The total train resistance at 20 miles per hour is, therefore = 6.5 + 51.4 + 6.5 = 64.4lbs. per short ton.

Total resistance of the conventional train

= 64.4 x 730 = 47,012lbs.

The available tractive effort of the locomotive must not be less than about 47,012lbs. Owing to steady torque, the adhesive tractive effort of an electric locomotive is about one-quarter the weight on driving wheels on clean, dry rails, and to maintain a speed of 20 miles per hour round 8-chain curves on the ruling grade, the weight on the driving wheels should be at least 4 x 47,012 = 188,048lbs.

To accelerate up to this speed under these conditions, a driving axle load of 100 tons, or 224,000lbs. has been adopted, the adhesive tractive effort of which is 224,000 + 4 = 56,000lbs.

To move the conventional train at a very slow speed the tractive effort required is 44,092lbs.; a margin of 56,000lbs. —44,092lbs., i.e., 11,908lbs. is, therefore, provided. This is equivalent to 11,908 ÷ 730 = 16.3lbs. per short ton for accelerating.

To maintain a speed of 20 miles per hour the tractive effort required is 47,012lbs.; a margin of 56,000lbs.—47,012lbs., i.e., 8,988lbs. is therefore provided, equivalent to a margin of 8,988 ÷ 730 = 12.3lbs. per short ton.

It is evident, therefore, that the adhesive weight adopted is sufficient for hauling the maximum train around curves of 8 chains radius on a grade of 1 in 39.

The next requirement to be fulfilled is that the total weight must be sufficient to allow the electrical equipment to develop the maximum power demanded.

The net power demanded around the sharpest curve on the ruling grade to maintain a speed of 20 miles an hour is

$$\frac{47,012}{33,000} \times \frac{20 \times 5,280}{60} = 2,500 \text{ h.p.}$$

The power required to maintain a speed of 60 miles per hour on a straight, level track is 1,986 horse-power.

Train resistance = 2 + $\frac{3}{4}$ = 17lbs. per ton.

Total resistance 17 x 730 = 12,410lbs.

$$\text{Horse Power required } \frac{12,410 \times 5.280 \times 60}{33,000 \times 60} = 1,986 \text{ h.p.}$$

The maximum output of the locomotive would be required around 8-chain curves on the ruling grade of 1 in 39. These conditions are the worst the locomotive is at any time likely to meet. The lengths of maximum grade would be short, and there appears to be no objection to run the locomotive at the

Plan No. 5.

TYPICAL ELECTRIC LOCOMOTIVES

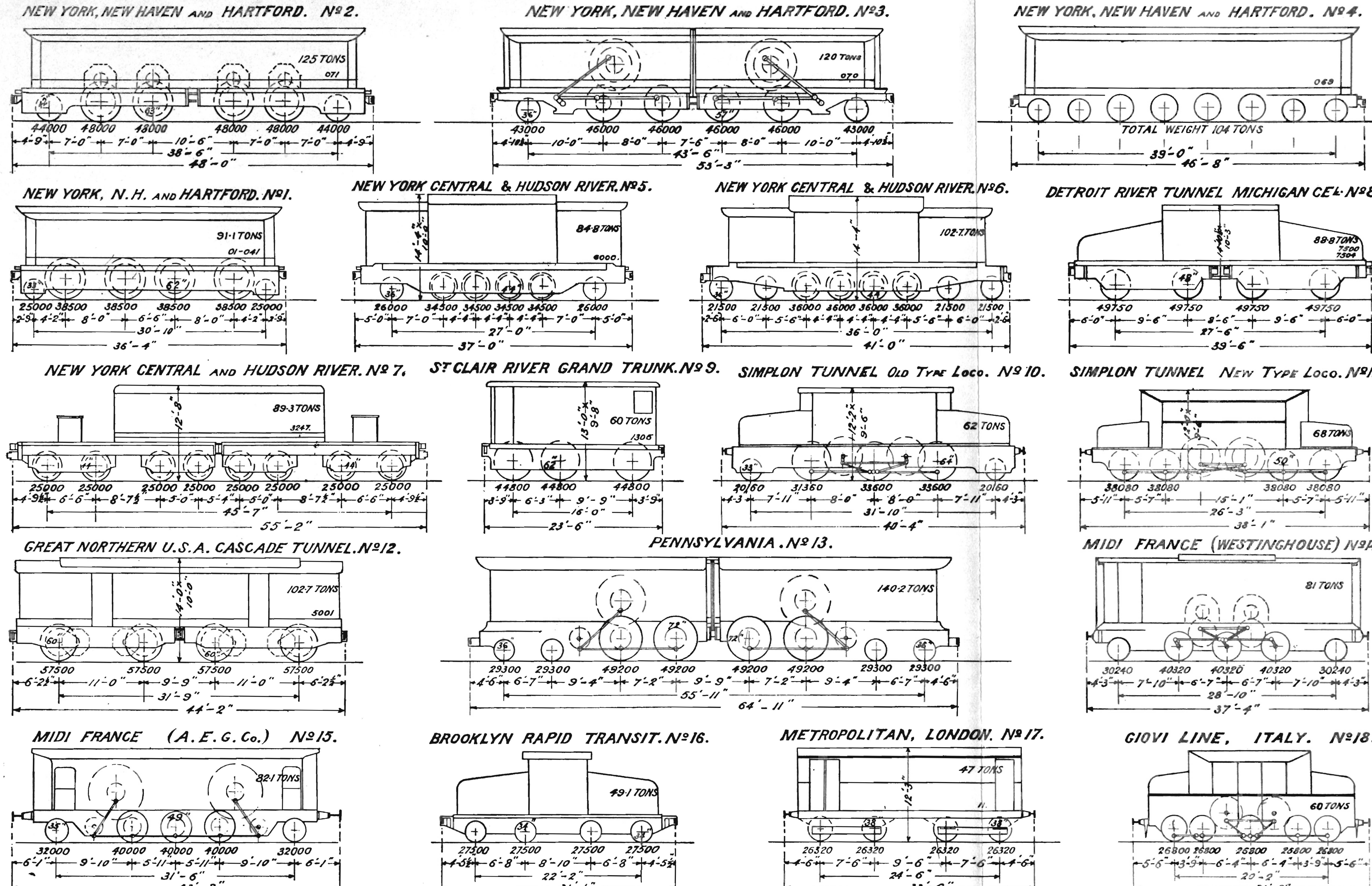


TABLE No. 6.—Details of Typical Electric Locomotives.

Company or Railway	Service	Wheels	Horse Power of Motors		Total Weight	Weight on Drivers	Horse Power per Ton		Length Overall		Weight per Foot of Length	Current	Reference	Year Built
			Hour Rating	Continuous Rating	Tons 2240 lbs.	Tons 2240 lbs.	Hour Rating	Continuous Rating	ft.	in.	lbs.			
1. New York, New Haven and Hartford	Passenger	2-4-4-2	960	800	91.1	68.7	10.5	8.8	36	4	5,615	Single phase	*Burch	1908
2. do.	Freight	2-4-4-2	1,260	1,120	125.0	85.5	10.5	9.0	48	0	5,833	,,	do.	1909
3. do.	,,	2-4-4-2	1,350	1,130	120.0	82.0	11.2	9.4	53	3	5,048	,,	do.	1910
4. do.	,,	4-4-4-4	1,396	...	104.0	...	13.5	...	46	8	4,991	,,	do.	1911
5. New York Central and Hudson River	Passenger	2-8-2	2,200	1 000	84.8	61.6	26.0	11.8	37	0	5,134	Direct	Eng. News 17/11/04	1906
6. do.	,,	4-8-4	2,200	1,000	102.7	64.2	21.3	9.7	41	0	5,611	,,	Burch	1909
7. do.	,,	4-4-4-4	1,750	1,400	89.3	89.3	19.6	15.7	55	2	3,625	,,	Eng. News 1/5/13; Eng. Rec. 12/4/13	1913
8. Detroit River Tunnel, Michigan Cent. Railway	Freight and Pass.	0-4-4-0	1,100	492	88.8	88.8	12.4	5.5	39	6	5,036	,,	Burch; Eng. News 24/6/09	1909
9. St. Clair Tunnel, Grand Trunk Railway	,,	0-6-0	720	570	60.0	60.0	12.0	9.5	23	6	5,719	Single phase	Burch; Eng. News 19/11/08	1908
10. Simplon Tunnel, Old type loco.	,,	2-6-2	1,100	800	62.0	44.0	17.8	12.9	40	4	3,443	Three phase	Burch; Engineering 1/10/09	1907
11. Simplon Tunnel, New type loco.	,,	0-4-4-0	1,700	1,100	68.0	68.0	25.0	16.2	38	1	4,000	,,	Burch; Engineering 1/10/09	1909
12. Great Northern U.S.A. Cascade Tunnel	,,	0-4-4-0	1,900	1,500	102.7	102.7	18.4	14.6	44	2	5,208	,,	R. R. Gazette 15/1/09; Eng. News 18/11/09	1909
13. Pennsylvania	Passenger	4-4-4-4	2,500	1,600	140.2	89.3	17.8	11.4	64	11	4,834	Direct	Burch	1911
14. Midi France (Westinghouse)	Freight and Pass.	2-6-2	1,500	1,200	81.0	54.0	18.5	14.8	37	4	4,860	Single phase	Engineer 31/1/13	1911
15. Midi France (A. E. G. Co.)	,,	2-6-2	1,500	1,200	82.1	54.0	18.3	14.6	43	8	4,213	,,	Burch	1911
16. Brooklyn Rapid Transit	Freight	0-4-4-0	900	...	49.1	49.1	18.4	...	31	1	3,539	Direct	Eng. News 29/9/10	1910
17. Metropolitan, London	Fr. & Pass.	0-4-4-0	...	800	47.0	47.0	...	17.0	33	6	3,143	,,	R. R. Gazette 17/1/08	1908
18. Giovi Line, Italy	Freight	0-10-0	2,000	1,440	60.0	60.0	33.3	24.0	31	2	4,312	Three p.	Burch	1909
						Average	17.9				4,676			

* "Electric Traction for Railway Trains"—E. P. BURCH.

present day electric locomotives, as shown on Table 6, the average weight being 4,708lbs. per foot. Had more examples of the lighter types been included in the table, the average would be even less. The heavy New York Central and Hudson River locomotive (No. 6) in Table 6, has now been superseded by a type (No. 7) weighing considerably less per foot, although much greater in tractive power. The tendency of the New York, New Haven and Hartford Railway has also been to reduce the weight per foot.

With a weight per foot of 5,500lbs., the total length required for 160 tons will be (160 x 2,240) ÷ 5,500 = 65 feet.

A distance of 4ft. 6in. from end wheel to buffer is a fair average figure, so the wheel base will be 56 feet.

Having derived the minimum wheel base, the question of arranging the wheels and the distribution of load had to be considered.

There are two general types which may be used:—

(1) An equal weight distribution over axles.

(2) Uneven weight distribution.

In case (1) the axles would in general be all driving; but as the adhesive weight necessary is only 100 tons, truck wheels may be used to make up the extra 60 tons required. It is not considered necessary to design for a greater axle load than 56,000lbs. Only one electric locomotive in the world has a greater axle load than this, i.e., the Great Northern, U.S.A., loco (No. 13), the axle load being 57,500lbs. The whole 100 tons adhesive weight can be carried by 4 driving axles, each with a load of 25 tons (56,000lbs.); the remaining 60 tons by two bogies, one at each end. This arrangement will give greater stresses than an even division of 20 tons over 8 axles, and in consequence it was adopted.

Some railroads show a tendency to eliminate truck wheels from their electric locomotives, but others have found their use necessary. The wheel spacings adopted are based on the latest Pennsylvania passenger locomotive, a type which fulfils the conditions to be met with here. A closer bunching of the driving axles would give worse stresses in short spans, but a concentration of power on a shorter wheel base than that proposed is not considered at all a likely contingency.

The New York Central locomotive of 1913 has the power spread over a much greater wheel base than the previous types.

Table 7 has been prepared to show the comparative stress effects of the conventional loading and existing heavy electric locomotives, either singly or coupled, for the stringer spans to be used in the proposed bridge.

TABLE No. 7.

Comparison of Stress Effects Sydney Harbour Bridge Conventional Loading and Existing Electric Locomotives.

One Locomotive.

No.	Locomotive	End Shear in Stringers in Tons					Bending Moments in Stringers in Foot Tons					Reactions to Cross Girders in Tons				
		35 ft. Span	40 ft. Span	45 ft. Span	50 ft. Span	55 ft. Span	35 ft. Span	40 ft. Span	45 ft Span	50 ft. Span	55 ft. Span	35 ft. Span	40 ft. Span	45 ft. Span	50 ft. Span	55 ft. Span
	Sydney Harbour Bridge ...	33.2	36.2	39.4	42.0	44.1	234	302	374	452	538	46.6	58.8	54.1	56.6	58.7
13.	Pennsylvania	29.1	31.8	33.9	36.8	38.7	206	266	329	392	474	41.0	44.6	47.5	49.7	51.6
12.	Great Northern U.S.A. Cascade Tunnel	28.1	30.9	33.2	35.0	36.5	188	255	318	382	445	36.2	38.0	39.7	40.7	41.7
3.	New York, New Haven and Hartford	27.7	30.6	32.8	34.6	36.4	204	262	325	390	465	39.3	41.9	43.9	45.6	46.9
6.	New York Central and Hudson River	29.9	31.4	32.6	33.6	34.5	243	302	365	430	494	39.2	40.7	41.8	42.7	43.6
8.	Detroit River Tunnel, Michigan Central Railway	27.1	29.3	31.0	32.4	33.5	196	250	306	382	417	33.2	34.6	35.8	36.6	37.4
14.	Midi France (Westinghouse) ...	24.2	25.9	27.5	28.8	29.9	198	248	299	350	400	31.6	32.6	33.6	34.3	34.8
7.	New York Central and Hudson River	19.9	21.6	22.9	24.3	26.2	142	184	225	284	340	28.9	30.8	32.4	33.6	34.6
9.	St. Clair Tunnel, Grand Trunk Railway	23.7	24.5	25.2	25.6	26.1	183	221	259	296	334	25.6	26.2	26.6	26.9	27.2
11.	Simplon Tunnel, New type loco.	21.2	22.8	24.1	25.1	25.9	136	176	218	259	301	24.0	25.2	26.2	27.0	27.6
81.	Giovi Line, Italy...	21.3	22.4	23.2	23.8	24.4	164	201	238	276	313	24.3	25.0	25.6	26.0	26.4

Two Locomotives.

No.	Locomotive	End Shear in Stringers in Tons					Bending Moments in Stringers in Foot Tons					Reactions to Cross Girders in Tons				
		35 ft. Span	40 ft. Span	45 ft. Span	50 ft. Span	55 ft. Span	35 ft. Span	40 ft. Span	45 ft. Span	50 ft. Span	55 ft. Span	35 ft. Span	40 ft. Span	45 ft. Span	50 ft. Span	55 ft. Span
6.	New York Central and Hudson River	30.6	33.2	35.9	39.1	42.6	243	302	369	488	565	43.5	49.8	56.0	60.6	64.5
11.	Simplon Tunnel	28.8	24.6	26.9	29.3	31.4	158	200	242	295	354	31.9	35.6	39.2	42.2	44.5
18.	Giovi Line, Italy...	22.0	24.4	26 9	29.3	31.9	155	202	247	307	370	33.2	36.5	39.1	41.2	42.5
7.	New York Central and Hudson River	19.9	21.6	23.5	25.5	27,2	148	188	235	284	340	29.8	32.8	36.5	40.6	44.5
8.	Detroit River Tunnel, Michigan Central Railway	27.0	29.3	32.2	34.8	37.7	194	249	306	375	445	40.2	45.0	49.8	53.6	57.0
12.	Great Northern U.S.A. Cascade Tunnel	28.0	30.9	33.4	36.6	39.2	204	255	318	386	466	41.3	47.4	52.5	57.4	61.4
14.	Midi France (Westinghouse) ...	25.7	28.2	30.8	33.5	36.5	198	248	301	383	455	37.8	43.2	47.5	50.7	53.5
3.	New York, New Haven and Hartford Railway	27.7	30.6	33.2	35.9	38.4	204	261	325	390	465	41.2	45.8	51.0	57.0	62.2

For single locomotives, the stress effects of the proposed loading are greater throughout except in one case of bending on a 35 span. In this case one of the N.Y.C. & H.R.R. locomotives (No. 6), v. Plan No. 5, exceeds the conventional loading by 4 per cent., but the latest type of locomotive adopted by this company (No. 7), with greater power and adhesion than No. 6, gives considerably less stresses.

With two coupled locomotives the stresses are generally less than those caused by the conventional locomotive loading, but where exceeded the corresponding power and adhesions are in general more than proportionately greater than the requirements. For example, in the reactions to cross girder, two coupled Great Northern locomotives exceed the reaction from the Sydney Harbour bridge conventional load by about 5 per cent,, but the adhesion of the Great Northern locomotives is over 100 per cent. greater, and the power 35 per cent. greater, than the requirements for Sydney. Similarly, with the coupled N.Y.C. locomotives, the adhesion is 28 per cent. greater, and power 57 per cent. greater, while the stresses can be only about 12 per cent. greater than those caused by the conventional load.

A contingency may, of course, arise in connection with the Sydney Harbour bridge that a standard locomotive may become inadequate, and if trains are then double-headed, the total weight of locomotives may exceed the actual requirements and the weight for which the bridge is designed. Such a train would increase the stresses in the bridge, but it was not thought necessary to increase the weight of the conventional locomotive above actual requirements, because the contingency can be avoided by using one or two locomotives per train, not exceeding 160 tons in weight, or by so regulating the traffic that two trains heavier than the conventional loading are not on the main span at the same time.

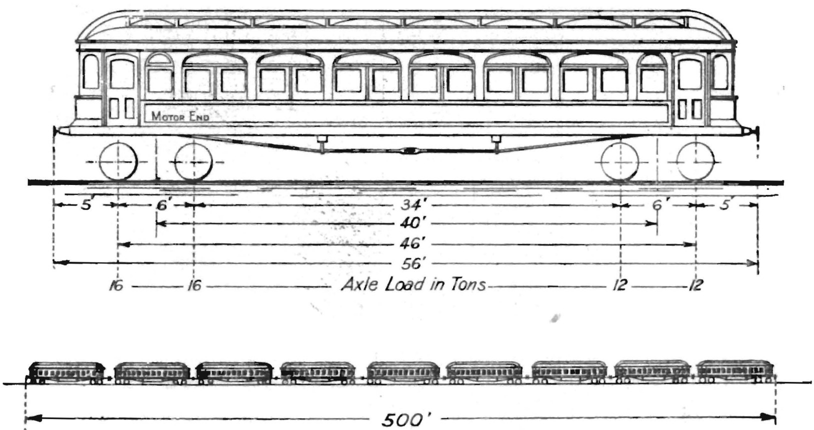
On account of the cost involved. some definite limit had to be fixed for the loading. The conventional load adopted will, it is thought, reasonably meet future requirements, whilst it will not impose undue restrictions on the locomotive engineer in the future. It is difficult now to foresee what electric locomotives may be required, but it should not be difficult for the locomotive engineer in the future to design electric locomotives capable of doing the work required without exceeding the maximum stresses provided for in the bridge.

Suburban Railways.—The two eastern railway tracks are to be designed for suburban electric railway traffic, viz., a train 500 feet long, weighing 2,240lbs. per foot with axle loads, as shown on Plan No. 6.

SYDNEY HARBOUR BRIDGE, SUBURBAN RAILWAY LOADING.

Conventional Electric Car and Train.

Plan No. 6.



Weight per Foot - 2240 lbs

In deriving the conventional loading, the chief considerations are:—

1. The train must be long enough to meet the proboble demands of traffic.

2. The weight per foot run of train must be sufficient to allow for the powerful rolling stock which will be required for an exacting service.

3. The axle loads and wheel-spacings adopted must be such that cars of any likely type or length can be used.

For the suburban passenger service, multiple unit electric trains made up of motor cars or motor cars and trailers will be used, and heavy axle loads will be required for the motor cars.

The longest suburban trains at present in use in Sydney consist of 10 cars, each about 50 feet long, seating 60 passengers.

For a quick electric passenger service the tendency is in the direction of small trains at frequent intervals, consequently a train 500 feet long, seating about 600 people, was considered the maximum provision required.

TABLE 8.

Weights, Etc., of Steel Passenger Cars.

Suburban Trailing Cars for Locomotive Service.

Railway.	Length Over Buffets.	Passengers Seated.	Weight Empty.	Weight Loaded.	Weight Per Foot Empty.	Weight Per Foot Loaded.	Reference.
	ft. in.		lbs.	lbs.	lbs.	lbs.	
Illinois Central R.R.	71 11$\frac{1}{4}$	100	82,800	97,800	1,150	1,360	"Engineering News," Sept. 3/'08.
Pennsylvania R.R.	64 5$\frac{3}{4}$	72	75,000	85,800	1,163	1,330	"Engineering News," June 20/'07.

Electric Motor Cars.

Railway.	Length Over Buffets.	Passengers Seated.	Weight Empty.	Weight Loaded.	Weight Per Foot Empty.	Weight Per Foot Loaded.	Reference.
New York Central R.R.	60 0	64	105.500	115,100	1,758	1,918	"Engineering News," Sept. 3/'08. "Engineering News," Nov. 16/'05.
Interborough Rapid Transit	51 5	46	79,400	85,840	1,544	1,669	Proc. Inst. C.E.. 1913.
Long Island R.R.	51 2	—	83,000	—	1,622	1,782	"Engineering News," Sept. 3'08. "Engineering News," Nov. 2/'05.
Metropolitan (elevated) Chicago ..	47 6$\frac{3}{4}$	48	60,000	67.200	1,261	1,413	"Engineering News," Sept. 3/'08.
New York Subway	51 0	44	73,400	80,000	1,439	1,569	"Elec. Rly. Jour.," Oct. 2/'09. ,, ,, Oct. 22/'10.
Hudson and Manhattan R.	48 2	44	69,600	76 200	1,443	1.582	"Engineering News," Sept. 3/'08.
New York, Westchester and Boston R.	72 0$\frac{3}{4}$	78	119,000	129,920	1,653	1,804	"Engineering News," June 12/'13.

Average 1,677
With Crush Load, say 1,800

The suburban railway service of Sydney, at present worked by steam locomotives, consists of one "S" class locomotive, weighing 72 tons, and wooden cars, about 50ft. long, weighing approximately, 1,000lbs. per foot loaded, from 7 to 10 cars are generally used. The average train weighs about 1,250lbs. per foot, including the weight of the engine.

The weight per foot of the suburban trains in the future will inevitably be greater than the present steam service. The multiple unit electric trains in London at the present time do not exceed 1,600lbs. per foot run. The American interurban trains weigh from 1,400 to 1,700lbs. per foot run. The car, as far as can be ascertained, having the greatest weight per foot is used by the Long Island Company, New York. It is 51 feet long, and weighs 106,000lbs. when heavily loaded, or 2,080lbs. per foot, the axle loads at the motor end being 30,800lbs.

Table No. 8 gives particulars of some typical modern steel electric motor cars, and some steel trailing cars for suburban locomotive service.

As the grades in the suburban zone on the northern side of the harbour will be heavy, there will probably be needed cars heavier than are in use elsewhere for similar traffic at the present day. On this account a load of 1 ton (2,240lbs.) per foot was considered a reasonable figure to adopt to allow for possible developments.

The stress effects caused by short and long cars will be considered in conjunction with the conventional suburban loading adopted.

Plan No. 7 shows the wheel arrangement of three types of car.

1. The conventional loading adopted for the Sydney harbour bridge.

2. A car, 72ft. long, in use on the New York, Westchester and Boston Railway.

3. A car, 51ft. long, the heaviest motor car in use on the Long Island Railway.

Table No. 9 shows the maximum bending moments and shears in the stringers and reactions to cross girders due to trains of the cars shown by Plan No. 7. Nos. 2 and 3 are representative of heavy, long steel cars and the heaviest type of short car respectively. In calculating bending moments, &c., motor ends of cars are taken adjoining.