must exceed 1,200 feet in length, the maximum alternation of stress is rarely likely to occur, and arbitrary values have been specified. This, it may be remarked, was also the view taken by the Boards of Engineers who reported on the proposed North River Suspension Bridge, New York.

Shearing and Bearing Stresses.

The specified allowances for impact must first be made before applying the unit stresses specified for shear and bearing. The steel for rivets is to be of softer quality, 50,000 to 60,000 lbs. per square inch, than that employed in the structural members; and, where the rivets are hand driven in the field, their number is to be increased thirty per cent.

Cables and Suspenders.

The wire used in cables and suspenders, if the latter are formed of wire ropes, is specified to have a minimum tensile strength of 200,000 lbs. (89·3 tons), per square inch. The main cables are to be preferably constructed of a number of separate parallel wires gathered and clamped together into a compact cable. This is in accordance with the practice followed in the Brooklyn Suspension Bridge, and in the new East River Bridge, of 1,600 feet span, now in course of construction.

Conclusion.—The foregoing paper represents the results of a study on unit stresses, etc., made in connection with the specification adopted by the Sydney Harbour Bridge Advisory Board, of which Professor Warren is a member, and Mr. Dare the Secretary.

APPENDIX I.

"Some Experiments on Bridges under Moving Train Loads" by F. E. Turneaure, Assoc. M. Ams. Soc. C.E.

Vol. 24 Proc. Am. Soc. C.E.

The following is a summary of the principal results and conclusions from the experiments:—

1. Speeds less than about twenty-five miles per hour are not likely to result in much vibration.

2. The increase in deflection due to vibrations, caused by locomotives running at speeds of forty to fifty miles per hour, is likely to be forty or fifty per cent. for girder spans of less than fify feet in length.

3. This percentage decreases rapidly for longer spans, becoming about twenty-five per cent. as a maximum for seventy-five feet spans.

4. Owing to cumulative effect, the percentage is likely to be a maximum of twenty or twenty-five, for spans from seventy-five feet to one hundred and fifty feet or more in length, but the experiments indicate no increase in per centage for increase in span.

5. The relative increase in chord stress is about the same as in deflection; that in centre diagonal is somewhat more than in the deflection; and in hip vertical it corresponds more nearly to that in girders of forty to fifty feet span-lengths.

6. The effect of speed of application of the load on mean deflection was of no consequence in the spans tested (the increase in deflection from live load being due to vibration), although theory points to an appreciable increase from this cause in very short spans without camber.

7. Secondary stresses are likely to be high in small girders with shelf-angles, and in some parts of trusses, and the discrepancy between observed and computed stress may be greater from this cause than from dynamic effect of moving loads.

APPENDIX II.

Extracts from Specification upon which Tenders are now invited for the Sydney Harbour Bridge.

WIND PRESSURE.

Provision is to be made throughout the structure against the following wind pressures acting at right-angles to the centre line of the bridge :—

(*a*) BRIDGE UNLOADED.—Fifty pounds per square foot of exposed surface, treated as a uniform load over the whole structure.

(*b*) BRIDGE LOADED.—Thirty pounds per square foot of exposed surface treated as a uniform load over the whole structure, together with 300 pounds per lineal foot over the whole length of the bridge, acting at eight feet six inches above the rail, and treated as a moving load.

The wind pressure on the main span is to be calculated from the details of the design submitted on the general principle, that the area of exposed surface will be equal to the area of one main truss × 2, plus the area of hand-rail × 2, plus the area of deck system × 1·5, the *area* in each case to be taken as the area seen in elevation, at right-angles to the direction of the wind. For the wind pressure on main towers of suspension bridges, the exposed surface to be taken to area × 2 for each pair of bents.

TEMPERATURE.

A range of 60° F. on either side of mean temperature is to be allowed for. The co-efficient of expansion of steel for 60° F. is to be taken at .0004.

TRAIN MOMENTUM STRESSES.

All portions of the structure are to be designed to resist the longitudinal stresses induced by suddenly stopping one or both the maximum trains specified, the co-efficient of friction of the wheels on the rails being assumed as 0·20.

CENTRIFUGAL FORCE OF TRAINS.

Such portions of the structure as are on a curve are to be designed to resist the centrifugal force due to one of the maximum trains specified on each track.

MAXIMUM LOADING.

All members of the structure shall be proportioned to resist either—

(*a*) A combination of dead load; maximum live load on railway tracks, roadways, and footways; train momentum stresses; and stresses due to the centrifugal force of trains (if any); or

(*b*) A combination of dead load; maximum live load on railway tracks; one-half the specified live load on roadways and footways; wind pressure on structure and train, at thirty pounds per square foot; train momentum stresses; temperature; and stresses due to the centrifugal force of trains (if any); or

(*c*) A combination of dead load; wind pressure on structure only, at 50 lb. per square foot; and temperature.

The sectional area to be provided is to be the maximum area required by either (*a*), (*b*), or (*c*), proportioned according to the specified unit stresses.

Impact.

Except in the case of the main towers and main trusses of cantilever bridges, and the main towers, cables, and stiffening trusses of suspension bridges, an addition for impact is to be made to the stresses due to live loads, determined in the following manner :—

$$I = C \times \left\{ L \times \frac{L}{L \times D} \right\}$$

Where D = calculated dead load stress in member.

L = calculated maximum live load stress in member.

I = addition to be made for impact to the maximum live load stress (including train momentum and centrifugal force).

C = a constant, representing seventy-five per cent. (0·75) for all train loads ; thirty per cent. (0·30) for the rolling load of twenty tons specified for the roadways ; and fifteen per cent. (0·15) for the live load of 100 pounds per square foot on the roadways and footways.

In the case of the main towers and main trusses of cantilever bridges, and the main towers, cables, and stiffening trusses of suspension bridges, no allowance need be made for impact ; but the specified allowance is to be made for impact in the case of the central suspended girders of cantilever bridges.

Unit Stresses.

All portions of the structure shall be so proportioned that the maximum loads shall not cause the stresses to exceed the following, *for medium steel* (*where not otherwise specified.*)

Tension.

(*a*) Dead load and live load, on all members, including train momentum, centrifugal force, and impact, were specified.

P = 17,000 pounds per square inch on the net section.

(*b*) Temperature and wind pressure on all members.

P = 24,000 pounds per square inch on net section.

(*c*) In the following members *no* addition is to be made for impact to the live-load stresses, and Clause 6 shall not be taken to apply. These members are to be proportioned, both for dead-load and live-load stresses, upon the following maximum unit stresses :—

Floor beam hangers and other similar members liable to sudden loading (bars with forged ends).

For loads due to railway—P = 7,000 pounds per square inch on net section.

For loads due to roadways or footways—P = 9,000 pounds per square inch on net section.

Floor beam hangers and other similar members liable to sudden loading (plates and shapes).

For loads due to railway—P = 6,000 pounds per square inch on net section.

For loads due to roadways or footways—P = 8,000 pounds per square inch on net section.

In determining net sections, all rivet holes are to be taken as $\frac{1}{8}$ inch larger than the nominal diameter of the rivet.

Compression.

(*a*) Dead-load and live-load, on all members, including train momentum, centrifugal force, and impact, where specified.

$$P = 17{,}000 - 80\frac{l}{r} \text{ pounds per square inch on gross section.}$$

(*b*) Temperature and wind pressure on all members.

$$P = 22{,}500 - 100\frac{l}{r} \text{ pounds per square inch or gross section.}$$

Where P = working stress per square inch.

l = length of member in inches, centre to centre of connections.

r = least radius of gyration of the section in inches.

No compression member shall have a length exceeding 100 times its least radius of gyration, except for the windbracing, where the length may be 125 times the least radius of gyration.

Alternating Stresses.

For all members subjected to stresses alternating between tension and compression, *no* addition shall be made for impact to the live-load stresses; but the sectional areas provided shall be proportioned upon the following unit stresses :—

(*a*) All members, other than stiffening trusses of suspension bridges.

For loads due to railway—

$$\text{Tension } P = 12{,}000 \left\{ 1 - \frac{1}{2} \cdot \frac{\text{minimum}}{\text{maximum}} \right\} \text{ per square inch on net section.}$$

$$\text{Compression } P = \left\{ 12{,}000 - 50\frac{l}{r} \right\} \left\{ 1 - \frac{1}{2} \cdot \frac{\text{minimum}}{\text{maximum}} \right\} \text{ per square inch on gross section.}$$

For loads due to roadways and footways—

$$\text{Tension } P = 15{,}000 \left\{ 1 - \frac{1}{2} \cdot \frac{\text{minimum}}{\text{maximum}} \right\} \text{ per square inch on net section.}$$

$$\text{Compression } P = \left\{ 15{,}000 - 60\frac{l}{r} \right\} \left\{ 1 - \frac{1}{2} . \frac{\text{minimum}}{\text{maximum}} \right\} \text{ per square inch on gross section.}$$

In applying the above, the resultant stresses shall be calculated for the member under consideration due to the *sum* of the dead-load stress and the live-load stress of the like sign, and also to the *difference* of the dead-load stress and the live-load stress of the opposite sign. The "minimum" stress shall then be taken to be the less and the "maximum" stress the greater of the resultant stresses so obtained.

(*b*) Stiffening trusses of suspension bridges.

Tension P = 14,000 pounds per square inch on net seetion.

$$\text{Compression } P = 14{,}000 - 60\frac{l}{r} \text{ pound per square inch on gross section.}$$

The greater of the two sectional areas required as so determined to be used in proportioning the members both for (*a*) and (*b*).

Combined Stresses.

In the case of members subjected to a bending stress in addition to a direct tensile or compressive stress, the extreme fibre stress due to a combination of the bending and direct stresses shall not exceed the limits specified for direct stress.

Shearing Stresses.

After making the specified allowance for impact, the shearing stress on pins, bolts, and machine driven rivets shall not exceed the following :—

Medium steel	..	..	..	12,000 lbs. per square inch.
Wrought iron	..	..	..	9,000 lbs. per square inch.

For field rivets, hand driven, the number of rivets determined as above shall be increased thirty per cent.

Bearing Stresses

After making the specified allowance for impact, the pressure upon the bearing surface (diameter x thickness) of pin, bolt, or machine-driven rivet holes shall not exceed the following :—

Medium steel	..	..	..	24,000 lb. per square inch.
Wrought iron	..	..	..	16,000 lb. per square inch.

For field rivets, hand-driven, the number of rivets, as determined above, shall be increased thirty per cent.

Bending Stresses on Pins.

After making the specified allowance for impact, the stresses upon the extreme fibres of pins due to bending shall not exceed 25,000 lbs. per square inch, providing that the bending moment in the pin is calculated upon the assumption that the pressure from each member is distributed evenly over the bearing surface of such member.

Plate Girders.

No portion of the web-plate shall be included when proportioning the flanges of plate girders.

The webs of plate girders must be stiffened at intervals about the depth of the girders, whenever the shearing stress per square inch exceeds the stress allowed by the following formula :—

$$\text{Allowing shearing stress} = \frac{C}{1 + \frac{H^2}{3000}}$$

Where C = 12,000 for girders in which the maximum stress is due to load of railway, and 15,000 where the maximum stress is due to load of roadways or footways.

H = ratio of depth of web to thickness.

No web-plates shall be less than $\frac{3}{8}$-in. thick in railway girders, nor less than $\frac{5}{16}$-in. thick in roadway or footway girders.

The stiffeners shall be a neat and close fit under the flanges of the girders.

Rolled Girders.

After making the specified allowance for impact, and deducting for rivet holes, all rolled girders shall be proportioned by their moment of inertia, allowing such value for the modulus of rupture that the unit stresses on the extreme fibres shall not exceed the limiting values specified.

Deflection.

The depth of all members shall be such as to prevent undue deflection under the maximum loads specified.

Pressure on Rollers.

In all expansion bearings turned rollers are to be provided, working between planed surfaces, nowhere less than six inches in diameter, and so proportioned that the pressure per lineal inch of roller shall not exceed 300 *d* for steel rollers between steel surfaces, where *d* is the diameter of roller in inches; such pressure not to exceed 3,000 lb. per lineal inch.

In the case of long rollers, great care is to be taken that the saddles and bedplates are made sufficiently deep and stiff to ensure an equal distribution of the load over the whole length of the roller.

Cables and Suspenders.

The main cables and suspenders of suspension bridges are to be proportioned for the maximum loads specified, with a factor of safety of $3\frac{1}{2}$ on the minimum ultimate strength of the material proposed to be used by the Tenderer.

Pressure upon Masonry and Concrete.

The maximum pressure upon any portion of the masonry or concrete in the piers shall not exceed the following:—

Trachyte, granite or Melbourne bluestone bedstones,	500 lbs. per square inch.
Masonry of selected sandstone	250 lbs. per square inch.
Concrete as specified	200 lbs. per square inch.

Pressure upon Foundations of Piers.

The maximum pressure on the sandstone upon which the piers are to be founded shall not exceed 25,000 lb. per square foot under the maximum loading specified. Such pressure to be the actual pressure upon the foundations due to the weight of the structure and loads thereon, without making any allowance for the weight of the water or material at present overlying the rock, or for skin friction on the sides of the pier.

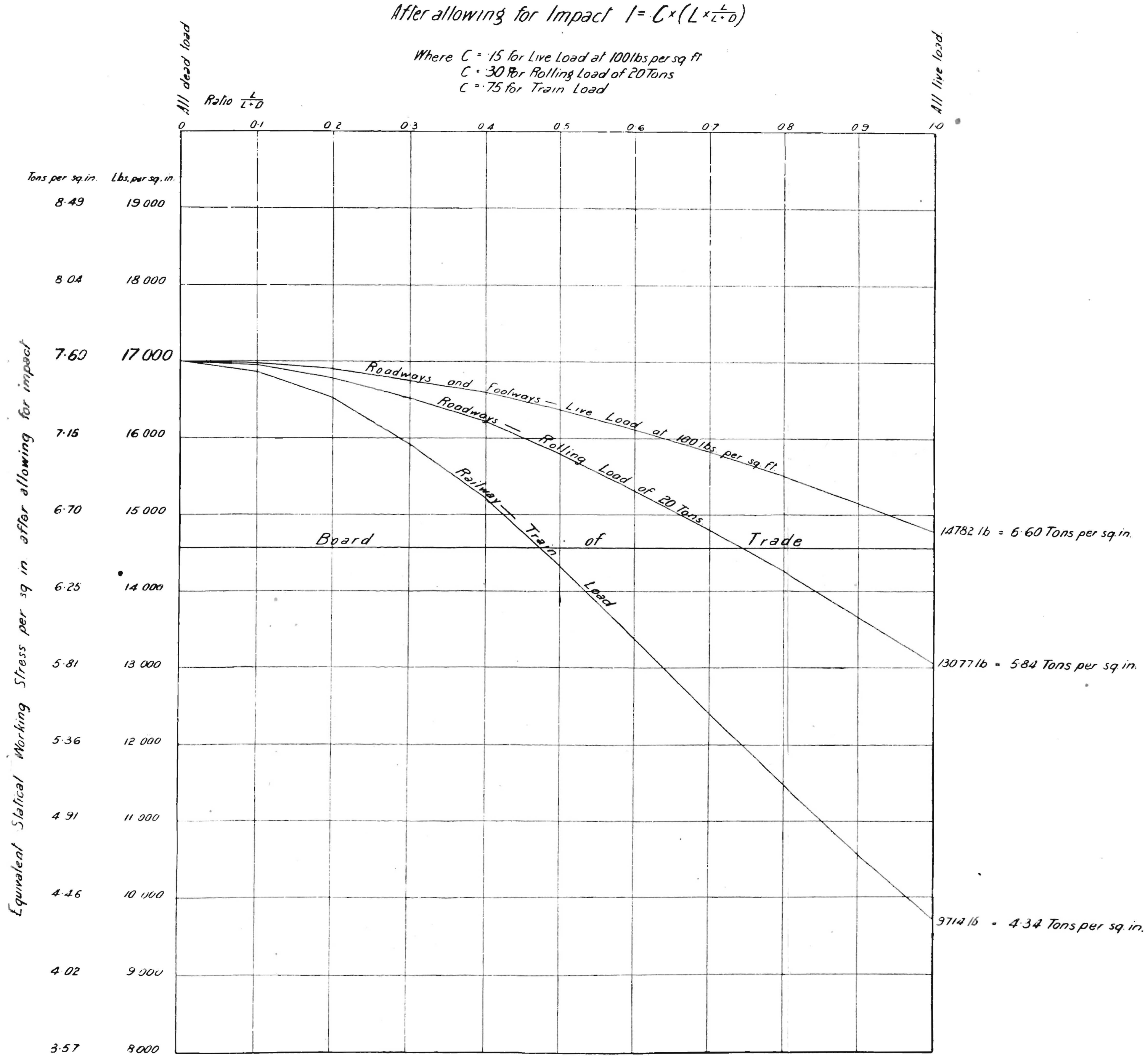
Diagram No. 1.

SYDNEY HARBOUR BRIDGE

Diagram showing Working Stresses in Tension

After allowing for Impact $I = C \times (L \times \frac{L}{L+D})$

Where C = ·15 for Live Load at 100 lbs per sq ft
C = ·30 for Rolling Load of 20 Tons
C = ·75 for Train Load



	Factor of Safety varies from			Measured on Ult. strength
Live Load at 100 lb per sq ft			3·5 to 4·06	
Rolling Load of 20 Tons	Do	Do	3·5 to 4·58	Do
Train Load	Do	Do	3·5 to 6·18	Do

Fig. 6.

SCHNEIDER – AMERICAN BRIDGE CO. RAILWAY BRIDGES 1900

(This is identical with the Pencoyd Bridge Co Specification 1895)

$I = \frac{300}{S+300}$ = 1.00 for S = 0 = ·23 for S = 1000'

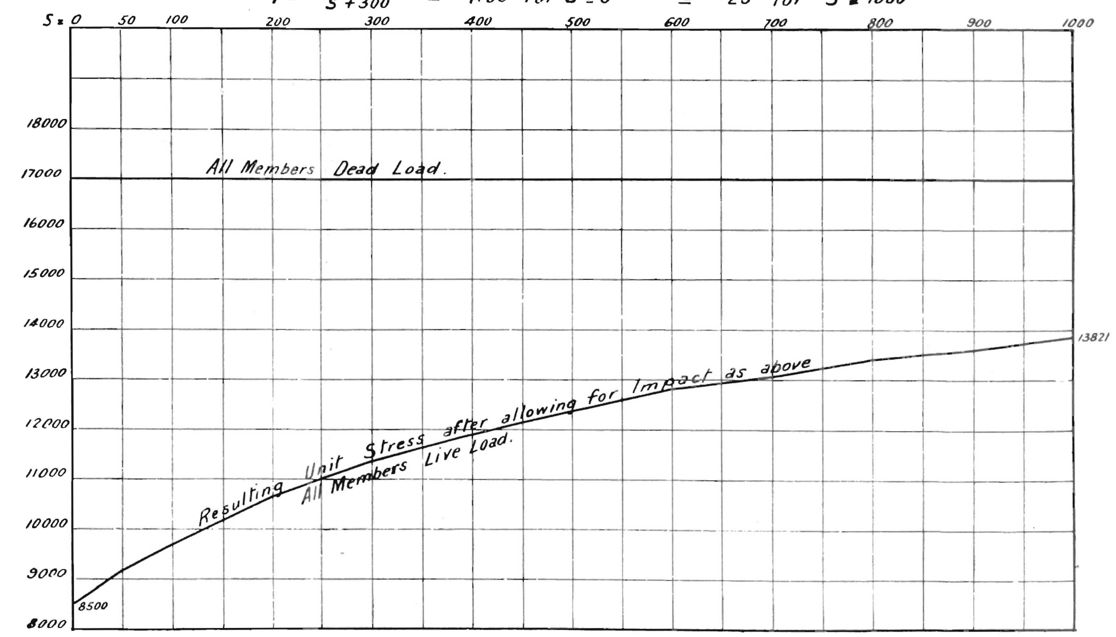
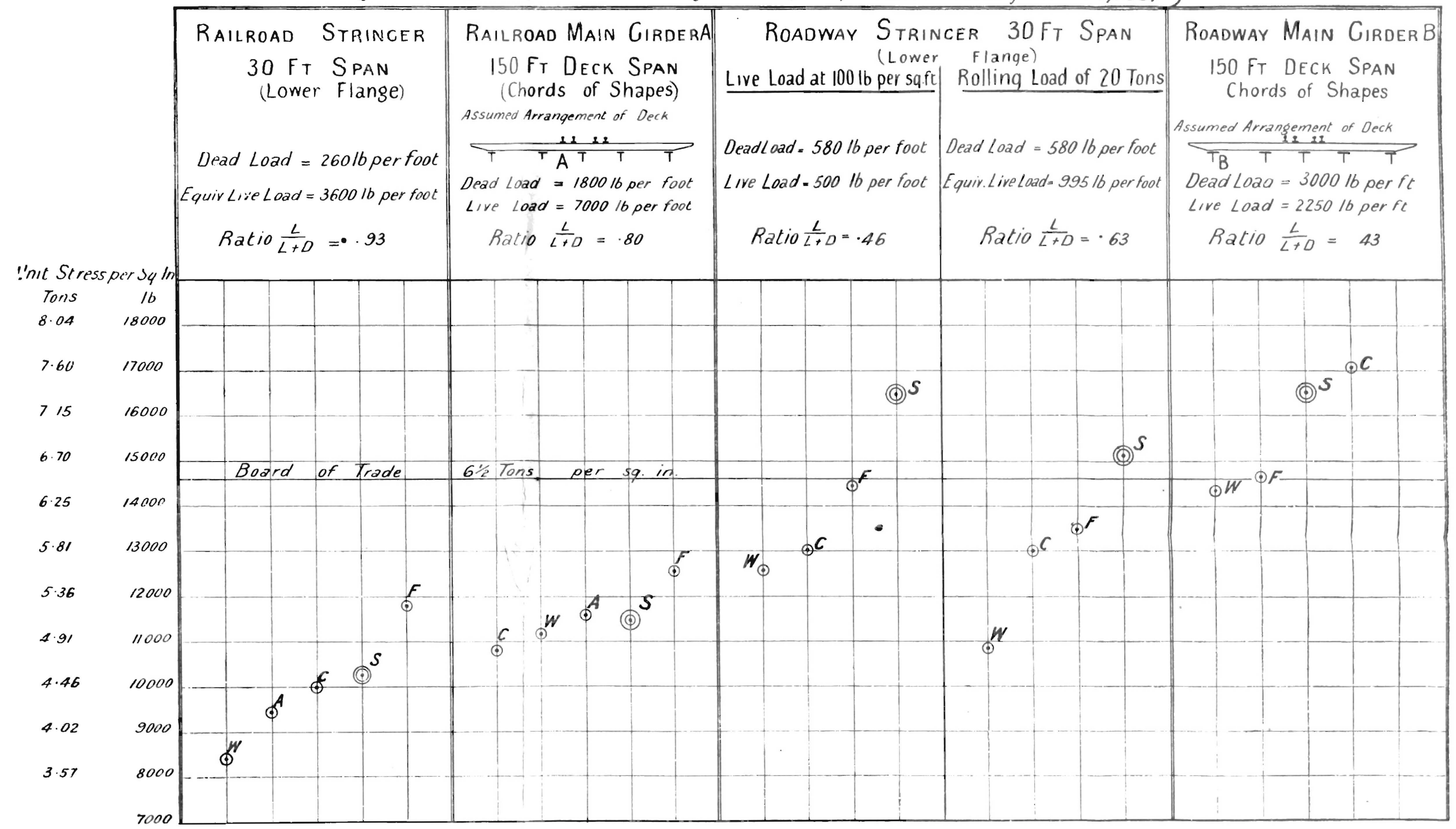


Diagram No. 3.

COMPARISON OF UNIT STRESSES IN TENSION FOR VARIOUS SPECIFICATIONS

(These are the Statical working stresses per sq. in. after allowing for Impact)



A = American Bridge Co Specification 1900 (Schneider)
C = Theodore Cooper's Specifications 1896 & 1901
F = French Government Specification 1892
W = J.A.L. Waddell's Specification 1899
S = Sydney Harbour Bridge Specification

NOTE. The Dead Load weights given above have been calculated approximately from the design of deck embodied in specification for Sydney Harbour Bridge