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16. Abstract

This document defines criteria for issuing permits for overweight vehicles passing over H15, H20, and HS20 highway bridges in the state of Texas. The resulting formulae have been developed to ensure that the maximum stress does not exceed the operational stress level.

Criteria is first developed for simple span bridges. The approach used analyzes the discrete point on the bridge where overstress is most likely to occur. This is done in the manner prescribed by the American Association of State Highway and Transportation Officials (AASHTO) in the *Standard Specifications for Highway Bridges* and the *Maintenance Manual for the Inspection of Bridges*. Two formulae for each bridge type, a general formula and a bridge specific formula, have been developed to limit the group axle weight on simple span bridges.

The general formula is a function of only the vehicle dimensions and is similar to the current Texas permit rules. The current Texas Department of Transportation (TxDOT) permit rules for mobile cranes and oil well equipment vehicles only apply for wheelbases up to 80 ft. (24.4 m). The proposed formula is calculated for wheelbases up to 120 ft. (36.6 m). The formula developed is significantly more restrictive than that currently used by TxDOT. A second formula has been developed based on the vehicle dimensions and the span length of any bridge along the permitted vehicle route. With this bridge-specific formula, higher permit weights can be safely authorized without additional engineering analysis.

In addition, several critical reinforced concrete continuous span slab bridges have been investigated to ensure that the formulae calculated for simple span bridges do not exceed the allowable stresses. The greatest concern of the continuous span bridges is at the supports where negative moments can become great. The results indicate that the capacities of the reinforced concrete continuous span slab bridges are well above those allowed by the proposed simple span formulae.

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OVERLOAD PERMIT PROCEDURES

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Research Report 1266-4F
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Sponsored by the
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Implementation Statement

The use of the proposed formulae for bridges designed to both H15 and H20 loadings will significantly expedite the issuance of permits by the Central Permit Office (CPO). These formulae better estimate the design strength of bridges typical to Texas highways by incorporating the effect of span length, span type (simple supported or continuous), and type of bridge (slab, concrete or steel stringer). Therefore, the routing of permit loads, especially "superheavy" vehicles, can be performed with consideration given to specific bridges on an intended route.

Disclaimer

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LIST OF ABBREVIATIONS AND SYMBOLS

β	correction factor for concentrated loadings
A	area (in.^{2} or cm^2)
A_s	area of steel in reinforced concrete slab (in^2 or cm^2)
b	width of cross section (ft. or m)
c	distance to neutral axis of a reinforced concrete section (in. or cm)
d	depth to tensile steel (in. or cm)
D	distance between center of gravity of a given axle group and its nearest axle (ft. or m)
DF	distribution factor for steel I-beam bridges used to calculate the number of wheel loads supported by a given stringer
E	effective width which will support one line of wheels (ft. or m)
E_L	effective width which will support one lane loading (ft. or m)
f_c	allowable stress of concrete (ksi or kPa)
f_s	allowable stress of steel (ksi or kPa)
F_y	yield stress of steel (k/sq. in. or kN/sq. m)
G	truck gage - transverse distance between axles (ft. or m)
GD	greatest distance between any two axles of an axle group (ft. or m)
GW	axle group weight (k or kN)
h	effective thickness of concrete (in. or cm)
I	AASHTO impact factor
$I_{section}$	moment of inertia of reinforced concrete section (in.^{4} or cm^4)
j	concrete section factor
k	concrete section factor
L	bridge span length (ft. or m)
M_{allow}	allowable live load moment which will not cause stresses greater than 0.75 F_y (k-ft. or kN-m)
M_{avg}	average moment across width of bridge for finite element analysis
M_D	moment due to dead load (k-ft. or kN-m)

LIST OF ABBREVIATIONS AND SYMBOLS (cont.)

M_{fc}	moment capacity of concrete (k-ft. or kN-m)
M_{fs}	moment capacity of steel (k-ft. or kN-m)
M_{IL}	maximum moment resulting from influence line analysis (k-ft. or kN-m)
M_{L+I}	moment due to live load plus impact (k-ft. or kN-m)
$M_{maximum}$	maximum moment in any bridge element (k-ft. or kN-m)
M_{ol}	allowable moment capacity of continuous slab bridge (k-ft. or kN-m)
M_{truck}	maximum moment caused by truck used to calculate β (k-ft. or kN-m)
n	number of axles
OSR	overstress ratio (M_{IL} / M_{ol})
R_i	reduction factor accounting for gages wider than 6 ft. (1.8 m)
S	distance between longitudinal stringers (ft. or m)
S_i	reduction factor accounting for more than four tires a given axle
T	summation of axle loads of a given axle group (k or kN)
w	allowable distributed load (k/ft. or kN/m)
w_{rev}	revised equivalent distributed load (k/ft. or kN/m)
w_{truck}	equivalent distributed load of a truck (k/ft. or kN/m)
w_{un}	unmodified equivalent distributed load (k/ft. or kN/m)
W	bridge width (ft. or m)
WB	wheelbase length of a given axle group (ft. or m)
WB_{eq}	wheelbase of equivalent distributed load which causes the same moment as a particular axle group (ft. or m)
WB_{permit}	distance between axles of a given axle group (ft. or m)
WBL	effective wheelbase on bridge (ft. or m)

SUMMARY

This document defines criteria for issuing permits for overweight vehicles passing over H15, H20 and HS20 highway bridges in the state of Texas. The resulting formulae have been developed to ensure that the maximum stress does not exceed the operational stress level.

Criteria is first developed for simple span bridges. The approach used analyzes the discrete point on the bridge where overstress is most likely to occur. This is done in the manner prescribed by the American Association of State Highway and Transportation Officials (AASHTO) in the *Standard Specifications for Highway Bridges* and the *Maintenance Manual for the Inspection of Bridges*. Two formulae for each bridge type, a general formula and a bridge specific formula, have been developed to limit the group axle weight on simple span bridges.

The general formula is a function of only the vehicle dimensions and is similar to the current Texas permit rules. The current Texas Department of Transportation (TxDOT) permit rules only apply for wheelbases up to 80 ft. (24.4 m). The proposed formula is calculated for wheelbases up to 120 ft. (36.6 m). The formula developed is significantly more restrictive than that currently used by the Texas Department of Transportation. A second formula has been developed based on the vehicle dimensions and the span length of any bridge along the permitted vehicle route. With this bridge-specific formula, higher permit weights can be safely authorized without additional engineering analysis.

In addition, several critical reinforced concrete continuous span slab bridges have been investigated to ensure that the formulae calculated for simple span bridges do not exceed the allowable stresses. The greatest concern of the continuous span bridges is at the supports where negative moments can become great. The results

indicate that the capacities of the reinforced concrete continuous span slab bridges are well above those allowed by the proposed simple span formulae.

1. INTRODUCTION

1.1 Historical Overview

The issuing of overweight permits is a matter of major importance to highway departments. On rural roads within Texas, there are many lightweight H15 and H20 type bridges. Many of these bridges were built forty or fifty years ago on farm-to-market (FM) roads assuming lighter truck traffic than was even present at the time. In recent years, some of these roads have been incorporated into the secondary or primary state highway system. The lightweight design of these bridges combined with continued pressure for heavier loads from the trucking industry have necessitated this study to develop criteria defining allowable permit loads. An example of a superheavy vehicle is shown in Figure 1-1. This research mainly emphasizes the older H15 and H20 type bridges designed and built in the 1940's and 1950's which are still in service today. These bridges are most susceptible to damage from overweight vehicles. In addition, criteria have also been defined for the more recently built simple span HS20 bridges.

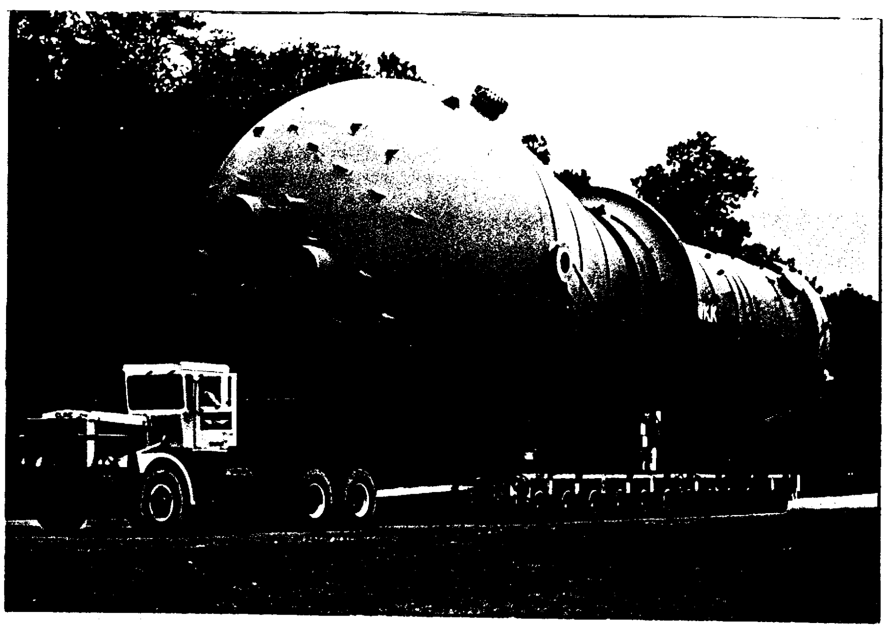


Figure 1-1: Example of 1.8 million pound (8.01 MN) superheavy load.

1.2 Design Requirements for H15 and H20 Bridges

H15 and H20 bridges are designed to support standard H15 and H20 loadings. The AASHTO *Standard Specifications for Highway Bridges* (10) specifies two different types of loadings shown in Figures 1-2 and 1-3. The first AASHTO loading is the standard truck loading, as shown in Figure 1-2, and usually controls the design of relatively short span bridges.

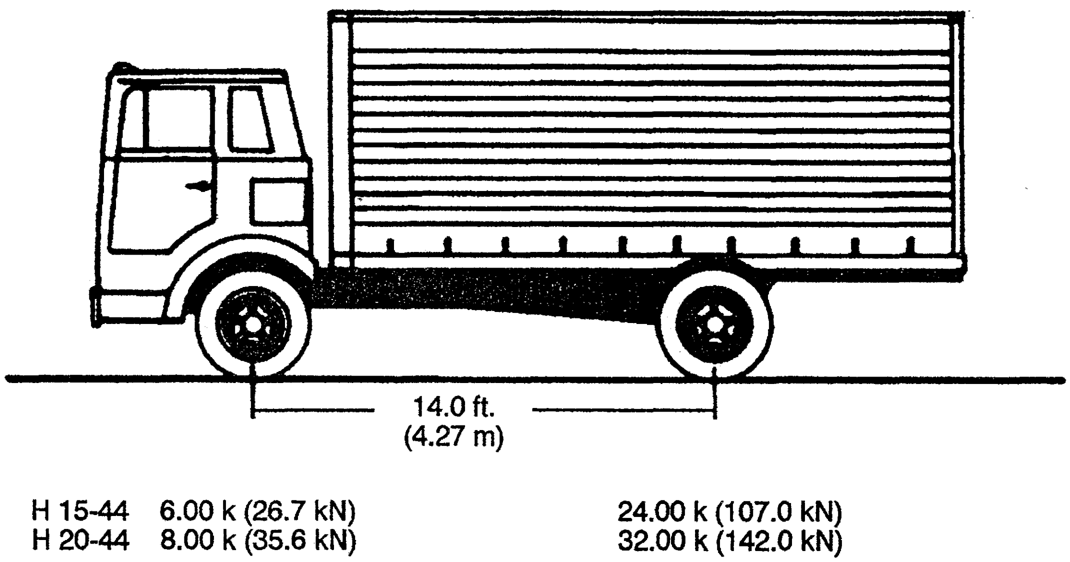


Figure 1-2: AASHTO H15 and H20 truck loading.

The second load type is a standard lane loading as shown in Figure 1-3. The standard lane loading consists of a distributed load and a concentrated load which is positioned to produce a maximum moment. For a simple span, this load is positioned at the midspan of the bridge. The lane load typically controls the design of longer span bridges. However, the condition which produces the maximum moment governs the design of the bridge for that particular span length.

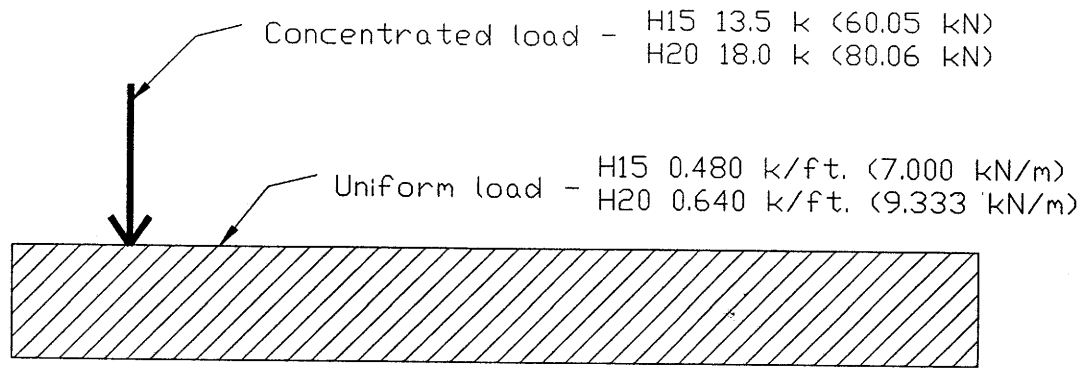


Figure 1-3: AASHTO H15 and H20 lane loading.

For a number of years, both the H15 and H20 load types were concurrent in the AASHTO *Standard Specifications for Highway Bridges* (10). This provided the designer with a certain degree of flexibility in matching bridge strength with intended use. Less traveled routes with lighter anticipated truck weights could be designed more cost effectively with the H15 loading.

1.3 TxDOT Permitting Procedures

The Texas Department of Transportation (TxDOT) currently issues over 20,000 oversize and/or overweight permits each month. The current restrictions for issuing overweight permits were adopted by the Texas legislature into the *Texas Administrative Code* (11) on May 29, 1991. Some of the heaviest of these overweight permits are issued to mobile cranes. An example of an actual permit vehicle is shown in Table 1-1. The gross weight of the vehicle is 199 kips (885 kN) and easily exceeds the gross weight of the H20 loading.

Axle	Axle Spacing (ft.)	(m)	Tires	Tire Width (in.)	(cm)	Weight per Axle (k)	(kN)	Axle Gage (ft.)	(m)
1			2	14.0	35.6	21.666	96.370	10.5	3.2
2	4.0	1.2	2	14.0	35.6	21.666	96.370	10.5	3.2
3	4.0	1.2	2	14.0	35.6	21.666	96.370	10.5	3.2
4	16.0	4.9	4	14.0	35.6	27.653	123.00	9.8	3.0
5	4.0	1.2	4	14.0	35.6	27.653	123.00	9.8	3.0
6	4.0	1.2	4	14.0	35.6	27.653	123.00	9.8	3.0
7	17.0	5.2	4	10.0	25.4	17.026	75.732	6.7	2.0
8	4.0	1.2	4	10.0	25.4	17.026	75.732	6.7	2.0
9	4.0	1.2	4	10.0	25.4	17.026	75.732	6.7	2.0

Table 1-1: Example of overweight permit vehicle.

Existing TxDOT permit rules for overweight vehicles are based on the wheelbase length and width. Wheelbase length is the distance from the center of the first axle to the center of the last axle in any axle group. The wheelbase width is referred to as "gage." Typical truck and trailer rigs have a standard gage of 6 ft. (1.8 m). Gage is defined as the transverse spacing distance between tires on an axle, usually expressed in feet. Gage is measured from center of tire to center of tire on an axle equipped with only two tires, or measured from the center of the dual wheels on one end of the axle to the center of the dual wheels on the opposite end of the axle. The gage distance for different tire and axle configurations is shown in Figure 1-4.

The *Texas Administrative Code* (11) imposes restrictions on axle groups of overweight vehicles, as given in Table 1-2:

Number of Axles in Group	Maximum Allowable Axle Group Weight
1	25.00 k (111.2 kN)
2	45.00 k (200.2 kN)
3	60.00 k (266.9 kN)
4	70.00 k (311.4 kN)
5	81.40 k (366.5 kN)

Table 1-2: Axle group weight restrictions.

Any subset of axles within a group cannot exceed the allowable weight in Table 1-2 for that number of axles. In addition, a restriction for any axle of 850 lb/in. (1490 N/cm) of tire width or 25.00 k (111.20 kN), whichever is less, is also imposed. This last restriction is primarily for the purpose of protecting the pavement.

To allow consideration of factors that may reduce the effect an axle group weight has on a bridge, an equivalent distributed load method is used. While this method was developed for the permitting of mobile cranes and oil well equipment, TxDOT applies these rules to other loads only as a guide at this time. The equivalent distributed load takes into account additional factors, such as number of tires, gage distance, and longitudinal distribution of the load by the deck. Therefore, the maximum allowable permit loads are usually controlled by this method.

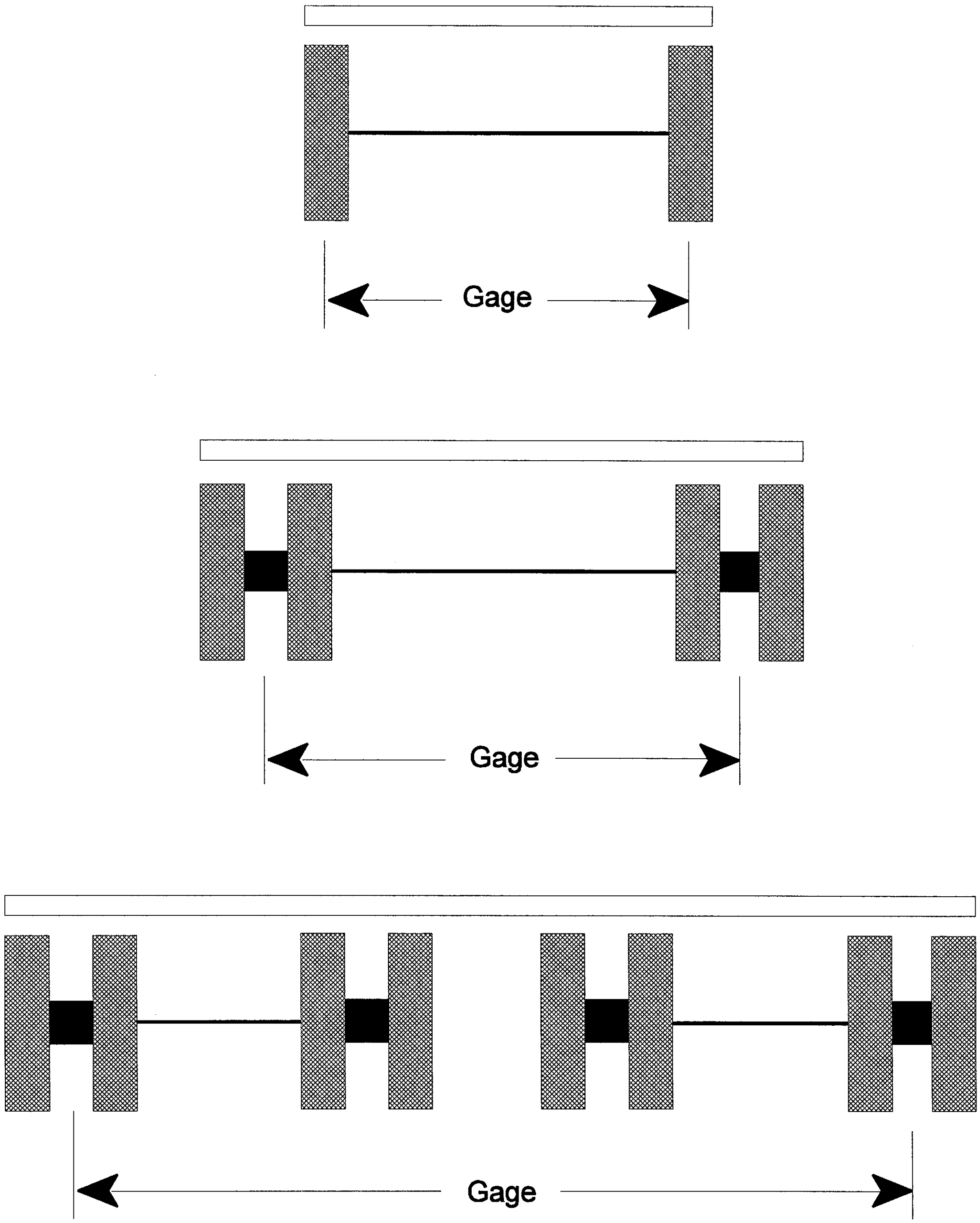


Figure 1-4: Gage distance for various axle configurations.

The *Texas Administrative Code* (11) specifies the maximum axle group distributed load for overweight mobile cranes and oil well equipment by using the formula:

$$W_{un} = \frac{T}{WB + 4} \tag{1-1}$$

Where

W_{un}	=	the unmodified equivalent distributed load per linear foot,
T	=	the summation of axle loads of group of two or more axles; any combination of axle loads may be considered as a group up to the total number of axles for the vehicle,
WB	=	wheelbase length (ft.).

A vehicle with axle groups composed of eight or more tires per axle, or with axle groups having a gage greater the 6.0 ft. (1.83 m) on an axle, may have additional reduction factors applied to each axle. This is done before summing the axle loads for the vehicle. The revised equivalent axle load is calculated by rewriting Equation 1-1 in the following form:

$$W_{rev} = \frac{\sum_{i=1}^{n} \left(R_i * S_i * T_i\right)}{WB + 4} \tag{1-2}$$

where

W_{rev}	=	revised equivalent distributed load per linear foot,
S_i	=	reduction factor accounting for each axle which may have more than four tires on the axle line,
	=	1.0 for axles with four tires or fewer,
	=	0.96 for axles with eight or more tires,

R_i = reduction factor accounting for wider gage axle groups and is calculated by the following formula:

where

$$R_i = \frac{6 + G}{2G} \tag{1-3}$$

G = gage (ft.),

n = number of axles.

The equivalent distributed load per linear foot is then compared to the corresponding maximum permit weight specified by the *Texas Administrative Code* (11) shown in columns 3 and 4 of Table 1-3. The current allowable permit loads are based on an analysis of previous permits issued. Examples of these maximum permit loads can be found in Appendix B. A vehicle that exceeds the values in columns 3 and 4 of Table 1-3 is denied a permit unless the vehicle is then analyzed by the Bridge Section of the Design Division of TxDOT. An engineer in the Bridge Section must do an analysis of each bridge on the route to be traveled to determine if a permit may be issued.

Columns 5 and 6 of Table 1-3 are calculated by multiplying the distributed load of columns 3 and 4 by the wheelbase plus 4 ft. (1.2 m). Therefore, columns 5 and 6 are the summation of the axle loads for the corresponding wheelbase (i.e., T from Equations 1-1 and 1-2). Typically, a weight in kips or kilonewtons is easier to conceptualize than a distributed load in kips per foot or kilonewtons per meter. Therefore, some subsequent calculations will be compared to columns 5 and 6. It should be noted that the total weight in columns 5 and 6 are for 6 ft. (1.8 m) gage only.

These provisions have been adopted in an attempt to limit the maximum stress in the bridge to an acceptable operational level and are consistent with the provisions contained in the AASHTO *Manual for Maintenance Inspection of Bridges* (2). The operating stress limits the load to which the bridge may be safely subjected to on an infrequent basis. For steel members, the operating level stress is taken as of 0.75 times the yield stress of the steel ($0.75F_y$). The original design of the bridge was based on inventory stresses. The inventory stress limits the load to which the bridge may be safely subjected to for an indefinite number of times. The inventory stress for steel members is $0.55F_y$. Therefore, a correctly permitted vehicle can result in steel member stresses 36 percent above the design stresses.

The operational and inventory limits on stresses for reinforced concrete bridges are similar to steel members but result in less conservative overstressing. For example, the inventory stress for 60 Grade reinforcing steel is 50 percent higher than the inventory stress. The operational compressive stress in concrete due to bending is approximately 50 percent higher than the inventory stress.

Wheelbase (ft.)	Wheelbase (m)	Dist. Load (k/ft.)	Dist. Load (kN/m)	Weight (k)	Weight (kN)
4	1.22	7.250	105.73	58.0	258.0
5	1.53	6.345	92.53	57.1	254.0
6	1.83	5.947	86.73	59.5	264.5
7	2.14	5.698	83.10	62.7	278.8
8	2.44	5.500	80.21	66.0	293.6
9	2.75	5.326	77.67	69.2	308.0
10	3.05	5.169	75.38	72.4	321.9
11	3.36	5.027	73.31	75.4	335.4
12	3.66	4.898	71.43	78.4	348.6
13	3.97	4.781	69.72	81.3	361.5
14	4.27	4.675	68.18	84.2	374.3
15	4.58	4.579	66.78	87.0	387.0
16	4.88	4.492	65.51	89.8	399.6
17	5.19	4.413	64.36	92.7	412.2
18	5.49	4.340	63.29	95.5	424.7
19	5.80	4.272	62.30	98.3	437.0
20	6.10	4.208	61.37	101.0	449.2
21	6.41	4.146	60.46	103.7	461.0
22	6.71	4.087	59.60	106.3	472.7
23	7.02	4.030	58.77	108.8	484.0
24	7.32	3.974	57.96	111.3	494.9
25	7.63	3.920	57.17	113.7	505.6
26	7.93	3.867	56.39	116.0	516.0
27	8.24	3.815	55.64	118.3	526.0
28	8.54	3.764	54.89	120.4	535.8
29	8.85	3.714	54.16	122.6	545.2
30	9.15	3.676	53.61	125.0	555.9
31	9.46	3.646	53.17	127.6	567.6
32	9.76	3.616	52.73	130.2	579.0
33	10.07	3.586	52.30	132.7	590.2
34	10.37	3.557	51.87	135.2	601.2
35	10.68	3.529	51.47	137.6	612.2
36	10.98	3.501	51.06	140.0	622.9
37	11.29	3.474	50.66	142.4	633.5
38	11.59	3.448	50.28	144.8	644.1
39	11.90	3.423	49.92	147.2	654.7
40	12.20	3.399	49.57	149.6	665.2
41	12.51	3.376	49.23	151.9	675.7

Table 1-3: TxDOT maximum permit weight table (11).

Wheelbase (ft.)	Wheelbase (m)	Dist. Load (k/ft.)	Dist. Load (kN/m)	Weight (k)	Weight (kN)
42	12.81	3.354	48.91	154.3	686.3
43	13.12	3.333	48.61	156.7	696.8
44	13.42	3.313	48.32	159.0	707.3
45	13.73	3.293	48.02	161.4	717.7
46	14.03	3.274	47.75	163.7	728.1
47	14.34	3.255	47.47	166.0	738.4
48	14.64	3.236	47.19	168.3	748.5
49	14.95	3.218	46.93	170.6	758.6
50	15.25	3.200	46.67	172.8	768.6
51	15.56	3.182	46.41	175.0	778.4
52	15.86	3.164	46.14	177.2	788.1
53	16.17	3.146	45.88	179.3	797.6
54	16.47	3.128	45.62	181.4	807.0
55	16.78	3.111	45.37	183.5	816.4
56	17.08	3.094	45.12	185.6	825.7
57	17.39	3.077	44.87	187.7	834.9
58	17.69	3.061	44.64	189.8	844.2
59	18.00	3.045	44.41	191.8	853.3
60	18.30	3.030	44.19	193.9	862.6
61	18.61	3.015	43.97	196.0	871.7
62	18.91	3.000	43.75	198.0	880.7
63	19.22	2.985	43.53	200.0	889.6
64	19.52	2.971	43.33	202.0	898.6
65	19.83	2.957	43.12	204.0	907.5
66	20.13	2.943	42.92	206.0	916.3
67	20.44	2.929	42.72	208.0	925.0
68	20.74	2.915	42.51	209.9	933.5
69	21.05	2.901	42.31	211.8	942.0
70	21.35	2.887	42.10	213.6	950.3
71	21.66	2.874	41.91	215.6	958.8
72	21.96	2.861	41.72	217.4	967.2
73	22.27	2.848	41.53	219.3	975.4
74	22.57	2.835	41.34	221.1	983.6
75	22.88	2.822	41.15	222.9	991.6
76	23.18	2.809	40.97	224.7	999.6
77	23.49	2.796	40.78	226.5	1007.4
78	23.79	2.783	40.59	228.2	1015.1
79	24.10	2.771	40.41	230.0	1023.0
80	24.40	2.759	40.24	231.8	1030.9

Table 1-3: TxDOT maximum permit weight table (cont.).

Example Permit Calculation

To better understand the current Texas permit rules for mobile cranes and oilwell equipment vehicles, the calculations involved in issuing a permit for an overweight vehicle will be done. An example of an overweight truck is shown in Figure 1-5.

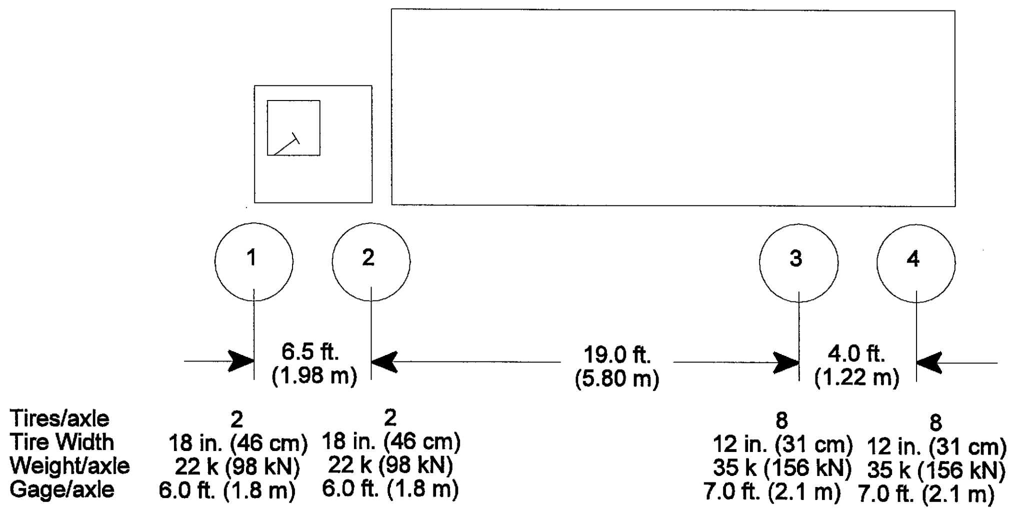


Figure 1-5: Overweight vehicle configuration example.

The two front axles (1 and 2) fall within the single axle group restriction of 25.00 k (111.2 kN). Also, each of the front axles has a total tire width of 36 in. (91.5 cm). Dividing 22 k (97.9 kN) by 36 in. (91.5 cm) results in a load of 611 lb/in. (1069 N/cm) of tire width for each of the two front axles. Hence, the two front axles also meet the individual axle restriction of 850 lb/in. (1490 N/cm) of tire width.

However, the two rear axles (3 and 4) of 35.00 k (155.7 kN) each clearly violate the two axle group restriction of 45.00 k (200.2 kN) in Table 1-2. By using Equations 1-2 and 1-3, an equivalent distributed load per foot can be calculated to determine if they fall within the restrictions of Table 1-3. Because the two rear axles do not have the standard gage or number of tires, the reduction factor S, for number of tires and R, for gage may be used. Since each axle has eight tires, $S = 0.96$. Substituting a gage of 7 ft. (2.14 m) into Equation 1-3 results in a gage reduction factor of R = 0.929. The wheelbase for the rear axle group is $WB = 4$ ft. (1.22 m). The summation of the axle loads for the rear axle group is $T = 70$ k (311 kN).

Substitution of R, S, T and WB into Equation 1-2 results in an equivalent distributed load of $W = 7.804$ k/ft. (113.8 kN/m). According to Table 1-3, the maximum allowable distributed load for an axle group with a 4 ft. (1.22 m) wheelbase is 7.250 k/ft. (105.7 kN/m).

A similar calculation will be done to determine the equivalent distributed load for axle groups 1, 2, 3, and 4. The values for R, S, and T for axles 3 and 4 will remain the same. For axles 1 and 2, $R_{1,2} = 1.0$, $S_{1,2} = 1.0$, and $T_{1,2} = 22$ k (97.9 kN). Since axles 1 through 4 are under consideration, the wheelbase is $WB = 29.5$ ft. (9.00 m). Substituting these values into Equation 1-2 results in an equivalent distributed load of 3.177 k/ft. (46.33 kN/m). Analysis for axle groups 1,2 and 3; 2 and 3; and 2,3, and 4 will result in equivalent distributed loads as summarized in Table 1-4.

Because the example vehicle violates the distributed load restrictions for axles 3 and 4, a routine permit will be denied. The Bridge Section of TxDOT will then have to perform a structural analysis of the bridges along the vehicle's route to determine if a permit may still be issued.

Axles	Wheelbase Length ft. (m)	Equivalent Dist. Load k/ft. (kN/m)	TxDOT Restriction (from Table 1-3)	Issue
1,2,3	25.5 (7.78)	2.550 (37.19)	3.894 (56.79)	Yes
1,2,3,4	29.5 (9.00)	3.177 (46.33)	3.695 (53.89)	Yes
2,3	19.0 (5.80)	2.314 (33.75)	4.272 (62.30)	Yes
2,3,4	23.0 (7.02)	3.127 (45.60)	4.030 (58.79)	Yes
3,4	4.0 (1.22)	7.804 (113.8)	7.250 (105.7)	No

Table 1-4: Summary of distributed loads for example vehicle.

1.4 Deficiencies in Current Procedures

The basis for the equivalent distribution load method (Table 1-3) is a compilation of numerous superheavy vehicles that were granted a permit over 10 years. This method probably protects most bridges in the state from significant damage or failure. However, an independent, engineering-based analysis has seldom been done to confirm the current restrictions for highway bridges. Of concern are the older bridges that were designed to lighter load conditions than newer bridges. The current permit criteria do not make any provisions for the bridge design type or span length. If this information is known, much higher loads may be safely allowed without the need of a complete engineering analysis.

The primary objective of this study is to develop permit criteria for H15, H20, and HS20 bridges. This set of criteria will incorporate the design load and the bridge span length so that a rigorous engineering analysis will not be necessary. H15 and H20 type bridges are examined because they have been designed for lighter loads, and thus, are more susceptible to damage than other types of bridges. HS20 bridges are examined because most bridges designed in the past twenty years have been designed for this load.

The method used to develop this criteria utilizes an assumed design bending moment capacity for different design loads. This moment capacity is based on the operating level stress of $0.75F_y$. As mentioned previously, this stress limit is for steel bridge members but can be conservatively applied to concrete bridges. Assuming an average dead load bending moment as a function of bridge type and span length, the live load moment capacity that is available to resist the permit load is calculated. The maximum uniformly distributed load that results in live load bending moment is then determined for different wheelbases and span lengths. A distributed load is used as an approximation for actual axle configurations because this provides a general formula which may be applied to all wheelbases. A correction factor may then be used to account for the deviation between the concentrated loads and the assumed distributed load.

It should be noted that the following analysis does not take into account any reduction in service life due to accelerated deterioration rates from the overloads. Repeated overloading of the structures may cause permanent deformations. Also, as the range of stress of a particular member increases, the number of cycles needed for crack propagation and failure is reduced. Because most bridges are designed to be functional for a 50 year period, the reduction in fatigue life due to the decreased number of cycles to failure might be significant.

2. DEVELOPMENT OF H15 AND H20 BRIDGE FORMULAE FOR SIMPLE SPANS

2.1 Procedure Overview

It is assumed that the H15 and H20 bridges were originally designed by the Allowable Stress Design (ASD) or working stress method according to AASHTO specifications so that the inventory stress level will not be exceeded. The inventory stress given by AASHTO *Manual for Maintenance Inspection of Bridges* (2) is 0.55 times the yield strength of the steel ($0.55F_y$) for steel bridge members. The operating level stress is increased to $0.75F_y$ for permit loading. This increase is allowed due to the infrequency of the permitted load and the fact that only a single truck is on the span. In addition, a greater amount of control may also be attained if permits are required for all vehicles which may cause stresses in excess of the inventory level.

Design details for typical H15 and H20 simple span bridges are provided from Seelye (8), Noel (5), and Whiteside (12). These sources all yield dead-load to live-load-plus-impact moment ratios for various span lengths. When the moment ratios and the live load moments are combined, allowable live load moments which produce the operational stress can then be calculated. The permit truck is then assumed to be a longitudinally distributed load positioned in the center of the bridge. This is done by placing a distributed load of a particular length on the bridge span as shown in Figure 2-1.

The magnitude of the distributed load necessary to produce the allowable live load moment is then calculated. A factor, β, is later calculated to account for differences between real axle groups and the assumed distributed load. This process is repeated for wheelbases from 4 ft. (1.22 m) to 120 ft. (36.6 m) and bridge span lengths from 10 ft. (3.05 m) to 150 ft. (45.8 m).

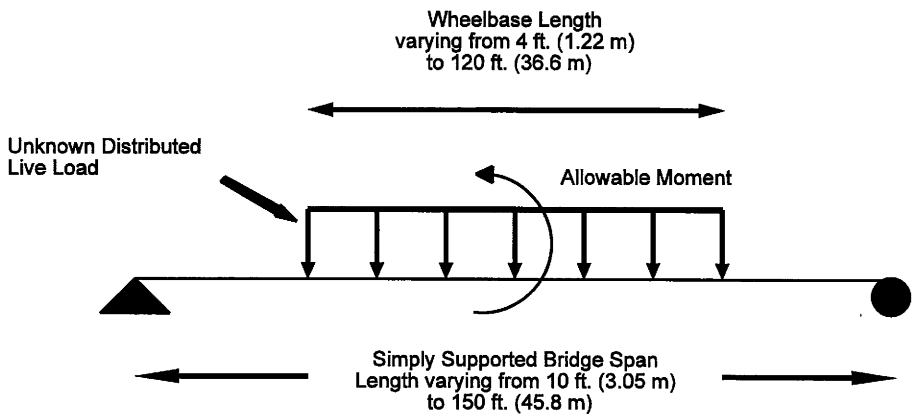


Figure 2-1: Unknown distributed load illustration.

AASHTO specifications state that the governing live load condition will be applied to each lane. If two standard H15 or H20 trucks are placed side-by-side in the center of a simple span bridge, they have a 16 ft. (4.9 m) effective gage. Because only one permit truck is allowed on a bridge, a reduction factor was calculated to ensure that the maximum stresses on the bridge are the same.

2.2 Determination of Moment Ratios

Bridge Design Specifications

Both reinforced concrete slab and steel I-beam bridges are studied. These two types of bridges were frequently built prior to the construction of the interstate system. Although designed for lighter truck weights than current standards, many of these bridges are still in use and are therefore critical when permitting loads are encountered. Because most of these lightweight bridges were designed and built before 1965, design specifications from older bridges have been used. Data were extracted from Noel (5), Whiteside (12), and Seelye (8), and from TxDOT standard bridge plans to describe these typical older bridges. Typical cross sections of standard TxDOT bridges are shown in Figures 2-2 and 2-3.

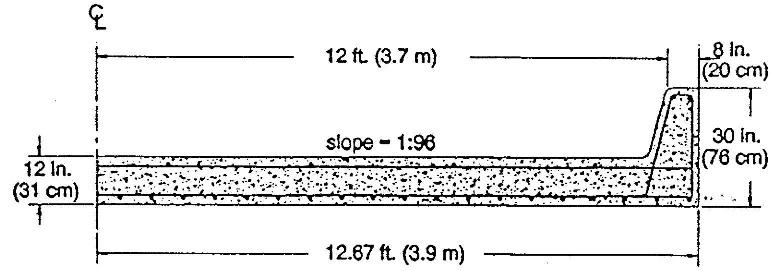


Figure 2-2: Typical H15 simple span reinforced concrete bridge (from TxDOT).

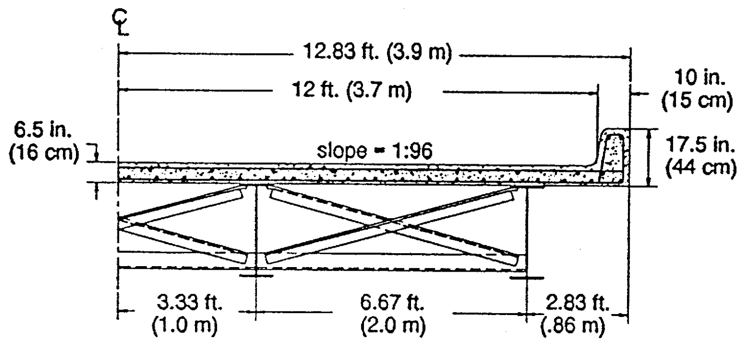


Figure 2-3: Typical H15 simple span steel I-beam bridge (from TxDOT).

Seelye (8) provides designs for span lengths up to 80 ft. (24.4 m) for these two types of H15 bridges. Although the Seelye bridges are not actual Texas bridges, they are quite similar to the most critical Texas bridges. Seelye also provides a standard design for many span lengths. For these reasons, Seelye designs are used along with data from Whiteside (12) and Noel (5). Seeyle (8) does not provide designs for H20 bridges. Therefore, data from Noel (5) and Whiteside (12) is checked against several actual TxDOT bridge designs. All H20 bridge calculations are derived from the same process as the H15 data and are given in Appendix A. Table 2-1 shows slab thicknesses for various H15 reinforced concrete bridges. Table 2-2 shows the sizes of steel I-beams used for various H15 span lengths. A 24 ft. (7.32 m) roadway is shown for the bridges given in Figures 2-2 and 2-3 and is therefore used for further calculations. This is the minimum width common to TxDOT bridge designs. As the roadway width increases, the load carrying capacity also increases. Therefore, the most critical bridge width is 24 ft. (7.32 m).

Span Length (ft.)	Span Length (m)	Thickness (in.)	Thickness (cm)
20	6.1	10.5	26.7
25	7.6	12.5	31.8
30	9.2	14.5	36.8
35	10.7	17.5	44.5

Table 2-1: Reinforced concrete slab thicknesses.

Span Length (ft.)	Span Length (m)	Exterior I-beams	Interior I-beams
20	6.1	18 WF 50	18 WF 60
25	7.6	21 WF 62	21 WF 68
30	9.2	24 WF 76	24 WF 76
35	10.7	24 WF 84	24 WF 94
40	12.2	27 WF 94	27 WF 102
45	13.7	30 WF 108	30 WF 116
50	15.3	33 WF 130	33 WF 130
60	18.3	36 WF 150	36 WF 160
70	21.4	33 WF 220	33 WF 220
80	24.4	36 WF 260	36 WF 260

Table 2-2: Steel I-beams for various span lengths.

Calculation of Moment Ratios

The bridge information may all be summarized in the dead-load to live-load-plus-impact moment ratios. The method used follows the same provisions of the AASHTO *Standard Specifications for Highway Bridges* (10) used in designing bridges. In this method, the analysis is simplified by idealizing the distribution of wheel loads to the main load carrying components of the bridge. For reinforced concrete slab bridges, it is assumed that each line of wheels is carried by an effective width of the slab defined as:

$$E = 4 + 0.06L \leq 7.0 \qquad \textbf{(2-1)}$$

where

L = bridge span length (ft.).

This concept is illustrated in Figure 2-4.

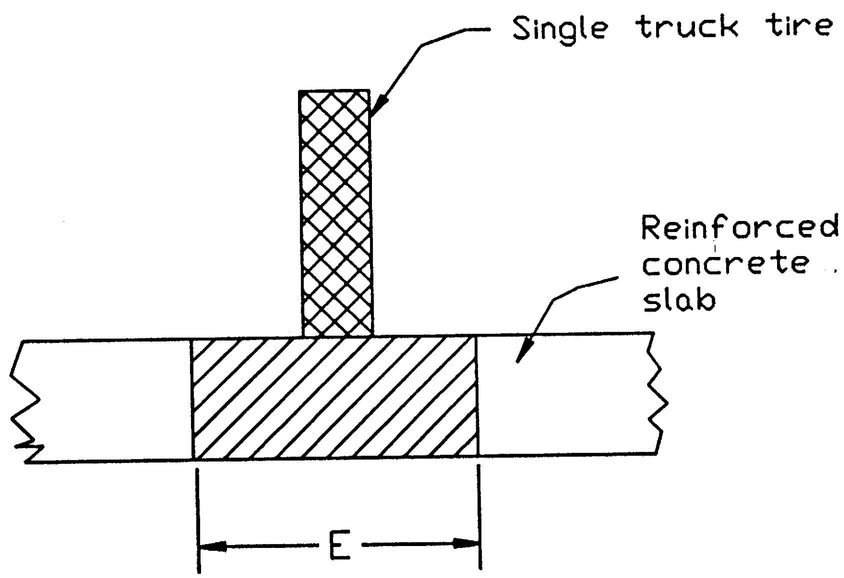


Figure 2-4: Slab bridge effective width.

For steel I-beam bridges, the stringer is assumed to be the critical member. A distribution factor, *DF*, is used to determine the portion of wheel load(s) carried by a single stringer and is a function of the stringer spacing, *S* (see Fig. 2-5). AASHTO states that for interior stringers sopporting multiple trucks, the distribution factor is given as:

$$DF = \frac{S}{5.5} \tag{2-2}$$

where

S = the center-to-center distance between the steel I-beams (ft.).

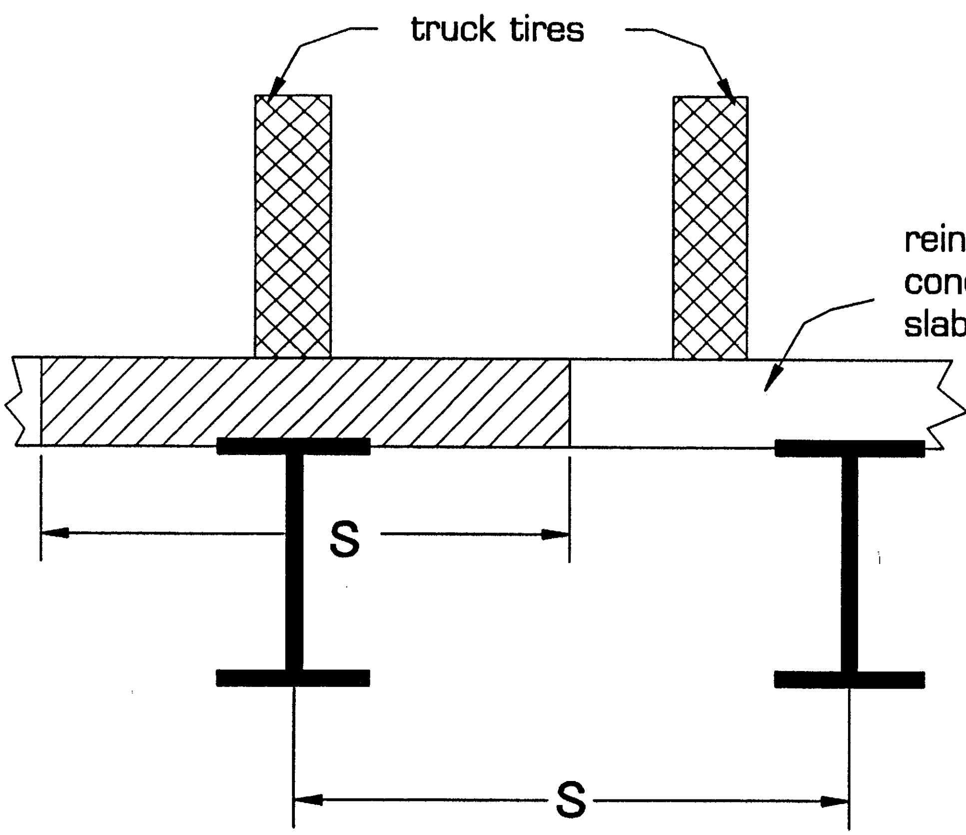


Figure 2-5: Steel I-beam bridge effective width.

The distributed dead loads and dead load moments for concrete slab and steel I-beam Seelye bridges are summarized in Tables 2-3 and 2-4. Notice that for span lengths greater than 35 ft. (10.7 m), concrete slab bridges are no longer considered economical and, therefore, are not listed. Slab bridges are often more economical for spans less than 25 ft. (7.6 m), but short span steel I-beam bridges do exist. Because data for these short span steel I-beam bridges is scarce, the stringer size in the 10 ft. (3.1 m) and 15 ft. (4.6 m) spans is assumed to be the same as the 20 ft. (6.1 m) spans.

Span Length (ft.)	Span Length (m)	Distributed Load (k/ft.)	Distributed Load (kN/m)	Dead Load Moment (k-ft.)	Dead Load Moment (kN-m)
20	6.1	0.68	10.0	34.1	46.3
25	7.6	0.86	12.5	67.1	91.1
30	9.2	1.05	15.3	118.3	160.4
35	10.7	1.33	19.5	204.3	277.2

Table 2-3: Distributed dead loads and dead load moments for slab bridges.

The live-load moment is determined according to the AASHTO *Standard Specifications for Highway Bridges* (10). The basic live load for an entire lane is found in Appendix A of the AASHTO Specifications. The maximum moments for H15 loading are shown in Table 2-5. The moment per unit width of a concrete slab bridge is obtained by dividing the moment given in Table 2-5 by two and dividing by the effective width. For a steel I-beam bridge, the moment per stringer is obtained by dividing the moment given in Table 2-5 by two and multiplying by the distribution factor.

Span Length (ft.)	Span Length (m)	Distributed Load (k/ft.)	Distributed Load (kN/m)	Dead Load Moment (k-ft.)	Dead Load Moment (kN-m)
10	3.1	0.63	9.2	7.9	10.7
15	4.6	0.63	9.2	17.8	24.1
20	6.1	0.63	9.2	31.6	42.9
25	7.6	0.64	9.3	50.1	67.9
30	9.2	0.65	9.5	73.0	99.0
35	10.7	0.67	9.7	102.1	138.5
40	12.2	0.67	9.8	135.0	183.1
45	13.7	0.69	10.0	174.4	236.6
50	15.3	0.70	10.3	219.7	298.0
60	18.3	0.73	10.7	329.8	447.4
70	21.4	0.79	11.6	485.7	658.9
80	24.4	0.83	12.1	666.3	904.0

Table 2-4: Distributed dead loads and dead load moments for steel I-beam bridges.

The moment due to impact is found by multiplying the live load moment by an impact factor, I, which is defined as:

$$I = \frac{50}{L + 125} \leq 0.3 \qquad \textbf{(2-3)}$$

where

L = bridge span length (ft.).

Span Length (ft.)	Span Length (m)	Maximum Moment (k-ft.)	Maximum Moment (kN-m)
10.0	3.1	60.0	81.4
15.0	4.6	90.0	122.1
20.0	6.1	120.0	162.8
25.0	7.6	150.0	203.5
30.0	9.2	185.0	250.9
35.0	10.7	222.2	301.4
40.0	12.2	259.5	352.0
45.0	13.7	296.8	402.7
50.0	15.3	334.2	453.4
55.0	16.8	371.6	504.1
60.0	18.3	418.5	567.8
65.0	19.8	472.9	641.5
70.0	21.4	530.3	719.4
75.0	22.9	590.6	801.3
80.0	24.4	654.0	887.2
85.0	25.9	720.4	977.3
90.0	27.5	789.8	1071.4
95.0	29.0	862.1	1169.6
100.0	30.5	937.5	1271.9
105.0	32.0	1015.9	1378.2
110.0	33.6	1097.3	1488.6
115.0	35.1	1181.6	1603.0
120.0	36.6	1269.0	1721.6
125.0	38.1	1359.4	1844.2
130.0	39.7	1452.8	1970.9
135.0	41.2	1549.1	2101.6
140.0	42.7	1648.5	2236.4
145.0	44.2	1750.9	2375.3
150.0	45.8	1856.3	2518.3

Table 2-5: Table of maximum moments for H15 loadings on simple span bridges from Appendix A of AASHTO *Standard Specifications for Highway Bridges*.

As an example calculation, consider a 30 ft. (9.2 m) Seelye steel stringer bridge. The live load moment from Table 2-5 is 185 k-ft. (250.9 kN-m). Dividing this value by 2 results in a live load of 92.5 k-ft. (125.5 kN-m) for a single line of wheels. This is multiplied by the distribution factor of 7.33/5.5 to give a moment of 123.3 k-ft. (167.2 kN-m). The impact factor for a 30 ft. (9.2 m) span is 0.3. Multiplying the live load moment of 123.3 k-ft. (167.2 kN-m) by the impact factor results in a live-load-plus-impact moment of 160.3 k-ft. (217.4 kN-m). The dead-load to live-load-plus-impact moment ratios are then computed. In the case of a 30 ft. (9.2 m) steel I-beam bridge, this would be 73.0/160.3 (99.0/217.4) which equals 0.455. The Seelye moment ratios for slab and stringer bridges are listed in Table 2-6.

Span Length		Seelye DL/(LL+I) Moment Ratios	
(ft.)	(m)	Slab Bridge	Steel I-Beam
10.0	3.1		0.152
15.0	4.6		0.228
20.0	6.1	0.438	0.304
25.0	7.6	0.689	0.385
30.0	9.2	0.984	0.455
35.0	10.7	1.415	0.530
40.0	12.2		0.600
45.0	13.7		0.681
50.0	15.3		0.767
55.0	16.8		0.863
60.0	18.3		0.931
65.0	19.8		1.011
70.0	21.4		1.094
80.0	24.4		1.229

Table 2-6: Design moment ratios for H15 Seelye bridges.

Because these are the moments actually used in designing bridge components, these ratios are referred to as design moment ratios. Seelye design moment ratios were compared with moment ratios from Whiteside, TxDOT, and the Federal Highway Administration (FHWA). The given dead-load to live-load-plus-impact moment ratios in Table 2-7 are average moment ratios over one 12 ft. (3.7 m) lane of the bridge. The live load moments used for these ratios are due to the larger of either one standard truck or the distributed lane load, and are equal to those listed in Table 2-5. Therefore, the average moment ratios differ from the design moment ratios because a 12 ft. (3.7 m) width is being analyzed instead of an effective width, and because a complete truck load is used instead of one line of wheels multiplied by a distribution factor. The average moment ratios in Table 2-7 are converted to design moment ratios by multiplying them by Equation 2-4 for slab bridges and Equation 2-5 for steel I-beam bridges.

$$Des\left(\frac{M_D}{M_{L+I}}\right) = \frac{E}{6} * Avg\left(\frac{M_D}{M_{L+I}}\right) \quad \textbf{(2-4)}$$

$$Des\left(\frac{M_D}{M_{L+I}}\right) = \frac{11}{12} * Avg\left(\frac{M_D}{M_{L+I}}\right) \quad \textbf{(2-5)}$$

where

$M_D\ /\ M_{L+I}$ = appropriate dead-load to live-load-plus-impact moment ratio,

E = effective width (ft.).

Span Length		Average DL/(LL+I) Moment Ratios			
		TxDOT	TxDOT	FHWA	NCHRP 141
(ft.)	(m)	Slab	Steel	Steel	Steel
		Bridge	I-Beam	I-Beam	I-Beam
10.0	3.1	0.147		0.863	
15.0	4.6	0.294		0.603	
20.0	6.1	0.500		0.342	
25.0	7.6	0.771		0.429	
30.0	9.2	1.085		0.515	0.500
35.0	10.7	1.455		0.619	
40.0	12.2	2.087	0.651	0.723	0.670
45.0	13.7		0.741	0.789	
50.0	15.3		0.827	0.855	0.840
55.0	16.8		0.921	0.940	
60.0	18.3		1.006	1.024	1.010
65.0	19.8		1.068	1.091	
70.0	21.4			1.158	1.150
75.0	22.9			1.194	
80.0	24.4			1.229	1.280
85.0	25.9			1.281	
90.0	27.5			1.333	1.400
95.0	29.0			1.388	
100.0	30.5			1.443	1.500
105.0	32.0			1.500	
110.0	33.6			1.557	1.590
115.0	35.1			1.613	
120.0	36.6			1.669	1.670
125.0	38.1			1.703	
130.0	39.7			1.737	1.740
135.0	41.2			1.798	
140.0	42.7			1.860	1.800
145.0	44.2			1.922	
150.0	45.8			1.984	

Table 2-7: Average moment ratios for H15 bridges.

The design dead-load to live-load-plus-impact moment ratios used to develop the permit formulas are listed in Table 2-8. Whenever data are available, design moment ratios from TxDOT are used. The minimum design moment ratio is selected when TxDOT data are not available. The minimum moment ratio is chosen because it corresponds to the lightest and most critical bridges.

A critical bridge type is chosen for each span length. The critical type is also selected by choosing the minimum moment ratio. From Figure 2-6, it is evident that steel I-beam bridges have the smallest moment ratio for all span lengths greater than 15 ft. (4.6 m).

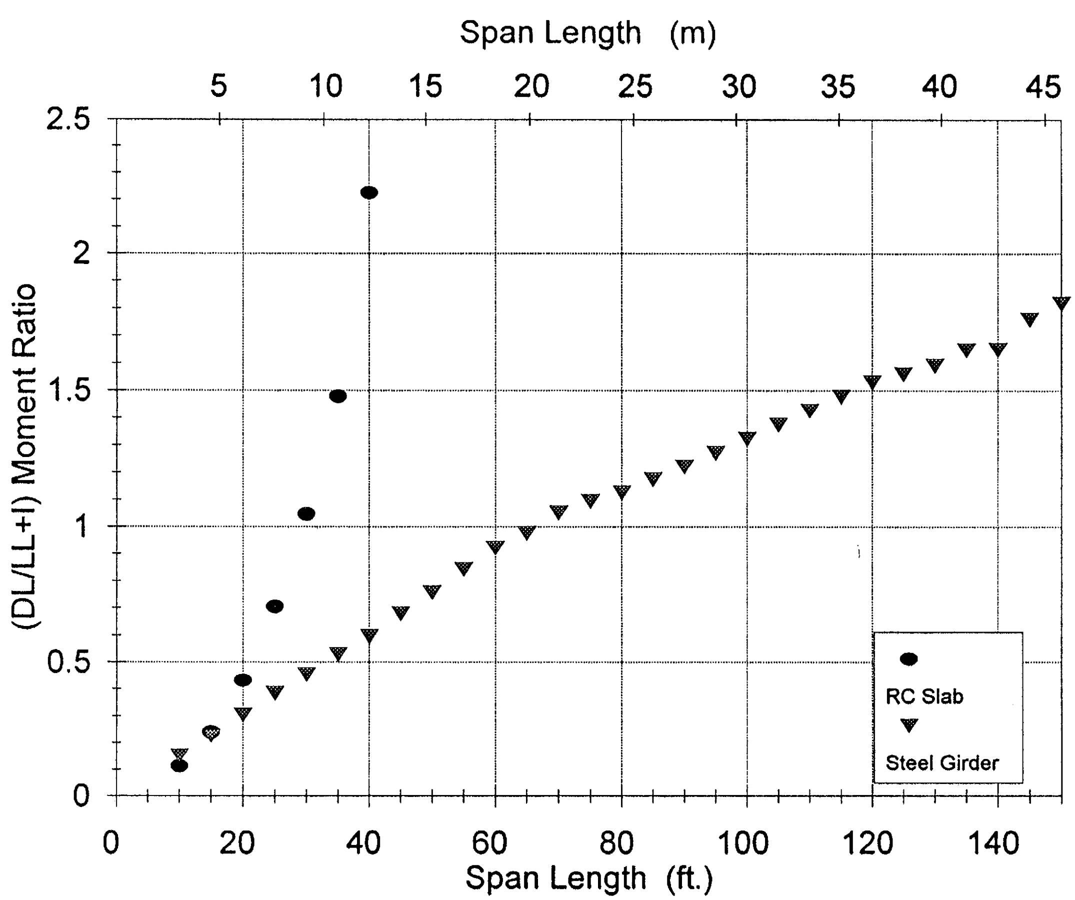


Figure 2-6: Design dead-load to live-load-plus-impact moment ratios for H15 bridges.

Span Length		Design DL/(LL+I) Moment Ratios	
(ft.)	(m)	Slab Bridge	Steel I-Beam
10.0	3.1	0.113	0.152
15.0	4.6	0.240	0.228
20.0	6.1	0.433	0.304
25.0	7.6	0.707	0.385
30.0	9.2	1.049	0.455
35.0	10.7	1.479	0.530
40.0	12.2	2.226	0.597
45.0	13.7		0.679
50.0	15.3		0.758
55.0	16.8		0.844
60.0	18.3		0.922
65.0	19.8		0.979
70.0	21.4		1.054
75.0	22.9		1.094
80.0	24.4		1.127
85.0	25.9		1.174
90.0	27.5		1.222
95.0	29.0		1.272
100.0	30.5		1.323
105.0	32.0		1.375
110.0	33.6		1.427
115.0	35.1		1.479
120.0	36.6		1.530
125.0	38.1		1.561
130.0	39.7		1.592
135.0	41.2		1.648
140.0	42.7		1.650
145.0	44.2		1.762
150.0	45.8		1.818

Table 2-8: Design moment ratios used for H15 bridges.

2.3 Group Weight for a 16 ft. (4.9 m) Gage

Development of Allowable Moments

For various span lengths from 10 to 150 ft. (3.1 to 46 m), it is desired to determine an allowable live load operational moment. It is assumed that all H15 and H20 bridges are designed to not exceed inventory stress levels. As stated previously, according to the AASHTO *Manual for Maintenance Inspection of Bridges* (2), a factor of 0.55 is used to obtain allowable inventory stresses. A factor of 0.75 is used to obtain the values for the operating stresses. While using operational moments will not cause failure, the loads allowed will do more long term damage to the bridge than the loads allowed by inventory levels. Therefore, the service life of a bridge will be shortened if repeated loadings based on operational values pass over it.

To determine the live load "allowable moment," based on operational stress levels, the total moment is multiplied by the 0.75/0.55 ratio. The moment due to dead load is then subtracted and the impact factor is divided out. The equation for the allowable moment is summarized in the following formula:

$$M_{allow} = \frac{\left(\frac{0.75}{0.55}\right)\left[\left(\frac{M_D}{M_{L+I}}\right) \cdot M_{L+I} + M_{L+I}\right] - \left[\left(\frac{M_D}{M_{L+I}}\right) \cdot M_{L+I}\right]}{1+I} \qquad \textbf{(2-6)}$$

where

M_D/M_{L+I}	=	minimum dead-load to live-load-plus-impact moment ratio from Figure 2-6,
M_{L+I}	=	live-load-plus-impact moment for one line of wheels,
I	=	AASHTO impact factor given in Equation 2-3.

This equation gives the allowable moment for a given line of wheels. For example, the minimum dead-load to live-load-plus-impact moment ratio for a 120 ft. (37 m) bridge span is 1.53. The live-load-plus-impact moment for one wheel line of an H15 truck on a 120 ft. (37 m) bridge span is 764 k-ft. (1036 kN-m). Substituting into Equation 2-7 results in an allowable moment of 1218 k-ft. (1652 kN-m). This is repeated for spans from 10 to 150 ft. (3.1 to 46 m).

Calculation of Distributed Loads and Group Weight

In order to make a general equation for all axle groups, the permit truck load is assumed to consist of a distributed load with a certain wheelbase. Because real axle groups do not create as great a positive moment as a distributed load of the same total weight, a correction factor is later calculated to account for this difference. The distributed load is placed at the center of the simple span bridge, as in Figure 2-1, so as to create a maximum moment. The magnitude of this distributed load may be determined by the following equation:

$$w = \frac{8M_{allow}}{WB(2L - WB)} \tag{2-7}$$

where

w = unknown distributed load (k/ft.),

M_{allow} = allowable moment (k-ft.),

L = bridge span length (ft.),

WB = wheelbase (ft.).

The distributed load is found for all combinations of wheelbases from 4 to 120 ft. (1.2 to 37 m) and span lengths from 10 to 150 ft. (3.1 to 46.3 m). For example, the allowable moment determined for a 120 ft. (37 m) simple span bridge is 1218 k-ft. (1652 kN-m). For a 70 ft. (21 m) wheelbase, the distributed load is 0.818 k/ft. (8.82 kN/m). This is the distributed load for one line of wheels which will create a maximum stress equal to the operational stress for this span length and wheelbase. The result of these calculations is a series of curves. For each wheelbase, a minimum critical distributed load occurs for a particular span length. This effect is illustrated in Figure 2-7.

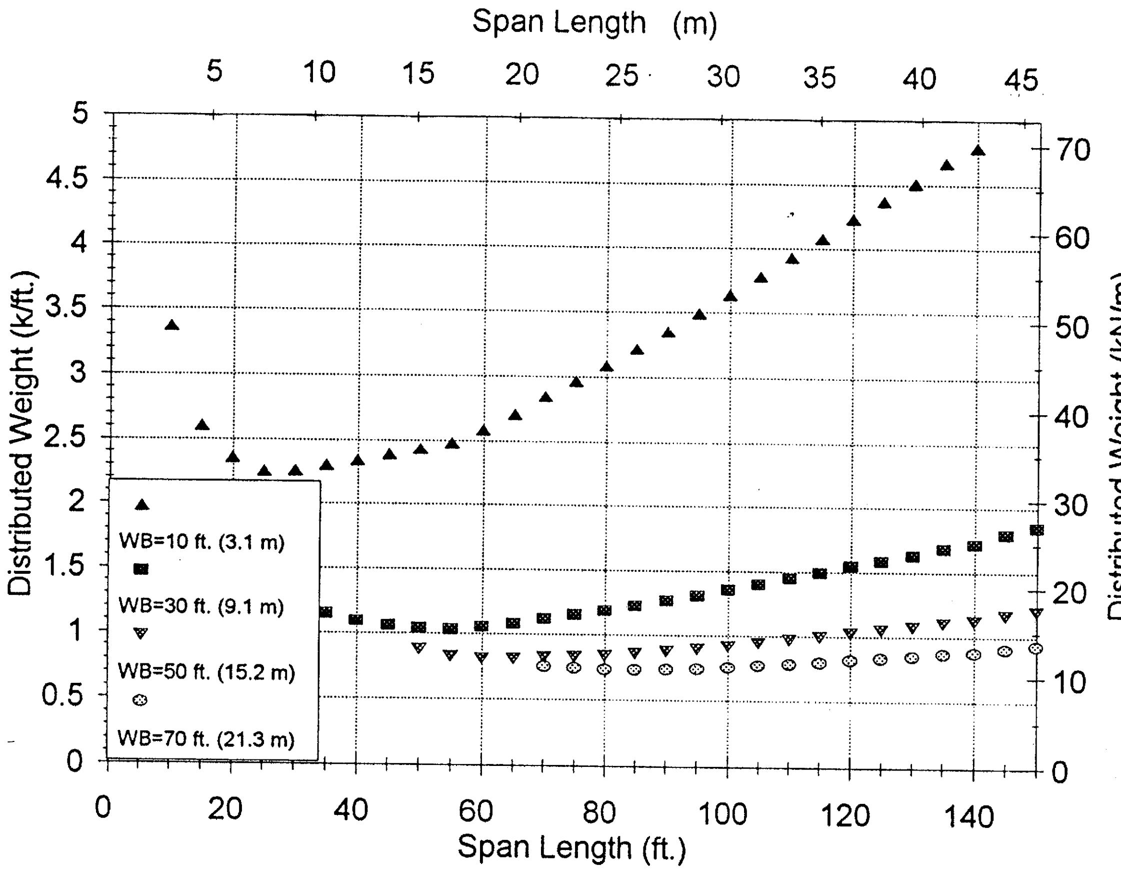


Figure 2-7: Illustration of minimum distributed loads.

The minimum distributed load corresponding to each wheelbase is noted and multiplied by the wheelbase to arrive at a minimum group weight for each wheel. The group weights listed in Table 2-9 apply for the design case outlined by AASHTO where one standard loading is placed on each lane of the bridge. Two standard 6 ft. (1.8 m) gage trucks side-by-side with the minimum 4 ft. (1.2 m) of clearance effectively have a 16 ft. (4.9 m) gage. Therefore, the group weight for a 16 ft. (4.9 m) gage truck can be arrived at by multiplying the group weight per wheel by 4 wheels to simulate 2 trucks on the bridge. In accordance with the current TxDOT standards in Equation 1-1, the equivalent distributed loads are then calculated by dividing the group weight by the wheelbase plus 4 ft. (1.2 m). This 4 ft. (1.2 m) factor is added to account for the difference in moments caused by the assumed distributed loading and the concentrated load patterns of actual trucks. Although preliminary finite element investigations have shown that this factor is probably quite conservative, further studies in this area need to be pursued. These resulting distributed loads may then be compared to those in Table 1-3. These group weights and equivalent distributed loads are summarized in Table 2-9.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
4.0	1.2	9.807	66.851	78.5	349.0
6.0	1.8	8.202	62.577	82.0	364.8
8.0	2.4	7.160	59.348	85.9	382.2
10.0	3.1	6.444	56.923	90.2	401.3
12.0	3.7	5.893	54.748	94.3	419.4
14.0	4.3	5.466	52.915	98.4	437.6
16.0	4.9	5.123	51.325	102.5	455.8
18.0	5.5	4.811	49.607	105.8	470.8
20.0	6.1	4.553	48.121	109.3	486.0
22.0	6.7	4.322	46.670	112.4	499.8
24.0	7.3	4.119	45.317	115.3	513.0
26.0	7.9	3.941	44.085	118.2	525.9
28.0	8.5	3.785	42.963	121.1	538.8
30.0	9.2	3.652	41.994	124.2	552.2
32.0	9.8	3.537	41.162	127.3	566.4
34.0	10.4	3.439	40.452	130.7	581.3
36.0	11.0	3.355	39.853	134.2	597.0
38.0	11.6	3.284	39.358	137.9	613.6
40.0	12.2	3.225	38.958	141.9	631.1
42.0	12.8	3.171	38.593	145.9	648.7
44.0	13.4	3.119	38.221	149.7	665.8
46.0	14.0	3.075	37.926	153.7	683.8
48.0	14.6	3.039	37.704	158.0	702.8
50.0	15.3	3.010	37.552	162.5	722.9
52.0	15.9	2.979	37.359	166.8	741.9
54.0	16.5	2.952	37.199	171.2	761.5
56.0	17.1	2.930	37.099	175.8	782.1
58.0	17.7	2.915	37.057	180.7	803.8
60.0	18.3	2.890	36.891	185.0	822.7

Table 2-9: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on H15 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
62.0	18.9	2.866	36.725	189.2	841.4
64.0	19.5	2.843	36.554	193.3	859.8
66.0	20.1	2.820	36.388	197.4	878.0
68.0	20.7	2.801	36.263	201.7	897.1
70.0	21.4	2.786	36.176	206.2	917.1
72.0	22.0	2.771	36.084	210.6	936.8
74.0	22.6	2.756	35.991	215.0	956.3
76.0	23.2	2.745	35.931	219.6	976.6
78.0	23.8	2.731	35.849	224.0	996.2
80.0	24.4	2.720	35.781	228.5	1016.2
82.0	25.0	2.711	35.743	233.1	1036.9
84.0	25.6	2.701	35.689	237.7	1057.1
86.0	26.2	2.691	35.642	242.2	1077.4
88.0	26.8	2.685	35.622	247.0	1098.6
90.0	27.5	2.676	35.576	251.5	1118.9
92.0	28.1	2.669	35.545	256.2	1139.6
94.0	28.7	2.664	35.540	261.0	1161.1
96.0	29.3	2.657	35.514	265.7	1181.9
98.0	29.9	2.652	35.497	270.5	1203.0
100.0	30.5	2.648	35.504	275.4	1224.9
102.0	31.1	2.642	35.485	280.1	1245.9
104.0	31.7	2.638	35.480	284.9	1267.4
106.0	32.3	2.635	35.492	289.9	1289.4
108.0	32.9	2.631	35.478	294.6	1310.6
110.0	33.6	2.628	35.483	299.6	1332.4
112.0	34.2	2.624	35.479	304.4	1353.9
114.0	34.8	2.617	35.434	308.9	1373.8
116.0	35.4	2.612	35.406	313.5	1394.3
118.0	36.0	2.606	35.366	318.0	1414.3
120.0	36.6	2.601	35.333	322.5	1434.5

Table 2-9: Calculated maximum permit weights for
16 ft. (4.9 m) gage trucks on H15 bridges (cont.).

The minimum values from Figure 2-7 are used so that a truck with any wheelbase length up to 120 ft. (37 m) can safely pass over any bridge span up to 150 ft. (46 m). The allowable group weights for the 16 ft. (4.9 m) gage truck can be closely approximated by a line. These group weights and the linear regression for the calculated data are graphed versus wheelbase in Figure 2-8.

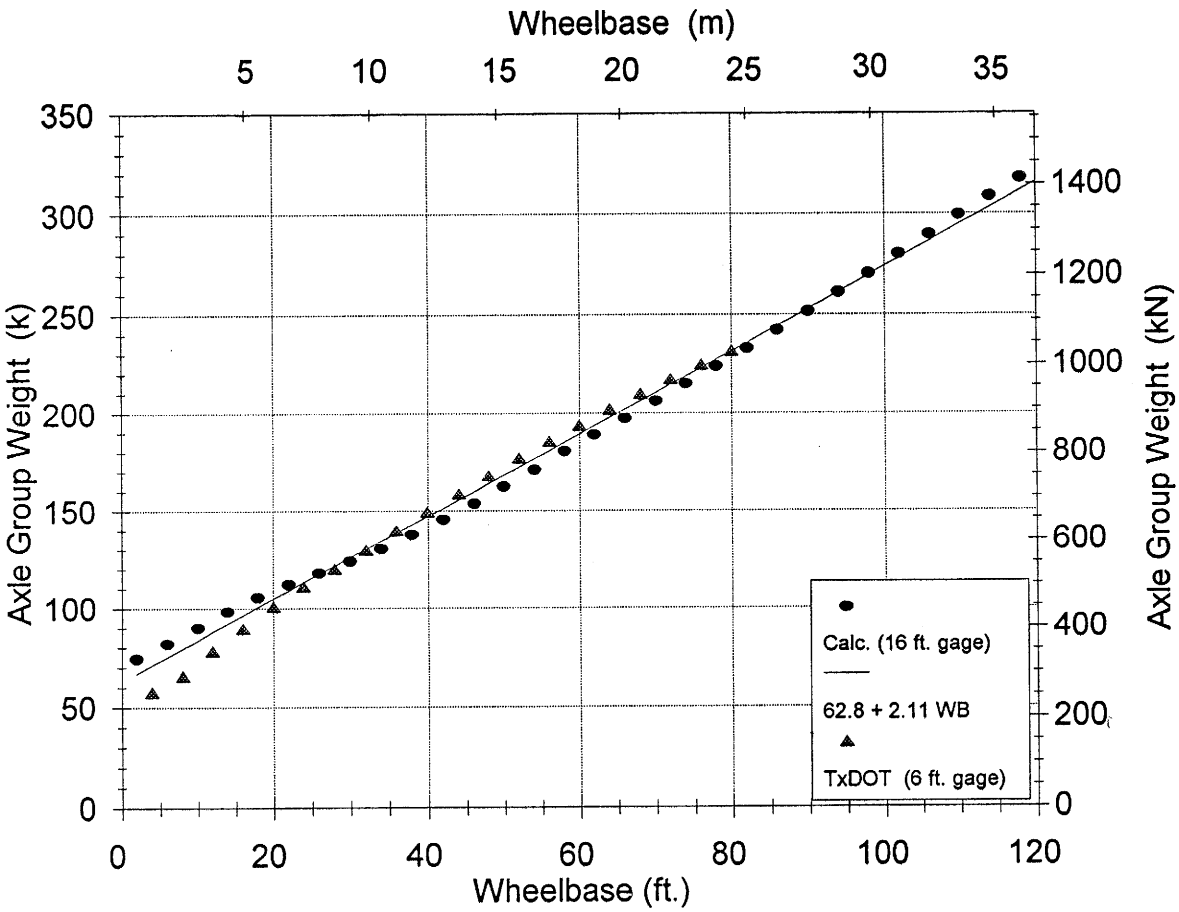


Figure 2-8: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on H15 bridges.

The 16 ft. (4.9 m) gage group weights correspond very closely to those calculated from the current TxDOT permit standards for a 6 ft. (1.8 m) gage truck. However, these group weights will produce higher local stresses when the gage is reduced to 6 ft. (1.8 m). Therefore, a reduction factor must be calculated to ensure the operational stress is not exceeded on a local level.

2.4 Gage Reduction Factor Formula

It is necessary to adjust the calculated values for a 16 ft. (4.9 m) gage truck in order to apply the values to a standard 6 ft. (1.8 m) gage truck. Developing a formula for the reduction factor as a function of gage is also of interest. This reduction factor formula for gage can then be compared to the formula currently used by TxDOT, shown in Equation 1-3. This reduction factor formula is usually used to increase the allowable load for gages larger than 6 ft. (1.8 m); but, in this case it is used to reduce the load for gages smaller than 16 ft. (4.9 m). As seen in Figure 2-9, by decreasing the gage, the intensity of the distributed load increases. Therefore, the total weight

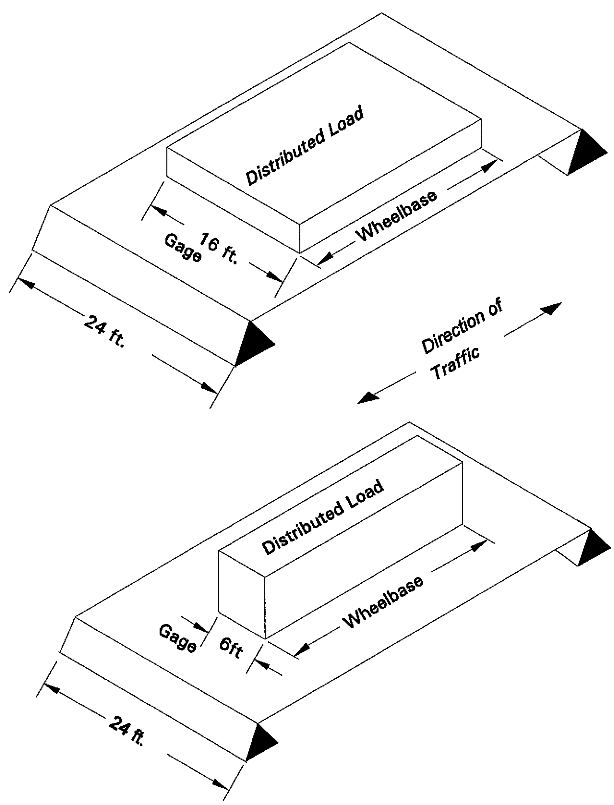


Figure 2-9: Distributed load increasing with decreasing gage.

of a 6 ft. (1.8 m) gage truck must be decreased if the maximum stresses are to remain the same.

The formula for the reduction factor is found by using the group weights for various wheelbases of a 16 ft. (4.9 m) gage truck. A finite element analysis program is then used to determine an equivalent load which produces the same maximum stresses as the 16 ft. gage truck. This is done for gages between 6 and 16 ft. (1.8 and 4.9 m) on several different wheelbases for both slab and steel I-beam bridges. The *SAFE (Slab Analysis by the Finite Element Method)* computer program is utilized in the analysis. *SAFE* is specifically designed to analyze slab type structures utilizing two types of elements. *SAFE* utilizes plate elements for modeling the slab and beam elements for modeling the steel I-beams, as shown in Figure 2-10.

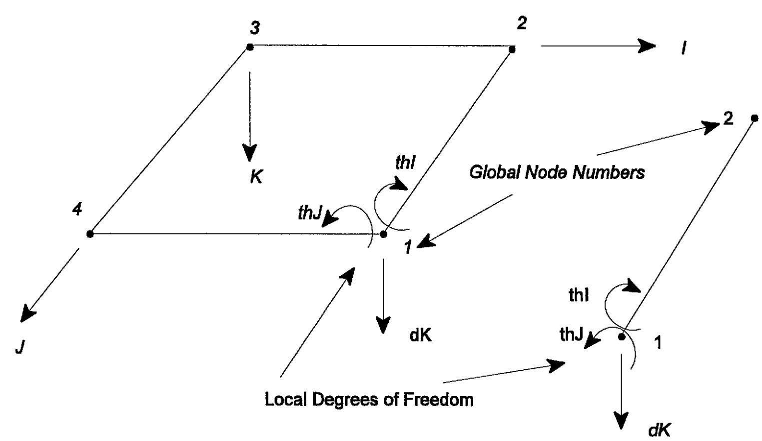


Figure 2-10: Slab and beam elements used in *SAFE*.

The program uses four node plate elements and two node beam elements with three degrees of freedom at each node. The beam elements may exist between any two nodes. The beam element in Figure 2-10, with global node numbers 1 and 2, exists along the length of the plate element with the same global node numbers.

The group weight for a particular wheelbase is then divided by the 16 ft. (4.9

m) gage and by the wheelbase. This results in a distributed load in kips per square foot or kilonewtons per square meter. This distributed load may then be applied to the finite element model of the bridge. Figure 2-11 shows a typical mesh used along with the applied distributed load.

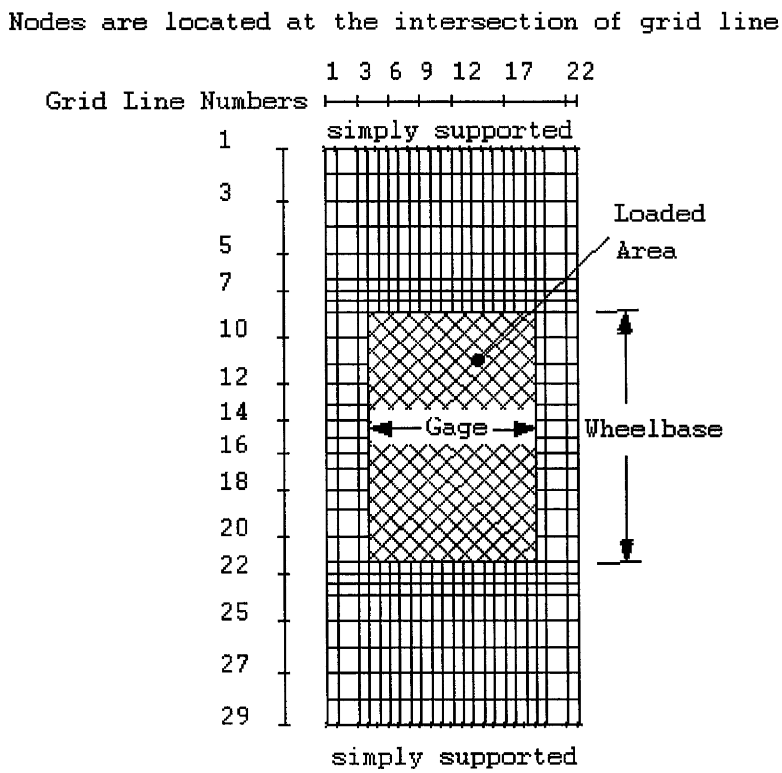


Figure 2-11: Typical finite element mesh for a concrete slab bridge used by *SAFE*.

The span length of the bridge is the span associated with the minimum distributed load for that wheelbase. This is shown in Figure 2-7. Between 308 and 616 elements are used for spans ranging from 15 to 55 ft. (4.6 to 16.8 m), respectively. The large number of elements are used for two reasons. First, the wide range of gages and wheelbases necessitates large numbers of nodal points. This results in a large number of elements. In most cases, elements that are one foot on a side are used. This is done because the width and length of the distributed loads are varied in one or two foot increments. Second, more accurate and reliable data result from a large number of elements. The program outputs the maximum resulting moment about the transverse axis on each individual finite element. Different distributed loads with gages between 6 and 16 ft. (1.8 and 4.9 m) are then applied to the bridge. The magnitude of this distributed load is then varied until it causes a maximum moment equal to the moment caused by the 16 ft. (4.9 m) gage truck. Results from the *SAFE* program then provide the means to develop a formula for a reduction factor for trucks with gages between 6 and 16 ft. (1.8 and 4.9 m). Note from Figure 2-11 that diaphragm members are not used in the finite element analysis due to *SAFE* limitations. It is not known if these members significantly affect the lateral distribution of the applied load.

For example, for a wheelbase of 8 ft. (2.4 m) and a gage of 16 ft. (4.9 m), a load of magnitude 1.0 is placed on the bridge. A load magnitude of 1.0 is used since it is only of interest to determine how much the load changes from one gage to another. By using 1.0, the calculation for determining the reduction factor is greatly simplified. The magnitude of the resulting moment is 0.0513. To generate the same moment of magnitude 0.0513 for the same wheelbase but with a gage of 14 ft. (4.3 m), a load of magnitude 0.925 is necessary. Dividing 0.925 by 1.000 results in a reduction factor of 0.925. This value is then plotted in Figure 2-12 for a 8 ft. (2.4 m) wheelbase and a 14 ft. (4.3 m) gage.

The formula for the gage depends on the wheelbase as shown in Figure 2-12. Only wheelbases from 4 to 28 ft. (1.2 to 8.5 m) in increments of 4 ft. (1.2 m) are examined. It is apparent that the reduction factor converges for the larger wheelbases. The data for a truck with an 8 ft. (2.4 m) wheelbase are used as the basis for a formula for the reduction factor. The 8 ft. (2.4 m) wheelbase is selected because it produces the minimum reduction factors. The minimum reduction factors reduce the loads as much as possible, protecting the bridge span lengths from excessive loads for any wheelbase.

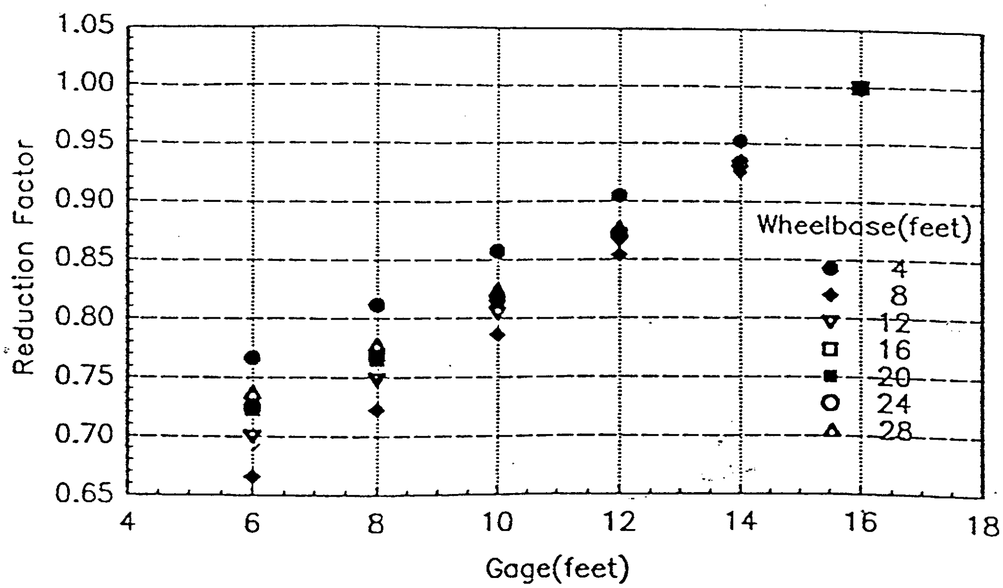


Figure 2-12: Reduction factor versus gage for wheelbases from 4 to 28 ft. (1.2 to 8.5 m) normalized for a 16 ft. (4.9 m) gage.

The reduction factors in Figure 2-12 are based on a truck with a 16 ft. (4.9 m) gage having a reduction factor equal to one. The TxDOT formula in Equation 1-3 is such that the reduction factor for a 6 ft. (1.8 m) gage is equal to one. The data for an 8 ft. (2.4 m) wheelbase are normalized so that a truck with a 6 ft. (1.8 m) gage would have a reduction factor equal to one. For a wheelbase of 8 ft. (2.4 m) and a gage of 14 ft. (4.3 m), a load of magnitude 0.925 results in a moment of magnitude 0.0513. To generate the same moment of magnitude 0.0513 for the same wheelbase, but with a gage of 6 ft. (1.8 m), the magnitude of the load is 0.666. Dividing 0.666 by 0.925 results in a reduction factor of 0.720. This value is then plotted in Figure 2-13 for a 8 ft. (2.4 m) wheelbase and a 14 ft. (4.3 m) gage. A graph of the reduction factor formula normalized for a 6 ft. (1.8 m) gage is shown in Figure 2-13. When increasing the allowable loads for gages greater than 6 ft. (1.8 m), one divided by the reduction factor should be used.

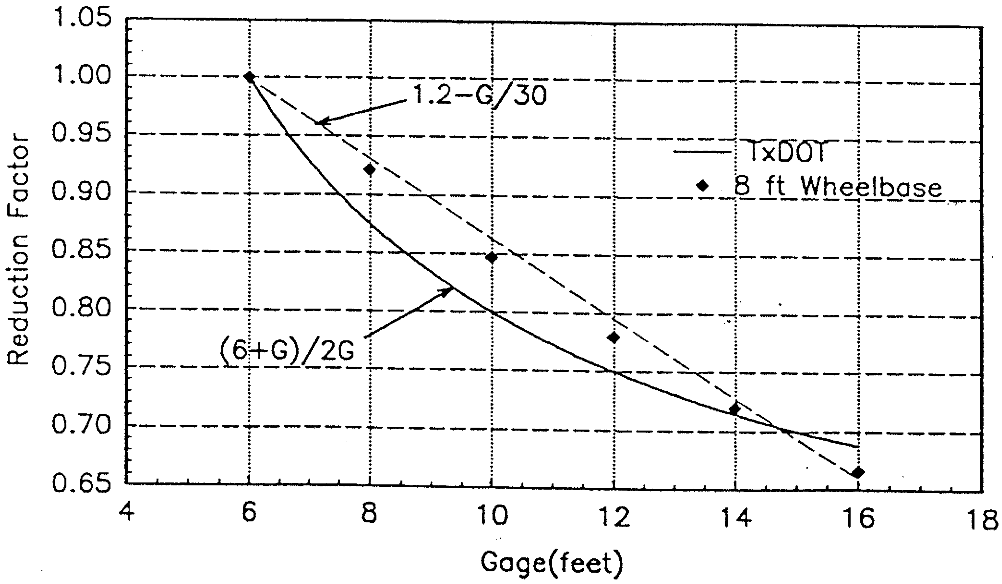


Figure 2-13: Reduction factor versus gage for 8 ft. (2.4 m) wheelbase normalized for a 6 ft. (1.8 m) gage.

It should be noted that the formula for gage based on the *SAFE* analysis indicates that the reduction factor formula should be more linear than is currently used by the TxDOT as shown in Equation 1-3. The normalized formula for a 6 ft. (1.8 m) gage fit to the data for an 8 ft. (2.4 m) wheelbase is given as:

$$\text{Reduction Factor} = 1.2 - \frac{G}{30} \tag{2-8}$$

where

G = gage (ft.).

2.5 Group Weight for a 6 ft. (1.8 m) Gage

The group weight of a wheelbase with a 6 ft. (1.8 m) gage is found by setting G equal to 16 ft. (4.9 m) in Equation 2-8 and multiplying the result by the allowable group weight of a 16 ft. (4.9 m) gage truck. This is done for wheelbases ranging from 4 to 120 ft. (1.2 to 36.6 m). As in the case of 16 ft. (4.9 m) gage trucks, in order to compare distributed loads to those in columns 3 and 4 of Table 1-3, Equation 1-1 is applied so the group weights in Table 2-10 must be divided by the wheelbase plus four feet. (The procedure of adding four feet to the wheelbase will be later replaced by a more accurate correction factor but is retained here for the purpose of comparison with the current TxDOT method.) The resulting group weights and distributed weights are shown in Figure 2-14 and tabulated in Table 2-10.

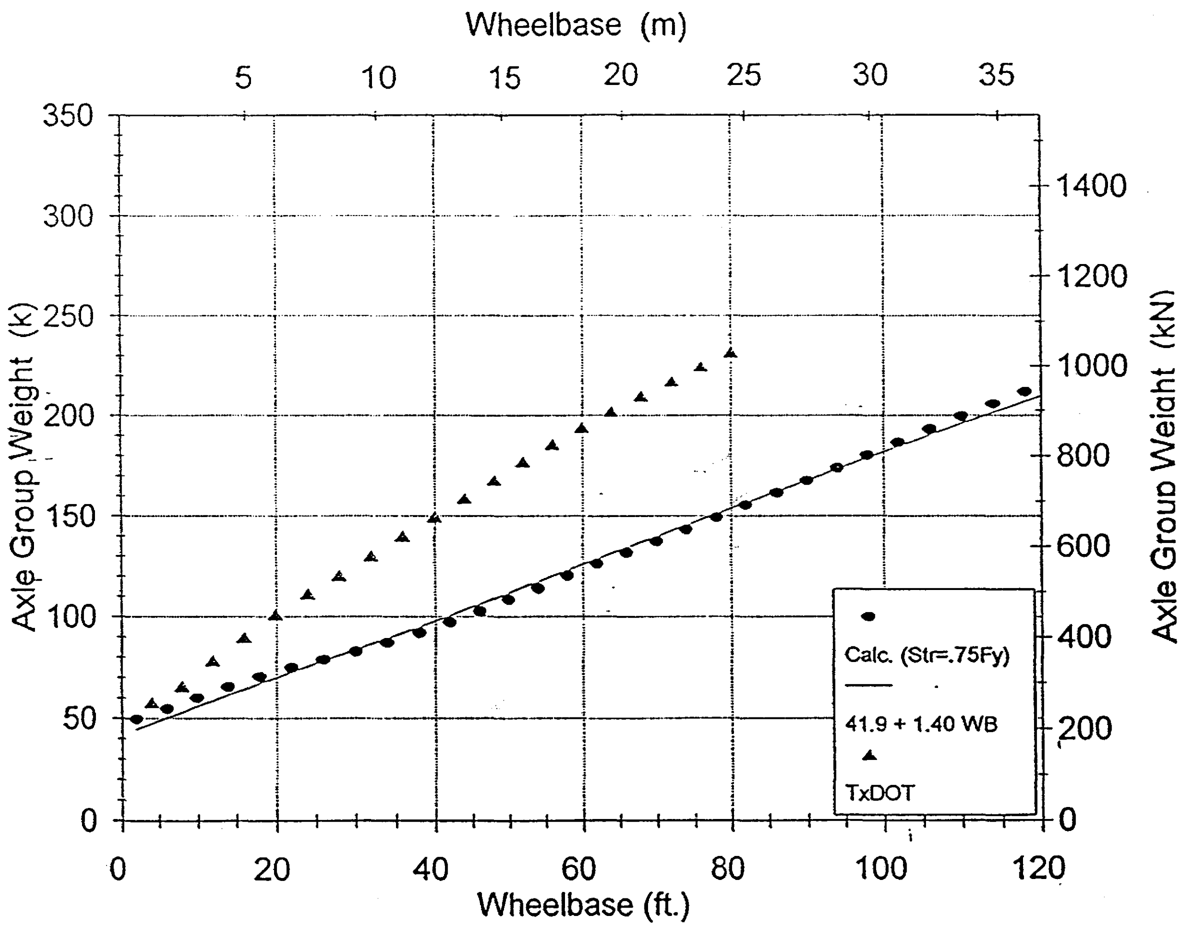


Figure 2-14: Calculated maximum permit weight for 6 ft. (1.8 m) gage on H15 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
4.0	1.2	6.538	44.568	52.30	232.6
6.0	1.8	5.468	41.718	54.68	243.2
8.0	2.4	4.774	39.565	57.28	254.8
10.0	3.1	4.296	37.949	60.15	267.5
12.0	3.7	3.928	36.499	62.86	279.6
14.0	4.3	3.644	35.277	65.59	291.7
16.0	4.9	3.416	34.217	68.31	303.8
18.0	5.5	3.207	33.072	70.56	313.8
20.0	6.1	3.035	32.081	72.85	324.0
22.0	6.7	2.881	31.113	74.91	333.2
24.0	7.3	2.746	30.211	76.89	342.0
26.0	7.9	2.628	29.390	78.83	350.6
28.0	8.5	2.523	28.642	80.75	359.2
30.0	9.2	2.434	27.996	82.77	368.2
32.0	9.8	2.358	27.441	84.89	377.6
34.0	10.4	2.293	26.968	87.12	387.5
36.0	11.0	2.237	26.569	89.48	398.0
38.0	11.6	2.190	26.238	91.96	409.1
40.0	12.2	2.150	25.972	94.59	420.7
42.0	12.8	2.114	25.728	97.23	432.5
44.0	13.4	2.079	25.481	99.79	443.9
46.0	14.0	2.050	25.284	102.49	455.9
48.0	14.6	2.026	25.136	105.34	468.5
50.0	15.3	2.006	25.035	108.35	481.9
52.0	15.9	1.986	24.906	111.20	494.6
54.0	16.5	1.968	24.800	114.13	507.6
56.0	17.1	1.954	24.733	117.21	521.4
58.0	17.7	1.943	24.705	120.47	535.9
60.0	18.3	1.927	24.594	123.30	548.5

Table 2-10: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges (4 ft. (1.2 m) added to wheelbase).

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
62.0	18.9	1.911	24.483	126.11	560.9
64.0	19.5	1.895	24.369	128.86	573.2
66.0	20.1	1.880	24.259	131.60	585.4
68.0	20.7	1.868	24.175	134.46	598.1
70.0	21.4	1.857	24.118	137.45	611.4
72.0	22.0	1.847	24.056	140.40	624.5
74.0	22.6	1.838	23.994	143.33	637.5
76.0	23.2	1.830	23.954	146.37	651.1
78.0	23.8	1.821	23.899	149.32	664.2
80.0	24.4	1.813	23.854	152.30	677.4
82.0	25.0	1.807	23.829	155.41	691.3
84.0	25.6	1.800	23.793	158.44	704.7
86.0	26.2	1.794	23.761	161.49	718.3
88.0	26.8	1.790	23.748	164.65	732.4
90.0	27.5	1.784	23.717	167.69	745.9
92.0	28.1	1.779	23.697	170.80	759.7
94.0	28.7	1.776	23.693	174.02	774.1
96.0	29.3	1.771	23.676	177.14	787.9
98.0	29.9	1.768	23.665	180.31	802.0
100.0	30.5	1.765	23.669	183.59	816.6
102.0	31.1	1.762	23.657	186.73	830.6
104.0	31.7	1.759	23.654	189.95	844.9
106.0	32.3	1.757	23.661	193.26	859.6
108.0	32.9	1.754	23.652	196.43	873.7
110.0	33.6	1.752	23.656	199.70	888.3
112.0	34.2	1.749	23.652	202.92	902.6
114.0	34.8	1.745	23.623	205.90	915.9
116.0	35.4	1.741	23.604	208.98	929.5
118.0	36.0	1.738	23.578	211.98	942.9
120.0	36.6	1.734	23.555	215.00	956.3

Table 2-10: Calculated maximum permit weights for6 ft. (1.8 m) gage trucks on H15 bridges (4 ft. (1.2 m) added to wheelbase) (cont.).

Also shown in Figure 2-14 are the group weights that are used by the TxDOT, which extend up to an 80 ft. (14.4 m) wheelbase. As already stated, the proposed allowable loads vary from the current TxDOT values by approximately the reduction factor of 0.667 (1.2-16/30). The actual values that the TxDOT uses are shown in Table 1-3. A simple linear regression of the calculated values in Figure 2-14 results in the following formula restricting the allowable gross weight of a truck axle group as a function of wheelbase:

$$GW = 41.9 + 1.4 * WB \qquad \text{H15 bridges} \qquad \textbf{(2-9)}$$

$$GW = 55.2 + 1.77 * WB \qquad \text{H20 bridges} \qquad \textbf{(2-10)}$$

where

GW = group weight (k),

WB = wheelbase (ft.).

Equations 2-9 and 2-10 assume the permit truck to be a linearly distributed load. In simple span bridges, the maximum moment due to real axle groups can never be as great as that due to an assumed distributed load of the same total weight. A correction factor is calculated to account for this difference.

2.6 Conversion Factor for Concentrated Loadings

The previous calculations assume that the permit truck is a distributed load positioned in the center of the bridge for maximum moment. This is illustrated in Figure 2-1. Actual wheel loads act as a series of point loads. To test the accuracy of the distributed load assumption on simple span bridges, several legal axle configurations are tested. These legal axle groups are among those used to determine the current TxDOT permit rules. Full sketches of these configurations may be found in Appendix B. The objective is to calculate a factor, β, which will transform the wheelbase of any real axle configuration to the wheelbase of a distributed load and provide a better estimate of the difference between the two load configurations than simply adding 4.0 ft. (1.2 m) to the wheelbase. The equivalent distributed loads and maximum moments for both cases are the same. This is illustrated in Figure 2-15.

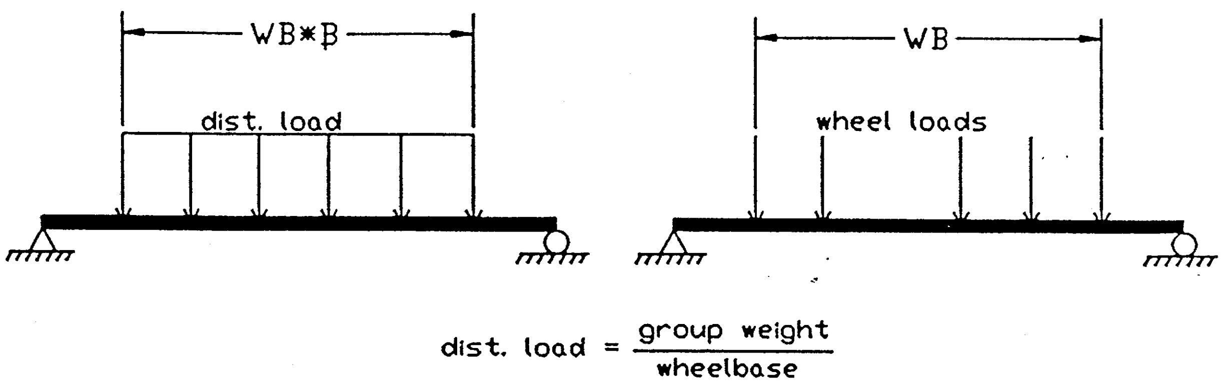


Figure 2-15: Illustration of correction factor for concentrated loadings.

The controlling axle group is placed on the critical span length bridge. The critical length bridge is associated with the minimum distributed load for the given wheelbase. This is shown in Figure 2-7. To position the axle group for maximum moment, the center line of the bridge must evenly divide the distance between the truck's center of gravity and the nearest axle. This is shown in Figure 2-16. The maximum moment due to the permit load is then calculated by basic static analysis. The equivalent wheelbase necessary to cause this maximum moment for a distributed load of the same magnitude is then determined by rearranging Equation 2-7. The wheelbase can then be derived by the following equation:

$$WB_{eq} = L - \sqrt{L^2 - \frac{8M_{truck}}{w_{truck}}} \qquad \textbf{(2-11)}$$

where

WB_{eq}	=	unknown wheelbase of equivalent distributed load (ft.),
L	=	bridge span length (ft.),
M_{truck}	=	maximum moment due to actual truck (k-ft.),
w_{truck}	=	equivalent distributed load (GW/WB_{permit}) (k/ft.).

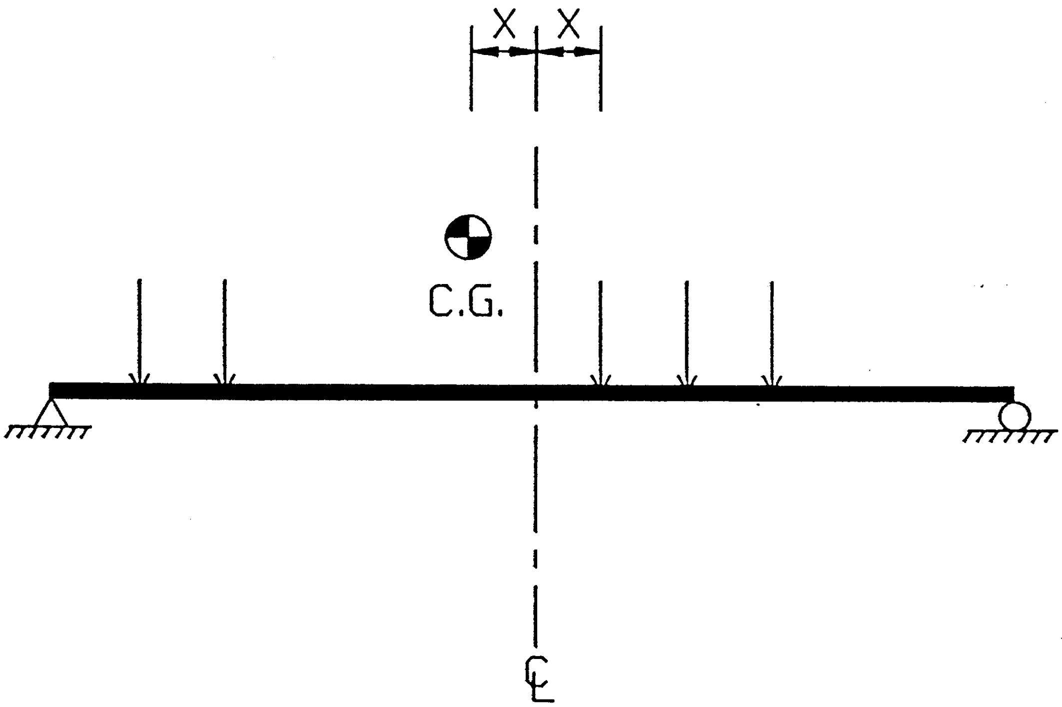


Figure 2-16: Concentrated loading positioned for maximum moment.

The correction factor, β, can then be calculated from the following formula:

$$\beta = \frac{WB_{eq}}{WB_{permit}} \tag{2-12}$$

It was found that many factors influence β. Among these factors are:

1) distance between axle groups,
2) distribution of weight within axle group,
3) distribution of weight between axle groups,
4) number of axle groups "critical" configuration,
5) "critical" bridge span length.

It is desired to keep a formula for β simple. Therefore, an attempt is made to parameterize β in terms of only one variable. The best model relates β to the distance between the axle group center of gravity and the nearest axle. A conservative formula is shown in Equation 2-13.

$$\beta = 0.97 - \frac{D}{40} < 0.92 \qquad \textbf{(2-13)}$$

where

D = distance between the center of gravity and nearest axle (ft.).

This formula is derived by calculating the correction factor for the axle configurations used to develop the current permit standards. These axle configurations are shown in Appendix B. A graphical representation of this formula and the linear regression for these actual correction factors are shown in Figure 2-17.

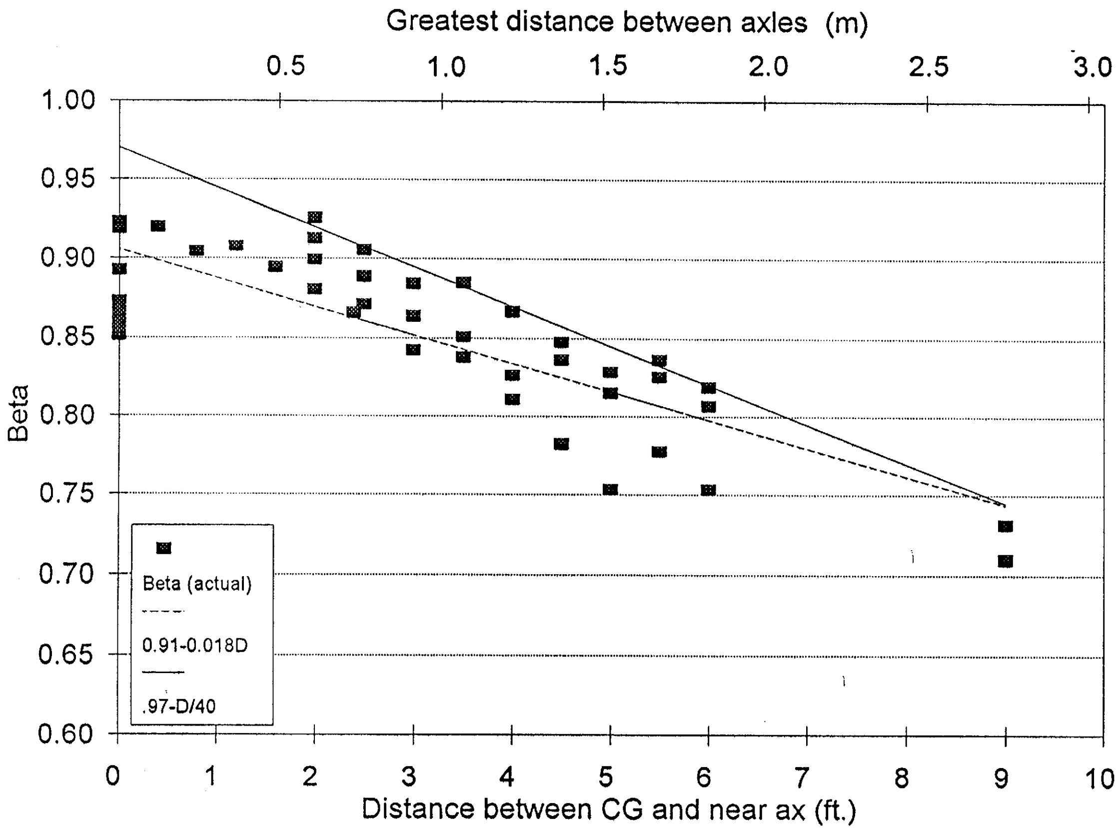


Figure 2-17: Correction factor based on the distance between the center of gravity and the nearest axle.

Parameterizing β in terms of the distance between the group center of gravity and the nearest axle has several limitations. First, calculation of the group center of gravity can be quite tedious. This is especially so if several axle group configurations have to be analyzed so that a critical one may be determined. Second, the formula overestimates β for cases where three or more axle groups are contained with a given configuration and the distance, D, is quite small. In Figure 2-17, the axle configurations with D equal to zero all contain three equally weighted groups of axles. These points all deviate significantly from the predicting formula.

A second, more simple, method is also used to approximate the correction factor. In this method, β is calculated as a function of the greatest distance between any two axles. While this method is not as accurate as the first method, it also does not have the limitations associated with it. A conservative formula using this method is:

$$\beta = 1 - \frac{GD}{70} < 0.92 \qquad \textbf{(2-14)}$$

where

GD = greatest distance between any two adjacent axles (ft.).

This method is shown in Figure 2-18.

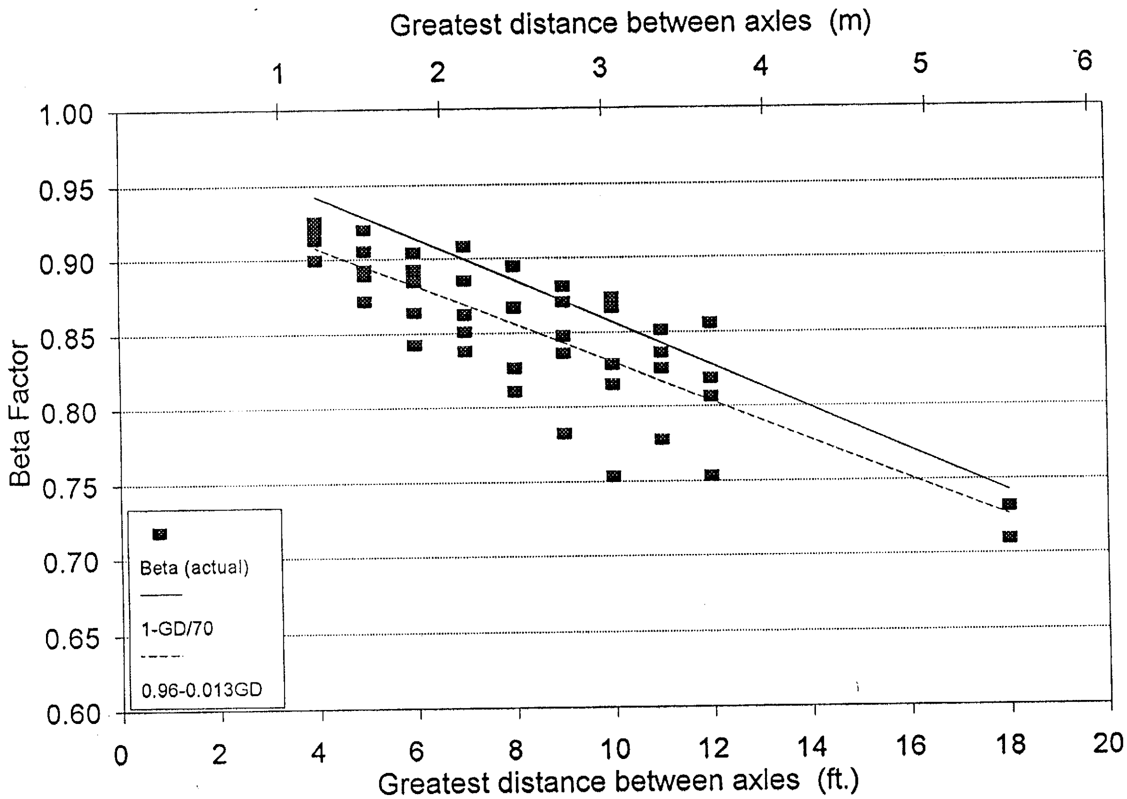


Figure 2-18: Correction factor based on the greatest distance between any two axles.

Because these β factors are all less than 1, the allowable loads carried by an actual axle configuration may be increased over simple span briges. Equations 2-9 and 2-10 have been modified to consider β.

$$GW = 41.9 + 1.4 * \frac{WB}{\beta} \qquad \text{H15 bridges} \qquad \textbf{(2-15)}$$

$$GW = 55.2 + 1.77 * \frac{WB}{\beta} \qquad \text{H20 bridges} \qquad \textbf{(2-16)}$$

where:

GW = group weight (k),

WB = wheelbase (ft.).

β = correction factor for concentrated loadings.

It is important to note that these formulae apply only to simple span bridges. The negative moments in continuous span bridges are maximum when adjacent spans are loaded with no load over the support. These axle configurations may consist of two axle groups with a large distance between axle groups. It is likely that approximating the load as a distributed load of the same total weight may produce maximum moments less than those produced by actual trucks. Therefore, use of the correction factor in Equations 2-15 and 2-16 for continuous span bridges would be non-conservative.

2.7 Bridge Formula Considering Span Length

The previous proposed weight restrictions (Equations 2-15 and 2-16) are only a function of the wheelbase of a truck's axle groups. This is done to ensure that the vehicle can safely pass over a bridge of any span length. Therefore, a permit may be issued for a given truck without knowing the specifics of the bridge to be crossed. In some cases, these weight restrictions limit the permit weights significantly more than necessary. When the route of the permit vehicle is known, a greater weight may be allowed. This is due to the fact that if a particular route is specified, the span length of bridges encountered will also be known. It is of interest, therefore, to develop a formula that is a function of both wheelbase and bridge span length. In the future, if TxDOT uses computers to assist in the permitting of trucks, such a formula can be used to assist in specifying the best route for a particular load. With this additional information, heavier loads can be safely granted permits.

By using the Marquardt-Levenberg algorithm, a formula for the allowable distributed load as a function of wheelbase and bridge span length is determined. With this method, the coefficients to a pre-determined characteristic equation are determined by minimizing the sum of the squares of the residuals. Because this is an iterative process, the *SigmaPlot* program is used to perform this task. The formula is based upon a truck with a gage of 6 ft. (1.8 m) and axles with less than eight tires per axle. This may be modified for different gages and more tires by applying the factors in Equations 1-2 and 2-8.

First, the distributed loads already calculated according to Equation 2-7 are multiplied by four wheels and the reduction factor. This results in the allowable distributed loads for a 6 ft. (1.8 m) gage truck. A general form describing this data is then determined. Using the general form of Equation 2-7 and the equation for standard H15 lane loadings, the general form is identified as:

$$w = \frac{k_1 \cdot L^2 + k_2 \cdot L + \dfrac{k_3}{L} + k_4}{WBL(2L - WBL)} \tag{2-17}$$

where

k_1, k_2, k_3, k_4	=	constants,
L	=	span length (ft.),
WBL	=	WB, wheelbase (ft.) when $WB < L$,
	=	L, span length (ft.) when $WB > L$,
w	=	allowable distributed load (k/ft.).

The Marquardt-Levenberg algorithm is then used to calculate values of the constants which will produce the best fit to the data. The cases where the wheelbase exceeds the span length are not included in the curve fitting process. For these cases, the maximum wheelbase on the bridge is limited to the span length. According to the results of the curve fit, k_2 is insignificant when compared to the other constants. Therefore, it is omitted. The other constants are then rounded for ease of use. These final formulae (Equations 2-18 and 2-19) have a maximum deviation from the data of 4.8 percent.

$$w = \frac{\frac{5L^2}{3} - \frac{11000}{L} + 1800}{WBL(2L - WBL)} \qquad \text{H15 bridges} \qquad \textbf{(2-18)}$$

$$w = \frac{2.1L^2 - \frac{15000}{L} + 2500}{WBL(2L - WBL)} \qquad \text{H20 bridges} \qquad \textbf{(2-19)}$$

Group weight as a function of wheelbase and bridge span length is graphed in Figure 2-19. The group weight is determined by multiplying the distributed load determined with Equations 2-18 and 2-19 by the wheelbase length.

$$GW = w * \frac{WB}{\beta} \qquad \textbf{(2-20)}$$

where

GW	=	group weight (k),
w	=	allowable distributed load from Equations 2-17 or 2-18 (k/ft.),
WB	=	wheelbase (ft.),
β	=	correction factor for concentrated loadings.

As can be seen in Figure 2-19, when the bridge span length is considered, significantly higher weights may be allowed for various span lengths. Equation 1-1 must still be applied to convert the group weights to TxDOT equivalent distributed weights.

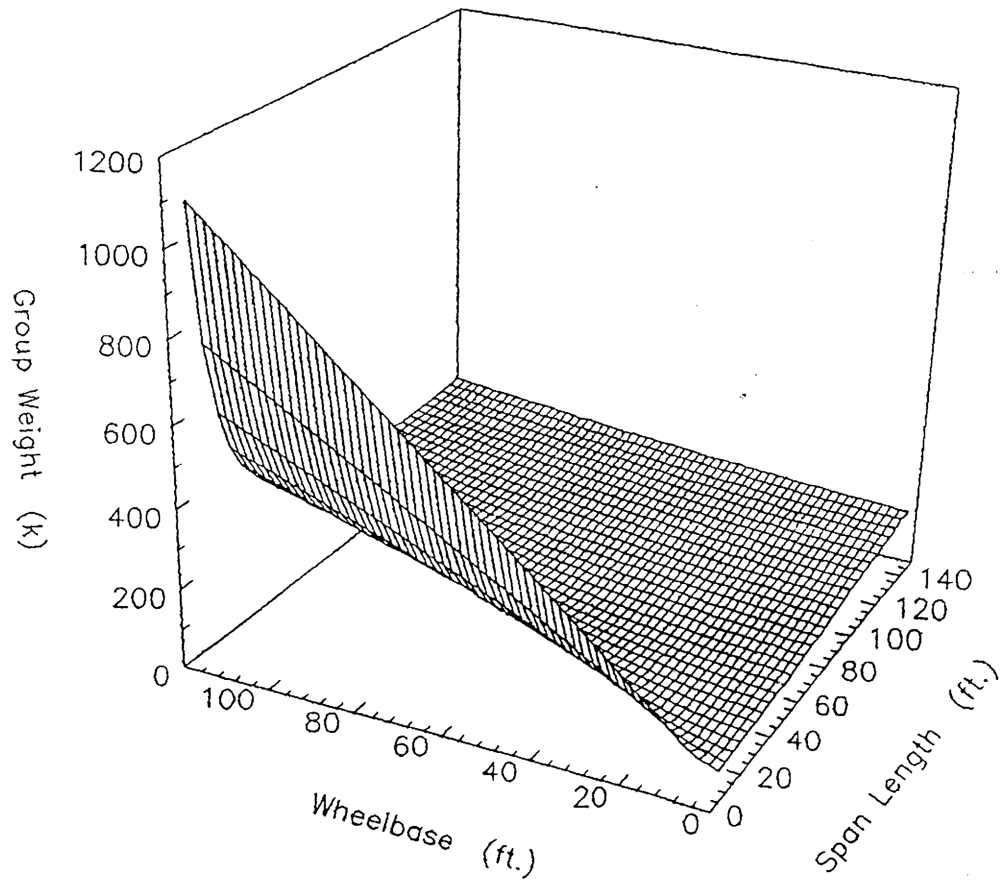


Figure 2-19: Calculated group weight versus wheelbase and bridge span length for a 6 ft. (1.8 m) gage.

Although the formulae are determined using data from span lengths from 10 to 150 ft. (3.1 to 45.7 m) and wheelbases from 4 to 120 ft. (1.2 to 36.6 m), they converge at larger values. Therefore, these formulae may be used for larger wheelbases and span lengths. A reference table in Appendix C is provided for quick calculation of the group weights.

2.8 Application Example

To better demonstrate how the proposed method should be utilized in overweight permitting, the truck in Figure 1-5 will be reexamined. This truck was denied a permit because axles 3 and 4 exceeded TxDOT restrictions. The equivalent distributed weight of each axle grouping can be calculated using the same criteria in Equations 1-1, 1-2, and 1-3. It will be assumed that the vehicle in Figure 1-5 will pass over a single H15 bridge with a single span of 45 ft. (13.7 m). Therefore, the limiting distributed weight will be calculated using Equations 1-1,2-14,2-18, and 2-20.

Equation 2-14 is used to calculate the correction factor β. This analysis is summarized in Table 2-11.

Axles	Max axle distance (ft.)	(m)	β
1,2,3	19.0	5.80	0.729
1,2,3,4	19.0	5.80	0.729
2,3	19.0	5.80	0.729
2,3,4	19.0	5.80	0.729
3,4	4.0	1.22	0.943

Table 2-11: Correction factors for example vehicle.

These correction factors may be used to develop the restricting distributed weight. Table 2-12 summarizes this information.

	Allowable Dist. Weight (from Eq. (2-18))		Group Weight (from Eq. (2-10))		Restrict Dist Weight (from Eq. (1-1))	
Axles	(k/ft.)	(kN/m)	(k)	(kN)	(k/ft.)	(kN/m)
1,2,3	3.00	43.7	104.9	466.7	3.56	51.9
1,2,3,4	2.76	40.3	111.9	497.5	3.34	48.7
2,3	3.65	53.3	95.3	424.0	4.14	60.4
2,3,4	3.20	46.7	101.0	449.3	3.74	54.6
3,4	14.33	209.0	60.8	270.5	7.60	110.8

Table 2-12: Restricting distributed weights for example vehicle.

From Table 2-13, the example truck would again be denied a permit due to its excessive load on axles 3 and 4. This table also shows that for larger wheelbases, the proposed criteria are more restrictive than the current criteria used by TxDOT. However, the correction factor for concentrated loadings and the use of the bridge specific formula (Equation 2-18) reduces this difference considerably.

	Equivalent Distributed Load		Current TxDOT Restriction		Proposed Restriction	
Axles	(k/ft)	(kN/m)	(k/ft)	(kN/m)	(k/ft)	(kN/m)
1,2,3	2.55	37.2	3.89	56.8	3.56	51.9
1,2,3,4	3.18	46.3	3.70	53.9	3.34	48.7
2,3	2.31	33.7	4.27	62.3	4.14	60.4
2,3,4	3.13	45.6	4.03	58.8	3.74	54.6
3,4	7.80	113.8	7.25	105.7	7.60	110.8

Table 2-13: Summary of distributed loads for example vehicle.

3. EVALUATION OF CONTINUOUS SPAN BRIDGES

3.1 Overview

Continuous H15 and H20 concrete slab span bridges have been analyzed to determine the effects of overweight permit vehicles. Three H15 and three H20 designed structures have been examined. The plans to these six structures represent typical designs used by the Texas Department of Transportation in the 1940's, 1950's, and 1960's. Tables 3-1 and 3-2 contain general geometrical information for these six structures, and Figure 3-1 shows a schematic drawing of a 50 ft. (15.3 m) span bridge in Cameron County. These structures are expected to be critical because of their short spans and because they have been designed for load conditions lighter than what is currently permitted on the state's highway system.

Bridge	Design Type	Span Lengths (ft.)	Span Lengths (m)	Date Const.
Cameron 50	H15	25-25	7.6-7.6	1965
Cameron 80	H15	25-30-25	7.6-9.2-7.6	1965
San Saba	H15	26-26-26-26	7.9-7.9-7.9-7.9	1963
CS 0-38-50	H20	25-25	7.6-7.6	1944
CS 18-28-80	H20	25-30-25	7.6-9.2-7.6	1944
CS 18-28-110	H20	25-30-30-25	7.6-9.2-9.2-7.6	1944

Table 3-1: Specifications for continuous span bridges.

Bridge	Deck Width		Roadway Width		Slab Thickness	
	(ft.)	(m)	(ft.)	(m)	(in.)	(cm)
Cameron 50	28.25	8.62	26.00	7.93	12.00	30.48
Cameron 80	28.25	8.62	26.00	7.93	12.00	30.48
San Saba	26.33	8.03	24.00	7.32	12.00	30.48
CS 0-38-50	40.00	12.20	38.00	11.59	14.25	36.20
CS 18-28-80	31.17	9.50	28.00	8.54	14.5	36.83
CS 18-28-110	31.17	9.50	28.00	8.54	14.5	36.83

Table 3-2: Specifications for continuous span bridges.

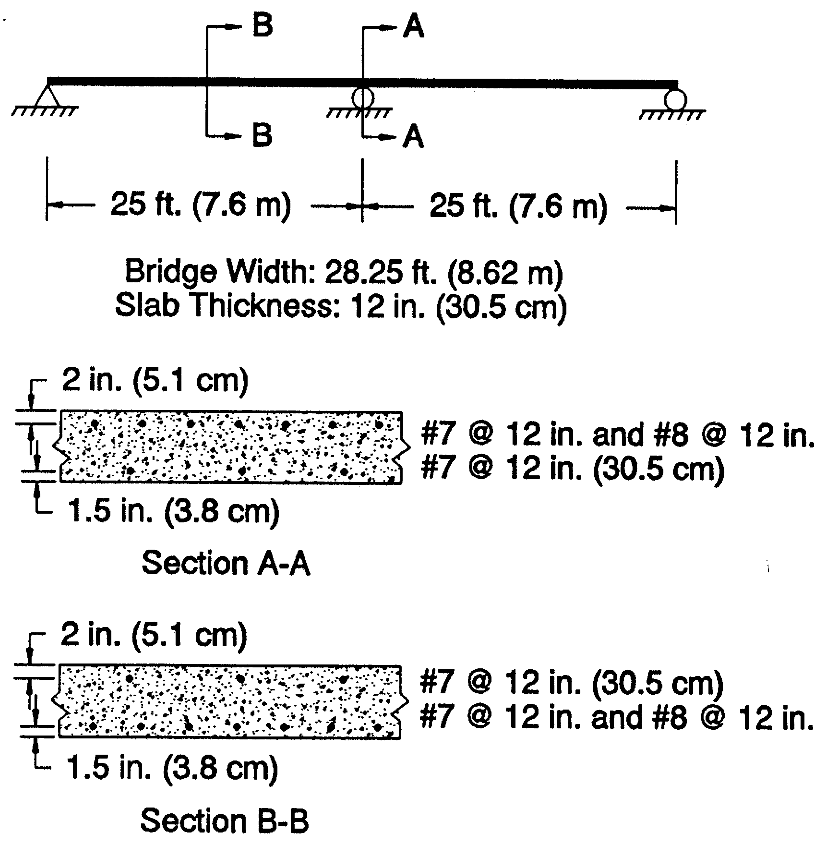


Figure 3-1: Cameron 50 bridge.

3.2 Current Methods of Calculating Moment Capacities for Slab Bridges

The operating level moment capacities are determined at critical locations along the spans based on the working stress method. These critical locations are places where both positive and negative maximum moments occur, i.e., near midspans and at interior supports. The moment capacity at each location is based on the maximum allowable stress for either the concrete or steel reinforcement. The lower of the two moments controls the capacity of the location. The formulae used to determine these capacities are given in *The Manual for Maintenance Inspection of Bridges* (2) and are shown below.

$$M_{fc} = 0.5\ f_c\ j\ k\ b\ d^2 \tag{3-1}$$

$$M_{fs} = A_s\ f_s\ j\ d \tag{3-2}$$

where

M_{fc}	=	moment capacity of concrete,
M_{fs}	=	moment capacity of steel,
f_c	=	allowable stress for concrete,
f_s	=	allowable stress for steel,
j, k	=	concrete section factors,
b	=	width of cross-section,
A_s	=	area of steel,
d	=	depth to tension steel.

M_{fc} and M_{fs} are the moment capacities based on the concrete and steel allowable stresses, respectively, in terms of moment per slab width. Values for f_c and f_s are determined from *The Manual for Maintenance Inspection of Bridges* (2). The other variables can be determined from the design plans of the bridges. The values for the bridge shown in Figure 3-1 at the interior support are as follows:

f_c = 1.9 ksi (13.1 kPa),

f_s = 28.0 ksi (193 kPa),

j = 0.874,

k = 0.379,

b = 12 in. (0.305 m),

d = 10 in. (0.254 m),

M_{fc} = 378 k-in. (42.7 kN-m),

M_{fs} = 410 k-in. (46.3 kN-m).

The operating level moment capacity, M_{OL}, is determined by multiplying the lesser of M_{fc} and M_{fs} by an effective width. The effective width is used to approximate a nonuniform longitudinal bending stress distribution in the slab by a constant distribution. This effective width may be a value for a single line of wheels, *E*, or a lane loading, E_L. Continuous span bridges are analyzed using E_L which is two times E. The effective width is a function of the position of the truck within its lane, the number of axles, and the vehicle gage. The current American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* (10) provides a simplified formula for estimating the effective width and is given as:

$$E_L = 2 * (4.0 + 0.06 * L) < 14.0 \qquad \textbf{(3-3)}$$

where

L = span length (ft.),

E_L = effective width (ft.).

This formula is based on the Westergaard theory for slab stress distribution (3). Another formula for determining effective slab width is one that is being proposed to replace the AASHTO formula. The Load Resistance Factor Design (LRFD) formula, based on finite element studies of typical slab bridges found around the country (13), is given as:

$$E_L = 1.00 + 0.50\sqrt{L*W} \tag{3-4}$$

where

L = bridge span length (ft.),

W = bridge width (ft.).

The LRFD formula may be used for the design of any slab bridge and may underestimate the effective width for the bridge under study. The LRFD specifications allow for a 10 percent decrease of the negative moment at interior spans of continuous bridges. However, this is based on load redistribution near ultimate strength and is therefore not applicable to permit loading.

3.3 Calculation of Effective Width

The six continuous span structures are studied using a simple influence line analysis. An influence line is a graphical representation of the resulting forces at a particular location as an applied load is moved across the bridge. In this case, several actual overweight permit vehicles, like the vehicle in Table 1-1, are run across the six bridges. The results from the influence line analysis, as well as the operating level moment capacities and overstress ratios, are shown in Table 3-3. The results from this method indicate that the bridges are overstressed, particularly in the negative moment regions. Thus, a more accurate analysis that incorporates the position of the truck within its lane, the number of axles, and the vehicle gage is needed to determine the effective widths of these bridges.

Bridge	Location	M_{permit} (k-in.)	M_{ol} (k-in.)	$M_{ol\ LRFD}$ (k-in.)	AASHTO *OSR*	LRFD *OSR*
Cam 50	1st int. support	5093	2195	2623	2.32	1.94
Cam 50	Max mom in span	4240	3102	3705	1.37	1.14
Cam 80	1st interior support	5289	2294	2734	2.31	1.93
Cam 80	Max mom in 1st span	4220	3304	3947	1.28	1.07
Cam 80	Max mom in 2nd span	3602	3625	4305	0.99	0.84
San Saba	1st interior support	4828	2514	2950	1.92	1.64
San Saba	2nd interior support	4010	2955	3469	1.36	1.16
San Saba	Max mom in 1st span	4357	3107	3641	1.40	1.20
San Saba	Max mom	2585	3605	4225	0.72	0.61

Table 3-3: Overstress ratios for actual permit vehicle.

A finite element software package, *SAFE,* is used to better approximate the effective slab width. It is a structural analysis program designed specifically for slabs. The effective width can be approximated by placing point loads (representing wheel loads) at critical locations to produce maximum moment. The gage, number of axles, and lateral position of the vehicle are changed to examine how these factors affect the behavior of the effective width in continuous slab bridges. Each *SAFE* model assumes a modular ratio of 10 and a Poisson's ratio of 0.15. Figure 3-2 shows a deflection contour for the "Cameron 50" bridge shown in Figure 3-1 when it is loaded with a single 25 k (111 kN) axle.

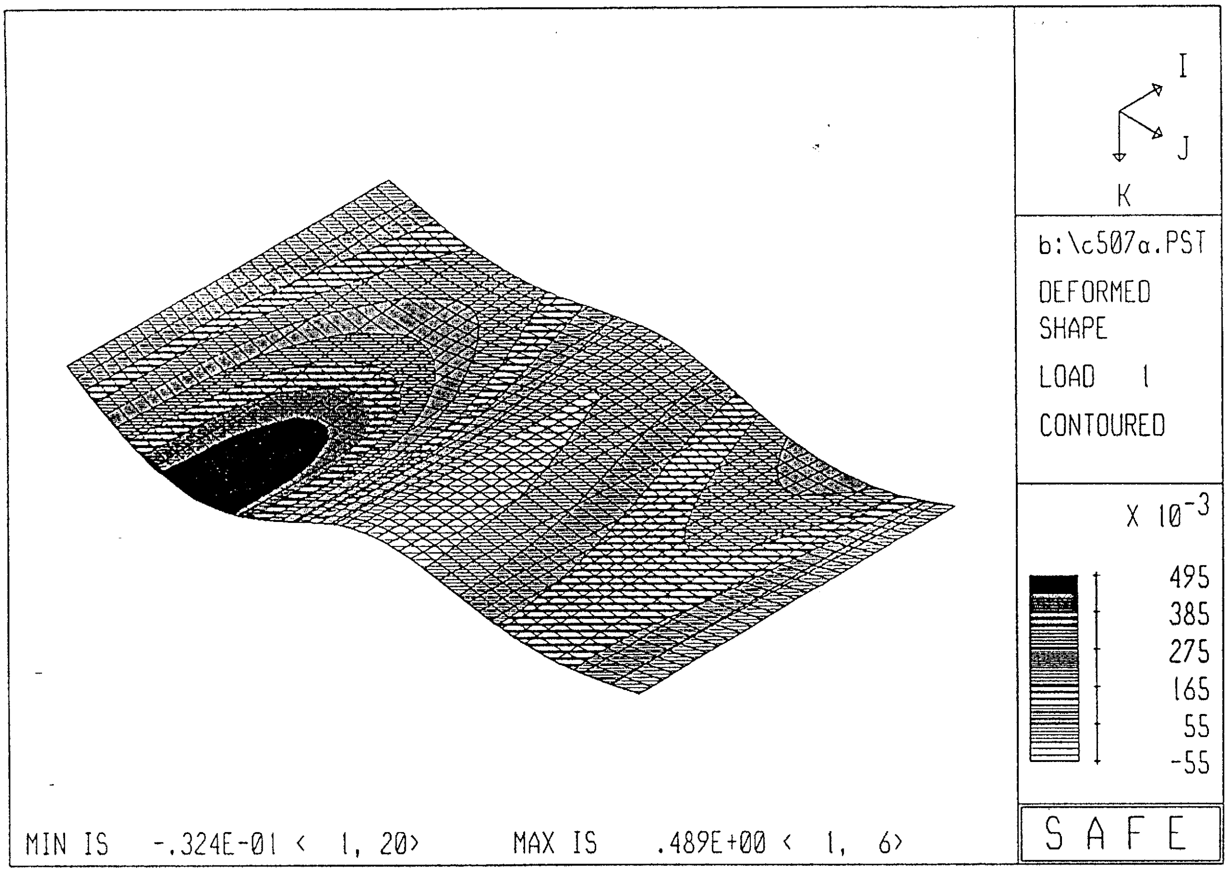
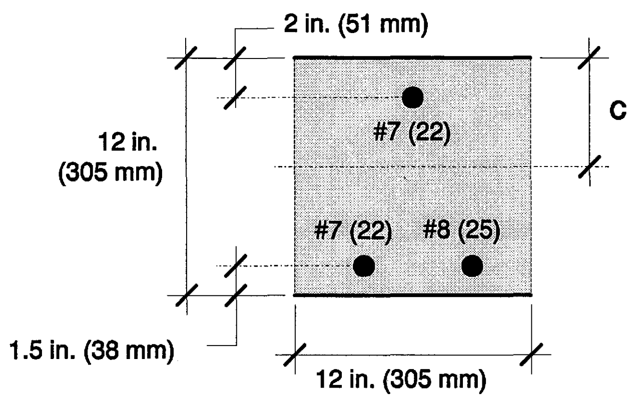


Figure 3-2: Deflection of Cameron 50 due to single axle loading.

The figure shows that the slab experiences both positive and negative curvature in both the I and J directions. The stiffness of the slab must be adjusted accordingly to represent this curvature. The stiffness is input in each *SAFE* run as an effective thickness of concrete. This effective thickness is defined as the uncracked concrete thickness plus the thickness of the transformed steel reinforcement. The stiffness of the slab influences the load distribution throughout the structure because the continuous slabs are statically indeterminate. An example of how to calculate the effective thickness is shown in Figure 3-3 and Tables 3-4 and 3-5.

The calculations in Figure 3-3 assume the top of the slab to be in compression and a modular ratio of 10 (2). The calculations in Table 3-3 assume the neutral axis to be between the top and bottom steel. All available reinforcing steel is used in determining the moment capacity of the slab. This includes tension zone steel that is carried through the slab at interior supports.



$(A_s)_{top}$ = 0.60 in.^{2}/ft.
Transformed Area = $(n\text{-}1)A_s$ = 5.4 in.^{2}
(compression)

$(A_s)_{bottom}$ = 0.6 + 0.79 = 1.39 in.^{2}/ft.
Transformed Area = $(n)A_s$ = 10.39 in.^{2}
(tension)

Figure 3-3: Cross section of Cameron 50 at center span.

	A (in.^{2})	*y* (in.)	*A*y* (in.^{3})
concrete	12c	c/2	6c^2
top steel	5.4	c - 2.0	5.4c - 10.8
bot steel	10.39	c - 10.5	10.39c - 109.1
		Σ A*y =	6c^2+15.79c-119.9
		c = 3.34 in.	(84.8mm)

Table 3-4: Neutral axis calculation.

	A (in.^{2})	y (in.)	$I_{own\ axis}$ (in.^{4})	$A*y^2$ (in.^{4})
concrete	40.1	1.67	37.3	111
top steel	5.4	1.34		9
bot steel	10.39	7.16		532
			ΣI_{tot} = 654 in.^{4}	($272\text{x}10^6 \text{mm}^4$)

Table 3-5: Moment of inertia calculation.

The moment of inertia, $I_{section}$, of any rectangular section about its centroid is defined in Equation 3-5.

$$I_{section} = \frac{b * h^3}{12} \qquad \textbf{(3-5)}$$

Using Equation 3-5, the effective thickness, h, can be calculated using the results of Table 3-5 as shown below.

$$I_{section} = \frac{b\ h^3}{12} = \frac{12\ h^3}{12} = 692 \text{ in.}^4 \ (288\text{x}10^6 \text{ mm}^4)$$

The effective thickness, h, can then be determined to be 8.85 in. (225 mm).

The curvature in both the I and J directions must first be assumed in order to input the effective thicknesses needed to run the program. Once the program has run with this initial input, the results are analyzed to determine the actual curvature since the amount and location of the top and bottom steel differ. The effective thicknesses must be reinput to reflect where the slab is experiencing positive and negative curvature in the I and J directions. Therefore, each *SAFE* run is an iterative process to ensure that positive and negative curvature is accounted for properly. An example of input and output *SAFE* files for Cameron 50 are shown in Appendix D.

The effective width at any location on a bridge can be calculated by analyzing the resulting moment contour. Figure 3-4 shows the longitudinal moment contour of Cameron 50 due to a single axle loading. The effective width is determined by finding the width of slab required to obtain the same moment as that occurring across the entire width of slab. While the moment varies across the width of the bridge, the maximum moment is assumed to occur across the entire effective slab width. The effective slab width can be calculated by the following formula:

$$E_L = \frac{M_{avg}}{M_{maximum}} W \tag{3-6}$$

where

Mavg	=	average moment over width of slab
$M_{maximum}$	=	maximum moment in any element
W	=	bridge width

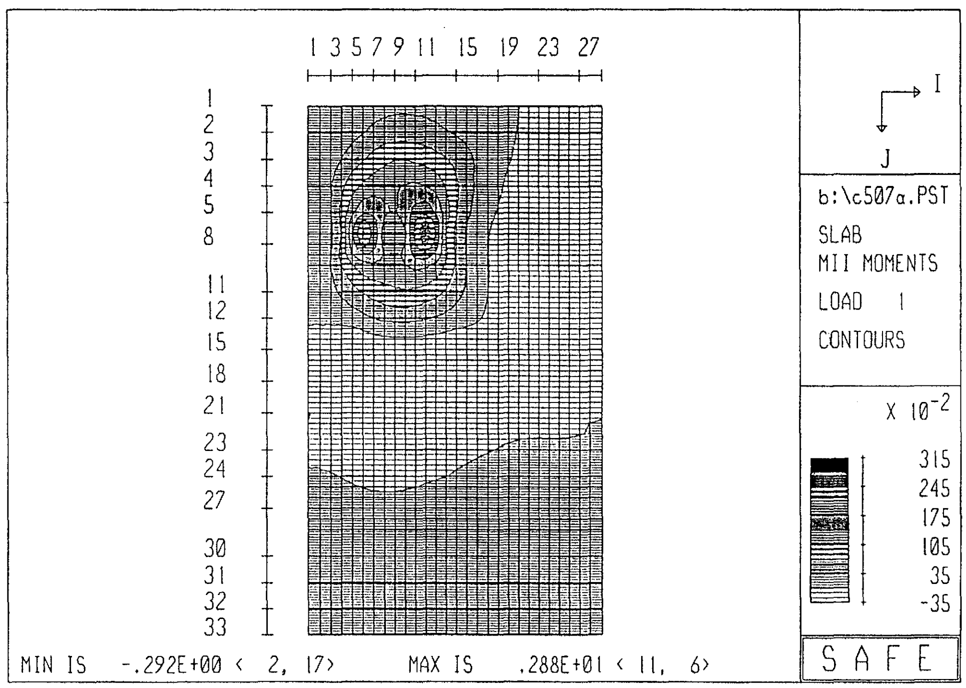


Figure 3-4: Moment contour for Cameron 50.

These effective widths are calculated by varying the loadings in order to better understand the flexural behavior of continuous span bridges. The number of axles are varied as well as the position of the vehicle within its lane. The loads applied are the maximum according to TxDOT permit standards. This is done for each H15 designed bridge at every critical location. Figures 3-5 and 3-6 show how the effective widths vary as the number of axles change and the vehicles move transversely from the edge to the center of the slab for Cameron 50 for a 6 ft. (1.83 m.) gage. Figures 3-5 and 3-6 show the results for the moment at the interior support and the maximum moment within the span, respectively. Similar figures for the other bridges are in Appendix E.

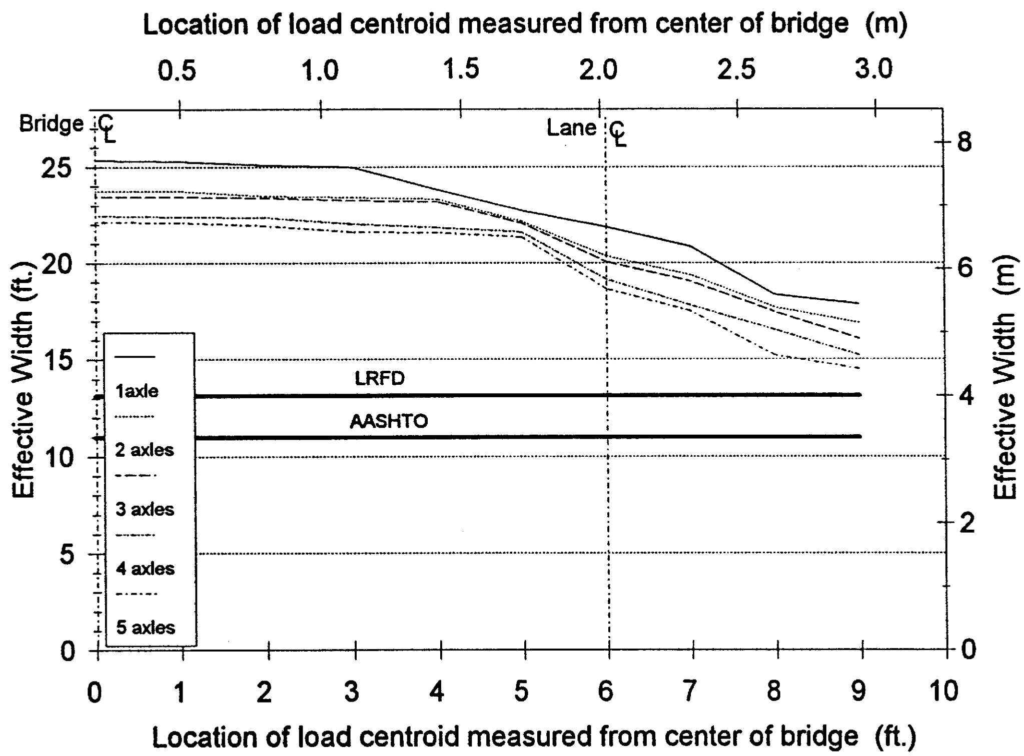


Figure 3-5: Effective width of Cameron 50 at interior support subjected to 6 ft. (1.8 m) gage axles.

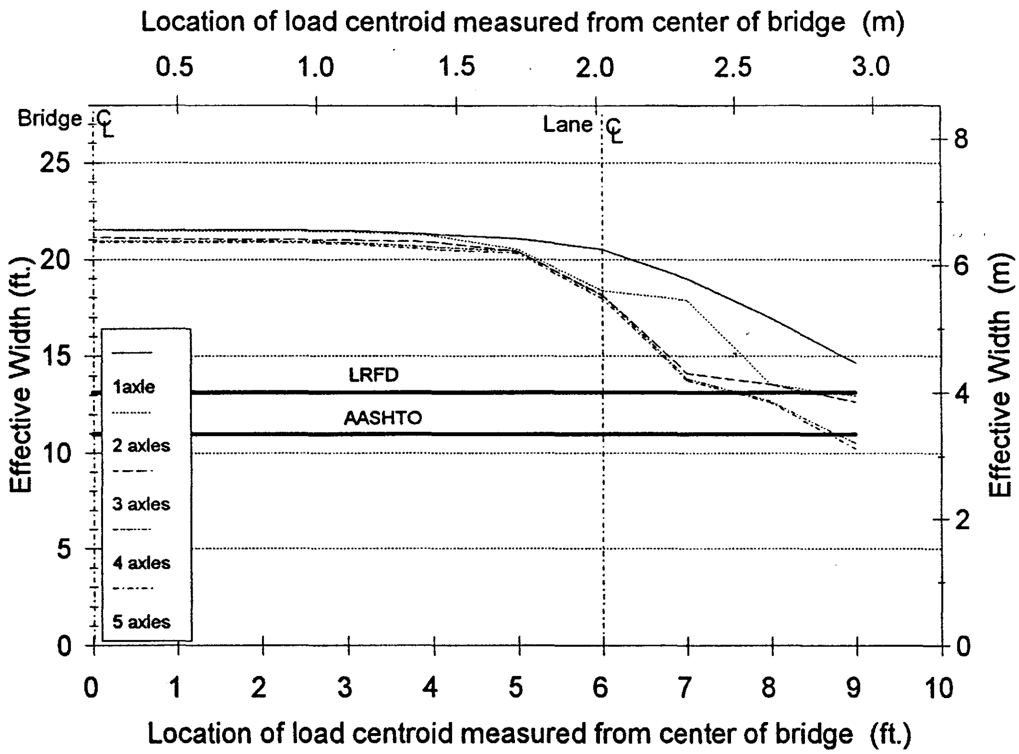


Figure 3-6: Effective width of Cameron 50 within span subjected to 6 ft. (1.8 m) gage axles.

3.4 Analysis of the Effective Width

Several conclusions can be made from the graphs of effective width versus the position of the load in Appendix E. First, the effective width increases as the transverse truck position tends toward the centerline of the bridge. This occurs because the average moment across the width of the bridge remains fairly constant, while the value for the maximum moment decreases as the truck is moved from the edge to the center of the bridge.

A second conclusion that can be made from the figures in Appendix E is that the axle configuration affects the effective width significantly. The effective width increases as the gage increases. This is expected because a wider wheel gage indicates that the load can be distributed to a greater area. The graphs also indicate that a smaller number of axles consistently produce a greater effective width than larger groups of axles. Because the maximum axle loads in Table 1-2 are used, the total live load on the bridge increases as the number of axles increase. This increase in the concentrated live load causes the maximum moment values to increase at a faster rate than the average moment values when the number of axles is increased. This occurs because the magnitude of the load is more important in determining the maximum moment than the group wheelbase. This greater rate causes the effective widths to decrease as the number of axles increase.

The most important conclusion of these results is that these finite element results indicate a greater effective width at the centerline of the lane than the AASHTO or LRFD results. This greater effective width indicates that as long as the permit vehicle drives in the middle of the lane, the actual moment capacities of these structures is greater than the capacities governed by the AASHTO and LRFD formulas. The importance of this can be seen when comparing the results of the continuous structures to the simple span formulae.

3.5 Simple Span Formulae Applied to Continuous Span Bridges

The proposed formulae for the simple span bridges are checked against H15 and H20 continuous span bridges by influence line analysis. Trucks with various axle configurations and spacing were positioned on the bridge by analyzing the influence line at critical locations so as to produce the maximum effect. The gross vehicle weight of each truck was determined by using the proposed formulae (Equations 2-9 and 2-10) and proportioned to each axle group to cause the maximum bending moment. The influence line for Cameron 50 moment at the first interior support is shown in Figure 3-7. The critical axle configuration consists of two axle groups spaced 21.14 ft. (6.45 m) apart (center-to-center). If two 5-axle groups are considered and if axles must be at least 4 ft. (1.2 m) apart, the wheelbase can be calculated as follows.

$$WB = 21.14 + (4 * 4) = 37.14 \text{ ft.} \tag{3-7}$$

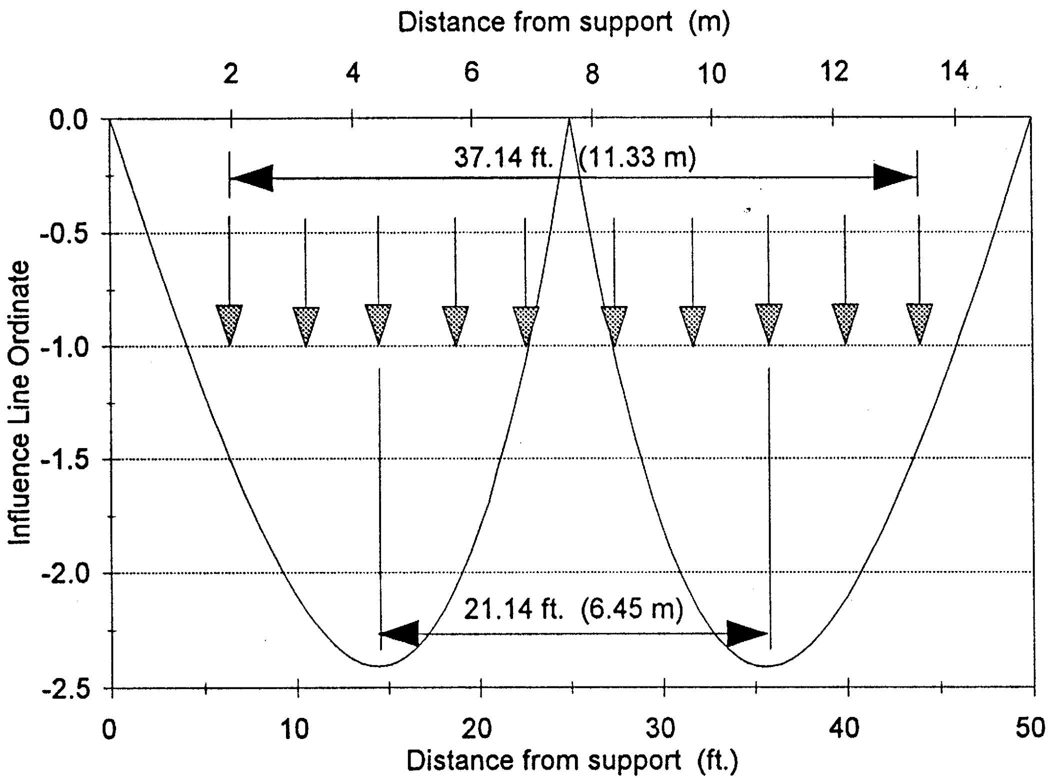


Figure 3-7: Influence line and critical axle configuration of Cameron 50 at interior support.

Substituting 37.14 ft. (11.32 m) into the simple span formula (Equation 2-10), the group weight is 93.90 kips (417.7 kN). This weight is distributed to the ten axles. Because the influence line is symmetrical, the most effective way to distribute the weight is evenly to each axle.

The β-factor, used for simple spans, should not be used. The β is used for simple spans because a distributed load produces the greatest possible moment. In continuous spans, the negative moments are maximum when the axle groups are placed in adjacent spans. Several axle configurations with different wheelbases are developed for each critical point. Each configuration is analyzed and a maximum moment for each case is determined using the influence line analysis. This maximum moment due to the influence line analysis (M_{IL}) is then compared to the operating level moment capacities using the AASHTO ($M_{OL\ AASHTO}$), LRFD ($M_{OL\ LRFD}$), and finite element center-of-lane ($M_{OL\ FEM}$) effective widths. Overstress ratios (OSR) are then determined for the AASHTO, LRFD, and FEM cases using Equation 3-7.

$$OSR = \frac{M_{IL}}{M_{OL}} \qquad \textbf{(3-8)}$$

If the influence line is symmetrical or if a single group of axles causes a maximum moment, the group axle weight used in the influence line analysis is adjusted using the overstress ratio. The overstress ratio is proportional to the amount the group axle weight needs to be reduced to produce no overstressing. If unsymmetrical groups of axles are expected to cause the maximum moments, the influence line analysis is repeated. Analyzing unsymmetrical groups of axles is an iterative process because the OSR is not directly proportional to the amount the group axle weight needs to be reduced. The final adjusted group axle weight is plotted against the wheelbase. These plots (AASHTO, LRFD, and FEM) are shown in Figures 3-8, 3-9 and 3-10. The data from the influence line analysis of each bridge are plotted against the general simple span formulae. Figure 3-11 shows that the positive moment within the span controls for wheelbases less than 20 ft. (6.1 m). Greater wheelbases cause the negative moment at the interior support to control.

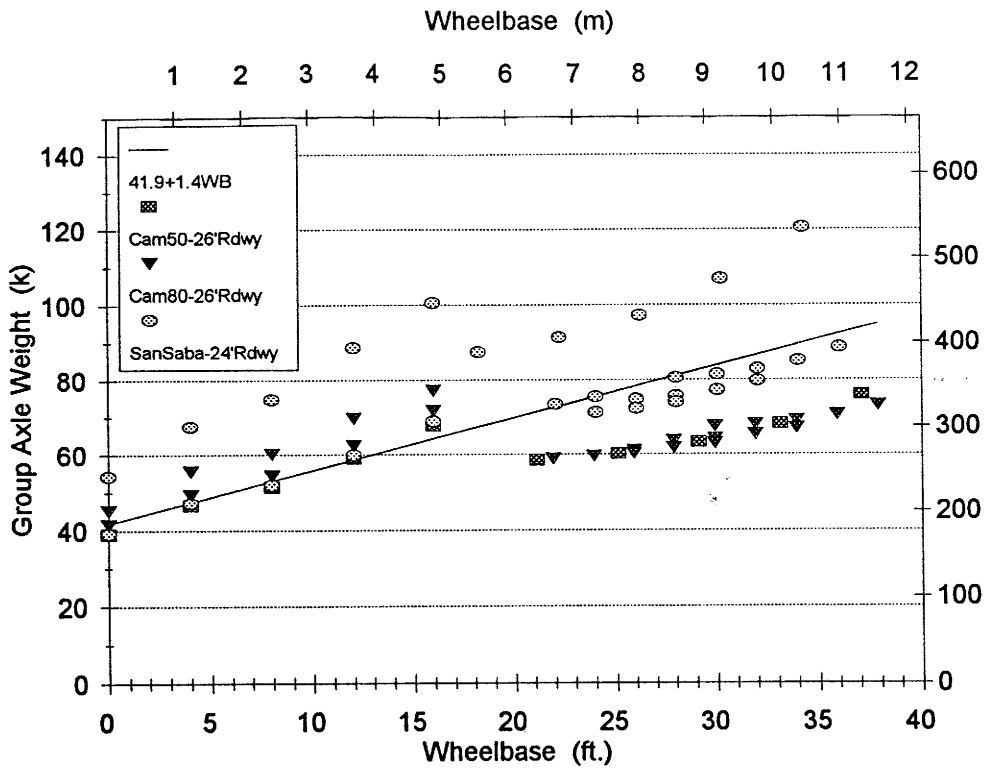


Figure 3-8: Group axle weight versus wheelbase for AASHTO effective widths for H15 bridges.

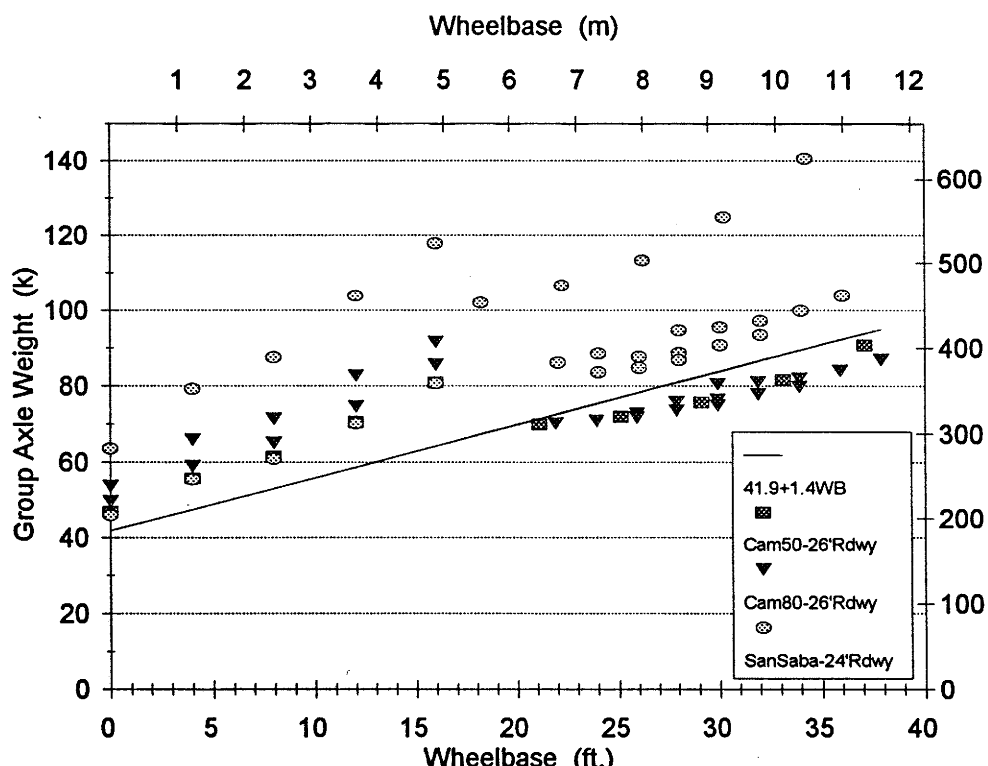


Figure 3-9: Group axle weight versus wheelbase for LRFD effective widths for H15 bridges.

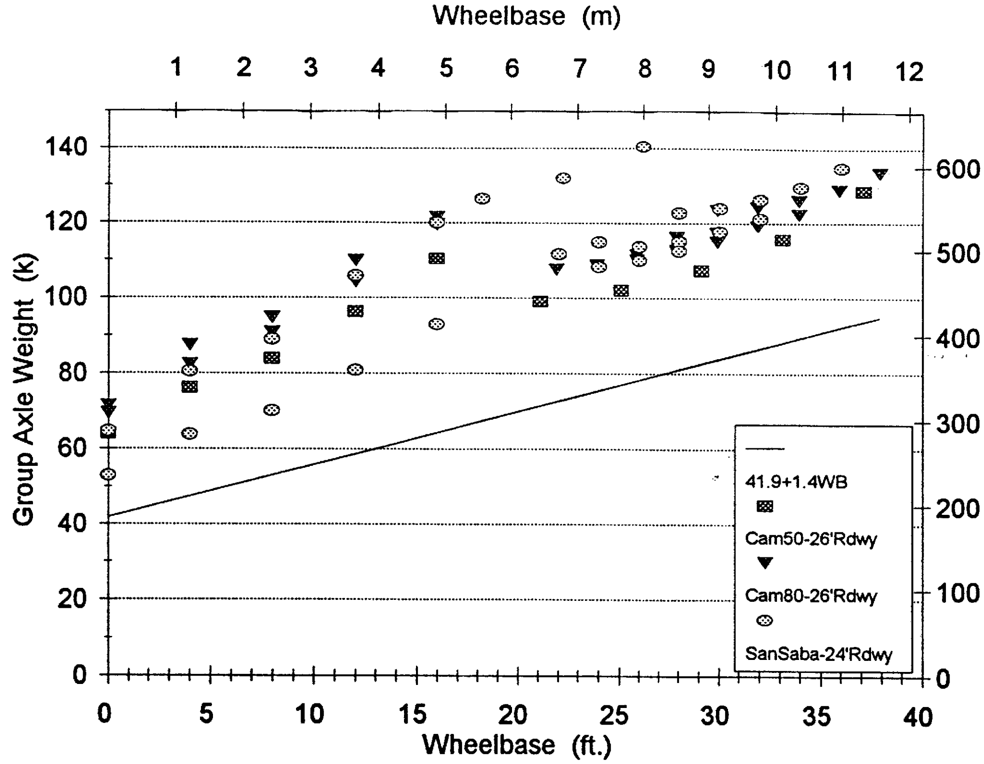


Figure 3-10: Group axle weight versus wheelbase for FEM effective widths for H15 bridges.

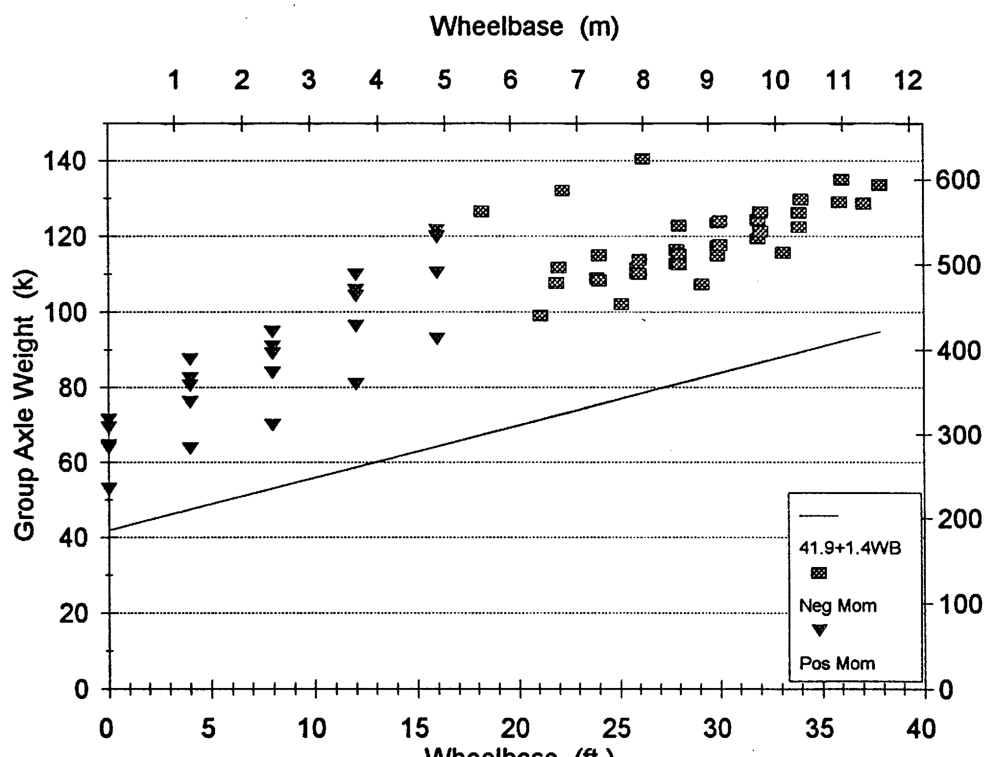


Figure 3-11: Group axle weight versus wheelbase for positive and negative moments for H15 bridges.

3.6 Summary of Results for Continuous Span Bridges

Figures 3-8, 3-9, 3-10, and 3-11 show that a greater group weight may be applied to the structures without causing them to overstress. These figures show that these bridges have a greater moment capacity than the calculated AASHTO or LRFD capacities. There are several points from each bridge below the proposed formula line on the AASHTO graph (Figure 3-8). The LRFD graph (Figure 3-9) is similar to the AASHTO graph; however, the loadings do not overstress the San Saba Bridge. The Cameron bridges are slightly wider than the San Saba bridge. This effect is not included on the AASHTO graph because bridge width is not a factor in the AASHTO effective width formula. However, the finite element effective widths are slightly lower for the narrower San Saba bridge. The effect of bridge width on the effective width and moment capacity is better shown in the case of the H20 bridges in Figures A-5 through A-7. The 38 ft. (16 m) roadway width of the CS 0-38-50 bridge produces much higher effective widths and moment capacities than the other 28 ft. (8.5 m) H20 bridges.

The LRFD effective widths are roughly 20 per cent greater than the AASHTO effective widths. This increase is reflected in the LRFD graph. The LRFD graph is very similar to the AASHTO graph; however, many of the data points shifted above the proposed formula line, indicating less overstressing in the structures. The only critical locations of overstressing occur at the interior supports (negative moment region) on the two Cameron bridges. The LRFD data indicate that a greater load can be placed on the structure while overstressing it less than the AASHTO data.

As shown in Fig. 3-10, no overstressing occurred in the continuous span H15 bridges when an effective width based on FEM was used. The FEM effective widths are generally greater than the LRFD widths; therefore, a greater vehicle weight may be allowed without overstressing the structure. Examination of the H20 formula (Equation 2-10) also showed that no overstressing occurred in continuous span H20 bridges when the FEM effective width was used (see Figures A-7 and A-8).

This final graph, Fig. 3-11, illustrates the importance of this research. The effective width is a function of the basic geometry of a bridge, as well as the axle configuration and placement. The proposed LRFD formula takes into account the width of the slab and allows a greater moment capacity than the more conservative AASHTO formula. These FEM results indicate that no overstressing occurs in the reinforced concrete continuous slab bridges when the group weights allowed by the proposed simple span formulae are applied. Therefore, simple span formulae can be used to limit the weights of overloaded vehicles on continuous slab bridges.

4. EVALUATION OF HS20 BRIDGES

4.1 Design Requirements for HS20 Bridges

Most modern bridges along state highways and federal interstates are designed to support the AASHTO HS20-44 loading. This consists of either a standard HS20 truck or the same lane loading used to design H20 bridges in Figure 1-3. The HS20 truck is shown in Figure 4-1.

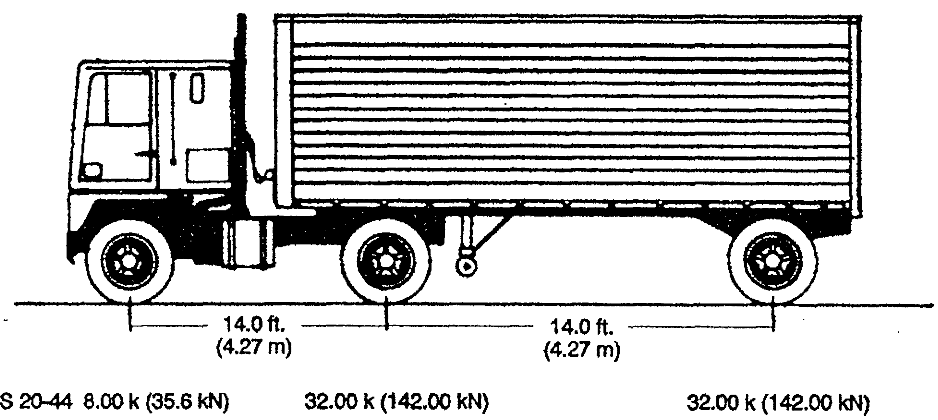


Figure 4-1: AASHTO HS20 truck loading.

The HS20 truck has several design advantages over either of the H-type trucks. Besides being a much heavier truck than either the H15 or the H20 trucks, the axle configuration of the HS20 truck more closely resembles that of a common semi-truck and trailer. Therefore, the stresses induced by a typical truck and trailer are more closely approximated by the HS20 design truck. This is especially critical in the case of continuous span bridges where the maximum negative moment at the support is produced when adjacent spans are loaded approximately in the center of each span. The 14 ft. (4.3 m) wheelbase of the H-type truck often underestimates the typical stresses at the support. The longer wheelbase of the HS20 design truck approximates the negative moments and, thus, the stresses of typical truck-trailer combinations much more accurately.

4.2 Moment Ratios for HS20 Bridges

The procedure to develop the formulae for simple span HS20 bridges is identical to that used to develop the H15 and H20 permit formulas. However, the physical dimensions of the bridges are slightly different. The HS20 reinforced concrete slab bridges all have a minimum roadway of 28 ft. (8.5 m) which is slightly wider than the H15 and H20 slab bridges. The slab thicknesses are also slightly greater for some span lengths. Table 4-1 lists the thicknesses recommended by Seelye (8).

Span Length		Thickness	
(ft.)	(m)	(in.)	(cm)
20	6.1	10.5	26.7
25	7.6	12.5	31.8
30	9.2	14.5	36.8
35	10.7	18.5	47.0

Table 4-1: Reinforced concrete slab thicknesses for HS20 bridges.

The steel I-beam bridges are also more durable. These bridges have a minimum roadway of 28 ft. (8.5 m), but use five stringers instead of four to support the slab. The smaller stringer spacing of 6.5 ft. (2.0 m) also distributes the truck load better. The stringer sizes recommended by Seelye for HS20 bridges are shown in Table 4-2.

Span Length (ft.)	(m)	Exterior I-beams	Interior I-beams
20	6.1	21 WF 62	21 WF 62
25	7.6	24 WF 76	24 WF 76
30	9.2	27 WF 94	27 WF 94
35	10.7	30 WF 108	30 WF 108
40	12.2	33 WF 116	33 WF 124
45	13.7	33 WF 130	33 WF 141
50	15.3	36 WF 150	36 WF 160
60	18.3	36 WF 194	36 WF 230
70	21.4	36 WF 245	36 WF 245

Table 4-2: Steel I-beams for various spans of HS20 bridges.

Following the same process as is outlined in section 2.2, the dead-load to live-load-plus-impact design moment ratios are calculated for the specifications recommended by Seelye (8). These are combined with those calculated from the average moment ratios given by TxDOT, FHWA (5), and Whiteside (12). As in the case of the H15 and H20 formulation, the moment ratios from TxDOT are used whenever available. The minimum moment ratios from the other three sources are used whenever TxDOT moment ratios are not available. The resulting design moment ratios are shown in Figure 4-2 and Table 4-3. These moment ratios are lower than the moment ratios for either of the H-type bridges because the increased live-plus-impact moment is proportionally much greater than the additional dead-load moment.

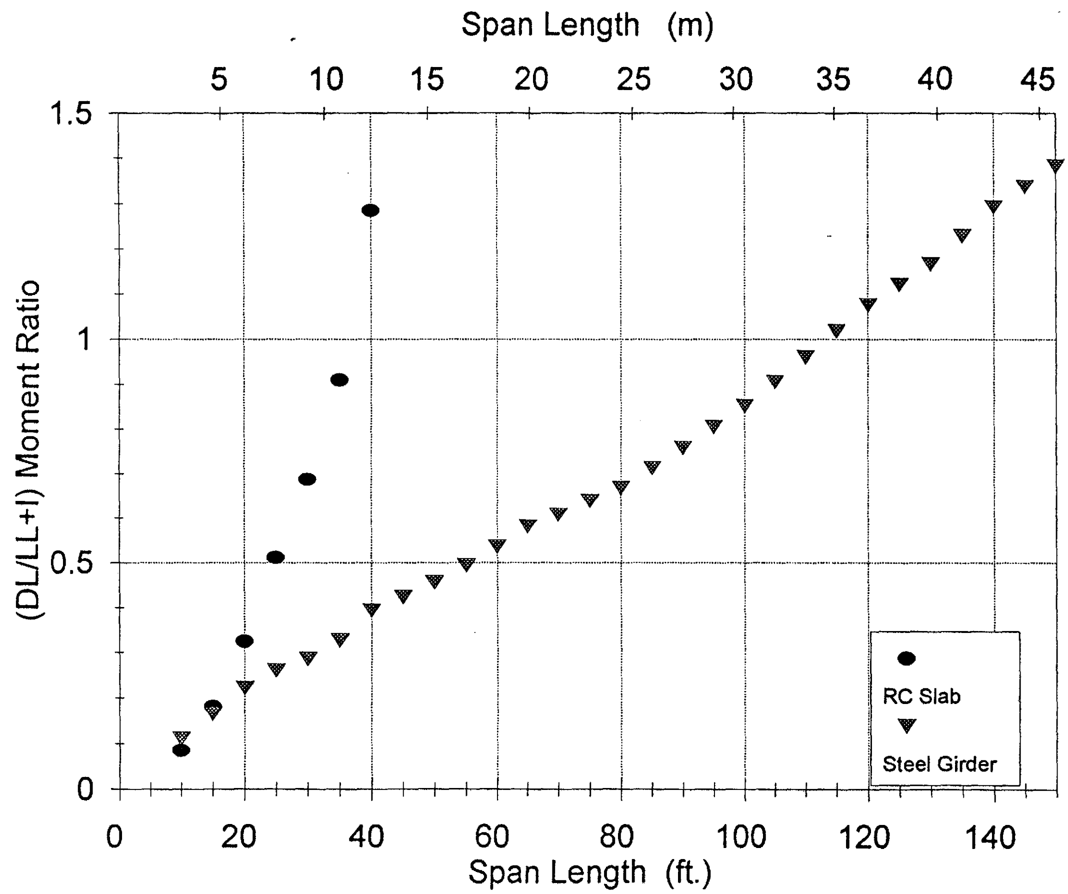


Figure 4-2: Dead-load to live-load-plus-impact moment ratios for HS20 bridges.

Span Length		Design DL/(LL+I) Moment Ratios	
(ft.)	(m)	Slab Bridge	Steel I-Beam
10.0	3.1	0.085	0.111
15.0	4.6	0.180	0.167
20.0	6.1	0.325	0.223
25.0	7.6	0.512	0.261
30.0	9.2	0.688	0.287
35.0	10.7	0.910	0.327
40.0	12.2	1.284	0.394
45.0	13.7		0.424
50.0	15.3		0.457
55.0	16.8		0.495
60.0	18.3		0.537
65.0	19.8		0.582
70.0	21.4		0.608
75.0	22.9		0.640
80.0	24.4		0.668
85.0	25.9		0.713
90.0	27.5		0.758
95.0	29.0		0.805
100.0	30.5		0.853
105.0	32.0		0.907
110.0	33.6		0.962
115.0	35.1		1.019
120.0	36.6		1.077
125.0	38.1		1.122
130.0	39.7		1.167
135.0	41.2		1.230
140.0	42.7		1.293
145.0	44.2		1.337
150.0	45.8		1.382

Table 4-3: Design moment ratios for HS20 bridges.

4.3 Group Weight for 16 ft. (4.9 m) Gage on HS20 Bridges

The allowable live load moments are determined by using Equation 2-7. The AASHTO HS20 live load moments are listed in Table 4-4. The allowable live load moments are then used to determine the unknown distributed loads by using Equation 2-8. A graphical representation of the distributed weights for HS20 bridges are shown in Figure 4-3.

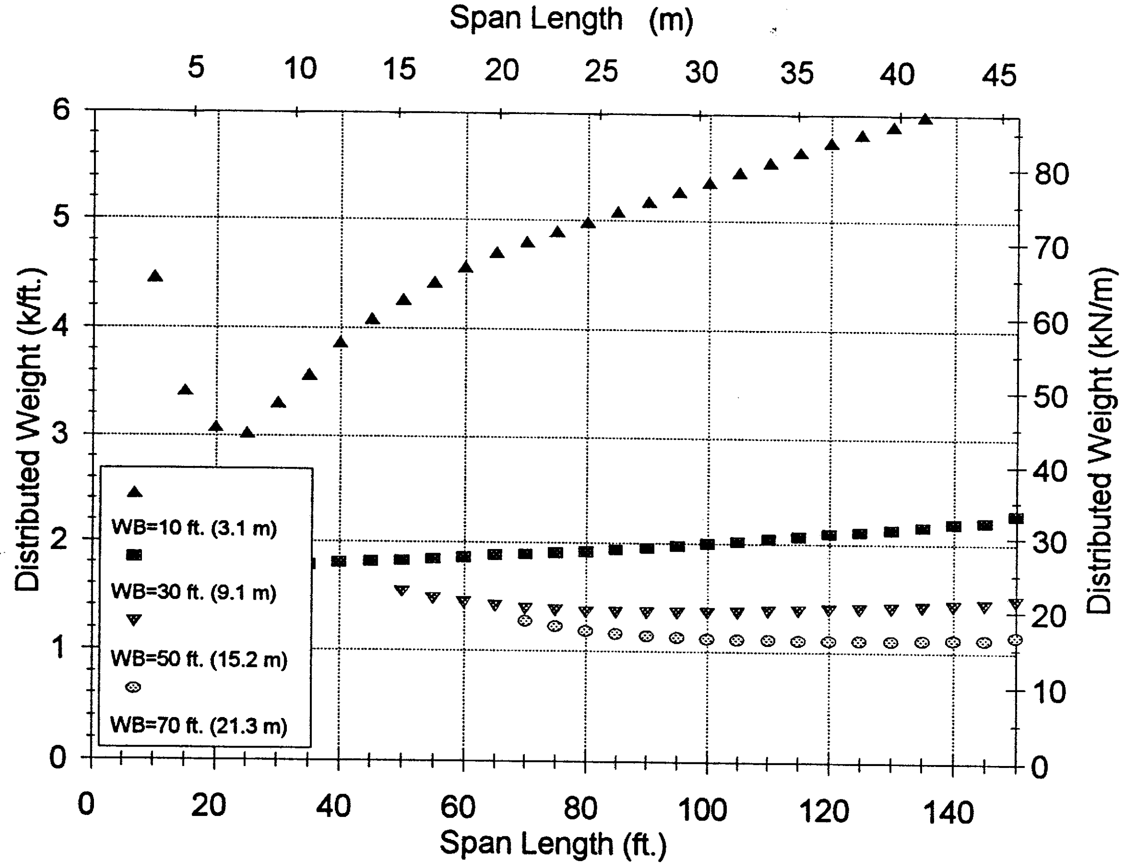


Figure 4-3: Illustration of minimum distributed loads for HS20 bridges.

The minimum distributed load for each wheelbase is then multiplied by 4 wheels and by the wheelbase to arrive at the group weights in Figure 4-4 and Table 4-5. It should be noted that the resulting group weight curve deviates noticeably from the nearly linear form in Figure 2-8. This is because the maximum moment applied by the HS20 truck is applied by three different axle groups, depending on the bridge span.

Span Length (ft.)	(m)	Maximum Moment (k-ft.)	(kN-m)
10.0	3.1	80.0	108.5
15.0	4.6	120.0	162.8
20.0	6.1	160.0	217.1
25.0	7.6	207.4	281.3
30.0	9.2	282.1	382.8
35.0	10.7	361.2	490.0
40.0	12.2	449.8	610.2
45.0	13.7	538.7	730.8
50.0	15.3	627.8	851.8
55.0	16.8	717.1	972.9
60.0	18.3	806.5	1094.2
65.0	19.8	896.0	1215.6
70.0	21.4	985.6	1337.1
75.0	22.9	1075.2	1458.7
80.0	24.4	1164.9	1580.3
85.0	25.9	1254.6	1702.1
90.0	27.5	1344.4	1823.8
95.0	29.0	1434.1	1945.6
100.0	30.5	1523.9	2067.4
105.0	32.0	1613.7	2189.3
110.0	33.6	1703.6	2311.1
115.0	35.1	1793.4	2433.0
120.0	36.6	1883.3	2554.9
125.0	38.1	1973.1	2676.8
130.0	39.7	2063.0	2798.8
135.0	41.2	2152.9	2920.7
140.0	42.7	2242.8	3042.7
145.0	44.2	2334.5	3167.1
150.0	45.8	2475.0	3357.7

Table 4-4: Table of maximum moments for HS20 loadings on simple span bridges from Appendix A of AASHTO *Standard Specifications for Highway Bridges*.

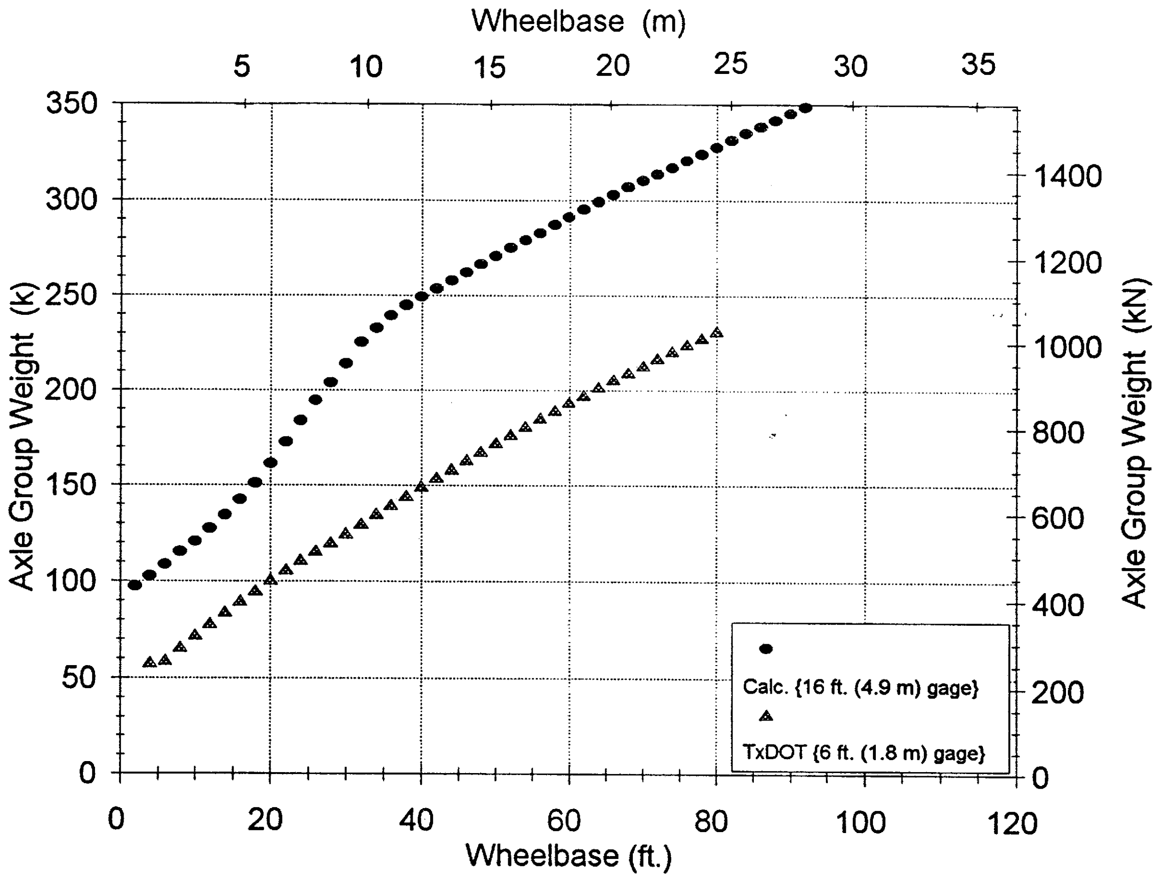


Figure 4-4: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on HS20 bridges.

For short span bridges, only one 32 k (142 kN) axle creates the maximum moment. As the span lengths increase, the maximum moment is controlled by both 32 k (142 kN) axles, then all three axles. Finally, with span lengths greater than 145 ft. (44.2 m), the lane load controls. The critical axle configuration for H-type loadings also varies in this same manner, but, the changes are less dramatic. The lane load for H-type loadings also controls for all span lengths greater than 57 ft. (17 m). The minimum distributed load from Figure 2-7 for all wheelbases greater than 30 ft. (9.1 m) occurs at span lengths greater than 57 ft. (17 m). Thus, all wheelbases greater than 30 ft. (9.1 m) in Figure 2-7, are controlled by the lane load. Because the HS20 truck loading controls for nearly all wheelbases, the nonlinearity, resulting from the different controlling axle groups, is more evident.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(kips)	(kN)
4.0	1.2	12.842	87.541	102.73	457.0
6.0	1.8	10.878	82.992	108.78	483.8
8.0	2.4	9.601	79.574	115.21	512.5
10.0	3.1	8.641	76.323	120.97	538.1
12.0	3.7	7.959	73.943	127.34	566.4
14.0	4.3	7.467	72.293	134.41	597.9
16.0	4.9	7.116	71.288	142.32	633.0
18.0	5.5	6.873	70.875	151.21	672.6
20.0	6.1	6.721	71.034	161.30	717.4
22.0	6.7	6.647	71.773	172.82	768.7
24.0	7.3	6.574	72.328	184.07	818.8
26.0	7.9	6.491	72.605	194.74	866.2
28.0	8.5	6.375	72.363	204.01	907.4
30.0	9.2	6.300	72.456	214.21	952.8
32.0	9.8	6.263	72.889	225.48	1002.9
34.0	10.4	6.128	72.080	232.87	1035.8
36.0	11.0	5.984	71.069	239.35	1064.6
38.0	11.6	5.834	69.906	245.02	1089.8
40.0	12.2	5.671	68.516	249.54	1110.0
42.0	12.8	5.517	67.149	253.77	1128.8
44.0	13.4	5.378	65.915	258.15	1148.2
46.0	14.0	5.254	64.802	262.68	1168.4
48.0	14.6	5.135	63.723	267.04	1187.8
50.0	15.3	5.023	62.674	271.24	1206.5
52.0	15.9	4.918	61.688	275.43	1225.1
54.0	16.5	4.819	60.729	279.48	1243.1
56.0	17.1	4.723	59.796	283.39	1260.5
58.0	17.7	4.635	58.933	287.38	1278.3
60.0	18.3	4.554	58.140	291.48	1296.5

Table 4-5: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on HS20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(kips)	(kN)
62.0	18.9	4.476	57.360	295.44	1314.1
64.0	19.5	4.402	56.613	299.36	1331.5
66.0	20.1	4.332	55.898	303.24	1348.8
68.0	20.7	4.267	55.230	307.19	1366.4
70.0	21.4	4.198	54.502	310.62	1381.6
72.0	22.0	4.131	53.788	313.92	1396.3
74.0	22.6	4.068	53.118	317.30	1411.3
76.0	23.2	4.009	52.490	320.75	1426.7
78.0	23.8	3.955	51.902	324.27	1442.4
80.0	24.4	3.903	51.352	327.88	1458.4
82.0	25.0	3.855	50.837	331.56	1474.8
84.0	25.6	3.811	50.356	335.33	1491.5
86.0	26.2	3.764	49.840	338.73	1506.7
88.0	26.8	3.718	49.338	342.08	1521.6
90.0	27.5	3.676	48.864	345.50	1536.8
92.0	28.1	3.635	48.419	348.99	1552.3
94.0	28.7	3.597	48.000	352.55	1568.1
96.0	29.3	3.562	47.606	356.19	1584.3
98.0	29.9	3.528	47.236	359.90	1600.8
100.0	30.5	3.497	46.889	363.68	1617.7
102.0	31.1	3.467	46.564	367.55	1634.9
104.0	31.7	3.440	46.261	371.51	1652.5
106.0	32.3	3.414	45.979	375.54	1670.4
108.0	32.9	3.390	45.717	379.67	1688.8
110.0	33.6	3.367	45.474	383.89	1707.5
112.0	34.2	3.347	45.250	388.20	1726.7
114.0	34.8	3.327	45.044	392.61	1746.3
116.0	35.4	3.309	44.856	397.13	1766.4
118.0	36.0	3.293	44.685	401.74	1787.0
120.0	36.6	3.278	44.532	406.47	1808.0

Table 4-5: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on HS20 bridges (cont.).

4.4 Group Weight for a 6 ft. (1.8 m) Gage on HS20 Bridges

The group weight for a 6 ft. (1.8 m) gage is calculated by multiplying the group weight for a 16 ft. (4.9 m) gage by the reduction factor in Equation 2-9. The 6 ft. (1.8 m) gage group weights are shown in Figure 4-5 and Table 4-6.

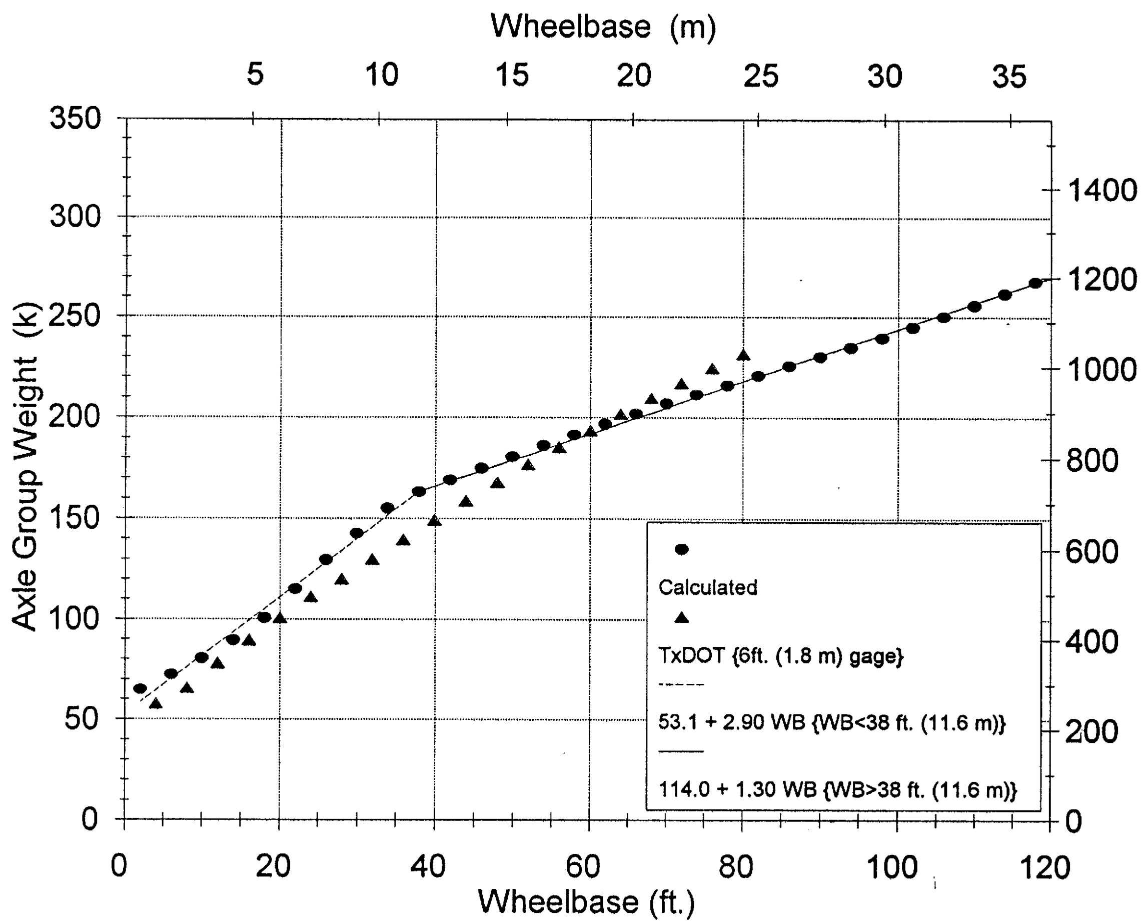


Figure 4-5: Calculated maximum permit weight for a 6 ft. (1.8 m) gage on HS20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(kips)	(kN)
4.0	1.2	8.561	58.361	68.49	304.6
6.0	1.8	7.252	55.328	72.52	322.6
8.0	2.4	6.401	53.049	76.81	341.6
10.0	3.1	5.761	50.882	80.65	358.7
12.0	3.7	5.306	49.295	84.89	377.6
14.0	4.3	4.978	48.196	89.61	398.6
16.0	4.9	4.744	47.525	94.88	422.0
18.0	5.5	4.582	47.250	100.81	448.4
20.0	6.1	4.480	47.356	107.53	478.3
22.0	6.7	4.431	47.849	115.21	512.5
24.0	7.3	4.383	48.219	122.72	545.8
26.0	7.9	4.327	48.404	129.82	577.5
28.0	8.5	4.250	48.242	136.01	605.0
30.0	9.2	4.200	48.304	142.81	635.2
32.0	9.8	4.176	48.592	150.32	668.6
34.0	10.4	4.085	48.053	155.24	690.5
36.0	11.0	3.989	47.380	159.57	709.7
38.0	11.6	3.889	46.604	163.34	726.6
40.0	12.2	3.781	45.678	166.36	740.0
42.0	12.8	3.678	44.766	169.18	752.5
44.0	13.4	3.585	43.943	172.10	765.5
46.0	14.0	3.502	43.202	175.12	778.9
48.0	14.6	3.424	42.482	178.03	791.9
50.0	15.3	3.349	41.782	180.83	804.3
52.0	15.9	3.279	41.125	183.62	816.7
54.0	16.5	3.212	40.486	186.32	828.8
56.0	17.1	3.149	39.864	188.93	840.3
58.0	17.7	3.090	39.289	191.59	852.2
60.0	18.3	3.036	38.760	194.32	864.3

Table 4-6: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(kips)	(kN)
62.0	18.9	2.984	38.240	196.96	876.1
64.0	19.5	2.935	37.742	199.57	887.7
66.0	20.1	2.888	37.266	202.16	899.2
68.0	20.7	2.844	36.820	204.79	910.9
70.0	21.4	2.798	36.335	207.08	921.1
72.0	22.0	2.754	35.859	209.28	930.9
74.0	22.6	2.712	35.412	211.53	940.9
76.0	23.2	2.673	34.994	213.83	951.1
78.0	23.8	2.636	34.602	216.18	961.6
80.0	24.4	2.602	34.235	218.58	972.3
82.0	25.0	2.570	33.891	221.04	983.2
84.0	25.6	2.540	33.571	223.55	994.4
86.0	26.2	2.509	33.226	225.82	1004.4
88.0	26.8	2.479	32.892	228.05	1014.4
90.0	27.5	2.450	32.576	230.33	1024.5
92.0	28.1	2.424	32.279	232.66	1034.9
94.0	28.7	2.398	32.000	235.03	1045.4
96.0	29.3	2.375	31.737	237.46	1056.2
98.0	29.9	2.352	31.490	239.93	1067.2
100.0	30.5	2.331	31.259	242.46	1078.4
102.0	31.1	2.312	31.043	245.04	1089.9
104.0	31.7	2.293	30.841	247.67	1101.6
106.0	32.3	2.276	30.653	250.36	1113.6
108.0	32.9	2.260	30.478	253.11	1125.9
110.0	33.6	2.245	30.316	255.93	1138.4
112.0	34.2	2.231	30.166	258.80	1151.2
114.0	34.8	2.218	30.029	261.74	1164.2
116.0	35.4	2.206	29.904	264.75	1177.6
118.0	36.0	2.195	29.790	267.83	1191.3
120.0	36.6	2.185	29.688	270.98	1205.3

Table 4-6: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges (cont.).

These calculated values may be closely approximated by two linear equations. The equation used depends upon the group axle wheelbase. The two equations result in the same value at 38 ft. (11.6 m). When these two equations are combined with the correction factor for concentrated loadings, a final form results. These formulae are shown in Equations 4-1 and 4-2.

$$GW = 53.1 + 2.90 * \frac{WB}{\beta} \qquad \text{WB}<38 \text{ ft. } (11.6 \text{ m}) \tag{4-1}$$

$$GW = 114.0 + 1.30 * \frac{WB}{\beta} \qquad \text{WB}>38 \text{ ft. } (11.6 \text{ m}) \tag{4-2}$$

where

GW = group weight (k),

WB = wheelbase (ft.),

β = correction factor for concentrated loadings on simple span bridges.

4.5 HS20 Bridge Formula Considering Span Length

Because the HS20 design truck moments are irregular, the complete form of Equation 2-18 must be used to calculate the allowable distributed load. Equation 4-3 is the best resulting fit for the curve.

$$w = \frac{L^2 + 200L + \frac{20000}{L} - 3000}{WBL(2L - WBL)} \tag{4-3}$$

where

L	=	span length (ft.),
WBL	=	WB, wheelbase (ft.) when $WB < L$,
	=	L, span length (ft.) when $WB > L$,
w	=	allowable distributed load (k/ft.).

Although this formula underestimates the allowable distributed load for span lengths 15 ft. (4.6 m) or less, the maximum error for all other spans is 6%. Because very few HS20 bridges exist with span lengths 15 ft. (4.6 m) or less, this curve fit should be adequate. This allowable group weight may then be calculated with Equation 2-21, (see Appendix C for tabulation).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

For simple span bridges, the proposed restriction for the unmodified equivalent distributed load utilizes the same longitudinal distribution factor as the current TxDOT criteria. This is restated in Equation 5-1.

$$w_{un} = \frac{GW}{WB + 4} \qquad \textbf{(5-1)}$$

where

w_{un}	=	unmodified equivalent distributed load (k/ft.),
GW	=	group weight (k),
WB	=	wheelbase (ft.).

The proposed group weight may be calculated by either a general formula for any bridge or a specific formula for a particular span length bridge. The general criteria are shown in Equations 5-2 through 5-7.

$$GW = 41.9 + 1.4 * \frac{WB}{\beta} \qquad \text{H15 bridges} \qquad \textbf{(5-2)}$$

$$GW = 55.2 + 1.77 * \frac{WB}{\beta} \qquad \text{H20 bridges} \qquad \textbf{(5-3)}$$

The HS20 bridges are better approximated by two linear equations.

$$GW = 53.1 + 2.90 * \frac{WB}{\beta} \qquad \text{WB}<\text{38ft. (11.6m)} \qquad \textbf{(5-4)}$$

$$GW = 114.0 + 1.30 * \frac{WB}{\beta} \qquad \text{WB}>\text{38ft. (11.6m)} \qquad \textbf{(5-5)}$$

where

GW = group weight (k),

WB = wheelbase (ft.),

β = correction factor for concentrated loadings on simple span bridges:

where

$$\beta = 0.97 - \frac{D}{40} < 0.92 \qquad \textbf{(5-6)}$$

or

$$\beta = 1 - \frac{GD}{70} \qquad \textbf{(5-7)}$$

D = distance between the center of gravity and nearest axle (ft.),

GD = greatest distance between any two axles (ft.).

If the bridge span length is known, greater loads may be allowed. This approach still uses Equations 5-1, 5-6, and 5-7, but calculates the allowable group weight using Equations 5-8, 5-9, 5-10, and 5-11.

$$GW = w * \frac{WB}{\beta} \qquad \textbf{(5-8)}$$

$$w = \frac{\frac{5L^2}{3} - \frac{11000}{L} + 1800}{WBL(2L - WBL)} \qquad \text{H15 bridges} \qquad \mathbf{(5\text{-}9)}$$

$$w = \frac{2.1L^2 - \frac{15000}{L} + 2500}{WBL(2L - WBL)} \qquad \text{H20 bridges} \qquad \mathbf{(5\text{-}10)}$$

$$w = \frac{L^2 + 200L + \frac{20000}{L} - 3000}{WBL(2L - WBL)} \qquad \text{HS20 bridges} \qquad \mathbf{(5\text{-}11)}$$

where

GW	=	group weight (k),
w	=	allowable distributed load from Equations 5-9 through 5-11 (k/ft.),
WB	=	wheelbase (ft.),
β	=	correction factor for concentrated loadings in Equations 5-6 or 5-7,
L	=	span length (ft.),
WBL	=	WB, wheelbase (ft.) when $WB < L$,
	=	L, span length (ft.) when $WB > L$.

The current reduction factor for additional tires may be applied to the unmodified equivalent distributed weight. A different reduction factor used to normalize the load for axles whose gage is not equal to the standard gage of 6 ft. (4.9 m) was calculated. This new reduction factor, shown in Equation 5-12, is a more linear version of that which is currently used by TxDOT.

$$\text{Reduction Factor} = 1.2 - \frac{G}{30} \tag{5-12}$$

where

G = gage (ft.).

The FEM results show that no overstressing occurs in the continuous span reinforced concrete structures (Figure 3-10). When these results are compared to the simple span formulae, the allowable group weights will be controlled by the simple span results, not by the continuous span capacities.

Because the proposed formulae are more restrictive than the current provisions, it should be asked why more problems have not arisen. Probably the biggest reason is that all bridges have been analyzed assuming no composite action. However, an as-built bridge always has some inherent composite action associated with the friction between the deck and the steel stringers. Due to the difficulty in measuring this additional capacity, it has not been included in this analysis.

Another factor which has not been considered is the use of diaphragm members to transmit forces laterally. Although it is commonly thought that cross members aid significantly in the distribution of stresses for overweight trucks, they are not considered in the development of the gage reduction factor. A final factor which may increase the overall moment capacity of bridges is the longitudinal transmission of forces by the deck. Preliminary investigations show that the addition of 4 ft. (1.2 m) in the unmodified equivalent loading equation is quite conservative. In fact, the deck might serve to distribute the load over an additional 12 ft. (3.7 m).

5.2 Additional Research

Additional research in the overweight permit restrictions should focus on three major areas. First, the factors of composite action in non-composite bridges, distribution of forces by diaphragm members, and longitudinal transmission of forces by the deck should be quantified. Second, a general and bridge specific formula for all H"X" and HS"X" trucks should be calculated. Additional analysis in these areas will safely allow for greater permit loads on all bridges.

Third, automating the issuing of permits should be studied and implemented. By using a computer system, overweight and oversize permits can be efficiently issued. This could be done by incorporating computer based formulae that calculate the maximum vehicle weight for any span length. Such a system with a database of the state highways and bridges will allow the issuance of heavier permits without time consuming and costly analysis. Currently, when a permit is issued, the span lengths and configurations of bridges along the truck's route cannot be determined. If the bridge configurations along the route are known, heavier permits can be issued without additional analysis.

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Appendix A

Summary of Calculations for H20 Bridges

A.1 Moment Ratios for H20 bridges

The moment ratios for H20 bridges are derived by the same procedure used for the H15 bridges. Because H20 bridges are less common, fewer designs exist. Therefore, dead-load to live-load-plus impact ratios are calculated almost exclusively from data in Whiteside (12). To ensure that these ratios are typical of H20 bridges in Texas, these moment ratios are supplemented with a few actual designs taken from TxDOT. The resulting design moment ratios are shown in Figure A-1 and Table A-1.

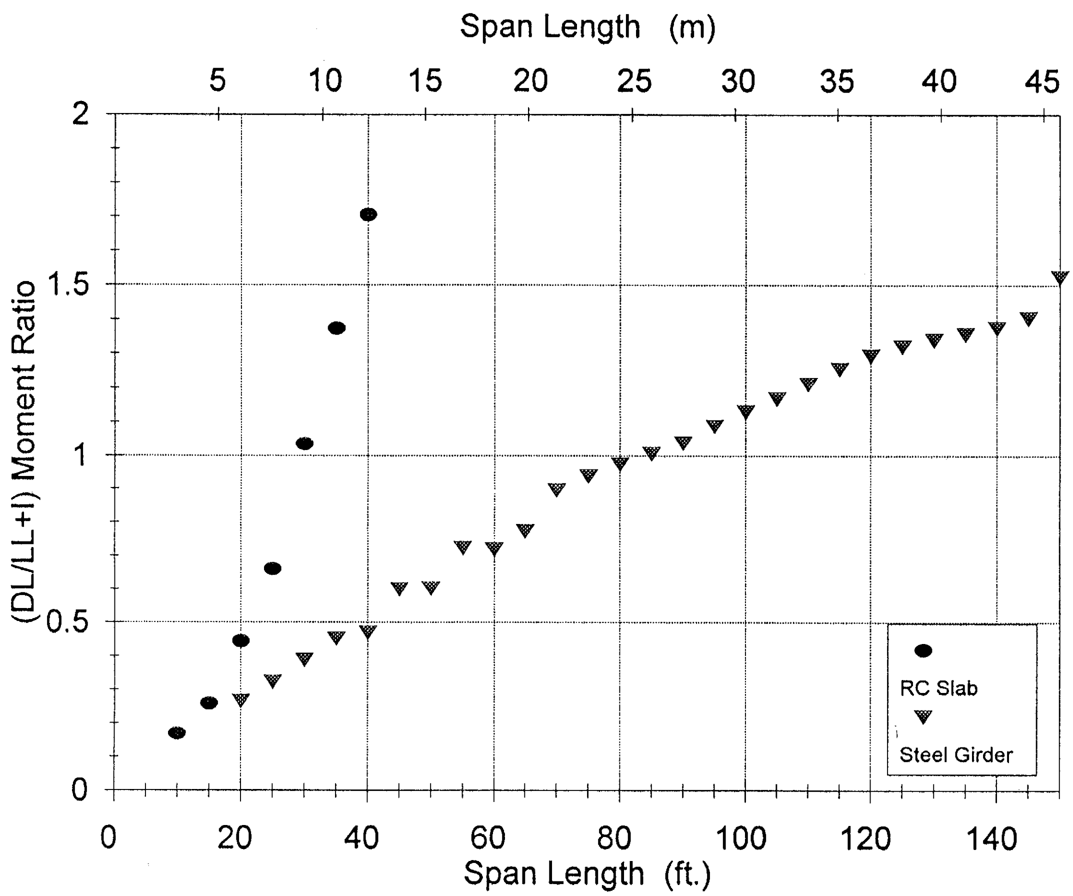


Figure A-1: Dead-load to live-load-plus-impact moment ratios for H20 bridges.

Span Length		Design DL/(LL+I) Moment Ratios	
(ft.)	(m)	Slab Bridge	Steel I-Beam
10.0	3.1	0.169	
15.0	4.6	0.260	
20.0	6.1	0.445	0.267
25.0	7.6	0.661	0.324
30.0	9.2	1.034	0.390
35.0	10.7	1.373	0.452
40.0	12.2	1.707	0.470
45.0	13.7		0.600
50.0	15.3		0.603
55.0	16.8		0.724
60.0	18.3		0.720
65.0	19.8		0.774
70.0	21.4		0.897
75.0	22.9		0.939
80.0	24.4		0.974
85.0	25.9		1.006
90.0	27.5		1.037
95.0	29.0		1.087
100.0	30.5		1.130
105.0	32.0		1.169
110.0	33.6		1.212
115.0	35.1		1.255
120.0	36.6		1.293
125.0	38.1		1.320
130.0	39.7		1.338
135.0	41.2		1.357
140.0	42.7		1.375
145.0	44.2		1.403
150.0	45.8		1.524

Table A-1: Design moment ratios for H20 bridges.

A.2 Group Weight for 16 ft. (4.9 m) Gage on H20 Bridges

The allowable live load moments are again determined by using Equation 2-7. Because, the AASHTO H20 design load is 133.33% of the H15 design load, the live load moments may be easily calculated from Table 2-5. The allowable live load moments are then used to determine the unknown distributed loads by using Equation 2-8. These distributed weights for H20 bridges are shown in Figure A-2.

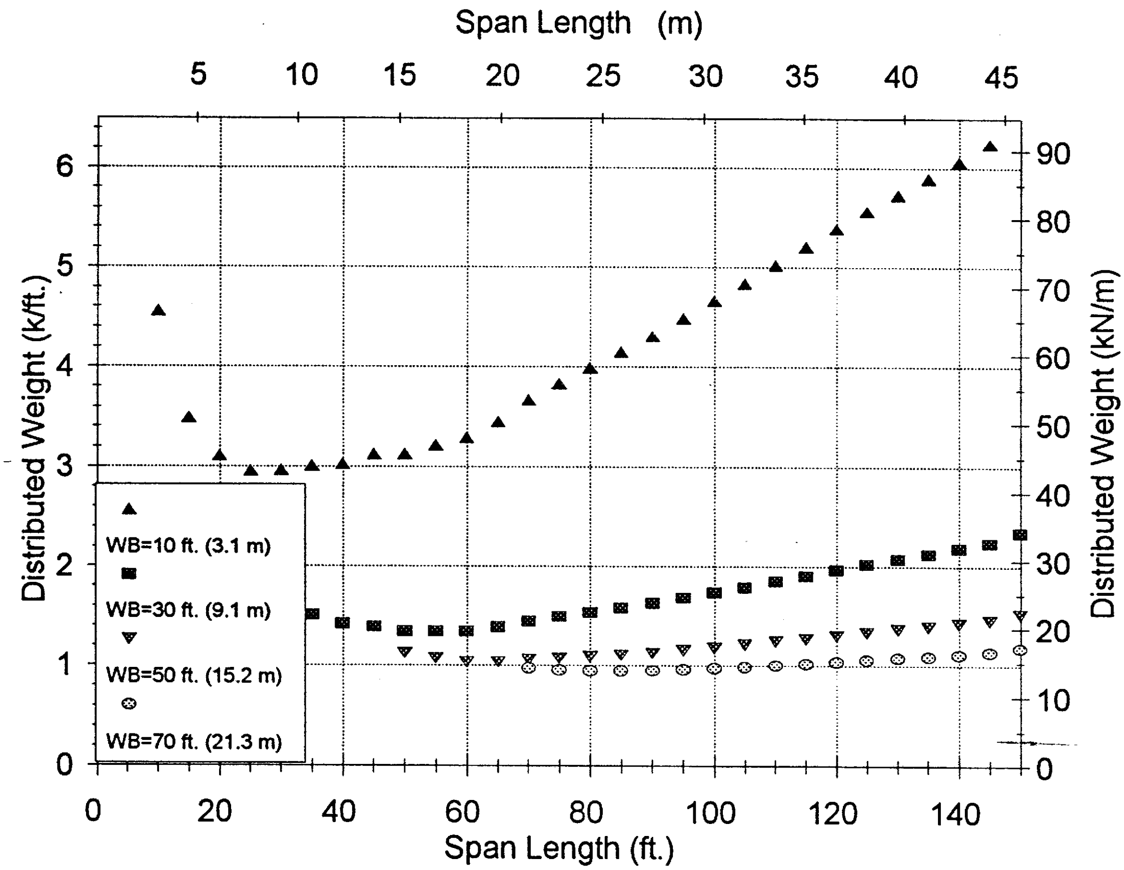


Figure A-2: Illustration of minimum distributed loads for H20 bridges.

The minimum distributed load for each wheelbase is then multiplied by 4 wheels and by the wheelbase to arrive at the group weights in Figure A-3 and Table A-2.

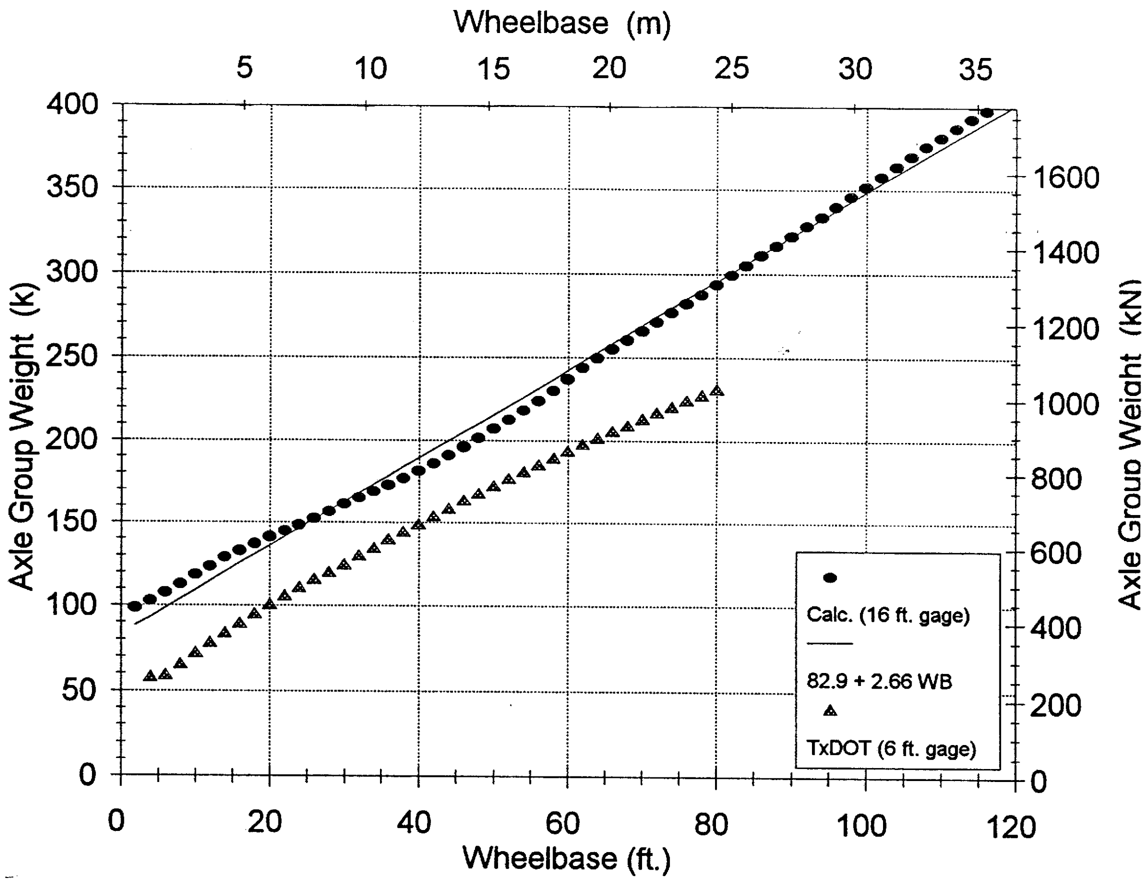


Figure A-3: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on H20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
4.0	1.2	12.881	87.807	103.05	458.4
6.0	1.8	10.773	82.193	107.73	479.2
8.0	2.4	9.405	77.951	112.86	502.0
10.0	3.1	8.465	74.767	118.50	527.1
12.0	3.7	7.734	71.855	123.74	550.4
14.0	4.3	7.149	69.214	128.69	572.4
16.0	4.9	6.635	66.473	132.71	590.3
18.0	5.5	6.227	64.207	136.99	609.3
20.0	6.1	5.877	62.121	141.06	627.4
22.0	6.7	5.564	60.085	144.67	643.5
24.0	7.3	5.303	58.343	148.48	660.4
26.0	7.9	5.083	56.856	152.49	678.3
28.0	8.5	4.898	55.593	156.73	697.1
30.0	9.2	4.741	54.529	161.21	717.1
32.0	9.8	4.581	53.306	164.90	733.5
34.0	10.4	4.441	52.230	168.74	750.6
36.0	11.0	4.319	51.297	172.76	768.4
38.0	11.6	4.214	50.492	176.97	787.2
40.0	12.2	4.123	49.805	181.39	806.8
42.0	12.8	4.044	49.229	186.05	827.5
44.0	13.4	3.978	48.755	190.94	849.3
46.0	14.0	3.922	48.378	196.10	872.3
48.0	14.6	3.876	48.095	201.55	896.5
50.0	15.3	3.839	47.902	207.31	922.1
52.0	15.9	3.799	47.650	212.75	946.3
54.0	16.5	3.765	47.447	218.35	971.2
56.0	17.1	3.738	47.319	224.26	997.5
58.0	17.7	3.717	47.266	230.48	1025.2
60.0	18.3	3.704	47.286	237.07	1054.5

Table A-2: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on H20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
62.0	18.9	3.698	47.381	244.04	1085.5
64.0	19.5	3.672	47.218	249.68	1110.6
66.0	20.1	3.643	47.004	254.99	1134.2
68.0	20.7	3.619	46.841	260.53	1158.9
70.0	21.4	3.591	46.631	265.76	1182.1
72.0	22.0	3.568	46.465	271.18	1206.2
74.0	22.6	3.547	46.315	276.66	1230.6
76.0	23.2	3.525	46.146	281.98	1254.3
78.0	23.8	3.506	46.019	287.51	1278.9
80.0	24.4	3.491	45.931	293.26	1304.4
82.0	25.0	3.480	45.883	299.25	1331.1
84.0	25.6	3.468	45.831	305.20	1357.5
86.0	26.2	3.456	45.770	311.07	1383.6
88.0	26.8	3.445	45.706	316.90	1409.6
90.0	27.5	3.433	45.634	322.66	1435.2
92.0	28.1	3.422	45.576	328.50	1461.2
94.0	28.7	3.410	45.497	334.17	1486.4
96.0	29.3	3.400	45.446	340.03	1512.4
98.0	29.9	3.393	45.425	346.10	1539.5
100.0	30.5	3.384	45.377	351.96	1565.5
102.0	31.1	3.377	45.345	357.92	1592.0
104.0	31.7	3.371	45.339	364.10	1619.5
106.0	32.3	3.363	45.298	369.98	1645.7
108.0	32.9	3.358	45.280	376.05	1672.7
110.0	33.6	3.350	45.232	381.85	1698.5
112.0	34.2	3.340	45.160	387.43	1723.3
114.0	34.8	3.329	45.062	392.77	1747.0
116.0	35.4	3.319	44.980	398.23	1771.3
118.0	36.0	3.309	44.908	403.74	1795.9
120.0	36.6	3.299	44.823	409.13	1819.8

Table A-2: Calculated maximum permit weights for 16 ft. (4.9 m) gage trucks on H20 bridges (cont.).

A.3 Group Weight for a 6 ft. (1.8 m) Gage

The group weight for a 6 ft. (1.8 m) gage is calculated by multiplying the group weight for a 16 ft. (4.9 m) gage by the reduction factor in Equation 2-9. The 6 ft. (1.8 m) gage group weights are shown in Figure A-4 and Table A-3.

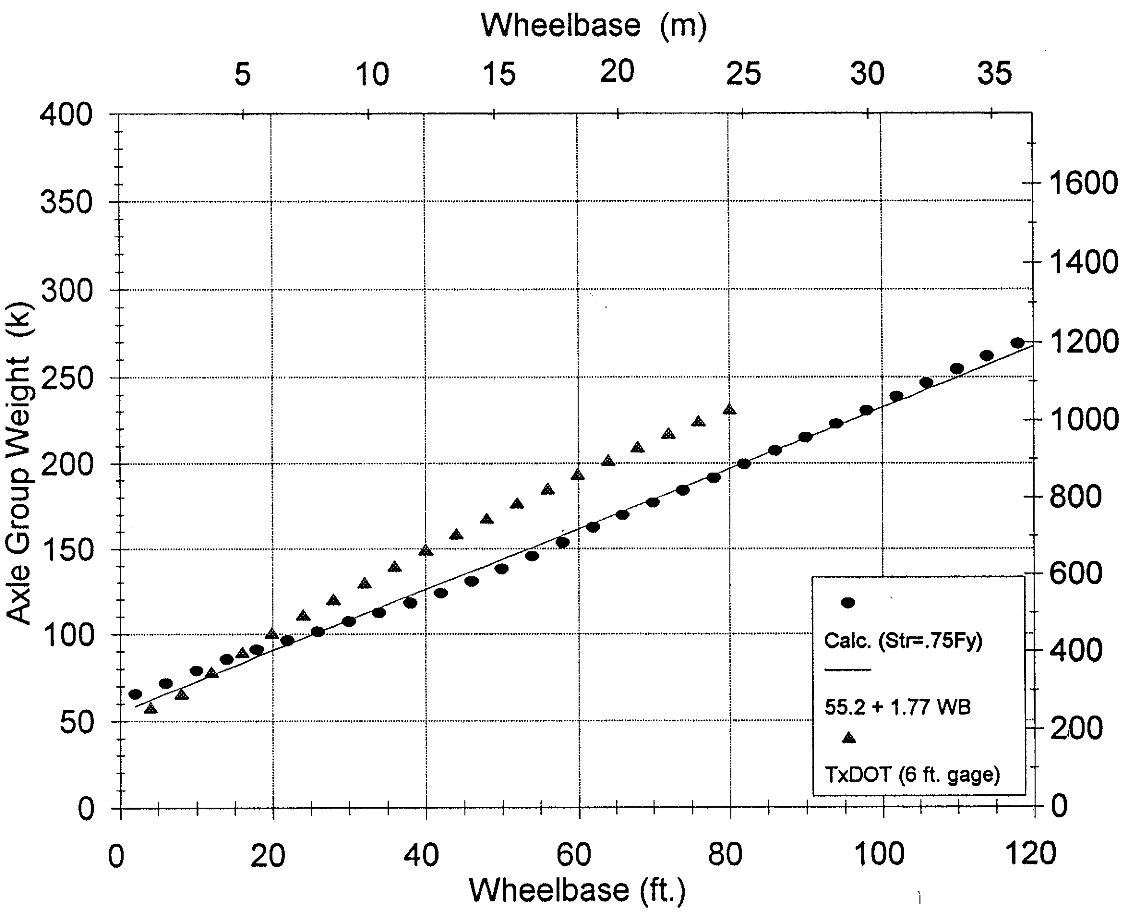


Figure A-4: Calculated maximum permit weights for a 6 ft. (1.8 m) gage on H20 bridges.

Wheelbase		Distributed Load		Group Weight	
(ft.)	(m)	(k/ft)	(kN/m)	(k)	(kN)
4.0	1.2	8.587	58.538	68.70	305.6
6.0	1.8	7.182	54.796	71.82	319.5
8.0	2.4	6.270	51.968	75.24	334.7
10.0	3.1	5.643	49.845	79.00	351.4
12.0	3.7	5.156	47.903	82.50	366.9
14.0	4.3	4.766	46.142	85.79	381.6
16.0	4.9	4.424	44.316	88.47	393.5
18.0	5.5	4.151	42.805	91.33	406.2
20.0	6.1	3.918	41.414	94.04	418.3
22.0	6.7	3.710	40.057	96.45	429.0
24.0	7.3	3.535	38.896	98.99	440.3
26.0	7.9	3.389	37.904	101.66	452.2
28.0	8.5	3.265	37.062	104.49	464.8
30.0	9.2	3.161	36.353	107.47	478.0
32.0	9.8	3.054	35.537	109.94	489.0
34.0	10.4	2.960	34.820	112.49	500.4
36.0	11.0	2.879	34.198	115.17	512.3
38.0	11.6	2.809	33.661	117.98	524.8
40.0	12.2	2.748	33.203	120.93	537.9
42.0	12.8	2.696	32.819	124.03	551.7
44.0	13.4	2.652	32.503	127.29	566.2
46.0	14.0	2.615	32.252	130.73	581.5
48.0	14.6	2.584	32.063	134.37	597.7
50.0	15.3	2.559	31.934	138.21	614.7
52.0	15.9	2.533	31.767	141.84	630.9
54.0	16.5	2.510	31.631	145.57	647.5
56.0	17.1	2.492	31.546	149.50	665.0
58.0	17.7	2.478	31.511	153.66	683.5
60.0	18.3	2.469	31.524	158.05	703.0

Table A-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges.

Wheelbase (ft.)	(m)	Distributed Load (k/ft)	(kN/m)	Group Weight (k)	(kN)
62.0	18.9	2.465	31.587	162.69	723.7
64.0	19.5	2.448	31.479	166.45	740.4
66.0	20.1	2.428	31.336	169.99	756.1
68.0	20.7	2.412	31.228	173.69	772.6
70.0	21.4	2.394	31.087	177.17	788.1
72.0	22.0	2.379	30.976	180.79	804.1
74.0	22.6	2.365	30.877	184.44	820.4
76.0	23.2	2.350	30.764	187.99	836.2
78.0	23.8	2.337	30.679	191.67	852.6
80.0	24.4	2.327	30.620	195.51	869.6
82.0	25.0	2.320	30.588	199.50	887.4
84.0	25.6	2.312	30.554	203.47	905.0
86.0	26.2	2.304	30.513	207.38	922.4
88.0	26.8	2.296	30.471	211.27	939.7
90.0	27.5	2.288	30.423	215.11	956.8
92.0	28.1	2.281	30.384	219.00	974.1
94.0	28.7	2.273	30.331	222.78	990.9
96.0	29.3	2.267	30.297	226.69	1008.3
98.0	29.9	2.262	30.283	230.73	1026.3
100.0	30.5	2.256	30.252	234.64	1043.7
102.0	31.1	2.251	30.230	238.62	1061.4
104.0	31.7	2.248	30.226	242.73	1079.7
106.0	32.3	2.242	30.199	246.65	1097.1
108.0	32.9	2.238	30.187	250.70	1115.1
110.0	33.6	2.233	30.155	254.57	1132.3
112.0	34.2	2.227	30.106	258.29	1148.9
114.0	34.8	2.219	30.041	261.85	1164.7
116.0	35.4	2.212	29.987	265.48	1180.9
118.0	36.0	2.206	29.938	269.16	1197.2
120.0	36.6	2.200	29.882	272.75	1213.2

Table A-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges (cont.).

The graphs checking the continuous span formula for continuous span bridges result in values very similar to the H15 bridges. The moment capacities using the effective width based on finite element analysis at the center line of the lane shows that the H20 slab bridges will safely carry the load allowed by the simple span formula. This is shown in Figures A-5 through A-8.

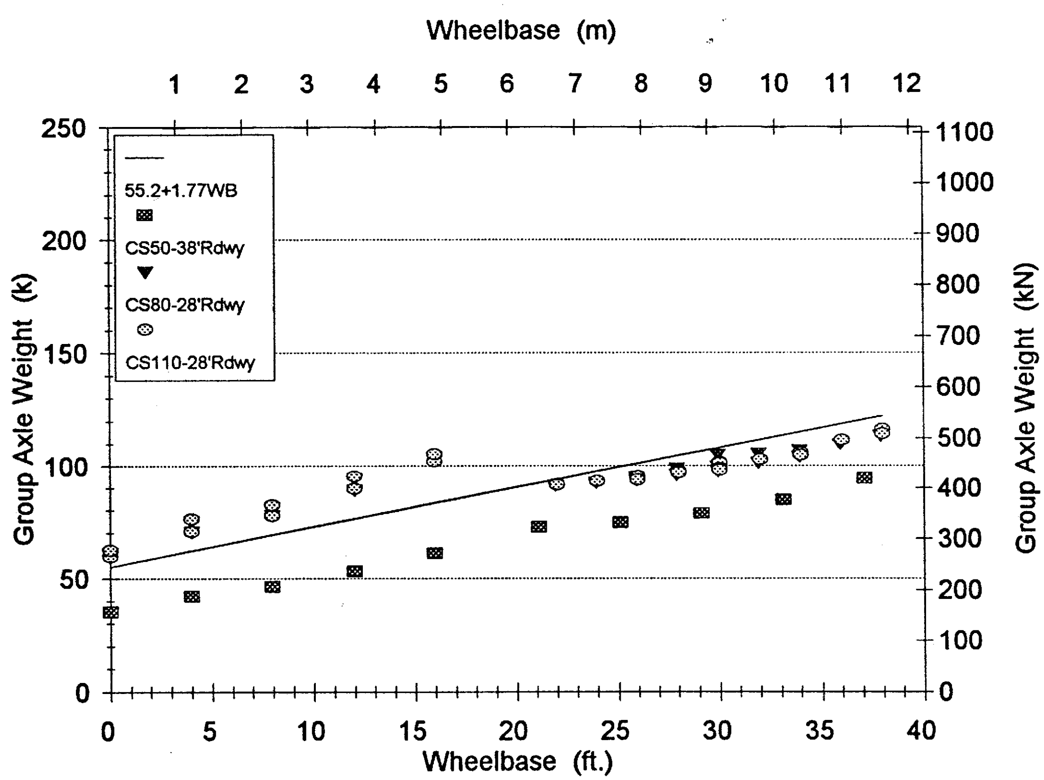


Figure A-5: Group axle weight versus wheelbase for AASHTO effective widths for H20 bridges.

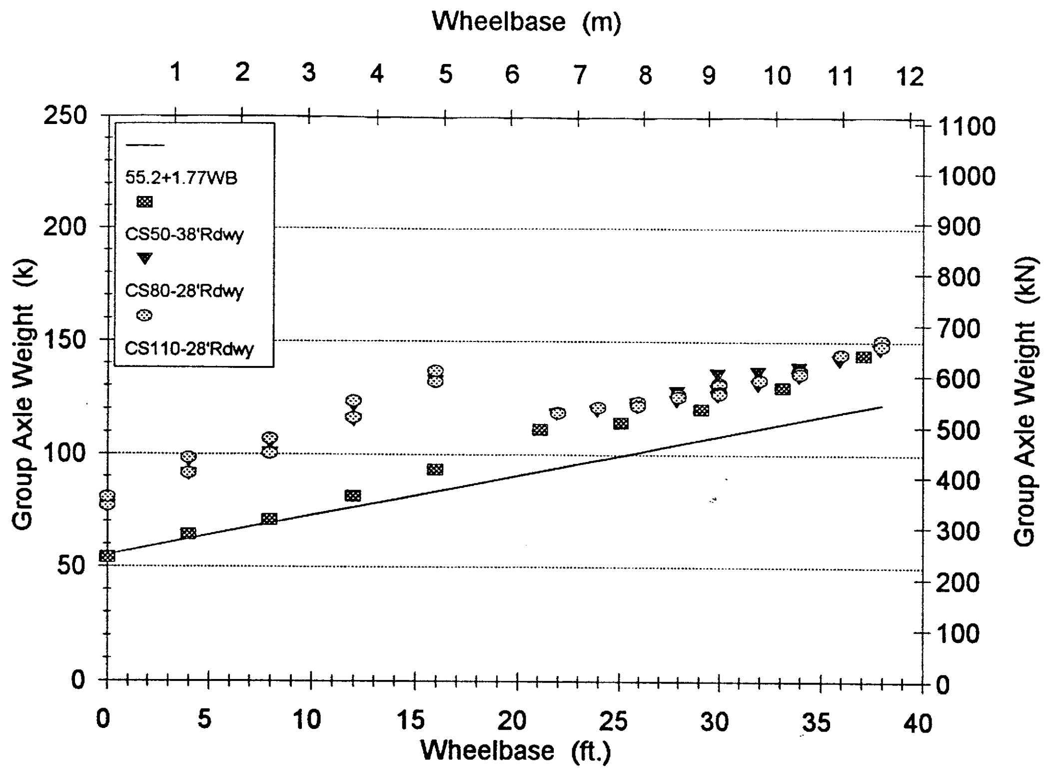


Figure A-6: Group axle weight versus wheelbase for LRFD effective widths for H20 bridges.

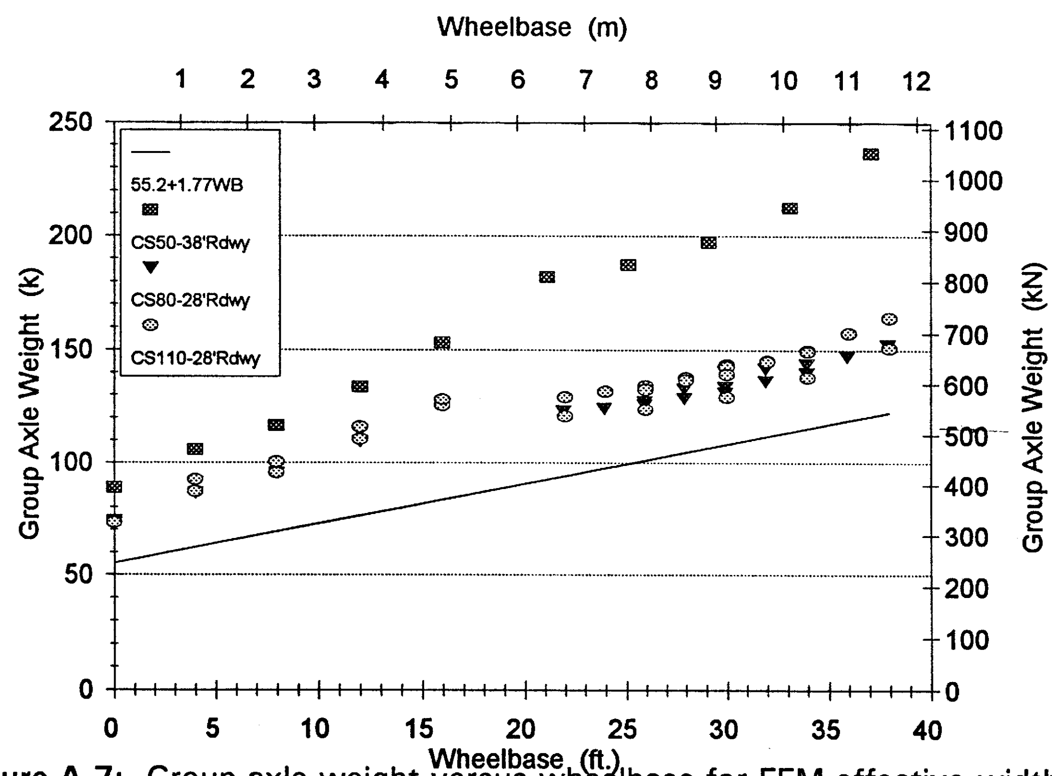


Figure A-7: Group axle weight versus wheelbase for FEM effective widths for H20 bridges.

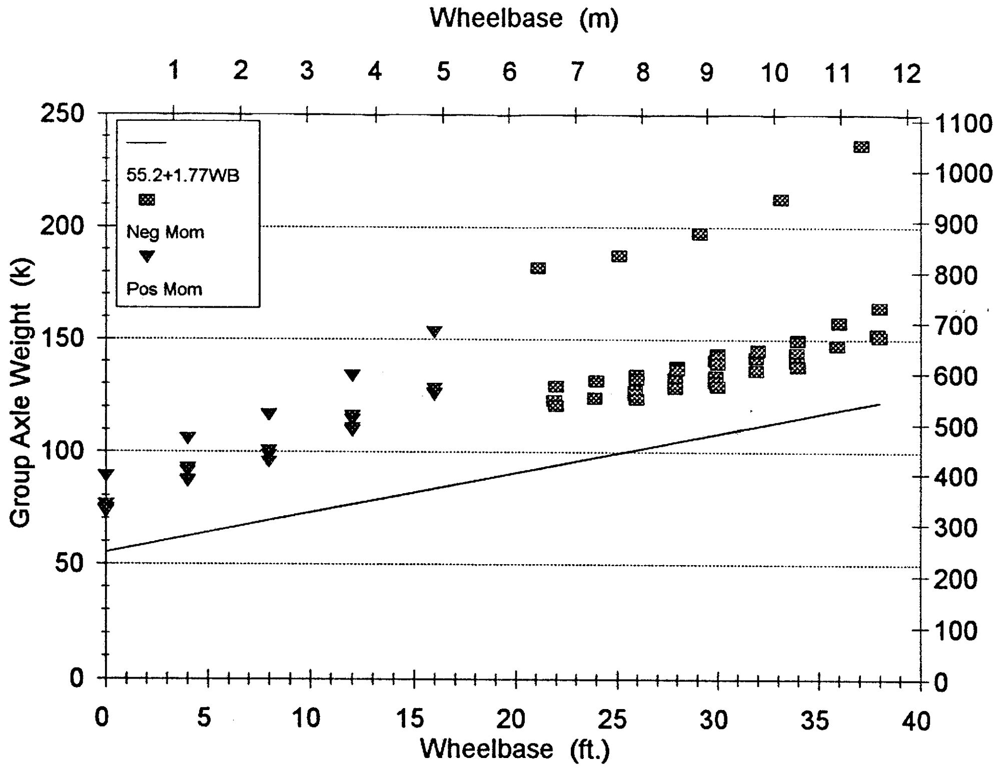


Figure A-8: Group axle weight versus wheelbase for positive and negative moments using FEM effective widths for H20 bridges.

Appendix B

Axle Configurations Used to Determine Current TxDOT Permit Standards (Obtained from D-18 Permit Regulations)

(This Chapeter is extracted from D-18 Permit Regulations)

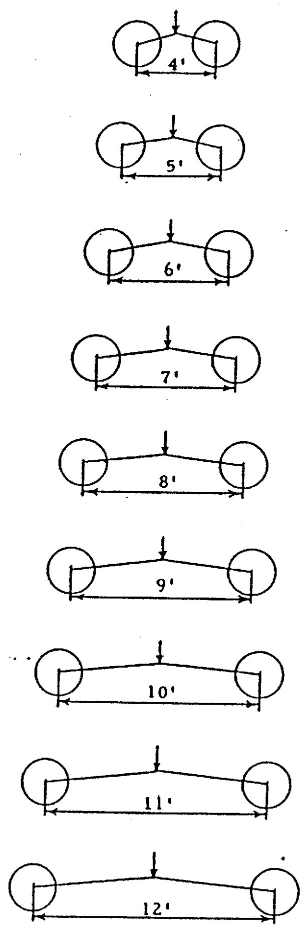
CHAPTER 13 - AXLE LOADING DIAGRAMS AND MAXIMUM WEIGHTS

The following diagrams show loads which may be permitted upon various axle groupings at various spacings. The maximum loadings shown for any group of axles at any of the various spacings will not be permitted, unless the individual groups are spaced at least 12 feet from the nearest single axle or tandem axle group. All applications with any of the following axle weights and spacings must meet the following conditions:

1. Tire Load Limitation of 650 pounds per inch of tire width shall not be exceeded.
2. Load must be distributed equally over axles of the group.
3. All other current requirements pertaining to oversize and/or overweight movements must be met.

Permits issued for the movement of an overweight load over a load zoned road shall not have a maximum axle weight that exceeds 90% of those shown on the following diagram.

$N = 2 \qquad W = 54.1 - 5.8N + \frac{5NL}{16}$

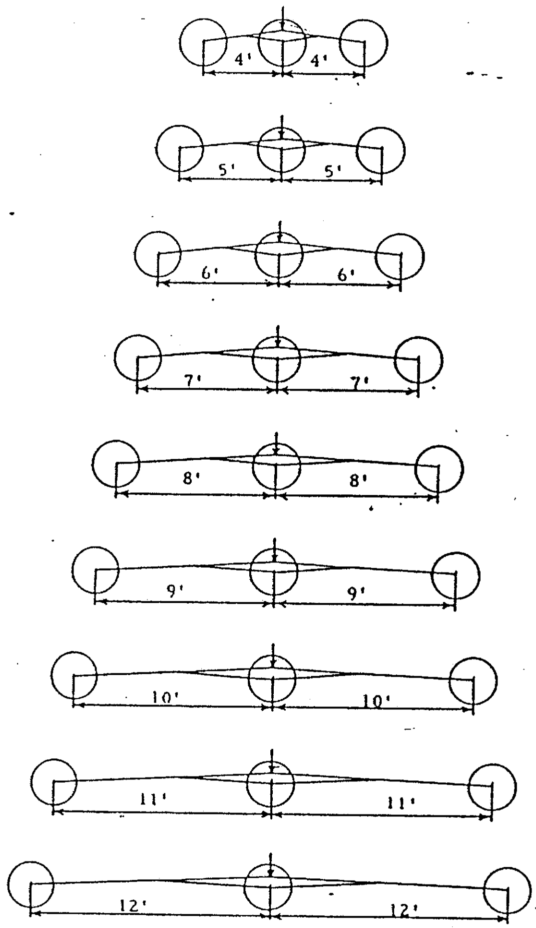


LEGAL	Spacing	PERMIT MAXIMUM W
34,000#	4'	45,000#
34,000#	5'	45,625#
34,000#	6'	46,250#
34,000#	7'	46,875#
34,000#	8'	47,500#
39,000#	9'	48,125#
40,000#	10'	48,750#
40,000#	11'	49,375#
40,000#	12'	50,000#

120

40

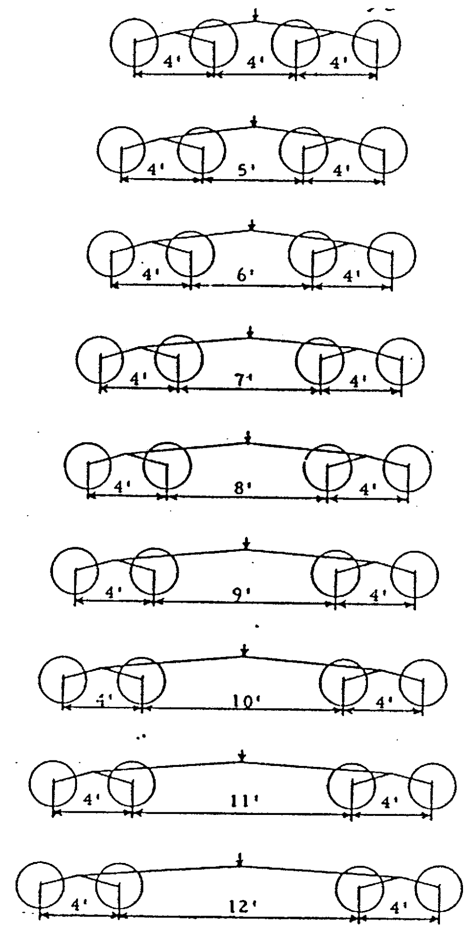
LEGAL $N = 3$ $W = 69.9 - 5.8N + \frac{5NL}{16}$ PERMIT MAXIMUM W



LEGAL	PERMIT MAXIMUM W
42,000#	60,000#
43,500#	61,875#
45;000#	63,750#
46,500#	65,625#
48,000#	67,500#
49,900#	69,375#
52,800#	71,250#
55,800#	73,125#
58,700#	75,000#

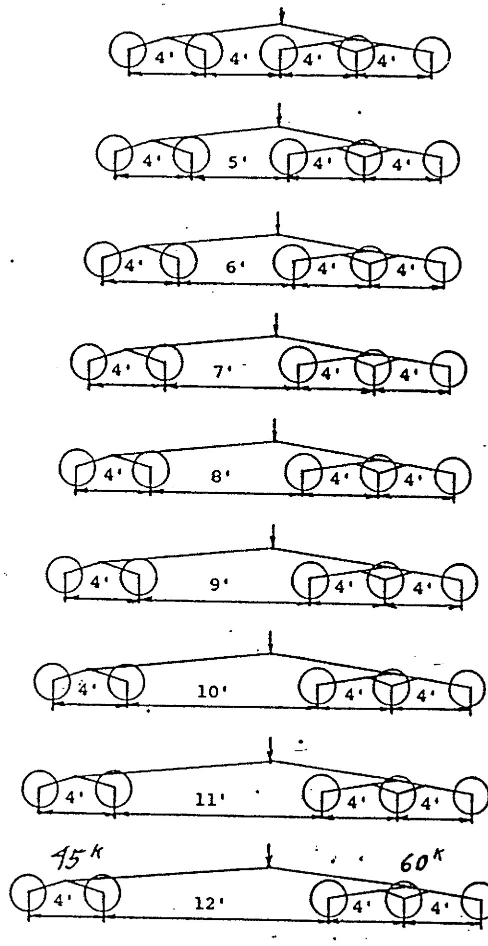
41

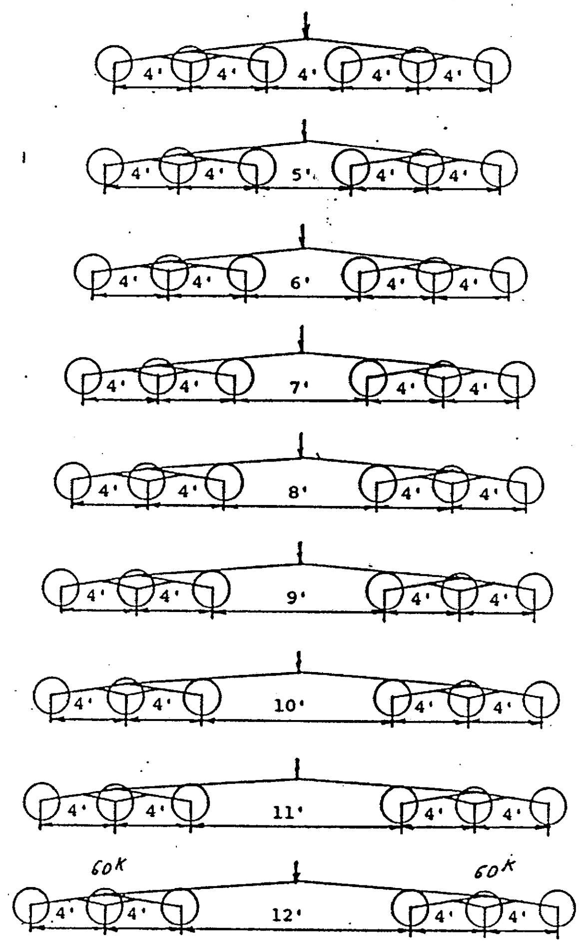
LEGAL $N = 4$ $W = 63.2 - 5.8 * N + \frac{10NL}{16}$ PERMIT MAXIMUM W



LEGAL	PERMIT MAXIMUM W
50,000#	70,000#
50,500#	72,500#
51,500#	75,000#
52,000#	77,500#
52,500#	80,000#
53,500#	82,500#
54,000#	85,000#
54,500#	87,500#
55,500#	90,000#

$$W = 63.2 - 5.8 * N + \frac{9.44NL}{16}$$





LEGAL (N = 5)	PERMIT MAXIMUM W	LEGAL (N = 6)	PERMIT MAXIMUM W
58,000#	81,400#	66,000#	94,200#
58,500#	84,350#	66,500#	97,425#
59,000#	87,300#	67,000#	100,650#
60,000#	90,250#	68,000#	103,875#
60,500#	93,200#	68,500#	107,100#
61,000#	96,150#	69,000#	110,325#
61,500#	99,100#	69,500#	113,550#
62,500#	102,050#	70,000#	116,775#
63,000#	105,000#	71,000#	120,000#

Appendix C

Proposed Axle Group Weight Restrictions Considering Bridge Span Length

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	2	4	6	8	10	12
10.0	48.1	54.2	61.9	72.2	86.7	104.0
15.0	51.5	55.4	60.1	65.5	72.1	80.1
20.0	50.4	53.2	56.4	59.9	63.9	68.5
25.0	50.0	52.2	54.6	57.2	60.0	63.2
30.0	50.6	52.4	54.3	56.4	58.7	61.1
35.0	51.9	53.4	55.1	56.9	58.8	60.8
40.0	53.7	55.2	56.6	58.2	59.9	61.6
45.0	56.0	57.3	58.7	60.1	61.6	63.2
50.0	58.6	59.9	61.1	62.5	63.9	65.3
55.0	61.5	62.7	63.9	65.1	66.4	67.8
60.0	64.5	65.7	66.8	68.0	69.2	70.5
65.0	67.8	68.8	69.9	71.1	72.3	73.5
70.0	71.1	72.1	73.2	74.3	75.5	76.6
75.0	74.5	75.5	76.6	77.7	78.8	79.9
80.0	78.0	79.0	80.1	81.1	82.2	83.3
85.0	81.6	82.6	83.6	84.6	85.7	86.8
90.0	85.3	86.2	87.2	88.2	89.3	90.3
95.0	89.0	89.9	90.9	91.9	92.9	94.0
100.0	92.7	93.7	94.6	95.6	96.6	97.6
105.0	96.5	97.4	98.4	99.4	100.4	101.4
110.0	100.3	101.2	102.2	103.1	104.1	105.1
115.0	104.1	105.1	106.0	107.0	107.9	108.9
120.0	108.0	108.9	109.9	110.8	111.8	112.8
125.0	111.9	112.8	113.7	114.7	115.6	116.6
130.0	115.8	116.7	117.6	118.6	119.5	120.5
135.0	119.8	120.7	121.6	122.5	123.4	124.4
140.0	123.7	124.6	125.5	126.4	127.4	128.3
145.0	127.7	128.6	129.5	130.4	131.3	132.3
150.0	131.6	132.5	133.4	134.3	135.3	136.2

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length.

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	14	16	18	20	22	24
10.0	121.3	138.7	156.0	173.3	190.7	208.0
15.0	90.1	102.5	115.3	128.1	141.0	153.8
20.0	73.7	79.9	87.1	95.8	105.4	115.0
25.0	66.7	70.6	75.1	80.1	85.8	92.4
30.0	63.8	66.7	69.8	73.3	77.2	81.5
35.0	63.0	65.3	67.8	70.5	73.5	76.7
40.0	63.5	65.5	67.6	69.9	72.3	74.9
45.0	64.9	66.6	68.5	70.4	72.5	74.7
50.0	66.8	68.4	70.1	71.8	73.7	75.6
55.0	69.2	70.7	72.2	73.8	75.5	77.2
60.0	71.9	73.2	74.7	76.2	77.7	79.3
65.0	74.8	76.1	77.4	78.8	80.3	81.8
70.0	77.9	79.1	80.4	81.7	83.1	84.6
75.0	81.1	82.3	83.5	84.8	86.2	87.5
80.0	84.4	85.6	86.8	88.1	89.3	90.7
85.0	87.9	89.0	90.2	91.4	92.7	93.9
90.0	91.4	92.5	93.7	94.9	96.1	97.3
95.0	95.0	96.1	97.2	98.4	99.6	100.8
100.0	98.7	99.8	100.9	102.0	103.1	104.3
105.0	102.4	103.5	104.5	105.6	106.8	107.9
110.0	106.1	107.2	108.3	109.3	110.4	111.6
115.0	109.9	111.0	112.0	113.1	114.2	115.3
120.0	113.8	114.8	115.8	116.9	117.9	119.0
125.0	117.6	118.6	119.6	120.7	121.7	122.8
130.0	121.5	122.5	123.5	124.5	125.6	126.6
135.0	125.4	126.4	127.4	128.4	129.4	130.5
140.0	129.3	130.3	131.3	132.3	133.3	134.3
145.0	133.2	134.2	135.2	136.2	137.2	138.2
150.0	137.2	138.1	139.1	140.1	141.1	142.1

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	26	28	30	32	34	36
10.0	225.3	242.7	260.0	277.3	294.7	312.0
15.0	166.6	179.4	192.2	205.0	217.9	230.7
20.0	124.6	134.2	143.8	153.3	162.9	172.5
25.0	99.9	107.6	115.3	123.0	130.7	138.3
30.0	86.3	91.7	97.8	104.3	110.8	117.3
35.0	80.2	84.0	88.2	92.8	98.0	103.7
40.0	77.6	80.6	83.8	87.3	91.1	95.3
45.0	77.0	79.5	82.2	85.0	88.0	91.3
50.0	77.7	79.8	82.1	84.5	87.1	89.8
55.0	79.1	81.0	83.0	85.1	87.4	89.8
60.0	81.0	82.8	84.6	86.6	88.6	90.7
65.0	83.4	85.0	86.7	88.5	90.3	92.3
70.0	86.0	87.6	89.2	90.8	92.5	94.3
75.0	88.9	90.4	91.9	93.5	95.1	96.7
80.0	92.0	93.4	94.8	96.3	97.9	99.4
85.0	95.2	96.6	97.9	99.4	100.8	102.3
90.0	98.6	99.9	101.2	102.6	104.0	105.4
95.0	102.0	103.2	104.5	105.9	107.2	108.6
100.0	105.5	106.7	108.0	109.3	110.6	111.9
105.0	109.1	110.3	111.5	112.8	114.0	115.3
110.0	112.7	113.9	115.1	116.3	117.6	118.8
115.0	116.4	117.6	118.7	119.9	121.2	122.4
120.0	120.1	121.3	122.4	123.6	124.8	126.0
125.0	123.9	125.0	126.2	127.3	128.5	129.7
130.0	127.7	128.8	129.9	131.1	132.2	133.4
135.0	131.5	132.6	133.7	134.8	136.0	137.2
140.0	135.4	136.5	137.6	138.7	139.8	140.9
145.0	139.3	140.3	141.4	142.5	143.6	144.7
150.0	143.2	144.2	145.3	146.4	147.5	148.6

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	38	40	42	44	46	48
10.0	329.3	346.7	364.0	381.3	398.7	416.0
15.0	243.5	256.3	269.1	281.9	294.7	307.6
20.0	182.1	191.7	201.3	210.8	220.4	230.0
25.0	146.0	153.7	161.4	169.1	176.8	184.4
30.0	123.9	130.4	136.9	143.4	149.9	156.4
35.0	109.4	115.2	120.9	126.7	132.5	138.2
40.0	99.8	104.8	110.0	115.3	120.5	125.8
45.0	94.8	98.6	102.7	107.2	112.0	116.9
50.0	92.7	95.8	99.1	102.6	106.4	110.5
55.0	92.2	94.9	97.7	100.6	103.8	107.1
60.0	92.9	95.2	97.6	100.2	102.9	105.8
65.0	94.3	96.4	98.6	100.8	103.2	105.8
70.0	96.2	98.1	100.1	102.2	104.4	106.6
75.0	98.5	100.3	102.1	104.0	106.0	108.1
80.0	101.1	102.7	104.5	106.3	108.2	110.1
85.0	103.9	105.5	107.1	108.8	110.6	112.4
90.0	106.9	108.4	110.0	111.6	113.3	115.0
95.0	110.0	111.5	113.0	114.6	116.2	117.8
100.0	113.3	114.7	116.2	117.7	119.2	120.8
105.0	116.7	118.1	119.5	120.9	122.4	123.9
110.0	120.1	121.5	122.8	124.2	125.7	127.1
115.0	123.7	125.0	126.3	127.7	129.1	130.5
120.0	127.3	128.5	129.8	131.2	132.5	133.9
125.0	130.9	132.2	133.4	134.7	136.0	137.4
130.0	134.6	135.8	137.1	138.3	139.6	141.0
135.0	138.3	139.5	140.8	142.0	143.3	144.6
140.0	142.1	143.3	144.5	145.7	147.0	148.2
145.0	145.9	147.1	148.2	149.5	150.7	151.9
150.0	149.7	150.9	152.0	153.2	154.4	155.7

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	50	52	54	56	58	60
10.0	433.3	450.7	468.0	485.3	502.7	520.0
15.0	320.4	333.2	346.0	358.8	371.6	384.4
20.0	239.6	249.2	258.8	268.3	277.9	287.5
25.0	192.1	199.8	207.5	215.2	222.9	230.6
30.0	163.0	169.5	176.0	182.5	189.0	195.6
35.0	144.0	149.7	155.5	161.3	167.0	172.8
40.0	131.0	136.2	141.5	146.7	151.9	157.2
45.0	121.7	126.6	131.5	136.4	141.2	146.1
50.0	114.9	119.5	124.1	128.7	133.3	137.9
55.0	110.7	114.5	118.6	123.0	127.3	131.7
60.0	108.8	112.0	115.4	119.0	122.8	126.9
65.0	108.4	111.2	114.1	117.2	120.5	123.9
70.0	109.0	111.5	114.1	116.8	119.6	122.6
75.0	110.3	112.5	114.9	117.3	119.9	122.5
80.0	112.1	114.2	116.3	118.5	120.9	123.3
85.0	114.3	116.2	118.2	120.3	122.4	124.7
90.0	116.8	118.6	120.5	122.4	124.4	126.5
95.0	119.5	121.2	123.0	124.8	126.7	128.7
100.0	122.4	124.0	125.7	127.5	129.3	131.1
105.0	125.4	127.0	128.7	130.3	132.0	133.8
110.0	128.6	130.2	131.7	133.3	135.0	136.7
115.0	131.9	133.4	134.9	136.5	138.1	139.7
120.0	135.3	136.7	138.2	139.7	141.3	142.8
125.0	138.8	140.2	141.6	143.1	144.6	146.1
130.0	142.3	143.7	145.1	146.5	147.9	149.4
135.0	145.9	147.2	148.6	150.0	151.4	152.8
140.0	149.5	150.8	152.2	153.5	154.9	156.3
145.0	153.2	154.5	155.8	157.1	158.5	159.9
150.0	156.9	158.2	159.5	160.8	162.1	163.4

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	62	64	66	68	70	72
10.0	537.3	554.7	572.0	589.3	606.7	624.0
15.0	397.3	410.1	422.9	435.7	448.5	461.3
20.0	297.1	306.7	316.3	325.8	335.4	345.0
25.0	238.2	245.9	253.6	261.3	269.0	276.7
30.0	202.1	208.6	215.1	221.6	228.1	234.7
35.0	178.5	184.3	190.0	195.8	201.6	207.3
40.0	162.4	167.7	172.9	178.1	183.4	188.6
45.0	151.0	155.8	160.7	165.6	170.4	175.3
50.0	142.5	147.1	151.7	156.3	160.9	165.5
55.0	136.1	140.5	144.9	149.3	153.7	158.1
60.0	131.2	135.4	139.6	143.9	148.1	152.3
65.0	127.5	131.4	135.5	139.6	143.7	147.8
70.0	125.8	129.1	132.6	136.2	140.1	144.1
75.0	125.3	128.2	131.3	134.5	137.9	141.4
80.0	125.8	128.4	131.2	134.0	137.0	140.1
85.0	127.0	129.4	131.8	134.4	137.1	139.9
90.0	128.6	130.8	133.1	135.5	138.0	140.5
95.0	130.7	132.7	134.9	137.1	139.4	141.7
100.0	133.0	135.0	137.0	139.1	141.2	143.4
105.0	135.6	137.5	139.4	141.3	143.4	145.4
110.0	138.4	140.2	142.0	143.9	145.8	147.7
115.0	141.3	143.0	144.8	146.6	148.4	150.3
120.0	144.4	146.1	147.7	149.5	151.2	153.0
125.0	147.6	149.2	150.8	152.5	154.2	155.9
130.0	150.9	152.5	154.0	155.6	157.3	158.9
135.0	154.3	155.8	157.3	158.9	160.5	162.1
140.0	157.7	159.2	160.7	162.2	163.8	165.3
145.0	161.3	162.7	164.1	165.6	167.1	168.7
150.0	164.8	166.2	167.6	169.1	170.6	172.0

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	74	76	78	80	82	84
10.0	641.3	658.7	676.0	693.3	710.7	728.0
15.0	474.1	487.0	499.8	512.6	525.4	538.2
20.0	354.6	364.2	373.8	383.3	392.9	402.5
25.0	284.4	292.0	299.7	307.4	315.1	322.8
30.0	241.2	247.7	254.2	260.7	267.3	273.8
35.0	213.1	218.8	224.6	230.4	236.1	241.9
40.0	193.9	199.1	204.3	209.6	214.8	220.1
45.0	180.2	185.0	189.9	194.8	199.7	204.5
50.0	170.1	174.7	179.3	183.9	188.5	193.1
55.0	162.5	166.9	171.3	175.6	180.0	184.4
60.0	156.6	160.8	165.0	169.3	173.5	177.7
65.0	151.9	156.0	160.1	164.2	168.3	172.4
70.0	148.1	152.1	156.2	160.2	164.2	168.2
75.0	145.1	149.0	152.9	156.8	160.8	164.7
80.0	143.4	146.8	150.4	154.1	158.0	161.8
85.0	142.8	145.9	149.0	152.4	155.8	159.4
90.0	143.2	145.9	148.8	151.8	154.9	158.1
95.0	144.2	146.7	149.3	152.1	154.9	157.8
100.0	145.7	148.0	150.5	153.0	155.6	158.2
105.0	147.6	149.8	152.0	154.4	156.8	159.3
110.0	149.8	151.9	154.0	156.2	158.5	160.8
115.0	152.2	154.2	156.2	158.3	160.4	162.6
120.0	154.9	156.8	158.7	160.7	162.7	164.8
125.0	157.7	159.5	161.4	163.3	165.2	167.2
130.0	160.7	162.4	164.2	166.0	167.9	169.8
135.0	163.7	165.4	167.2	168.9	170.7	172.5
140.0	166.9	168.6	170.2	171.9	173.7	175.4
145.0	170.2	171.8	173.4	175.1	176.8	178.5
150.0	173.6	175.1	176.7	178.3	179.9	181.6

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	86	88	90	92	94	96
10.0	745.3	762.7	780.0	797.3	814.7	832.0
15.0	551.0	563.9	576.7	589.5	602.3	615.1
20.0	412.1	421.7	431.3	440.8	450.4	460.0
25.0	330.5	338.2	345.8	353.5	361.2	368.9
30.0	280.3	286.8	293.3	299.9	306.4	312.9
35.0	247.6	253.4	259.2	264.9	270.7	276.4
40.0	225.3	230.5	235.8	241.0	246.3	251.5
45.0	209.4	214.3	219.1	224.0	228.9	233.7
50.0	197.7	202.3	206.9	211.5	216.1	220.7
55.0	188.8	193.2	197.6	202.0	206.4	210.8
60.0	182.0	186.2	190.4	194.6	198.9	203.1
65.0	176.5	180.6	184.7	188.8	192.9	197.1
70.0	172.2	176.2	180.2	184.2	188.2	192.2
75.0	168.6	172.5	176.5	180.4	184.3	188.2
80.0	165.7	169.5	173.4	177.2	181.1	184.9
85.0	163.2	167.0	170.8	174.6	178.4	182.2
90.0	161.5	165.0	168.6	172.4	176.1	179.9
95.0	160.8	164.0	167.3	170.7	174.2	177.9
100.0	161.0	163.9	166.9	170.0	173.2	176.5
105.0	161.9	164.5	167.3	170.1	173.0	176.1
110.0	163.2	165.7	168.2	170.8	173.5	176.3
115.0	164.9	167.2	169.6	172.1	174.6	177.2
120.0	166.9	169.1	171.4	173.7	176.1	178.5
125.0	169.2	171.3	173.5	175.7	177.9	180.2
130.0	171.7	173.7	175.8	177.9	180.0	182.2
135.0	174.4	176.3	178.3	180.3	182.3	184.4
140.0	177.3	179.1	181.0	182.9	184.9	186.9
145.0	180.2	182.0	183.8	185.7	187.6	189.5
150.0	183.3	185.0	186.8	188.6	190.4	192.3

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	98	100	102	104	106	108
10.0	849.3	866.7	884.0	901.3	918.7	936.0
15.0	627.9	640.7	653.6	666.4	679.2	692.0
20.0	469.6	479.2	488.8	498.3	507.9	517.5
25.0	376.6	384.3	392.0	399.6	407.3	415.0
30.0	319.4	325.9	332.4	339.0	345.5	352.0
35.0	282.2	287.9	293.7	299.5	305.2	311.0
40.0	256.7	262.0	267.2	272.5	277.7	282.9
45.0	238.6	243.5	248.4	253.2	258.1	263.0
50.0	225.3	229.9	234.5	239.1	243.7	248.3
55.0	215.2	219.6	224.0	228.3	232.7	237.1
60.0	207.3	211.6	215.8	220.0	224.3	228.5
65.0	201.2	205.3	209.4	213.5	217.6	221.7
70.0	196.2	200.2	204.2	208.2	212.2	216.2
75.0	192.1	196.1	200.0	203.9	207.8	211.7
80.0	188.8	192.6	196.5	200.3	204.2	208.1
85.0	186.0	189.8	193.6	197.4	201.2	205.0
90.0	183.6	187.4	191.1	194.9	198.6	202.4
95.0	181.6	185.3	189.0	192.7	196.4	200.2
100.0	180.0	183.6	187.2	190.9	194.6	198.3
105.0	179.2	182.5	185.8	189.3	193.0	196.6
110.0	179.2	182.2	185.3	188.5	191.8	195.2
115.0	179.9	182.7	185.5	188.5	191.5	194.6
120.0	181.0	183.6	186.3	189.0	191.9	194.8
125.0	182.6	185.0	187.5	190.1	192.7	195.4
130.0	184.5	186.8	189.1	191.6	194.0	196.6
135.0	186.6	188.8	191.0	193.3	195.7	198.1
140.0	188.9	191.0	193.2	195.4	197.6	199.9
145.0	191.5	193.5	195.6	197.7	199.8	202.0
150.0	194.2	196.1	198.1	200.1	202.2	204.3

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	110	112	114	116	118	120
10.0	953.3	970.7	988.0	1005.3	1022.7	1040.0
15.0	704.8	717.6	730.4	743.3	756.1	768.9
20.0	527.1	536.7	546.3	555.8	565.4	575.0
25.0	422.7	430.4	438.1	445.7	453.4	461.1
30.0	358.5	365.0	371.6	378.1	384.6	391.1
35.0	316.7	322.5	328.3	334.0	339.8	345.5
40.0	288.2	293.4	298.7	303.9	309.1	314.4
45.0	267.8	272.7	277.6	282.4	287.3	292.2
50.0	252.9	257.5	262.0	266.6	271.2	275.8
55.0	241.5	245.9	250.3	254.7	259.1	263.5
60.0	232.7	237.0	241.2	245.4	249.7	253.9
65.0	225.8	229.9	234.0	238.1	242.2	246.3
70.0	220.2	224.2	228.2	232.2	236.2	240.2
75.0	215.7	219.6	223.5	227.4	231.3	235.3
80.0	211.9	215.8	219.6	223.5	227.3	231.2
85.0	208.8	212.6	216.4	220.2	224.0	227.7
90.0	206.1	209.9	213.6	217.4	221.1	224.9
95.0	203.9	207.6	211.3	215.0	218.7	222.4
100.0	201.9	205.6	209.3	212.9	216.6	220.3
105.0	200.2	203.9	207.5	211.2	214.8	218.5
110.0	198.8	202.4	206.0	209.6	213.2	216.9
115.0	197.9	201.2	204.7	208.3	211.9	215.5
120.0	197.8	200.8	204.0	207.3	210.7	214.2
125.0	198.2	201.1	204.1	207.1	210.3	213.5
130.0	199.2	201.9	204.7	207.5	210.4	213.4
135.0	200.6	203.1	205.7	208.4	211.1	214.0
140.0	202.3	204.7	207.2	209.7	212.3	214.9
145.0	204.3	206.5	208.9	211.3	213.8	216.3
150.0	206.5	208.7	210.9	213.2	215.5	217.9

Table C-1: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H15 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	2	4	6	8	10	12
10.0	67.2	75.6	86.4	100.8	121.0	145.2
15.0	70.4	75.9	82.2	89.7	98.6	109.6
20.0	68.2	71.9	76.2	80.9	86.3	92.5
25.0	66.9	69.8	73.0	76.5	80.3	84.5
30.0	67.1	69.5	72.0	74.8	77.8	81.0
35.0	68.3	70.4	72.6	74.9	77.4	80.1
40.0	70.3	72.2	74.1	76.2	78.4	80.7
45.0	72.9	74.6	76.4	78.3	80.2	82.3
50.0	76.0	77.6	79.3	81.0	82.8	84.7
55.0	79.4	80.9	82.5	84.1	85.8	87.5
60.0	83.1	84.6	86.1	87.6	89.2	90.8
65.0	87.0	88.4	89.9	91.3	92.8	94.4
70.0	91.1	92.5	93.8	95.3	96.7	98.2
75.0	95.4	96.7	98.0	99.4	100.8	102.3
80.0	99.7	101.0	102.3	103.6	105.0	106.4
85.0	104.1	105.4	106.7	108.0	109.4	110.7
90.0	108.7	109.9	111.2	112.5	113.8	115.1
95.0	113.3	114.5	115.7	117.0	118.3	119.6
100.0	117.9	119.1	120.4	121.6	122.9	124.2
105.0	122.6	123.8	125.0	126.3	127.5	128.8
110.0	127.4	128.6	129.8	131.0	132.3	133.5
115.0	132.2	133.4	134.6	135.8	137.0	138.3
120.0	137.0	138.2	139.4	140.6	141.8	143.0
125.0	141.9	143.1	144.2	145.4	146.6	147.9
130.0	146.8	147.9	149.1	150.3	151.5	152.7
135.0	151.7	152.9	154.0	155.2	156.4	157.6
140.0	156.7	157.8	159.0	160.1	161.3	162.5
145.0	161.6	162.8	163.9	165.1	166.2	167.4
150.0	166.6	167.7	168.9	170.0	171.2	172.4

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length.

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	14	16	18	20	22	24
10.0	169.4	193.6	217.8	242.0	266.2	290.4
15.0	123.3	140.3	157.8	175.3	192.9	210.4
20.0	99.6	107.9	117.7	129.5	142.5	155.4
25.0	89.2	94.5	100.4	107.1	114.7	123.6
30.0	84.6	88.4	92.6	97.3	102.4	108.1
35.0	82.9	86.0	89.3	92.9	96.7	101.0
40.0	83.1	85.7	88.5	91.4	94.6	97.9
45.0	84.5	86.7	89.2	91.7	94.4	97.3
50.0	86.6	88.7	90.9	93.1	95.5	98.0
55.0	89.4	91.3	93.3	95.3	97.5	99.8
60.0	92.5	94.3	96.2	98.1	100.1	102.2
65.0	96.0	97.7	99.5	101.3	103.2	105.1
70.0	99.8	101.4	103.1	104.8	106.6	108.4
75.0	103.8	105.3	106.9	108.6	110.3	112.0
80.0	107.9	109.4	110.9	112.5	114.1	115.8
85.0	112.2	113.6	115.1	116.6	118.2	119.8
90.0	116.5	117.9	119.4	120.9	122.4	124.0
95.0	121.0	122.4	123.8	125.3	126.8	128.3
100.0	125.5	126.9	128.3	129.7	131.2	132.7
105.0	130.2	131.5	132.9	134.3	135.7	137.1
110.0	134.8	136.1	137.5	138.9	140.3	141.7
115.0	139.5	140.9	142.2	143.5	144.9	146.3
120.0	144.3	145.6	146.9	148.3	149.6	151.0
125.0	149.1	150.4	151.7	153.0	154.4	155.7
130.0	154.0	155.2	156.5	157.8	159.1	160.5
135.0	158.8	160.1	161.4	162.6	164.0	165.3
140.0	163.7	165.0	166.2	167.5	168.8	170.1
145.0	168.7	169.9	171.1	172.4	173.7	175.0
150.0	173.6	174.8	176.1	177.3	178.6	179.9

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	26	28	30	32	34	36
10.0	314.6	338.8	363.0	387.2	411.4	435.6
15.0	227.9	245.5	263.0	280.5	298.1	315.6
20.0	168.4	181.3	194.3	207.2	220.2	233.1
25.0	133.6	143.9	154.2	164.5	174.8	185.0
30.0	114.4	121.6	129.7	138.3	147.0	155.6
35.0	105.5	110.6	116.1	122.2	129.0	136.5
40.0	101.6	105.5	109.7	114.3	119.2	124.7
45.0	100.3	103.5	107.0	110.7	114.6	118.9
50.0	100.7	103.5	106.4	109.6	112.9	116.4
55.0	102.1	104.6	107.2	110.0	112.9	115.9
60.0	104.4	106.6	109.0	111.5	114.1	116.8
65.0	107.1	109.2	111.4	113.7	116.1	118.5
70.0	110.3	112.3	114.3	116.4	118.6	120.9
75.0	113.8	115.7	117.6	119.6	121.7	123.8
80.0	117.6	119.3	121.2	123.1	125.0	127.0
85.0	121.5	123.2	125.0	126.8	128.6	130.6
90.0	125.6	127.3	129.0	130.7	132.5	134.3
95.0	129.8	131.4	133.1	134.8	136.5	138.3
100.0	134.2	135.8	137.4	139.0	140.7	142.4
105.0	138.6	140.2	141.7	143.3	144.9	146.6
110.0	143.2	144.7	146.2	147.7	149.3	150.9
115.0	147.8	149.2	150.7	152.2	153.8	155.4
120.0	152.4	153.8	155.3	156.8	158.3	159.9
125.0	157.1	158.5	160.0	161.4	162.9	164.5
130.0	161.9	163.3	164.7	166.1	167.6	169.1
135.0	166.6	168.0	169.4	170.8	172.3	173.8
140.0	171.5	172.8	174.2	175.6	177.0	178.5
145.0	176.3	177.7	179.0	180.4	181.8	183.3
150.0	181.2	182.5	183.9	185.3	186.7	188.1

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	38	40	42	44	46	48
10.0	459.8	484.0	508.2	532.4	556.6	580.8
15.0	333.1	350.7	368.2	385.7	403.3	420.8
20.0	246.1	259.0	272.0	284.9	297.9	310.8
25.0	195.3	205.6	215.9	226.2	236.4	246.7
30.0	164.2	172.9	181.5	190.2	198.8	207.5
35.0	144.1	151.6	159.2	166.8	174.4	182.0
40.0	130.6	137.1	144.0	150.8	157.7	164.6
45.0	123.4	128.4	133.7	139.5	145.8	152.2
50.0	120.2	124.2	128.4	133.0	138.0	143.3
55.0	119.2	122.6	126.2	130.0	134.1	138.4
60.0	119.6	122.6	125.8	129.1	132.6	136.3
65.0	121.1	123.8	126.6	129.6	132.6	135.9
70.0	123.3	125.8	128.3	131.0	133.8	136.7
75.0	126.0	128.3	130.7	133.1	135.7	138.4
80.0	129.1	131.3	133.5	135.8	138.2	140.6
85.0	132.5	134.6	136.7	138.9	141.1	143.4
90.0	136.2	138.2	140.2	142.2	144.4	146.5
95.0	140.1	142.0	143.9	145.9	147.9	150.0
100.0	144.1	145.9	147.8	149.7	151.6	153.6
105.0	148.3	150.1	151.8	153.7	155.5	157.5
110.0	152.6	154.3	156.0	157.8	159.6	161.5
115.0	157.0	158.6	160.3	162.1	163.8	165.6
120.0	161.5	163.1	164.7	166.4	168.1	169.9
125.0	166.0	167.6	169.2	170.8	172.5	174.2
130.0	170.6	172.2	173.7	175.3	177.0	178.7
135.0	175.3	176.8	178.3	179.9	181.5	183.2
140.0	180.0	181.5	183.0	184.5	186.1	187.7
145.0	184.7	186.2	187.7	189.2	190.8	192.4
150.0	189.5	191.0	192.4	193.9	195.5	197.0

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	50	52	54	56	58	60
10.0	605.0	629.2	653.4	677.6	701.8	726.0
15.0	438.3	455.9	473.4	490.9	508.5	526.0
20.0	323.8	336.7	349.7	362.6	375.6	388.5
25.0	257.0	267.3	277.6	287.8	298.1	308.4
30.0	216.1	224.8	233.4	242.0	250.7	259.3
35.0	189.5	197.1	204.7	212.3	219.9	227.5
40.0	171.4	178.3	185.1	192.0	198.8	205.7
45.0	158.5	164.8	171.2	177.5	183.9	190.2
50.0	149.0	155.0	160.9	166.9	172.8	178.8
55.0	143.0	147.9	153.2	158.8	164.5	170.2
60.0	140.1	144.3	148.6	153.3	158.2	163.5
65.0	139.3	142.8	146.6	150.6	154.7	159.2
70.0	139.7	142.9	146.2	149.7	153.4	157.2
75.0	141.1	144.0	147.0	150.1	153.4	156.8
80.0	143.2	145.9	148.6	151.5	154.4	157.5
85.0	145.8	148.3	150.8	153.5	156.2	159.1
90.0	148.8	151.1	153.5	156.0	158.6	161.2
95.0	152.1	154.3	156.6	158.9	161.3	163.8
100.0	155.7	157.8	159.9	162.2	164.4	166.8
105.0	159.4	161.5	163.5	165.6	167.8	170.1
110.0	163.4	165.3	167.3	169.4	171.4	173.6
115.0	167.5	169.3	171.3	173.2	175.2	177.3
120.0	171.7	173.5	175.3	177.3	179.2	181.2
125.0	176.0	177.7	179.6	181.4	183.3	185.2
130.0	180.4	182.1	183.9	185.7	187.5	189.4
135.0	184.8	186.5	188.2	190.0	191.8	193.6
140.0	189.4	191.0	192.7	194.4	196.2	198.0
145.0	194.0	195.6	197.2	198.9	200.6	202.4
150.0	198.6	200.2	201.8	203.5	205.2	206.9

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	62	64	66	68	70	72
10.0	750.2	774.4	798.6	822.8	847.0	871.2
15.0	543.5	561.1	578.6	596.1	613.7	631.2
20.0	401.5	414.4	427.4	440.3	453.3	466.2
25.0	318.7	329.0	339.2	349.5	359.8	370.1
30.0	268.0	276.6	285.3	293.9	302.6	311.2
35.0	235.0	242.6	250.2	257.8	265.4	272.9
40.0	212.5	219.4	226.3	233.1	240.0	246.8
45.0	196.5	202.9	209.2	215.6	221.9	228.2
50.0	184.8	190.7	196.7	202.6	208.6	214.6
55.0	175.8	181.5	187.2	192.9	198.5	204.2
60.0	169.0	174.4	179.9	185.3	190.8	196.2
65.0	163.8	168.8	174.0	179.3	184.6	189.9
70.0	161.2	165.5	169.9	174.7	179.7	184.8
75.0	160.4	164.1	168.0	172.1	176.4	180.9
80.0	160.7	164.1	167.6	171.2	175.0	179.0
85.0	162.0	165.1	168.2	171.5	175.0	178.5
90.0	163.9	166.8	169.7	172.7	175.8	179.1
95.0	166.4	169.0	171.7	174.5	177.5	180.5
100.0	169.2	171.7	174.3	176.9	179.6	182.4
105.0	172.4	174.7	177.2	179.6	182.2	184.9
110.0	175.8	178.0	180.3	182.7	185.2	187.7
115.0	179.4	181.6	183.8	186.1	188.4	190.8
120.0	183.2	185.3	187.4	189.6	191.9	194.1
125.0	187.2	189.2	191.3	193.4	195.5	197.7
130.0	191.3	193.2	195.2	197.3	199.3	201.5
135.0	195.5	197.4	199.3	201.3	203.3	205.4
140.0	199.8	201.6	203.5	205.4	207.4	209.4
145.0	204.2	206.0	207.8	209.7	211.6	213.5
150.0	208.6	210.4	212.2	214.0	215.9	217.8

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	74	76	78	80	82	84
10.0	895.4	919.6	943.8	968.0	992.2	1016.4
15.0	648.7	666.3	683.8	701.3	718.9	736.4
20.0	479.2	492.1	505.1	518.0	531.0	543.9
25.0	380.4	390.6	400.9	411.2	421.5	431.8
30.0	319.8	328.5	337.1	345.8	354.4	363.1
35.0	280.5	288.1	295.7	303.3	310.9	318.4
40.0	253.7	260.5	267.4	274.3	281.1	288.0
45.0	234.6	240.9	247.3	253.6	259.9	266.3
50.0	220.5	226.5	232.4	238.4	244.4	250.3
55.0	209.9	215.6	221.2	226.9	232.6	238.2
60.0	201.7	207.1	212.6	218.0	223.5	228.9
65.0	195.1	200.4	205.7	211.0	216.2	221.5
70.0	189.9	195.1	200.2	205.3	210.5	215.6
75.0	185.7	190.7	195.7	200.7	205.7	210.7
80.0	183.2	187.5	192.1	196.9	201.8	206.8
85.0	182.3	186.1	190.2	194.4	198.8	203.4
90.0	182.5	186.0	189.6	193.4	197.4	201.5
95.0	183.6	186.8	190.1	193.6	197.2	200.9
100.0	185.3	188.3	191.4	194.6	197.9	201.3
105.0	187.6	190.4	193.3	196.2	199.3	202.5
110.0	190.2	192.9	195.6	198.4	201.3	204.2
115.0	193.2	195.7	198.3	200.9	203.7	206.5
120.0	196.5	198.9	201.3	203.8	206.4	209.1
125.0	200.0	202.3	204.6	207.0	209.5	212.0
130.0	203.6	205.8	208.1	210.4	212.8	215.2
135.0	207.5	209.6	211.8	214.0	216.3	218.6
140.0	211.4	213.5	215.6	217.8	220.0	222.2
145.0	215.5	217.5	219.6	221.7	223.8	226.0
150.0	219.7	221.7	223.6	225.7	227.8	229.9

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	86	88	90	92	94	96
10.0	1040.6	1064.8	1089.0	1113.2	1137.4	1161.6
15.0	753.9	771.5	789.0	806.5	824.1	841.6
20.0	556.9	569.8	582.8	595.7	608.7	621.6
25.0	442.0	452.3	462.6	472.9	483.2	493.4
30.0	371.7	380.4	389.0	397.6	406.3	414.9
35.0	326.0	333.6	341.2	348.8	356.4	363.9
40.0	294.8	301.7	308.5	315.4	322.2	329.1
45.0	272.6	279.0	285.3	291.6	298.0	304.3
50.0	256.3	262.2	268.2	274.2	280.1	286.1
55.0	243.9	249.6	255.3	260.9	266.6	272.3
60.0	234.4	239.8	245.3	250.7	256.2	261.6
65.0	226.8	232.1	237.3	242.6	247.9	253.2
70.0	220.7	225.8	231.0	236.1	241.2	246.4
75.0	215.8	220.8	225.8	230.8	235.8	240.9
80.0	211.7	216.6	221.5	226.4	231.4	236.3
85.0	208.3	213.1	217.9	222.8	227.6	232.5
90.0	205.8	210.3	214.9	219.7	224.5	229.3
95.0	204.8	208.8	212.9	217.3	221.8	226.5
100.0	204.8	208.5	212.3	216.2	220.3	224.5
105.0	205.7	209.1	212.6	216.2	219.9	223.8
110.0	207.3	210.4	213.6	217.0	220.4	224.0
115.0	209.3	212.3	215.3	218.4	221.6	224.9
120.0	211.8	214.6	217.4	220.4	223.4	226.5
125.0	214.6	217.2	220.0	222.7	225.6	228.5
130.0	217.7	220.2	222.8	225.4	228.2	230.9
135.0	221.0	223.4	225.9	228.4	231.0	233.7
140.0	224.5	226.8	229.2	231.7	234.2	236.7
145.0	228.2	230.4	232.7	235.1	237.5	239.9
150.0	232.0	234.2	236.4	238.7	241.0	243.4

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	98	100	102	104	106	108
10.0	1185.8	1210.0	1234.2	1258.4	1282.6	1306.8
15.0	859.1	876.7	894.2	911.7	929.3	946.8
20.0	634.6	647.5	660.5	673.4	686.4	699.3
25.0	503.7	514.0	524.3	534.6	544.8	555.1
30.0	423.6	432.2	440.9	449.5	458.2	466.8
35.0	371.5	379.1	386.7	394.3	401.8	409.4
40.0	336.0	342.8	349.7	356.5	363.4	370.2
45.0	310.7	317.0	323.3	329.7	336.0	342.4
50.0	292.0	298.0	304.0	309.9	315.9	321.8
55.0	278.0	283.6	289.3	295.0	300.6	306.3
60.0	267.1	272.5	278.0	283.4	288.9	294.3
65.0	258.4	263.7	269.0	274.3	279.5	284.8
70.0	251.5	256.6	261.8	266.9	272.0	277.2
75.0	245.9	250.9	255.9	260.9	265.9	271.0
80.0	241.2	246.1	251.1	256.0	260.9	265.8
85.0	237.3	242.2	247.0	251.8	256.7	261.5
90.0	234.0	238.8	243.6	248.4	253.1	257.9
95.0	231.2	236.0	240.7	245.4	250.1	254.8
100.0	228.9	233.5	238.2	242.8	247.5	252.2
105.0	227.8	231.9	236.2	240.7	245.3	249.9
110.0	227.7	231.4	235.4	239.4	243.6	248.0
115.0	228.3	231.9	235.5	239.2	243.1	247.1
120.0	229.7	233.0	236.3	239.8	243.4	247.1
125.0	231.5	234.6	237.8	241.0	244.4	247.8
130.0	233.8	236.7	239.7	242.8	245.9	249.2
135.0	236.4	239.2	242.0	244.9	247.9	251.0
140.0	239.3	242.0	244.7	247.5	250.3	253.2
145.0	242.4	245.0	247.6	250.3	253.0	255.8
150.0	245.8	248.3	250.8	253.3	255.9	258.6

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	110	112	114	116	118	120
10.0	1331.0	1355.2	1379.4	1403.6	1427.8	1452.0
15.0	964.3	981.9	999.4	1016.9	1034.5	1052.0
20.0	712.3	725.2	738.2	751.1	764.1	777.0
25.0	565.4	575.7	586.0	596.2	606.5	616.8
30.0	475.4	484.1	492.7	501.4	510.0	518.7
35.0	417.0	424.6	432.2	439.8	447.3	454.9
40.0	377.1	384.0	390.8	397.7	404.5	411.4
45.0	348.7	355.0	361.4	367.7	374.1	380.4
50.0	327.8	333.8	339.7	345.7	351.6	357.6
55.0	312.0	317.7	323.3	329.0	334.7	340.4
60.0	299.8	305.2	310.7	316.1	321.6	327.0
65.0	290.1	295.4	300.6	305.9	311.2	316.5
70.0	282.3	287.4	292.6	297.7	302.8	308.0
75.0	276.0	281.0	286.0	291.0	296.0	301.1
80.0	270.7	275.7	280.6	285.5	290.4	295.4
85.0	266.4	271.2	276.1	280.9	285.7	290.6
90.0	262.7	267.5	272.2	277.0	281.8	286.6
95.0	259.5	264.3	269.0	273.7	278.4	283.1
100.0	256.9	261.5	266.2	270.9	275.5	280.2
105.0	254.5	259.1	263.8	268.4	273.0	277.7
110.0	252.5	257.1	261.7	266.3	270.9	275.4
115.0	251.2	255.4	259.8	264.4	268.9	273.5
120.0	250.9	254.8	258.8	263.0	267.3	271.8
125.0	251.4	255.0	258.8	262.6	266.6	270.7
130.0	252.5	255.9	259.4	263.0	266.7	270.5
135.0	254.1	257.4	260.6	264.0	267.5	271.1
140.0	256.2	259.2	262.4	265.6	268.8	272.2
145.0	258.6	261.5	264.5	267.5	270.6	273.8
150.0	261.3	264.1	266.9	269.8	272.8	275.8

Table C-2: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on H20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	2	4	6	8	10	12
10.0	61.1	68.8	78.6	91.7	110.0	132.0
15.0	55.7	59.9	64.9	70.8	77.9	86.6
20.0	63.2	66.7	70.6	75.0	80.0	85.7
25.0	71.4	74.5	77.8	81.5	85.6	90.1
30.0	78.7	81.5	84.6	87.8	91.3	95.1
35.0	85.2	87.8	90.6	93.5	96.6	99.9
40.0	91.0	93.4	95.9	98.6	101.4	104.4
45.0	96.2	98.5	100.8	103.3	105.9	108.6
50.0	101.0	103.1	105.3	107.6	110.0	112.5
55.0	105.5	107.4	109.5	111.7	113.9	116.2
60.0	109.6	111.5	113.5	115.5	117.6	119.8
65.0	113.5	115.3	117.2	119.1	121.1	123.2
70.0	117.3	119.0	120.8	122.6	124.5	126.5
75.0	120.9	122.5	124.2	126.0	127.8	129.6
80.0	124.4	126.0	127.6	129.3	131.0	132.8
85.0	127.7	129.3	130.9	132.5	134.1	135.8
90.0	131.0	132.5	134.0	135.6	137.2	138.8
95.0	134.2	135.7	137.1	138.7	140.2	141.8
100.0	137.4	138.8	140.2	141.7	143.2	144.7
105.0	140.5	141.8	143.2	144.6	146.1	147.6
110.0	143.5	144.8	146.2	147.6	149.0	150.4
115.0	146.5	147.8	149.1	150.4	151.8	153.2
120.0	149.4	150.7	152.0	153.3	154.6	156.0
125.0	152.4	153.6	154.9	156.1	157.4	158.8
130.0	155.2	156.5	157.7	158.9	160.2	161.5
135.0	158.1	159.3	160.5	161.7	163.0	164.2
140.0	160.9	162.1	163.3	164.5	165.7	167.0
145.0	163.8	164.9	166.1	167.2	168.4	169.7
150.0	166.6	167.7	168.8	170.0	171.1	172.3

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length.

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	14	16	18	20	22	24
10.0	154.0	176.0	198.0	220.0	242.0	264.0
15.0	97.4	110.8	124.7	138.5	152.4	166.2
20.0	92.3	100.0	109.1	120.0	132.0	144.0
25.0	95.1	100.7	107.0	114.2	122.3	131.7
30.0	99.3	103.8	108.7	114.2	120.2	126.9
35.0	103.5	107.3	111.5	115.9	120.8	126.0
40.0	107.6	110.9	114.5	118.3	122.4	126.8
45.0	111.4	114.5	117.6	121.0	124.6	128.3
50.0	115.1	117.9	120.7	123.8	126.9	130.3
55.0	118.6	121.2	123.8	126.5	129.4	132.4
60.0	122.0	124.4	126.8	129.3	132.0	134.7
65.0	125.3	127.5	129.8	132.1	134.6	137.1
70.0	128.5	130.5	132.7	134.9	137.2	139.5
75.0	131.6	133.5	135.5	137.6	139.8	142.0
80.0	134.6	136.5	138.4	140.4	142.4	144.5
85.0	137.6	139.4	141.2	143.1	145.0	147.0
90.0	140.5	142.2	144.0	145.8	147.6	149.5
95.0	143.4	145.0	146.7	148.4	150.2	152.0
100.0	146.2	147.8	149.5	151.1	152.8	154.5
105.0	149.1	150.6	152.2	153.8	155.4	157.1
110.0	151.9	153.3	154.9	156.4	158.0	159.6
115.0	154.6	156.1	157.5	159.0	160.6	162.1
120.0	157.4	158.8	160.2	161.7	163.1	164.7
125.0	160.1	161.5	162.9	164.3	165.7	167.2
130.0	162.8	164.2	165.5	166.9	168.3	169.7
135.0	165.5	166.8	168.1	169.5	170.9	172.2
140.0	168.2	169.5	170.8	172.1	173.4	174.8
145.0	170.9	172.1	173.4	174.7	176.0	177.3
150.0	173.5	174.8	176.0	177.3	178.5	179.8

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	26	28	30	32	34	36
10.0	286.0	308.0	330.0	352.0	374.0	396.0
15.0	180.1	193.9	207.8	221.6	235.5	249.3
20.0	156.0	168.0	180.0	192.0	204.0	216.0
25.0	142.5	153.4	164.4	175.4	186.3	197.3
30.0	134.3	142.7	152.2	162.4	172.5	182.7
35.0	131.7	138.0	144.9	152.5	161.0	170.3
40.0	131.5	136.5	142.0	147.9	154.3	161.4
45.0	132.3	136.6	141.2	146.0	151.2	156.8
50.0	133.8	137.5	141.4	145.6	150.0	154.7
55.0	135.6	138.9	142.4	146.0	149.9	153.9
60.0	137.6	140.6	143.7	147.0	150.4	154.0
65.0	139.7	142.5	145.3	148.3	151.4	154.6
70.0	142.0	144.5	147.1	149.9	152.7	155.6
75.0	144.3	146.7	149.1	151.6	154.2	156.9
80.0	146.6	148.9	151.2	153.5	156.0	158.5
85.0	149.0	151.1	153.3	155.5	157.8	160.2
90.0	151.4	153.4	155.5	157.6	159.7	162.0
95.0	153.9	155.8	157.7	159.7	161.8	163.9
100.0	156.3	158.1	160.0	161.9	163.9	165.9
105.0	158.8	160.5	162.3	164.1	166.0	167.9
110.0	161.2	162.9	164.6	166.4	168.2	170.0
115.0	163.7	165.3	167.0	168.7	170.4	172.2
120.0	166.2	167.8	169.4	171.0	172.7	174.3
125.0	168.7	170.2	171.8	173.3	174.9	176.6
130.0	171.2	172.6	174.1	175.7	177.2	178.8
135.0	173.7	175.1	176.6	178.0	179.5	181.1
140.0	176.2	177.6	179.0	180.4	181.9	183.4
145.0	178.6	180.0	181.4	182.8	184.2	185.7
150.0	181.1	182.5	183.8	185.2	186.6	188.0

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	38	40	42	44	46	48
10.0	418.0	440.0	462.0	484.0	506.0	528.0
15.0	263.2	277.0	290.9	304.7	318.6	332.4
20.0	228.0	240.0	252.0	264.0	276.0	288.0
25.0	208.2	219.2	230.2	241.1	252.1	263.0
30.0	192.8	203.0	213.1	223.3	233.4	243.6
35.0	179.8	189.3	198.7	208.2	217.7	227.1
40.0	169.0	177.5	186.4	195.3	204.1	213.0
45.0	162.9	169.4	176.4	184.1	192.4	200.8
50.0	159.7	165.0	170.7	176.8	183.3	190.4
55.0	158.2	162.7	167.5	172.6	177.9	183.7
60.0	157.7	161.7	165.8	170.2	174.8	179.6
65.0	158.0	161.5	165.1	169.0	173.0	177.2
70.0	158.7	161.9	165.2	168.6	172.2	175.9
75.0	159.7	162.7	165.7	168.8	172.0	175.4
80.0	161.1	163.8	166.5	169.4	172.4	175.4
85.0	162.6	165.1	167.7	170.3	173.1	175.9
90.0	164.2	166.6	169.0	171.5	174.0	176.7
95.0	166.0	168.2	170.5	172.8	175.2	177.7
100.0	167.9	170.0	172.2	174.4	176.6	178.9
105.0	169.9	171.9	173.9	176.0	178.1	180.3
110.0	171.9	173.8	175.7	177.7	179.8	181.9
115.0	174.0	175.8	177.7	179.6	181.5	183.5
120.0	176.1	177.8	179.6	181.5	183.3	185.2
125.0	178.2	179.9	181.7	183.4	185.2	187.1
130.0	180.4	182.1	183.7	185.4	187.2	188.9
135.0	182.6	184.2	185.8	187.5	189.2	190.9
140.0	184.9	186.4	188.0	189.6	191.2	192.9
145.0	187.2	188.7	190.2	191.7	193.3	194.9
150.0	189.4	190.9	192.4	193.9	195.4	197.0

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	50	52	54	56	58	60
10.0	550.0	572.0	594.0	616.0	638.0	660.0
15.0	346.3	360.1	374.0	387.9	401.7	415.6
20.0	300.0	312.0	324.0	336.0	348.0	360.0
25.0	274.0	285.0	295.9	306.9	317.8	328.8
30.0	253.7	263.9	274.0	284.1	294.3	304.4
35.0	236.6	246.1	255.5	265.0	274.4	283.9
40.0	221.9	230.8	239.6	248.5	257.4	266.3
45.0	209.1	217.5	225.9	234.2	242.6	250.9
50.0	198.0	205.9	213.8	221.8	229.7	237.6
55.0	189.8	196.4	203.4	210.8	218.4	225.9
60.0	184.8	190.2	196.0	202.1	208.6	215.6
65.0	181.7	186.3	191.2	196.4	201.8	207.6
70.0	179.8	183.9	188.2	192.7	197.4	202.3
75.0	178.9	182.6	186.4	190.3	194.5	198.8
80.0	178.6	181.9	185.4	188.9	192.6	196.5
85.0	178.8	181.9	185.0	188.2	191.6	195.1
90.0	179.4	182.2	185.1	188.1	191.2	194.4
95.0	180.3	182.9	185.6	188.3	191.2	194.1
100.0	181.3	183.8	186.3	188.9	191.5	194.3
105.0	182.6	184.9	187.3	189.7	192.2	194.8
110.0	184.0	186.2	188.4	190.7	193.1	195.5
115.0	185.5	187.6	189.8	191.9	194.2	196.5
120.0	187.2	189.2	191.2	193.3	195.4	197.6
125.0	188.9	190.8	192.8	194.8	196.8	198.9
130.0	190.7	192.6	194.4	196.3	198.3	200.3
135.0	192.6	194.4	196.2	198.0	199.9	201.8
140.0	194.5	196.2	198.0	199.7	201.5	203.4
145.0	196.5	198.2	199.8	201.6	203.3	205.1
150.0	198.5	200.1	201.8	203.4	205.1	206.8

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	62	64	66	68	70	72
10.0	682.0	704.0	726.0	748.0	770.0	792.0
15.0	429.4	443.3	457.1	471.0	484.8	498.7
20.0	372.0	384.0	396.0	408.0	420.0	432.0
25.0	339.8	350.7	361.7	372.6	383.6	394.6
30.0	314.6	324.7	334.9	345.0	355.2	365.3
35.0	293.4	302.8	312.3	321.8	331.2	340.7
40.0	275.1	284.0	292.9	301.8	310.6	319.5
45.0	259.3	267.7	276.0	284.4	292.8	301.1
50.0	245.5	253.4	261.4	269.3	277.2	285.1
55.0	233.4	240.9	248.5	256.0	263.5	271.1
60.0	222.7	229.9	237.1	244.3	251.5	258.7
65.0	213.7	220.2	227.0	233.9	240.8	247.7
70.0	207.5	213.0	218.7	224.8	231.2	237.8
75.0	203.3	208.0	213.0	218.2	223.6	229.4
80.0	200.5	204.7	209.0	213.6	218.3	223.3
85.0	198.7	202.5	206.3	210.4	214.6	219.0
90.0	197.6	201.1	204.6	208.2	212.0	215.9
95.0	197.2	200.3	203.5	206.8	210.3	213.9
100.0	197.1	200.0	203.0	206.1	209.2	212.5
105.0	197.4	200.1	202.9	205.7	208.7	211.7
110.0	198.0	200.5	203.1	205.8	208.5	211.4
115.0	198.8	201.2	203.7	206.2	208.7	211.4
120.0	199.8	202.1	204.4	206.8	209.2	211.7
125.0	201.0	203.1	205.4	207.6	209.9	212.3
130.0	202.3	204.4	206.5	208.6	210.8	213.1
135.0	203.7	205.7	207.7	209.8	211.9	214.0
140.0	205.2	207.1	209.1	211.1	213.1	215.1
145.0	206.9	208.7	210.5	212.4	214.4	216.3
150.0	208.5	210.3	212.1	213.9	215.8	217.7

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	74	76	78	80	82	84
10.0	814.0	836.0	858.0	880.0	902.0	924.0
15.0	512.5	526.4	540.2	554.1	567.9	581.8
20.0	444.0	456.0	468.0	480.0	492.0	504.0
25.0	405.5	416.5	427.4	438.4	449.4	460.3
30.0	375.5	385.6	395.8	405.9	416.1	426.2
35.0	350.2	359.6	369.1	378.5	388.0	397.5
40.0	328.4	337.3	346.1	355.0	363.9	372.8
45.0	309.5	317.9	326.2	334.6	343.0	351.3
50.0	293.0	301.0	308.9	316.8	324.7	332.6
55.0	278.6	286.1	293.7	301.2	308.7	316.2
60.0	265.9	273.0	280.2	287.4	294.6	301.8
65.0	254.5	261.4	268.3	275.2	282.1	288.9
70.0	244.4	251.0	257.7	264.3	270.9	277.5
75.0	235.4	241.7	248.1	254.5	260.8	267.2
80.0	228.5	233.9	239.6	245.6	251.8	257.9
85.0	223.5	228.3	233.3	238.4	243.9	249.5
90.0	220.0	224.3	228.6	233.2	238.0	242.9
95.0	217.5	221.4	225.3	229.4	233.7	238.1
100.0	215.9	219.4	223.0	226.7	230.5	234.5
105.0	214.8	218.0	221.3	224.7	228.2	231.9
110.0	214.3	217.2	220.3	223.4	226.7	230.0
115.0	214.1	216.9	219.7	222.7	225.7	228.8
120.0	214.3	216.9	219.5	222.3	225.1	228.0
125.0	214.7	217.2	219.7	222.3	224.9	227.6
130.0	215.3	217.7	220.1	222.5	225.0	227.6
135.0	216.2	218.4	220.7	223.0	225.4	227.8
140.0	217.2	219.3	221.5	223.7	226.0	228.3
145.0	218.3	220.4	222.5	224.6	226.7	228.9
150.0	219.6	221.6	223.6	225.6	227.7	229.8

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	86	88	90	92	94	96
10.0	946.0	968.0	990.0	1012.0	1034.0	1056.0
15.0	595.6	609.5	623.3	637.2	651.0	664.9
20.0	516.0	528.0	540.0	552.0	564.0	576.0
25.0	471.3	482.2	493.2	504.2	515.1	526.1
30.0	436.4	446.5	456.7	466.8	477.0	487.1
35.0	406.9	416.4	425.9	435.3	444.8	454.3
40.0	381.6	390.5	399.4	408.3	417.1	426.0
45.0	359.7	368.1	376.4	384.8	393.1	401.5
50.0	340.6	348.5	356.4	364.3	372.2	380.2
55.0	323.8	331.3	338.8	346.4	353.9	361.4
60.0	309.0	316.1	323.3	330.5	337.7	344.9
65.0	295.8	302.7	309.6	316.5	323.3	330.2
70.0	284.1	290.7	297.3	303.9	310.5	317.1
75.0	273.5	279.9	286.3	292.6	299.0	305.4
80.0	264.0	270.2	276.3	282.5	288.6	294.8
85.0	255.4	261.4	267.3	273.3	279.2	285.1
90.0	248.1	253.5	259.1	264.9	270.7	276.4
95.0	242.6	247.4	252.4	257.5	262.9	268.4
100.0	238.6	242.9	247.3	251.9	256.6	261.5
105.0	235.6	239.5	243.5	247.6	251.9	256.3
110.0	233.4	237.0	240.6	244.4	248.3	252.3
115.0	231.9	235.2	238.6	242.0	245.6	249.2
120.0	231.0	234.0	237.1	240.3	243.6	247.0
125.0	230.4	233.2	236.2	239.1	242.2	245.4
130.0	230.2	232.9	235.6	238.4	241.3	244.2
135.0	230.3	232.8	235.4	238.1	240.8	243.5
140.0	230.6	233.0	235.5	238.0	240.6	243.2
145.0	231.2	233.5	235.8	238.2	240.6	243.1
150.0	231.9	234.1	236.3	238.6	240.9	243.3

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	98	100	102	104	106	108
10.0	1078.0	1100.0	1122.0	1144.0	1166.0	1188.0
15.0	678.7	692.6	706.4	720.3	734.1	748.0
20.0	588.0	600.0	612.0	624.0	636.0	648.0
25.0	537.0	548.0	559.0	569.9	580.9	591.8
30.0	497.3	507.4	517.6	527.7	537.9	548.0
35.0	463.7	473.2	482.6	492.1	501.6	511.0
40.0	434.9	443.8	452.6	461.5	470.4	479.3
45.0	409.9	418.2	426.6	435.0	443.3	451.7
50.0	388.1	396.0	403.9	411.8	419.8	427.7
55.0	369.0	376.5	384.0	391.5	399.1	406.6
60.0	352.1	359.3	366.4	373.6	380.8	388.0
65.0	337.1	344.0	350.8	357.7	364.6	371.5
70.0	323.7	330.3	336.9	343.5	350.1	356.7
75.0	311.7	318.1	324.4	330.8	337.2	343.5
80.0	300.9	307.0	313.2	319.3	325.5	331.6
85.0	291.1	297.0	303.0	308.9	314.8	320.8
90.0	282.2	287.9	293.7	299.4	305.2	311.0
95.0	274.0	279.6	285.2	290.8	296.4	302.0
100.0	266.7	272.0	277.4	282.9	288.3	293.8
105.0	260.9	265.6	270.5	275.6	280.9	286.2
110.0	256.4	260.7	265.1	269.7	274.4	279.3
115.0	253.0	256.9	260.9	265.1	269.3	273.8
120.0	250.5	254.0	257.7	261.5	265.4	269.4
125.0	248.6	251.9	255.3	258.8	262.4	266.1
130.0	247.2	250.3	253.5	256.8	260.1	263.5
135.0	246.4	249.3	252.2	255.3	258.4	261.6
140.0	245.8	248.6	251.4	254.2	257.1	260.1
145.0	245.6	248.2	250.9	253.6	256.3	259.1
150.0	245.7	248.2	250.7	253.2	255.8	258.5

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Span Length (ft.)	Allowable Group Weight (k) with the following wheelbases (ft.)					
	110	112	114	116	118	120
10.0	1210.0	1232.0	1254.0	1276.0	1298.0	1320.0
15.0	761.9	775.7	789.6	803.4	817.3	831.1
20.0	660.0	672.0	684.0	696.0	708.0	720.0
25.0	602.8	613.8	624.7	635.7	646.6	657.6
30.0	558.1	568.3	578.4	588.6	598.7	608.9
35.0	520.5	530.0	539.4	548.9	558.3	567.8
40.0	488.1	497.0	505.9	514.8	523.6	532.5
45.0	460.1	468.4	476.8	485.2	493.5	501.9
50.0	435.6	443.5	451.4	459.4	467.3	475.2
55.0	414.1	421.7	429.2	436.7	444.3	451.8
60.0	395.2	402.4	409.6	416.7	423.9	431.1
65.0	378.4	385.2	392.1	399.0	405.9	412.8
70.0	363.4	370.0	376.6	383.2	389.8	396.4
75.0	349.9	356.2	362.6	369.0	375.3	381.7
80.0	337.7	343.9	350.0	356.2	362.3	368.4
85.0	326.7	332.7	338.6	344.6	350.5	356.4
90.0	316.7	322.5	328.2	334.0	339.8	345.5
95.0	307.6	313.2	318.8	324.4	329.9	335.5
100.0	299.2	304.6	310.1	315.5	321.0	326.4
105.0	291.5	296.8	302.1	307.4	312.7	318.0
110.0	284.4	289.6	294.7	299.9	305.1	310.2
115.0	278.3	283.0	287.9	293.0	298.0	303.1
120.0	273.6	277.9	282.3	286.8	291.5	296.4
125.0	269.9	273.8	277.8	282.0	286.3	290.7
130.0	267.0	270.6	274.3	278.2	282.1	286.1
135.0	264.8	268.2	271.6	275.2	278.8	282.5
140.0	263.2	266.3	269.5	272.8	276.2	279.6
145.0	262.0	265.0	268.0	271.1	274.2	277.4
150.0	261.2	264.0	266.8	269.7	272.7	275.7

Table C-3: Calculated maximum permit weights for 6 ft. (1.8 m) gage trucks on HS20 bridges of known span length (cont.).

Appendix D

SAFE Input and Output Files
for Cameron 50

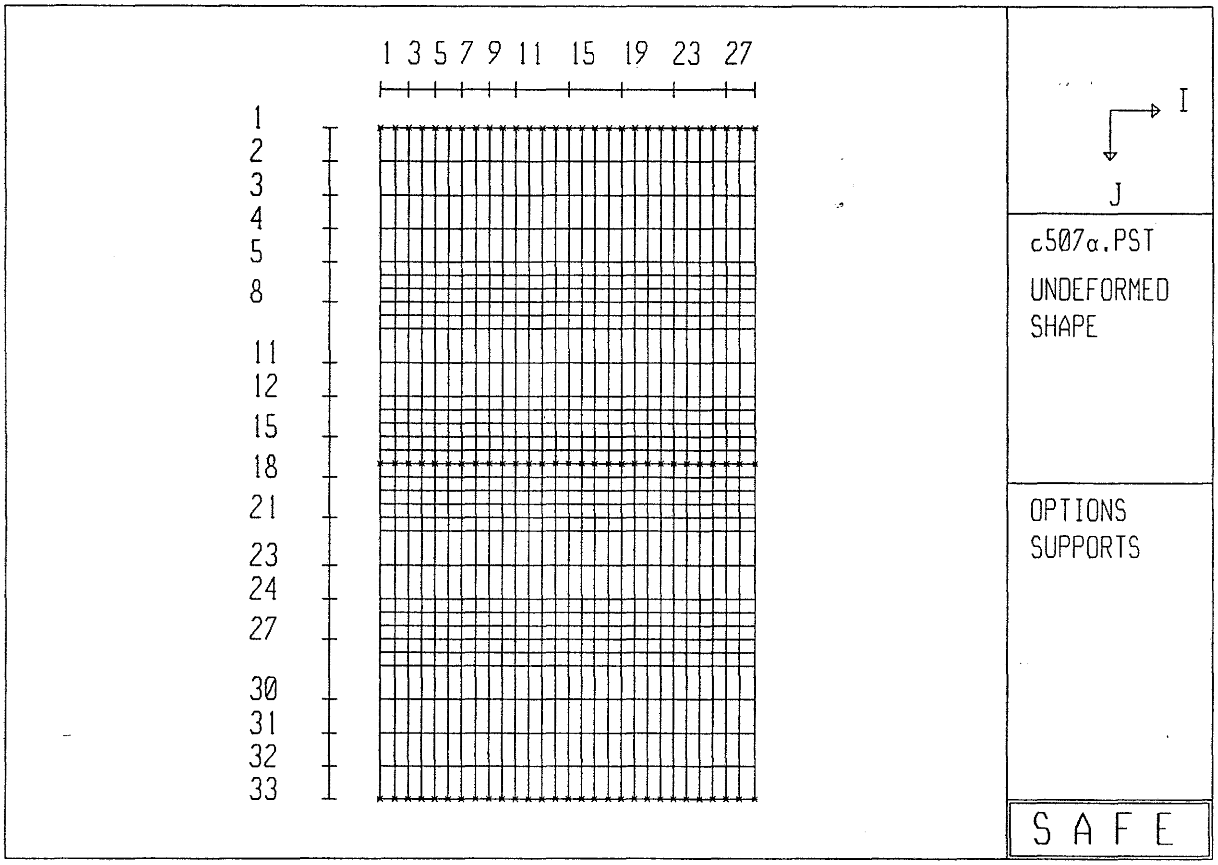


Figure D-1: Finite element model of Cameron 50.

SAFE Input File

Cameron 50

```
$ SAFE file c507a written by SAFEIN on Thu Dec 09 01:05:28 1993
$ Units are KIP and INCHES
$ Heading
Cameron50
Moment at 1st interior support
$ Job Control
29 33 0 8 1 0 1 0 80 0 0
$ Input Echo Control
0 0 0 0 0
$ Output Control
0 0 0 0 0 0 0 4 0 0 0 0 0 0 10 10 10 10
$ Spacing of Grid Points on the I-Axis
 13.5 12 12 12 12 12 12 12
 12 12 12 12 12 12 12 12
 12 12 12 12 12 12 12 12
 12 12 12 13.5
$ Spacing of Grid Points on the J-Axis
 30 30 30 30 12 12 12 12
 12 30 30 12 12 12 12 12
 12 12 12 12 12 30 30 12
 12 12 12 12 30 30 30 30
$ Slab Property Table
1 2900 0.15 0 6.685 9.513 0
2 2900 0.15 0 4.77 9.5126 0
3 2900 0.15 0 6.6856 7.441 0
4 2900 0.15 0 4.7712 7.4409 0
```

```
5 2900 0.15 0 5.9628 7.6589 0
6 2900 0.15 0 4.7706 7.6589 0
7 2900 0.15 0 5.9628 9.204 0
8 2900 0.15 0 4.7706 9.204 0
$ Support Property Table
1  L 1E+35 0
$ Slab Location Data
*   1  25   1  12   1
*  25  29  12  17   2
*  25  29   1  12   3
*   1  25  12  17   8
*  25  29  17  22   8
*  25  29  22  33   1
*   1  25  17  22   2
*   1  25  22  33   3
*   1  29   1  12   1
*   1  29  17  22   2
*   1  29  22  33   1
*   1  25  12  17   2
*   1  29   1  33   0
*   1  18   1  12   1
*  18  20   1  11   1
*  20  22   1  10   1
*  22  25   1   9   1
*  25  28   1  10   1
*  28  29   1  11   1
*   1  29  24  33   1
*  14  29  23  24   1
*   1  29  22  23   2
*   1  14  23  24   2
```

```
*  18  29  11  12   2
*  20  28  10  11   2
*  22  25   9  10   2
*  21  29  21  22   6
*   1  16  12  13   7
*  16  29  12  13   8
*   1  21  21  22   8
*   1  29  13  21   8
*   1  29   1  33   0
*   1  18   1  12   1
*  18  22   1   2   1
*  18  21   2   3   1
*  18  20   3   4   1
*  18  19   4   5   1
*  22  29   1  12   2
*  21  22   2   3   2
*  20  22   3   4   2
*  19  22   4   5   2
*  18  22   5  12   2
*   1  18  12  13   7
*   1  29  13  22   8
*  18  29  12  13   8
*  16  29  22  23   1
*   1  29  22  23   4
*  16  29  23  24   1
*  14  29  24  25   1
*   1  29  25  33   1
*   1  14  23  25   2
*  14  16  23  24   2
END
```

```
$ Support Location Data
* L   1  29   1   1   1
* L   1  29  33  33   1
* L   1  29  17  17   1
END
$ Load Data
CASE  1  1
test
* S   1  29   1  33 0.00104
* P   6   6   7   7 12.5 0 0
* P  12  12   7   7 12.5 0 0
END
```

SAFE Output File

Cameron 50

```
  $$$$$$$$   $$$$$$   $$$$$$$$   $$$$$$$$  $$$$$$$$   $$$$$$$$
    $$$$$$$$   $$$$$$$$   $$$$$$$$   $$$$$$$$  $$$$$$$$
$$$$$$$$
    $$       $$   $$   $$      $$      $$      $$   $$
   $$       $$   $$   $$      $$      $$      $$   $$
   $$$$$$$$   $$$$$$$$   $$$$$$    $$$$$$    $$      $$   $$
     $$   $$   $$   $$      $$      $$      $$   $$
     $$   $$   $$   $$      $$      $$      $$   $$
  $$$$$$$$   $$   $$   $$      $$$$$$$$  $$$$$$$$   $$$$$$$$
 $$$$$$$$   $$   $$   $$      $$$$$$$$  $$$$$$$$   $$$$$$$$
```

LOAD COMBINATIONS AND STRESS INTEGRATION FOR SAFE

VERSION 5.10

BY

ASHRAF HABIBULLAH

S A F E C O   C O N T R O L   I N F O R M A T I O N

NUMBER OF LOADING COMBINATIONS-------------- 1

NUMBER OF I-DIRECTION INTEGRATION SEGMENTS-- 0

NUMBER OF J-DIRECTION INTEGRATION SEGMENTS-- 1

LOAD COMBINATION OUTPUT FLAG---------------- 0

MAXIMUM WIDTH OF OUTPUT PAGE---------------- 80

POST PROCESSING FILE CREATION FLAG---------- 0

CONTROL INFORMATION OF SAFE RUN

NUMBER OF GRID POINTS ON I-AXIS--------------- 29

NUMBER OF GRID POINTS ON J-AXIS--------------- 33

NUMBER OF BEAM SECTION PROPERTIES------------- 0

NUMBER OF SLAB SECTION PROPERTIES------------- 8

NUMBER OF SUPPORT PROPERTIES------------------ 1

FLAG INDICATING EXISTENCE OF RELEASES--------- 0

NUMBER OF LOAD CASES-------------------------- 1

NUMBER OF ITERATIONS FOR NO-TENSION SUPPORTS-- 0

POST PROCESSING FILE FLAG--------------------- 0

TYPE OF PLATE BENDING ELEMENT FORMULATION----- 0

O U T P U T   P R I N T   F L A G S

PRINT FLAGS FOR DISPLACEMENT COMPONENTS

VERTICAL DISPLACEMENTS---------------------- 0

ROTATIONS ABOUT THE I-AXIS------------------ 0

ROTATIONS ABOUT THE J-AXIS------------------ 0

PRINT FLAGS FOR BEAM FORCES

MOMENTS------------------------------------- 0

TORQUES------------------------------------- 0

SHEARS-------------------------------------- 0

PRINT FLAGS FOR SLAB FORCES

MOMENTS CAUSING I-DIRECTION STRESSES (MII)-- 0

MOMENTS CAUSING J-DIRECTION STRESSES (MJJ)-- 0

TWISTING MOMENTS (MIJ)---------------------- 0

OUT-OF-PLANE SHEARS (VII)------------------- 0

OUT-OF-PLANE SHEARS (VJJ)------------------- 0

PRINT FLAGS FOR REACTION COMPONENTS

VERTICAL REACTIONS & REACTIVE PRESSURES----- 0

ROTATIONAL REACTIONS ABOUT THE I-AXIS------- 0

ROTATIONAL REACTIONS ABOUT THE J-AXIS------- 0

OUTPUT SPACING FLAGS

FLAG FOR DISPLACEMENTS----------------------	10
FLAG FOR BEAM FORCES------------------------	10
FLAG FOR SLAB FORCES------------------------	10
FLAG FOR REACTIONS--------------------------	10

C O M B I N A T I O N D A T A

C O M B I N A T I O N N U M B E R 1

IHED	LOAD	FACTOR
*	1	1.0000

S L A B S T R E S S I N T E G R A T I O N

J-DIRECTION SEGMENT NUMBER------------------ 1

NUMBER OF STRIPS IN SEGMENT----------------- 29

J-GRID NUMBER AT START OF SEGMENT----------- 5

J-GRID NUMBER AT END OF SEGMENT----------- 7

MOMENT/SHEAR INTEGRATION FLAG--------------- 1

STRIP NO	STRIP ID	START I-GRID	END I-GRID	STRIP WIDTH
1	I28-29	28	29	13.500
2	I27-28	27	28	12.000
3	I26-27	26	27	12.000
4	I25-26	25	26	12.000
5	I24-25	24	25	12.000
6	I23-24	23	24	12.000

7	I22-23	22	23	12.000
8	I21-22	21	22	12.000
9	I20-21	20	21	12.000
10	I19-20	19	20	12.000
11	I18-19	18	19	12.000
12	I17-18	17	18	12.000
13	I16-17	16	17	12.000
14	I15-16	15	16	12.000
15	I14-15	14	15	12.000
16	I13-14	13	14	12.000
17	I12-13	12	13	12.000
18	I11-12	11	12	12.000
19	I10-11	10	11	12.000
20	I9-10	9	10	12.000
21	I8-9	8	9	12.000
22	I7-8	7	8	12.000
23	I6-7	6	7	12.000
24	I5-6	5	6	12.000
25	I4-5	4	5	12.000
26	I3-4	3	4	12.000
27	I2-3	2	3	12.000
28	I1-29	1	29	339.000
29	I1-2	1	2	13.500

MOMENT INTEGRATION FOR J-SEGMENT 1

NUMERICAL MAXIMA OF COMBINATIONS

			J	J	J
STRIP	WIDTH	STATION	12.00	12.00	
			5	6	7
		I 28	(1)	(1)	
I28-29	13.50	LEFT	6.078	5.899	
I28-29	13.50	RIGHT	5.899	5.579	
		I 29	(1)	(1)	
		I 27	(1)	(1)	
I27-28	12.00	LEFT	6.236	6.065	
I27-28	12.00	RIGHT	6.065	5.751	
		I 28	(1)	(1)	
		I 26	(1)	(1)	
I26-27	12.00	LEFT	6.409	6.245	
I26-27	12.00	RIGHT	6.245	5.936	
		I 27	(1)	(1)	
		I 25	(1)	(1)	
I25-26	12.00	LEFT	6.610	6.451	

I25-26	12.00	RIGHT	6.451	6.145
		I 26	(1)	(1)
		I 24	(1)	(1)
I24-25	12.00	LEFT	6.840	6.687
I24-25	12.00	RIGHT	6.687	6.383
		I 25	(1)	(1)
		I 23	(1)	(1)
I23-24	12.00	LEFT	7.103	6.954
I23-24	12.00	RIGHT	6.954	6.649
		I 24	(1)	(1)
		I 22	(1)	(1)
I22-23	12.00	LEFT	7.401	7.254
I22-23	12.00	RIGHT	7.254	6.947
		I 23	(1)	(1)
		I 21	(1)	(1)
I21-22	12.00	LEFT	7.736	7.590
I21-22	12.00	RIGHT	7.590	7.280
		I 22	(1)	(1)
		I 20	(1)	(1)
I20-21	12.00	LEFT	8.110	7.968
I20-21	12.00	RIGHT	7.968	7.654
		I 21	(1)	(1)
		I 19	(1)	(1)
I19-20	12.00	LEFT	8.532	8.391

I19-20	12.00	RIGHT	8.391	8.074
		I 20	(1)	(1)
		I 18	(1)	(1)
I18-19	12.00	LEFT	9.006	8.877
I18-19	12.00	RIGHT	8.877	8.559
		I 19	(1)	(1)
		I 17	(1)	(1)
I17-18	12.00	LEFT	9.497	9.387
I17-18	12.00	RIGHT	9.387	9.074
		I 18	(1)	(1)
		I 16	(1)	(1)
I16-17	12.00	LEFT	10.098	10.022
I16-17	12.00	RIGHT	10.022	9.707
		I 17	(1)	(1)
		I 15	(1)	(1)
I15-16	12.00	LEFT	10.800	10.756
I15-16	12.00	RIGHT	10.756	10.457
		I 16	(1)	(1)
		I 14	(1)	(1)
I14-15	12.00	LEFT	11.592	11.648
I14-15	12.00	RIGHT	11.648	11.373
		I 15	(1)	(1)
		I 13	(1)	(1)
I13-14	12.00	LEFT	12.080	12.925

I13-14	12.00	RIGHT	12.925	12.670
		I 14	(1)	(1)
		I 12	(1)	(1)
I12-13	12.00	LEFT	12.235	13.418
I12-13	12.00	RIGHT	13.418	15.856
		I 13	(1)	(1)
		I 11	(1)	(1)
I11-12	12.00	LEFT	12.664	13.863
I11-12	12.00	RIGHT	13.863	16.306
		I 12	(1)	(1)
		I 10	(1)	(1)
I10-11	12.00	LEFT	13.382	14.289
I10-11	12.00	RIGHT	14.289	14.036
		I 11	(1)	(1)
		I 9	(1)	(1)
I9-10	12.00	LEFT	13.831	13.984
I9-10	12.00	RIGHT	13.984	13.729
		I 10	(1)	(1)
		I 8	(1)	(1)
I8-9	12.00	LEFT	14.028	14.186
I8-9	12.00	RIGHT	14.186	13.930
		I 9	(1)	(1)
		I 7	(1)	(1)
I7-8	12.00	LEFT	13.979	14.899

I7-8	12.00	RIGHT	14.899	14.644
		I 8	(1)	(1)
		I 6	(1)	(1)
I6-7	12.00	LEFT	13.676	14.894
I6-7	12.00	RIGHT	14.894	17.332
		I 7	(1)	(1)
		I 5	(1)	(1)
I5-6	12.00	LEFT	13.682	14.889
I5-6	12.00	RIGHT	14.889	17.316
		I 6	(1)	(1)
		I 4	(1)	(1)
I4-5	12.00	LEFT	13.987	14.857
I4-5	12.00	RIGHT	14.857	14.580
		I 5	(1)	(1)
		I 3	(1)	(1)
I3-4	12.00	LEFT	13.982	14.053
I3-4	12.00	RIGHT	14.053	13.741
		I 4	(1)	(1)
		I 2	(1)	(1)
I2-3	12.00	LEFT	13.684	13.630
I2-3	12.00	RIGHT	13.630	13.274
		I 3	(1)	(1)
		I 1	(1)	(1)
I1-29	339.00	LEFT	10.590	10.825

I1-29	339.00	RIGHT	10.825	10.911
		I 29	(1)	(1)
		I 1	(1)	(1)
I1-2	13.50	LEFT	13.463	13.329
I1-2	13.50	RIGHT	13.329	12.933
		I 2	(1)	(1)

5 6 7

STRIP WIDTH STATION 12.00 12.00

J J J

Appendix E

Effective Width Graphs for H15 and H20 Continuous Span Bridges

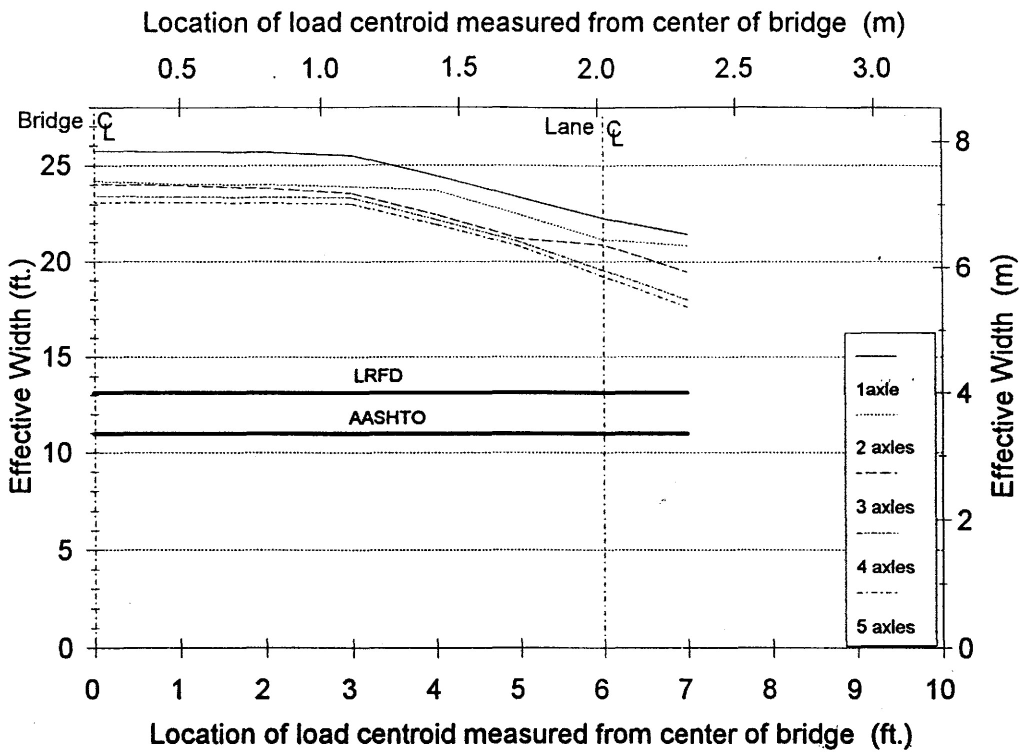


Figure E-1: Effective width of Cameron 50 at interior support subjected to 11 ft. (3.4 m) gage axles.

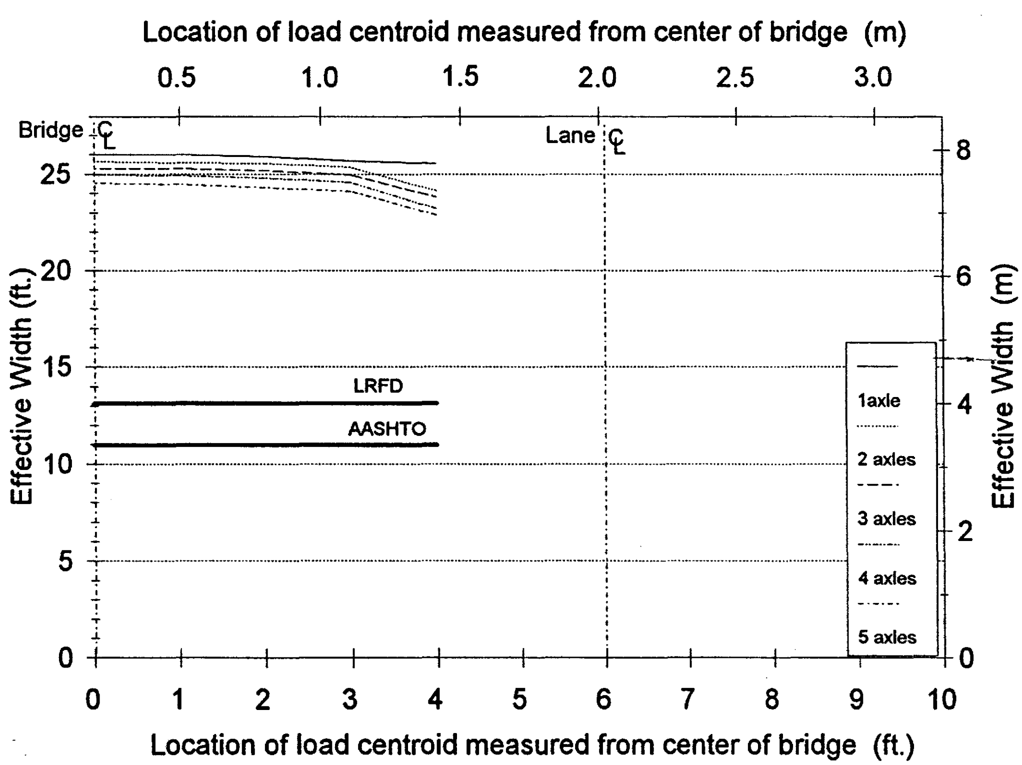


Figure E-2: Effective width of Cameron 50 at interior support subjected to 16 ft. (4.9 m) gage axles.

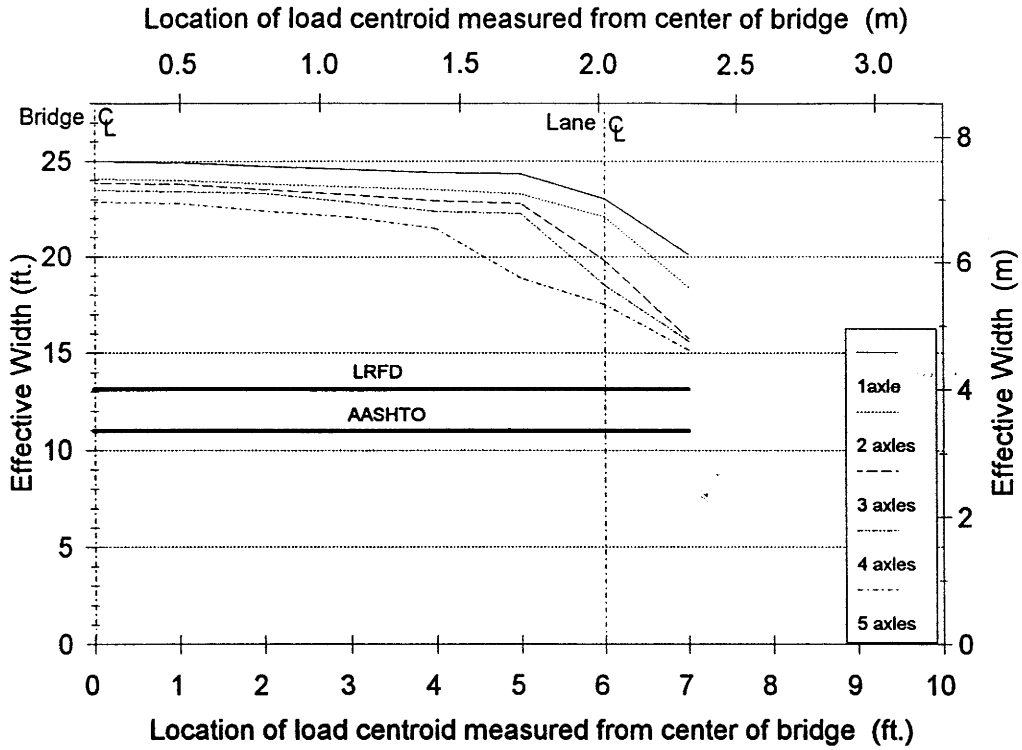


Figure E-3: Effective width of Cameron 50 within span subjected to 11 ft. (3.4 m) gage axles.

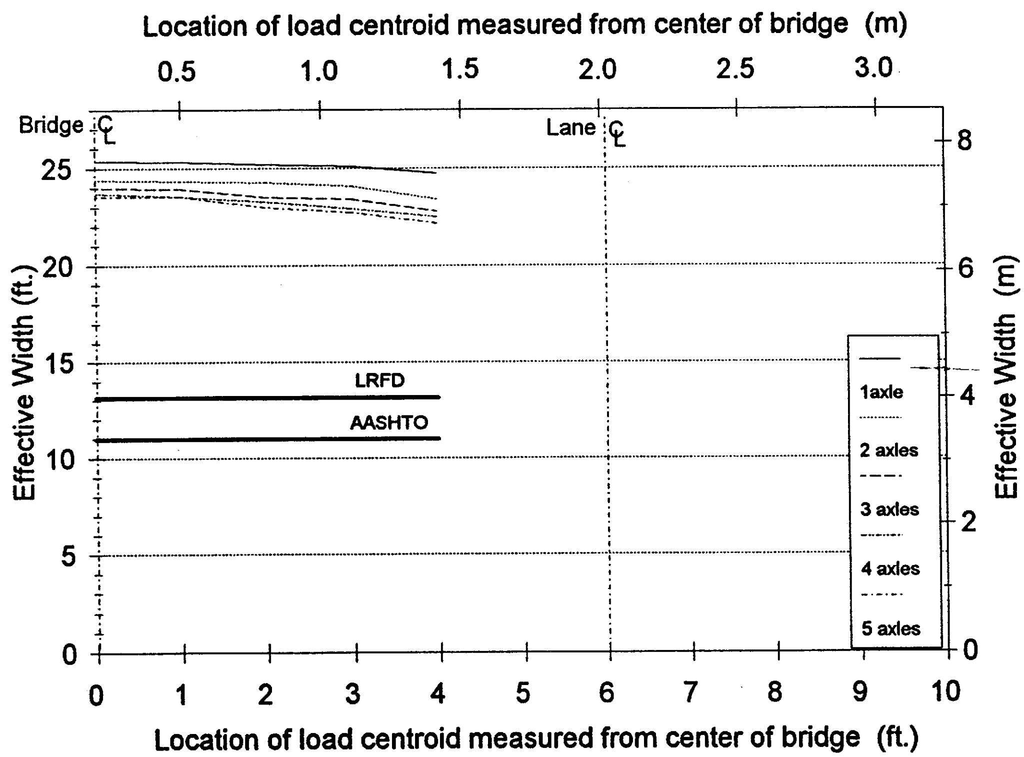


Figure E-4: Effective width of Cameron 50 within span subjected to 16 ft. (4.9 m) gage axles.

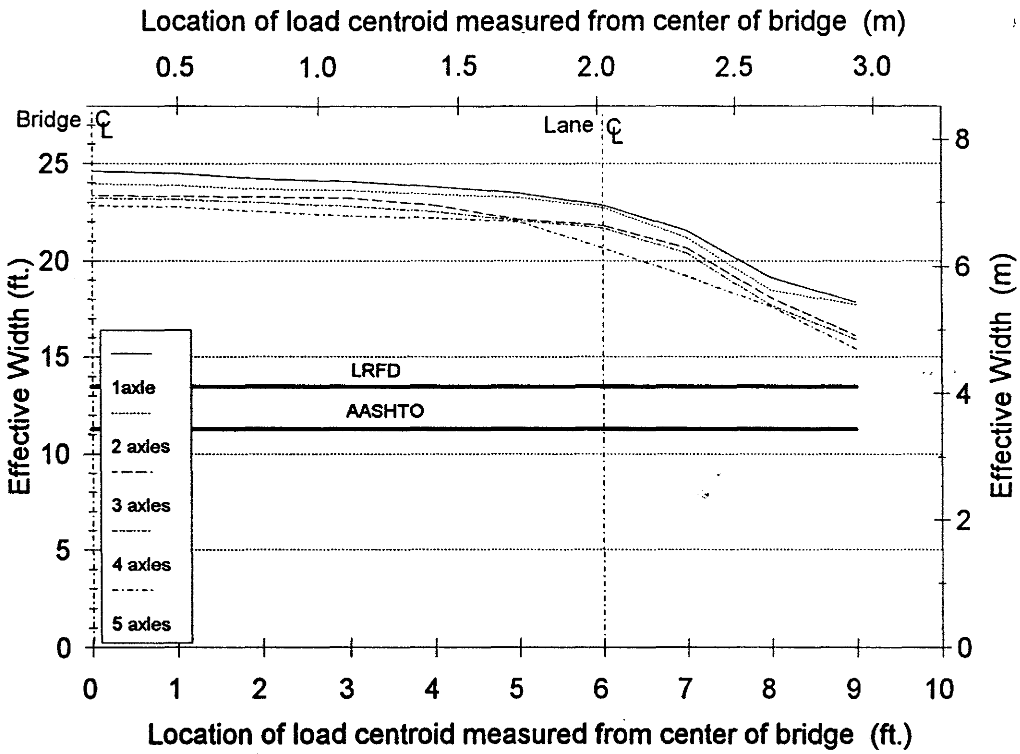


Figure E-5: Effective width of Cameron 80 at first interior support subjected to 6 ft. (1.8 m) gage axles.

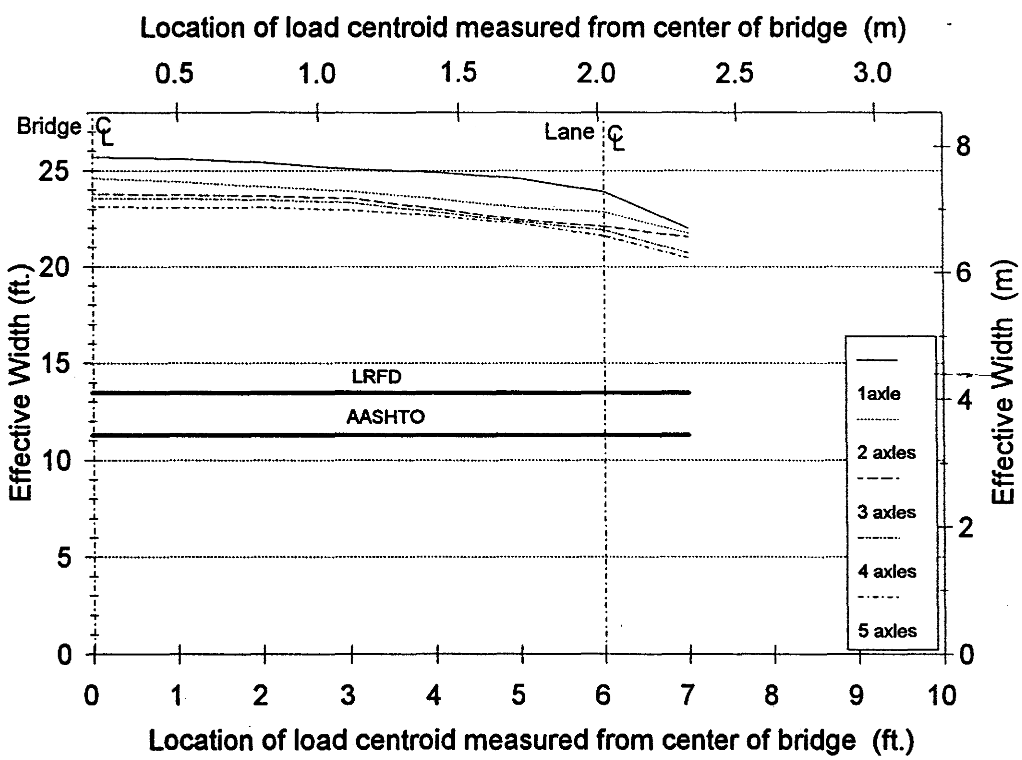


Figure E-6: Effective width of Cameron 80 at first interior support subjected to 11 ft. (3.4 m) gage axles.

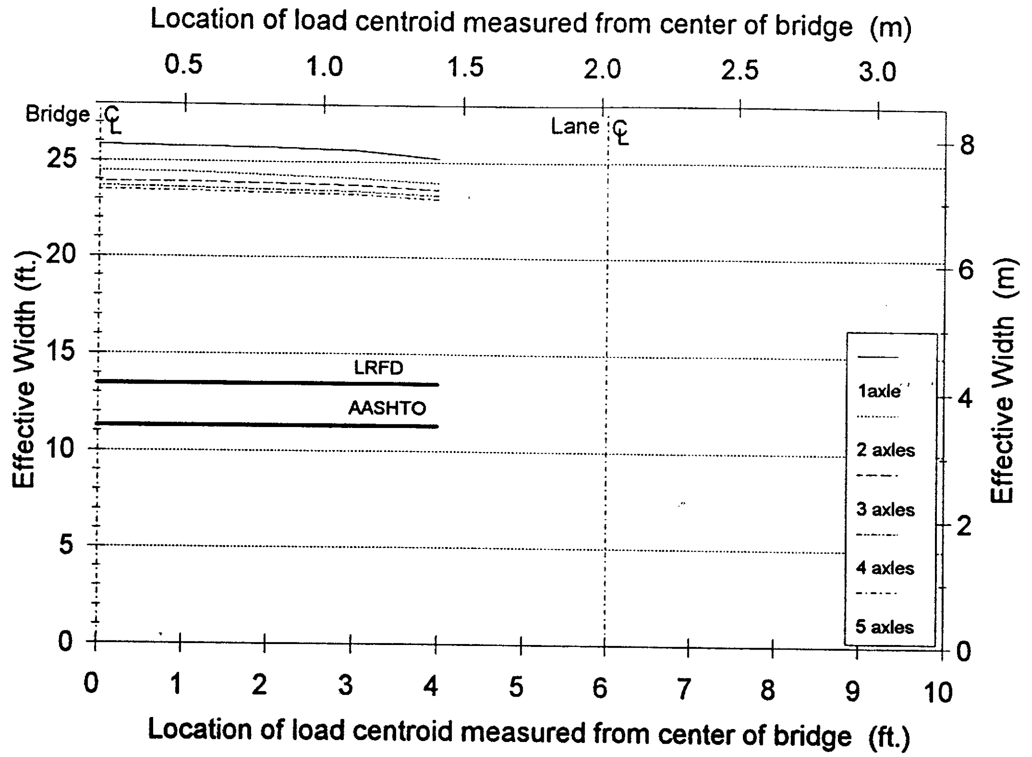


Figure E-7: Effective width of Cameron 80 at first interior support subjected to 16 ft. (4.9 m) gage axles.

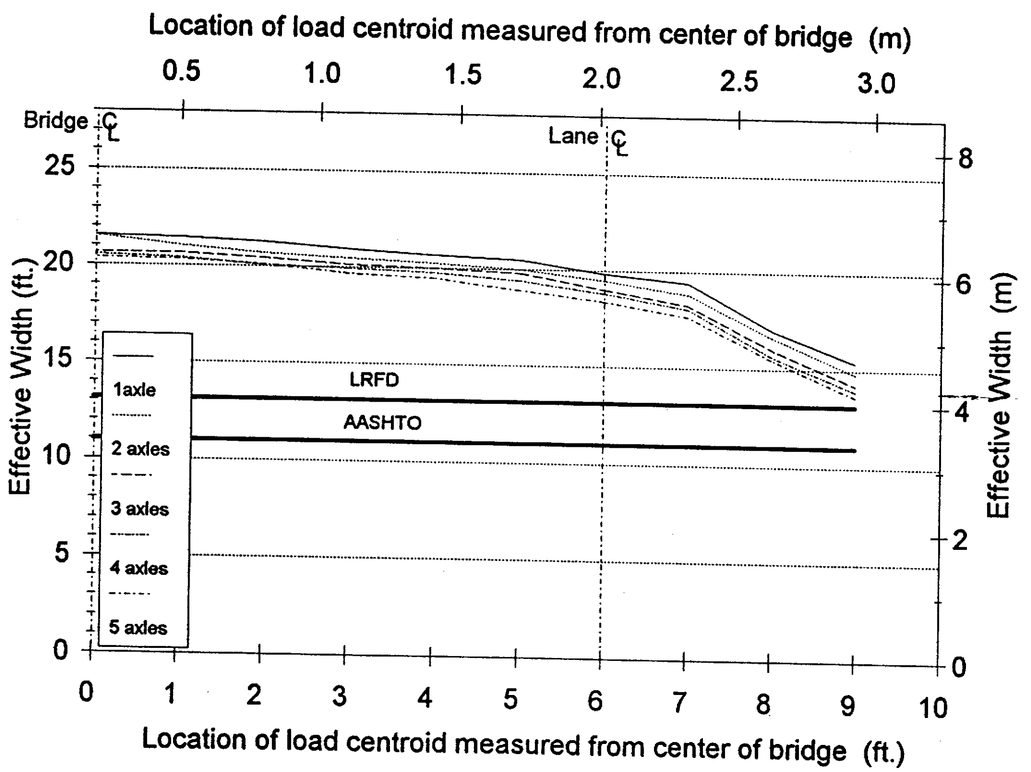


Figure E-8: Effective width of Cameron 80 within first span subjected to 6 ft. (1.8 m) gage axles.

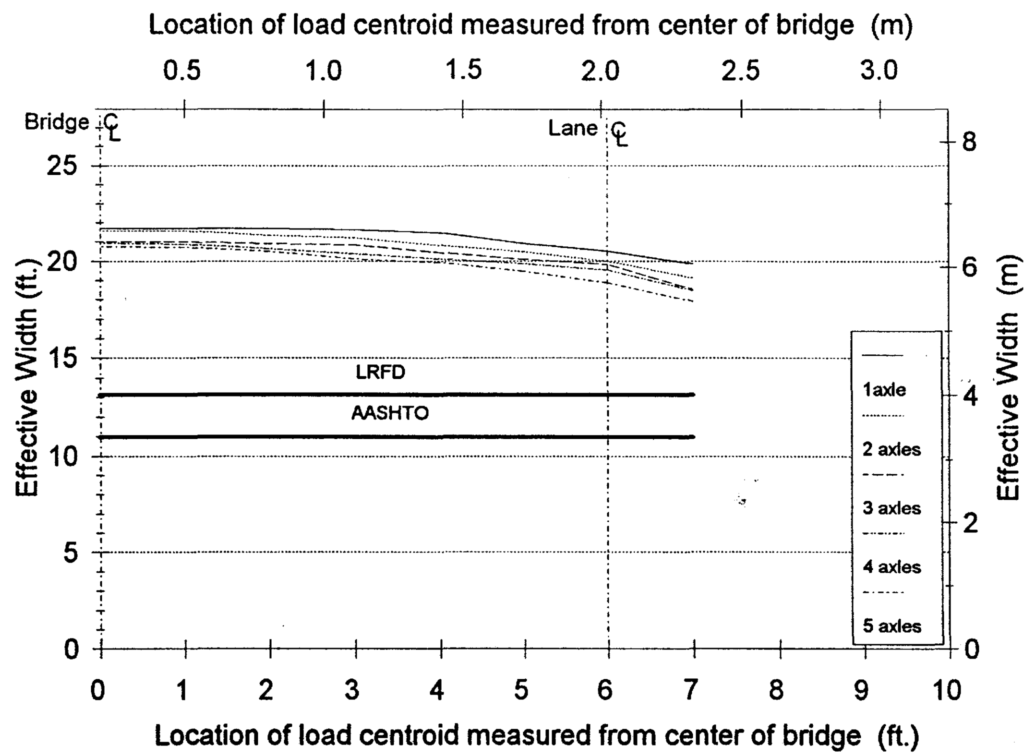


Figure E-9: Effective width of Cameron 80 within first span subjected to 11 ft. (3.4 m) gage axles.

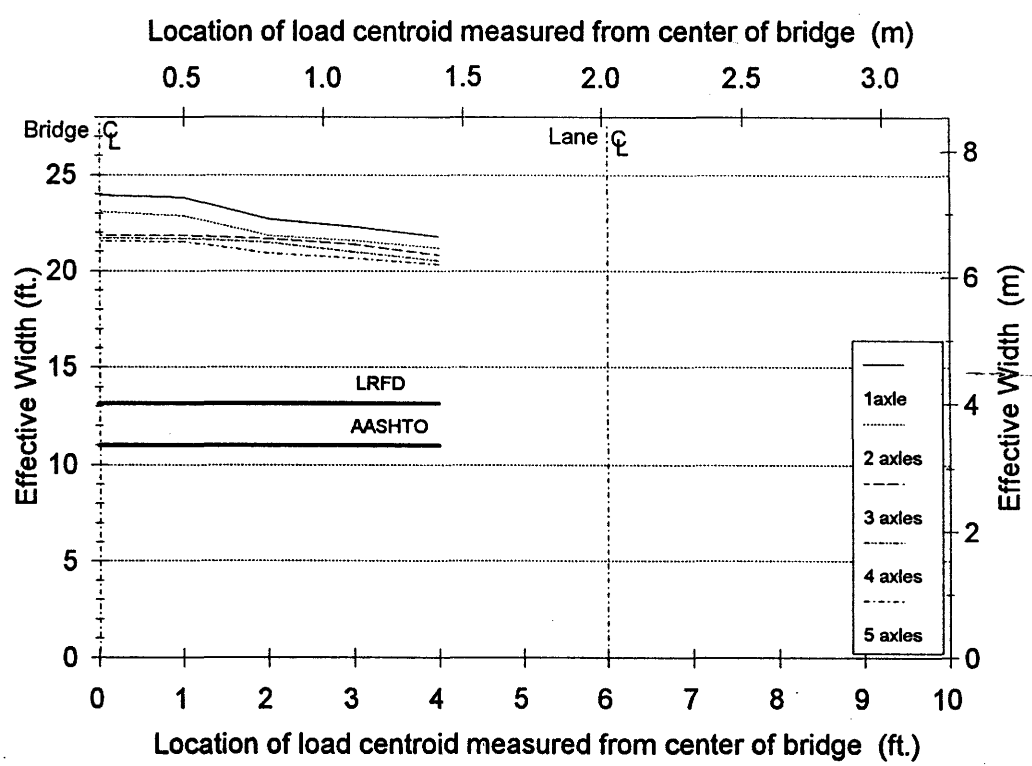


Figure E-10: Effective width of Cameron 80 within first span subjected to 16 ft. (4.9 m) gage axles.

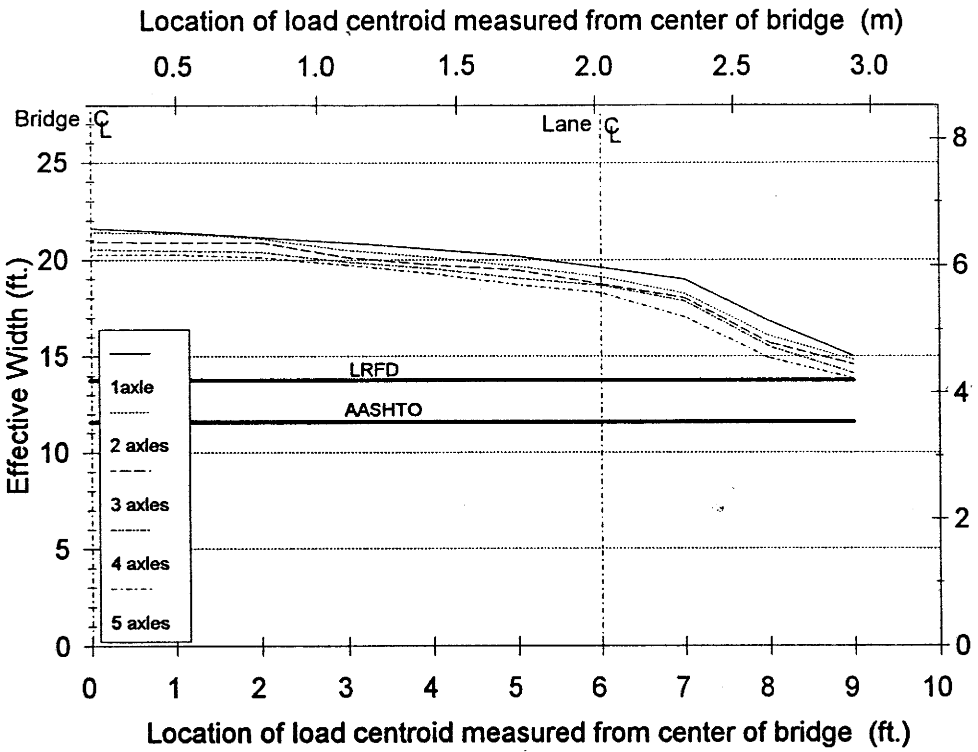


Figure E-11: Effective width of Cameron 80 within second span subjected to 6 ft. (1.8 m) gage axles.

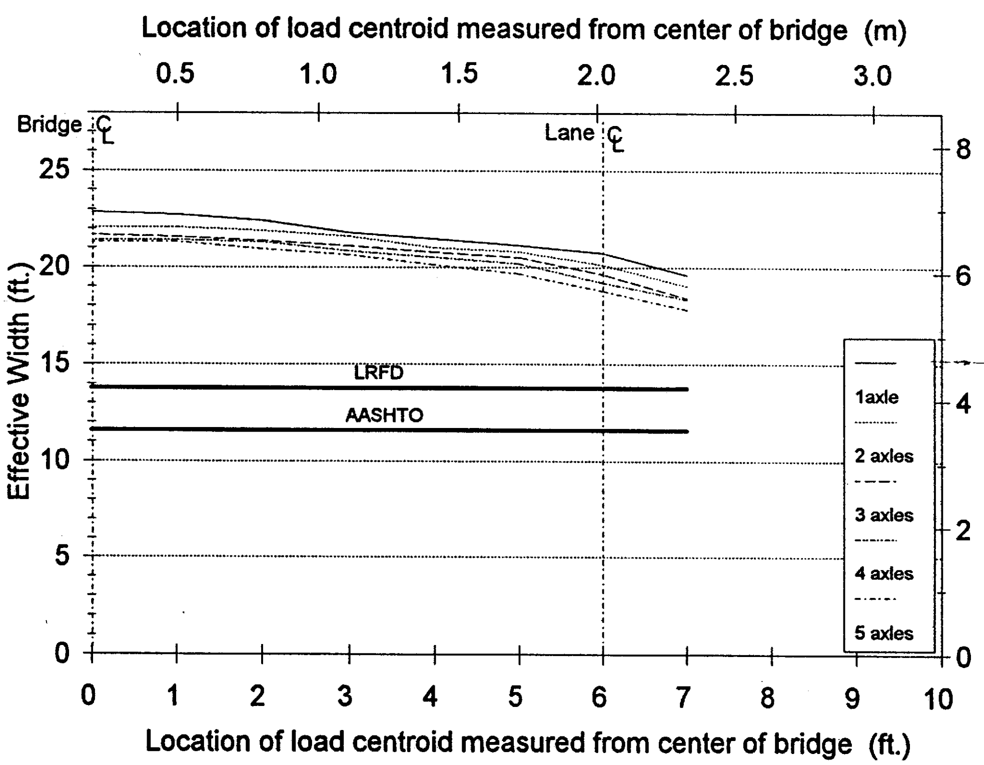


Figure E-12: Effective width of Cameron 80 within second span subjected to 11 ft. (3.4 m) gage axles.

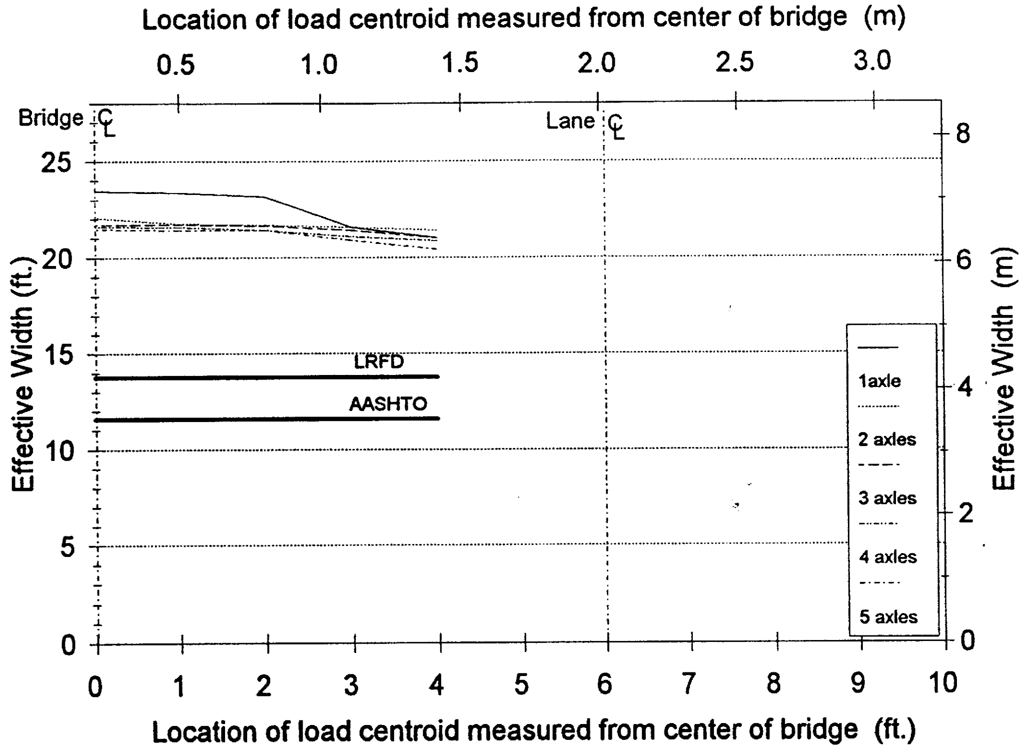


Figure E-13: Effective width of Cameron 80 within second span subjected to 16 ft. (4.9 m) gage axles.

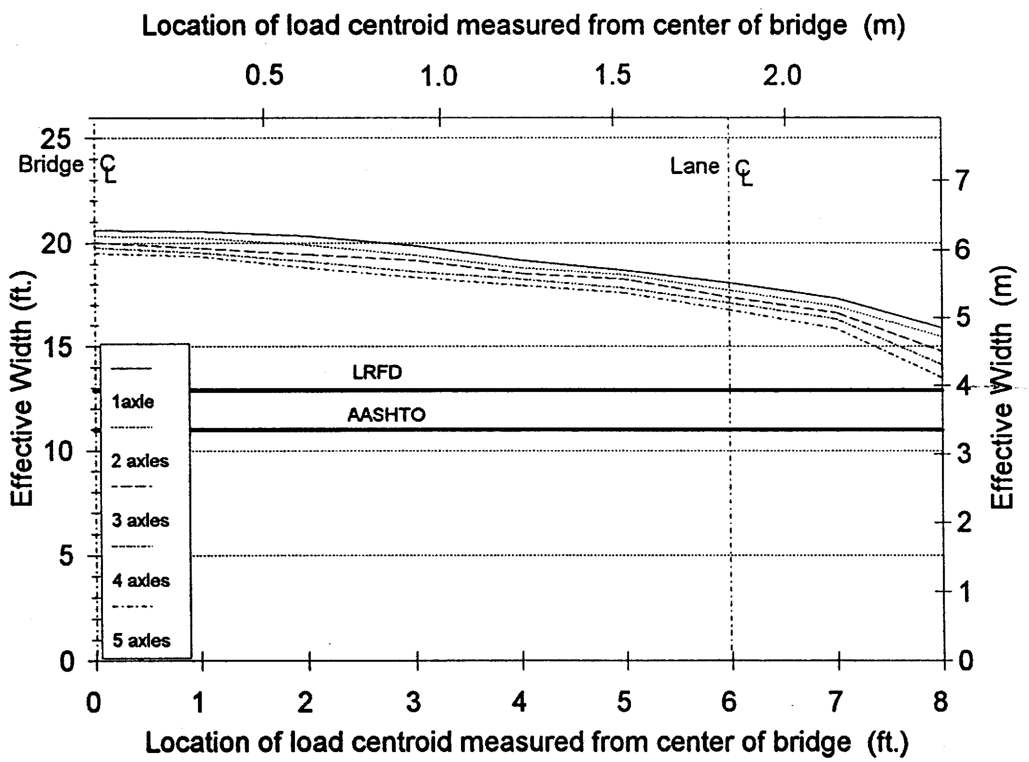


Figure E-14: Effective width of San Saba at first interior support subjected to 6 ft. (1.8 m) gage axles.

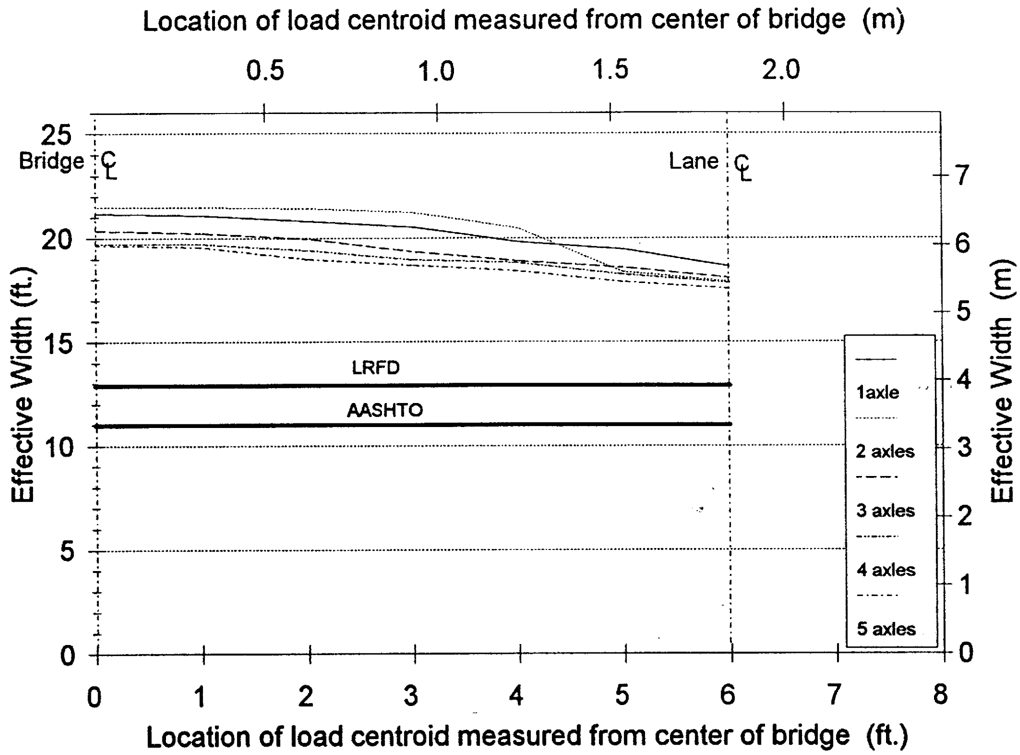


Figure E-15: Effective width of San Saba at first interior support subjected to 11 ft. (3.4 m) gage axles.

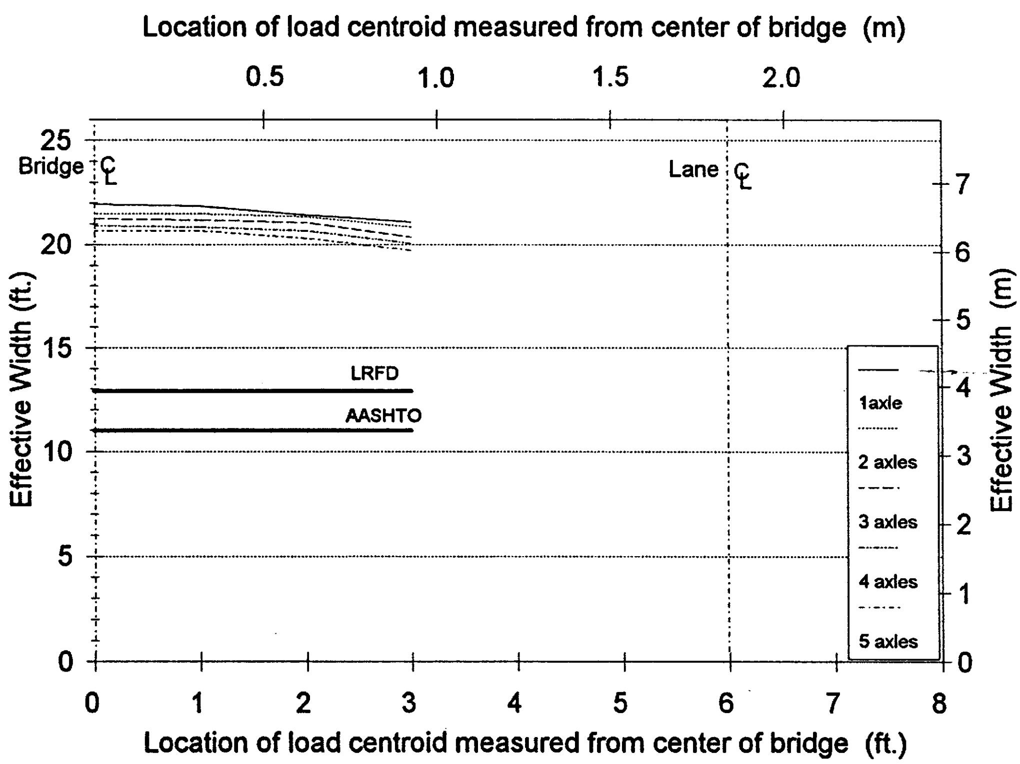


Figure E-16: Effective width of San Saba at first interior support subjected to 16 ft. (4.9 m) gage axles.

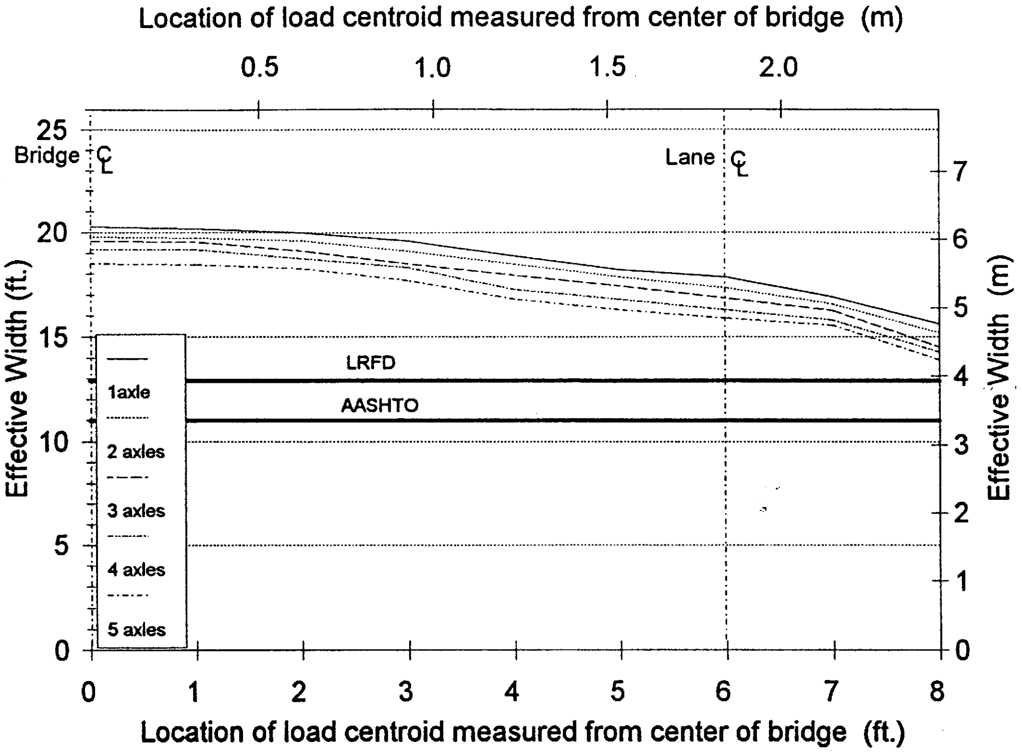


Figure E-17: Effective width of San Saba at second interior support subjected to 6 ft. (1.8 m) gage axles.

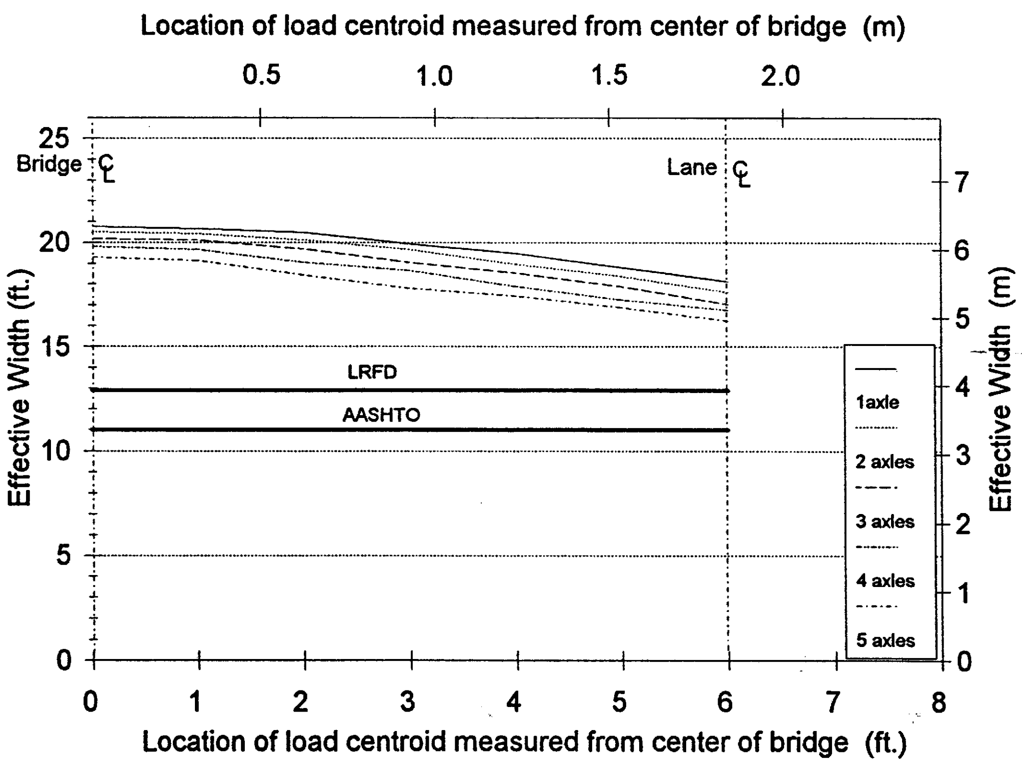


Figure E-18: Effective width of San Saba at second interior support subjected to 11 ft. (3.4 m) gage axles.

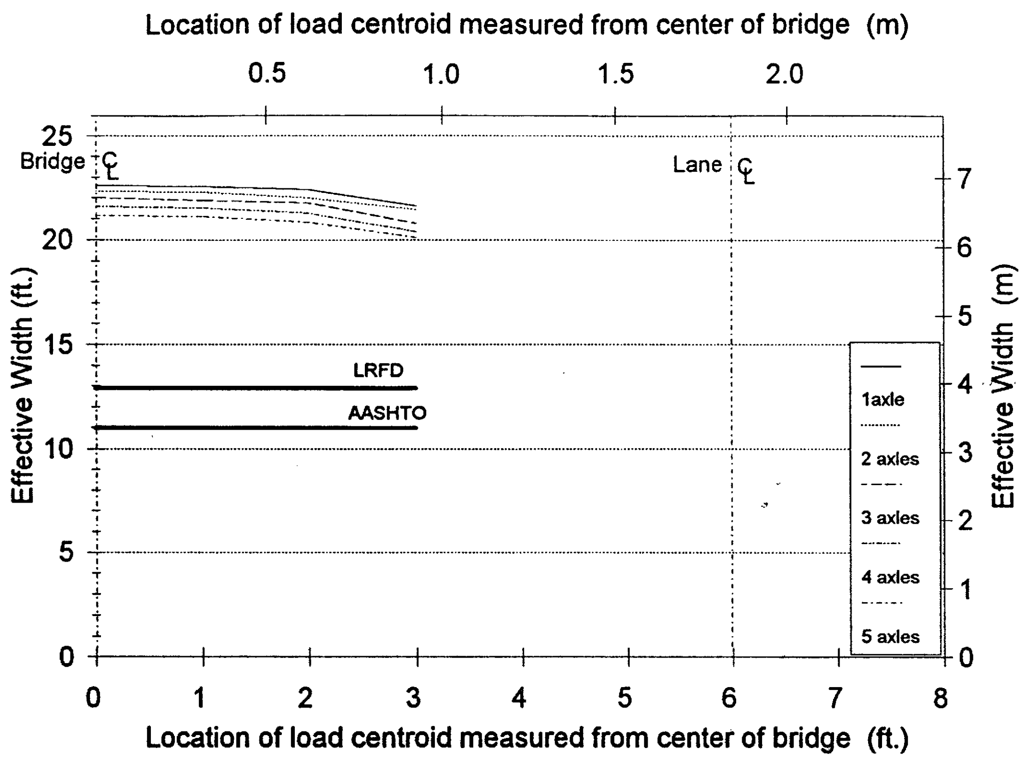


Figure E-19: Effective width of San Saba at second interior support subjected to 16 ft. (4.9 m) gage axles.

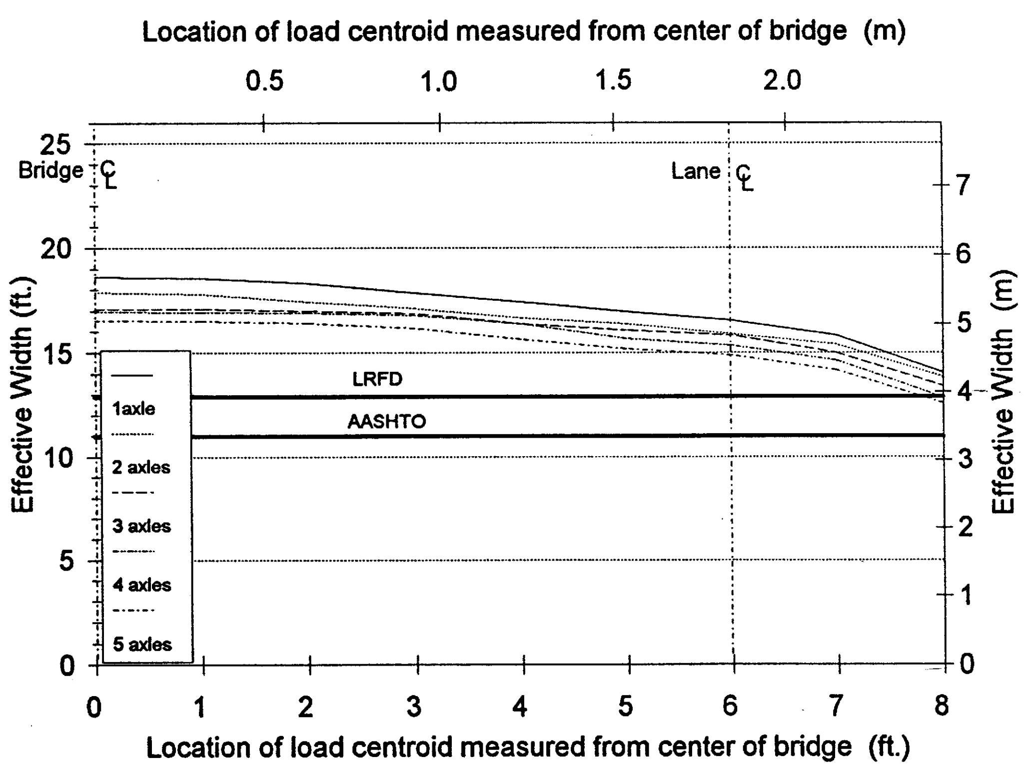


Figure E-20: Effective width of San Saba within first span subjected to 6 ft. (1.8 m) gage axles.

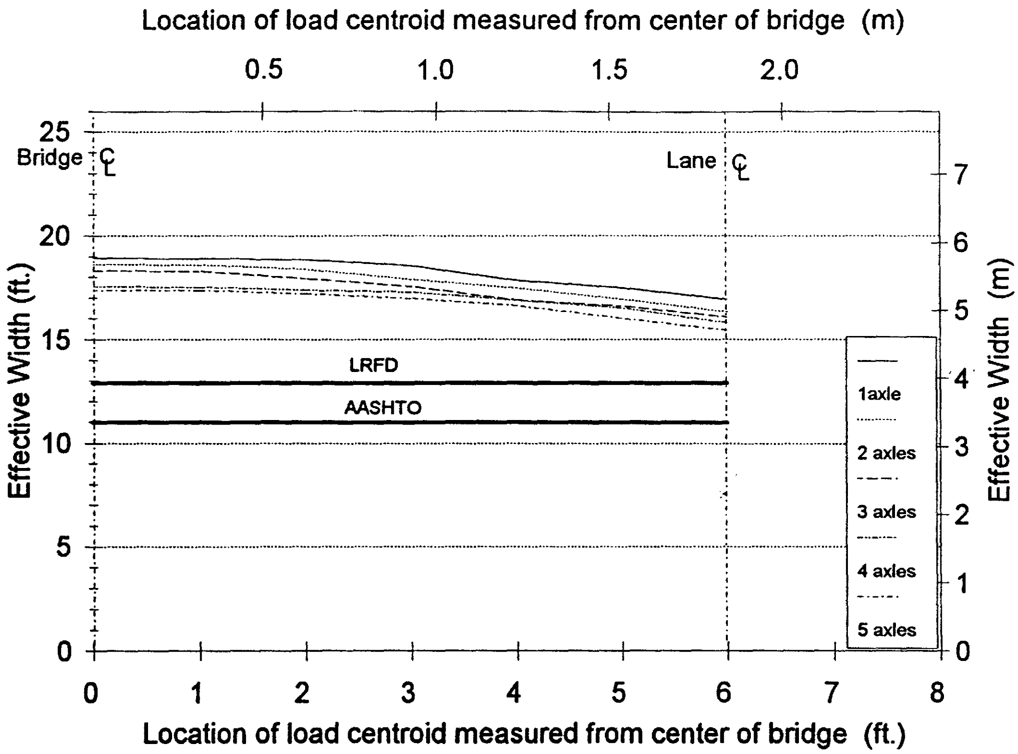


Figure E-21: Effective width of San Saba within first span subjected to 11 ft. (3.4 m) gage axles.

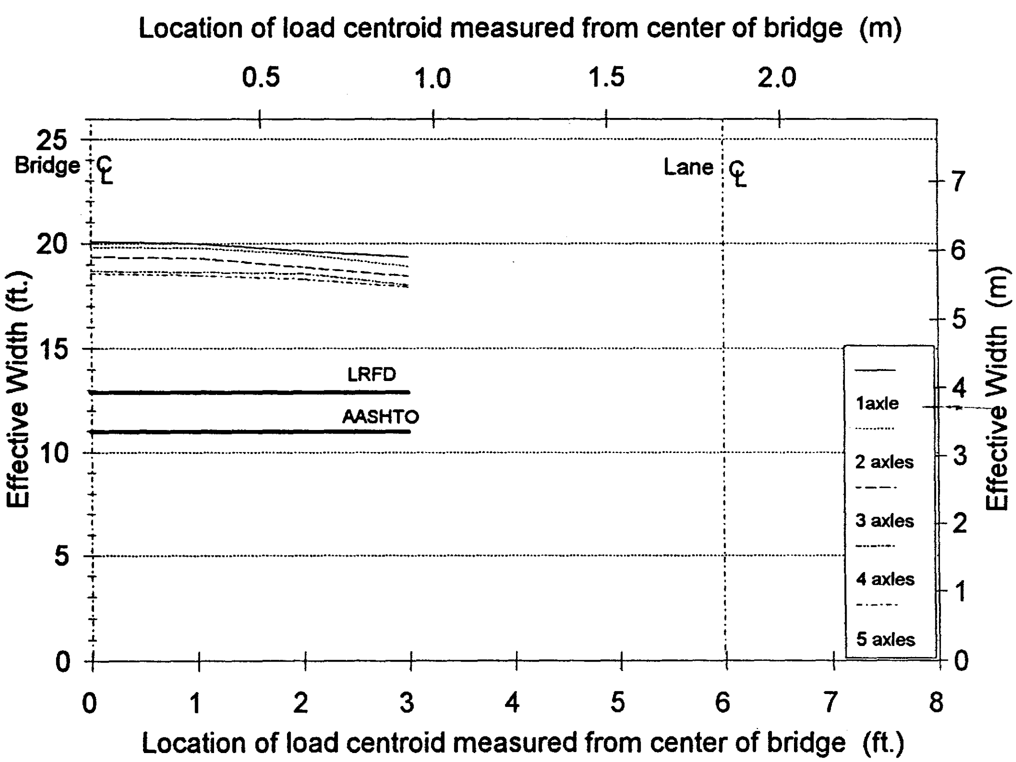


Figure E-22: Effective width of San Saba within first span subjected to 16 ft. (4.9 m) gage axles.

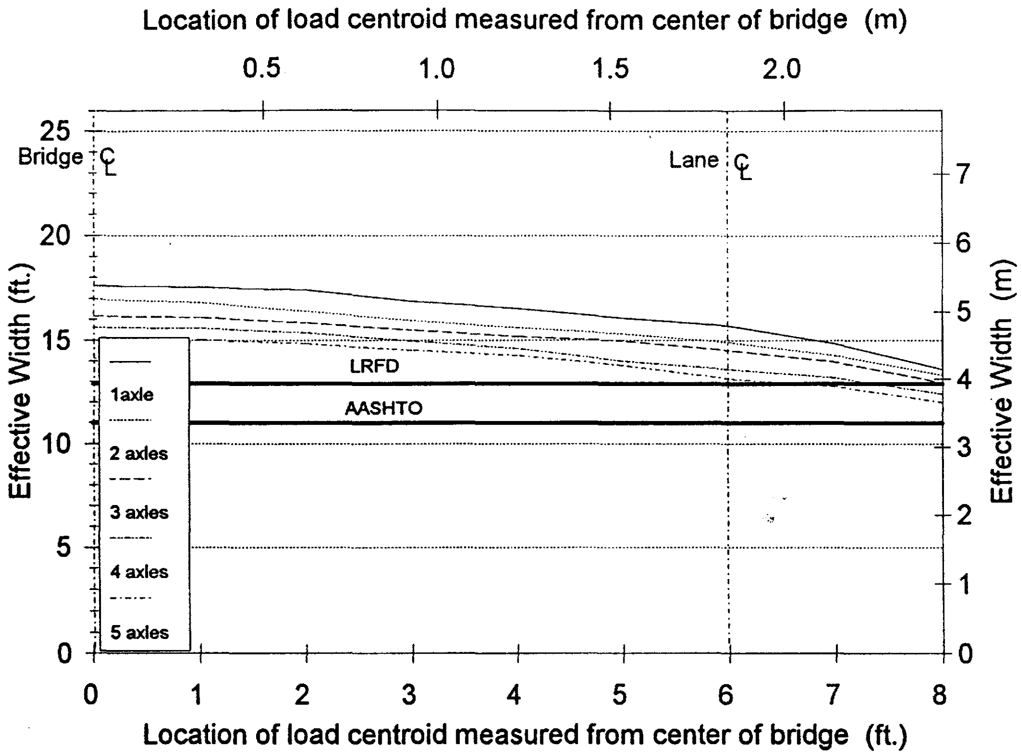


Figure E-23: Effective width of San Saba within second span subjected to 6 ft. (1.8 m) gage axles.

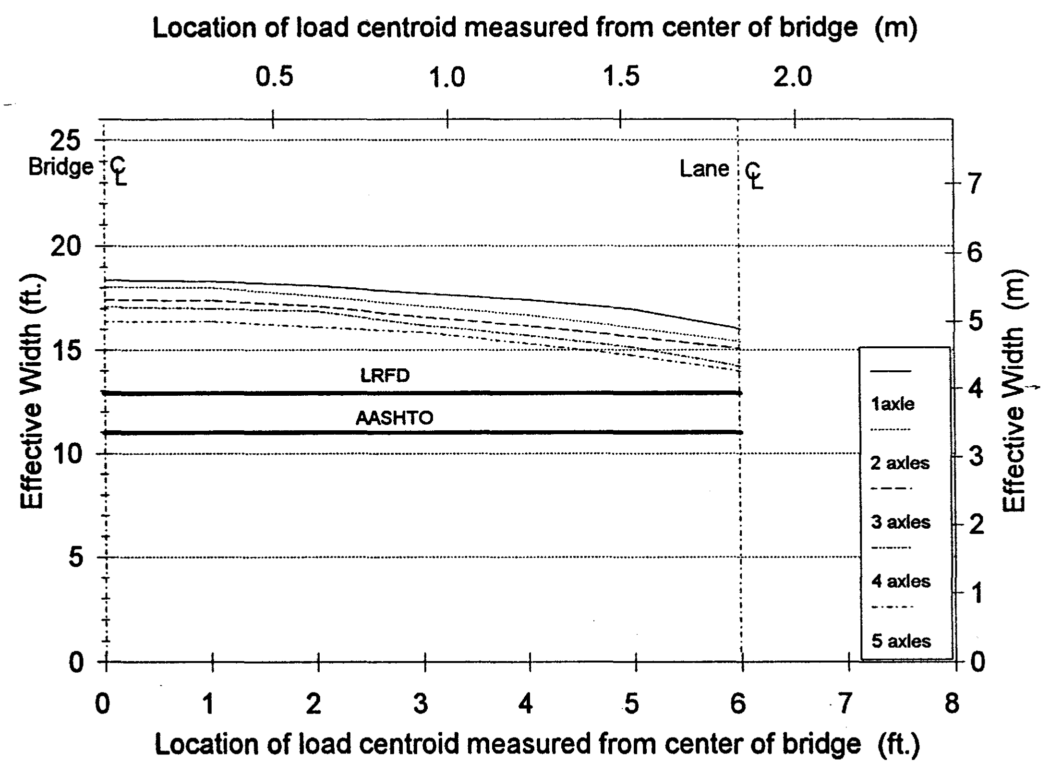


Figure E-24: Effective width of San Saba within second span subjected to 11 ft. (3.4 m) gage axles.

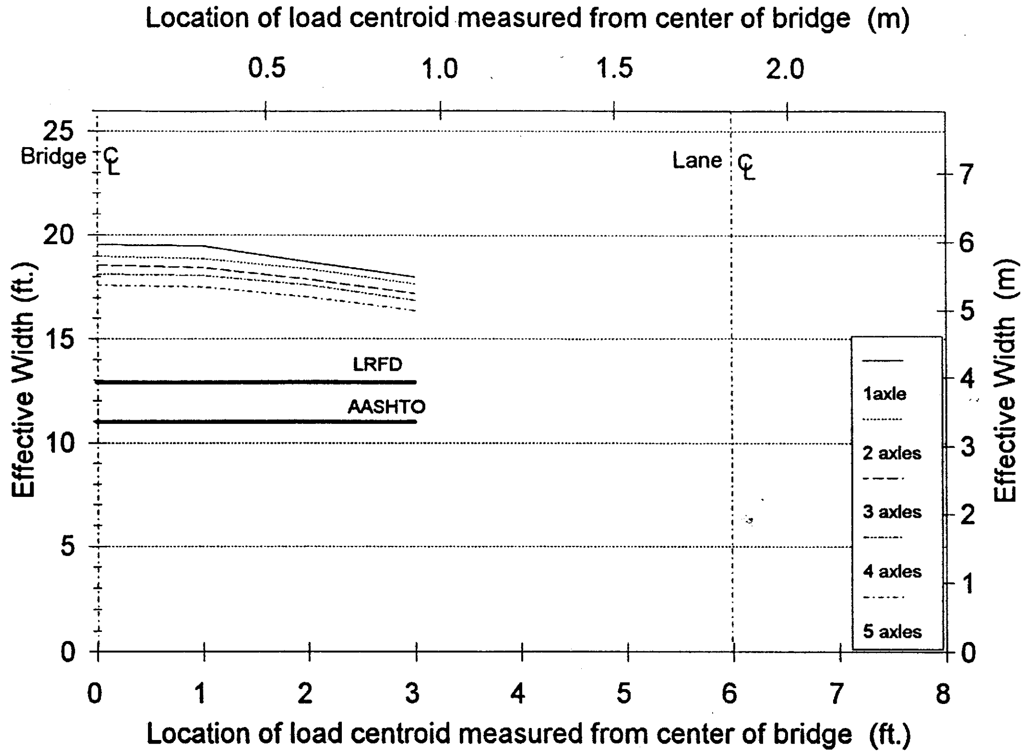


Figure E-25: Effective width of San Saba within second span subjected to 16 ft. (4.9 m) gage axles.

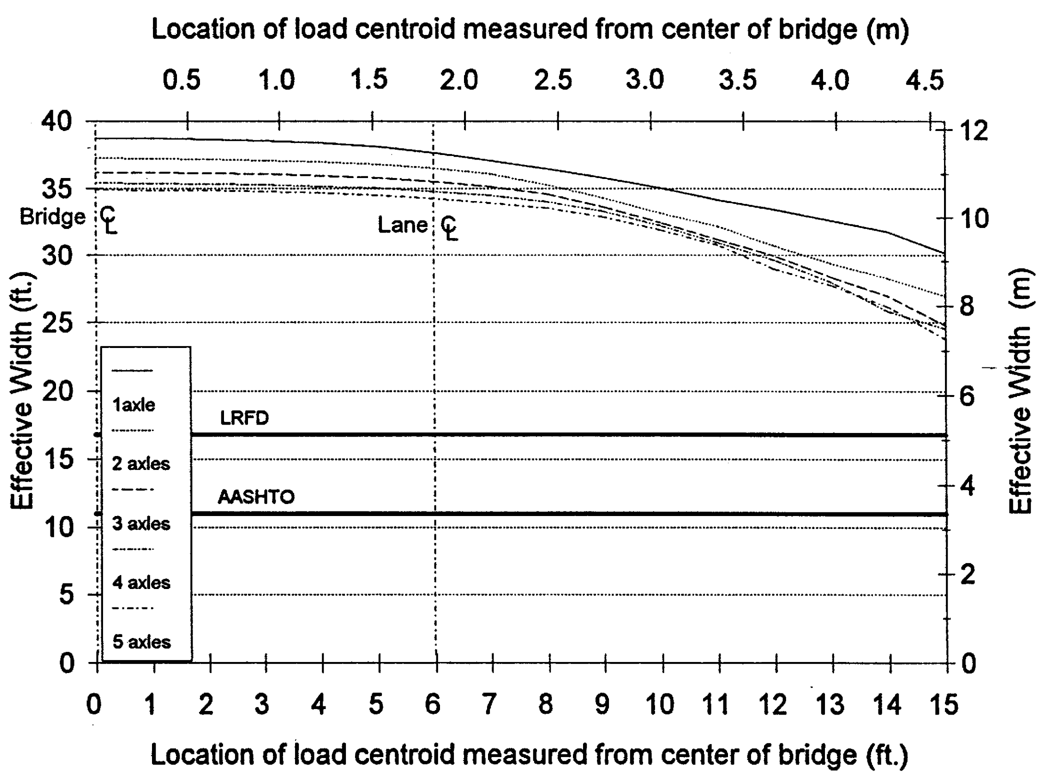


Figure E-26: Effective width of CS-0-38-50 at first interior support subjected to 6 ft. (1.8 m) gage axles.

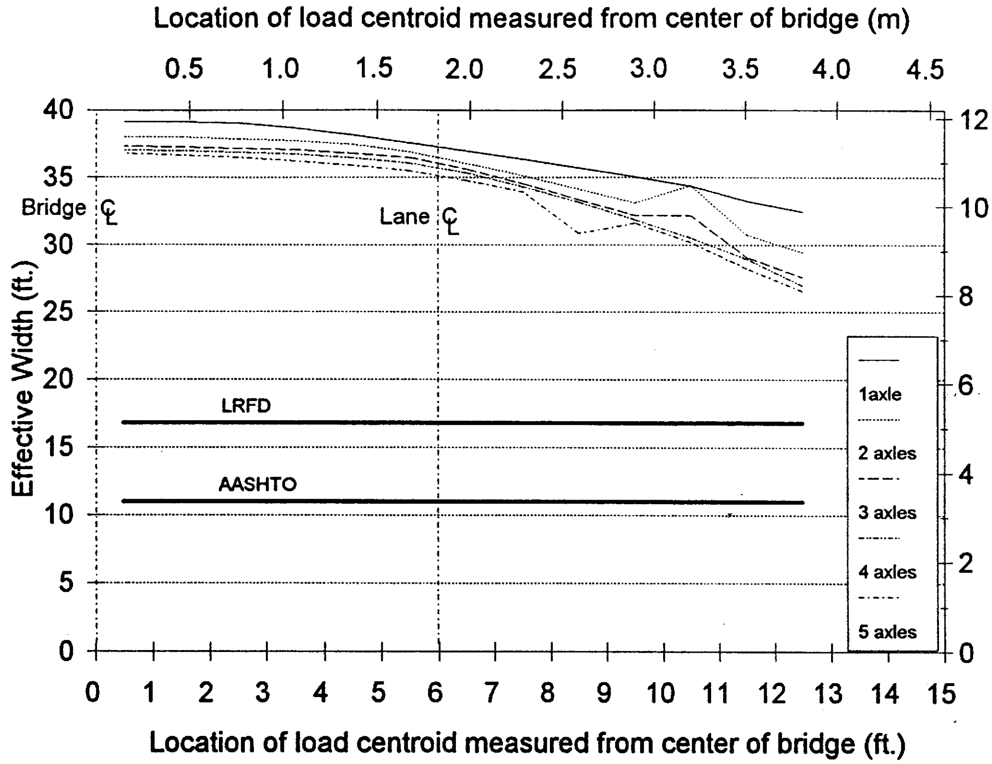


Figure E-27: Effective width of CS-0-38-50 at first interior support subjected to 11 ft. (3.4 m) gage axles.

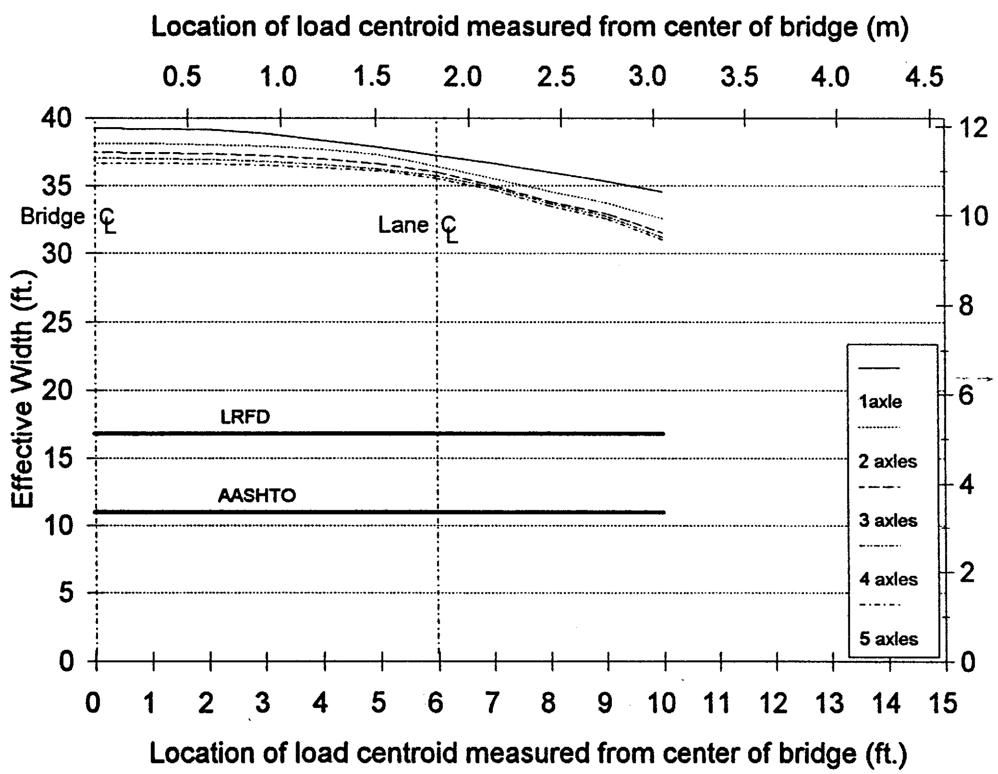


Figure E-28: Effective width of CS-0-38-50 at first interior support subjected to 16 ft. (4.9 m) gage axles.

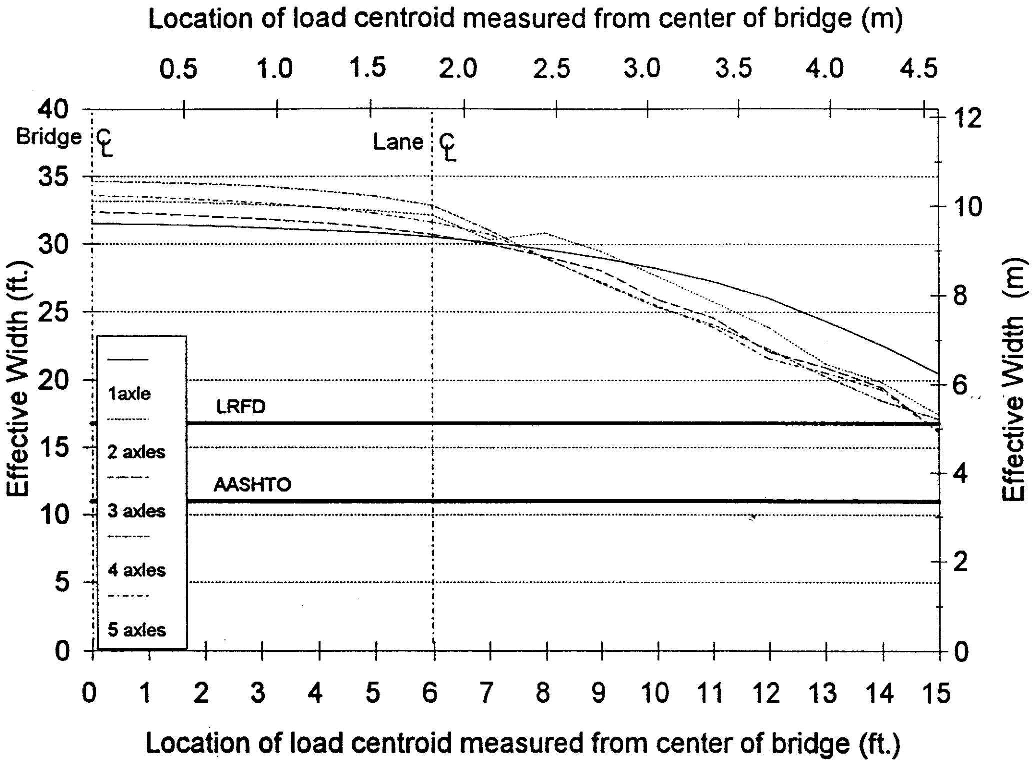


Figure E-29: Effective width of CS-0-38-50 within span subjected to 6 ft. (1.8 m) gage axles.

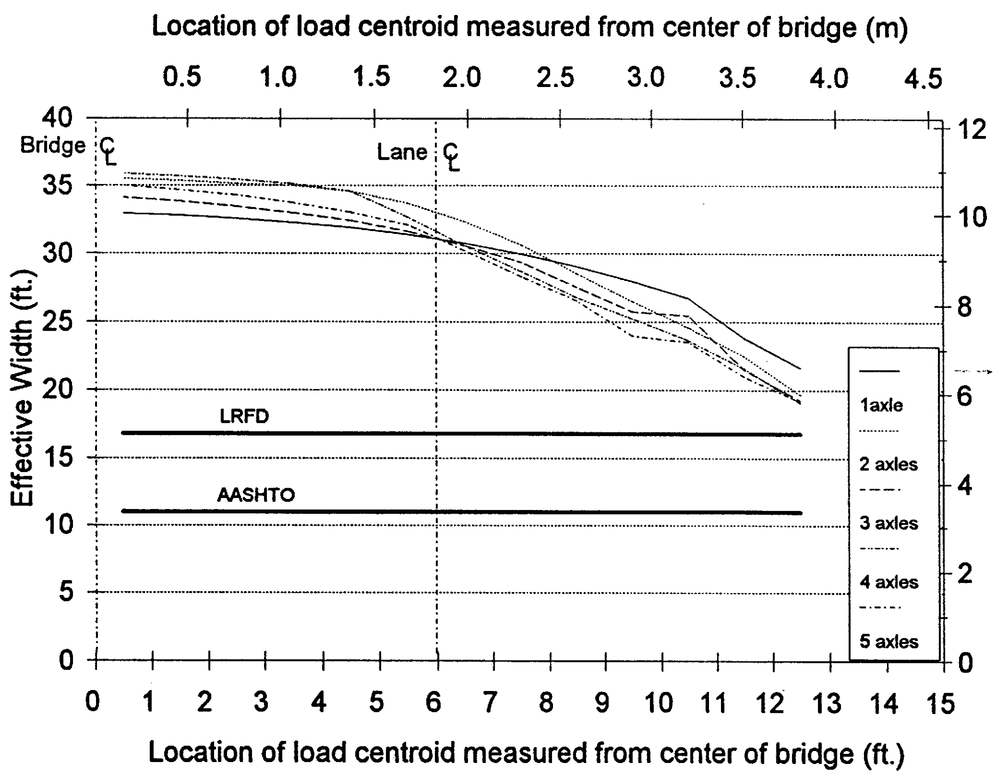


Figure E-30: Effective width of CS-0-38-50 within span subjected to 11 ft. (3.4 m) gage axles.

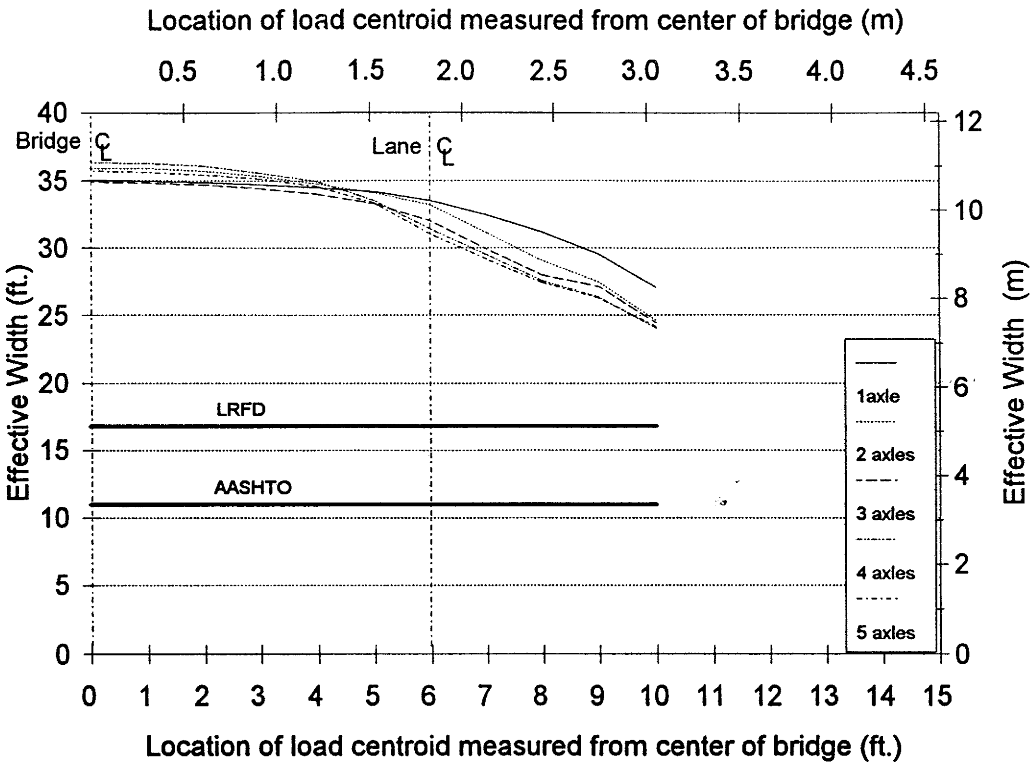


Figure E-31: Effective width of CS-0-38-50 within span subjected to 16 ft. (4.9 m) gage axles.