LOAD LIMITATIONS ON HIGHWAYS

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SYNOPSIS

In order to protect the present highways and to avoid the necessity of designing our future highways for unreasonably heavy loads, legal limitations on loads have been imposed by all states. The States have generally acted independently in the matter so that we now find a great variety of restrictions which often impose handicaps on truck traffic without achieving their aim of protecting the highways. It has been shown by tests that truck wheels may be placed in tandem at the minimum practicable spacing without producing greater stresses in pavements than are produced by a single wheel carrying a load equal to that on each wheel in tandem. It is, therefore, necessary to limit only the wheel load to adequately protect pavements. Bridges are designed for concentrated loads on short spans and a uniform load or a combination of uniform and concentrated loads for longer spans. It is obviously desirable to specify load restrictions of a form similar to the design load so that it will be applicable to any type of truck train and any span length avoiding the necessity, as far as possible, of making provision for special cases. Such a form of limitation could then be made applicable to bridges designed for any load by varying the constants controlling the intensity of load. Load limitations based on the design loads of the American Association of State Highway Officials are presented in the report and a study has been made of the stresses which are produced by the loads permitted under these restrictions as compared with the stresses produced by the loadings of the A. A. S. H. O. and Bureau of Public Roads of 1919.

Legal restrictions on the vehicular loads which may be hauled over the public highways have been imposed by the various states of the Union independently of one another and, as a consequence, show a pronounced lack of uniformity in their requirements. Most of the regulations are intended to protect the highway pavements, little attention being given to the danger of destruction or serious overloading of bridges. It has been more or less generally assumed that an axle load limitation is sufficient protection for all parts of the highway. However, considerations of transportation economy have led to the use of excessively heavy truck trains and this development is apparently destined to continue to the limit of capacity of the highways. Under many of the present regulations, truck trains may be used which are safe for pavements and short bridge spans but are excessively heavy for main trusses or girders of bridges within certain ranges of spans, and some combinations are prohibited which may be safely used. Such conditions are a source of confusion to the state highway officials, the users of the highways and the producers of trucks.

It would be an obvious advantage to all agencies interested in highways to use a method of load limitation which would not only prevent destruction of the highway pavements and structures, but which would, also, permit truck manufacturers and users to know definitely what loads would be allowed on any combination which they might choose to use Such a method should be applicable to any type of truck train which may be proposed for use, obviating, as far as possible, special consideration of new types which may be developed It would be a further convenience for all concerned with interstate trucking to be able to make easy comparisons of the regulations of different states The present study has been made for the purpose of furnishing a basis for discussion of the problem by the Committee on Bridges and Structures of the American Association of State Highway Officials with a view to arriving at a solution of the problem which will be satisfactory to the state highway commissions and to those interested in the trucking industry

Any logical system of load restriction makes necessary a classification of routes or regions according to their importance and to the weight of traffic which will be allowed upon them It is obviously unreasonable to apply the same restriction to all highways ranging from country roads with a preponderance of light traffic units to highways in industrial regions on which much of the traffic consists of heavy units Restrictions for different classes of highways should have the same approximate relations to one another as the design loads for the structures on the highways

There are three elements of the highway which must be taken into consideration in determining the effects of heavy truck loads: The pavement, the floor systems of bridges and, within certain ranges of span, the main girders or trusses of bridges The protection of pavements requires a limitation on wheel loads Tests at the Bureau of Public Roads have shown that the spacing of wheels in tandem may be reduced to the practicable minimum without producing greater stresses in a pavement than those produced by a single wheel with a load equal to the load on each of the wheels in tandem Stresses in girders of short span bridges and in the floor systems of bridges of any span are dependent on axle loads and spacings of individual vehicles or adjacent axles in combinations of vehicles Stresses in main girders or trusses are dependent upon the entire gross load rather than the axle loads The design loads in practically all highway bridge specifications are concentrated wheel loads for short spans and some form of uniform or combined uniform and concentrated loads for main girders or trusses of longer spans It appears logical, therefore, that a load restriction should be of the same type so that it may apply to any vehicle combination for any span length and so that it may be applied to bridges designed for any load by simply applying a factor

The restrictions proposed herein are based on the bridge classification of the American Association of State Highway Officials specifications: Classes AA, A and B, with the corresponding design loads, H20, H15 and H10, respectively These restrictions must be modified for bridges designed in accordance with other specifications by changing the factors For the purpose of determining the effect on old bridges of loads permitted under the proposed restrictions, the specification loading of the Bureau of Public Roads of 1919 is also used for comparison because there are many existing bridges throughout the country designed in accordance with this type of specification The loading provisions of the A A S H O specifications and the B P. R 1919 specifications are given

The design loads of the A A S H O specifications are shown in Figures 1, 2 and 3, the truck loads being used for loaded lengths of bridge less than 60 ft and either truck train or equivalent loads for loaded lengths of 60 ft or more These specifications provide that the members be proportioned for a basic unit tensile stress of 16,000 lbs for live load and 24,000 lbs for dead load with corresponding working units for other stresses It also provides that, when the live load is doubled the stresses due to combined dead and live load shall not exceed 24,000 lbs The practical effect of this overload provision is to design always for double the standard design loads at what may be considered a maximum unit stress of 24,000 lbs

The 1919 specifications of the Bureau of Public Roads provide typical truck loads as shown in Figure 4 or uniform live loads over the whole width of roadway varying in intensity with the span of the bridge These uniform loads are as follows:

Span Feet	Uniform load per sq ft of roadway Pounds
100 or less	80
110	78
120	76
130	74
140	72
150	70
160	68
170	66
180 or more	64

The load to be used is chosen as follows

1 For concrete masonry and brick arches.
   Typical 15 ton trucks and 100 lbs per sq ft

2 For encased steel and reinforced concrete structures:
   Typical 15 ton trucks or tabular uniform live load

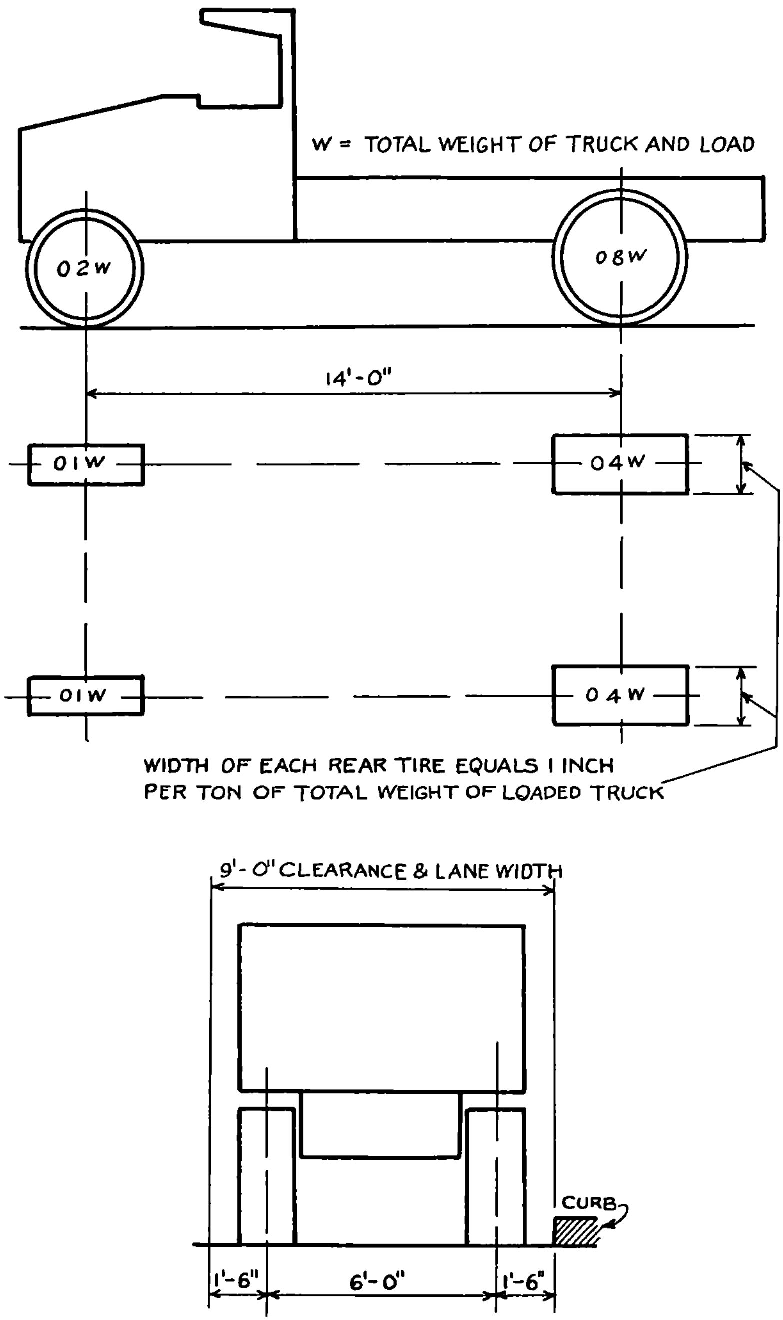

Figure 1. Truck

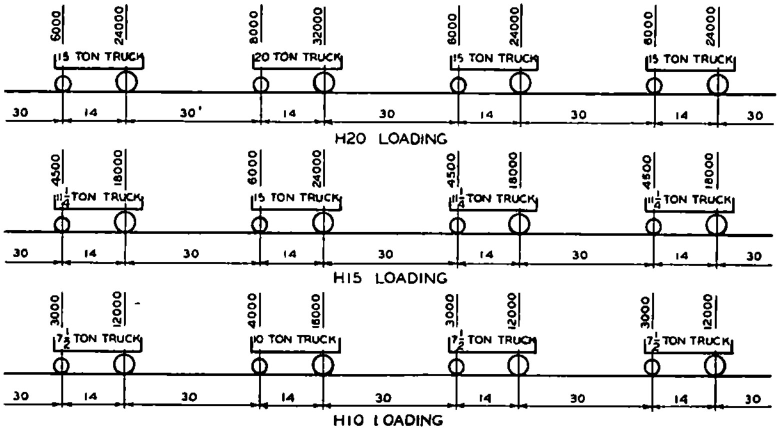

Figure 2. Truck Train Loading

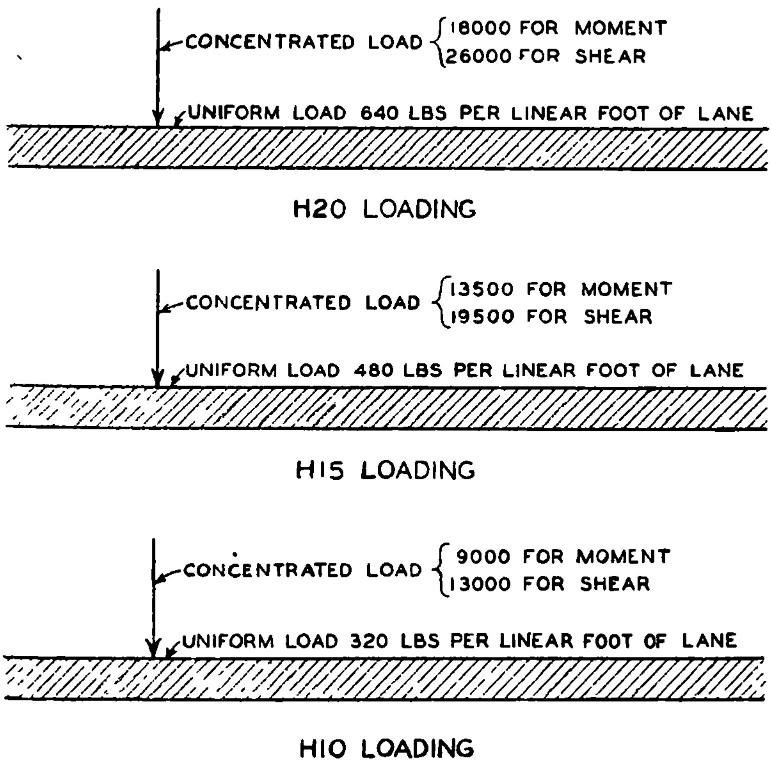

Figure 3. Equivalent Loading

3 For steel structures not encased
Typical 15 ton trucks or tabular uniform load
4 For housed timber structures, or structures of treated timber
Typical 15 ton trucks or tabular uniform live load
5 For exposed timber structures of untreated timber
Typical 10 ton trucks, or tabular uniform live load

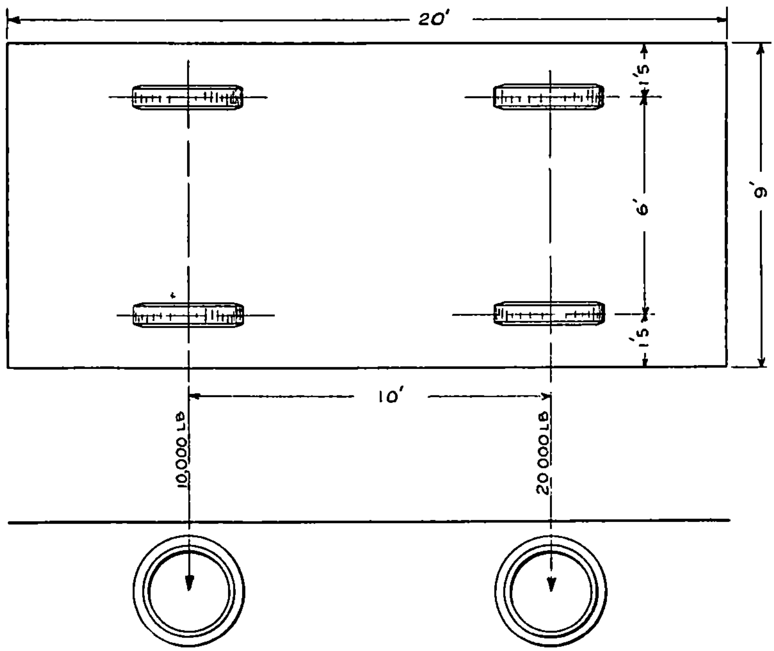

Figure 4 15-Ton Truck Loading, B P R Specifications, 1919

The following restrictions are proposed for the three classes of bridges of the A A S H O .

1 The gross load on any axle of a vehicle or combination of vehicles shall not exceed 16,000 lbs for H10 bridges, 18,000 lbs for H15 bridges and 22,400 lbs for H20 bridges
2 The total gross load in pounds on any two or more consecutive axles of a vehicle or combination of vehicles shall not exceed the amounts computed as follows
670 (L + 40) for H10 bridges with 100 per cent overload
1000 (L + 40) for H15 bridges with 100 per cent overload
1330 (L + 40) for H20 bridges with 100 per cent overload
Where L is the distance between the first and last axles of the group of axles under consideration When any axle ex-

cept the first in a combination of vehicles carries a load less than 50 per cent of the maximum axle load in the combination, the distance between this axle and the nearest adjacent axle shall be subtracted from the value of L in the above formulas

3 The total length of any combination of vehicles shall not exceed 85 ft between the first and last axle of the combination

An axle load shall be considered as the total load on all wheels spaced longitudinally so that their centers may be included between two vertical transverse parallel planes 40 inches apart This provision is thought necessary to limit the use of trailers having axles spaced less than the diameter of the wheels with wheel clearance provided by offset

The factor 40 which is added to L in determining the allowable gross load serves the purpose of preventing discrimination against the shorter combinations, its proportionate influence decreasing as the length of combination increases The provision that axles with loads less than 50 per cent of the maximum axle load in the combination shall not be considered in determining the value of L in the formulas is intended to prevent the addition of light trailers to a combination for the express purpose of securing a greater allowable load, and to prevent the grouping of heavy axle loads in a short length

In order to determine the effect of the above regulations, a number of possible types of combinations are shown in Figures 5 to 14 and designated as types A to J Average axle spacings are used All of these types, with the possible exception of J, are in actual use somewhere in the country and there may be demands for their introduction into any state if warranted by transportation economy The loads shown are those which would be permitted under the above regulations on highways with bridges designed for the A A S H O H15 loads plus 100 per cent overload Tables I to IX show comparisons between these combinations and the design loadings of the A A S H O and the 1919 specifications of the Bureau of Public Roads The comparisons are based on maximum bending moments and maximum end shears for spans from 2 to 220 ft, and floor beam loads for panels from 10 to 30 ft One entire traffic lane 9 ft wide is used in the computations In the case of the B P R specifications, the uniform load per sq ft of traffic lane is taken as the specified load per sq ft of roadway, so that one truss load for an 18 ft roadway is used in the comparisons The ratios shown in Tables VII, VIII and IX apply to bridges with roadways of widths equal to multiples of a traffic lane and would be smaller for intermediate widths

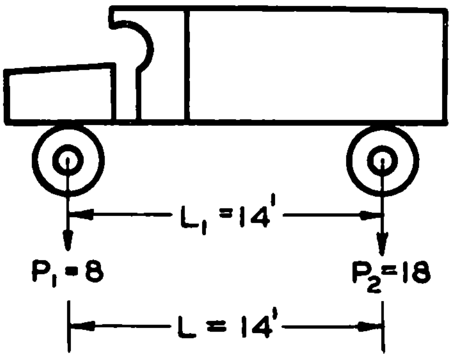

Figure 5 Type A—Single 4-Wheel Truck
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 54,000 Lbs.

Permissible Loads Are for Bridges Designed for
A A S H O. — H15 Loading Plus 100% Overload

NOTE—P_1 is assumed to be 8,000 pounds as a reasonable proportion of the total load, although any value up to 18,000 pounds would be permitted

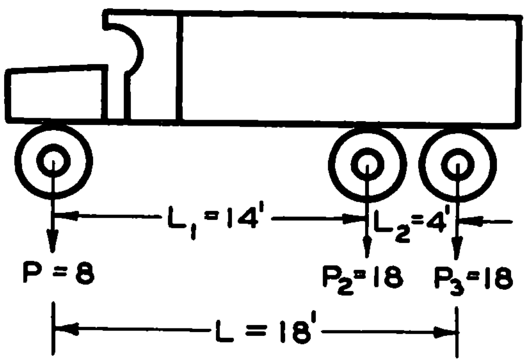

Figure 6 Type B—6-Wheel Truck
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 58,000 Lbs.

Permissible Loads Are for Bridges Designed for
A. A. S. H O. — H15 Loading Plus 100% Overload

NOTE—P_1 is assumed to be 8,000 pounds as a reasonable proportion of the total load, although any value up to 18,000 pounds would be permitted

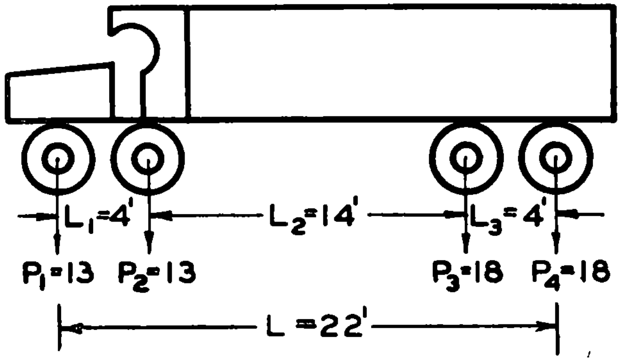

Figure 7 Type C—Single 8-Wheel Truck
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 62,000 Lbs

Permissible Loads Are for Bridges Designed for A. A. S H O —H15 Loading Plus 100% Overload

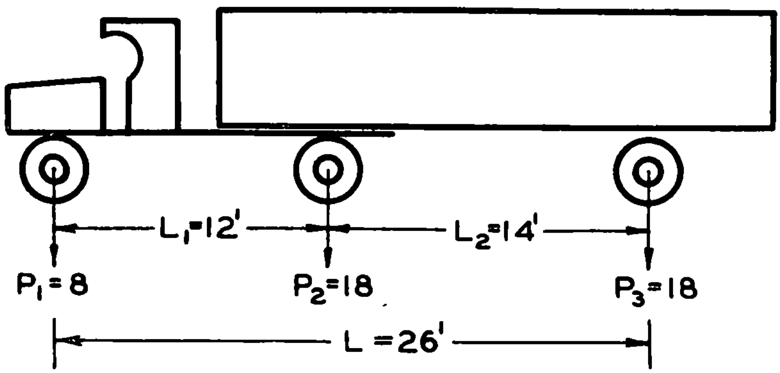

Figure 8 Type D—4-Wheel Semi-Trailer
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs
Gross Load = 1,000 (L + 40) = 66,000 Lbs.

Permissible Loads Are for Bridges Designed for A. A. S. H. O. – H15 Loading Plus 100% Overload

NOTE—P_1 is assumed to be 8,000 pounds as a reasonable proportion of the total load, although any value up to 18,000 pounds would be permitted

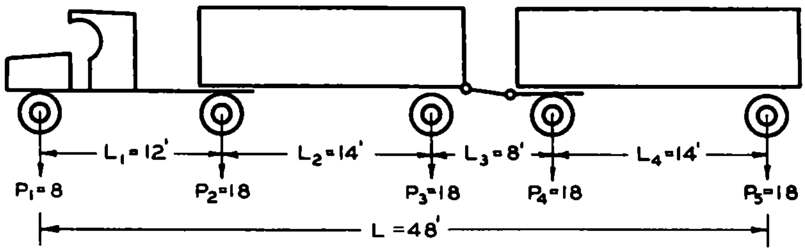

Figure 9 Type E—4-Wheel Dual Semi-Trailer

Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 88,000 Lbs

Permissible Loads Are for Bridges Designed for
A A S H O. – H15 Loading Plus 100% Overload

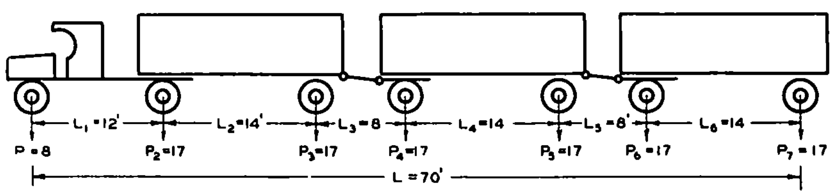

Figure 10` Type F—4-Wheel Triple Semi-Trailer

Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 110,000 Lbs

Permissible Loads Are for Bridges Designed for
A A S H. O. – H15 Loading Plus 100% Overload

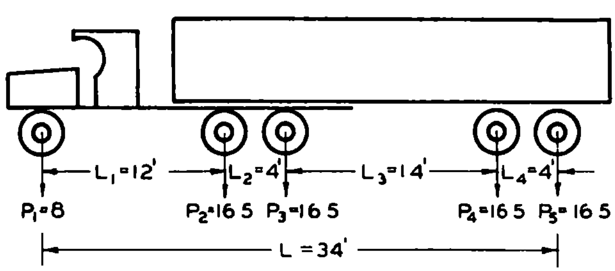

Figure 11 Type G—6-Wheel Semi-Trailer

Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 74,000 Lbs

Permissible Loads Are for Bridges Designed for
A A S H O – H15 Loading Plus 100% Overload

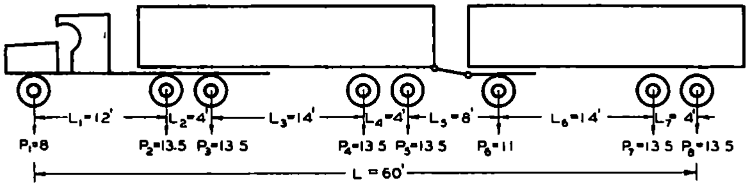

Figure 12 Type H—6-Wheel Dual Semi-Trailer
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 100,000 Lbs

Permissible Loads Are for Bridges Designed for
A. A. S. H O. — H15 Loading Plus 100% Overload

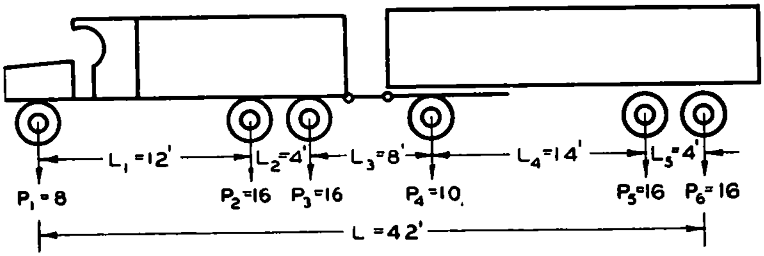

Figure 13 Type I—6-Wheel Truck and Trailer
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 82,000 Lbs.

Permissible Loads Are for Bridges Designed for
A A S H O — H15 Loading Plus 100% Overload

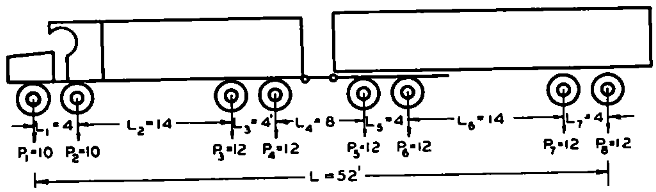

Figure 14 Type J—8-Wheel Truck and Trailer
Value of " P " in Thousands of Pounds

Maximum Permissible

Axle Load = 18,000 Lbs.
Gross Load = 1,000 (L + 40) = 92,000 Lbs.

Permissible Loads Are for Bridges Designed for
A. A. S H O — H15 Loading Plus 100% Overload

TABLE I

MAXIMUM BENDING MOMENTS KIP FT DUE TO LOADS A TO J, A A S H O LOADING H15 AND B P R LOADING OF 1919

Span	A	B	C	D	E	F	G	H	I	J	A A S H O H15	B P R 1919
2	9 00	9 00	9 00	9 00	9 00	8 50	8 25	6 75	8 00	6 00	12 00	10 00
4	18 00	18 00	18 00	18 00	18 00	17 00	16 50	13 50	16 00	12 00	24 00	20 00
6	27 00	27 00	27 00	27 00	27 00	25 50	24 75	20 25	24 00	18 00	36 00	30 00
8	36 00	40 50	40 50	36 00	36 00	34 00	37 12	30 38	36 00	27 00	48 00	40 00
10	45 00	57 60	57 60	45 00	45 00	42 50	52 80	43 20	51 20	38 40	60 00	50 00
14	63 00	92 57	92 57	63 00	64 28	60 71	84 86	69 43	82 28	61 71	84 00	70 00
18	81 00	128 00	128 00	81 00	98 00	92 55	117 33	96 00	113 78	85 33	108 00	90 00
20	90 00	145 80	145 80	90 00	115 20	108 79	133 65	119 28	138 10	97 20	120 00	104 08
22	99 00	163 64	163 64	99 00	132 55	125 18	150 00	138 25	159 62	128 72	132 00	118 70
24	108 00	181 50	181 50	108 38	150 00	141 66	166 37	157 22	180 08	152 00	144 00	133 39
26	117 72	199 38	199 38	124 96	167 54	158 22	182 76	176 20	201 07	175 38	156 00	148 12
30	143 11	238 50	242 67	158 70	202 80	191 52	226 51	214 16	243 07	222 40	184 96	177 69
40	207 10	348 42	387 62	257 84	343 35	312 80	388 87	301 29	326 93	340 80	259 47	251 99
60	336 10	568 35	693 62	465 87	661 33	680 38	755 75	584 07	728 00	700 03	408 98	401 29
80	483 51	788 31	1001 63	684 88	1061 00	1202 46	1124 18	1199 53	1128 00	1138 92	654 00	576 00
100	595 30	1008 29	1310 43	904 29	1700 90	1751 34	1493 25	1699 43	1538 00	1618 25	937 50	900 00
140	854 95	1448 26	1929 06	1343 61	2260 57	2850 07	2232 17	2699 30	2358 00	2537 49	1648 50	1587 60
180	1114 65	1888 25	2548 30	1783 24	3060 44	3931 37	2917 58	3699 23	3178 00	3457 08	2551 50	2478 60
220	1374 65	2328 24	3167 81	2223 00	4940 45	5048 92	3711 28	4699 19	3998 00	4376 81	3646 50	3702 60

TABLE II

MAXIMUM END SHEARS IN KIPS DUE TO LOADS A TO J, A A S H O LOADING H15 AND B P R LOADING OF 1919

Span	A	B	C	D	E	F	G	H	I	J	A A S H O H15	B P R 1919
2	18 00	18 00	18 00	18 00	18 00	17 00	16 50	13 50	16 00	12 00	24 00	20 00
4	18 00	18 00	18 00	18 00	18 00	17 00	16 50	13 50	16 00	12 00	24 00	20 00
6	18 00	24 00	24 00	18 00	18 00	17 00	22 00	18 00	21 33	16 00	24 00	20 00
8	18 00	27 00	27 00	18 00	18 00	17 00	24 75	20 25	24 00	18 00	24 00	20 00
10	18 00	28 80	28 80	18 00	21 60	20 40	26 40	21 60	25 60	19 20	24 00	20 00
14	18 00	30 86	30 86	18 00	25 71	24 28	28 29	24 71	28 85	22 28	24 00	22 86
18	19 79	32 00	32 00	22 00	28 00	26 44	29 33	27 67	32 78	26 67	25 33	24 45
20	20 41	33 20	33 76	23 40	28 80	27 20	31 35	28 70	32 70	28 80	25 80	25 00
22	20 92	34 18	35 10	24 55	29 45	27 81	33 00	29 55	33 64	30 55	26 18	25 46
24	21 34	35 00	37 33	25 50	31 50	29 75	35 75	30 25	34 33	32 00	26 50	25 83
26	21 70	35 69	39 23	26 31	33 23	31 38	38 08	30 85	34 92	33 24	26 77	26 15
30	22 27	36 80	42 26	30 27	36 00	34 00	37 40	34 20	38 00	35 20	27 20	26 67
40	23 21	38 60	47 20	33 70	41 75	42 50	49 04	41 90	47 00	43 20	27 90	27 50
60	24 14	40 40	52 13	37 18	52 00	56 07	57 36	54 50	57 40	53 07	33 90	28 37
80	24 60	41 30	54 60	38 85	59 00	66 03	61 52	65 88	63 55	63 80	38 70	28 88
100	24 88	41 84	56 08	39 88	63 20	74 82	64 01	72 70	67 24	68 64	43 50	36 00
140	25 20	42 46	57 77	41 06	68 00	84 87	66 87	80 50	71 46	75 31	53 10	45 36
180	25 38	42 80	58 71	41 71	70 67	90 45	68 45	84 83	73 80	79 02	62 90	55 08
220	25 49	43 02	59 31	42 12	72 36	94 01	69 46	87 59	75 29	81 38	72 30	67 32

TABLE III

MAXIMUM FLOOR BEAM LOADS DUE TO LOADS A TO J, A A S H O LOADING H15 AND B P R LOADING OF 1919

Panel	A	B	C	D	E	F	G	H	I	J	A A S H O H15	B P R 1919
10	18 00	28 80	28 80	18 00	21 60	20 40	26 40	23 80	27 60	21 60	24 00	20 00
14	18 00	30 86	30 86	19 14	25 71	24 28	29 43	27 85	31 71	27 43	24 00	22 86
18	19 79	33 78	34 89	24 67	32 00	30 22	33 89	30 11	34 89	32 00	25 33	24 45
20	20 41	34 80	39 60	26 60	34 20	32 30	37 90	34 10	36 40	34 80	25 80	25 00
22	20 92	35 64	39 82	28 18	36 00	34 00	41 18	36 90	37 64	37 09	26 18	25 46
24	21 34	36 33	41 67	29 50	39 00	38 25	43 92	39 25	40 00	40 00	26 50	25 83
26	21 70	36 92	43 23	30 62	41 54	41 85	46 23	41 23	42 00	42 46	26 77	26 15
30	22 27	37 87	45 73	32 40	46 67	47 60	49 03	47 67	47 33	47 07	27 20	26 67

TABLE IV

RATIOS OF MAXIMUM BENDING MOMENTS DUE TO LOADS A TO J AND THOSE DUE TO A A S H O LOADING H15

Span	A	B	C	D	E	F	G	H	I	J
2	0 75	0 75	0 75	0 75	0 75	0 71	0 69	0 56	0 67	0 50
4	0 75	0 75	0 75	0 75	0 75	0 71	0 69	0 56	0 67	0 50
6	0 75	0 75	0 75	0 75	0 75	0 71	0 69	0 56	0 67	0 50
8	0 75	0 84	0 84	0 75	0 75	0 71	0 77	0 63	0 75	0 56
10	0 75	0 96	0 96	0 75	0 75	0 71	0 88	0 72	0 85	0 64
14	0 75	1 10	1 10	0 75	0 77	0 72	1 01	0 83	0 98	0 73
18	0 75	1 19	1 19	0 75	0 91	0 86	1 09	0 89	1 05	0 79
20	0 75	1 21	1 21	0 75	0 96	0 91	1 11	0 99	1 15	0 81
22	0 75	1 24	1 24	0 75	1 00	0 95	1 14	1 05	1 ·21	0 98
24	0 75	1 26	1 26	0 75	1 04	0 98	1 16	1 09	1 25	1 03
26	0 75	1 28	1 28	0 80	1 07	1 02	1 17	1 13	1 29	1 12
30	0 78	1 29	1 32	0 86	1 10	1 04	1 23	1 16	1 32	1 15
40	0 80	1 35	1 50	0 99	1 32	1 21	1 50	1 16	1 26	1 31
60	*0 82*	*1 39*	*1 70*	*1 14*	1 62	1 66	*1 85*	1 43	*1 78*	1 71
80	0 74	1 21	1 54	1 05	1 62	1 84	1 72	*1 83*	1 72	*1 74*
100	0 64	1 08	1 40	0 97	*1 82*	*1 87*	1 59	1 81	1 64	1 73
140	0 52	0 88	1 17	0 82	1 37	1 73	1 36	1 64	1 43	1 54
180	0 44	0 74	1 00	0 70	1 20	1 54	1 14	1 45	1 25	1 36
220	0 38	0 64	0 87	0 61	1 35	1 38	1 02	1 29	1 10	1 20

TABLE V

RATIOS OF MAXIMUM END SHEARS DUE TO LOADS A TO J AND THOSE DUE TO A A S H O LOADING H15

Span	A	B	C	D	E	F	G	H	I	J
2	0 75	0 75	0 75	0 75	0 75	0 71	0 69	0 56	0 67	0 50
4	0 75	0 75	0 75	0 75	0 75	0 71	0 69	0 56	0 67	0 50
6	0 75	1 00	1 00	0 75	0 75	0 71	0 92	0 75	0 89	0 67
8	0 75	1 11	1 11	0 75	0 75	0 71	1 03	0 84	1 00	0 75
10	0 75	1 20	1 20	0 75	0 90	0 85	1 10	0 90	1 07	0 80
14	0 75	1 29	1 29	0 75	1 07	1 01	1 18	1 03	1 20	0 93
18	0 78	1 26	1 26	0 87	1 11	1 05	1 16	1 09	1 29	1 05
20	0 79	1 29	1 31	0 91	1 12	1 05	1 21	1 11	1 27	1 12
22	0 80	1 30	1 34	0 93	1 12	1 06	1 26	1 12	1 28	1 17
24	0 81	1 32	1 41	0 96	1 19	1 12	1 35	1 14	1 30	1 21
26	0 81	1 34	1 47	0 98	1 25	1 17	1 43	1 16	1 31	1 25
30	0 81	1 34	1 56	1,11	1 33	1 25	1 38	1 26	1 40	1 30
40	*0 83*	*1 38*	*1 69*	*1 21*	1 50	1 52	*1 76*	1 50	*1 69*	1 55
60	0 71	1 19	1 54	1 10	*1 53*	1 66	1 69	1 61	*1 69*	1 57
80	0 68	1 07	1 41	1 00	1 52	1 71	1 59	*1 70*	1 64	*1 62*
100	0 57	0 96	1 29	0 92	1 45	*1 72*	1 47	1 67	1 55	1 58
140	0 48	0 80	1 09	0 77	1 28	1 60	1 26	1 52	1 35	1 42
180	0 40	0 68	0 94	0 67	1 13	1 44	1 09	1 35	1 18	1 26
220	0 35	0 60	0 82	0 58	1 00	1 30	0 96	1 21	1 00	1 12

Most of the existing highway bridges have been designed for comparatively low basic unit stresses, 16,000 lbs unit tensile stress for steel and 650 lbs unit compressive stress for concrete Infrequent

TABLE VI

RATIOS OF MAXIMUM FLOOR LOADS DUE TO LOADS A TO J AND THOSE DUE TO A A S H O LOADING H15

Panel	A	B	C	D	E	F	G	H	I	J
10	0 75	1 20	1 20	0 75	0 90	0 85	1 10	0 99	1 15	0 90
14	0 75	1 29	1 29	0 80	1 07	1 01	1 23	1 16	1 32	1 14
18	0 78	1 28	1 33	0 98	1 26	1 20	1 34	1 19	1 38	1 26
20	0 79	1 30	1 54	1 03	1 33	1 25	1 47	1 32	1 41	1 35
22	0 80	1 36	1 52	1 08	1 38	1 30	1 58	1 41	1 44	1 42
24	0 81	1 37	1 58	1 11	1 47	1 44	1 66	1 48	1 51	1 51
26	0 81	1 38	1 62	1 15	1 56	1 57	1 73	1 54	1 57	1 59
30	*0 82*	*1 40*	*1 68*	*1 19*	*1 72*	*1 76*	*1 84*	*1 76*	*1 74*	*1 73*

TABLE VII

RATIOS OF MAXIMUM BENDING MOMENTS DUE TO LOADS A TO J AND THOSE DUE TO LOADING OF THE B P R SPECIFICATIONS OF 1919

Span	A	B	C	D	E	F	G	H	I	J
2	0 90	0 90	0 90	0 90	0 90	0 85	0 83	0 68	0 80	0 60
4	0 90	0 90	0 90	0 90	0 90	0 85	0 83	0 68	0 80	0 60
6	0 90	0 90	0 90	0 90	0 90	0 85	0 83	0 68	0 80	0 60
8	0 90	1 01	1 01	0 90	0 90	0 85	0 93	0 76	0 90	0 68
10	0 90	1 15	1 15	0 90	0 90	0 85	1 06	0 86	1 02	0 77
14	0 90	1 32	1 32	0 90	0 92	0 87	1 21	0 99	1 17	0 88
18	*0 90*	*1 42*	1 42	0 90	1 08	1 03	1 30	1 07	1 53	0 99
20	0 86	1 39	1 39	0 86	1 10	1 04	1 28	1 15	1 32	0 93
22	0 84	1 38	1 38	0 84	1 12	1 06	1 27	1 17	1 35	1 08
24	0 81	1 36	1 54	0 81	1 13	1 06	1 25	1 18	1 36	1 14
26	0 79	1 35	1 34	0 84	1 13	1 08	1 23	1 19	1 36	1 19
30	0 81	1 35	1 37	0 89	1 14	1 08	1 28	1 20	1 37	1 26
40	0 82	1 39	1 54	1 02	1 36	1 20	1 54	1 20	1 30	1 35
60	0 84	*1 42*	1 73	1 16	1 65	1 67	1 89	1 46	1 82	1 74
80	0 84	1 37	*1 74*	*1 19*	1 84	*2 01*	*1 95*	*2 04*	*1 96*	*1 97*
100	0 66	1 12	1 45	1 05	*1 89*	1 95	1 66	1 89	1 71	1 80
140	0 54	0 91	1 22	0 85	1 43	1 80	1 41	1 70	1 49	1 60
180	0 45	0 76	1 03	0 72	1 24	1 59	1 18	1 49	1 28	1 40
220	0 37	0 63	0 86	0 60	1 33	1 36	1 00	1 27	1 08	1 18

overloads have been permitted by allowing the design unit stresses to be exceeded by as much as 50 per cent The actual overloads in such cases are represented by the amounts by which the stresses produced by combined dead and live loads exceed the design stresses and, for any particular member of a structure, are dependent upon the ratio of dead to live load stresses in that member The ratios given in Tables VII, VIII and IX show true overloads only for those

TABLE VIII

RATIOS OF MAXIMUM END SHEARS DUE TO LOADS A TO J AND THOSE DUE TO THE LOADING OF THE B P R SPECIFICATIONS OF 1919

Span	A	B	C	D	E	F	G	H	I	J
2	0 90	0 90	0 90	0 90	0 90	0 85	0 83	0 68	0 80	0 60
4	0 90	0 90	0 90	0 90	0 90	0 85	0 83	0 68	0 80	0 60
6	0 90	1 20	1 20	0 90	0 90	0 85	1 10	0 90	1 07	0 80
8	0 90	1 35	1 35	0 90	0 90	0 85	1 24	1 01	1 20	0 90
10	0 90	*1 44*	1 44	0 90	1 08	1 02	1 32	1 08	1 28	0 96
14	0 79	1 35	1 35	0 79	1 12	1 06	1 24	1 08	1 26	0 97
18	0 81	1 31	1 31	0 90	1 14	1 08	1 20	1 13	1 34	1 09
20	0 82	1 33	1 35	0 94	1 15	1 09	1 25	1 15	1 31	1 05
22	0 82	1 34	1 38	0 96	1 16	1 09	1 30	1 16	1 32	1 20
24	0 82	1 36	1 39	0 95	1 22	1 15	1 38	1 17	1 33	1 24
26	0 83	1 36	1 50	1 01	1 27	1 20	1 46	1 18	1 33	1 28
30	0 84	1 38	1 58	1 14	1 35	1 28	1 41	1 28	1 43	1 32
40	0 84	1 41	1 72	1 23	1 52	1 55	1 78	1 52	1 71	1 57
60	*0 85*	*1 43*	*1 84*	1 31	1 84	1 98	2 02	1 93	2 03	1 87
80	*0 85*	*1 43*	*1 84*	*1 35*	*2 04*	*2 30*	*2 13*	*2 20*	*2 20*	*2 18*
100	0 69	1 16	1 56	1 29	1 76	2 08	1 78	2 02	1 87	1 91
140	0 56	0 94	1 28	1 09	1 50	1 87	1 47	1 78	1 57	1 66
180	0 46	0 78	1 07	0 94	1 28	1 64	1 24	1 54	1 34	1 44
220	0 38	0 64	0 97	0 82	1 07	1 40	1 03	1 30	1 12	1 21

TABLE IX

RATIOS OF MAXIMUM FLOOR BEAM LOADS DUE TO LOADS A TO J AND THOSE DUE TO THE LOADING OF THE B P R SPECIFICATIONS OF 1919

Panel	A	B	C	D	E	F	G	H	I	J
10	0 90	1 44	1 44	0 90	1 08	1 02	1 32	1 19	1 38	1 08
14	0 79	1 35	1 35	0 84	1 13	1 06	1 29	1 22	1 39	1 26
18	0 81	1 38	1 43	1 01	1 31	1 24	1 39	1 23	1 43	1 31
20	0 82	1 39	1 58	1 07	1 37	1 29	1 52	1 37	1 46	1 39
22	0 82	1 40	1 57	1 11	1 41	1 34	1 62	1 45	1 48	1 46
24	0 83	1 41	1 58	1 14	1 51	1 48	1 70	1 52	1 55	1 55
26	0 83	1 41	1 66	1 17	1 66	1 60	1 77	1 58	1 61	1 62
30	*0 84*	*1 42*	*1 72*	*1 22*	*1 75*	*1 75*	*1 87*	*1 79*	*1 78*	*1 77*

members in which the dead load stress is zero For all other members, the overloads decrease as the ratios of dead to live loads increase However, since in all steel trusses, there are web members near the center of the span with zero or very small dead load stress, these members will limit the capacity of the structure

For bridges designed without overload provision, it is consequently, necessary to restrict the loads to those producing moments and shears which exceed those produced by design loads by an amount equal to the amount by which the working stress may be exceeded

For B P R designs it will be considered that a 50 per cent overstress will be permitted

For A A S H O designs where 100 per cent overload is used with the ultimate allowable unit stress of 24,000 lbs, the overload may be allowed to reach the full 100 per cent or, in other words, loads may be allowed which will produce moments and shears twice those produced by the design loads

Tables IV, V and VI show that loads A to J, permitted under the proposed H15 restriction, do not produce on any span overloads greater than 100 per cent The greatest ratio of moments is 1 87 for load F on a 100 ft span, shears, 1 76 on a 40 ft span for load G; and floor beam load, 1 84 for load G in a 30 ft panel For B. P R designs these ratios are 2 04 for load H on an 80 ft span; 2 30 for load F on an 80 ft span and 1 87 in a 30 ft panel. These ratios for B P R designs do not represent true overloads except for members where the dead load is zero The ratio 2 30 for end shears on an 80 ft span would also apply to shears at the center of a 160 ft span where the dead load shear is zero and would represent the true overload It is, therefore, necessary that a restriction be used which will reduce this ratio to 1 50 This may be done by using the formula 670 (L + 40) for the total gross load The ratio 2 04 for moments on an 80 ft span does not represent true overload because there is always a dead load moment the amount of which depends upon the span and design of floor system. It is therefore necessary to investigate this case for actual ratios of dead and live load in B P R designs

A mathematical relation between overload, dead load, live load, and overstress may be expressed as follows:

Let A = moment or shear due to dead load

B = moment or shear due to live load and impact

$A = rB$ for any particular member

nB = moment or shear due to any particular truck train

Then $\dfrac{A + nB}{A + B} = s$ = ratio of stresses due to truck train and design loads combined with dead load

Substitute $A = rB$ and we have

$$s = \frac{rB + nB}{rB + B} = \frac{r + n}{r + 1} \text{ or } n = s(r + 1) - r$$

As an illustration, let us consider a truss bridge of 80 ft span and 18 ft roadway, designed in accordance with the B P R specifications and provided with a plank floor. The trusses will have chords with an approximate value of $r = 0.50$. If a permissible value of s is assumed at 1.50, then $n = (1.5 \times 1.5) - 0.5 = 2.25 - 0.50 = 1.75$. In other words, an overstress of 50 per cent would permit, for this case, a ratio of maximum moments of 1.75. The formula 670(L + 40) limits the load to that which will result in a ratio of moments of approximately two-thirds of the maximum moment ratio 2.04 given in Table VII which equals 1.36. For heavier spans the overstress is decreased. It is, therefore, only for a comparatively small number of members of truss bridges and for short spans where the dead load is relatively unimportant that advantage can be taken of the full permissible overstress.

The proposed restrictions permit any axle spacing and distribution of load subject to the total gross load provisions and to the provision that no axle load shall be more than twice the smallest axle load in the combination exclusive of the first axle of the combination.

In order to determine the worst effect of bunching heavy axles which might occur under these restrictions, let us consider loads H and J. Even though impracticable, let us assume the following distribution of axle loads for type H with a total gross load of 100,000 lbs.: $P_1 = 8$, $P_2 = P_3 = 9.5$, $P_4 = P_5 = P_6 = 18$, $P_7 = P_8 = 9.5$. Then the maximum ratios of moments, shears and floor beam loads for an 80 ft. span become 2.04, 1.71 and 2.09, respectively, instead of 1.83, 1.70 and 1.76, respectively, for the distribution as shown on the sketch of type H load. For load J let us assume the following distribution of loads on the axles: $P_1 = P_2 = 8$, $P_3 = P_4 = P_5 = P_6 = 15$, $P_7 = P_8 = 8$. The above ratios become 1.96, 1.65 and 2.00, respectively, instead of 1.74, 1.62 and 1.73, respectively. Such axle load distributions as are assumed are the worst possible cases and would never actually occur.

If it is desired to increase the total gross load on a combination, it can be done by increasing the overall spacing of axles up to a maximum of 85 ft. On the contrary, a shortening of this distance requires a decrease in gross load.

Table X shows allowable gross loads for all A. A. S. H. O. load classifications with the axle spacings used in type loads A to J and, also, with axle spacings reduced to the minimum which would be at all practicable. Where axle loads control, ratios for H10 and H20 loadings would not be equal to those given in Tables IV to VI because the allowable wheel loads for different classes of loading are not proportionate to the lane loads and the loads given by the formulas. Since there is proportionately less difference between the H20 and H15 allowable axle loads than between the lane loads for these classes, the ratios for H20 would be less than those given in Tables

TABLE X

TOTAL GROSS LOADS IN 1000 LBS PERMITTED ON TRUCK COMBINATIONS A TO J WITH MINIMUM AND AVERAGE AXLE SPACINGS FOR BRIDGES DESIGNED FOR LOADINGS H10, H15 AND H20

Type of Vehicle	H10—A A S H O Max Axle Load 16,000 Lbs		H15—A A S H O Max Axle Load 18,000 Lbs		H20—A A S H O Max Axle Load 22,400 Lbs	
	a = 10 ft b = 3 ft -4 in c = 8 ft 100% overload G L = 670 (L+40)	a = 14 ft b = 4 ft c = 8 ft 100% overload G L = 670 (L+40)	a = 10 ft b = 3 ft -4 in c = 8 ft 100% overload G L = 1000 (L+40)	a = 14 ft b = 4 ft c = 8 ft 100% overload G L = 1000 (L+40)	a = 10 ft b = 3 ft -4 in c = 8 ft 100% overload G L = 1330 (L+40)	a = 14 ft b = 4 ft c = 8 ft 100% overload G L = 1330 (L+40)
A	*24 0*	*24 0*	*26 0*	*26 0*	*30 4*	*30 4*
B	35 7	38 9	*44 0*	*44 0*	*52 8*	*52 8*
C	38 0	41 5	56 7	*62 0*	75 4	82 5
D	*40 0*	*40 0*	*44 0*	*44 0*	*52 8*	*52 8*
E	52 3	59 0	78 0	*80 0*	*97 6*	*97 6*
F	64 3	73 7	96 0	110 0	127 7	*141 4*
G	44 4	49 6	66 7	74 0	88 2	*97 6*
H	59 0	67 0	88 0	100 0	117 0	133 0
I	50 0	54 9	74 7	82 0	99 3	*107 4*
J	54 5	61 6	81 3	92 0	108 2	122 4

a = distance between widely spaced axles of a vehicle
b = distance between closely spaced axles of a vehicle
c = distance between adjacent axles of two vehicles in a combination
Italic figures indicate weights controlled by axle limitations in which it is assumed that 8,000 lbs is carried on the front axles of vehicles or combinations of vehicles

IV to VI For H10, the ratios would be greater than the tabular values for H15 in the cases of load combinations A to E where the axle loads control For these load combinations and H10 loading, the maximum values for the ratios of moments, shears and floor beam loads will be as follows:

Load Combinations	Ratios and Spans or Panels		
	Moment	Shear	F B Load
A	1 12–60 ft	1 21–40 ft	1 12–30 ft
B	1 77–60 ft	1 77–40 ft	1 79–30 ft
C	1 75–60 ft	1 76–40 ft	1 79–30 ft
D	1 62–60 ft	1 57–40 ft	1 62–30 ft
E	1 96–100 ft	1 87–60 ft	2 28–30 ft

In all other cases of H10 and H20 restrictions, the ratios are equal to or less than those given for the H15 restriction in Tables IV, V and VI

As a purely hypothetical case let us consider axles spaced four feet apart and combinations of two or more axles Under the proposed restriction for H15 bridges the following loads would be allowed on such axles

Number of axles	Total gross load 1000 (L + 40)	Load per axle
2	44,000	18,000
3	48,000	16,000
4	52,000	13,000
5	56,000	11,200
6	60,000	10,000
7	64,000	9,140

This indicates the manner in which the gross axle load on such an unusual combination would be reduced as the number of axles is increased The effects of such loads are never equal to those produced by the 100 per cent overload

Figures 15, 16 and 17 show the gross load formulas plotted on a basis of gross load and length between first and last axle The horizontal lines represent total gross load when the maximum axle loads are used, it being assumed that one-half the maximum axle load is carried on the first axle The gross loads represented by these horizontal lines, are, therefore, the maximum axle loads multiplied by the number of axles minus one-half. The intersections of the horizontal and sloped lines give the length of combination at which the control of gross load changes from maximum axle load to total gross load as determined by the formulas

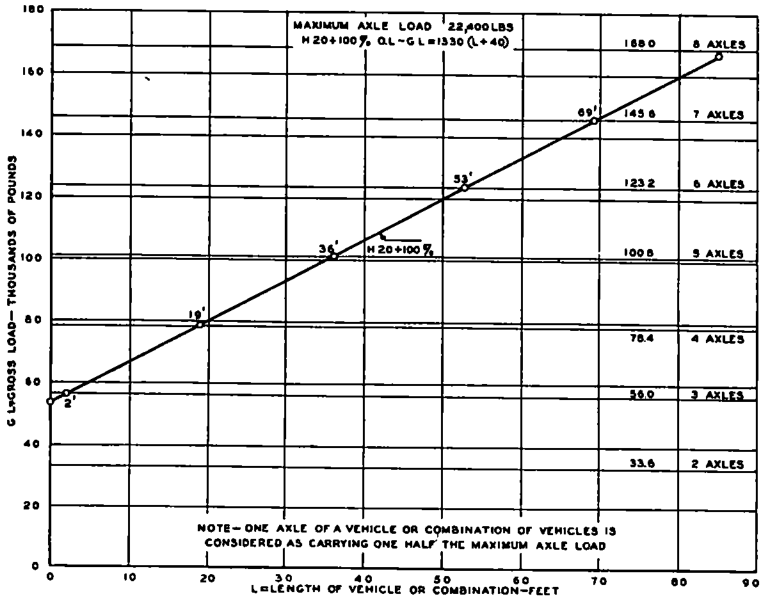

Figure 15 Sketch Showing Maximum Permissible Gross Loads for Highways with Structures Designed for A. A S. H. O. Loading H20 + 100% Overload

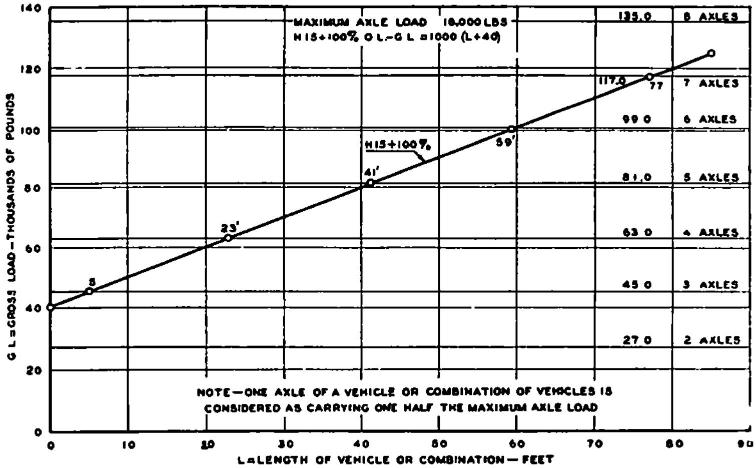

Figure 16. Sketch Showing Maximum Permissible Gross Loads for Highways with Structures Designed for A. A S H O Loading H15 — 100% Overload

It is felt that this method is easy of application, effective in protecting all parts of the highway and may be applied to all conditions by selecting appropriate constants for the formulas

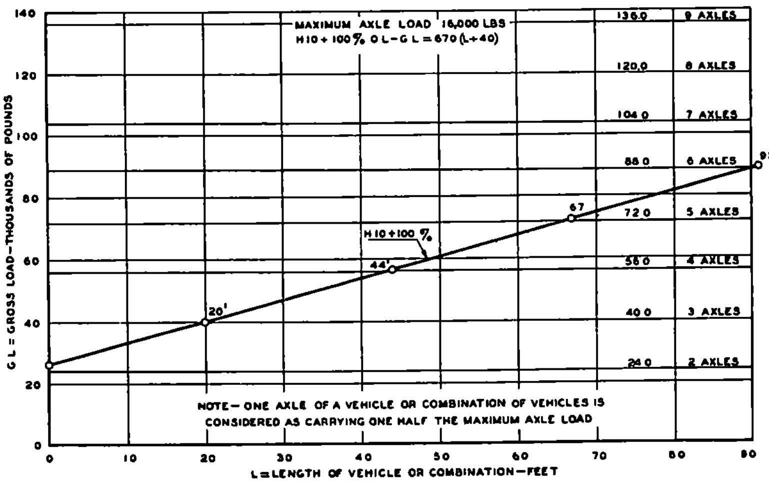

Figure 17 Sketch Showing Maximum Permissible Gross Loads for Highways with Structures Designed for A. A. S. H. O Loading H10 + 100% Overload

DISCUSSION ON LOAD LIMITATIONS

Abstracted

MR W H ROOT, *Maintenance Engineer, Iowa Highway Commission* Will Mr Gemeny's recommendations be as satisfactory for road design as for that of bridges? His recommended axle loads are in excess of those now permissible in many states and his lengths are greater than are desirable from a traffic standpoint Mr Root does not believe that we should attempt to build pavements to take care of any traffic that may come along He suggested that the road, bridge, and traffic engineers together work out recommendations for weight, length, and height of vehicles

MR J A BUCHANAN, *U S Bureau of Public Roads* The tire equipment permissible with maximum wheel loads should be specified, since the maximum allowable load depends to some extent upon that factor A factor differentiating between solid and pneumatic tires should be set up