are not likely ever to limit the draught of vessels in the future, or obstruct the harbour in any way, but the grades for railway, vehicular, and pedestrian traffic would be worse than those proposed by the Royal Commission in 1909, and consequently the working expenses.

BRIDGE OR SUBWAY.

The foregoing facts and figures show:—

(1) Railway communication by bridge is unquestionably better than railway communication by subway.

(2) The tram, via bridge, would serve the population much better, and the revenue would be greater than by subway, whilst the working expenses on account of the better grades would be less by bridge than by subway.

(3) The vehicular and pedestrian traffic would be very much better served by bridge than by subway.

(4) Subways, to provide the same accommodation as the bridge, would cost £863,000 more than the bridge.

(5) Railway, tramway and vehicular subways could be separately undertaken and completed independently of each other. A bridge embracing similar facilities must be completed before any of the respective services would be available. In the end, however, the subways would cost more than the bridge and would not serve the traffic nearly so well.

(6) Ventilation, drainage and lighting, ever present with subways, are highly detrimental factors and a continual source of expense.

(7) Subways must of necessity be noisy.

(8) The bridge does not obstruct the waterway in any way, or restrict the draught of vessels; it limits the height of masts to 170 feet at high water.

(9) Sailing ships are becoming fewer each year, and it is easy to strike the top-masts.

(10) All steamships trading to Sydney at present could pass under the bridge. In the future larger steamers will trade to Sydney, but such vessels can be constructed with masts not exceeding 170 feet in height, or with telescopic masts.

(11) Motor ships may replace steam ships; if so the tendency will be to reduce the height of masts.

(12) Wireless authorities agree that a headway of 170 feet will be ample for all time, and that masts can be made telescopic if necessary.

(13) Other ports have found it necessary to erect bridges. The headway fixed for the Sydney Harbour Bridge is greater than that provided under any bridge already constructed, whilst the most recent bridge proposed across the Hudson River, New York—one of the most important ports of the world—provides for the same headway as contemplated at Sydney.

(14) The subways recommended by the Royal Commission would restrict the draught of vessels to about 37 feet at low water.

(15) It is possible to construct subways which would provide a depth of 50 feet or more of water; such subways are not likely ever to limit the draught of vessels or interfere with the harbour in any way, but the cost would be greater, and the facilities for the railway, tramway, vehicular and pedestrian traffic would be worse with the subways compared with the bridge.

A careful study indicates conclusively that a bridge is the best means of connecting Sydney with North Sydney. It will not obstruct the commerce of the port; will be cheaper than subways, and will afford much better facilities for the railway, tramway and vehicular traffic.

Mr. David Hay, of London, reported: "From an engineering and utilitarian standpoint he considered a bridge would be the best means of connecting Sydney and North Sydney, and that the best and shortest route was the one chosen by Mr. J. J. C. Bradfield in placing his scheme for a one-span bridge before the Public Works Committee."

IS A BRIDGE NECESSARY?

The metropolitan area may be divided into the City of Sydney, the suburbs south of the harbour and the suburbs north of the harbour. The following figures, prepared by Mr. H. A. Smith, Acting Government Statistician, show the population of these divisions at each census since the year 1881, and what the population is estimated to reach in the years 1921 and 1931.

TABLE 1.

Density of Population, and the Number of Persons Per Acre as Shown by the Census taken in 1881, and by each Subsequent Census.

Division.	Census, 3rd April, 1881.			Census, 5th April, 1891.		Census, 31st March, 1901.		Census, 2nd April, 1911.	
	Area in Acres.	Pop.	Persons per Acre.	Pop.	Persons per Acre.	Pop.	Persons per Acre.	Pop.	Persons per Acre.
City of Sydney	3,327	105,901	31.93	118,358	35.57	126,138	37.91	119,771	36.00
Suburbs South of Harbour	65,980	107,423	1.63	238,362	3.61	312,907	4.74	421,162	6.38
Suburbs Nth. of Harbour	48,992	14,835	0.30	32,038	0.65	53,364	1.09	95,416	1.99
Total, Metropolis.	118,299	228,159	1.93	388,758	3.29	492,409	4.16	636,349	5.38

TABLE 2.

Total Increase and the Proportional Increase in Population Between Each Census, 1881-1911.

Increase During Decade.

	1881-1891.		1891-1901.		1901-1911.		Increase per Cent. per annum.		
	Total.	Per Cent.	Total.	Per Cent.	Total.	Per Cent.	1881-1891.	1891-1901.	1901-1911.
City of Sydney ...	12,457	11.8	7,780	6.6	−6,367	−5.0	1.12	0.64	−.52
Suburbs South of Harbour	130,939	121.9	74,545	31.3	108,255	34.6	8.30	2.76	3.02
Suburbs North of Harbour	17,203	116.0	21,326	66.6	42,052	78.8	8.00	5.23	5.98
Metropolis	160,599	70.4	103,651	26.7	143,940	29.2	5.47	2.39	2.60

From these tables it will be seen that the population of the metropolis as a whole increased 70.4 per cent. between 1881 and 1891, or at the rate of 5.47 per cent. per annum; by 26.7 between 1891 and 1901, or at the rate of 2.39 per cent. per annum; and by 29.2 per cent. between 1901 and 1911, or at the rate of 2.60 per cent. per annum.

During the next ten years the annual rate of increase should be much more favourable. As bearing on the probable growth of population in the metropolis in the near future, in 1911 the increase in the population of the State exceeded 55,000—being the greatest increase in any year ever recorded. During the five years immediately preceding 1911 the average annual increase was slightly over 33,000.

FUTURE POPULATION.

Assuming that the population of the metropolitan area increases at the rates of 3 per cent., 3½ per cent. and 4 per cent. per annum, the population will probably be distributed as shown by Table 3.

TABLE No. 3.

IN YEAR 1921.

	3 per cent. p.a.	3½ per cent. p.a.	4 per cent. p.a.
In City	120,000	120,000	120,000
In Suburbs South of Harbour	588,100	622,100	657,500
In Suburbs North of Harbour	147,100	158,500	164,600
Metropolis	855,200	897,600	942,100

IN YEAR 1931.

	3 per cent. p.a.	3½ per cent. p.a.	4 per cent. p.a.
In City	120,000	120,000	120,000
In Suburbs South of Harbour	805,100	897,100	997,800
In Suburbs North of Harbour	224,200	249,100	276,500
Metropolis	1,149,300	1,266,200	1,394,300

The earliest date the bridge could be completed would be about the year 1921. The Acting Government Statistician estimates, under present conditions, i.e., without the bridge, the population of the suburbs north of the harbour of 95,416 in 1911 will, by the year 1912 have increased to a number between 147,100 to 164,600. In other parts of the world statistics show that the number of passengers carried by any service increases more rapidly than the population increases. In the Annual Report of the Public Service Commission, First District, State of New York, 1910. Vol. 3, Page 22, is an account of an investigation and discussion which indicates that the number of passengers increases as the square of the population.

The ferry service is somewhat congested now during the busy hours of the day. Before the bridge can be opened for traffic it will have to cope with at least double the number of passengers, and the time has arrived when the construction of the bridge must be seriously considered.

THE SERVICES TO BE TAKEN ACROSS THE HARBOUR.

The various schemes for linking Sydney with North Sydney provide either wholly or in part for railway, tramway, vehicular, and pedestrian traffic to be taken across the harbour. The bridge recommended by the Advisory Board and the subways recommended by the Royal Commission on "Communication between Sydney and North Sydney" provided for all these services.

The Chief Commissioner for Railways and Tramways, Mr. T. R. Johnson, in giving evidence before the above Royal Commission in 1908, stated that the tramway should not be taken across the harbour, but that North Sydney should be developed by a system of electric railways to which the tramways should be feeders, and that if a bridge were to be built, provision should be made for four lines of electric suburban railway. The Chief Commissioner also stated that goods traffic would not be taken across the bridge, as other arrangements had been made.

The Royal Commission did not act on the Chief Commissioner's advice, but recommended that the tramway should be the first service to be taken across the harbour by subway.

The railway proposed by the author and shown by Plan No. 13 would serve North Sydney better than a tramway could, as the travelling public would be transported more quickly and in greater numbers to and from the City, and at much less cost than by a tramway service.

For the seven years ending June 30th, 1913, the average percentage of working expenses to earnings for the railways, including all non-paying railways and every class of passenger and goods traffic, was 60.08, whilst for the same period for the tramways the average percentage of working expenses to earnings was 82.91.

When roadway communication is brought about, either by bridge or subway, there will be a large increase in the vehicular traffic. With bridge connection, on account of the great facilities afforded, the increase will be much more marked than with subway connection. Again, when the hinterland on the northern side of the harbour is developed—and it is capable of almost unlimited expansion—the vehicular traffic will become very great. At least six lines of vehicular traffic should be provided for, necessitating a roadway width of at least 53 feet.

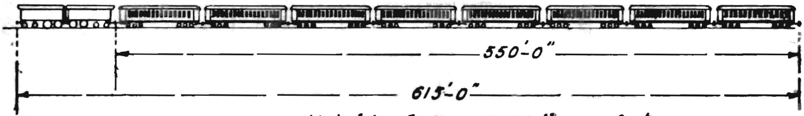
The pedestrian traffic across the harbour will always be small, as the least distance to be traversed is 1¼ miles; one footway, 15 feet wide, should give ample accommodation for the ordinary pedestrian traffic. On special holidays the motor roadway could be used for pedestrian traffic.

A bridge to adequately meet future requirements should provide for a main roadway 35 feet wide for the heaviest vehicular traffic, a roadway 18 feet wide for light motor-car and bicycle traffic, a footway 15 feet wide, and for four lines of suburban electric railway. In the future it may be found necessary to take long distance railway traffic across the bridge, so the two western railway tracks should be also designed to carry heavy electric locomotive traffic. There may eventually be a light goods traffic to and from North Sydney, Mosman, Manly and Narrabeen, and each of the four tracks should be able to carry this class of traffic.

LOADING.

One of the most important factors in the design of the bridge is the loading to be adopted. Reasonable provision must be made for future requirements.

Long Distance Railway Traffic.—For this traffic the two western tracks of the bridge will be designed to carry a conventional train 615ft. long, consisting of an electric locomotive 65ft. long, weighing 160 tons, and cars for a length of 550ft., weighing 2,000lbs. per foot, as shown by Plan No. 4.



Weight of Cars 2000 lbs. per foot.

The reasons for adopting this loading will now be given.

Ordinary long distance trains in New South Wales, consisting of lavatory box-cars, weigh 1,100lbs. per foot run loaded. The heaviest long distance trains, consisting of sleeping-cars, with mail van, weigh 1,300lbs. per foot run loaded. The above cars are constructed of wood, but in the future it is likely that steel cars will be used as in America.

The heaviest cars in use in New South Wales are lighter per foot run than the corresponding cars in the United States, which average about 1,570lbs. per foot loaded. A comparison of typical American wood and steel cars is given by Table 4, whilst Table 5 shows the heaviest types of modern steel cars for passenger traffic.

SYDNEY HARBOUR BRIDGE—LONG DISTANCE RAILWAY LOADING.

PLAN No. 4.

CONVENTIONAL ELECTRIC PASSENGER LOCOMOTIVE AND TRAIN.

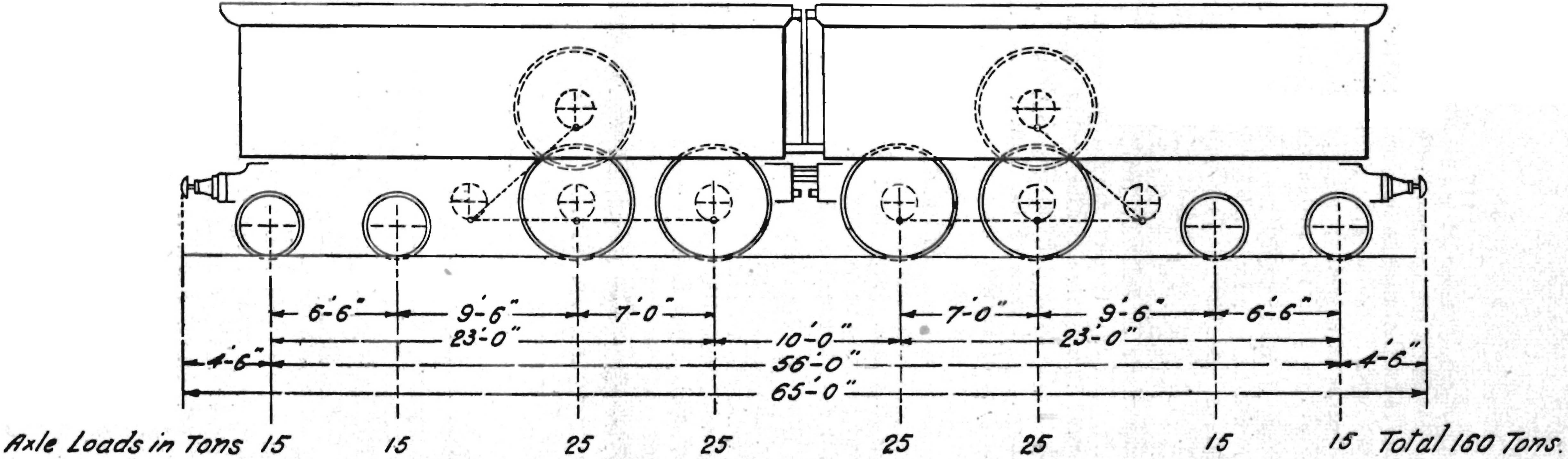


TABLE 4.

Comparison of Steel and Wooden Cars

mentioned in Report by the Master Car Builders' Convention at Atlanta City.

(" Electric Railway Journal," June 27th, 1908, Vol. xxx.)

Class or No.	Road.	Material.	Length over body.	Seating Capacity	Weight.	Weight per passenger	Weight per foot of body.
			feet				
290-295	Lehigh Valley ...	Wood	70.00	77.0	118,000	1532.4	1685.7
1015-51	Frisco	,,	70.00	80.0	106,200	1327.5	1517.1
P. L. ...	Pennsylvania ...	,,	70.00	80.0	106,000	1325.0	1514.2
1st Class	N.Y.C. Lines ...	,,	61.00	76.0	92,800	1221.0	1521.3
P. K. ...	Pennsylvania ..	,,	53.75	62.0	85,000	1370.9	1581.4
	Average ...		64.95	75.0	101,600	1355.4	1564.0
P-70 ...	Pennsylvania ...	Steel	70.75	88.0	*116,100	1319.3	1640.9
Coach ...	Southern Pacific	,,	60.00	70.0	†107,000	1528.5	1783.3
Coach ...	Union Pacific ...	,,	68.00	78.0	† 89,300	1144.8	1313.2
	Average ...		66.25	78.6	104,133	1331.0	1579.2

* Includes storage batteries.
† Includes storage battery and axle generator.

From Table 5 it will be seen that the heaviest passenger cars weigh 1,771lbs. per foot loaded, whilst baggage and mail cars reach 2,613lbs. per foot when fully loaded. A train made up of steel cars, sleepers, day coaches, baggage and mail cars and guard's van would weigh when loaded about 1,800lbs. per lineal foot.

To allow for the heaviest probable passenger traffic, a train 550 feet long, weighing 2,000lbs. per foot, has been adopted. This loading is much in excess of the requirements of the long distance traffic in this State at the present time.

To forecast the type of electric locomotive which will be used is, of course, impossible. Locomotives differing in power, weight and wheel spacings will pass over the bridge. Some of these locomotives must be suitable for hauling fast long-distance passenger traffic and light goods traffic.

The leading considerations in drawing up a conventional locomotive for the purposes of design may be summarised as follows:—

(1) The adhesive weight must be sufficient to handle the maximum train on the sharpest curves on the ruling grade.

(2) The total weight must be sufficient to allow the electrical equipment to develop the maximum power demanded.

(3) The conventional locomotive must be suitable for the sharpest curves and the greatest speeds that will be required.

TABLE 5.

Modern Steel Cars for Locomotive Service.

(1). Day Coaches for Locomotive Service.

Details of Car.

Railway.	Length over Buffers.	Passengers Seated.	Weight Empty.	Weight Loaded Pass. 150 lbs.	Weight Per Foot Empty.	Weight Per Foot Loaded.	Reference.
	ft. in.		lbs.	lbs.	lbs.	lbs.	
Pennsylvania R.R.	80 3¾	88	113 500	126,700	1,413	1,578	"Engineering News," June 20/'07.
South Pacific R.	66 4	70	107,000	117,500	1,613	1,771	"Engineering News," Sept. 3/'08.
Union Pacific R.R.	*68 0	78	89.300	101,000	†1,313	†1,485	"Engineering News," Sept. 3/'08.
Southern Railway, U.S.A.	74 6	74	110,000	121,100	1,476	1,625	"Engineering News," Sept. 3/'08.
Long Island R.R.	67 4	72	94,500	105,300	1,403	1,564	"Engineering News," Sept. 3/'08.

Average 1,605

(2). Postal Cars for Locomotive Service.

Railway.	Length Over Buffers.	To Carry Tons.	Weight Empty.	Weight Loaded.	Weight Per Foot Empty.	Weight Per Foot Loaded.	References.
	ft. in.		lbs.	lbs.	lbs.	lbs.	{ "Engineering News," June 20/'07.
Pennsylvania R.R.	74 9¾	†25	128,500	†184,500	1,718	†2.466	{ "Engineering News," Sept. 3/'08.
Southern Pacific R.	63 0	†20	119,800	†164,600	1,901	†2,613	"Engineering News," Sept. 3/'08.

(3). Baggage Cars for Locomotive Service.

Pennsylvania R.R.	*70 0	60,000 lbs.	120,000	180,000	†1,600	†2.400	"Engineering News," June 20/'07.
Pennsylvania R.R.	*60 10⅜	40,000 ,,	91,000	131,000	†1,400	†2,010	"Engineering News," June 20/'07.

* Length over end sills exclusive of vestibules. † Approximate.

(4) The conventional locomotive should allow other types of equal power and adhesion to pass over any part of the bridge without increase of stress.

The ruling grade will be about 1 in 39 with curves of 8 chains radius, and the author considered that the locomotive should be sufficiently powerful to accelerate up to 20 miles per hour with the maximum train under the above conditions of grade and curve.

On starting the train, resistance will be approximately 2.5lbs. per ton. The grade resistance will be 20 x rate of grade per cent.

A grade of 1 in 39 = 2.57 per cent.

Grade resistance = 20 x 2.57 = 51.4lbs. per ton.

Curve resistance will depend on the rigid wheel base of the cars. This is assumed at 10ft.

Raymond's formula for curve resistance is:—

$$R_c = .4 + (.21 + .035 \times a)D.$$

Where a — rigid wheel base — 10ft. (assumed).

D = curvature in degrees.

$$D = \frac{5730}{8 \times 66} = 10.1$$

Thus $R_c = .4 + (.21 + .035 \times 10)\ 10.8 = 6.5$lbs. per ton.

Total resistance at very slow speed:—

= 2.5 + 51.4 + 6.5 = 60.4lbs. per ton.

Weight of train 550ft., at 2,000lbs. per foot = 550 short tons.

A locomotive weighing 180 short tons, i.e., 360,000lbs., has been assumed.

Total weight of train = 550 + 180 = 730 short tons.

Tractive effort required to move this train at slow speed = 730 x 60.4 = 44,092lbs.

The tractive effort required to pull the train at a speed of 20 miles an hour will be greater, owing to greater train resistance.

The train resistance at a speed of 20 miles per hour is as follows:—

Baldwin formula $R = 3 + \frac{3}{6} = 6.33$lbs. per ton.
Engineering News $R = 2 + \frac{3}{4} = 7.00$lbs. „ „
Where R = resistance in pounds per ton of 2,000lbs.
s = speed in miles per hour.

An average train resistance of 6.5lbs. per short ton has been taken.