RECOMMENDATIONS FOR MICHIGAN SPECIFIC LOAD AND RESISTANCE FACTOR DESIGN LOADS AND LOAD AND RESISTANCE FACTOR RATING PROCEDURES

MDOT

Michigan Department of Transportation

CONSTRUCTION AND TECHNOLOGY DIVISION

Technical Report Documentation Page

1. Report No. R-1511	2. Government Accession No.	3. MDOT Project Manager
4. Title and Subtitle Recommendations for Michigan Specific Load and Resistance Factor Design Loads and Load and Resistance Factor Rating Procedures		5. Report Date April 2008 6. Performing Organization Code
7. Author(s) Rebecca Curtis, P.E., and Roger Till, P.E.		8. Performing Org. Report No.
9. Performing Organization Name and Address Michigan Department of Transportation Construction and Technology Division P.O. Box 30049 Lansing, MI 48909		10. Work Unit No. (TRAIS) 11. Contract No. 11(a). Authorization No.
12. Sponsoring Agency Name and Address Michigan Department of Transportation Construction and Technology Division P.O. Box 30049 Lansing, MI 48909		13. Type of Report & Period Covered Final Report, 3/07-3/08 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Load and Resistance Factor Rating (LRFR) code for load rating bridges and Load and Resistance Factor Design (LRFD) code for designing bridges are based on factors calibrated from structural load and resistance statistics to achieve a more uniform level of reliability for all bridges. The live load factors in the LRFR code are based on load data thought to be representative of heavy truck traffic nationwide. However, the code allows for recalibrating live load factors for a jurisdiction if weigh-in-motion data are available. The Michigan Department of Transportation anticipates implementing customized live load factors based on the analysis described in this report. Additional clarifications are made regarding gross vehicle weight to use for determining the live load factor and loading configurations for use with the LRFR code.

The revised LRFD live load factors and other LRFR recommendations are compared to the HL-93 loading and recommendations are made to meet the operational needs of the Michigan Department of Transportation.

17. Key Words		18. Distribution Statement	
LRFR, LRFD, HL-93, Load Rating, Live Load, Load Factors, Legal Load, Overload, Permit Load		No restrictions. This document is available to the public through the Michigan Department of Transportation.	
19. Security Classification - report	20. Security Classification - page	21. No. of Pages	22. Price
Unclassified	Unclassified	64	

MICHIGAN DEPARTMENT OF TRANSPORTATION
MDOT

Recommendations for Michigan Specific Load and Resistance Factor Design Loads and Load and Resistance Factor Rating Procedures

Rebecca Curtis, P.E. and Roger Till, P.E.

Structural Section
Construction and Technology Division

Research Report R-1511

Lansing, Michigan
April 2008

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY

The Load and Resistance Factor Rating (LRFR) code for load rating bridges and Load and Resistance Factor Design (LRFD) code for designing bridges are based on factors calibrated from structural load and resistance statistics to achieve a more uniform level of reliability for all bridges. The live load factors in the LRFR code are based on load data thought to be representative of heavy truck traffic nationwide. However, the code allows for recalibrating live load factors for a jurisdiction if weigh-in-motion data are available. The Michigan Department of Transportation anticipates implementing customized live load factors based on the analysis described in this report. Additional clarifications are made regarding gross vehicle weight to use for determining the live load factor and loading configurations for use with the LRFR code.

The revised LRFD live load factors and other LRFR recommendations are compared to the HL-93 loading and recommendations are made to meet the operational needs of the Michigan Department of Transportation.

ACTION PLAN

Engineering Operations Committee

- Approve Report R-1511, Recommendations for Michigan Specific Load and Resistance Factor Design Loads and Load and Resistance Factor Rating Procedures.

Design Division – Structures Section

- Implement the LRFD HL-93-mod loading that replaces the 25-kip tandem axle with a single 60-kip axle and adds a 1.2 factor to the lane and maximum of the truck or axle loading.

Bridge Operations Section

- Rate LRFR structures according to the modifications given in R-1511 including the modified live load factors and loading configurations.
- Engage a university consultant to review current practice and recommend a loading procedure for spans greater than 200 feet based on a reliability method. This issue is already an approved State Planning and Research (SPR) project.

Structural Section

- Research and recommend a method for adjusting Permit Loads for gage widths greater than 6 feet in a manner that would provide consistent results regardless of the method of rating of the structure (LFR or LRFR).
- Investigate loading scenarios and recommend method of rating of decks for Overloads and Superloads.

1.0 INTRODUCTION

The Load and Resistance Factor Rating (LRFR) code for load rating bridges and Load and Resistance Factor Design (LRFD) Code for designing bridges are based on factors calibrated from structural load and resistance statistics to achieve a more uniform level of reliability for all bridges. The live load factors in the LRFR code are based on load data thought to be representative of heavy truck traffic nationwide. However, the code allows for recalibrating live load factors for a jurisdiction if weigh-in-motion (WIM) data are available. The Michigan Department of Transportation (MDOT) anticipates implementing customized live load factors based on the analysis described in this report. Additional clarifications are made regarding gross vehicle weight to use for determining the live load factor and loading configurations for use with the LRFR code.

More than 30,000 Overweight Permits have been issued each year since 2002, providing a vital service to Michigan's economy. The revised LRFD live load factors and other LRFR recommendations are compared to the HL-93 loading and recommendations are made to meet the operational needs of the Michigan Department of Transportation and our motorists.

2.0 BACKGROUND

A number of changes have been instituted in the bridge design/load rating community. In 2000, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) set a transition date of October 1, 2007 after which all new bridges that states initiate preliminary engineering shall be designed by the Load and Resistance Factor Design (LRFD) Specifications. While FHWA created a sample LRFD Implementation Plan to aid states in adopting the new specifications, the document did not mention comparing structures designed by LRFD to Load and Resistance Factor Rating (LRFR).

While the FHWA does not intend to mandate re-rating existing and valid bridge load ratings by LRFR, they are requiring that beginning in 2010, all structures designed by LRFD must also be rated using LRFR.

The standard resource for bridge load rating according to LFR is the Manual for Condition Evaluation of Bridges[1], while the LRFR resource is the Guide Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges (Guide Manual)[2]. The two manuals are currently being combined into a new reference, the Manual for Bridge Evaluation (MBE). This reference is scheduled to be released in 2008 by AASHTO. A preliminary version of the MBE is referenced in this report.

Michigan legal loads are greater than the AASHTO legal loads that were used in the development of the AASHTO Standard Specifications for Highway Bridges and LRFD codes. The AASHTO Legal Loads are also used as the legal load of numerous states. Because of this, Michigan has, in the past, adjusted the AASHTO design truck to account for the heavier loads.

---

[1] Manual for Condition Evaluation of Bridges, Second Edition, AASHTO.
[2] Guide Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges, First Edition with 2005 Interim Revisions, AASHTO.

The HS-25 truck was derived by multiplying the axle loads of the AASHTO HS-20 truck by 1.25. The HS-20 truck has axle weights of 8,000 pounds, 32,000 pounds, and 32,000 pounds for a total truck weight of 72,000 pounds or 36 tons. However, in Michigan, legal loads can weigh as much as 164,000 pounds or 82 tons, spread over 11 axles.

3.0 LOAD RATING

The operational ratings used by MDOT can be separated into 3 categories: Federal Ratings, Michigan Legal Loads and Overload Classification. In general, the Federal Ratings are for informational purposes only in order to provide FHWA with a common reference point for comparing structures within a state and across the country, and do not directly measure the operational capacity of a structure in Michigan. The Legal Loads and Overload Classifications are the items that have a direct impact on motorists and industry. A number of assumptions have been made in this report. They are:

- The bridges rated using LRFR were designed by LRFD.
- The future wearing surface "allowance" in LRFD has been placed at the time of the operational ratings.
- The Average Daily Truck Traffic (ADTT) in one direction of the structures is greater than 5000, as this would apply to freeway structures that would generally also be carrying the heaviest loads.
- The structure is designed as efficiently as possible (meaning that no reserve capacity is available).

4.0 FEDERAL RATINGS - INVENTORY AND OPERATING

The MBE refers to the Federal Inventory and Operating Ratings as the "Design Load Rating" (6A.1.7.1)[3]. This rating is "a measure of the performance of existing bridges to current LRFD bridge design standards" in "its present as-inspected condition". This analysis screens bridges for the strength and service limit designs. Table 1 in this report is taken from Table 6A.4.3.2.2-1[4] of the MBE.

Table 1
Design-Load Rating Live Load Factors for the Strength I Limit State

Evaluation Level	Load Factor
Inventory	1.75
Operating	1.35

As the structure would have been designed for the loading and load factors required at the Federal Inventory Level, this rating factor would be a minimum of 1. Most likely, due to choosing standard sizes and other engineering decisions, this rating would be greater than one. The Federal Operating Rating would then be 1.3, regardless of whether strength or service limit states controlled.

[3] Section 6.1.7.1 in the "Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges" (Guide Manual).
[4] Table 6-4 in the Guide Manual.

Even if MDOT adopts a design loading greater than HL-93, the Federal Inventory and Operating Ratings must be calculated at the HL-93 level in order to be consistent with national standards. This report recommends that the calculation of Federal Inventory and Operating Ratings remains at the unmodified HL-93 loading using load factors identified in the MBE Table 6A.4.3.2.2-1.

5.0 AXLE WEIGHTS ON THE BRIDGE AFFECTS THE LOAD FACTOR

In the MBE[5], the load rating of permits has been calibrated to provide a uniform and acceptable level of reliability for these heavy vehicles. The live load distribution for LRFR is based upon the simultaneous side-by-side presence of two equally heavy vehicles in each lane. The authors of the LRFR method found this to be conservative. The load factors for permit trucks were lowered to account for the permit vehicle in one lane and simultaneous heavy, non-permit trucks in the other available lanes. For an ADTT of 5000 or greater, one way, the lower bound of the permit truck is set to 100-kips with a live load factor of 1.8 to match with legal loads. As the weight of the permit truck increases to 150-kips, the live load factor is linearly interpolated to 1.3. Vehicles with a gross vehicle weight greater than 150-kips use a constant live load factor of 1.3.

One complication in the MBE[6] is that only the axle weights on the bridge can be included in the interpolation of permit load factors, and therefore shorter spans do not get the full benefit of this reduction. This would require close inspection to get the true maximum combination of moment and load factor based on axle placement, weight on the span, and resultant load factor. This check is designed for short spans where a small group of axles and not the entire vehicle would control the loading. It is possible that a 50-kip truck could have a 20-kip tandem axle that exceeds the calculated capacity of a structure when using the 1.8 live load factor. Now consider a second vehicle that also has a 20-kip tandem axle that is isolated from the other axles on the truck. If the total weight of the vehicle was 150-kip, the live load factor would be reduced to 1.3. The heavier truck, although it creates the same force effect on the structure as the smaller vehicle, would be allowed to pass as the live load factor is reduced. The authors of the MBE considered this situation to be unreasonable, and added the axle weight restriction.

Michigan requires the analysis of twenty-eight vehicles for legal loading. The AASHTO legal load rating includes only three vehicles (and possibly the Notional Rating Load from the proposed MBE). An additional twenty vehicles are analyzed to find the Overload Classification. The number of trucks is an acknowledgement of the unique loading situation in Michigan. This increased level of detail from the standard, on which the code is based, addresses the concern of restricting the structure for axle weights on smaller structures and for identifying the Overload Classification used in evaluating routine permit loads. Load Posting and Overload Classification are all-or-nothing situations, where the amount by which each truck passes the limit (a Rating Factor of 1.0) does not impact the final result. As long as the rule is satisfied for all vehicles, RF≥1.0, the trucks of those types and Gross Vehicle Weight (GVW) or less are allowed to pass over the structure. When a structure does require posting, it is possible that certain heavy vehicles may be affected by this check, as 1, 2 and 3-unit vehicles are separated for signing.

---

[5] Subsection 6A.4.5.4.2 in the MBE and Subsection 6.4.5.4.2 in the Guide Manual.
[6] Table 6A.4.5.4.2.1-1 in the MBE and Table 6-6 2 in the Guide Manual.

If any of the rating factors for the vehicles in the Permit Class are less than 1.0, then the entire Overload Classification drops until the rating factors for all twenty vehicles are greater than or equal to 1.0. In certain cases, vehicles with axle weights or gross vehicle weights in excess of the overload classifications are required for transport of goods. These vehicles are referred to as “Superloads” and require analysis of the specific vehicle, weights, and structure. For Superload situations the axle weights may affect the final result. This report recommends the following:

1. MDOT base the load factor on the GVW for a standard analysis.
2. MDOT base the load factor on the portion of the vehicle on the span for Load Postings and Superload analyses.

6.0 MICHIGAN LEGAL LOAD RATINGS – LEGAL VEHICLES

According to the MBE[7] subsection 6A.4.3.1:

> Bridges that pass HL-93 screening at the Inventory level will have adequate capacity for all AASHTO legal loads and State legal loads that fall within the exclusion limits described in the *AASHTO LRFD Bridge Design Specifications*.

The exclusion vehicles are shown in Appendix A. The Michigan Legal Loads are shown in Appendix B. Designated Loading will be used to compare Michigan Legal Loads with the LRFR Legal Load Ratings. According to the MBE[8] subsection 6A.2.3.1:

> State legal loads significantly heavier than the AASHTO legal loads should be load rated using the load factors specified for routine permits in this Manual, if the span has sufficient capacity for AASHTO legal loads.

In practice, the routine permit vehicles are treated differently than legal loads by the MBE when the GVW exceeds 100-kips. This is the threshold for modifying the live load factor. Table 2 summarizes the Michigan Legal Loads that are greater than 100-kips. While the Gross Vehicle Weight of some of the Exclusion Vehicles approaches the maximum of the Michigan Legal Loads (149.0-kip versus 154-kip), the load is spread over a much longer vehicle (73 feet versus 49.5 feet) in the exclusion case. As shown, a number of the 2 and 3-unit trucks exceed the effects of the Exclusion Vehicles, with ratios as high as 1.34.

[7] Subsection 6.4.3.1 in the Guide Manual.
[8] Subsection 6.2.3.1 in the Guide Manual.

Table 2
Ratio of Unfactored MI Legal Load Truck Moment with Impact to Unfactored HL93 loading or Exclusion Truck with Impact

Span	Michigan Truck Number												
(ft)	#6	#7	#12	#13	#14	#15	#16	#17	#18	#21	#22	#23	#25
30	-	-	-	-	-	-	1.01	1.04	1.04	-	-	-	-
40	-	-	-	-	-	-	1.05	1.10	1.09	-	-	-	-
50	-	-	-	-	1.03	-	1.13	1.19	1.17	-	-	1.05	1.04
60	-	-	1.01	1.01	1.11	1.04	1.20	1.27	1.24	1.01	1.07	1.15	1.13
70	-	-	1.05	1.08	1.17	1.14	1.26	1.34	1.31	1.11	1.16	1.24	1.23
80	-	-	1.04	1.06	1.15	1.14	1.23	1.32	1.30	1.14	1.19	1.25	1.25
90	-	-	-	1.03	1.10	1.11	1.18	1.27	1.25	1.12	1.17	1.21	1.23
100	-	-	-	-	1.07	1.09	1.14	1.23	1.21	1.10	1.16	1.18	1.21
110	-	-	-	-	1.05	1.07	1.11	1.20	1.19	1.09	1.15	1.16	1.19
120	-	-	-	-	1.03	1.06	1.09	1.17	1.17	1.08	1.14	1.15	1.18
130	-	-	-	-	1.01	1.05	1.07	1.16	1.16	1.07	1.13	1.13	1.17
140	-	-	-	-	-	1.04	1.06	1.14	1.14	1.07	1.13	1.13	1.17
150	-	-	-	-	-	1.03	1.05	1.13	1.14	1.06	1.12	1.12	1.16
160	-	-	-	-	-	1.03	1.04	1.12	1.13	1.06	1.12	1.11	1.15
170	-	-	-	-	-	1.02	1.03	1.11	1.12	1.06	1.12	1.10	1.15
180	-	-	-	-	-	1.02	1.02	1.11	1.11	1.05	1.12	1.10	1.15
190	-	-	-	-	-	1.01	1.02	1.10	1.11	1.05	1.11	1.09	1.14
200	-	-	-	-	-	1.01	1.01	1.10	1.10	1.05	1.11	1.09	1.14

As it is unwieldy to calculate moments of a certain truck and then compare to the exclusion vehicles for any given span configuration, this report shall treat all trucks greater than 100-kips as Legal-Heavy Vehicles. Trucks 6 and 7 are therefore included as Legal-Heavy Vehicles even though they do not exceed the Exclusion Truck Moment Envelope. Legal-Heavy Vehicles are to be differentiated from Overload-Permit Vehicles, which will be discussed later in the report. It is reasonable to combine MI Trucks 6-7, 12-19 and 21-25 with the load factors specified for Permit Vehicles in Table 6A.4.5.4.2.1-1[9] of the MBE. The benefit of treating these heavy vehicles as Permit Vehicles is that the load factor is reduced on a sliding scale as the weight increases for Strength I/II Limit State checks. The load factor for Service II checks (steel structures only) is reduced from 1.3 to 1.0 for Service II Limit State checks.

Adding this load factor reduction into the equation reduces the ratio of the factored Design HL-93 Load Moment to the factored MI Legal Load Truck Moment by up to 30 percent. Table 3 lists the few truck and span combinations that exceed a ratio of 1.0.

[9] Table 6.6 in the Guide Manual.

Table 3
Ratios 1.00 or Greater of Factored Michigan Legal Load Truck Moment plus Impact to Factored HL-93 Design Moment plus Impact (Ignoring Axle Groupings, see Section 6)

SPAN	#14	#16	#17
60	-	1.02	-
70	1.00	1.04	1.01
80	1.01	1.04	1.02
90	1.01	1.03	1.02
100	-	1.02	1.01
110	-	1.01	-

As shown in Table 3, even with the “permit” sliding load factors, some legal truck/span configurations exceed the designed condition.

7.0 OVERLOAD CLASSIFICATION – OVERLOAD PERMIT VEHICLES

In addition to legal loads, structures are also rated to assign an overload classification for standard permit vehicles. In the current system under the 2005 Bridge Analysis Guide[10] (BAG), these trucks are assumed to occupy a single lane on the structure and therefore a lower girder distribution factor is used. However, in the MBE[11] single lane distributions are reserved for vehicles that would cross the structure less than 100 times during the structure’s lifetime. Under these definitions, the current permit vehicles that MDOT uses for overload classification would be considered Routine or Annual Permits and would need to be analyzed using multi-lane distribution factors and the load factors discussed above for the Legal-Heavy Vehicles. Special or Limited Crossing permit loads should be analyzed using single lane girder distribution factors, load factors based on the ADTT of the structure and whether or not the truck is escorted.

The Michigan Overload Trucks are presented in Appendix C. Figure 1 shows the ratio of Factored Moments with Impact for Legal Loads and the Overload Classes to the factored HL93 moments with Impact. As shown, the maximum ratio is 1.59 for Classes A, B and C as Trucks 1 and 2 are the same for all classes and control for 10 feet spans.

[10] Bridge Analysis Guide, 2005 Edition, Michigan Department of Transportation.
[11] Subsection 6A.4.5.4 in the MBE or Subsection 6.4.5.4 in the Guide Manual.

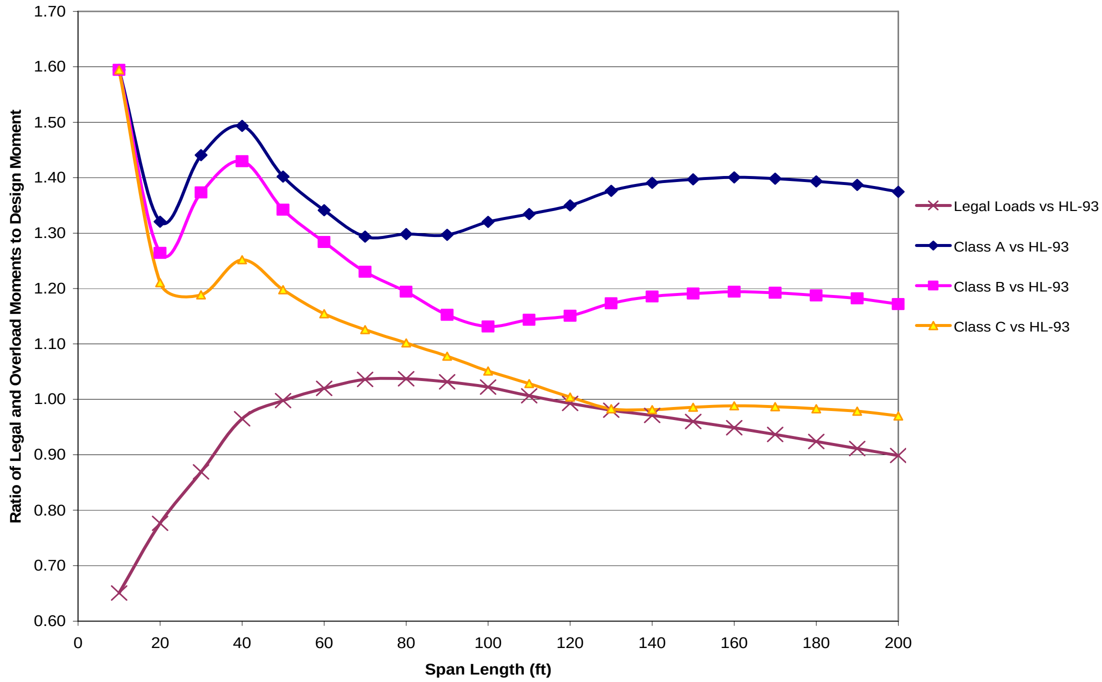


Figure 1
Ratios of Factored MI Legal and Overload Truck Moments
With Impact to Factored HL-93 Design Moment with Impact

8.0 LOAD FACTOR DESIGN (LFD) HS-25 VERSUS LOAD FACTOR RATING (LFR) LEGAL AND OPERATING LOADS

The Legal and Operating Moments with load factors are generally less than the HS-25 LFD Design Loading. Figure 2 illustrates the ratios of the maximum factored MI Legal Load including impact and the maximum factored Overload moment including impact for each class compared to the factored HS-25 design loading including impact. As shown, the maximum legal load ratio is below 1.00, while the maximum Class A load ratio is less than 1.10. The design load factor is 2.17, while the operating load factor for legal and overload moments is 1.3. The Overload Moments were reduced by a factor of 11/14 (0.785) to account for a single lane distribution.

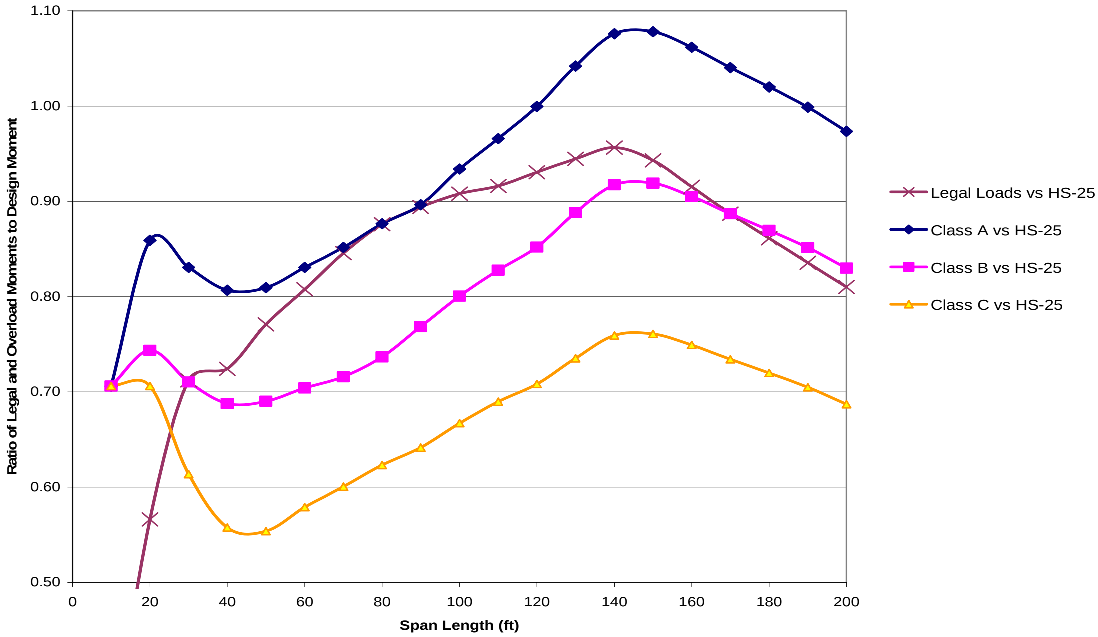


Figure 2
Maximum Ratios of Factored MI Legal Truck Moments Including Impact and Overload Truck Moments Including Impact to Factored HS-25 Design Moment Including Impact (LFR vs. LFD)

9.0 LRFR – RECOMMENDED REFINEMENTS

The results of switching to LRFR/LRFD from LFR/LFD are quite significant for Michigan. Under the previous design/rating system, the design moments would allow most new structures to carry all legal loads and Class A overloads for permits. For the typical maximum span length between 70 and 80 feet, there is a 10-15 percent allowance for many unknowns – future overlays (in excess of the 25-psf accounted for in design), possible deterioration, and Superload Vehicles (vehicles heavier than Overload Classes). However, in the LRFR/LRFD system, new structures (if designed 100 percent efficiently) would have some span lengths that did not meet legal loads and would most likely be restricted from Overloads, as shown in Figure 1. According to the Permits Section, more than 30,000 Overweight Permits have been issued each year since 2002, providing a vital service to our State's economy. The new design/rating system, if left unmodified, would prevent these vehicles from driving across any new structure.

The LRFR code in the MBE was developed based on a two-lane maximum loading event of 240-kips, a legal truck (the 3S-2) of 72-kips and a legal load factor of 1.8. The NCHRP Report 454[12] gives a formula to convert this baseline live load factor to be vehicle and traffic specific for permit vehicles. And, as discussed previously, we recommend that legal loads greater than 100-kips use routine permit vehicle live load factors. The formula is:

---

[12] NCHRP Report 454 Calibration of Load Factors for LRFR Bridge Evaluation, 2001, Transportation Research Board.

$$\gamma_{L,2lane} = 1.8 * \frac{(P + A_T)}{240} * \frac{72}{P},$$ Equation 1

where:

> $\gamma_{L,2lane}$ is the live load factor for multi lane loading,
> P is the weight of the permit truck in question,
> A_T is the weight of the "Alongside Truck", or the probable maximum weight of a heavy vehicle that crosses the structure next to the permit vehicle.

In recognition of the unique legal and permit load situation in Michigan, Weigh-In-Motion (WIM) Data was analyzed to compare the loading condition in Michigan to that used in development of the LRFR code. Using information gathered from WIM sites in the Metro Detroit area, the load effects of the actual trucks that drive in Michigan were tabulated for 20 bridges, selected as representative examples of structures recently constructed[13]. These load effects were converted to 3S-2 equivalents for use in Equation 1 by comparing the load effects of the WIM data to the load effects produced by a 3S-2 vehicle over the same structure. The unprojected WIM data as well as the 3S-2 equivalents can be found in Appendix D.

The means and standard deviations (in 3S-2 equivalents) were analyzed to find mean of the top 20 percent of vehicles using the following equation:

$$\mu_{20\%} = \mu + 0.85 * \sigma + \left\{ [(\mu + 3 * \sigma) - (\mu + 0.85 * \sigma)] - - \frac{[(\mu + 3 * \sigma) - (\mu + 0.85 * \sigma)]}{6 * \left(1 - \frac{\pi}{4}\right)} \right\}$$ Equation 2

where μ is the mean of the sample and σ is the standard deviation of the sample. This equation is based on 80 percent of the values in the sample being below 0.85σ and the center of gravity of an elliptical complement using three standard deviations from the mean as the value of the normal deviation intersecting zero. The value calculated using the equation compare favorably to the value calculated using actual numbers based on the standard normal distribution curve. The equation was used because it was easier to apply when various sets of means and standard deviations are involved. Five thousand numbers were randomly generated with a mean of 0 and standard deviation of 1. These numbers were sorted, and the top 20 percent of values were retained. The standard deviation of these top 20 percent of values was found, and the process was repeated for twenty generations. The standard deviations were averaged to find a value that could be applied to the top 20 percent mean as calculated in Equation. 2. The standard deviation of the top 20 percent of trucks was found to be:

$$\sigma_{20\%} = \mu_{20\%} * 0.4674$$ Equation 3

[13] MDOT Research Report RC-1413, "Investigation of the Adequacy of Current Bridge Design Loads In the State of Michigan", 2002 and MDOT Research Report RC-1466, "LRFD Load Calibration for State of Michigan Trunkline Bridges", 2006.

The number of side by side crossings, N, was calculated as:

$$N = ADTT * (365days/year) * (Evaluation\ period) * (P_{s/s}) * (\%) \qquad \text{Equation 4}$$

where:

$P_{s/s}$ = Probability of side-by-side = 1/30,
ADTT = 5000,
% = Percent of largest vehicles, 20 percent.

The probability of side-by-side events of 1/30 deviates from the MBE value of 1/15 (6.7 percent). The assumption of 1/15 was based on visual observations and is conservative for most sites. WIM studies completed in NCHRP 575 determined that much lower multiple presence probabilities than used in NCHRP Report 454 are appropriate even for very high ADTT sites. US-23 in Michigan was monitored. In this study, side-by-side events were recorded for ADTT and headway distances. Headway distance is the distance between the front axles of trucks in adjacent lanes. This distance was set at 60 feet in the study, as for most spans the effect of headway greater than this value is negligible. As the headway and ADTT increases, the probability of a side-by-side event increases. In the WIM data from US-23, the extreme event near 5000 ADTT with headway of 60 feet was selected. The percentage of a side-by-side event was 3.47 percent. This correlates closely to a probability of 1/30. Additional WIM studies in Idaho and Ohio further substantiate this finding. These studies suggest that a 1/30 value is more appropriate, and that is the value chosen in this report.

The evaluation period was chosen as 5 years. This value is considered appropriate for load rating, as discussed in the MBE. Using the above equation yields:

$$N = 5000 * 365 * 5 * 1/30 * 0.20$$

and consequently:

$$1/N = 1.644E\text{-}5 \qquad \text{Equation 5}$$

From NCHRP Report 454, Appendix A (Normal Distribution tables), find $t_{ADTT=5000} = 4.153$ based on 1/N. The Alongside Truck for each 3S-2 equivalent is calculated as:

$$A_T = \mu_{20\%} + t_{ADTT} * \sigma_{20\%} \qquad \text{Equation 6}$$

The projected 3S-2 equivalents were reviewed. These data contained shear and moment values at typical controlling locations for each span of a structure. The data was further divided into Michigan freeway Functional Classes. The maximum for each limit state and location combination was found. This was Functional Class 11 for all structures. The maximum values were averaged to find the Alongside Truck (A_T) to be used for Michigan freeways. The Alongside Truck is dependent upon ADTT and, similar to the MBE, A_T values were calculated at 5000, 1000 and 100 ADTT, which are shown below.

Table 4
A_T values based on ADTT

ADTT	N	1/N	t_{ADTT}	A_T
5000	60833	0.000016	4.153	188.6
1000	12167	0.000082	3.769	181.3
100	1217	0.000822	3.148	169.4

The corresponding live load factors were calculated using Equation 1 and are presented in Table 5. These values represent multi-lane or two-lane loading, for example heavy-legal or routine permit loading scenarios. The value "P" in Table 6 corresponds to the weight of the Legal-Heavy or routine permit that is being analyzed.

Table 5
Two-Lane Live Load Factors for Legal-Heavy/Permit Vehicles based on Equation 1

ADTT (one way)	Calculated $\gamma_{L,\,2lane}$ for sample P values						
	100 kips	125 kips	150 kips	175 kips	200 kips	225 kips	250 kips
5000	1.56	1.35	1.22	1.12	1.05*	0.99*	0.95*
1000	1.52	1.32	1.19	1.10	1.03*	0.98*	0.93*
100	1.45	1.27	1.15	1.06*	1.00*	0.95*	0.91*

*Live load factors smaller than 1.10 are not recommended by this report

Although the Michigan alongside truck is larger than that used in the development of the code, the factors in Table 5 of this report are lower than those suggested in Table 6A.4.5.4.2.1-1[14] of the MBE, which range from 1.80 to 1.30 for 100-kip to 150-kip vehicles, respectively, for an ADTT level of 5000. There are three reasons for this difference: the side-by-side probability for an ADTT of 5000 is different; the code is trying to prevent situations where legal trucks would be prevented from crossing a structure, but permitted vehicles would be allowed; and situations where single lane loading would control.

For the concern that permit trucks would be allowed to cross structures that legal vehicles are not allowed to cross, the heavy alongside truck in Michigan creates a different sliding scale than that present in the MBE. If a 72-kip truck was evaluated using Equation 1 for the "permit" live load factor using the Alongside Truck from NCHRP 454 (120-kip), the corresponding load factor would be 1.44 for 5000 ADTT. However, using the Michigan-specific Alongside Truck of 188.6-kip would increase the load factor to the legal load cap of 1.80. Adjustment is not required for Michigan loads as the permit and legal load factors converge automatically.

It is generally thought that a multi-lane loading situation always controls. As the MBE Alongside Truck is very large compared to the AASHTO legal loads, the uncertainty of the load effect, and therefore the magnitude of the live load factor, is dominated by the MBE Alongside Truck. However, as the Permit truck (P) gets very large, the weight of the permit vehicle itself begins to dominate the load effect, and therefore the single lane loading can control the required live load factor. This can be shown in the following series of equations taken from NCHRP 454.

[14] Table 6-6 of the Guide Manual.

NCHRP 454 developed the target safety margin for load rating by comparing resistance to expected loading. This can expressed as the following:

$$\frac{R}{\overline{L}} = \frac{\gamma_L * W_L * g}{\overline{L}} \qquad \text{Equation 7}$$

where:

$\frac{R}{\overline{L}}$ is the target safety margin of component resistance to expected mean live load,
γ_L is the live load factor,
W_L is the nominal weight of the rating vehicle,
g is the lateral distribution factor for the girder being checked,
$\overline{L}$ is the expected mean maximum live load effect.

As mentioned previously, the expected maximum loading, $\overline{L}$, used in creation of the MBE is based on the effect of two side-by-side similar 120-kip vehicles and a corresponding live load factor of 1.8. Assuming *g*, the lateral distribution factor, would not change depending on the actual vehicle being checked, then a change in the expected mean maximum live load would require a corresponding change in the live load factor in order to maintain the target safety margin. This relationship of live load factor to vehicle weight can be re-written:

$$\frac{\gamma_L}{W_T} = \frac{1.8}{240} \qquad \text{Equation 8}$$

where:

W_T is the expected two-lane effect.

This target reliability is for legal loads, which assumes that the load rater is evaluating W_L as a nominal 3S2 vehicle, or a weight of 72-kips. In order to achieve this same target reliability in permit review, the ratio of a 3S2 vehicle to the Permit vehicle must be inserted into the equation. The maximum expected two-lane event would be the permit vehicle and the maximum alongside truck, and W_T can be written:

$$W_T = A_T + P \qquad \text{Equation 9}$$

thus deriving a form of Equation 1:

$$\frac{\gamma_{L,2lane}}{P + A_T} = \frac{1.8}{240} * \frac{72}{P}$$

Referring to the numerator of Equation 7, the nominal factored live load effect for two lanes is given as:

$$L_{2lane} = \gamma_{L,2lane} * P * g_m \qquad \text{Equation 10}$$

where:

g_m is the multi-lane lateral distribution factor.

NCHRP 454 cites work by Zokaie that developed a different method for comparing the effect of a permit vehicle in one lane with a different vehicle in the next lane. This assumption, proven empirically according to NCHRP 454, is used so that the lateral distribution factors from AASHTO LRFD may be used (which were developed assuming similar side-by-side vehicles) without doing independent grillage analyses. The equation is found by adding the effect of the single lane permit truck to the multi-lane effect of the Alongside Truck, and then subtracting the single lane effect of Alongside Truck.

$$W_1 = P * g_1 + A_T * (g_m - g_1) \qquad \text{Equation 11}$$

where:

W_1 is the single lane maximum girder effect,
g_1 is the single lane lateral distribution factor.

Returning to the premise that a reference ratio of resistance to loading is desired, Equation 7 may be rewritten for the single lane case as follows:

$$\frac{R}{\overline{L}} = \frac{\gamma_{L,1lane} * P * g_1}{\overline{L}} \qquad \text{Equation 12}$$

where:

$\gamma_{L,1lane}$ is the live load factor for single lane loading.

In this equation, the mean maximum live load event is based on a single 120-kip vehicle. The 1.8 value derived in Section 6.2.2 of NCHRP 454 was based on multi-lane distribution factors of random traffic. In order to have a true reference ratio, the single lane live load factor must be based on this ratio:

$$\frac{R}{\overline{L}} = \frac{1.8 * 72 * g_1}{120 * g_1} = \frac{\gamma_{L,1lane} * P * g_1}{W_1} \qquad \text{Equation 13}$$

Solving for $\gamma_{L,1lane}$ changes the Equation 13 to:

$$\gamma_{L,1lane} = \frac{1.8}{120} * \frac{72}{P * g_1} * \left[P * g_1 + A_T * (g_m - g_1)\right] \quad \text{Equation 14}$$

Similar to the multi-lane case, the nominal live load effect for single lane loading, using the numerator of Equation 7, is:

$$L_{1lane} = \gamma_{L,1lane} * P * g_1 \quad \text{Equation 15}$$

In order to compare the single and multilane live load factors to find the controlling case, an "equivalent" multilane live load factor from the single lane loading can be found by setting the nominal live load effects equal to each other.

$$L_{1lane} = L_{equiv} \quad \text{Equation 16}$$

substituting in Equation 10 and Equation 15:

$$\gamma_{L,1lane} * P * g_1 = \gamma_{equiv} * P * g_m \quad \text{Equation 17}$$

substituting in Equation 14 and solving for γ_{equiv}:

$$\gamma_{equiv} = 1.8 * \frac{(P + \left(\frac{g_m}{g_1} - 1\right) A_T)}{120} * \frac{72}{P} * \frac{g_1}{g_m} \quad \text{Equation 18}$$

Table 6 contains the γ_{equiv} that would be needed to produce the same live load effect in a multi-lane analysis as would be found in a single-lane analysis.

Table 6
Two-Lane Live Load Factors for Legal-Heavy Permit Vehicles based on Equation 18

g_m/g_1	ADTT (one way)	Calculated γ_{equiv} for sample P values						
		100 kips	125 kips	150 kips	175 kips	200 kips	225 kips	250 kips
1.4	5000	1.35	1.24	1.16	1.10	1.06*	1.03*	1.00*
	1000	1.33	1.22	1.14	1.09*	1.05*	1.02*	1.00*
	100	1.29	1.19	1.12	1.07*	1.03*	1.00*	0.98*
1.7	5000	1.47	1.31	1.19	1.11	1.05*	1.01*	0.97*
	1000	1.44	1.28	1.17	1.10	1.04*	0.99*	0.96*
	100	1.39	1.24	1.14	1.07*	1.01*	0.97*	0.94*
2	5000	1.56	1.35	1.22	1.12	1.05*	0.99*	0.95*
	1000	1.44	1.28	1.17	1.10	1.04*	0.99*	0.96*
	100	1.39	1.24	1.14	1.07*	1.01*	0.97*	0.94*

*Live load factors smaller than 1.10 are not recommended by this report

The live load distribution ratio of 2, a conservative upper limit for typical cross-sections, is the controlling case for single lane loading. If the γ_{equiv} in Table 6 was larger than the $\gamma_{L,2lane}$ given in Table 5, then the single lane loading case would control. Upon inspection, γ_{equiv} only exceeds $\gamma_{L,2lane}$ for the 100 ADTT case for 175-kip permit loads and then at 200-kip permit loads and above. In these situations, the live load factor is less than 1.10. It is reasonable to set upper and lower bounds for live load factors. A value of 1.10 will be set as the minimum live load factor in order to eliminate possible situations where a single lane loading might produce a greater effect than multi-lane and to establish a lower limit. Upper limits are based on the Legal Live Load Factors in Table 6A.4.4.2.3.1-1 of the MBE if the GVW is less than or equal to 100-kips and the Permit Live Load Factors in Table 6A.4.5.4.2.1-1[15] when the GVW is greater than 100-kips. Table 7 summarizes the recommended Designated Load legal vehicle live load factors. This report recommends to use the Live Load Factors given in Tables 7 thru 10 and Appendix E.

Table 7
Michigan Designated Legal Vehicle Load Factors based on ADTT

Michigan Designated Legal Vehicle Load Factors for Strength Limit States				
Vehicle Number	GVW (kips)	5000 ADTT γ_{LL}	1000 ADTT γ_{LL}	100 ADTT γ_{LL}
1	33.4	1.80	1.65	1.40
2	47.4	1.80	1.65	1.40
3	54.4	1.80	1.65	1.40
4	67.4	1.80	1.65	1.40
5	84.0	1.75	1.65	1.40
6	101.4	1.54	1.51	1.40
7	119.4	1.39	1.36	1.31
8	91.4	1.65	1.61	1.40
9	51.4	1.80	1.65	1.40
10	65.4	1.80	1.65	1.40
11	83.4	1.76	1.65	1.40
12	117.4	1.41	1.37	1.32
13	125.4	1.35	1.32	1.27
14	132.4	1.31	1.28	1.23
15	143.3	1.25	1.22	1.18
16	138.4	1.28	1.25	1.20
17	151.4	1.21	1.19	1.14
18	154.0	1.20	1.18	1.13
19	117.4	1.41	1.37	1.32
20	87.4	1.71	1.65	1.40
21	151.4	1.21	1.19	1.14
22	161.4	1.17	1.15	1.11
23	154.0	1.20	1.18	1.13
24	122.0	1.37	1.34	1.29
25	164.0	1.16	1.14	1.10
26	50.0	1.80	1.65	1.40
27	72.0	1.80	1.65	1.40
28	80.0	1.80	1.65	1.40

[15] Tables 6-5 and 6-6 in the Guide Manual, respectively

Table 8
Michigan Overload Class A Vehicle Load Factors Based on ADTT

Michigan Overload Class A Vehicle Load Factors for Strength Limit States				
Vehicle Number	GVW (kips)	5000 ADTT γ_{LL}	1000 ADTT γ_{LL}	100 ADTT γ_{LL}
1	120.0	1.39	1.36	1.30
2	120.0	1.39	1.36	1.30
3	120.0	1.39	1.36	1.30
4	120.0	1.39	1.36	1.30
5	120.0	1.39	1.36	1.30
6	126.0	1.35	1.32	1.27
7	138.0	1.28	1.25	1.20
8	149.6	1.22	1.19	1.15
9	158.4	1.18	1.16	1.12
10	177.0	1.12	1.10	1.10
11	180.0	1.11	1.10	1.10
12	190.6	1.10	1.10	1.10
13	195.0	1.10	1.10	1.10
14	211.2	1.10	1.10	1.10
15	238.0	1.10	1.10	1.10
16	244.4	1.10	1.10	1.10
17	272.6	1.10	1.10	1.10
18	283.4	1.10	1.10	1.10
19	277.2	1.10	1.10	1.10
20	264.0	1.10	1.10	1.10

Table 9
Michigan Overload Class B Vehicle Load Factors based on ADTT

Michigan Overload Class B Vehicle Load Factors for Strength Limit States				
Vehicle Number	GVW (kips)	5000 ADTT γ_{LL}	1000 ADTT γ_{LL}	100 ADTT γ_{LL}
1	120.0	1.39	1.36	1.30
2	120.0	1.39	1.36	1.30
3	118.0	1.40	1.37	1.32
4	108.0	1.48	1.45	1.39
5	104.0	1.52	1.48	1.40
6	108.0	1.48	1.45	1.39
7	114.0	1.43	1.40	1.34
8	127.6	1.34	1.31	1.26
9	129.6	1.33	1.30	1.25
10	146.4	1.24	1.21	1.16
11	159.0	1.18	1.16	1.12
12	160.2	1.18	1.15	1.11
13	168.8	1.14	1.12	1.10
14	179.2	1.11	1.10	1.10
15	204.0	1.10	1.10	1.10
16	203.6	1.10	1.10	1.10
17	232.4	1.10	1.10	1.10
18	241.6	1.10	1.10	1.10
19	234.4	1.10	1.10	1.10
20	225.8	1.10	1.10	1.10

Table 10
Michigan Overload Class C Vehicle Load Factors based on ADTT

Michigan Overload Class C Vehicle Load Factors for Strength Limit States				
Vehicle Number	GVW (kips)	5000 ADTT γ_{LL}	1000 ADTT γ_{LL}	100 ADTT γ_{LL}
1	120.0	1.39	1.36	1.30
2	120.0	1.39	1.36	1.30
3	114.0	1.43	1.40	1.34
4	98.0	1.58	1.54	1.40
5	88.0	1.70	1.65	1.40
6	90.0	1.67	1.63	1.40
7	93.0	1.64	1.59	1.40
8	105.6	1.50	1.47	1.40
9	105.6	1.50	1.47	1.40
10	122.0	1.37	1.34	1.29
11	138.0	1.28	1.25	1.20
12	134.4	1.30	1.27	1.22
13	147.4	1.23	1.20	1.16
14	153.6	1.20	1.18	1.14
15	170.0	1.14	1.12	1.10
16	173.0	1.13	1.11	1.10
17	182.8	1.10	1.10	1.10
18	200.0	1.10	1.10	1.10
19	200.8	1.10	1.10	1.10
20	191.4	1.10	1.10	1.10

10.0 LRFD – RECOMMENDED MODIFICATIONS

Despite the effort taken to modify the LRFR load factors (LRFR-mod) to meet the needs of Michigan trucks, the operational capacity of bridges designed/rated under LRFD and HL-93/ LRFR-mod will still be less than the current LFR/LFD (HS-25) system. As shown in Figure 2, for the typical span lengths constructed in Michigan (40 to 70 feet), all single-span factored legal and overload permit class moments are less than 90 percent of the factored HS-25 design moments. In contrast, Figure 3 shows the factored LRFR-mod/LRFD comparisons. In the most common span lengths, the factored overload permit class moments exceed the factored design moment by 15 to 30 percent. This would make it likely that new structures would be restricted from Overload Permit Vehicles even if designed correctly according to LRFD.

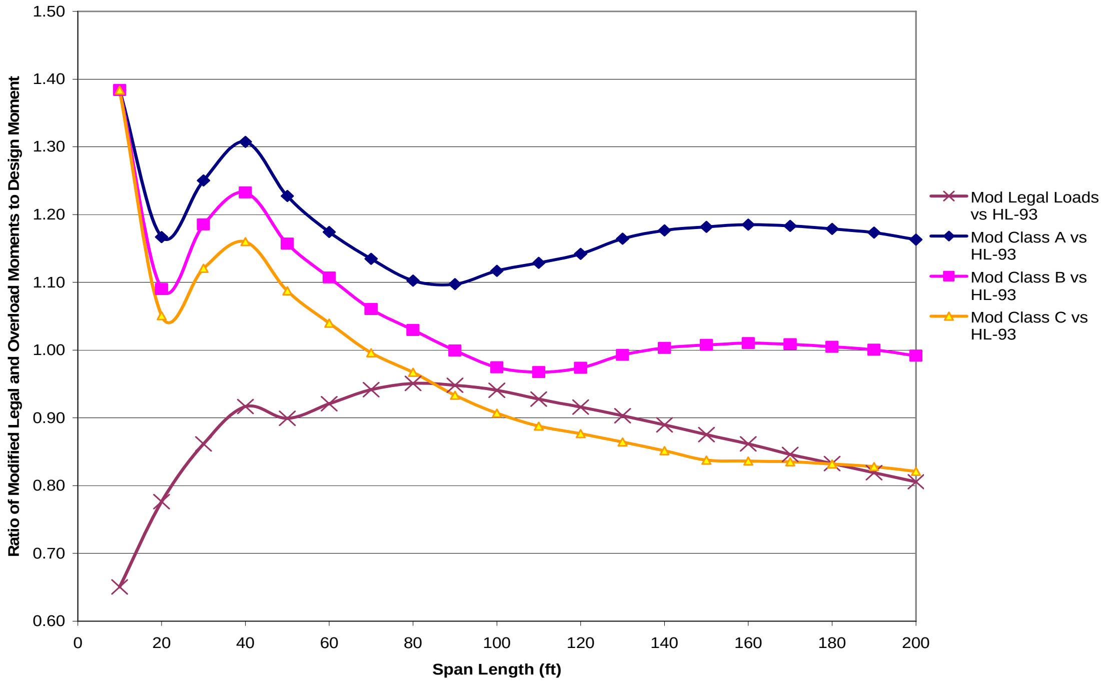


Figure 3
Maximum Ratios of LRFR-mod to LRFD, including Impact

In order to have our design meet the operational needs of our state, increasing the design load was investigated. As can be seen in Figure 3, a factor of 1.2 is needed to lower most ratios below 1.0. When checking the "spikes" in Figure 3 in the shorter spans, it is found that the 60-kip axle allowed in the Overload Classes is the controlling vehicle, and that the current HL-93 loading does not accurately model this configuration.

In order to address this issue, a modified loading scenario, HL-93-mod, is proposed. This loading would replace the 25-kip tandem axle truck with a single 60-kip axle. In addition, a 1.2 factor would be added to the combined lane and truck/axle loading. The modified loading can be written as:

$$\gamma_{LL} * 1.2 * \lfloor Lane + \max(HS-20, 60_{kip}\, axle) * I \rfloor \qquad \text{Equation 19}$$

The ratio of LRFR-mod to HL-93-mod are given in Figure 4. Appendix F provides possible changes to the LRFD code language.

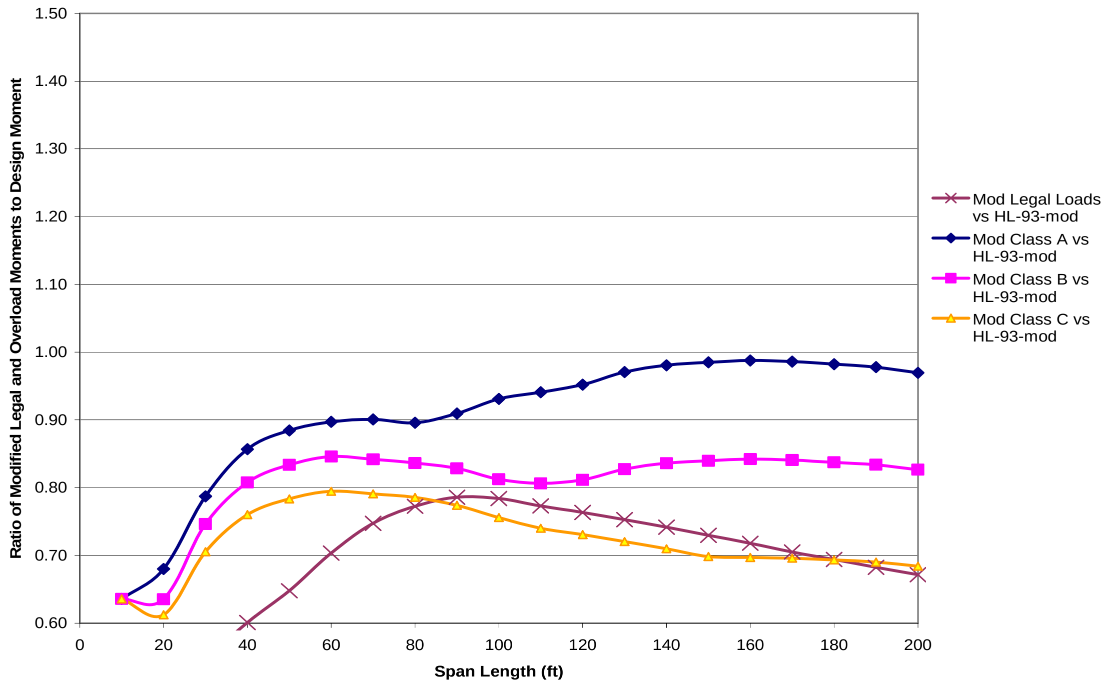


Figure 4
Maximum Ratios of LRFR-mod to LRFD-mod, including Impact

As shown in Figure 4, using the modified LRFD loading and the modified LRFR factors, the operational capacity versus design ratios return to current levels. The most common spans are near 90 percent for Class A Overloads. This report recommends creating the HL-93-mod loading that replaces the 25-kip tandem axle truck with a single 60-kip axle and adds a 1.2 factor to the lane and maximum of the truck or axle loading.

11.0 LONG SPAN/CONTINUOUS SPAN LOADING

This report does not analyze the effect of long spans or continuous spans on the load rating versus design moment ratios. Long spans are considered to be spans over 200 feet in length. While all span lengths should be evaluated for the legal vehicle, long spans and continuous spans have additional requirements. For Legal Load Ratings, the MBE[16] required load for long spans is the AASHTO Type 3-3 Truck, multiplied by 0.75, and combined with a lane load of 0.2-klf. For negative moments and reactions, a lane load of 0.2-klf combined with two AASHTO Type 3-3 multiplied by 0.75 heading in the same direction separated by 30 feet is required. The other AASHTO Legal Load trucks do not have to be checked in combination with the lane load for Legal Load Ratings as they would not control on long spans. The truck portion of this load would have impact added and all applicable load factors would apply to the total live load.

For permit loads, subsection 6A4.5.4.1 of the MBE[17] specifies that for spans between 200 feet and 300 feet, and when calculating negative moments, a 0.2-klf lane load shall be applied in

[16] Subsection 6A.4.4.2.1 in the MBE and Subsection 6.4.4.2.1 in the Guide Manual.
[17] Subsection 6.4.5.4 in the Guide Manual.

addition to the permit vehicle. This portion of the MBE does not mention the application of the 0.75 factor to the truck loading nor does it clarify the use of impact. There is also no mention of what is appropriate practice for spans greater than 300 feet. Finally, what loading to be applied in the other lanes of the structure is not specified.

In the code, the multiple presence factors are meant to address the likelihood of multiple heavily loaded vehicles crossing a structure at the same time. For a structure under 200 feet, the code is calibrated around one permit truck and alongside vehicles in the remaining lanes. For AASHTO legal vehicles, which are considerably lighter than the Alongside Truck used in NCHRP 454, the loading of a long span bridge with multiple lanes is less than the HL-93 design loading. However, as Permit trucks (and Legal-Heavy Vehicles in Michigan's case) are evaluated, applying a permit vehicle in each lane appears to contradict the calibration method used in NCHRP 454. Permit vehicles often exceed the Alongside Truck. Using the most conservative interpretation of the MBE, a five lane bridge over 200 feet in length would need to withstand the maximum live load event of 0.2-klf lane loads plus the simultaneous crossing of five permit vehicles that are heavier than the maximum expected two lane event.

In review of the Legal and Overload Vehicles in Michigan, Overload Class A Vehicle #18 was identified as the controlling vehicle for long spans. Using a live load factor of 1.1 and using a design live load factor increased by 1.2, the ratio of the factored plus impact loading for the Overload Vehicle to the factored plus impact HL-93 Design Loading was calculated. This ratio is near or less than 1.0 for two to five lanes loaded with the corresponding multiple presence factor applied.

In calculating the Alongside Truck, and therefore the live load factors recommended by this report, a side-by-side probability of 1/30 was selected for two-lane loading. As the span length increases, the headway distance between trucks in adjacent lanes can increase while still creating a significant effect on the loading of the structure. This would imply the side-by-side probability would increase, leading to an Alongside Truck, and the required load factors would increase for long spans. Conversely, the probability of side-by-side events occurring in three or more lanes at one time is assumed to be much less than 1/30. This assumption is not verified as WIM data for three or more lanes were not available at the time of this report. Due to these uncertainties and the ambiguous language of the code, a very conservative interpretation of the code is recommended. It is acknowledged that further research for specific structures may yield more accurate and therefore more desirable results. Any such research should consider the side-by-side truck probabilities of the long span, the headway separation of trucks in the same lane, and the probability of multiple lanes loaded.

This report recommends that loading configurations for LRFR analysis be according to Table 11. The loads (using the Legal, Legal-Heavy, or Permit Truck being analyzed) should be applied in each lane as required to produce the maximum load effect with corresponding multiple presence factors applied. Where truck and lane loads are applied coincidentally, the lane load may either be applied across the entire span for simplicity of analysis or may be excluded from the portion of the span occupied by the truck or trucks. Live load factors based on the GVW of the truck being rated should be applied to the total load.

Additionally, this report limits the recommendations to spans less than 400 feet. Spans greater than 400 feet may require site-specific analysis to determine the appropriate loading configuration and live load factors.

Table 11
LRFR Loading Configurations for Legal, Legal-Heavy and Permit Loads

Span Length	Load Effect	Legal Trucks GVW ≤ 100-kips	Legal-Heavy and Permit Trucks GVW > 100-kips
L≤200-ft	Positive Moment and Reactions at Exterior Supports	Truck + Impact	Truck + Impact
	Negative Moment and Reactions at Interior Supports	0.75*(Two Trucks Spaced 30-ft Apart + Impact) + 0.2-klf	(Truck + Impact) + 0.2-klf
200-ft<L≤400-ft	Positive Moment and Reactions at Exterior Supports	0.75*(Truck + Impact) + 0.2-klf	(Truck + Impact) + 0.2-klf
	Negative Moment and Reactions at Interior Supports	0.75*(Two Trucks Spaced 30-ft Apart + Impact) + 0.2-klf	(Truck + Impact) + 0.2-klf

12.0 COST IMPACT

Previous research has investigated the cost impact of adding a live load factor to the HL-93 Design Load in order to account for the Legal and Overload Vehicles used for commerce in the State of Michigan. Research Report RC-1466 determined that a 4 percent increase in the cost of construction is expected with a 1.2 factored increase of HL-93.

13.0 FUTURE RESEARCH NEEDS

As the application of LRFR is a relatively recent undertaking, there are numerous areas that require further investigation. The following are areas of load rating that would benefit from future research and refinement.

- Adjusting Permit Loads for gage widths greater than 6 feet in a method that would provide consistent results regardless of the method of rating of the structure (LFR or LRFR).
- Rating of Decks for Overloads and Superloads.
- Loading procedure for spans greater than 200 feet.
- Loading procedure for multi-lane structures that are not multi-girder configurations.

14.0 RECOMMENDATIONS

This report recommends the following:

- That the calculation of Federal Inventory and Operating Ratings remains at the unmodified HL-93 loading using load factors identified in the MBE Table 6A.4.3.2.2-1.
- That:
  - MDOT base the load factor on the GVW for a standard analysis.
  - MDOT base the load factor on the portion of the vehicle on the span for Load Postings and Superload analyses.
- Using the Live Load Factors for legal and permit loads given in Tables 7 through 10 and Appendix E.
- Creating the HL-93-mod loading that replaces the 25-kip tandem axle with a single 60-kip axle and adds a 1.2 factor to the lane and maximum of the truck or axle loading.
- LRFR loading configurations be according to Table 11. The loads (using the Legal, Legal-Heavy, or Permit Truck being analyzed) should be applied in each lane as required to produce the maximum load effect with corresponding multiple presence factors applied. Where truck and lane loads are applied coincidentally, the lane load may either be applied across the entire span for simplicity of analysis or may be excluded from the portion of the span occupied by the truck or trucks. Live load factors based on the GVW of the truck being rated should be applied to the total load.
- That the recommendations of this report are limited to spans less than 400 feet. Spans greater than 400 feet may require site-specific analysis to determine the appropriate loading configuration and live load factors.

REFERENCES

AASHTO (1994). *Manual for Condition Evaluation of Bridges, 4th Edition*. Washington, DC.

AASHTO (2003). *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges 1st Edition, 2005 Interim*. Washington, DC.

AASHTO (2007). *LRFD Bridge Design Specifications, 4th Edition*. Washington, DC.

AASHTO (2007). *The Manual for Bridge Evaluation, Draft Edition*, Washington, DC.

AASHTO (2002). *Standard Specifications for Highway Bridge Design, 17th Edition*. Washington, DC.

Fu, G. and van de Lindt, J.W (2006). *LRFD Load Calibration for State of Michigan Trunkline Bridges.* Research Report RC-1466. Michigan Department of Transportation, Lansing, Michigan.

Kulicki, J., Mertz, D. Evolution of Vehicular Live Load Models During the Interstate Design Era and Beyond. In *Transportation Research Circular E-C10*, Transportation Research Board, National Research Council, Washington, DC, 2006, pp. 1-26.

Michigan Department of Transportation. *Bridge Analysis Guide*. Lansing, Michigan, 2005.

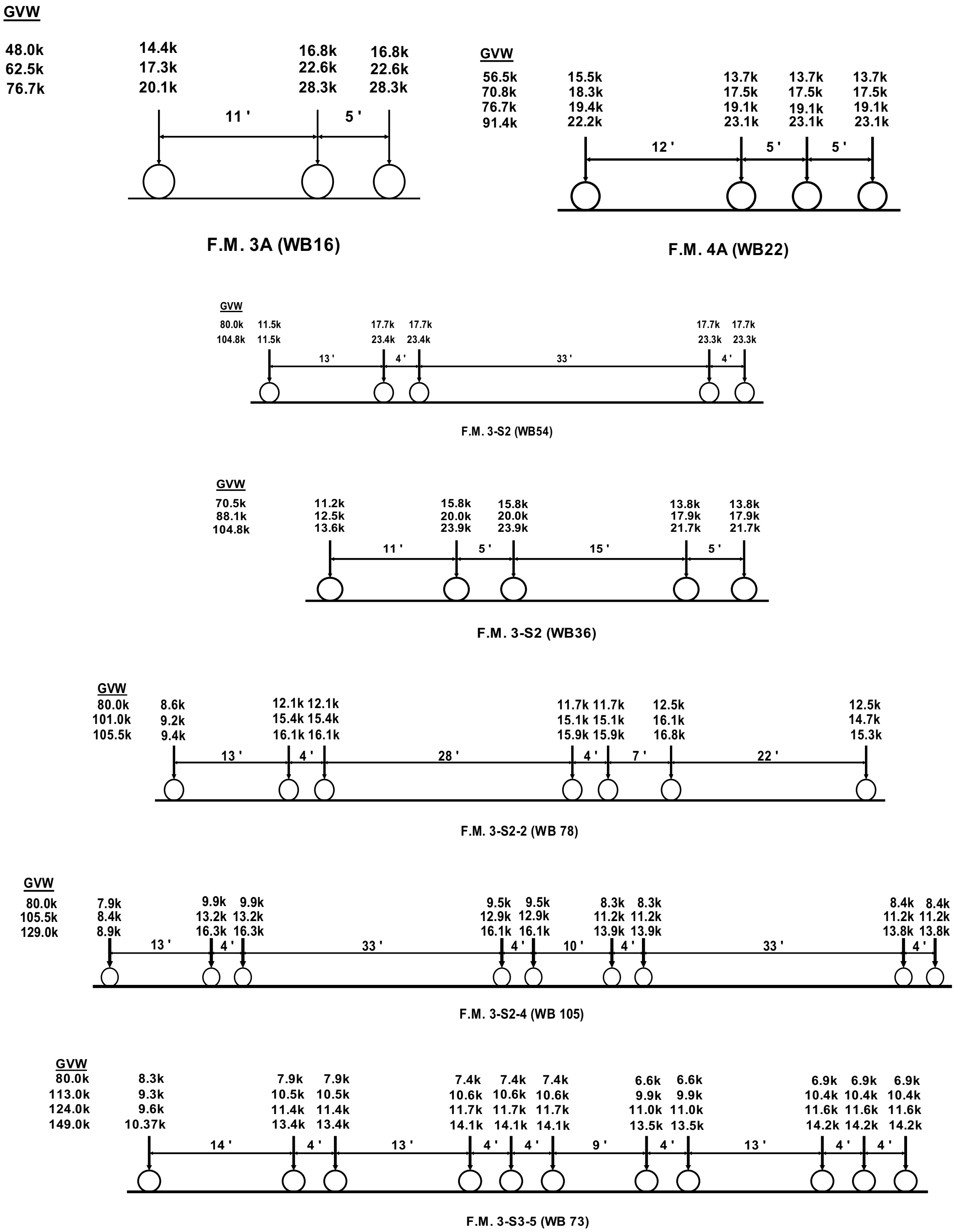
Moses, F. *NCHRP Report 454: Calibration of Load Factors for LRFR Bridge Evaluation*. Transportation Research Board, National Research Council, Washington, DC, 2001.

Pelphrey, J., and Higgins, C. *Calibration of LRFR Live Load Factors Using Weigh-In-Motion Data Interim Report.* SPR 635. Oregon Department of Transportation, Salem, Oregon, 2006.

Sivakumar, B., Moses, F., Fu, G. and Ghosn, M. *NCHRP Report 575: Legal Truck Loads and AASHTO Legal Loads for Posting*. Transportation Research Board, National Research Council, Washington, DC, 2007.

van de Lindt, J.W. and Fu. G (2002). *Investigation of the Adequacy of Current Bridge Design Loads In the State of Michigan*. Research Report RC-1413. Michigan Department of Transportation, Lansing, Michigan.

Appendix A

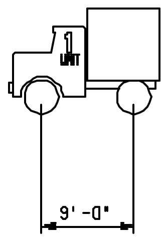


(b)

FIGURE 2 (b) Exclusion vehicles.

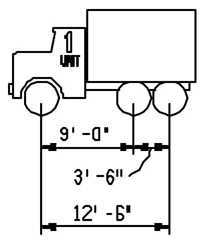
Appendix B

TRUCK NO.
1



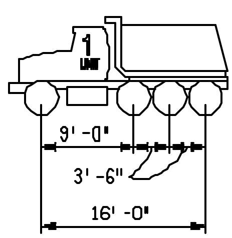
	Axle 1	Axle 2	Totals	Equivalent train load
NL (kips)	15.4	18	33.4	0.86 klf
DL (kips)	15.4	18	33.4	0.86 klf
SD (kips)	19	20	39	1.00 klf

TRUCK NO.
2



	Axle 1	Axle 2	Axle 3	Totals	Equivalent train load
NL (kips)	15.4	13	13	41.4	0.97 klf
DL (kips)	15.4	16	16	47.4	1.12 klf
SD (kips)	11.4	17	17	45.4	1.07 klf

TRUCK NO.
3



	Axle 1	Axle 2	Axle 3	Axle 4	Totals	Equivalent train load
NL (kips)	15.4	13	13	13	54.4	1.18 klf
DL (kips)	15.4	13	13	13	54.4	1.18 klf

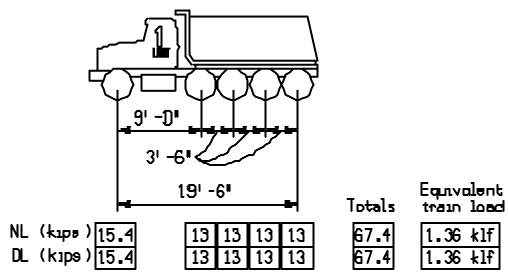
NL Denotes Normal loading

DL Denotes Designated loading

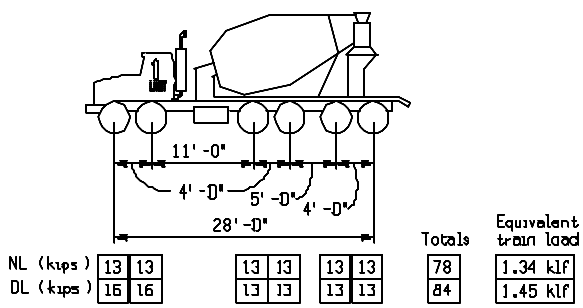
SD Denotes Special Designated loading

FIGURE 2.1
Michigan Legal Vehicles

TRUCK NO. 4



TRUCK NO. 5



TRUCK NO. 6

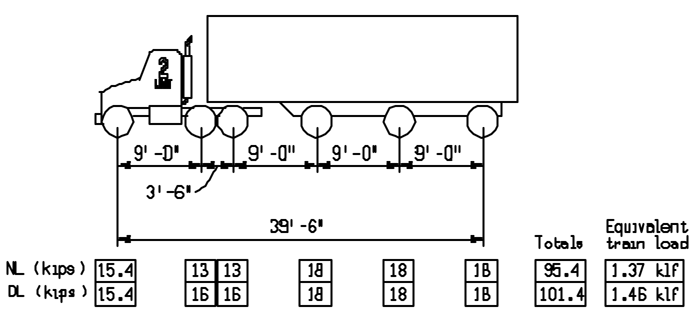
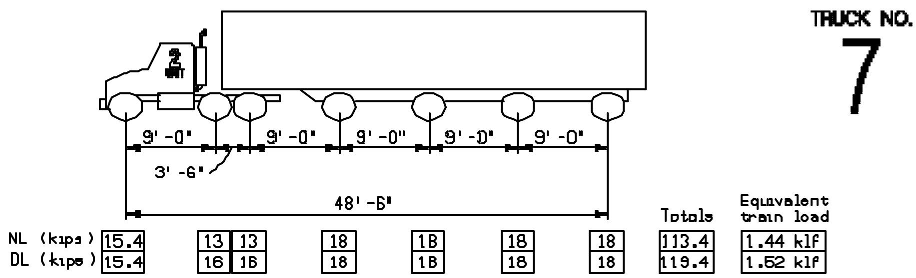
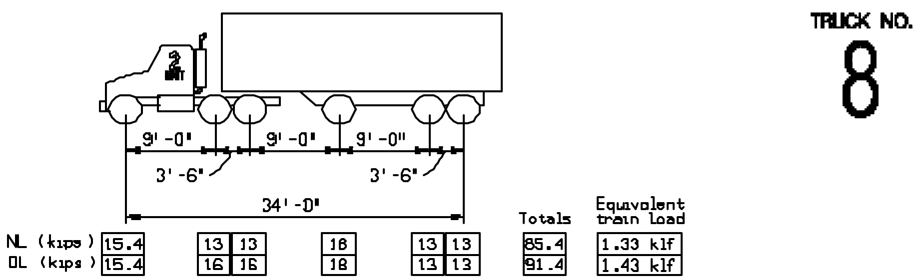


FIGURE 2.1 (Continued)
Michigan Legal Vehicles





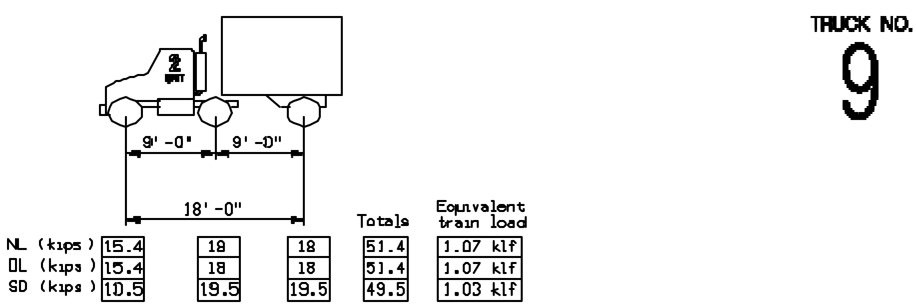
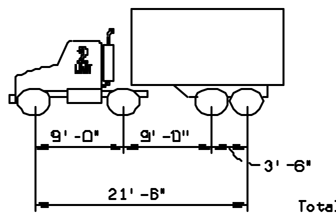


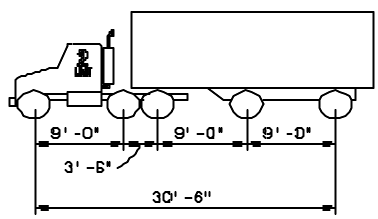
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
10



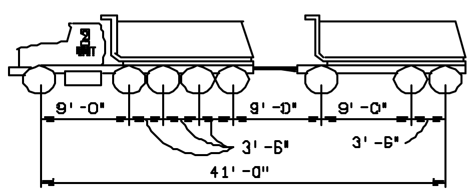
					Totals	Equivalent train load
NL (kips)	15.4	18	13	13	59.4	1.15 klf
DL (kips)	15.4	18	16	16	65.4	1.25 klf
SD (kips)	11	11.4	17	17	56.4	1.10 klf

TRUCK NO.
11



						Totals	Equivalent train load
NL (kips)	15.4	13	13	18	18	77.4	1.28 klf
DL (kips)	15.4	16	16	18	18	83.4	1.38 klf
SD (kips)	7.1	10.5	10.5	19.5	19.5	67.1	1.11 klf

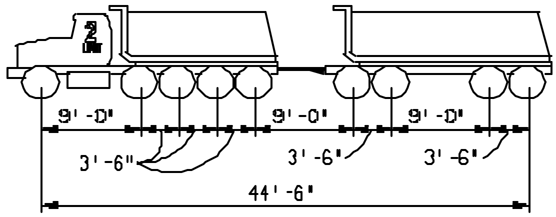
TRUCK NO.
12



									Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	18	13	13	111.4	1.57 klf
DL (kips)	15.4	13	13	13	13	18	16	16	117.4	1.65 klf

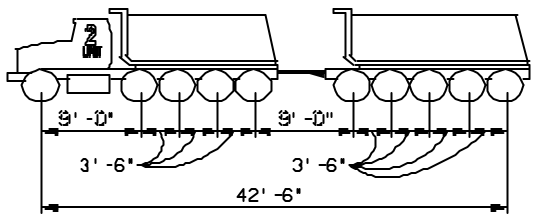
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO. **13**



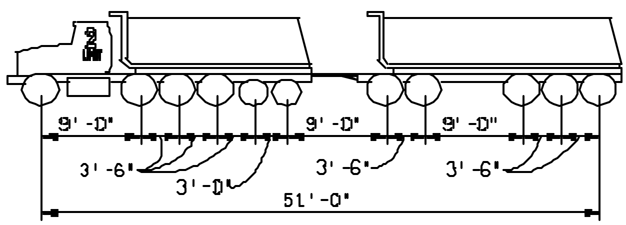
											Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13		119.4	1.60 klf
DL (kips)	15.4	13	13	13	13	13	13	16	16		125.4	1.68 klf

TRUCK NO. **14**



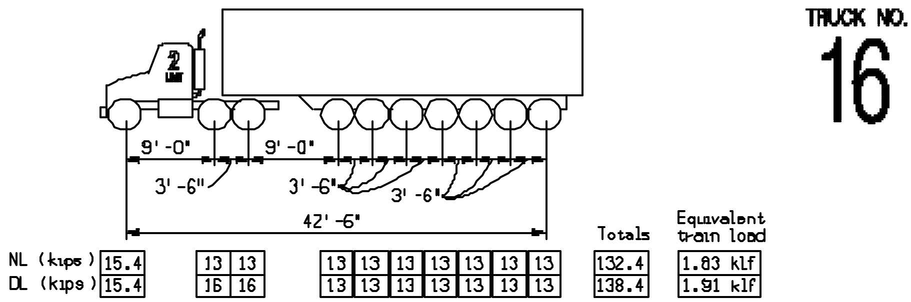
											Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13	13	132.4	1.83 klf
DL (kips)	15.4	13	13	13	13	13	13	13	13	13	132.4	1.83 klf

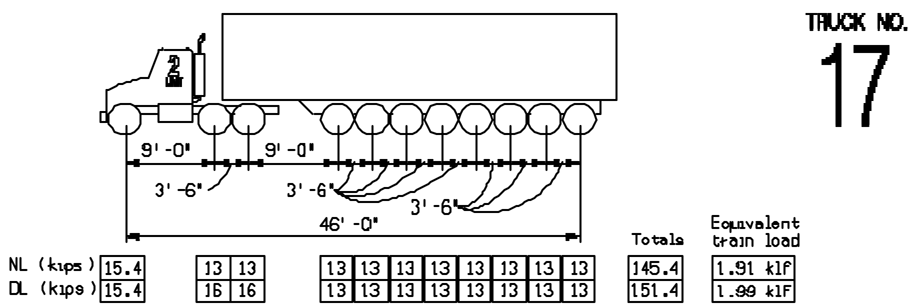
TRUCK NO. **15**



													Totals	Equivalent train load
NL (kips)	15.4	13	13	13	9	9	13	13	13	13	13		137.4	1.70 klf
DL (kips)	15.4	13	13	13	9	9	16	16	13	13	13		143.4	1.77 klf

FIGURE 2.1 (Continued)
Michigan Legal Vehicles





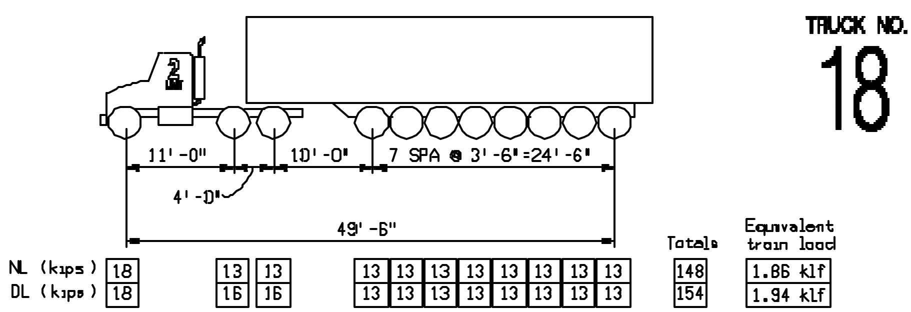
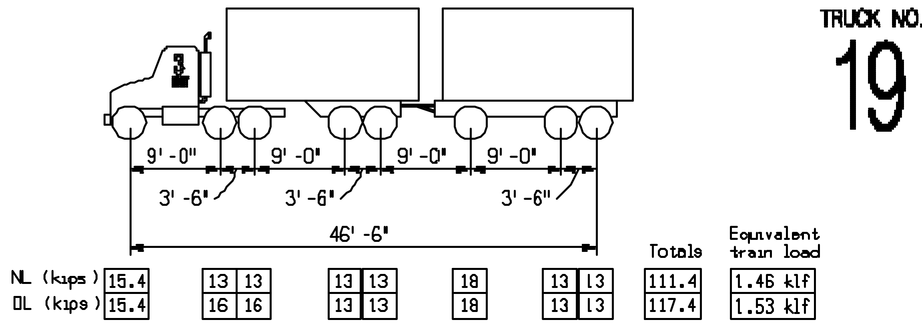
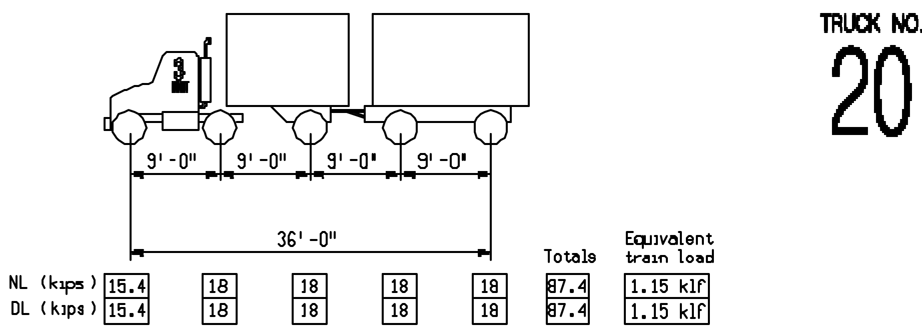


FIGURE 2.1 (Continued)
Michigan Legal Vehicles





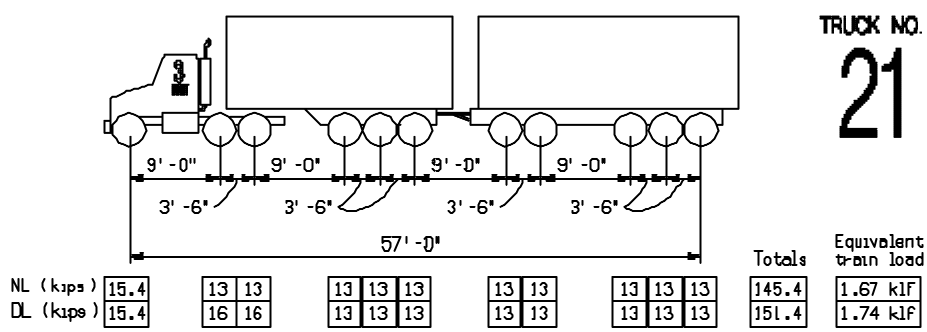
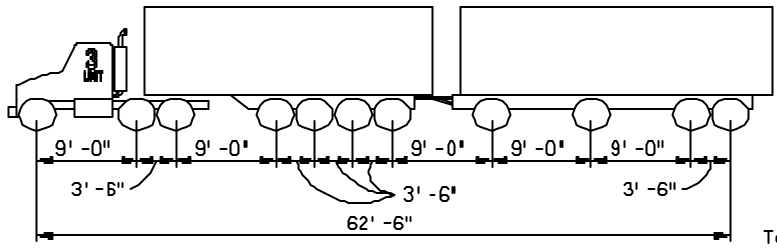


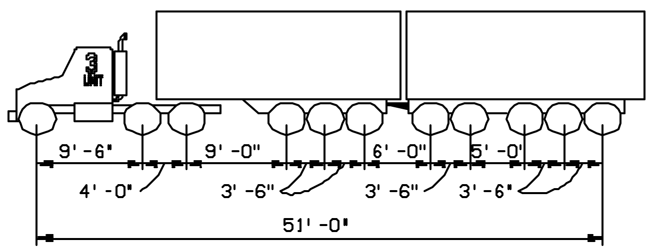
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
22



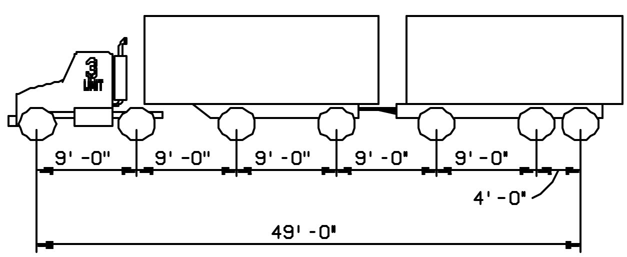
													Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	18	18	13	13		155.4	1.68 klf
DL (kips)	15.4	16	16	13	13	13	13	18	18	13	13		161.4	1.74 klf

TRUCK NO.
23



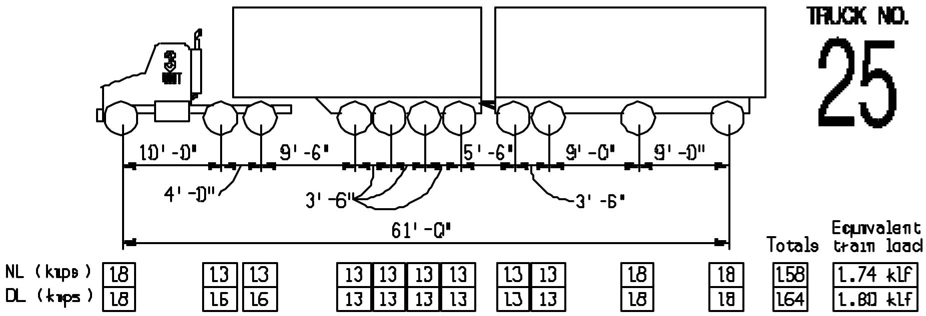
												Totals	Equivalent train load
NL (kips)	18	13	13	13	13	13	13	13	13	13	13	148	1.83 klf
DL (kips)	18	16	16	13	13	13	13	13	13	13	13	154	1.90 klf

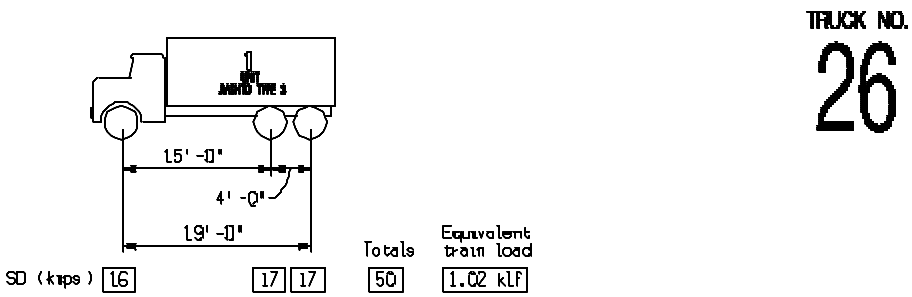
TRUCK NO.
24



								Totals	Equivalent train load
NL (kips)	18	18	18	18	18	13	13	116	1.47 klf
DL (kips)	18	18	18	18	18	16	16	122	1.54 klf

FIGURE 2.1 (Continued)
Michigan Legal Vehicles





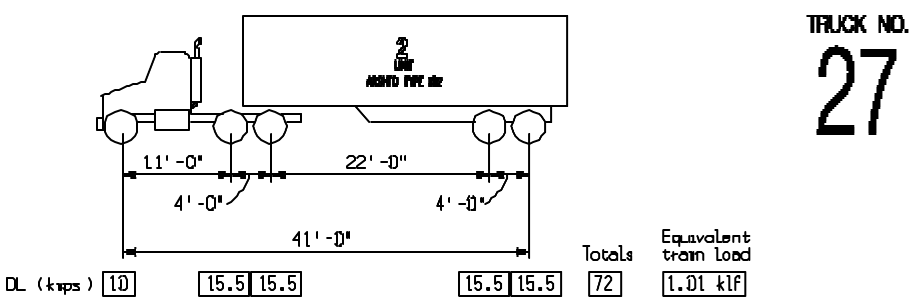
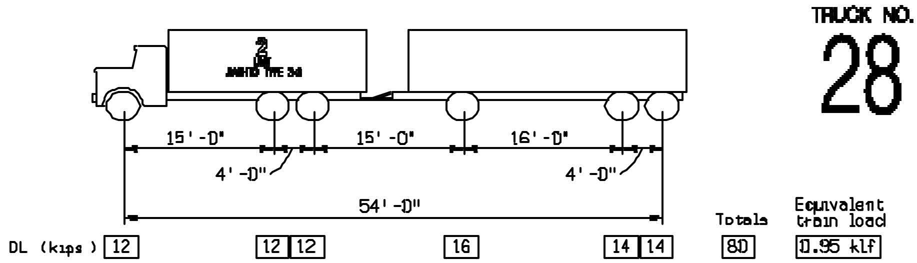


FIGURE 2.1 (Continued)
Michigan Legal Vehicles



NOTES:

NL Denotes Normal axle loading

DL Denotes Designated axle loading

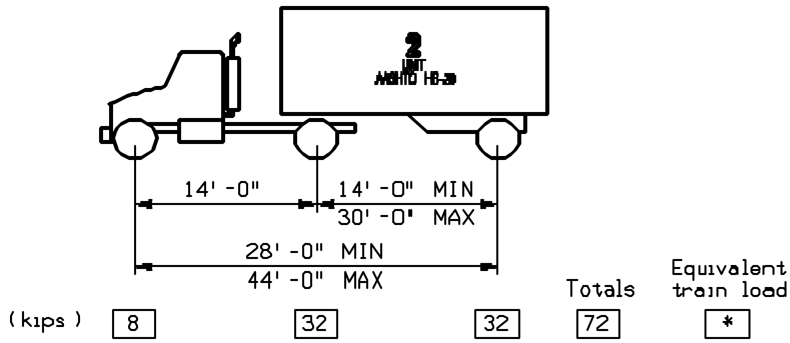
SD Denotes Special Designated axle loading

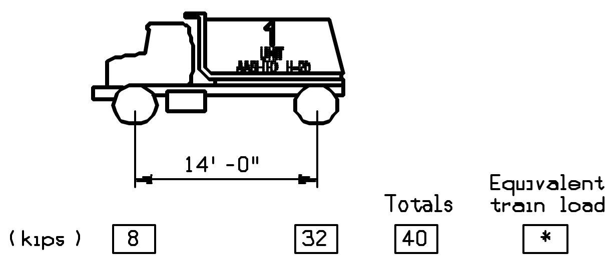
The maximum load of any tire is limited to 700 lbs per inch of tire width.

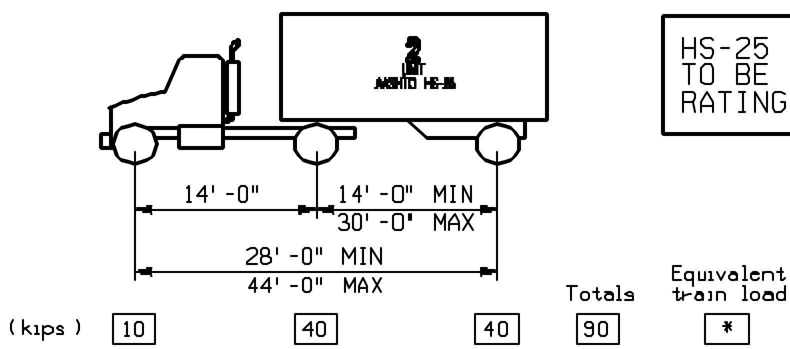
Normal, Designated and Special Designated loadings are defined in Chapter 2 of this guide.

FIGURE 2.1 (Continued)
Michigan Legal Vehicles

FIGURE 2.2
Design Live Loads







HS-25 TRUCKS ARE NOT TO BE USED FOR ANY LOAD RATING CALCULATIONS

NOTE:

* See Figure 3.7.6B in the AASHTO Standard Specifications for Highway Bridges.

Appendix C

	PERMISSIBLE AXLE LOADS (P)+						
	CLASS A++		CLASS B++		CLASS C++		
	Axle (kips)	Gross (tons)	Axle (kips)	Gross (tons)	Axle (kips)	Gross (tons)	
1	60	60	60/38	60/38	60/38	60/38	*
2	60	60	60/38	60/38	60/38	60/38	*
3	60	60	59/38	59/38	57/38	57/38	*
4	60	60	54/38	54/38	49/38	49/38	*
5	60	60	52/38	52/38	44/38	44/38	*
6	42	63	36	54	30	45	
7	46	69	38	57	31	46.5	
8	34	74.8	29	63.8	24	52.8	
9	33	79.2	27	64.8	22	52.8	
10	29	88.5	24	73.2	20	61	

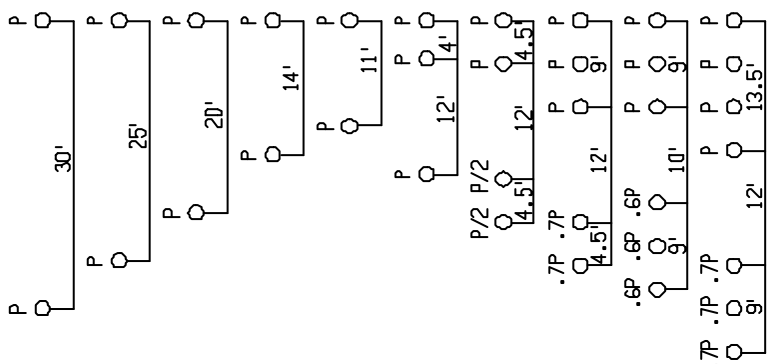


FIGURE 8.1
Permissible Overload Classes on State Bridges

PERMISSIBLE AXLE LOADS (P)†

	CLASS A††		CLASS B††		CLASS C††	
	Axle (kips)	Gross (tons)	Axle (kips)	Gross (tons)	Axle (kips)	Gross (tons)
11 *	60	90	53 38	79.5 57	46 38	69 57
12	44	95.3	37	80.1	31	67.2
13 *	45	97.5	39 38	84.4 82.3	34	73.7
14	33	105.6	28	89.6	24	76.8
15	28	119	24	102	20	85.0
16	24	122.2	20	101.8	17	86.5
17	25.8	136.3	22	116.2	17.3	91.4
18	34	141.7	29	120.8	24	100
19	29.7	138.6	25.1	117.2	21.5	100.4
20	28.3	132	24.2	112.9	20.5	95.7

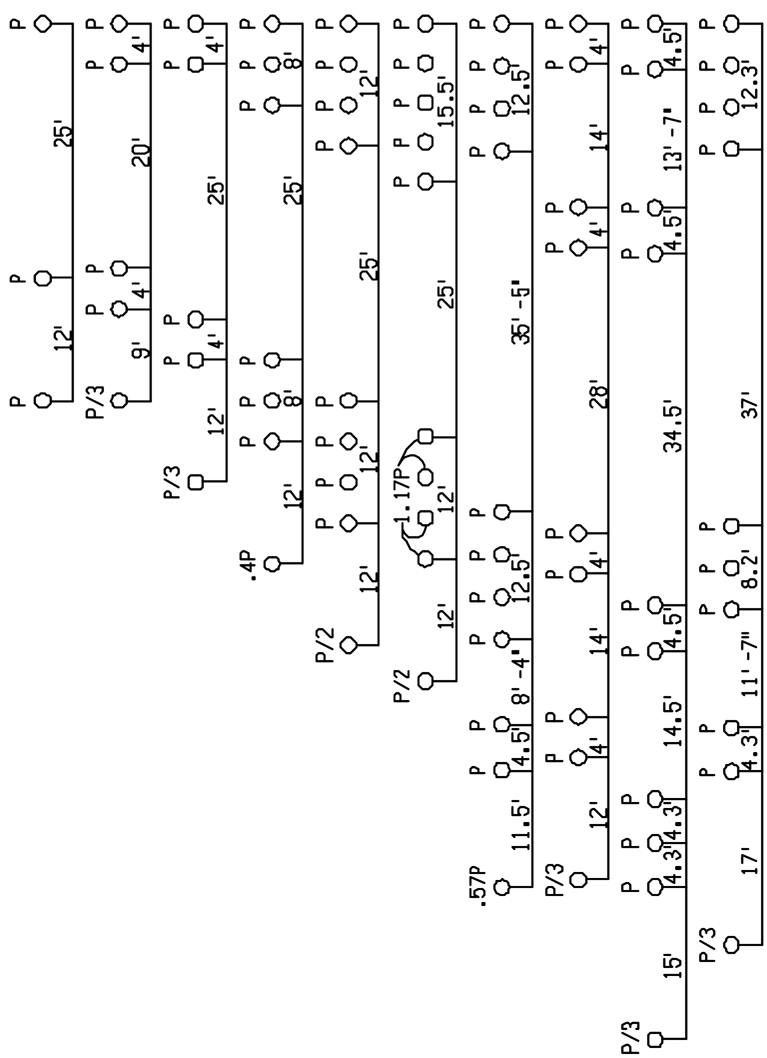


FIGURE 8.1 (Continued)
Permissible Overload Classes on State Bridges

Appendix D

Each moment or shear location is identified in the following manner: The bridge type and bridge ID in the leftmost columns; in the column labeled “Load Effect” and “M” indicates a moment in K-ft and a “V” indicates a shear in K. The first number after the M or V indicates the span number, and the second number indicates how far from the leftmost support for that span in terms of percent of the span.

Bridge types are defined as: steel beam bridges (SC), prestressed concrete I beam bridges (PI), adjacent prestress concrete box beam bridges (PCA), and spread prestressed box beam bridges (PCS).

For example, bridge no. B01-11072 is a steel beam bridge, the M14 indicates the moment on the first span at a location 40 percent from the leftmost support. The v20 indicates the negative shear at the second support.

The 3S2 is the AASHTO truck designation.

The FC indicates Functional Class designation.

	Bridge	Load Effect	3S2	FC01					FC02					FC11					FC12					FC14					Max
				mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	
SC	S18-41064	M15	2156.0	1447.8	691.4				1607.3	990.8				1588.0	1268.2				1409.5	937.1				1065.6	735.8				
		3S2 M15	72.0	48.3	23.1	79.1	10.8	123.9	53.7	33.1	97.7	15.5	161.9	53.0	42.4	109.4	19.8	191.6	47.1	31.3	88.7	14.6	149.4	35.6	24.6	68.3	11.5	116.0	191.6
		V10	62.8	42.0	19.8				46.2	28.1				45.7	35.9				40.6	26.4				30.7	20.8				
		3S2 V10	72.0	48.1	22.7	78.3	10.6	122.4	53.0	32.2	95.8	15.1	158.3	52.4	41.1	107.1	19.2	187.0	46.5	30.3	86.8	14.1	145.5	35.2	23.8	66.9	11.1	113.2	187.0
	S20-41064	M15	1879.4	1254.5	595.5				1395.4	856.6				1381.2	1101.0				1225.5	813.3				929.6	637.1				
		3S2 M15	72.0	48.1	22.8	78.4	10.7	122.7	53.5	32.8	97.1	15.3	160.8	52.9	42.2	109.0	19.7	190.9	46.9	31.2	88.4	14.6	148.9	35.6	24.4	68.1	11.4	115.5	190.9
		V10	61.7	41.1	19.2				45.2	27.3				44.8	35.1				39.8	25.8				30.2	20.3				
		3S2 V10	72.0	47.9	22.4	77.7	10.5	121.2	52.7	31.8	95.1	14.9	156.9	52.2	40.9	106.7	19.1	186.2	46.4	30.1	86.4	14.1	144.9	35.2	23.7	66.7	11.1	112.7	186.2
	B01-11072	M14	574.8	379.1	163.5				426.8	241.0				413.3	311.9				366.6	231.6				286.4	177.4				
		3S2 M14	72.0	47.5	20.5	74.7	9.6	114.5	53.5	30.2	93.6	14.1	152.2	51.8	39.1	103.7	18.3	179.6	45.9	29.0	84.5	13.6	140.8	35.9	22.2	65.4	10.4	108.6	179.6
		M20	353.5	339.8	157.0				366.6	213.6				357.1	264.7				322.7	200.8				237.2	156.0				
		3S2 M20	72.0	69.2	32.0	111.7	14.9	173.8	74.7	43.5	132.5	20.3	217.0	72.7	53.9	144.5	25.2	249.1	65.7	40.9	120.1	19.1	199.5	48.3	31.8	90.6	14.9	152.3	249.1
		V10	47.8	30.6	13.0				34.3	19.5				34.4	25.6				30.5	18.7				23.9	14.3				
		3S2 V10	72.0	46.1	19.6	72.1	9.2	110.1	51.7	29.4	90.7	13.7	147.7	51.8	38.6	103.1	18.0	178.0	45.9	28.2	83.4	13.2	138.1	36.0	21.5	64.7	10.1	106.5	178.0
		V20	55.9	45.7	22.4				50.5	31.9				49.7	40.3				44.1	29.8				33.0	23.5				
		3S2 V20	72.0	58.9	28.9	97.2	13.5	153.2	65.0	41.1	119.7	19.2	199.5	64.0	51.9	133.1	24.3	233.8	56.8	38.4	107.9	17.9	182.4	42.5	30.3	82.8	14.1	141.5	233.8
	S19-63174	M14	1745.7	1170.9	554.0				1300.5	793.8				1285.3	1018.2				1141.0	752.3				864.0	590.0				
		3S2 M14	72.0	48.3	22.8	78.7	10.7	123.0	53.6	32.7	97.2	15.3	160.7	53.0	42.0	108.9	19.6	190.4	47.1	31.0	88.3	14.5	148.6	35.6	24.3	68.0	11.4	115.2	190.4
		M20	1124.6	767.4	378.5				846.1	534.6				829.8	673.1				737.2	497.8				550.0	394.0				
		3S2 M20	72.0	49.1	24.2	81.4	11.3	128.4	54.2	34.2	99.7	16.0	166.1	53.1	43.1	110.5	20.1	194.1	47.2	31.9	89.6	14.9	151.5	35.2	25.2	68.8	11.8	117.7	194.1
		M26	1935.4	1305.8	621.2				1448.5	888.1				1430.0	1136.1				1269.7	839.6				959.2	659.3				
		3S2 M26	72.0	48.6	23.1	79.3	10.8	124.2	53.9	33.0	97.8	15.4	162.0	53.2	42.3	109.4	19.8	191.5	47.2	31.2	88.8	14.6	149.4	35.7	24.5	68.3	11.5	115.9	191.5
		V10	60.7	40.3	18.6				44.3	26.6				44.0	34.4				39.1	25.2				29.8	19.8				
		3S2 V10	72.0	47.8	22.1	77.2	10.3	120.0	52.6	31.6	94.5	14.7	155.8	52.2	40.8	106.5	19.1	185.7	46.4	29.9	86.2	14.0	144.2	35.4	23.5	66.6	11.0	112.2	185.7
		V20l	65.9	44.4	21.3				48.8	30.1				48.1	38.2				42.8	28.2				32.2	22.3				
		3S2 V20l	72.0	48.5	23.3	79.5	10.9	124.7	53.4	32.9	97.1	15.4	161.0	52.6	41.8	108.2	19.5	189.2	46.8	30.8	87.8	14.4	147.7	35.2	24.4	67.6	11.4	115.0	189.2
		V20r	66.9	45.2	21.7				49.7	30.7				48.9	38.9				43.5	28.7				32.6	22.7				
		3S2 V20r	72.0	48.7	23.4	79.8	10.9	125.1	53.5	33.1	97.5	15.5	161.7	52.7	41.9	108.4	19.6	189.7	46.8	30.9	88.0	14.4	147.9	35.1	24.4	67.6	11.4	115.1	189.7
		V30	61.6	41.0	19.1				45.1	27.2				44.8	35.0				39.8	25.7				30.2	20.2				
		3S2 V30	72.0	48.0	22.3	77.7	10.4	121.0	52.8	31.8	95.1	14.9	156.8	52.4	40.9	106.9	19.1	186.3	46.6	30.1	86.5	14.1	144.9	35.3	23.6	66.8	11.0	112.6	186.3
	S03-19042	M20	1163.0	783.9	386.0				865.0	546.1				849.0	688.6				754.0	509.1				562.9	402.5				
		3S2 M20	72.0	48.5	23.9	80.3	11.2	126.7	53.6	33.8	98.5	15.8	164.2	52.6	42.6	109.3	19.9	192.0	46.7	31.5	88.6	14.7	149.8	34.8	24.9	68.0	11.6	116.4	192.0
		M25	1178.5	788.5	366.9				879.5	530.4				873.4	687.3				774.9	508.2				591.6	396.2				
		3S2 M25	72.0	48.2	22.4	78.0	10.5	121.5	53.7	32.4	96.8	15.1	159.7	53.4	42.0	109.2	19.6	190.7	47.3	31.0	88.6	14.5	148.9	36.1	24.2	68.3	11.3	115.3	190.7
		M30	738.7	493.8	241.1				547.0	343.8				538.8	436.7				477.9	322.2				358.9	253.5				
		3S2 M30	72.0	48.1	23.5	79.4	11.0	125.0	53.3	33.5	97.9	15.7	162.9	52.5	42.6	109.1	19.9	191.8	46.6	31.4	88.4	14.7	149.3	35.0	24.7	67.9	11.5	115.8	191.8
		M40	1180.5	800.2	394.2				882.7	557.5				866.4	702.8				769.5	519.6				574.3	410.9				
		3S2 M40	72.0	48.8	24.0	80.8	11.2	127.5	53.8	34.0	99.1	15.9	165.1	52.8	42.9	109.9	20.0	193.1	46.9	31.7	89.1	14.8	150.6	35.0	25.1	68.4	11.7	117.0	193.1
		V20l	66.8	45.0	21.6				49.5	30.6				48.7	38.8				43.3	28.6				32.5	22.6				
		3S2 V20l	72.0	48.5	23.3	79.4	10.9	124.6	53.3	33.0	97.2	15.4	161.2	52.5	41.8	108.1	19.5	189.2	46.6	30.8	87.6	14.4	147.4	35.0	24.3	67.4	11.4	114.7	189.2
		V20r	62.3	41.2	19.2				45.4	27.4				45.0	35.3				40.0	25.9				30.4	20.4				
		3S2 V20r	72.0	47.6	22.2	77.1	10.4	120.1	52.4	31.6	94.5	14.8	156.0	52.0	40.8	106.2	19.1	185.3	46.2	29.9	86.0	14.0	144.1	35.1	23.6	66.5	11.0	112.2	185.3
		V30l	63.3	41.9	19.7				46.2	28.0				45.8	36.0				40.7	26.4				30.8	20.8				
		3S2 V30l	72.0	47.7	22.4	77.5	10.5	121.0	52.6	31.9	94.9	14.9	156.8	52.1	41.0	106.6	19.1	186.1	46.3	30.0	86.3	14.0	144.5	35.0	23.7	66.5	11.1	112.4	186.1
		V30r	63.3	41.8	19.6				46.1	27.9				45.7	35.9				40.6	26.4				30.8	20.7				
		3S2 V30r	72.0	47.6	22.3	77.2	10.4	120.5	52.4	31.7	94.7	14.8	156.3	52.0	40.8	106.3	19.1	185.6	46.2	30.0	86.1	14.0	144.4	35.0	23.5	66.4	11.0	112.1	185.6
		V40l	62.3	41.3	19.3				45.5	27.5				45.1	35.4				40.1	26.0				30.4	20.4				
		3S2 V30r	72.0	47.7	22.3	77.4	10.4	120.7	52.6	31.8	94.8	14.9	156.5	52.1	40.9	106.5	19.1	185.9	46.3	30.0	86.3	14.0	144.6	35.1	23.6	66.5	11.0	112.2	185.9
		V40r	66.9	45.1	21.7				49.6	30.6				48.8	38.8				43.4	28.7				32.5	22.7				
		3S2 V30r	72.0	48.5	23.4	79.6	10.9	125.0	53.4	32.9	97.2	15.4	161.1	52.5	41.8	108.1	19.5	189.1	46.7	30.9	87.8	14.4	147.8	35.0	24.4	67.5	11.4	114.9	189.1
		V50	60.8	40.4	18.7				44.4	26.7				44.1	34.4				39.2	25.2				29.8	19.9				
		3S2 V30r	72.0	47.8	22.1	77.3	10.4	120.3	52.6	31.6	94.7	14.8	156.0	52.2	40.7	106.4	19.0	185.5	46.4	29.8	86.1	13.9	144.1	35.3	23.6	66.6	11.0	112.4	185.5

	Bridge	Load Effect	3S2	FC01					FC02					FC11					FC12					FC14					Max
				mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	
PI	S11-19033	M15	1803.21	1235.1	585.8				1374.1	843.2				1360.4	1084.2				1207.0	800.9				915.9	627.2				
		3S2 M15	72.0	49.3	23.4	80.4	10.9	125.8	54.9	33.7	99.7	15.7	165.0	54.3	43.3	111.9	20.2	195.9	48.2	32.0	90.7	14.9	152.8	36.6	25.0	69.9	11.7	118.5	195.9
		V10	61.39	40.9	19.1				45.1	27.2				44.7	35.0				39.7	25.7				30.1	20.2				
		3S2 V10	72.0	48.0	22.4	77.8	10.5	121.2	52.9	31.9	95.3	14.9	157.2	52.4	41.0	107.0	19.2	186.7	46.6	30.1	86.7	14.1	145.2	35.3	23.7	66.8	11.1	112.8	186.7
	B02-11052	M15	1291.21	852.4	396.7				954.5	578.2				951.0	753.8				842.5	556.8				646.6	432.6				
		3S2 M15	72.0	47.5	22.1	77.0	10.3	119.9	53.2	32.2	96.1	15.1	158.7	53.0	42.0	108.9	19.6	190.5	47.0	31.0	88.3	14.5	148.5	36.1	24.1	68.1	11.3	115.0	190.5
		V10	58.3	38.2	17.4				42.2	25.2				42.1	32.7				37.3	23.9				28.6	18.7				
		3S2 V10	72.0	47.2	21.5	75.8	10.0	117.5	52.1	31.1	93.5	14.5	153.9	52.0	40.4	105.7	18.9	184.1	46.1	29.5	85.3	13.8	142.6	35.3	23.1	66.0	10.8	110.9	184.1
	B04-11057	M15	1717.08	1169.2	553.2				1301.9	797.5				1290.0	1027.2				1144.3	758.8				869.6	593.6				
		3S2 M15	72.0	49.0	23.2	79.9	10.8	124.9	54.6	33.4	99.1	15.6	164.0	54.1	43.1	111.4	20.1	195.0	48.0	31.8	90.3	14.9	152.1	36.5	24.9	69.6	11.6	117.9	195.0
		V10	60.97	40.6	18.9				44.7	26.9				44.4	34.7				39.4	25.5				30.0	20.0				
		3S2 V10	72.0	47.9	22.3	77.6	10.4	121.0	52.8	31.8	95.0	14.8	156.7	52.4	41.0	106.9	19.2	186.5	46.5	30.1	86.6	14.1	145.0	35.4	23.6	66.8	11.0	112.7	186.5
	B02-11112	M15	1648.72	1103.6	520.7				1230.0	752.0				1219.8	970.6				1081.8	716.9				823.4	560.2				
		3S2 M15	72.0	48.2	22.7	78.4	10.6	122.6	53.7	32.8	97.4	15.3	161.1	53.3	42.4	109.7	19.8	191.9	47.2	31.3	88.9	14.6	149.7	36.0	24.5	68.5	11.4	116.0	191.9
		M25	1616.98	1078.3	508.2				1202.2	734.5				1192.7	948.7				1057.7	700.7				805.6	547.3				
		3S2 M25	72.0	48.0	22.6	78.1	10.6	122.0	53.5	32.7	97.0	15.3	160.5	53.1	42.2	109.3	19.7	191.3	47.1	31.2	88.6	14.6	149.2	35.9	24.4	68.3	11.4	115.6	191.3
		V10	60.61	40.1	18.6				44.2	26.6				43.9	34.3				39.0	25.2				29.7	19.8				
		3S2 V10	72.0	47.6	22.1	77.0	10.3	119.9	52.5	31.6	94.5	14.8	155.9	52.1	40.7	106.4	19.0	185.4	46.3	29.9	86.2	14.0	144.3	35.3	23.5	66.6	11.0	112.2	185.4
		V20	60.44	40.0	18.5				44.0	26.5				43.8	34.2				38.9	25.0				29.6	19.7				
		3S2 V20	72.0	47.7	22.0	77.0	10.3	119.7	52.4	31.6	94.4	14.8	155.7	52.2	40.7	106.4	19.0	185.4	46.3	29.8	86.0	13.9	143.8	35.3	23.5	66.5	11.0	112.0	185.4
	R01-19034	M15	314.34	248.0	103.1				276.0	145.4				275.9	195.5				247.1	147.7				189.4	113.2				
		3S2 M15	72.0	56.8	23.6	88.2	11.0	134.1	63.2	33.3	107.5	15.6	172.2	63.2	44.8	122.8	20.9	209.7	56.6	33.8	101.6	15.8	167.3	43.4	25.9	77.9	12.1	128.2	209.7
		M25	234.41	179.6	74.7				199.6	103.5				194.4	133.1				174.4	101.6				133.4	78.2				
		3S2 M25	72.0	55.2	22.9	85.7	10.7	130.2	61.3	31.8	103.6	14.9	165.3	59.7	40.9	114.1	19.1	193.4	53.6	31.2	95.1	14.6	155.7	41.0	24.0	72.9	11.2	119.5	193.4
		V10	38.18	27.9	11.2				31.1	16.4				31.0	21.6				27.8	16.1				21.7	12.2				
		3S2 V10	72.0	52.6	21.1	80.7	9.9	121.7	58.6	30.9	99.8	14.5	159.8	58.5	40.7	112.6	19.0	191.7	52.4	30.4	92.8	14.2	151.7	40.9	23.0	71.5	10.8	116.2	191.7
		V20	34.21	26.1	10.2				28.9	14.6				28.5	18.8				25.7	14.3				20.0	10.8				
		3S2 V20	72.0	54.9	21.5	83.5	10.0	125.2	60.8	30.7	101.7	14.4	161.3	60.0	39.6	112.6	18.5	189.4	54.1	30.1	94.1	14.1	152.5	42.1	22.7	72.3	10.6	116.4	189.4

	Bridge	Load Effect	3S2	FC01					FC02					FC11					FC12					FC14					Max
				mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	
PCS	B04-03072	M15	476.15	342.3	144.2				382.4	208.1				383.8	281.5				342.5	211.3				264.3	160.8				
		3S2 M15	72.0	51.8	21.8	80.8	10.2	123.1	57.8	31.5	99.7	14.7	160.8	58.0	42.6	114.7	19.9	197.3	51.8	32.0	94.3	14.9	156.3	40.0	24.3	72.3	11.4	119.5	197.3
		V10	46.21	29.9	12.7				33.6	18.9				33.8	25.0				29.9	18.3				23.5	14.0				
		3S2 V10	72.0	46.6	19.8	72.9	9.2	111.3	52.4	29.4	91.5	13.8	148.7	52.7	39.0	104.5	18.2	180.1	46.6	28.5	84.5	13.3	139.9	36.6	21.8	65.6	10.2	108.0	180.1
	R01-55011	M15	845	537.8	241.0				607.4	358.0				612.5	480.2				541.1	354.5				423.6	272.9				
		3S2 M15	72.0	45.8	20.5	73.1	9.6	113.0	51.8	30.5	92.3	14.3	151.5	52.2	40.9	106.6	19.1	186.0	46.1	30.2	86.3	14.1	144.9	36.1	23.3	67.0	10.9	112.2	186.0
		V10	53.6	34.2	15.2				38.2	22.5				38.3	29.5				33.9	21.4				26.3	16.5				
		3S2 V10	72.0	45.9	20.4	73.1	9.5	112.7	51.3	30.2	91.5	14.1	150.2	51.4	39.6	104.2	18.5	181.1	45.5	28.7	83.8	13.4	139.6	35.3	22.2	64.8	10.4	107.8	181.1
	S06-63081	M15	215.42	146.9	60.9				163.0	83.9				161.4	108.6				144.9	83.6				110.8	63.7				
		3S2 M15	72.0	49.1	20.4	76.2	9.5	115.7	54.5	28.0	91.8	13.1	146.2	53.9	36.3	102.2	17.0	172.7	48.4	27.9	85.6	13.1	139.8	37.0	21.3	65.4	10.0	106.7	172.7
		M25	895.8	549.6	247.0				620.7	366.8				625.7	491.4				552.8	362.7				432.5	279.3				
		3S2 M25	72.0	44.2	19.9	70.6	9.3	109.1	49.9	29.5	89.1	13.8	146.3	50.3	39.5	102.8	18.5	179.5	44.4	29.2	83.2	13.6	139.8	34.8	22.4	64.6	10.5	108.2	179.5
		M35	215.42	153.9	63.9				170.9	88.1				169.5	114.6				152.1	87.5				116.3	67.2				
		3S2 M35	72.0	51.4	21.4	79.8	10.0	121.3	57.1	29.4	96.3	13.8	153.4	56.7	38.3	107.6	17.9	181.9	50.8	29.2	89.7	13.7	146.5	38.9	22.5	68.7	10.5	112.3	181.9
		V10	33.78	24.9	9.7				27.6	13.7				27.2	17.5				24.6	13.4				19.1	10.1				
		3S2 V10	72.0	53.1	20.7	80.6	9.7	120.7	58.8	29.2	97.7	13.6	154.3	58.0	37.3	107.6	17.4	180.0	52.4	28.6	90.4	13.3	145.9	40.7	21.5	69.3	10.1	111.1	180.0
		V20	54.28	34.4	15.3				38.4	22.6				38.5	29.6				34.1	21.5				26.5	16.6				
		3S2 V20	72.0	45.6	20.3	72.6	9.5	112.0	50.9	30.0	90.8	14.0	149.0	51.1	39.3	103.3	18.4	179.5	45.2	28.5	83.2	13.3	138.5	35.2	22.0	64.4	10.3	107.2	179.5
		V30	33.78	25.2	9.8				27.9	13.9				27.6	17.8				24.9	13.6				19.3	10.3				
		3S2 V30	72.0	53.7	20.9	81.5	9.8	122.0	59.5	29.6	98.9	13.8	156.4	58.8	37.9	109.3	17.7	182.9	53.1	29.0	91.6	13.5	147.9	41.1	22.0	70.3	10.3	113.0	182.9
	S14-33084	M15	304.97	226.5	94.2				248.2	130.0				251.6	176.8				225.5	134.0				172.7	102.9				
		3S2 M15	72.0	53.5	22.2	83.1	10.4	126.2	58.6	30.7	99.4	14.3	159.0	59.4	41.7	114.9	19.5	195.9	53.2	31.6	95.3	14.8	156.7	40.8	24.3	73.1	11.4	120.2	195.9
		M25	868.36	515.0	229.4				581.4	340.6				586.5	458.0				518.4	338.2				406.0	260.1				
		3S2 M25	72.0	42.7	19.0	68.0	8.9	104.9	48.2	28.2	85.8	13.2	140.6	48.6	38.0	99.1	17.7	172.9	43.0	28.0	80.3	13.1	134.7	33.7	21.6	62.4	10.1	104.2	172.9
		M35	269.26	198.3	82.5				220.5	114.9				211.5	146.2				189.9	111.4				145.3	85.9				
		3S2 M35	72.0	53.0	22.1	82.4	10.3	125.2	59.0	30.7	99.8	14.4	159.5	56.6	39.1	108.6	18.3	184.4	50.8	29.8	90.4	13.9	148.2	38.9	23.0	69.4	10.7	114.0	184.4
		V10	37.6	27.4	10.9				30.5	15.8				30.4	20.8				27.2	15.6				21.3	11.8				
		3S2 V10	72.0	52.5	20.9	80.2	9.8	120.7	58.4	30.3	98.7	14.1	157.4	58.2	39.8	111.2	18.6	188.5	52.1	29.9	91.8	14.0	149.8	40.8	22.6	70.8	10.6	114.7	188.5
		V20	53.9	33.8	15.0				37.8	22.2				37.9	29.1				33.5	21.2				26.1	16.3				
		3S2 V20	72.0	45.2	20.0	71.8	9.4	110.7	50.5	29.7	89.9	13.9	147.5	50.6	38.9	102.3	18.2	177.8	44.7	28.3	82.4	13.2	137.4	34.9	21.8	63.8	10.2	106.1	177.8
		V30	35.14	26.7	10.5				29.6	15.0				29.1	19.4				26.2	14.7				20.4	11.1				
		3S2 V30	72.0	54.7	21.5	83.3	10.1	125.1	60.6	30.7	101.5	14.4	161.2	59.6	39.7	112.5	18.6	189.7	53.7	30.1	93.7	14.1	152.2	41.8	22.7	72.1	10.6	116.2	189.7
	B01-79031	M15	391.44	295.4	123.1				329.4	176.0				329.8	237.6				295.1	178.9				226.5	136.2				
		3S2 M15	72.0	54.3	22.6	84.5	10.6	128.4	60.6	32.4	103.7	15.1	166.5	60.7	43.7	118.8	20.4	203.6	54.3	32.9	98.1	15.4	161.9	41.7	25.1	75.0	11.7	123.6	203.6
		V10	43.23	28.9	11.9				32.4	17.6				32.5	23.4				28.9	17.3				22.7	13.2				
		3S2 V10	72.0	48.1	19.8	74.5	9.3	113.0	54.0	29.3	93.0	13.7	149.9	54.1	39.0	106.0	18.2	181.6	48.1	28.8	86.5	13.5	142.4	37.8	22.0	67.1	10.3	109.7	181.6

	Bridge	Load Effect	3S2	FC01					FC02					FC11					FC12					FC14					Max
				mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	mean	stdev	>80% mean	>80% stdev	Truck	
PCA	S05-82022	M15	823.45	540.1	242.2				609.3	359.5				615.0	482.4				543.3	356.1				425.3	274.1				
		3S2 M15	72.0	47.2	21.2	75.4	9.9	116.5	53.3	31.4	95.1	14.7	156.1	53.8	42.2	109.9	19.7	191.8	47.5	31.1	88.9	14.6	149.4	37.2	24.0	69.1	11.2	115.6	191.8
		V10	53.27	34.3	15.2				38.3	22.6				38.3	29.5				33.9	21.4				26.4	16.5				
		3S2 V10	72.0	46.4	20.5	73.7	9.6	113.6	51.8	30.5	92.4	14.3	151.7	51.8	39.9	104.8	18.6	182.2	45.8	28.9	84.3	13.5	140.4	35.7	22.3	65.3	10.4	108.6	182.2
	S06-82022	M15	819	537.4	240.4				606.3	357.5				612.0	479.8				540.7	354.2				423.3	272.6				
		3S2 M15	72.0	47.2	21.1	75.4	9.9	116.4	53.3	31.4	95.1	14.7	156.1	53.8	42.2	109.9	19.7	191.8	47.5	31.1	89.0	14.6	149.4	37.2	24.0	69.1	11.2	115.6	191.8
		V10	53.2	34.2	15.2				38.3	22.5				38.3	29.5				33.9	21.4				26.3	16.5				
		3S2 V10	72.0	46.3	20.6	73.7	9.6	113.6	51.8	30.5	92.3	14.2	151.4	51.8	39.9	104.9	18.7	182.4	45.9	29.0	84.4	13.5	140.6	35.6	22.3	65.3	10.4	108.6	182.4
	S25-82022	M15	1252.7	816.1	378.8				914.0	552.9				912.2	722.6				808.0	533.8				621.0	414.2				
		3S2 M15	72.0	46.9	21.8	75.9	10.2	118.1	52.5	31.8	94.8	14.9	156.5	52.4	41.5	107.7	19.4	188.3	46.4	30.7	87.3	14.3	146.8	35.7	23.8	67.4	11.1	113.6	188.3
		V10	58	37.8	17.2				41.8	24.9				41.7	32.4				37.0	23.6				28.4	18.4				
		3S2 V10	72.0	46.9	21.4	75.3	10.0	116.8	51.9	30.9	93.0	14.4	153.0	51.8	40.2	105.3	18.8	183.3	45.9	29.3	84.9	13.7	141.8	35.3	22.8	65.6	10.7	110.0	183.3
	S01-11015	M15	288.3	212.3	88.3				235.5	123.2				235.4	164.5				211.2	124.9				161.6	96.2				
		3S2 M15	72.0	53.0	22.1	82.4	10.3	125.2	58.8	30.8	99.7	14.4	159.5	58.8	41.1	113.4	19.2	193.2	52.7	31.2	94.2	14.6	154.8	40.4	24.0	72.3	11.2	118.9	193.2
		V10	36.5	27.1	10.7				30.1	15.5				29.9	20.3				26.9	15.3				20.9	11.5				
		3S2 V10	72.0	53.5	21.1	81.5	9.9	122.5	59.4	30.6	100.0	14.3	159.4	59.0	40.0	112.2	18.7	190.0	53.1	30.2	93.2	14.1	151.8	41.2	22.7	71.4	10.6	115.4	190.0
		M25	915.2	591.8	268.3				667.1	397.2				672.0	529.6				593.9	391.1				463.3	301.3				
		3S2 M25	72.0	46.6	21.1	74.6	9.9	115.6	52.5	31.2	94.0	14.6	154.7	52.9	41.7	108.3	19.5	189.2	46.7	30.8	87.7	14.4	147.4	36.4	23.7	68.0	11.1	114.0	189.2
		V20	54.53	35.1	15.7				39.1	23.1				39.1	30.2				34.6	21.9				26.8	17.0				
		3S2 V20	72.0	46.3	20.7	73.9	9.7	114.2	51.6	30.5	92.2	14.3	151.4	51.7	39.9	104.7	18.6	182.1	45.7	28.9	84.2	13.5	140.3	35.4	22.4	65.2	10.5	108.8	182.1
		M45	344.4	257.8	107.2				286.5	151.3				229.4	159.8				205.8	121.5				157.5	93.6				
		3S2 M45	72.0	53.9	22.4	83.7	10.5	127.2	59.9	31.6	102.0	14.8	163.4	48.0	33.4	92.4	15.6	157.2	43.0	25.4	76.8	11.9	126.1	32.9	19.6	59.0	9.1	96.9	163.4
		V40	40.08	28.1	11.3				31.4	16.7				29.7	20.0				26.7	15.1				20.8	11.4				
		3S2 V40	72.0	50.5	20.3	77.5	9.5	116.9	56.4	30.0	96.3	14.0	154.5	53.4	35.9	101.1	16.8	170.9	48.0	27.1	84.0	12.7	136.7	37.4	20.5	64.6	9.6	104.4	170.9
	B02-46082	M15	337.94	250.8	104.3				279.2	147.2				279.0	197.9				250.0	149.5				191.5	114.5				
		3S2 M15	72.0	53.4	22.2	83.0	10.4	126.1	59.5	31.4	101.2	14.7	162.1	59.4	42.2	115.5	19.7	197.4	53.3	31.9	95.6	14.9	157.5	40.8	24.4	73.3	11.4	120.6	197.4
		V10	39.59	28.0	11.2				31.2	16.4				31.2	21.7				27.8	16.2				21.8	12.3				
		3S2 V10	72.0	50.9	20.4	78.0	9.5	117.6	56.7	29.8	96.4	13.9	154.3	56.7	39.5	109.2	18.4	185.8	50.6	29.5	89.7	13.8	146.9	39.6	22.4	69.4	10.5	112.8	185.8

Average	188.631
Std Dev	11.52

	Bridge	Load Effect	3S2	mean	stdev	>80% mean	>80% stdev	5000 ADTT Truck	1000 ADTT Truck	100 ADTT Truck
SC	S18-41064	M15	2156.0	1588.0	1268.2					
		3S2 M15	72.0	53.0	42.4	109.4	19.8	191.6	184.0	171.7
		V10	62.8	45.7	35.9					
		3S2 V10	72.0	52.4	41.1	107.1	19.2	187.0	179.6	167.7
	S20-41064	M15	1879.4	1381.2	1101.0					
		3S2 M15	72.0	52.9	42.2	109.0	19.7	190.9	183.3	171.1
		V10	61.7	44.8	35.1					
		3S2 V10	72.0	52.2	40.9	106.7	19.1	186.2	178.8	166.9
	B01-11072	M14	574.8	413.3	311.9					
		3S2 M14	72.0	51.8	39.1	103.7	18.3	179.6	172.6	161.2
		M20	353.5	357.1	264.7					
		3S2 M20	72.0	72.7	53.9	144.5	25.2	249.1	239.4	223.8
		V10	47.8	34.4	25.6					
		3S2 V10	72.0	51.8	38.6	103.1	18.0	178.0	171.0	159.8
		V20	55.9	49.7	40.3					
		3S2 V20	72.0	64.0	51.9	133.1	24.3	233.8	224.5	209.4
	S19-63174	M14	1745.7	1285.3	1018.2					
		3S2 M14	72.0	53.0	42.0	108.9	19.6	190.4	182.9	170.7
		M20	1124.6	829.8	673.1					
		3S2 M20	72.0	53.1	43.1	110.5	20.1	194.1	186.4	173.9
		M26	1935.4	1430.0	1136.1					
		3S2 M26	72.0	53.2	42.3	109.4	19.8	191.5	183.9	171.6
		V10	60.7	44.0	34.4					
		3S2 V10	72.0	52.2	40.8	106.5	19.1	185.7	178.4	166.5
		V20l	65.9	48.1	38.2					
		3S2 V20l	72.0	52.6	41.8	108.2	19.5	189.2	181.7	169.6
		V20r	66.9	48.9	38.9					
		3S2 V20r	72.0	52.7	41.9	108.4	19.6	189.7	182.2	170.0
		V30	61.6	44.8	35.0					
		3S2 V30	72.0	52.4	40.9	106.9	19.1	186.3	179.0	167.1
	S03-19042	M20	1163.0	849.0	688.6					
		3S2 M20	72.0	52.6	42.6	109.3	19.9	192.0	184.4	172.0
		M25	1178.5	873.4	687.3					
		3S2 M25	72.0	53.4	42.0	109.2	19.6	190.7	183.2	171.0
		M30	738.7	538.8	436.7					
		3S2 M30	72.0	52.5	42.6	109.1	19.9	191.8	184.1	171.8
		M40	1180.5	866.4	702.8					
		3S2 M40	72.0	52.8	42.9	109.9	20.0	193.1	185.4	172.9
		V20l	66.8	48.7	38.8					
		3S2 V20l	72.0	52.5	41.8	108.1	19.5	189.2	181.7	169.6
		V20r	62.3	45.0	35.3					
		3S2 V20r	72.0	52.0	40.8	106.2	19.1	185.3	178.0	166.2
		V30l	63.3	45.8	36.0					
		3S2 V30l	72.0	52.1	41.0	106.6	19.1	186.1	178.7	166.8
		V30r	63.3	45.7	35.9					
		3S2 V30r	72.0	52.0	40.8	106.3	19.1	185.6	178.3	166.4
		V40l	62.3	45.1	35.4					
		3S2 V30r	72.0	52.1	40.9	106.5	19.1	185.9	178.6	166.7
		V40r	66.9	48.8	38.8					
		3S2 V30r	72.0	52.5	41.8	108.1	19.5	189.1	181.7	169.5
		V50	60.8	44.1	34.4					
		3S2 V30r	72.0	52.2	40.7	106.4	19.0	185.5	178.2	166.4

	Bridge	Load Effect	3S2	mean	stdev	>80% mean	>80% stdev	5000 ADTT Truck	1000 ADTT Truck	100 ADTT Truck
PI	S11-19033	M15	1803.21	1360.4	1084.2					
		3S2 M15	72.0	54.3	43.3	111.9	20.2	195.9	188.2	175.6
		V10	61.39	44.7	35.0					
		3S2 V10	72.0	52.4	41.0	107.0	19.2	186.7	179.3	167.4
	B02-11052	M15	1291.21	951.0	753.8					
		3S2 M15	72.0	53.0	42.0	108.9	19.6	190.5	183.0	170.8
		V10	58.3	42.1	32.7					
		3S2 V10	72.0	52.0	40.4	105.7	18.9	184.1	176.9	165.1
	B04-11057	M15	1717.08	1290.0	1027.2					
		3S2 M15	72.0	54.1	43.1	111.4	20.1	195.0	187.3	174.8
		V10	60.97	44.4	34.7					
		3S2 V10	72.0	52.4	41.0	106.9	19.2	186.5	179.1	167.2
	B02-11112	M15	1648.72	1219.8	970.6					
		3S2 M15	72.0	53.3	42.4	109.7	19.8	191.9	184.3	172.0
		M25	1616.98	1192.7	948.7					
		3S2 M25	72.0	53.1	42.2	109.3	19.7	191.3	183.7	171.5
		V10	60.61	43.9	34.3					
		3S2 V10	72.0	52.1	40.7	106.4	19.0	185.4	178.1	166.3
		V20	60.44	43.8	34.2					
		3S2 V20	72.0	52.2	40.7	106.4	19.0	185.4	178.1	166.3
	R01-19034	M15	314.34	275.9	195.5					
		3S2 M15	72.0	63.2	44.8	122.8	20.9	209.7	201.7	188.6
		M25	234.41	194.4	133.1					
		3S2 M25	72.0	59.7	40.9	114.1	19.1	193.4	186.1	174.2
		V10	38.18	31.0	21.6					
		3S2 V10	72.0	58.5	40.7	112.6	19.0	191.7	184.4	172.6
		V20	34.21	28.5	18.8					
		3S2 V20	72.0	60.0	39.6	112.6	18.5	189.4	182.3	170.8

	Bridge	Load Effect	3S2	mean	stdev	>80% mean	>80% stdev	5000 ADTT Truck	1000 ADTT Truck	100 ADTT Truck
PCS	B04-03072	M15	476.15	383.8	281.5					
		3S2 M15	72.0	58.0	42.6	114.7	19.9	197.3	189.6	177.3
		V10	46.21	33.8	25.0					
		3S2 V10	72.0	52.7	39.0	104.5	18.2	180.1	173.1	161.8
	R01-55011	M15	845	612.5	480.2					
		3S2 M15	72.0	52.2	40.9	106.6	19.1	186.0	178.7	166.8
		V10	53.6	38.3	29.5					
		3S2 V10	72.0	51.4	39.6	104.2	18.5	181.1	174.0	162.5
	S06-63081	M15	215.42	161.4	108.6					
		3S2 M15	72.0	53.9	36.3	102.2	17.0	172.7	166.2	155.6
		M25	895.8	625.7	491.4					
		3S2 M25	72.0	50.3	39.5	102.8	18.5	179.5	172.4	160.9
		M35	215.42	169.5	114.6					
		3S2 M35	72.0	56.7	38.3	107.6	17.9	181.9	175.1	164.0
		V10	33.78	27.2	17.5					
		3S2 V10	72.0	58.0	37.3	107.6	17.4	180.0	173.3	162.5
		V20	54.28	38.5	29.6					
		3S2 V20	72.0	51.1	39.3	103.3	18.4	179.5	172.5	161.1
		V30	33.78	27.6	17.8					
		3S2 V30	72.0	58.8	37.9	109.3	17.7	182.9	176.1	165.1
	S14-33084	M15	304.97	251.6	176.8					
		3S2 M15	72.0	59.4	41.7	114.9	19.5	195.9	188.5	176.3
		M25	868.36	586.5	458.0					
		3S2 M25	72.0	48.6	38.0	99.1	17.7	172.9	166.0	155.0
		M35	269.26	211.5	146.2					
		3S2 M35	72.0	56.6	39.1	108.6	18.3	184.4	177.4	166.1
		V10	37.6	30.4	20.8					
		3S2 V10	72.0	58.2	39.8	111.2	18.6	188.5	181.4	169.8
		V20	53.9	37.9	29.1					
		3S2 V20	72.0	50.6	38.9	102.3	18.2	177.8	170.8	159.5
		V30	35.14	29.1	19.4					
		3S2 V30	72.0	59.6	39.7	112.5	18.6	189.7	182.5	171.0
	B01-79031	M15	391.44	329.8	237.6					
		3S2 M15	72.0	60.7	43.7	118.8	20.4	203.6	195.8	183.1
		V10	43.23	32.5	23.4					
		3S2 V10	72.0	54.1	39.0	106.0	18.2	181.6	174.6	163.3

	Bridge	Load Effect	3S2	mean	stdev	>80% mean	>80% stdev	5000 ADTT Truck	1000 ADTT Truck	100 ADTT Truck
PCA	S05-82022	M15	823.45	615.0	482.4					
		3S2 M15	72.0	53.8	42.2	109.9	19.7	191.8	184.2	171.9
		V10	53.27	38.3	29.5					
		3S2 V10	72.0	51.8	39.9	104.8	18.6	182.2	175.1	163.5
	S06-82022	M15	819	612.0	479.8					
		3S2 M15	72.0	53.8	42.2	109.9	19.7	191.8	184.2	172.0
		V10	53.2	38.3	29.5					
		3S2 V10	72.0	51.8	39.9	104.9	18.7	182.4	175.3	163.7
	S25-82022	M15	1252.7	912.2	722.6					
		3S2 M15	72.0	52.4	41.5	107.7	19.4	188.3	180.8	168.8
		V10	58	41.7	32.4					
		3S2 V10	72.0	51.8	40.2	105.3	18.8	183.3	176.1	164.4
	S01-11015	M15	288.3	235.4	164.5					
		3S2 M15	72.0	58.8	41.1	113.4	19.2	193.2	185.8	173.9
		V10	36.5	29.9	20.3					
		3S2 V10	72.0	59.0	40.0	112.2	18.7	190.0	182.8	171.2
		M25	915.2	672.0	529.6					
		3S2 M25	72.0	52.9	41.7	108.3	19.5	189.2	181.7	169.6
		V20	54.53	39.1	30.2					
		3S2 V20	72.0	51.7	39.9	104.7	18.6	182.1	175.0	163.4
		M45	344.4	229.4	159.8					
		3S2 M45	72.0	59.9	31.6	102.0	14.8	163.4	157.7	148.5
		V40	40.08	29.7	20.0					
		3S2 V40	72.0	53.4	35.9	101.1	16.8	170.9	164.4	154.0
	B02-46082	M15	337.94	279.0	197.9					
		3S2 M15	72.0	59.4	42.2	115.5	19.7	197.4	189.8	177.6
		V10	39.59	31.2	21.7					
		3S2 V10	72.0	56.7	39.5	109.2	18.4	185.8	178.8	167.3
					Average	109.1	19.2			
							Average	188.6	181.3	169.4

Appendix E

Alongside Truck 188.6 kips

Michigan Legal Vehicle Load Factors for Strength Limit States, 5000 ADTT

	Normal Loading		Designated Loading		Special Designated Loading	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	33.4	1.80	33.4	1.80	39.0	1.80
2	41.4	1.80	47.4	1.80	45.4	1.80
3	54.4	1.80	54.4	1.80	54.4	1.80
4	67.4	1.80	67.4	1.80	67.4	1.80
5	78.0	1.80	84.0	1.75	84.0	1.75
6	95.4	1.61	101.4	1.54	101.4	1.54
7	113.4	1.44	119.4	1.39	119.4	1.39
8	85.4	1.73	91.4	1.65	91.4	1.65
9	51.4	1.80	51.4	1.80	49.5	1.80
10	59.4	1.80	65.4	1.80	56.4	1.80
11	77.4	1.80	83.4	1.76	67.1	1.80
12	111.4	1.45	117.4	1.41	117.4	1.41
13	119.4	1.39	125.4	1.35	125.4	1.35
14	132.4	1.31	132.4	1.31	132.4	1.31
15	137.4	1.28	143.3	1.25	143.3	1.25
16	132.4	1.31	138.4	1.28	138.4	1.28
17	145.4	1.24	151.4	1.21	151.4	1.21
18	148.0	1.23	154.0	1.20	154.0	1.20
19	111.4	1.45	117.4	1.41	117.4	1.41
20	87.4	1.71	87.4	1.71	87.4	1.71
21	145.4	1.24	151.4	1.21	151.4	1.21
22	155.4	1.20	161.4	1.17	161.4	1.17
23	148.0	1.23	154.0	1.20	154.0	1.20
24	116.0	1.42	122.0	1.37	122.0	1.37
25	158.0	1.18	164.0	1.16	164.0	1.16
26	50.0	1.80	50.0	1.80	50.0	1.80
27	72.0	1.80	72.0	1.80	72.0	1.80
28	80.0	1.80	80.0	1.80	80.0	1.80

Overload Class Vehicle Load Factors for Strength Limit States, Annual Permits, 5000 ADTT

	Class A		Class B		Class C	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	120.0	1.39	120.0	1.39	120.0	1.39
2	120.0	1.39	120.0	1.39	120.0	1.39
3	120.0	1.39	118.0	1.40	114.0	1.43
4	120.0	1.39	108.0	1.48	98.0	1.58
5	120.0	1.39	104.0	1.52	88.0	1.70
6	126.0	1.35	108.0	1.48	90.0	1.67
7	138.0	1.28	114.0	1.43	93.0	1.64
8	149.6	1.22	127.6	1.34	105.6	1.50
9	158.4	1.18	129.6	1.33	105.6	1.50
10	177.0	1.12	146.4	1.24	122.0	1.37
11	180.0	1.11	159.0	1.18	138.0	1.28
12	190.6	1.10	160.2	1.18	134.4	1.30
13	195.0	1.10	168.8	1.14	147.4	1.23
14	211.2	1.10	179.2	1.11	153.6	1.20
15	238.0	1.10	204.0	1.10	170.0	1.14
16	244.4	1.10	203.6	1.10	173.0	1.13
17	272.6	1.10	232.4	1.10	182.8	1.10
18	283.4	1.10	241.6	1.10	200.0	1.10
19	277.2	1.10	234.4	1.10	200.8	1.10
20	264.0	1.10	225.8	1.10	191.4	1.10

Alongside Truck 181.3 kips

Michigan Legal Vehicle Load Factors for Strength Limit States, 1000 ADTT

	Normal Loading		Designated Loading		Special Designated Loading	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	33.4	1.65	33.4	1.65	39.0	1.65
2	41.4	1.65	47.4	1.65	45.4	1.65
3	54.4	1.65	54.4	1.65	54.4	1.65
4	67.4	1.65	67.4	1.65	67.4	1.65
5	78.0	1.65	84.0	1.65	84.0	1.65
6	95.4	1.57	101.4	1.51	101.4	1.51
7	113.4	1.40	119.4	1.36	119.4	1.36
8	85.4	1.65	91.4	1.61	91.4	1.61
9	51.4	1.65	51.4	1.65	49.5	1.65
10	59.4	1.65	65.4	1.65	56.4	1.65
11	77.4	1.65	83.4	1.65	67.1	1.65
12	111.4	1.42	117.4	1.37	117.4	1.37
13	119.4	1.36	125.4	1.32	125.4	1.32
14	132.4	1.28	132.4	1.28	132.4	1.28
15	137.4	1.25	143.3	1.22	143.3	1.22
16	132.4	1.28	138.4	1.25	138.4	1.25
17	145.4	1.21	151.4	1.19	151.4	1.19
18	148.0	1.20	154.0	1.18	154.0	1.18
19	111.4	1.42	117.4	1.37	117.4	1.37
20	87.4	1.65	87.4	1.65	87.4	1.65
21	145.4	1.21	151.4	1.19	151.4	1.19
22	155.4	1.17	161.4	1.15	161.4	1.15
23	148.0	1.20	154.0	1.18	154.0	1.18
24	116.0	1.38	122.0	1.34	122.0	1.34
25	158.0	1.16	164.0	1.14	164.0	1.14
26	50.0	1.65	50.0	1.65	50.0	1.65
27	72.0	1.65	72.0	1.65	72.0	1.65
28	80.0	1.65	80.0	1.65	80.0	1.65

Overload Class Vehicle Load Factors for Strength Limit States, Annual Permits, 1000 ADTT

	Class A		Class B		Class C	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	120.0	1.36	120.0	1.36	120.0	1.36
2	120.0	1.36	120.0	1.36	120.0	1.36
3	120.0	1.36	118.0	1.37	114.0	1.40
4	120.0	1.36	108.0	1.45	98.0	1.54
5	120.0	1.36	104.0	1.48	88.0	1.65
6	126.0	1.32	108.0	1.45	90.0	1.63
7	138.0	1.25	114.0	1.40	93.0	1.59
8	149.6	1.19	127.6	1.31	105.6	1.47
9	158.4	1.16	129.6	1.30	105.6	1.47
10	177.0	1.10	146.4	1.21	122.0	1.34
11	180.0	1.10	159.0	1.16	138.0	1.25
12	190.6	1.10	160.2	1.15	134.4	1.27
13	195.0	1.10	168.8	1.12	147.4	1.20
14	211.2	1.10	179.2	1.10	153.6	1.18
15	238.0	1.10	204.0	1.10	170.0	1.12
16	244.4	1.10	203.6	1.10	173.0	1.11
17	272.6	1.10	232.4	1.10	182.8	1.10
18	283.4	1.10	241.6	1.10	200.0	1.10
19	277.2	1.10	234.4	1.10	200.8	1.10
20	264.0	1.10	225.8	1.10	191.4	1.10

Alongside Truck 169.4 kips

Michigan Legal Vehicle Load Factors for Strength Limit States, 100 ADTT

	Normal Loading		Designated Loading		Special Designated Loading	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	33.4	1.40	33.4	1.40	39.0	1.40
2	41.4	1.40	47.4	1.40	45.4	1.40
3	54.4	1.40	54.4	1.40	54.4	1.40
4	67.4	1.40	67.4	1.40	67.4	1.40
5	78.0	1.40	84.0	1.40	84.0	1.40
6	95.4	1.40	101.4	1.40	101.4	1.40
7	113.4	1.35	119.4	1.31	119.4	1.31
8	85.4	1.40	91.4	1.40	91.4	1.40
9	51.4	1.40	51.4	1.40	49.5	1.40
10	59.4	1.40	65.4	1.40	56.4	1.40
11	77.4	1.40	83.4	1.40	67.1	1.40
12	111.4	1.36	117.4	1.32	117.4	1.32
13	119.4	1.31	125.4	1.27	125.4	1.27
14	132.4	1.23	132.4	1.23	132.4	1.23
15	137.4	1.21	143.3	1.18	143.3	1.18
16	132.4	1.23	138.4	1.20	138.4	1.20
17	145.4	1.17	151.4	1.14	151.4	1.14
18	148.0	1.16	154.0	1.13	154.0	1.13
19	111.4	1.36	117.4	1.32	117.4	1.32
20	87.4	1.40	87.4	1.40	87.4	1.40
21	145.4	1.17	151.4	1.14	151.4	1.14
22	155.4	1.13	161.4	1.11	161.4	1.11
23	148.0	1.16	154.0	1.13	154.0	1.13
24	116.0	1.33	122.0	1.29	122.0	1.29
25	158.0	1.12	164.0	1.10	164.0	1.10
26	50.0	1.40	50.0	1.40	50.0	1.40
27	72.0	1.40	72.0	1.40	72.0	1.40
28	80.0	1.40	80.0	1.40	80.0	1.40

Overload Class Vehicle Load Factors for Strength Limit States, Annual Permits, 100 ADTT

	Class A		Class B		Class C	
Number	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}	GVW (kips)	Load Factor, γ_{LL}
1	120.0	1.30	120.0	1.30	120.0	1.30
2	120.0	1.30	120.0	1.30	120.0	1.30
3	120.0	1.30	118.0	1.32	114.0	1.34
4	120.0	1.30	108.0	1.39	98.0	1.40
5	120.0	1.30	104.0	1.40	88.0	1.40
6	126.0	1.27	108.0	1.39	90.0	1.40
7	138.0	1.20	114.0	1.34	93.0	1.40
8	149.6	1.15	127.6	1.26	105.6	1.40
9	158.4	1.12	129.6	1.25	105.6	1.40
10	177.0	1.10	146.4	1.16	122.0	1.29
11	180.0	1.10	159.0	1.12	138.0	1.20
12	190.6	1.10	160.2	1.11	134.4	1.22
13	195.0	1.10	168.8	1.10	147.4	1.16
14	211.2	1.10	179.2	1.10	153.6	1.14
15	238.0	1.10	204.0	1.10	170.0	1.10
16	244.4	1.10	203.6	1.10	173.0	1.10
17	272.6	1.10	232.4	1.10	182.8	1.10
18	283.4	1.10	241.6	1.10	200.0	1.10
19	277.2	1.10	234.4	1.10	200.8	1.10
20	264.0	1.10	225.8	1.10	191.4	1.10

Appendix F

3.6.1.2 Design Vehicular Live Load

3.6.1.2.1 General

Vehicular live loading on the roadways of bridges or incidental structures, designated HL-93-**mod**, shall consist of a **1.2 factor times the** combination of the:

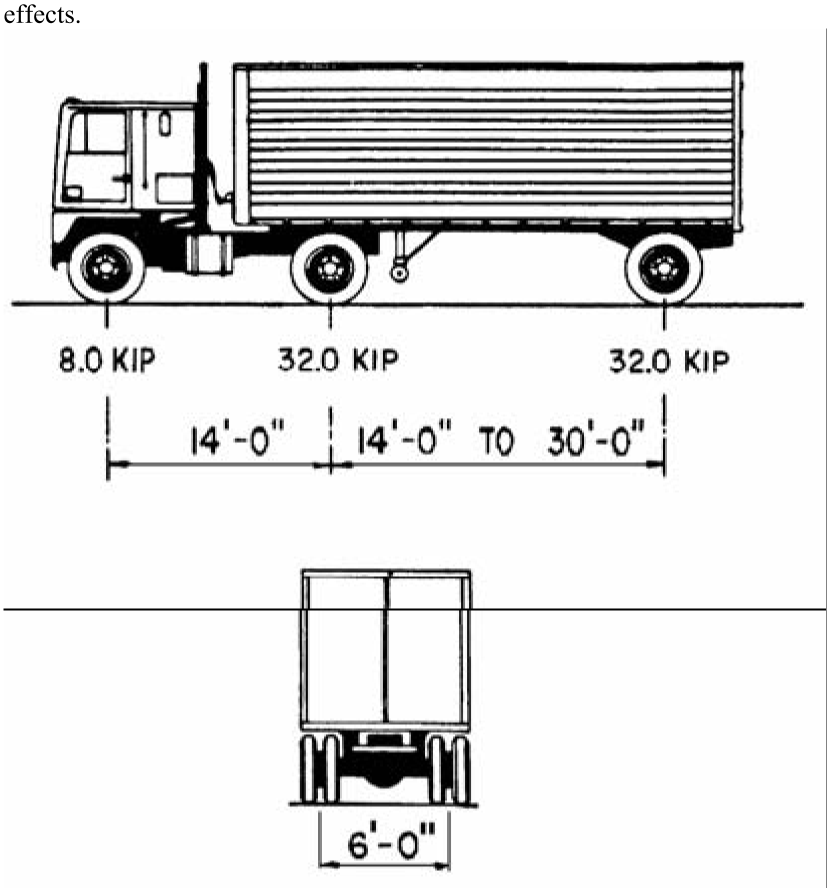
- Design truck or design **axle**, and
- Design lane load.

Except as modified in Article 3.6.1.3.1, each design lane under consideration shall be occupied by either the design truck or **axle**, coincident with the lane load, where applicable. The loads shall be assumed to occupy 10.0 ft. transversely within a design lane.

3.6.1.2.2 Design Truck

The weights and spacings of axles and wheels for the design truck shall be as specified in Figure 1. A dynamic load allowance shall be considered as specified in Article 3.6.2.

Except as specified in Articles 3.6.1.3.1 and 3.6.1.4.1, the spacing between the two 32.0-kip axles shall be varied between 14.0 ft. and 30.0 ft. to produce extreme force effects.



*3.6.1.2.3 Design **Axle***

The design tandem shall consist of a **single 60.0**-kip **Axle**. The transverse spacing of wheels shall be taken as 6.0 ft. A dynamic load allowance shall be considered as specified in Article 3.6.2.

3.6.1.2.5 Tire Contact Area

The tire contact area of a wheel consisting of one or two tires shall be assumed to be a single rectangle, whose width is 20.0 in. and whose length is 10.0 in.

The tire pressure shall be assumed to be uniformly distributed over the contact area. The tire pressure shall be assumed to be distributed as follows:

- On continuous surfaces, uniformly over the specified contact area, and
- On interrupted surfaces, uniformly over the actual contact area within the footprint with the pressure increased in the ratio of the specified to actual contact areas.

3.6.1.2.6 Distribution of Wheel Loads Through Earth Fills

Where the depth of fill is less than 2.0 ft., live loads shall be distributed to the top slabs of culverts as specified in Article 4.6.2.10.

In lieu of a more precise analysis, or the use of other acceptable approximate methods of load distribution permitted in Section 12, where the depth of fill is 2.0 ft. or greater, wheel loads may be considered to be uniformly distributed over a rectangular area with sides equal to the dimension of the tire contact area, as specified in Article 3.6.1.2.5, and increased by either 1.15 times the depth of the fill in select granular backfill, or the depth of the fill in all other cases. The provisions of Articles 3.6.1.1.2 and 3.6.1.3 shall apply.

Where such areas from several wheels overlap, the total load shall be uniformly distributed over the area.

For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length; for multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between faces of end walls.

Where the live load and impact moment in concrete slabs, based on the distribution of the wheel load through earth fills, exceeds the live load and impact moment calculated according to Article 4.6.2.10, the latter moment shall be used.

3.6.1.3 Application of Design Vehicular Live Loads

3.6.1.3.1 General

Unless otherwise specified, the extreme force effect shall be taken as the larger of the following:

- **1.2 times the sum of** the effect of the design **axle and** the effect of the design lane load, or
- **1.2 times the sum of** the effect of one design truck with the variable axle spacing specified in Article 3.6.1.2.2, **and** the effect of the design lane load, and
- For both negative moment between points of contraflexure under a uniform load on all spans, and reaction at interior piers only, 90 percent of the effect of two design trucks spaced a minimum of 50.0 ft. between the lead axle of one truck and the rear axle of the other truck, combined with 90 percent of the effect of the design lane load. The distance between the 32.0-kip axles of each truck shall be taken as 14.0 ft.

Axles that do not contribute to the extreme force effect under consideration shall be neglected.

Both the design lanes and the 10.0-ft. loaded width in each lane shall be positioned to produce extreme force effects. The design truck or **axle** shall be positioned transversely such that the center of any wheel load is not closer than:

- For the design of the deck overhang—1.0 ft. from the face of the curb or railing, and
- For the design of all other components—2.0 ft. from the edge of the design lane.

Unless otherwise specified, the lengths of design lanes, or parts thereof, that contribute to the extreme force effect under consideration, shall be loaded with the design lane load.