## Analysis of Permit Vehicle Loads In

 WisconsinSPR \# 0092-08-15

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# WISCONSIN HIGHWAY RESEARCH PROGRAM \#0092-08-15 

## ANALYSIS OF PERMIT VEHICLE LOADS IN WISCONSIN

## FINAL REPORT

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SUBMITTED TO THE WISCONSIN DEPARTMENT OF TRANSPORTATION

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| Abstract <br> This study evaluated the impact of the 250 -kip Wisconsin Standard Permit Vehicle against the overloaded vehicles operating on Wisconsin roads in recent years. The evaluation was conducted using three sets of data: 1) overloaded vehicle records within weigh-in-motion data collected in 2007; 2) the single-trip permit application records from 2004 to 2007; and 3) overloaded vehicles in neighboring states, including Minnesota, Iowa, Michigan, and Illinois. Descriptive statistical analyses were conducted for the collected overloaded vehicle data, and model vehicles that represent heavies $5 \%$ of the overloaded vehicles were created. The maximum moment/shear in simply supported, 2-span and 3span continuous girders by the representative vehicles were calculated and compared with the impact of Wis-SPV. The study indicates Wis-SPV envelopes almost all single-unit trucks with less than 9 axles, which attributes $80 \%$ of the total permit records. The analysis of WIM records shows that about $0.035 \%$ of total overloaded vehicles (records) may exceed the impact of the 250 -kip Wis-SPV. A $5-$ axle short truck was proposed to supplement Wis-SPV for possible use in the WisDOT Bridge Manual. |  |  |  |  |  |
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## EXECUTIVE SUMMARY

## Summary

This study evaluated the impact of the 250-kip Wisconsin Standard Permit Vehicle against the overloaded vehicles operating on Wisconsin roads in recent years. The evaluation was conducted using three sets of data: 1) overloaded vehicle records within weigh-in-motion data collected in 2007; 2) the single-trip permit application records from 2004 to 2007; and 3) overloaded vehicles in neighboring states, including Minnesota, Iowa, Michigan, and Illinois.

The weigh-in-motion records were categorized into legal loads and overloads per Wisconsin Statute 348 and WisDOT Bridge manual. A total of 1.4 million overloaded vehicle records out of over 6 million total truck records were used to evaluate the WisDOT Standard Permit Vehicle. The recorded overloads in individual classes (per FHWA definitions) were further divided into groups, in which the vehicles had similar axle configurations. Descriptive statistical analyses were conducted for the vehicles in each class/group to define representative vehicles that best describe the heaviest $5 \%$ vehicles in the class/group. The representative vehicles were evaluated using randomly selected vehicles within the heaviest $10 \%$ vehicles in the corresponding class/group. The girder responses (i.e., moments and shear) due to loading from the randomly selected vehicles were calculated for randomly selected span lengths to assess whether the heavy vehicles in each class/group might cause larger girder responses than Wis-SPV.

The application records for single-trip permits from July 2004 to July 2007 were used to further evaluate the 250 -kip Wisconsin Standard Permit Vehicle. Only the overloaded vehicle records were used, resulting in roughly 50 thousand records in total. The number of axles in over $99 \%$ of the records was from three to thirteen. Hence, the recorded vehicles were classified based upon their total number of axles. The configurations for each class/group were determined such that representative vehicles can be configured. The trucks in the WIM records were checked against the configuration patterns of the single-trip permit vehicles in order to properly define the configurations of the representative vehicles. The pattern comparison was conducted for the permit vehicles with less than 9 axles, which contributes about $80 \%$ of the total records. Multiple tandem axles were assumed for vehicles with more axles because only nondivisible vehicles are eligible for permits in Wisconsin. The responses in simply-supported girders with various span lengths by the representative vehicles were then compared with those by the Wis-SPV.
The Standard Permit Vehicle in Wisconsin is being used for permit rating of new bridges and for posting bridges. Hence the impact of the representative overloaded vehicles utilized in the neighboring states was compared with that by the WisDOT Standard Permit Vehicle. Again, the comparison was made using the worst girder responses using the influence line concept.

Based upon the above analyses, modifications to the current permitting practice were proposed. Wis-SPV is a $63-\mathrm{ft}$ long tractor-trailer, which is longer than the length limits for single-unit vehicles eligible for permits. Hence, the recommended change focused on a supplementary and shorter 5-axle truck to the Wis-SPV to increase the positive moments (and potential negative moments) in short span girders.

## Conclusions

The analysis of WIM records indicated that $0.035 \%$ of total overloaded vehicles (records) may exceed the impact of the 250 -kip Wis-SPV. A close examination of the selected overloaded vehicles indicated that some short vehicles with 5 to 7 axles, currently on Wisconsin highway with annual permits, could exceed the maximum anticipated internal forces. These vehicles were likely Class 7 trucks with multiple lift axles as well as Class 9 short trailers. The representative vehicles for Classes 11 through 14 indicated that the Wis-SPV envelopes almost all truck-trailer combinations, except Class 13 vehicles. Class 13 records includes large portion of vehicles with permits, hence the representative vehicles did not address Type 3S2-2 truck-trailer combinations well.

The analysis of Wisconsin single-trip permit trucks indicated that Wis-SPV envelopes almost all single-unit trucks with less than 9 axles, which attributes $80 \%$ of the total permit records. Representative vehicles with 7 axles could cause larger girder responses than the Wis-SPV. A closer close look at these vehicles indicated that the potential worst vehicles are short vehicles with distributed multiple axles (oftentimes with lift axles). This observation was similar to that obtained in the analysis of WIM records in Chapter 4.

Comparison with the typical representative overloaded vehicles in the neighboring states indicated that longer vehicles, similar to the MnDOT Type P413 vehicle, could cause larger negative moments for two- and three-span simply supported girders. This situation was discussed in Chapters 4 and 5 of this report using representative vehicles and randomly selected vehicles. Specifically, some representative vehicles may have a variable spacing that ranges from 4 ft to over 70 ft . Hence the vehicle with the smaller spacing may cause severe positive moments (and likely shear) while the vehicle with greater spacing may cause severe negative moments. Nevertheless, the proposed Short Permit Truck (SPT) did not consider long vehicle option because most likely the vehicles are longer than 50 ft (for trucks) and 75 ft (for trailers and vehicle combinations), the limit for vehicles eligible for permits. In such cases the vehicles will need a single-trip permit, and would be rigorously examined before the permit is issued.

## Future studies

It is generally believed that heavy weights distributed on multiple axles that spaced far would cause less bridge damage than short closely spaced overloads. Hence, the permitting fee may be based upon the ration of the gross vehicle weight with the legal weight calculated using the Federal bridge formula. It was shown in Chapter 3 that plot of the maximum girder responses vs. this ratio showed less scattering than the gross vehicle weight. A simple yet reasonably accurate permitting fee base should be studied in details to reflect the level of damage overload vehicles may cause to bridges. The consideration should include damage to bridge decks and the related potential damage to durability of the bridges.

The gross weight distribution of Class 9 vehicles showed some deviation from the characteristics described in an NCHRP study. ${ }^{10}$ Specifically the low peak (representing the empty trailers) and the high peak (representing overloaded trailers) are higher. This might be due to the special freight transport needs in Wisconsin, or this might indicate larger variations in the WIM recording. The accuracy of the WIM records needs to be studied before these records can e used for other purposes.

The WIM records can be used to assess and predict the traffic patterns, especially for trucks and overloads. The number of the overloads recorded by each station is very uneven as shown below, indicating drastically different overloads on Wisconsin highway bridges. For example, Station \# 410240 on Interstate highway 94 near Tomah, WI captured nearly $50 \%$ of the total overloads. This might be duo to the fact that overloads on highway 90 captured by Station \#410253 near Sparta, WI would also pass Station \# 410240. Hence, highway bridges near Tomah, WI would be more likely subjected to accumulated overloads, leading to less service life or higher maintenance costs. The reasonably predicted truck and overload pattern would help the design to tailor to the specific loads to the bridges.

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# Chapter 1 <br> Introduction 

## Background

Trucking accounts for about eighty percent of expenditures on freight transportation in the United States; ${ }^{1}$ thus, allowing heavy trucks to operate on highways will improve the efficiency of the highway system and benefit the economy. Wisconsin Department of Transportation (WisDOT) issues more than two hundred oversize/overweight (OSOW) permits everyday on average to trucking businesses ${ }^{2}$ (as indicated by Fig. 1.1). Permits are required when the gross vehicle weight exceeds 80 kips or the size and/or the axle weights exceed the legal limits stipulated in Wisconsin Statute $348 .{ }^{3}$ Currently, carriers that occasionally haul OSOW loads can purchase a single trip permit, which is rigorously controlled through a review of the route. ${ }^{4}$ Note that these occasional loads are not necessarily the heavier loads as revealed in Chapters 4 and 5. Meanwhile, multi-trip permits can be purchased for frequent OSOW loads regardless the configurations and the gross weight of the loads. ${ }^{5}$ WisDOT does not control the route and the number of trips of the loads with multi-trip permits. As the total weight of the trucks increases (with an increased permit fee), permit application review and decision making become a concern for WisDOT. It is necessary to understand the overweight loads currently on the highways and their impacts on the bridges in order to manage safe and sustainable freight transportation.


Fig. 1.1 Wisconsin OSOW permits in recent years
Furthermore, fees for overweight permits in Wisconsin currently increase over a base fee as the gross vehicle weight increases. As shown in Table 1.1, the fee increase for single-trip permits is $\$ 10$ per $10,000 \mathrm{lbs}$ up to $150,000 \mathrm{lbs} .{ }^{4}$ For annual permits, the fee increase is $\$ 100$ per $10,000 \mathrm{lbs}$ up to $170,000 \mathrm{lbs} .{ }^{5}$ Permit fee system is not a focus of this research; nevertheless, it should be noted that the permit fees should reflect the actual potential damage the overweight vehicles may cause to the highway infrastructure. The impact of heavy axle weight generally is more significant to shorter-span bridges and pavements, especially when combined with closely spaced axles; whereas the gross vehicle weight is more significant to longer-span bridges. In addition, as the gross vehicle weight increase, moment and shear in bridge members may not be the sole parameters that need to be considered in bridge rating; other significant load effects such as overstresses in concrete decks (for crack control and durability checking) and stress ranges in steel girders (for potential fatigue checking) become important as well. ${ }^{7,8}$

Table 1.1 Wisconsin Permit Fees

| GVW (lbs) | Single-trip permits | Annual permits |
| :---: | :---: | :---: |
| $<90,000$ | $\$ 20$ | $\$ 200$ |
| 100,000 | $\$ 35$ | $\$ 350$ |
| 110,000 | $\$ 45$ | $\$ 450$ |
| 120,000 | $\$ 55$ | $\$ 550$ |
| 130,000 | $\$ 65$ | $\$ 650$ |
| 140,000 | $\$ 75$ | $\$ 750$ |
| 150,000 | $\$ 85$ | $\$ 850$ |
| 160,000 | $\$ 85$ | $\$ 950$ |
| 170,000 | $\$ 85$ | $\$ 1050$ |

WisDOT has used the AASHTO HL-93 loading as well as the Standard Permit Vehicle (WisSPV) to describe the maximum safe load carrying capacity of highway bridges. ${ }^{6}$ The Wis-SPV shown in Fig. 1.2 represents the typical configuration of nondivisible trucks with single-trip permits. The steering axle is 25 kips , higher than the limits of the trucks eligible for multi-trip permits. The rest of the axles are divided into two groups, in which the axle spacings are idealized as 4 ft - the typical spacing for tandem axles. The WisDOT SPV is 63 ft long, which is within the 75 -ft limit for an annual permit. The Wis-SPV is an important design parameter in the Bridge Manual because all newly designed bridges are required to safely carry this load. ${ }^{6}$ The Wis-SPV is also important for issuing annual permits and/or single-trip permits because all bridges are rated using this vehicle, and the permit rating values are available for truck operators to evaluate their permit application needs.
The Standard Permit Vehicle (Wis-SPV) load was increased from 190 kips to 250 kips in 1999 to accommodate the increase in truck loads in Wisconsin. ${ }^{6}$ The axle configuration, on the other hand, remained the same to facilitate the transition. However, this change may not sufficiently reflect the impact of the overweight loads on Wisconsin highway. Both the axle configurations and the gross weight of a vehicle can affect the bridge responses. ${ }^{9}$ Hence the effect of Wis-SPV needs to be evaluated, and compared with the effects of the existing overloaded vehicles on Wisconsin highways.


Fig. 1.2 Wisconsin Standard Permit Vehicle

## Research Objectives and Scope

The objectives of this project were to:

- Gather and evaluate information on overloaded vehicles operating on Wisconsin highways. Three datasets were collected and analyzed: 1) the database of single-trip permits that WisDOT has collected from 2004 to 2007, 2) the Weigh-in-Motion (WIM) truck records in Wisconsin in 2007, and 3) the representative overloaded vehicles in the
neighboring States. Detailed vehicle configurations were collected, including the gross vehicle weights, axle weights, and axle spacings.
- Identify vehicle configurations that best envelop the overloaded vehicles in Wisconsin. The bridge responses subjected to overloaded vehicles were compared with those of WisSPV. The exceeding probability based on the maximum moment and shear in representative bridge spans were calculated for the collected overloaded vehicles.
- Provide modifications to the Wis-SPV. A short permit truck (Wis-SPT) was proposed to compliment the existing standard permit vehicle. The 150-kip Wis-SPT would be suitable for using in short-span bridges such as slab bridges less than 80ft. The rating example in Chapter 45 of the Wisconsin Bridge Manual was reevaluated and modified. Peak moments/shear in single and continuous span bridges were tabulated to facilitate the implementation.
- Establish tools for future evaluation and adaptation of further increased permit vehicle weights and future overloaded vehicle configurations.


## Organization of the report

A review of the permitting vehicles in the bordering states, including Minnesota, Iowa, and Michigan, and Illinois is provided in Chapter 2. The Wis-SPV was compared with the collected permit vehicles in Chapter 3. The Weight-in-Motion (WIM) data obtained from the Wisconsin Transportation Center is analyzed in Chapter 4. Representative vehicles were proposed and compared with the Wis-SPV. In Chapter 5, the trucks in the single-trip permit records were analyzed using the same methodology. Modifications to the Wis-SPV are proposed based on the comparison of these representative vehicles in Chapter 6. A summary was provided in Chapter 7.
The line girder analysis using SAP2000 ${ }^{\circledR}$ is summarized in Appendix 1. The two computer tools produced in this project are explained in Appendix 2. The fundamentals of the statistical analysis used in this project were provided in Appendix 3 to analyze the effect of overloaded vehicles. The multivariate statistical analysis of the WIM records is shown in Appendix 4.

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# Chapter 2 Review of Permitting Practice 

## Introduction

Truck size and weight regulations are needed to promote safety and to prevent excessive damage to highways and bridges. ${ }^{10-11}$ Frequent overweight loads on bridges may reduce their service life or cause permanent structural damage if the impacts are not assessed properly. ${ }^{12-14}$ Bridges that cannot carry the "Maximum Weight by Statutes" of standard trucks are typically posted. ${ }^{15}$ Various idealized trucks have been used in the bridge rating practice. The representative overloaded vehicles in the states of Minnesota, Michigan, Iowa, and Illinois are reviewed in this chapter. The legal vehicle loads are briefly presented while the focus is on the trucks used for permit rating. The collected overloaded vehicles will be compared to the Wis-SPV in Chapter 3.

## Federal Regulations

## Legal Dimensions and Weights

The federal Truck Size and Weight (TS\&W) limits were first enacted in the Federal-Aid Highway Act of $1956 .{ }^{16}$ The Act established the following limits:

- Single-axle weight limit of $18,000 \mathrm{lb}$;
- Tandem-axle weight limit of $32,000 \mathrm{lb}$;
- Gross Vehicle Weight (GVW) of $73,280 \mathrm{lb}$; and
- Maximum width limit of 96 inches.

The limits were increased in 1974 based on the Federal-Aid Highway Amendments: ${ }^{17}$

- Single-axle weight limit of $20,000 \mathrm{lb}$;
- Tandem-axle weight limit of $34,000 \mathrm{lb}$; and
- Gross Vehicle Weight (GVW) of $80,000 \mathrm{lb}$ except where lower gross vehicle weight is dictated by the "bridge formula":
For axle groups and vehicles, the maximum legal weight is calculated using the Federal Bridge Formula: ${ }^{18}$

$$
\begin{equation*}
W=500\left(\frac{L N}{N-1}+12 N+36\right) \tag{2.1}
\end{equation*}
$$

where $W$ is the maximum weight in pounds that can be carried on a group of two or more axles to the nearest 500 pounds, $L$ is the spacing in feet between the outer axles of any two or more consecutive axles, and $N$ is the number of axles being considered. Federal law states that two or more consecutive axles may not exceed the weight computed by the Bridge Formula even though single axles, tandem axles, and gross vehicle weights are within legal limits. For the 250-kip Wis-SPV, with 8 axles and a 63 ft maximum spacing, the maximum gross weight should be 102 kips according to the Bridge Weight Formula in Eq. (2.1).

## Vehicle Configuration for Load Rating

AASHTO Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges suggests using the design vehicular live load, designated as HL-93, in permit load rating. ${ }^{19}$ HL-93 consists of a combination of a design truck (Fig. 2.1) or a design Tandem (a pair of 25 -kip axles spaced 4 ft apart) with a design lane load (0.64kips/ft in the longitudinal direction and distributed over a10 ft width in the transverse direction).


Fig. 2.1 Design truck in AASHTO LRFD and WisDOT Bridge Manual

## State of Wisconsin (WisDOT) Regualtions

## Legal Dimensions and Weights ${ }^{3}$

The maximum legal dimensions of vehicles that may be operated without permits on Wisconsin highways are in general $8^{\prime}-66^{\prime \prime}$ (Width) and 13'-6" (Height) with exceptions for seasonal loads. The general length limits (including front and rear overhang) are shown below:

| Single motor vehicle | $40^{\prime}$ |
| :--- | :--- |
| Semi trailer or trailer operated as part of a 2-vehicle combination | $48^{\prime}$ |
| Tractor - semi trailer combination | $75^{\prime}$ |
| Mobile homes, motor homes, and motorbuses. | $45^{\prime}$ |
| Mobile crane | $48^{\prime}$ |

The weight limitations for vehicles on Class "A" highways: all state trunk highways, connecting highways, and some county trunk highways, town highways and city and village streets are

- Single wheel or multiple wheels on one end of an axle - 11,000 Pounds;
- Single axle - 20,000 pounds, and steering axle - 13,000 Pounds,
- Gross weight for any vehicle or vehicle combination- 80,000 Pounds.


## Legal Sizes and Weights for Annual Permits

Permits are required when the load dimension exceeds the above statutory limits. There is a length limitation of 50 feet for single-unit vehicles and 75 feet for vehicle combinations for vehicles with annual permits. ${ }^{3-6}$ The following gross weights are allowed for vehicles with annual permits:

| Single Axle (steering axle) | 20,000 Pounds (2 Tires) |
| :--- | :--- |
| Single Axle | 30,000 Pounds (3 Tires) |
| 2-Axle Tandem | 55,000 Pounds |
| 3-Axle Tandem | 70,000 Pounds |
| 4-Axle Tandem | 80,000 Pounds |
| Total Gross Vehicle Weight | 170,000 Pounds |

## Load Rating in Bridge Manual

The Standard Permit Vehicle, as shown in Fig. 1.2, is intended to roughly represent the most vehicles with single-trip permits and to envelope all vehicles with multi-trip permits. The 250kip vehicle is used to estimate whether a bridge should be posted, and the rating is usually determined by

$$
\frac{\text { Live load moment cap acity }}{\text { by the } 250 \text { - kip Standard Permit Vehicle load }} \times 250 \text { (kips). }
$$

The calculation of the live load capacity (or resistance) must consider various failure modes depending upon the bridge structure types (e.g., reinforced concrete slab, slab on steel girders, and slab on prestressed concrete girders). The live load moment should also be modified by lateral load distribution factors.

## State of Minnesota (MnDOT) Regulations

## Legal Dimensions and Weights ${ }^{20}$

The Maximum legal dimensions of vehicles (loaded or unloaded) that may be operated without special permits on Minnesota highways are 13'-6" (Height), 8'-6" (Width), and the legal vehicle length (include front and rear overhang) is shown below

| Single motor vehicle | $40^{\prime}$ |
| :--- | :--- |
| Each trailer or semi-trailer of a twin trailer combination | $28^{\prime}-6^{\prime \prime}$ |
| Trailer of two-vehicle combination | $45^{\prime}$ |
| Semi-trailer of two-vehicle combination | $48^{\prime}$ |
| Mobile crane | $48^{\prime}$ |
| Drive-away saddle mount combination | $75^{\prime}$ |
| Truck-tractor with semi-trailer combination, | $75^{\prime}$ |

Weight, axle and tire limitations for vehicles on Minnesota highways and certain designated local (county) highways are:

- Single or dual wheel - 10,000 pounds;
- Single axle - 20,000 pounds; and
- Vehicle combination with five or more axles and minimum spacing - 80,000 pounds.


## Legal Sizes and Weights for Annual Permits ${ }^{20}$

The annual permit can be issued to vehicles within the following limits on the total overall dimensions, maximum axle weight, or special limits. The vehicle width must not exceed 8'. The vehicle height limit is $14^{\prime}$, and the vehicle length limit is $60^{\prime}$ for single motor vehicle and $85^{\prime}$ for vehicle combinations. The maximum overall axle spacing is 75 ' while the minimum axle spacing between any two axles is $3^{\prime}-9{ }^{\prime \prime}$. The weight limits are

| Single Axle | 20,000 Pounds | GVW for 5-axle vehicles | 92,000 Pounds |
| :--- | :--- | :--- | :--- |
| 2-Axle Tandem | 40,000 Pounds | GVW for 6-axle vehicles | 112,000 Pounds |
| 3-Axle Tandem | 60,000 Pounds | GVW for 7-axle vehicles | 132,000 Pounds |
| 4-Axle Tandem | 72,000 Pounds | GVW for 8-axle vehicles | 145,000 Pounds |
| 5 or more axles group | Not allowed for annual <br> permits | GVW for 9+-axle <br> vehicles | Not allowed for annual <br> permits |

## Load Rating in Minnesota Bridge Manual ${ }^{21}$

The bridge load rating determines the safe load carrying capacity. In addition to the operating and inventory rating, bridge capacities are calculated for a new bridge and are recalculated throughout the bridge's life as changes occur. In addition to the two different levels ("inventory rating" and "operating rating") that have historically been used for load rating, the Standard MnDOT Overload Permit Trucks as shown in Fig. 2.2 should be checked. The lowest or critical rating factor should be reported for each permit truck. Influence lines should be used for calculating the critical negative and positive moment (and shear if critical).


Fig. 2.2 Standard Mn/DOT Overload Permit Trucks

## State of lowa (laDOT) Regulations

## Legal Dimensions and Weights ${ }^{22}$

The dimensions of vehicles (loaded or unloaded) that may be operated without special permits on Iowa highways should not exceed $13^{\prime}-6^{\prime \prime}$ (height), $8^{\prime}-6^{\prime \prime}$ (width), and the length (inclusive of front and rear bumpers) should not exceed $40^{\prime}$ for single trucks and $70^{\prime}$ for three-vehicle combinations.
Vehicle gross weight and axle weight limitations are:

- Single axle - 20,000 pounds for pneumatic tires, and 14,000 pounds for solid rubber tires;
- Tandem-axle weight limit of $34,000 \mathrm{lbs}$;
- the maximum gross vehicle weight of the fence-line feeder, grain cart, tank wagon, or tracked implement of husbandry shall not exceed $96,000 \mathrm{lbs}$; and
- The maximum gross weight allowed to be carried on a vehicle or combination of vehicles on interstate highways is controlled by the bridge formula, with a maximum $80,000 \mathrm{lbs}$.


## Legal Sizes and Weights for Annual Permits ${ }^{22}$

Vehicles with the following maximum dimensions and weights can be issued an annual permit:

- Vehicles with indivisible loads having a maximum width of $12^{\prime}-5$ ", a maximum length of $120^{\prime}$, a maximum overall height of $13^{\prime}-10^{\prime \prime}$, and a total gross weight of $80,000 \mathrm{lbs}$.
- Vehicles with indivisible loads, or mobile homes including appurtenances, having a maximum width of $13^{\prime}-5^{\prime \prime}$, a maximum length of $120^{\prime}$, a maximum height of $15^{\prime}-5^{\prime \prime}$, and a total gross weight not to exceed $156,000 \mathrm{lbs}$.


## Load Rating for Standard Bridges ${ }^{23}$

The inventory and operating ratings are based on the AASHTO design vehicle loading shown in Fig. 2.1. The legal load ratings are based on the five typical Iowa legal vehicles using allowable operating rating stresses. The term "Legal" indicates the Iowa vehicle does not induce stresses exceeding allowable operating rating stresses. The Iowa rating vehicles are shown in Fig. 2.3.


Fig. 2.3 Iowa rating vehicles

## State of Michigan (MDOT) Regulations

## Legal Weight in Bridge Analysis Guide ${ }^{24}$

Michigan law allows the use of trucks that far exceed the federal limit of $80,000 \mathrm{lbs}$. Maximum total weights are not directly controlled by the State; however, weights are indirectly controlled by a combination of the maximum legal vehicle lengths, maximum legal axle loads and axle spacing. The combined effect of those items yields legal trucks that can weigh as much as 164,000 lbs. Individual axle loads and tandem axle loads have a variety of legal limits based on spacing, but the overall maximums are limited to the federal limits for axle weights. Meanwhile, Michigan requires a lower weight per axle than other states, which more evenly distributes the load and reduces wear and tear on roads. Selected Michigan legal vehicles are shown in Fig. 2.4, which have gross weight larger than the federal legal loads:


Fig. 2.4 Michigan Legal Vehicles with GVW larger than federal limit

## Permit Vehicles in Bridge Analysis Guide ${ }^{24}$

Overload vehicles are required to obtain a permit from the State or local agencies. It is prudent to analyze the capacity of the specific bridges to be crossed for their ability to safely carry the overload. Permit Load Rating is used when a request has been made to transport a load that is not included in the Michigan legal loads. The load to be carried may have heavier axles or more closely spaced axles, larger gross weight than those allowed by law, or a combination of these features. The load to be used for analysis should be the exact load requested to be transported, with that one vehicle placed so as to produce the maximum desired effect. Load rating calculations for overload vehicles are identical to normal load ratings for operating level ratings. MDOT has established a list of 20 different common overload vehicle configurations; however, the vehicles have smaller gross weight than the vehicle shown in Fig. 2.4 while the vehicle lengths are comparable. Hence, the vehicles in Fig. 2.4 will be used for the purpose of this study.

## State of Illinois (IDT) Regulations

## Legal Dimensions and Weights ${ }^{25}$

The maximum length of a single vehicle on any Illinois highway may not exceed 42 with exceptions, the maximum height $13^{\prime}-66^{\prime \prime}$, and the maximum width $8^{\prime}-6{ }^{\prime \prime}$. The Maximum legal weight of any vehicle in Illinois is $80,000 \mathrm{lb}$ except where lower gross vehicle weight is dictated by the Federal bridge formula. Permit vehicles may exceed this weight but are limited to IDT's "Practical Maximum Weights," which is based upon the federal bridge weight formula. The following rating trucks (Fig. 2.5) are used in the load rating and bridge posting.


Fig. 2.5 Illinois load rating and posting trucks

## Maximum Permit Vehicles in Structural Services Manual ${ }^{26}$

Overweight trucks in excess of the practical maximums or on nonstandard vehicles or with nonstandard axle configurations may be authorized. Annual overweight permits for loads up to $120,000 \mathrm{lbs}$ may be issued. Note that IDT regulates the maximum axle weights while the axle spacings are not limited except that the maximum vehicle dimensions, including a tractor and a semi-trailer are 14 '6"wide, 145 ' long and 15 ' high. The vehicle configuration shown in Fig. 2.6 was created from the IDT legal document. Note that the vehicles are not used for bridge rating or posting; hence they were not used in Chapter 3 for the comparison with WisDOT SPV


Fig. 2.6 Truck configurations for multi-trip permits in Illinois

# Chapter 3 Comparison of Wis-SPV with Collected Overloaded Vehicles from Neighboring States 

## Introduction

Trucks and tractors with permits in the neighboring state, including Minnesota, Iowa, Illinois, and Michigan, are likely to operate on Wisconsin highways. Hence, it is necessary to compare the Wisconsin Standard Permit Vehicle with the collected overloaded vehicles in Chapter 2. Note that not all the collected vehicles are for permit rating purposes. For example, the four vehicles in Illinois are the maximum vehicles that are eligible for multi-trip permits. Such comparison may help evaluate the Wisconsin permitting practices. The moment and shear envelopes of 250-kip Wis-SPV were compared with those of the collected 26 vehicles and the AASHTO design truck as described in Chapter 2. The envelopes were obtained using SAP2000 ${ }^{\circledR}$ moving load analysis as illustrated in Appendix 1. ${ }^{27-28}$

A vehicle load effect index ( R ) (also a root mean square error) ${ }^{29}$ in curve fitting was established to compare the effect of a certain vehicle load on the girder,

$$
\begin{equation*}
R=\sqrt{\frac{\sum_{1}^{n}\left(\frac{M_{\text {envelope }}}{M_{\text {Wis-SPV }}}\right)^{2}}{n}} \text { and } R=\sqrt{\frac{\sum_{1}^{n}\left(\frac{V_{\text {envelope }}}{V_{\text {Wis-SPV }}}\right)^{2}}{n}}, \tag{3.1}
\end{equation*}
$$

where, $M_{\text {envelope }}$ and $V_{\text {envelope }}$ are results from the moving load analysis of the vehicle, $M_{\text {Wis-SPV }}$ and $V_{\text {Wis-SPV }}$ are those of the Wis-SPV, and $n$ is the number of point used in the moving load analysis, where the moment and shear envelope values are calculated. It was envisioned that an R -value larger than one will indicate that the effect of the vehicle exceeds that of the WisDOT Standard Permit Vehicle. For R-values smaller than unit, the larger the R-value is, the closer effects caused by the vehicle to those of WisDOT Standard Permit Vehicle. Meanwhile it is possible that the vehicle may cause larger moment/shear at certain sections (especially the peak values) than the Wis-SPV while the R-value remains below one. Therefore the peak moments and peak shear values were also compared in this chapter.
A Matlab ${ }^{\circledR}$ program was written to automate the moving load analysis and to summarize the analysis results. The program (MoLan) is briefly explained in Appendix 2.

## Comparison of moment envelopes with WisDOT Bridge Manual

The results of moving load analysis were first compared with the listed moment envelopes in the WisDOT Bridge Manual ${ }^{6}$ to validate the analysis method and the program MoLan. The comparison for one-span simply supported girder is shown in Fig. 3.1. The calculated moment values are shown as a surface while the circles represent the values in the WisDOT Bridge Manual. The full circles below the surface indicate that the SAP2000 analysis results are slightly higher while circles above the surface indicate that the SAP2000 analysis results are slightly lower than those in the WisDOT Bridge Manual. The differences were found to be less than $1 \%$.


Span length (ft)
Fig. 3.1 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (one-span)
The comparison for two-span girders is shown in Fig. 3.2. The complete envelop for maximum and minimum moments are not available in the WisDOT Bridge Manual; hence a transition line exists in the calculated values shown as a surface in Fig. 3.2. The comparison indicated that the negative peak moments at the interior support are identical. One circle fell below the surface, representing a possible typographic in the moment value in the WisDOT Bridge Manual.


Fig. 3.2 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (two-span)

The comparison for three equal span girders is shown in Fig. 3.3. The moment table in the WisDOT Bridge Manual (LRFD version) includes an impact factor. The impact factor, $1+\frac{50}{(L+125)} \leq 1.3$, where $L$ is span length, was considered in the comparison.


Fig. 3.3 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (three-span)

## One-span simply supported girders

The comparison focuses on the maximum positive moments. Note that the moment envelops of the permitting vehicles are not shown in the report due to limitation in report space. Instead, the maximum positive moments and shear in girders with various plan lengths by the vehicles are shown in Fig. 3.4, and the values are listed in Table 3.1. The R-values for the envelopes are shown in Fig. 3.5 and Table 3.2.

The peak moment increases with an increase in girder spans. The Wis-SPV moment envelopes may be simplified as two straight lines connection and changing slope at around 60 ft , which is close to the maximum axle spacing of the Wis-SPV. The two lines have different slopes, indicating that the gross vehicle weight controls the responses for long girders while an axle group (likely the rear tandem axle) controls the responses of short girders. Wis-SPV envelopes the effects of all the permitting vehicles collected from the neighboring states. However, many permit vehicles, which have shorter length, may cause similar moments to Wis-SPV for short girders (less than 60ft) though their gross weight is much smaller than that of Wis-SPV.
The comparison figures are presented to show whether the Wis-SPV envelops the collected permitting vehicles. Hence, the Wis-SPV is shown in solid (blue) lines in the following comparison figures while other vehicles are shown in various colors and line types. The details of the comparisons are shown in the tables following the comparison figures.


Fig. 3.4 Comparison of the maximum moments in simply-supported girders


Fig. 3.5 R-values for the moment/shear envelopes in simply-supported girders
Note that labels were not included in the figures to simplify the presentations.

Table 3.1(a) Peak positive moment in one-span girders (kips-ft)

| Span (ft) | $\begin{aligned} & \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ \text { Type4 } \\ \hline \end{array}$ | $\begin{gathered} \text { IA } \\ 353 \mathrm{~A} \end{gathered}$ | $\begin{array}{r} \text { IA } \\ 453 \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No5} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No7 } \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 8 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 12 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No13 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No14 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No17 } \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{array}{\|c} \hline \mathrm{Mi} \\ \mathrm{No} 21 \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 22 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 23 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 25 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 723.7 | 326.6 | 322.3 | 421.1 | 447.4 | 403.7 | 419.6 | 285.3 | 280.0 | 285.3 | 308.3 | 318.8 | 318.8 | 318.8 | 358.5 | 355.5 | 387.8 | 361.1 | 470.5 | 470.5 | 332.4 | 365.4 | 393.6 | 396.8 |
| 36 | 843. | 397. | 378. | 496.6 | 534.3 | 491.4 | 494. | 338.7 | 322.0 | 338.7 | 381.2 | 388.0 | 388.0 | 385.2 | 442.9 | 441.2 | 476.0 | 435.3 | 574.1 | 574 | 414.8 | 455.4 | 497.3 | 483.7 |
| 40 | 962.9 | 468. | 433.8 | 572. | 621.3 | 595.6 | 568.6 | 392.2 | 364.0 | 392.2 | 463.7 | 470.9 | 470.9 | 464.5 | 528.2 | 534.6 | 578.2 | 535.6 | 680.8 | 678.0 | 511.7 | 557.4 | 600.9 | 583.8 |
| 44 | 1085.3 | 539.7 | 491.9 | 647.7 | 708.3 | 705.5 | 643.3 | 445.9 | 406.0 | 445.9 | 547.4 | 554.0 | 554.0 | 554.7 | 619.6 | 628.0 | 692.9 | 639.6 | 802.5 | 792.9 | 608.7 | 659.3 | 704.6 | 693.8 |
| 48 | 121 | 6 | 568.8 | 723 | 795 | 815 | 719 | 499 | 45 | 499 | 631.4 | 638 | 638 | 645 | 727 | 722.3 | 809.5 | 743.6 | 938.5 | 91 | 712.5 | 762.8 | 825.3 | 5.8 |
| 52 | 134 | 682.5 | 670. | 799.2 | 882.2 | 925.6 | 818. | 553.2 | 525.5 | 553.2 | 715.3 | 739.3 | 739.3 | 735.7 | 844.5 | 839.4 | 926.3 | 861.3 | 1074.5 | 1054.5 | 824.8 | 879.7 | 961.2 | 943.8 |
| 56 | 1473. | 754.0 | 773.3 | 886.6 | 969.2 | 1035.9 | 943. | 607.0 | 592.7 | 607.0 | 799.3 | 840.6 | 851.3 | 826.5 | 961.7 | 964.4 | 1054.3 | 989.1 | 1212.8 | 1190.5 | 942.6 | 1015.1 | 1097.1 | 1071.8 |
| 60 | 1603. | 825 | 875 | 1002. | 1057. | 1146.2 | 1076 | 66 | 66 | 66 | 883 | 941.8 | 970 | 917.3 | 1078.9 | 1089.3 | 1186.2 | 111 | 1363.7 | 1326.5 | 1078.4 | 1150.5 | 1238.0 | . 8 |
| 64 | 1732. | 897.2 | 978.6 | 1136.2 | 1184.0 | 1257.0 | 1209.9 | 714.6 | 733.2 | 714.6 | 967.2 | 1043.1 | 1089.7 | 1008.1 | 1196.2 | 1214.3 | 1318.1 | 1261.6 | 1514.8 | 1472.8 | 1225.9 | 1285.9 | 1389.8 | 1354.8 |
| 68 | 1865. | 969.0 | 1081. | 1270.2 | 1325.0 | 1368.0 | 1343. | 768.5 | 811. | 768.5 | 1051.2 | 1144.5 | 1208.9 | 1099.0 | 1313.6 | 1339.2 | 1450.0 | 1404.4 | 1665.9 | 1626.2 | 1376.8 | 1426.8 | 1541.8 | 1518.8 |
| 72 | 20 | 104 | 118 | 14 | 14 | 14 | 14 | 82 | 88 | 822 | 1135 | 124 | 132 | 119 | 143 | 1464 | 1582. | 15 | 18 | 17 | 1527.6 | 1587.9 | 1693.7 | 1682.8 |
| 76 | 2267. | 1112. | 1287.5 | 1538.8 | 1633.6 | 1590.0 | 1610.9 | 880. | 967.9 | 880.4 | 1219.1 | 1347.2 | 1447.4 | 1281.2 | 1548.3 | 1589.4 | 1714.3 | 1690.2 | 1968.3 | 1933.1 | 1678.5 | 1749.2 | 1845.7 | 1846.8 |
| 80 | 2509.5 | 1184. | 1390. | 1673. | 1789.5 | 1701.0 | 1744.9 | 966.4 | 1046.4 | 966.4 | 1303.1 | 1448.5 | 1566.6 | 1372.2 | 1665.6 | 1714.6 | 1846.4 | 1833.3 | 2119.4 | 2086.6 | 1829.3 | 1910.5 | 1997.6 | 2010.8 |
| 84 | 2753 | 1255 | 1494. | 1808. | 1946. | 1812. | 1879 | 1058 | 1125 | 1058. | 1387 | 1549. | 1685. | 1463 | 1783.0 | 1839.8 | 1978.6 | 1976 | 2270.6 | 2240.1 | 1980.5 | 2071.9 | 2149.5 | 2174.8 |
| 88 | 2996. | 1327. | 1597. | 1942.7 | 2104.3 | 1923.0 | 2013.2 | 1151. | 1204.1 | 1151.8 | 1471.0 | 1651.2 | 1805.2 | 1554.4 | 1900.3 | 1965.0 | 2110.8 | 2119.6 | 2421.7 | 2393.8 | 2131.9 | 2233.2 | 2301.5 | 2338.8 |
| 92 | 3241. | 1399.6 | 1700.9 | 2077.7 | 2261.7 | 2034.0 | 2147.3 | 1245.9 | 1282.9 | 1245.9 | 1555.0 | 1752.6 | 1924.5 | 1645.4 | 2017.7 | 2090.2 | 2243.0 | 2262.8 | 2572.9 | 2547.6 | 2283.3 | 2394.5 | 2453.4 | 2502.8 |
| 96 | 348 | 1471.5 | 1804.2 | 2212.8 | 2419.6 | 2145.0 | 2281. | 1340 | 1362.0 | 1340.1 | 1639.0 | 1854.0 | 2043.9 | 1736.6 | 2135.0 | 2215.4 | 2375.2 | 2406.0 | 2724.1 | 2701.3 | 2434.7 | 2555.9 | 2605.4 | 2666.8 |
| 100 | 3731.3 | 1543. | 1907.8 | 2347.9 | 2577.6 | 2270.3 | 2415.7 | 1434.7 | 1441.2 | 1434.7 | 1723.0 | 1955.3 | 2163.2 | 1827.9 | 2252.4 | 2340.6 | 2507.4 | 2549.1 | 2875.2 | 2855.1 | 2586.1 | 2717.2 | 2757.3 | 2830.8 |
| 104 | 3976. | 1615.2 | 2011. | 2483. | 2735.6 | 2416.7 | 2550.3 | 1529.3 | 1520. | 1529.3 | 1807.0 | 2056.7 | 2282.6 | 1919.1 | 2369.7 | 2465.8 | 2639.6 | 2692.3 | 3026.5 | 3008.9 | 2737.5 | 2878.5 | 2909.2 | 2994.8 |
| 108 | 4222. | 1687. | 2115.0 | 2618.2 | 2893.6 | 2563.5 | 2742.6 | 1624.0 | 1599.6 | 1624.0 | 1891.0 | 2158.0 | 2401.9 | 2010.4 | 2487.1 | 2591.0 | 2771.8 | 2835.5 | 3177.8 | 3162.6 | 2888.9 | 3039.9 | 3061.2 | 3158.8 |
| 112 | 4469.2 | 1759.0 | 2218.6 | 2753.3 | 3051.5 | 2731.3 | 2937.3 | 1718.6 | 1678.8 | 1718.6 | 1975.0 | 2259.4 | 2521.3 | 2101.6 | 2604.4 | 2716.2 | 2904.0 | 2978.6 | 3329.2 | 3316.4 | 3040.3 | 3201.2 | 3213.1 | 3322.8 |
| 116 | 4715.6 | 1830.9 | 2322.3 | 2888.6 | 3209.5 | 2933.0 | 3132.0 | 1813.6 | 1758.1 | 1813.6 | 2059.0 | 2360.8 | 2640.6 | 2192.9 | 2721.8 | 2841.4 | 3036.1 | 3121.8 | 3480.5 | 3470.1 | 3191.7 | 3362.6 | 3365.0 | 3486.8 |
| 120 | 4962.0 | 1902.8 | 2425.9 | 3024.1 | 3367.6 | 3135.1 | 3326.6 | 1908.6 | 1837.6 | 1908.6 | 2143.0 | 2462.1 | 2760.0 | 2284.2 | 2839.1 | 2966.6 | 3168.4 | 3265.0 | 3631.8 | 3623.9 | 3343.1 | 3523.9 | 3517.0 | 3650.8 |
| 124 | 5208.7 | 1974.7 | 2529.5 | 3159.6 | 3526.0 | 3338.1 | 3521.3 | 2003.6 | 1917.1 | 2003.6 | 2227.0 | 2563.5 | 2879.3 | 2375.4 | 2956.5 | 3091.9 | 3300.8 | 3408.1 | 3783.2 | 3777.6 | 3494.5 | 3685.2 | 3668.9 | 3814.8 |
| 128 | 5456.2 | 2046.6 | 2633.1 | 3295.1 | 3684.5 | 3541.0 | 3716.0 | 2098.7 | 1996.6 | 2098.7 | 2311.0 | 2664.8 | 2998.7 | 2466.7 | 3073.9 | 3217.3 | 3433.1 | 3551.3 | 3934.5 | 3931.4 | 3645.9 | 3846.6 | 3820.9 | 3978.8 |
| 132 | 5703.7 | 2118.4 | 2736.8 | 3430.6 | 3842.9 | 3744.0 | 3924.0 | 2193.7 | 2076.1 | 2193.7 | 2395.0 | 2766.2 | 3118.0 | 2557.9 | 3191.2 | 3342.6 | 3565.5 | 3694.6 | 4085.9 | 4085.1 | 3797.3 | 4007.9 | 3972.8 | 4142.8 |
| 136 | 5951.3 | 2190.3 | 2840.4 | 3566.1 | 4001.3 | 3946.9 | 4162.2 | 2288.8 | 2155.6 | 2288.8 | 2479.0 | 2867.6 | 3237.4 | 2649.2 | 3308.6 | 3468.0 | 3697.8 | 3838.0 | 4237.2 | 4238.9 | 3948.7 | 4169.2 | 4124.7 | 4306.8 |
| 140 | 6198.8 | 2262.2 | 2944.3 | 3701.6 | 4159.7 | 4151.3 | 4413.3 | 2384.0 | 2235.0 | 2384.0 | 2563.0 | 2968.9 | 3356.7 | 2740.4 | 3425.9 | 3593.3 | 3830.2 | 3981.3 | 4388.5 | 4392.7 | 4100.1 | 4330.6 | 4276.7 | 4470.8 |

Table 3.1(b) Peak shear in one-span girders (kips)

| Span (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ \text { Type4 } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ 353 \mathrm{~A} \\ \hline \end{array}$ | $\begin{gathered} \hline \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No5} \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 7 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No8} \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 12 \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 13 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No14 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 17 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 21 \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 22 \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 23 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 25 \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 100.4 | 52.5 | 46.0 | 59.5 | 63.2 | 62.4 | 59.0 | 41.2 | 38.4 | 41.2 | 47.4 | 47.9 | 47.9 | 48.3 | 52.2 | 52.2 | 57.5 | 53.7 | 64.2 | 64.2 | 51.2 | 54.2 | 58.1 | 57.0 |
| 36 | 103.7 | 54.7 | 50.6 | 61.3 | 65.8 | 66.1 | 60.8 | 42.7 | 41.7 | 42.7 | 51.5 | 52.2 | 52.2 | 51.4 | 57.8 | 57.0 | 63.5 | 58.0 | 69.7 | 69.3 | 56.2 | 59.2 | 63.2 | 61.3 |
| 40 | 106.3 | 56.4 | 55.2 | 62.8 | 67.9 | 69.1 | 66.0 | 43.8 | 44.3 | 43.8 | 54.7 | 55.6 | 55.8 | 53.8 | 62.2 | 62.3 | 68.9 | 62.9 | 75.9 | 74.9 | 60.3 | 63.2 | 68.3 | 65.9 |
| 44 | 108.5 | 57.8 | 58.9 | 66.8 | 69.7 | 71.5 | 70.9 | 44.7 | 46.7 | 44.7 | 57.4 | 58.3 | 60.2 | 56.4 | 65.8 | 66.7 | 73.8 | 68.2 | 81.4 | 80.5 | 64.5 | 67.9 | 73.9 | 70.3 |
| 48 | 110.8 | 59.0 | 62.3 | 71.2 | 73.5 | 74.8 | 75.6 | 45.5 | 49.5 | 45.5 | 59.6 | 60.6 | 63.8 | 59.3 | 69.4 | 70.3 | 78.7 | 73.2 | 86.6 | 85.1 | 69.3 | 72.2 | 79.0 | 74.8 |
| 52 | 118.2 | 60.0 | 65.5 | 75.9 | 78.9 | 77.5 | 80.2 | 46.1 | 51.8 | 46.1 | 61.5 | 63.1 | 66.9 | 61.8 | 73.1 | 73.7 | 82.8 | 77.4 | 91.6 | 89.9 | 74.4 | 76.4 | 83.7 | 78.9 |
| 56 | 125.9 | 60.8 | 68.3 | 80.2 | 83.6 | 79.9 | 84.1 | 46.7 | 53.8 | 46.7 | 63.1 | 65.8 | 69.6 | 63.9 | 76.3 | 77.4 | 86.3 | 81.0 | 95.8 | 94.5 | 78.8 | 81.0 | 88.6 | 83.0 |
| 60 | 132.5 | 61.6 | 70.7 | 83.9 | 88.3 | 82.0 | 87.5 | 49.0 | 55.6 | 49.0 | 64.5 | 68.2 | 71.9 | 65.8 | 79.0 | 80.6 | 89.4 | 84.5 | 99.5 | 98.4 | 82.6 | 85.3 | 92.8 | 87.2 |
| 64 | 138.6 | 62.2 | 72.7 | 87.2 | 92.7 | 83.8 | 90.5 | 51.6 | 57.1 | 51.6 | 65.7 | 70.3 | 74.6 | 67.4 | 81.4 | 83.4 | 92.1 | 88.2 | 102.8 | 101.9 | 86.0 | 89.1 | 96.5 | 90.9 |
| 68 | 145.2 | 62.8 | 74.6 | 90.0 | 96.6 | 85.4 | 93.1 | 54.2 | 58.5 | 54.2 | 66.8 | 72.1 | 77.3 | 68.8 | 83.5 | 85.9 | 94.5 | 91.5 | 105.6 | 105.0 | 89.6 | 92.5 | 99.8 | 94.1 |
| 72 | 151.0 | 63.3 | 76.2 | 92.6 | 100.1 | 86.9 | 95.4 | 56.5 | 59.7 | 56.5 | 67.7 | 73.7 | 79.6 | 70.0 | 85.4 | 88.1 | 96.6 | 94.3 | 108.2 | 107.7 | 93.0 | 95.4 | 102.7 | 97.0 |
| 76 | 156.2 | 63.8 | 77.7 | 94.9 | 103.2 | 89.7 | 97.5 | 58.6 | 60.7 | 58.6 | 68.6 | 75.2 | 81.7 | 71.2 | 87.1 | 90.1 | 98.5 | 96.9 | 110.5 | 110.1 | 96.1 | 98.1 | 105.3 | 99.6 |
| 80 | 160.9 | 64.2 | 79.0 | 96.9 | 106.0 | 93.1 | 99.4 | 60.4 | 61.7 | 60.4 | 69.4 | 76.5 | 83.6 | 72.2 | 88.6 | 91.8 | 100.2 | 99.2 | 112.5 | 112.3 | 98.8 | 100.5 | 107.6 | 101.9 |
| 84 | 165.1 | 64.6 | 80.2 | 98.8 | 108.5 | 97.1 | 101.1 | 62.1 | 62.6 | 62.1 | 70.1 | 77.7 | 85.3 | 73.1 | 90.0 | 93.4 | 101.7 | 101.3 | 114.4 | 114.3 | 101.3 | 102.7 | 109.7 | 104.6 |
| 88 | 169.0 | 64.9 | 81.3 | 100.5 | 110.8 | 101.4 | 104.3 | 63.7 | 63.4 | 63.7 | 70.7 | 78.8 | 86.8 | 73.9 | 91.2 | 94.9 | 103.1 | 103.3 | 116.0 | 116.1 | 103.6 | 105.1 | 111.7 | 107.3 |
| 92 | 172.5 | 65.2 | 82.2 | 102.0 | 112.9 | 105.4 | 107.6 | 65.1 | 64.1 | 65.1 | 71.3 | 79.7 | 88.3 | 74.7 | 92.4 | 96.2 | 104.4 | 105.0 | 117.6 | 117.8 | 105.7 | 107.5 | 113.4 | 109.8 |
| 96 | 175.8 | 65.5 | 83.2 | 103.4 | 114.8 | 109.4 | 110.6 | 66.4 | 64.7 | 66.4 | 71.8 | 80.7 | 89.6 | 75.4 | 93.4 | 97.4 | 105.5 | 106.6 | 119.0 | 119.3 | 107.6 | 109.8 | 115.0 | 112.0 |
| 100 | 178.7 | 65.8 | 84.0 | 104.7 | 116.6 | 113.3 | 113.6 | 67.6 | 65.4 | 67.6 | 72.3 | 81.5 | 90.7 | 76.0 | 94.4 | 98.5 | 106.6 | 108.1 | 120.3 | 120.7 | 109.3 | 111.9 | 116.5 | 114.1 |
| 104 | 181.5 | 66.0 | 84.8 | 105.9 | 118.2 | 116.9 | 117.1 | 68.6 | 65.9 | 68.6 | 72.7 | 82.2 | 91.9 | 76.6 | 95.2 | 99.6 | 107.6 | 109.4 | 121.5 | 121.9 | 111.0 | 113.8 | 117.9 | 116.0 |
| 108 | 184.0 | 66.2 | 85.5 | 107.1 | 119.7 | 120.3 | 121.1 | 69.7 | 66.4 | 69.7 | 73.2 | 83.0 | 92.9 | 77.2 | 96.1 | 100.5 | 108.5 | 110.7 | 122.6 | 123.1 | 112.5 | 115.5 | 119.1 | 117.8 |
| 112 | 186.4 | 66.4 | 86.1 | 108.1 | 121.1 | 123.4 | 125.3 | 70.6 | 66.9 | 70.6 | 73.5 | 83.6 | 93.8 | 77.7 | 96.8 | 101.4 | 109.4 | 111.9 | 123.6 | 124.2 | 113.9 | 117.2 | 120.3 | 119.5 |
| 116 | 188.6 | 66.6 | 86.8 | 109.1 | 122.4 | 126.3 | 129.3 | 71.5 | 67.4 | 71.5 | 73.9 | 84.2 | 94.7 | 78.1 | 97.5 | 102.2 | 110.2 | 112.9 | 124.6 | 125.3 | 115.1 | 118.7 | 121.4 | 121.0 |
| 120 | 190.6 | 66.8 | 87.3 | 110.0 | 123.7 | 129.0 | 133.3 | 72.3 | 67.8 | 72.3 | 74.2 | 84.8 | 95.5 | 78.6 | 98.2 | 103.0 | 110.9 | 114.0 | 125.5 | 126.2 | 116.4 | 120.1 | 122.4 | 122.4 |
| 124 | 192.5 | 67.0 | 87.9 | 110.8 | 124.8 | 131.5 | 137.3 | 73.1 | 68.2 | 73.1 | 74.6 | 85.3 | 96.3 | 79.0 | 98.8 | 103.7 | 111.6 | 114.9 | 126.3 | 127.1 | 117.5 | 121.4 | 123.4 | 123.8 |
| 128 | 194.3 | 67.1 | 88.4 | 111.6 | 125.9 | 133.8 | 141.0 | 73.8 | 68.6 | 73.8 | 74.9 | 85.8 | 97.0 | 79.4 | 99.4 | 104.4 | 112.2 | 115.8 | 127.1 | 127.9 | 118.5 | 122.7 | 124.3 | 125.0 |
| 132 | 196.0 | 67.3 | 88.8 | 112.3 | 126.9 | 136.1 | 144.4 | 74.4 | 68.9 | 74.4 | 75.1 | 86.3 | 97.7 | 79.7 | 99.9 | 105.1 | 112.9 | 116.6 | 127.8 | 128.7 | 119.5 | 123.9 | 125.1 | 126.2 |
| 136 | 197.6 | 67.4 | 89.3 | 113.0 | 127.8 | 138.1 | 147.7 | 75.1 | 69.2 | 75.1 | 75.4 | 86.8 | 98.3 | 80.1 | 100.5 | 105.7 | 113.4 | 117.4 | 128.5 | 129.5 | 120.5 | 125.0 | 125.9 | 127.3 |
| 140 | 199.1 | 67.5 | 89.7 | 113.7 | 128.7 | 140.1 | 150.7 | 75.7 | 69.5 | 75.7 | 75.6 | 87.2 | 98.9 | 80.4 | 100.9 | 106.2 | 114.0 | 118.2 | 129.2 | 130.2 | 121.4 | 126.0 | 126.6 | 128.4 |

## Two-span simply supported girders

The peak moments and shear for two-span girders with various span lengths by all the permitting vehicles are shown in Fig. 3.6 and the corresponding R-values in Fig. 3.7. The comparison of the maximum positive moment shows a similar trend to the one-span cases, in which some vehicles produce comparable positive moments for short girders. The negative moments by the vehicles are comparable to those of Wis-SPV for girders with a span around 60ft as indicated by R-values in Fig. 3.7. Furthermore, a permitting vehicle, MnDOT Standard P413 causes larger negative moments than Wis-SPV for girders with $82-\mathrm{ft}$ to 124 -ft spans) as shown in Table 3.2. The P413 vehicle has a gross weight similar to that of the Wisconsin Standard Permit Vehicle (255kips); however, the weight is distributed to thirteen axles with a total vehicle length of 117 ft as illustrated below. In particular, the center of the first two tandem axles and the last two tandem axles are spaced 71 ft such that the axles may be placed in an optimized position to cause larger negative moment. Table 3.2(b) indicates that the MnDOT Standard P413 vehicle can cause about $15 \%$ more negative moments than Wis-SPV though the gross weight is only $2 \%$ more. Nevertheless, this vehicle exceeds the maximum length limit for an annual permit in Wisconsin. The vehicle was not further studied in this project because such a vehicle, likely nondivisible, is required to obtain a single-trip permits and the vehicle will likely be studied for all bridges on the proposed route.



Fig. 3.6 Comparison of the peak moments in 2-span simply-supported girders


Fig. 3.7 R-values for the moment/shear envelopes in two-span girders

Table 3.2(a) Peak positive moment in two-span girders (kips-ft)

| Span (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ \text { Type4 } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ 353 \mathrm{~A} \\ \hline \end{array}$ | $\begin{gathered} \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No5 } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 7 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No8} \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 12 \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No13 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{Nol} 4 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No17} \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 21 \\ \hline \end{array}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 22 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 23 \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 25 \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 577. | 264.2 | 261.5 | 339.4 | 354.1 | 325.4 | 338.1 | 232.0 | 224.9 | 232.0 | 244.2 | 250.5 | 250.5 | 250.5 | 283.8 | 283.6 | 309.3 | 283.3 | 364.6 | 364.6 | 260.1 | 290.9 | 304.9 | 312.4 |
| 36 | 675. | 316.8 | 306.0 | 399.7 | 423.2 | 390.7 | 397.8 | 274.1 | 259.5 | 274.1 | 303.6 | 306.2 | 306.2 | 303.6 | 346.5 | 343.8 | 376.4 | 345.8 | 446.6 | 446.6 | 322.0 | 355.2 | 384.5 | 377.7 |
| 40 | 774.3 | 373 | 35 | 460.5 | 492. | 473 | 45 | 316 | 294 | 316.8 | 367.1 | 370.2 | 370.2 | 368.6 | 413.7 | 414.4 | 457.2 | 418.4 | 530. | 529 | 393.3 | 430.0 | 465.6 | . 7 |
| 44 | 878 | 430. | 39 | 52 | 563 | 55 | 51 | 35 | 333.5 | 35 | 43 | 435.3 | 43 | 438.0 | 487.5 | 487.9 | 545 | 8.9 | 631.7 | 621.5 | 9.3 | 510.2 | 547.9 | 44.3 |
| 48 | 982.8 | 487 | 461. | 583. | 633 | 645.2 | 581. | 403.3 | 379.1 | 403.3 | 497.3 | 506.0 | 506.0 | 508.6 | 575.3 | 570.2 | 634.6 | 580.5 | 736.7 | 725.6 | 553.8 | 598.8 | 643.9 | 630.1 |
| 52 | 10 | 5 | 53 | 645.5 | 70 | 732 | 66 | 446. | 428.8 | 44 | 56 | 58 | 582 | 580.0 | 66 | 66 | 725.4 | 669.1 | 843.0 | 831.1 | 640.6 | 689.8 | . 9 | 7.4 |
| 56 | 11 | 60 | 60 | 72 | 77 | 82 | 75 | 4 | 47 | 490.8 | 63 | 660.1 | 660.1 | 652.2 | 755.5 | 756.3 | 825.8 | 764.5 | 952.4 | 937.8 | 730.9 | 781.8 | 853.2 | 831.0 |
| 60 | 1299. | 661.7 | 687.5 | 816.6 | 85 | 909.2 | 858.3 | 534.8 | 531. | 534.8 | 697.5 | 738.7 | 750.7 | 724.9 | 847.3 | 852.5 | 928.9 | 871.8 | 1068.8 | 1045.4 | 836.9 | 887.1 | 959.7 | 942.8 |
| 64 | 14 | 720.2 | 76 | 915.2 | 95 | 99 | 958.8 | 5 | 589.4 | 578.9 | 764.9 | 818.0 | 843.9 | 798.0 | 93 | 949.8 | 10 | 5 | 1187.6 | 11 | 951.8 | 7 | . 3 | . 9 |
| 68 | 15 | 778 | 8 | 1015.5 | 1068. | 1087.8 | 1060. | 62 | 649.9 | 62 | 83 | 898.0 | 938.0 | 871.6 | 1033.0 | 1047.8 | 1137.9 | 1092.5 | 1307.7 | 1282.0 | 1068.2 | 1114.8 | 1196.9 | 1170.5 |
| 72 |  | 837. | 931.7 | 1117.5 | 1185. | 1177. | 1163. | 667.3 | 711. | 667.3 | 900.7 | 978.5 | 1032.6 | 945.3 | 1126.7 | 1146.6 | 1243.4 | 1205.3 | 1428.7 | 1403.6 | 1185.7 | 1238.5 | 1317.4 | 1297.9 |
| 76 | 18 | 896.6 | 10 | 12 | 13 | 12 | 12 | 72 | 77 | 72 | 96 | 10 | 11 | 10 | 1220.8 | 12 | 1349.4 | 1318.8 | 15 | 1526.0 | 1304.1 | 4 | 5 | . |
| 80 | 202 | 955 | 1096. | 13 | 1423. | 1358. | 1373 | 79 | 835.8 | 794.3 | 1037. | 1140.4 | 1223.2 | 1093.6 | 1315.3 | 1347.4 | 1455.8 | 1433.0 | 1672.2 | 1649.0 | 1423.6 | 1489.2 | 1560.1 | 1555.9 |
| 84 | 2203 | 1014. | 1180 | 1429. | 1544.9 | 1448.5 | 1481 | 863. | 898. | 863.6 | 1105.9 | 1221.8 | 1319 | 1167.9 | 1410.1 | 1448.6 | 1562.6 | 1547.6 | 1794.5 | 1772.5 | 1543.8 | 1615.9 | 1682.2 | 1686.4 |
| 88 |  | 10 |  |  |  |  |  | 93 | 96 | 93 | 11 | 1303 | 14 | 124 | 1505 | 15 | 16 | 1662.6 | 191 | 18 | 1664.6 | 17 | 1804.6 | 0 |
| 92 | 25 | 1133. | 13 | 1641. | 1790. | 1629.8 | 1697. | 10 | 1025.3 | 1005.1 | 1243.3 | 1386.5 | 1511.8 | 1317.0 | 1600.4 | 1651.9 | 1777.0 | 1778.1 | 2040.2 | 2020.7 | 1785.9 | 1871.5 | 1927.4 | 1949.9 |
| 96 | 27 | 1192. | 143 | 17 | 191 | 1738.5 | 1806. | 1077. | 1089 | 1077. | 1312.2 | 1469. | 1608. | 1391.8 | 1695.8 | 1753.8 | 1884.6 | 1893.8 | 2163.3 | 2145.3 | 1907.5 | 2000.1 | 2050.6 | 2082.2 |
| 10 | 2951. | 1251 | 15 | 1858. | 2039. | 1850.8 | 1915 | 1149.5 | 1153.0 | 1149.5 | 1381. | 1552.3 | 1705. | 1466.6 | 1791.5 | 1856.0 | 1992.3 | 2009.9 | 2286.7 | 2270.2 | 2029.4 | 2129.1 | 2173.8 | 2214.9 |
| 10 | 3146. | 1310. | 1600.2 | 1967. | 2164 | 1964.2 | 2024. | 1222. | 1217.1 | 1222.7 | 1450.0 | 1635.3 | 1802.4 | 1541.5 | 1887.2 | 1958.2 | 2100.3 | 2126.1 | 2410.3 | 2395.3 | 2151.7 | 2258.6 | 2297.5 | 2347.7 |
| 108 |  | 137 | 168 | 20 | 22 | 2078.5 | 2148.5 | 1296.3 | 12 | 1296.3 | 1519.0 | 1718.4 | 1899.6 | 1616.5 | 1983.1 | 2060.6 | 2208.3 | 2242.6 | 2534.0 | 2520.6 | 2274.2 | 2388.6 | 2421.3 | 2480.8 |
| 112 | 3537. | 1429. | 1769.4 | 2186.8 | 2416. | 2197.0 | 2298.0 | 1370.3 | 1345.9 | 1370.3 | 1588.1 | 1801.6 | 1996.9 | 1691.5 | 2079.1 | 2163.1 | 2316.6 | 2359.2 | 2657.8 | 2646.2 | 2397.0 | 2519.2 | 2545.1 | 2614.1 |
| 116 | 3734. | 1489. | 1854.2 | 2296.9 | 2543.3 | 2331.2 | 2448.4 | 1444.7 | 1410.5 | 1444.7 | 1657.2 | 1884.9 | 2094.5 | 1766.6 | 2175.2 | 2265.8 | 2424.9 | 2476.1 | 2781.8 | 2771.8 | 2519.9 | 2650.0 | 2669.3 | 2747.5 |
| 120 | 393 | 154 | 1939 | 240 | 2670.3 | 2407.9 | 2599. | 1519.5 | 14 | 1519.5 | 1726.4 | 1968.2 | 2192.2 | 1841.8 | 2271.4 | 2368.5 | 2533.3 | 2593.0 | 2905.9 | 2897.6 | 2643.1 | 2780.9 | 2793.5 | 2881.2 |
| 124 | 4131.0 | 1607.8 | 2024.1 | 2517.5 | 2797.6 | 2640.4 | 2751.7 | 1594.5 | 1539.9 | 1594.5 | 1795.6 | 2051.6 | 2289.9 | 1917.0 | 2367.7 | 2471.3 | 2641.9 | 2710.2 | 3030.1 | 3023.6 | 2766.3 | 2912.2 | 2917.8 | 3015.1 |
| 128 | 4330.0 | 1667.2 | 2109.2 | 2628.0 | 2925.3 | 2796.8 | 2913.1 | 1670.1 | 1604.8 | 1670.1 | 1864.8 | 2135.1 | 2387.8 | 1992.2 | 2464.0 | 2574.2 | 2750.5 | 2827.4 | 3154.4 | 3149.7 | 2889.8 | 3043.5 | 3042.3 | 3149.0 |
| 132 | 4529.5 | 1726.7 | 2194.4 | 2738.8 | 3053.1 | 2954.2 | 3096.1 | 1746.0 | 1669.7 | 1746.0 | 1934.1 | 2218.5 | 2485.7 | 2067.5 | 2560.4 | 2677.2 | 2859.2 | 2944.7 | 3278.7 | 3275.8 | 3013.4 | 3175.1 | 3166.9 | 3283.1 |
| 136 | 4729.4 | 1786.2 | 2279.6 | 2849.7 | 3181.2 | 3112.6 | 3284.8 | 1822.1 | 1734.8 | 1822.1 | 2003.3 | 2302.0 | 2583.7 | 2142.8 | 2656.9 | 2780.2 | 2968.0 | 3062.2 | 3403.2 | 3402.1 | 3137.1 | 3306.8 | 3291.6 | 3417.3 |
| 140 | 4929.8 | 1845.7 | 2364.9 | 2960.6 | 3309.5 | 3271.8 | 3474.9 | 1898.5 | 1799.9 | 1898.5 | 2072.6 | 2385.6 | 2681.7 | 2218.1 | 2753.4 | 2883.3 | 3076.8 | 3179.7 | 3527.6 | 3528.5 | 3260.9 | 3438.5 | 3416.3 | 3551.6 |

Table 3.2(b) Peak negative moment in two-span girders (kips-ft)

| Span (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ \text { Type } 4 \\ \hline \end{array}$ | $\begin{gathered} \text { IA } \\ 353 \mathrm{~A} \end{gathered}$ | $\begin{gathered} \hline \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No5 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No6 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 7 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 8 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 12 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No13 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No14 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 17 \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 21 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 22 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 23 \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 25 \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -548 | -209 | -287 | -359 | -383 | -284 | -368 | -196 | -221 | -196 | -220 | -245 | -277 | -226 | -293 | -309 | -337 | -338 | -358 | -361 | -318 | -318 | -328 | -319 |
| 36 | -688 | -238 | -326 | -427 | -470 | -313 | -426 | -252 | -254 | -252 | -239 | -276 | -325 | -249 | -331 | -353 | -379 | -397 | -416 | -425 | -388 | -384 | -390 | -380 |
| 40 | -832 | -266 | -360 | -484 | -548 | -377 | -476 | -312 | -282 | -312 | -255 | -304 | -366 | -268 | -363 | -391 | -415 | -448 | -466 | -481 | -451 | -456 | -447 | -433 |
| 44 | -961 | -290 | -389 | -534 | -616 | -501 | -519 | -365 | -307 | -365 | -273 | -329 | -402 | -286 | -391 | -424 | -445 | -492 | -510 | -530 | -506 | -521 | -498 | -496 |
| 48 | -1074 | -311 | -413 | -578 | -676 | -634 | -570 | -412 | -328 | -412 | -311 | -350 | -433 | -316 | -414 | -452 | -472 | -530 | -549 | -574 | -555 | -578 | -544 | -553 |
| 52 | -1175 | -330 | -435 | -615 | -728 | -762 | -680 | -454 | -346 | -454 | -349 | -370 | -460 | -359 | -435 | -476 | -494 | -563 | -584 | -613 | -598 | -629 | -584 | -604 |
| 56 | -1265 | -348 | -454 | -649 | -775 | -888 | -821 | -492 | -362 | -492 | -386 | -416 | -484 | -401 | -472 | -498 | -535 | -592 | -616 | -648 | -636 | -674 | -621 | -652 |
| 60 | -1345 | -379 | -471 | -679 | -816 | -1005 | -971 | -525 | -376 | -525 | -422 | -463 | -505 | -441 | -527 | -539 | -597 | -619 | -670 | -680 | -670 | -716 | -654 | -695 |
| 64 | -1417 | -408 | -490 | -705 | -853 | -1111 | -1116 | -555 | -389 | -555 | -458 | -509 | -541 | -482 | -581 | -597 | -657 | -642 | -739 | -727 | -701 | -753 | -691 | -735 |
| 68 | -1482 | -438 | -538 | -729 | -887 | -1210 | -1261 | -582 | -406 | -582 | -494 | -554 | -597 | -521 | -634 | -655 | -717 | -704 | -807 | -793 | -729 | -787 | -762 | -775 |
| 72 | -1541 | -467 | -585 | -751 | -917 | -1300 | -1398 | -607 | -442 | -607 | -529 | -599 | -652 | -561 | -686 | -712 | -775 | -771 | -875 | -862 | -756 | -825 | -832 | -819 |
| 76 | -1594 | -497 | -632 | -770 | -945 | -1384 | -1526 | -629 | -478 | -629 | -564 | -643 | -706 | -599 | -738 | -768 | -833 | -837 | -941 | -931 | -828 | -862 | -900 | -890 |
| 80 | -1643 | -526 | -678 | -827 | -970 | -1461 | -1645 | -650 | -514 | -650 | -599 | -686 | -760 | -638 | -789 | -823 | -890 | -902 | -1007 | -999 | -899 | -932 | -968 | -967 |
| 84 | -1688 | -555 | -723 | -889 | -993 | -1532 | -1757 | -669 | -549 | -669 | -633 | -730 | -813 | -676 | -839 | -878 | -947 | -966 | -1072 | -1066 | -969 | -1007 | -1036 | -1043 |
| 88 | -1730 | -584 | -768 | -950 | -1052 | -1599 | -1862 | -687 | -584 | -687 | -668 | -773 | -865 | -714 | -889 | -932 | -1003 | -1030 | -1137 | -1133 | -1038 | -1081 | -1102 | -1118 |
| 92 | -1768 | -613 | -813 | -1010 | -1125 | -1660 | -1960 | -703 | -618 | -703 | -702 | -815 | -917 | -752 | -938 | -985 | -1059 | -1092 | -1201 | -1199 | -1106 | -1155 | -1168 | -1192 |
| 96 | -1803 | -641 | -857 | -1070 | -1197 | -1718 | -2052 | -718 | -652 | -718 | -736 | -857 | -969 | -789 | -988 | -1039 | -1114 | -1154 | -1265 | -1264 | -1174 | -1227 | -1233 | -1265 |
| 100 | -1883 | -670 | -901 | -1130 | -1269 | -1772 | -2138 | -732 | -687 | -732 | -770 | -899 | -1020 | -826 | -1037 | -1092 | -1169 | -1216 | -1328 | -1329 | -1240 | -1299 | -1298 | -1338 |
| 104 | -1997 | -698 | -945 | -1188 | -1339 | -1822 | -2220 | -754 | -720 | -754 | -804 | -941 | -1070 | -864 | -1085 | -1144 | -1224 | -1277 | -1391 | -1394 | -1306 | -1370 | -1363 | -1410 |
| 108 | -2110 | -727 | -988 | -1247 | -1409 | -1869 | -2296 | -798 | -754 | -798 | -837 | -983 | -1121 | -901 | -1134 | -1196 | -1279 | -1338 | -1453 | -1458 | -1372 | -1441 | -1427 | -1481 |
| 112 | -2223 | -755 | -1032 | -1305 | -1479 | -1913 | -2369 | -841 | -787 | -841 | -871 | -1024 | -1171 | -938 | -1182 | -1248 | -1333 | -1399 | -1516 | -1522 | -1437 | -1511 | -1490 | -1552 |
| 116 | -2334 | -784 | -1075 | -1363 | -1547 | -1955 | -2437 | -884 | -820 | -884 | -904 | -1066 | -1220 | -974 | -1230 | -1300 | -1387 | -1459 | -1578 | -1586 | -1502 | -1580 | -1554 | -1622 |
| 120 | -2444 | -812 | -1117 | -1420 | -1616 | -1975 | -2501 | -927 | -854 | -927 | -938 | -1107 | -1270 | -1011 | -1278 | -1351 | -1441 | -1518 | -1640 | -1649 | -1566 | -1649 | -1617 | -1691 |
| 124 | -2554 | -840 | -1160 | -1477 | -1684 | -2031 | -2563 | -969 | -886 | -969 | -971 | -1148 | -1319 | -1047 | -1325 | -1403 | -1495 | -1578 | -1701 | -1713 | -1630 | -1718 | -1679 | -1761 |
| 128 | -2663 | -869 | -1202 | -1534 | -1751 | -2066 | -2621 | -1011 | -919 | -1011 | -1004 | -1189 | -1368 | -1084 | -1373 | -1454 | -1548 | -1637 | -1763 | -1775 | -1694 | -1786 | -1742 | -1830 |
| 132 | -2771 | -897 | -1245 | -1590 | -1818 | -2100 | -2676 | -1053 | -952 | -1053 | -1038 | -1230 | -1417 | -1120 | -1420 | -1505 | -1601 | -1696 | -1824 | -1838 | -1757 | -1854 | -1804 | -1898 |
| 136 | -2878 | -925 | -1287 | -1646 | -1885 | -2131 | -2728 | -1095 | -985 | -1095 | -1071 | -1270 | -1466 | -1157 | -1467 | -1555 | -1655 | -1755 | -1885 | -1901 | -1820 | -1922 | -1866 | -1967 |
| 140 | -2985 | -953 | -1329 | -1702 | -1952 | -2161 | -2778 | -1136 | -1017 | -1136 | -1104 | -1311 | -1515 | -1193 | -1514 | -1606 | -1708 | -1813 | -1946 | -1963 | -1883 | -1989 | -1928 | -2035 |

Table 3.2(c) Peak shear in two-span girders (kips)

| Span (ft) | $\begin{aligned} & \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \mathrm{AASH} \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { IA } \\ \text { Type4 } \\ \hline \end{array}$ | $\begin{gathered} \text { IA } \\ 353 \mathrm{~A} \end{gathered}$ | $\begin{gathered} \hline \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No5 } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 7 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No8 } \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 12 \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 13 \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No14} \\ \hline \end{array}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No17 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 21 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No22 } \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 23 \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 25 \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 107.4 | 55.9 | 51.0 | 65.8 | 70.3 | 68.9 | 66.4 | 44.1 | 40.6 | 44.1 | 51.9 | 53.3 | 53.3 | 53.7 | 58.3 | 58.2 | 63.1 | 60.5 | 75.1 | 75.0 | 59.8 | 63.1 | 67.3 | 66.6 |
| 36 | 111.8 | 58.2 | 55.2 | 68.7 | 74.1 | 72.9 | 69.0 | 45.6 | 44.4 | 45.6 | 56.4 | 58.0 | 58.0 | 57.0 | 64.5 | 63.6 | 69.9 | 65.5 | 79.8 | 79.9 | 64.7 | 69.3 | 73.1 | 71.5 |
| 40 | 115.9 | 59.9 | 60.5 | 70.9 | 77.3 | 75.9 | 72.3 | 47.2 | 47.4 | 47.2 | 59.9 | 61.6 | 61.9 | 59.5 | 69.3 | 69.5 | 75.9 | 70.8 | 84.0 | 83.6 | 68.5 | 74.1 | 77.6 | 76.6 |
| 44 | 119.7 | 61.3 | 64.6 | 73.1 | 79.8 | 79.9 | 78.4 | 48.7 | 50.1 | 48.7 | 62.7 | 64.5 | 66.8 | 62.2 | 73.2 | 74.3 | 81.3 | 76.1 | 90.0 | 88.9 | 72.2 | 77.8 | 81.6 | 81.4 |
| 48 | 123.0 | 62.4 | 68.0 | 78.1 | 81.6 | 83.9 | 84.8 | 50.1 | 53.3 | 50.1 | 65.0 | 66.9 | 70.8 | 65.3 | 76.5 | 78.1 | 86.7 | 81.7 | 95.7 | 93.9 | 77.1 | 80.7 | 87.4 | 85.5 |
| 52 | 126.4 | 63.4 | 71.4 | 82.3 | 86.6 | 87.4 | 90.8 | 51.2 | 55.9 | 51.2 | 66.8 | 69.7 | 74.1 | 67.9 | 80.5 | 81.4 | 91.2 | 86.3 | 101.1 | 99.1 | 82.9 | 85.1 | 92.5 | 89.9 |
| 56 | 135.3 | 64.1 | 74.3 | 87.2 | 91.9 | 90.5 | 95.8 | 52.1 | 58.1 | 52.1 | 68.4 | 72.6 | 76.9 | 70.0 | 83.9 | 85.4 | 95.0 | 90.1 | 105.7 | 104.1 | 87.8 | 90.2 | 97.9 | 93.5 |
| 60 | 142.9 | 64.8 | 76.9 | 91.4 | 96.4 | 93.4 | 99.9 | 53.3 | 60.0 | 53.3 | 69.7 | 75.1 | 79.3 | 71.8 | 86.7 | 88.8 | 98.2 | 93.6 | 109.6 | 108.3 | 91.9 | 95.0 | 102.5 | 97.7 |
| 64 | 149.9 | 65.3 | 79.0 | 95.0 | 101.4 | 96.1 | 103.6 | 55.8 | 61.6 | 55.8 | 70.8 | 77.2 | 82.5 | 73.4 | 89.2 | 91.8 | 100.9 | 97.6 | 112.9 | 111.9 | 95.5 | 99.1 | 106.5 | 101.6 |
| 68 | 157.4 | 65.8 | 80.9 | 98.1 | 105.7 | 98.4 | 106.9 | 58.5 | 63.0 | 58.5 | 71.8 | 79.0 | 85.3 | 74.7 | 91.3 | 94.3 | 103.2 | 101.0 | 115.8 | 115.1 | 99.2 | 102.6 | 109.9 | 105.0 |
| 72 | 164.0 | 66.2 | 82.6 | 100.8 | 109.5 | 100.4 | 110.1 | 61.2 | 64.2 | 61.2 | 72.6 | 80.6 | 87.7 | 75.9 | 93.2 | 96.5 | 105.3 | 104.0 | 118.3 | 117.8 | 102.9 | 105.7 | 112.9 | 107.9 |
| 76 | 169.8 | 66.6 | 84.0 | 103.2 | 112.9 | 102.1 | 113.1 | 63.5 | 65.2 | 63.5 | 73.4 | 81.9 | 89.9 | 76.9 | 94.8 | 98.4 | 107.1 | 106.7 | 120.5 | 120.3 | 106.2 | 108.5 | 115.5 | 110.5 |
| 80 | 175.0 | 66.9 | 85.3 | 105.3 | 115.8 | 103.5 | 115.7 | 65.6 | 66.2 | 65.6 | 74.0 | 83.2 | 91.7 | 77.8 | 96.2 | 100.1 | 108.7 | 109.0 | 122.5 | 122.4 | 109.1 | 110.9 | 117.8 | 113.2 |
| 84 | 179.6 | 67.2 | 86.4 | 107.2 | 118.5 | 105.6 | 117.9 | 67.5 | 67.0 | 67.5 | 74.6 | 84.3 | 93.4 | 78.6 | 97.5 | 101.7 | 110.1 | 111.1 | 124.2 | 124.3 | 111.7 | 113.6 | 119.9 | 116.3 |
| 88 | 183.7 | 67.5 | 87.4 | 108.8 | 120.8 | 110.6 | 119.9 | 69.2 | 67.8 | 69.2 | 75.1 | 85.2 | 94.9 | 79.3 | 98.6 | 103.0 | 111.4 | 113.0 | 125.8 | 126.0 | 114.0 | 116.4 | 121.8 | 119.1 |
| 92 | 187.4 | 67.7 | 88.3 | 110.3 | 123.0 | 115.1 | 121.7 | 70.7 | 68.4 | 70.7 | 75.6 | 86.1 | 96.3 | 80.0 | 99.6 | 104.3 | 112.5 | 114.7 | 127.2 | 127.5 | 116.1 | 118.9 | 123.4 | 121.6 |
| 96 | 190.8 | 67.9 | 89.1 | 111.7 | 124.9 | 119.2 | 123.2 | 72.0 | 69.0 | 72.0 | 76.0 | 86.9 | 97.5 | 80.6 | 100.6 | 105.4 | 113.6 | 116.2 | 128.4 | 128.9 | 117.9 | 121.2 | 124.9 | 123.8 |
| 100 | 193.8 | 68.1 | 89.9 | 112.9 | 126.6 | 123.6 | 124.6 | 73.3 | 69.6 | 73.3 | 76.4 | 87.6 | 98.6 | 81.1 | 101.4 | 106.4 | 114.5 | 117.6 | 129.6 | 130.2 | 119.6 | 123.2 | 126.3 | 125.9 |
| 104 | 196.6 | 68.3 | 90.6 | 114.1 | 128.2 | 127.7 | 128.3 | 74.4 | 70.1 | 74.4 | 76.8 | 88.3 | 99.6 | 81.6 | 102.2 | 107.3 | 115.3 | 118.8 | 130.6 | 131.3 | 121.2 | 125.1 | 127.5 | 127.7 |
| 108 | 199.1 | 68.5 | 91.2 | 115.1 | 129.7 | 131.5 | 132.8 | 75.4 | 70.5 | 75.4 | 77.1 | 88.9 | 100.5 | 82.0 | 102.9 | 108.1 | 116.1 | 120.0 | 131.6 | 132.4 | 122.6 | 126.8 | 128.7 | 129.4 |
| 112 | 201.4 | 68.6 | 91.7 | 116.0 | 131.0 | 135.0 | 137.7 | 76.4 | 71.0 | 76.4 | 77.4 | 89.4 | 101.4 | 82.4 | 103.5 | 108.9 | 116.8 | 121.0 | 132.4 | 133.3 | 123.9 | 128.4 | 129.7 | 131.0 |
| 116 | 203.6 | 68.7 | 92.3 | 116.9 | 132.2 | 138.2 | 142.2 | 77.2 | 71.3 | 77.2 | 77.6 | 89.9 | 102.1 | 82.8 | 104.1 | 109.6 | 117.5 | 122.0 | 133.2 | 134.2 | 125.1 | 129.8 | 130.7 | 132.4 |
| 120 | 205.6 | 68.9 | 92.7 | 117.7 | 133.3 | 139.7 | 146.4 | 78.0 | 71.7 | 78.0 | 77.9 | 90.4 | 102.8 | 83.1 | 104.6 | 110.2 | 118.1 | 122.9 | 134.0 | 135.0 | 126.2 | 131.2 | 131.5 | 133.8 |
| 124 | 207.4 | 69.0 | 93.2 | 118.4 | 134.4 | 143.9 | 150.8 | 78.8 | 72.0 | 78.8 | 78.1 | 90.8 | 103.5 | 83.5 | 105.1 | 110.8 | 118.7 | 123.7 | 134.7 | 135.8 | 127.2 | 132.4 | 132.3 | 135.0 |
| 128 | 209.1 | 69.1 | 93.6 | 119.1 | 135.4 | 146.4 | 155.0 | 79.5 | 72.3 | 79.5 | 78.3 | 91.2 | 104.1 | 83.8 | 105.6 | 111.4 | 119.2 | 124.4 | 135.3 | 136.5 | 128.2 | 133.5 | 133.1 | 136.1 |
| 132 | 210.6 | 69.2 | 94.0 | 119.7 | 136.3 | 148.8 | 158.9 | 80.1 | 72.6 | 80.1 | 78.5 | 91.6 | 104.7 | 84.0 | 106.0 | 111.9 | 119.7 | 125.2 | 135.9 | 137.1 | 129.0 | 134.6 | 133.8 | 137.2 |
| 136 | 212.1 | 69.3 | 94.3 | 120.3 | 137.1 | 151.0 | 162.5 | 80.7 | 72.9 | 80.7 | 78.7 | 91.9 | 105.2 | 84.3 | 106.4 | 112.4 | 120.1 | 125.8 | 136.4 | 137.7 | 129.9 | 135.6 | 134.5 | 138.2 |
| 140 | 213.5 | 69.4 | 94.7 | 120.9 | 137.9 | 153.1 | 165.9 | 81.2 | 73.1 | 81.2 | 78.9 | 92.3 | 105.7 | 84.5 | 106.8 | 112.8 | 120.5 | 126.4 | 137.0 | 138.3 | 130.6 | 136.5 | 135.1 | 139.1 |

## Three-span simply supported girders

Similar to two-span girders, Wis-SPV envelops the positive peak positive moments of the permitting vehicles as shown in Fig. 3.8. The peak negative moments by MnDOT Type P413 vehicle exceed those of the Wisconsin Standard Permit Vehicle for girders with span between 84 ft and 118 ft . The R-values in Fig. 3.9 indicates that the breaches of the peak moments by WisSPV is contained because all R -values are smaller than 0.9 . The limited number of breaches are demonstrated within a circle in Fig. 3.10 for a girder with three equal spans of 92 ft : the peak negative moments (dashed (yellow) lines) are larger than those of the Wis-SPV (solid (blue) line) only at the interior supports.


Fig. 3.8 Comparison of the peak moments in3-span simply-supported girders


Fig. 3.9 R-values for the moment/shear envelopes in three-span girders


Fig. 3.10 Demonstration of breaching peak negative moment of Wis-SPV

Table 3.3(a) Peak positive moment in two-span girders (kips-ft)

| Span (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \end{gathered}$ | $\begin{gathered} \text { IA } \\ \text { Type4 } \end{gathered}$ | $\begin{gathered} \text { IA } \\ 353 \mathrm{~A} \end{gathered}$ | $\begin{gathered} \text { IA } \\ 453 \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 5 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No6 } \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 7 \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} \mathrm{~B} \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 12 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 13 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 14 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No17 } \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 21 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 22 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 23 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 25 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 575.6 | 260.5 | 257.7 | 334.5 | 348.4 | 335.3 | 336.5 | 228.8 | 221.6 | 228.8 | 240.2 | 246.2 | 246.2 | 246.2 | 279.3 | 279.1 | 304.3 | 278.7 | 358.0 | 358.0 | 255.6 | 286.2 | 299.3 | 307.2 |
| 36 | 667.4 | 311.7 | 301.6 | 393.9 | 416.4 | 407.5 | 405.3 | 270.2 | 255.7 | 270.2 | 298.7 | 300.9 | 300.9 | 298.4 | 340.5 | 338.3 | 370.1 | 340.2 | 438.9 | 438.9 | 316.3 | 349.4 | 377.4 | 2 |
| 40 | 763.4 | 367.3 | 345.9 | 453.9 | 485.1 | 487.7 | 468.4 | 312.3 | 289.9 | 312.3 | 361.0 | 363.9 | 363.9 | 362.4 | 406.6 | 407.2 | 449.6 | 411.0 | 521.7 | 520.8 | 385.9 | 422.1 | 457.3 | 451.9 |
| 44 | 865. | 423.5 | 392.3 | 51 | 55 | 562 | 53 | 35 | 32 | 35 | 424 | 42 | 428.0 | 430.5 | 479.4 | 479.5 | 535.8 | 48 | 621.0 | 611.3 | 460.7 | 501.1 | 538.6 | 35.0 |
| 48 | 968.8 | 480.2 | 454.8 | 575. | 623.9 | 637 | 603 | 397.6 | 374. | 397.6 | 489.2 | 497 | 497.8 | 499.8 | 565.4 | 560.7 | 623.8 | 570.2 | 724.2 | 713.4 | 544.1 | 588.5 | 632.7 | 619.4 |
| 52 | 10 | 53 | 52 | 636 | 6 | 720 | 68 | 4 | 42 | 440.6 | 554 | 572 | 572.8 | 570.2 | 653.2 | 650.5 | 713.2 | 657.6 | 828.7 | 817.2 | 629.4 | 677.9 | 734.7 | 8 |
| 56 | 117 | 59 | 59 | 71 | 76 | 807 | 768. | 48 | 4 | 483.8 | 620.3 | 649.1 | 6 | 641.2 | 742.4 | 743.7 | 811.1 | 75 | 937.0 | 922.1 | 718.6 | 768.4 | 838.3 | 816.2 |
| 6 | 80 | 652.0 | 675.8 | 804.6 | 845.7 | 894.4 | 852.4 | 527.2 | 523.3 | 527.2 | 686.6 | 726.5 | 736.8 | 712.9 | 832.6 | 838.2 | 912.6 | 856.0 | 1051.5 | 1028.1 | 821.4 | 870.5 | 943.0 | 926.0 |
| 64 | 1385.6 | 70 | 75 | 901.2 | 941.7 | 98 | 9 | 570.6 | 58 | 5 | 75 | 80 | 82 | 784.9 | 923.8 | 93 | 10 | 0 | 1167.6 | 11 | 934.1 | 80.0 | 1057.8 | 1037.8 |
| 68 | 150 | 76 | 835 | 99 | 10 | 1070. | 1043 | 61 | 639.9 | 61 | 820.0 | 883.5 | 920.9 | 857.4 | 1015.5 | 1030.5 | 1118.4 | 1073.3 | 1286.2 | 1260.8 | 1048.3 | 1095.7 | 1175.5 | 1150.7 |
| 72 | 165 | 825.5 | 916.2 | 1099. | 1166 | 1159. | 1145.3 | 657 | 700.2 | 657.8 | 887. | 962.8 | 1014.0 | 930.1 | 1107.8 | 1127.9 | 1222.3 | 1184.0 | 1405.4 | 1380.6 | 1164.1 | 1217.1 | 1294.0 | 1274.3 |
| 76 | 1818.0 | 88 | 997.5 | 12 | 12 | 12 | 12 | 716.5 | 76 | 7 | 95 | 10 | 11 | 10 | 12 | 12 | 13 | 12 | 1525.2 | 1501.1 | 1281.1 | 1339.9 | 1413.2 | 0.6 |
| 80 | 19 | 94 | 1079.2 | 1303. | 14 | 1337. | 1351 | 78 | 82 | 783.0 | 1021.7 | 1122.6 | 1201.8 | 1076.3 | 1293.7 | 1325.2 | 1431.5 | 1408.2 | 1645.5 | 1622.3 | 1398.9 | 1463.6 | 1532.9 | 1528.1 |
| 84 | 216 | 999.9 | 1161.3 | 1407 | 1519. | 1426 | 1457 | 850.9 | 884. | 850.9 | 1089.2 | 1202.9 | 1296.5 | 1149.7 | 1387.2 | 1425.0 | 1536.8 | 1521.1 | 1766.1 | 1744.0 | 1517.3 | 1588.3 | 1653.2 | 1657.2 |
| 88 |  | 1058 | 12 | 15 | 16 | 15 | 15 | 91 | 94 | 919.9 | 11 | 12 | 139 | 1223 | 1480. | 152 | 164 | 1634.5 | 188 | 18 | 1636.3 | 1713 | 1773.8 | 7 |
| 92 | 2531.3 | 1116.7 | 1326.2 | 1615. | 17 | 1605. | 16 | 989.7 | 1009. | 989.7 | 1224.6 | 1364.9 | 1486.9 | 1296.9 | 1574.9 | 1625.5 | 1748.4 | 1748.4 | 2008.5 | 1988.8 | 1755.9 | 1840.0 | 1894.8 | 1916.7 |
| 96 | 27 | 1175.2 | 1409.0 | 1721. | 1882. | 1713. | 1777.2 | 1060.4 | 1072.0 | 1060.4 | 1292.4 | 1446.7 | 1582.4 | 1370.7 | 1669.1 | 1726.1 | 1854.5 | 1862.5 | 2130.0 | 2111.7 | 1875.7 | 1966.6 | 2016.1 | 2047.1 |
| 10 | 2901. | 1233. | 1491.9 | 1829. | 20 | 1823. | 1884.4 | 1131.7 | 1135.0 | 1131.7 | 1360.5 | 1528.7 | 1678.1 | 1444.5 | 1763.5 | 1826.9 | 1960.8 | 1976.9 | 2251.7 | 2234.9 | 1995.9 | 2093.8 | 2137.9 | 2177.8 |
| 10 | 3093.2 | 1292.4 | 1575.2 | 1936. | 2129.0 | 1935. | 1992.1 | 1203.8 | 1198.4 | 1203.8 | 1428.6 | 1610.7 | 1774.0 | 1518.5 | 1858.0 | 1927.8 | 2067.4 | 2091.6 | 2373.7 | 2358.3 | 2116.5 | 2221.4 | 2260.1 | 2308.7 |
| 108 | 3285.5 | 1350.9 | 1658.5 | 204 | 2253 | 2047 | 2110.6 | 1276.3 | 1261.8 | 1276.3 | 1496.7 | 1692.8 | 1870.1 | 1592.5 | 1952.7 | 2028.9 | 2174.0 | 2206.6 | 2495.8 | 2482.0 | 2237.4 | 2349.5 | 2382.4 | 2439.8 |
| 11 | 3478.8 | 1409.6 | 1741.9 | 2152. | 2377. | 2165.4 | 2257.3 | 1349.2 | 1325.5 | 1349.2 | 1565.0 | 1775.0 | 1966.2 | 1666.6 | 2047.5 | 2130.1 | 2280.9 | 2321.6 | 2618.1 | 2605.9 | 2358.5 | 2477.8 | 2504.8 | 2571.3 |
| 116 | 3673.0 | 1468.3 | 1825.5 | 2261.2 | 2502.5 | 2292. | 2404.9 | 1422.5 | 1389.2 | 1422.5 | 1633.2 | 1857.3 | 2062.6 | 1740.8 | 2142.3 | 2231.5 | 2387.8 | 2437.0 | 2740.5 | 2729.9 | 2479.8 | 2606.4 | 2627.4 | 2702.8 |
| 120 | 386 | 1527.0 | 1909 | 2369. | 2627. | 2442.9 | 2553.5 | 1496.2 | 1453.1 | 1496.2 | 1701.5 | 1939.6 | 2159.0 | 1815.0 | 2237.3 | 2332.9 | 2494.9 | 2552.4 | 2863.0 | 2854.1 | 2601.3 | 2735.4 | 2750.2 | 2834.7 |
| 124 | 4063.5 | 1585.7 | 1992.9 | 2478.6 | 2753.5 | 2595.3 | 2703.1 | 1570.2 | 1517.0 | 1570.2 | 1769.9 | 2021.9 | 2255.5 | 1889.3 | 2332.4 | 2434.4 | 2602.1 | 2668.0 | 2985.7 | 2978.4 | 2723.0 | 2864.7 | 2873.0 | 2966.6 |
| 128 | 4259.8 | 1644.4 | 2076.8 | 2587. | 2879.4 | 2748.8 | 2863.6 | 1644.5 | 1581.1 | 1644.5 | 1838.3 | 2104.3 | 2352.1 | 1963.6 | 2427.5 | 2536.0 | 2709.3 | 2783.8 | 3108.4 | 3103.0 | 2844.8 | 2994.5 | 2996.1 | 3098.7 |
| 132 | 4456.5 | 1703.2 | 2160.9 | 2696.5 | 3005.6 | 2903.5 | 3042.1 | 1719.1 | 1645.3 | 1719.1 | 1906.7 | 2186.8 | 2448.8 | 2037.9 | 2522.7 | 2637.7 | 2816.6 | 2899.6 | 3231.2 | 3227.5 | 2966.8 | 3124.5 | 3119.1 | 3231.0 |
| 136 | 4653.8 | 1762.0 | 2245.1 | 2805.8 | 3132.1 | 3059.2 | 3226.8 | 1793.8 | 1709.5 | 1793.8 | 1975.2 | 2269.3 | 2545.6 | 2112.3 | 2618.0 | 2739.4 | 2924.1 | 3015.6 | 3354.1 | 3352.2 | 3089.0 | 3254.6 | 3242.3 | 3363.3 |
| 140 | 4851.5 | 1820.8 | 2329.3 | 2915.1 | 3258.7 | 3215.8 | 3413.9 | 1868.8 | 1773.9 | 1868.8 | 2043.7 | 2351.8 | 2642.4 | 2186.7 | 2713.3 | 2841.2 | 3031.5 | 3131.6 | 3477.0 | 3477.0 | 3211.2 | 3384.8 | 3365.6 | 3495.8 |

Table 3.3(b) Peak negative moment in two-span girders (kips-ft)

| Span <br> (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \text { AASH } \\ \text { TO } \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 411 \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \end{gathered}$ | $\begin{array}{\|c\|c} \hline \text { IA } \\ \text { Type4 } \\ \hline \end{array}$ | $\begin{gathered} \hline \text { IA } \\ 353 \mathrm{~A} \end{gathered}$ | $\begin{gathered} \hline \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 5 \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 7 \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 8 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 12 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No13 } \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 14 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \text { No15 } \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No17} \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 18 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 21 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 22 \end{gathered}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 23 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 25 \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -504 | -200 | -272 | -337 | -355 | -283 | -348 | -178 | -210 | -178 | -218 | -237 | -263 | -217 | -282 | -294 | -321 | -318 | -353 | -353 | -300 | -303 | -314 | -309 |
| 36 | -641 | -228 | -312 | -405 | -440 | -31 | -40 | -233 | -243 | -233 | -239 | -272 | -311 | -244 | -322 | -339 | -363 | -376 | -414 | -419 | -367 | -368 | -383 | -371 |
| 40 | -776 | -255 | -347 | -464 | -518 | -366 | -459 | -291 | -272 | -291 | -257 | -303 | -353 | -271 | -355 | -378 | -399 | -426 | -467 | -478 | -431 | -440 | -444 | -427 |
| 44 | -900 | -281 | -377 | -515 | -587 | -463 | -503 | -34 | -297 | -344 | -291 | -330 | -389 | -294 | -385 | -411 | -431 | -470 | -514 | -531 | -488 | -506 | -498 | -491 |
| 48 | -101 | -306 | -403 | -560 | -649 | -582 | -542 | -392 | -318 | -392 | -332 | -354 | -421 | -337 | -413 | -441 | -459 | -509 | -557 | -578 | -538 | -565 | -547 | -552 |
| 52 | -111 | -339 | -426 | -600 | -703 | -70 | -6 | -435 | -33 | -435 | -372 | -392 | -453 | -383 | -444 | -474 | -511 | -544 | -595 | -620 | -583 | -618 | -591 | -607 |
| 56 | -1209 | -371 | -446 | -636 | -752 | -826 | -765 | -473 | -354 | -473 | -411 | -443 | -485 | -427 | -504 | -511 | -571 | -575 | -642 | -658 | -623 | -667 | -631 | -658 |
| 60 | -129 | -40 | -471 | -66 | -795 | -94 | -90 | -50 | -36 | -508 | -450 | -493 | -516 | -471 | -562 | -575 | -636 | -614 | -714 | -711 | -660 | -712 | -671 | -705 |
| 64 | -136 | -436 | -523 | -696 | -835 | -1045 | -103 | -539 | -393 | -539 | -489 | -542 | -577 | -514 | -620 | -637 | -701 | -678 | -788 | -770 | -694 | -761 | -736 | -757 |
| 68 | -1434 | -467 | -574 | -721 | -870 | -114 | -117 | -568 | -432 | -568 | -527 | -591 | -636 | -556 | -676 | -699 | -764 | -751 | -861 | -845 | -736 | -807 | -812 | -806 |
| 72 | -149 | -49 | -62 | -74 | -903 | -1235 | -130 | -59 | -47 | -594 | -564 | -638 | -695 | -598 | -732 | -759 | -827 | -822 | -933 | -920 | -807 | -850 | -887 | -868 |
| 76 | -1552 | -530 | -674 | -815 | -932 | -132 | -143 | -618 | -510 | -618 | -602 | -685 | -753 | -639 | -78 | -819 | -888 | -893 | -1004 | -993 | -884 | -912 | -960 | -949 |
| 80 | -1603 | -561 | -723 | -882 | -964 | -1399 | -1552 | -640 | -548 | -640 | -639 | -732 | -810 | -680 | -841 | -878 | -949 | -962 | -1074 | -1065 | -959 | -994 | -1033 | -1031 |
| 84 | -165 | -59 | -772 | -94 | -1044 | -147 | -166 | -66 | -58 | -661 | -676 | -77 | -867 | -721 | -895 | -936 | -1010 | -1030 | -1144 | -1137 | -1034 | -1074 | -1105 | -1112 |
| 88 | -1695 | -622 | -820 | -1013 | -1122 | -154 | -176 | -679 | -622 | -679 | -712 | -824 | -923 | -762 | -948 | -994 | -1070 | -109 | -1212 | -1208 | -1107 | -1153 | -1175 | -1192 |
| 92 | -17 | -653 | -867 | -1078 | -1200 | -1605 | -186 | -697 | -659 | -697 | -749 | -869 | -978 | -802 | -1001 | -1051 | -1129 | -1165 | -1281 | -1278 | -1180 | -1231 | -1246 | -1271 |
| 96 | -188 | -68 | -914 | -114 | -127 | -166 | -196 | -713 | -696 | -713 | -785 | -914 | -1033 | -842 | -1053 | -1108 | -1188 | -1231 | -1349 | -1348 | -1252 | -1309 | -1316 | -1349 |
| 100 | -2008 | -714 | -961 | -1205 | -1353 | -172 | -2050 | -757 | -732 | -757 | -821 | -959 | -108 | -881 | -1106 | -1164 | -1247 | -1297 | -1416 | -1418 | -1323 | -1385 | -1385 | -1427 |
| 104 | -2129 | -745 | -1008 | -1268 | -1428 | -1773 | -213 | -804 | -768 | -804 | -857 | -1004 | -1142 | -921 | -1157 | -1220 | -1306 | -1362 | -1483 | -148 | -1393 | -1461 | -1453 | -1503 |
| 108 | -2251 | -775 | -1054 | -1330 | -1503 | -1823 | -221 | -851 | -804 | -851 | -893 | -1048 | -1195 | -961 | -1209 | -1276 | -1364 | -1427 | -1550 | -1555 | -1464 | -1536 | -1522 | -1579 |
| 112 | -2371 | -805 | -1100 | -1392 | -1577 | -1869 | -2287 | -897 | -840 | -897 | -929 | -1093 | -1249 | -1000 | -1261 | -1331 | -1422 | -1492 | -1617 | -162 | -1533 | -1611 | -1590 | -1655 |
| 116 | -2489 | -836 | -1146 | -1453 | -1650 | -1913 | -235 | -943 | -875 | -943 | -964 | -1137 | -1302 | -1039 | -1312 | -1386 | -1479 | -1556 | -1683 | -1692 | -1602 | -1685 | -1657 | -1730 |
| 120 | -260 | -866 | -1192 | -1514 | -1723 | -1955 | -2425 | -989 | -910 | -989 | -1000 | -1181 | -1355 | -1078 | -1363 | -1441 | -1537 | -1619 | -1749 | -1759 | -1671 | -1759 | -1724 | -1804 |
| 124 | -2724 | -896 | -1237 | -1575 | -1796 | -1995 | -2489 | -1034 | -945 | -1034 | -1036 | -1224 | -1407 | -1117 | -1413 | -1496 | -1594 | -1683 | -1815 | -1827 | -1739 | -1832 | -1791 | -1878 |
| 128 | -2840 | -927 | -1282 | -1636 | -1868 | -2032 | -254 | -1079 | -980 | -1079 | -1071 | -1268 | -1460 | -1156 | -1464 | -1551 | -1651 | -1746 | -1880 | -189 | -1806 | -1905 | -1858 | -1952 |
| 132 | -2955 | -957 | -1328 | -1696 | -1940 | -2068 | -2607 | -1123 | -1015 | -1123 | -1107 | -1311 | -1512 | -1195 | -1515 | -1605 | -1708 | -1809 | -1945 | -1961 | -1874 | -1978 | -1924 | -2025 |
| 136 | -3070 | -987 | -1373 | -1756 | -2011 | -2152 | -2662 | -1168 | -1050 | -1168 | -1142 | -1355 | -1564 | -1234 | -1565 | -1659 | -1765 | -1872 | -2010 | -2027 | -1941 | -2050 | -1991 | -2098 |
| 140 | -3184 | -1017 | -1418 | -1816 | -2082 | -2256 | -2714 | -1212 | -1085 | -1212 | -1177 | -1398 | -1616 | -1272 | -1615 | -1713 | -1822 | -1934 | -2075 | -2094 | -2008 | -2121 | -2057 | -2171 |

Table 3.3(c) Peak shear in two-span girders (kips)

| Span (ft) | $\begin{aligned} & \hline \text { Wis } \\ & \text { SPV } \end{aligned}$ | $\begin{array}{\|c\|} \hline \mathrm{AASH} \\ \mathrm{TO} \end{array}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mn} \\ \mathrm{C} \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mn} \\ \mathrm{P} 411 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mn} \\ \mathrm{P} 413 \\ \hline \end{gathered}$ | IA <br> Type4 | $\begin{gathered} \hline \text { IA } \\ 353 \mathrm{~A} \\ \hline \end{gathered}$ | $\begin{gathered} \hline \text { IA } \\ 453 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No5} \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No6 } \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 7 \\ \hline \end{array}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} \mathrm{~B} \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 12 \\ \hline \end{array}$ | $\begin{gathered} \mathrm{Mi} \\ \mathrm{No} 13 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No14 } \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 15 \\ \hline \end{array}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 17 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \text { No18 } \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 21 \\ \hline \end{array}$ | $\begin{gathered} \hline \mathrm{Mi} \\ \mathrm{No} 22 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \mathrm{No} 23 \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \mathrm{Mi} \\ \text { No25 } \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 107.7 | 56.1 | 50.3 | 65.3 | 70.0 | 69.1 | 65.7 | 44.2 | 40.8 | 44.2 | 52.2 | 53.3 | 53.3 | 53.8 | 58.4 | 58.3 | 63.4 | 60.3 | 74.8 | 74.6 | 59.2 | 62.7 | 66.9 | 66.2 |
| 36 | 111.6 | 58.4 | 55.4 | 68.0 | 73.5 | 73.1 | 68.1 | 45.7 | 44.6 | 45.7 | 56.7 | 58.1 | 58.1 | 57.1 | 64.7 | 63.8 | 70.4 | 65.4 | 79.6 | 79.5 | 64.0 | 68.8 | 72.8 | 71.1 |
| 40 | 115.2 | 60.2 | 60.7 | 70.0 | 76.4 | 76.2 | 72.5 | 47.1 | 47.6 | 47.1 | 60.3 | 61.8 | 62.1 | 59.7 | 69.6 | 69.8 | 76.4 | 70.7 | 84.6 | 83.3 | 67.8 | 73.5 | 77.4 | 76.3 |
| 44 | 118.5 | 61.6 | 64.9 | 73.2 | 78.7 | 79.8 | 78.2 | 48.4 | 50.3 | 48.4 | 63.1 | 64.7 | 67.1 | 62.6 | 73.5 | 74.6 | 81.8 | 76.5 | 90.6 | 89.5 | 72.2 | 77.3 | 82.1 | 81.1 |
| 48 | 121.5 | 62.7 | 68.3 | 78.4 | 80.6 | 83.8 | 84.4 | 49.6 | 53.5 | 49.6 | 65.3 | 67.1 | 71.1 | 65.7 | 76.9 | 78.5 | 87.3 | 82.1 | 96.3 | 94.5 | 77.5 | 80.9 | 87.9 | 85.6 |
| 52 | 126.9 | 63.6 | 71.7 | 82.8 | 86.9 | 87.1 | 90.2 | 50.6 | 56.2 | 50.6 | 67.2 | 70.2 | 74.4 | 68.3 | 81.0 | 81.9 | 91.8 | 86.7 | 101.8 | 99.7 | 83.3 | 85.5 | 93.1 | 90.0 |
| 56 | 135.9 | 64.3 | 74.7 | 87.7 | 92.3 | 90.0 | 95.1 | 51.6 | 58.4 | 51.6 | 68.7 | 73.1 | 77.2 | 70.4 | 84.4 | 85.9 | 95.5 | 90.6 | 106.4 | 104.7 | 88.2 | 90.6 | 98.5 | 93.7 |
| 60 | 143.6 | 65.0 | 77.3 | 91.9 | 96.9 | 92.7 | 99.3 | 53.5 | 60.3 | 53.5 | 70.0 | 75.5 | 79.8 | 72.2 | 87.3 | 89.4 | 98.7 | 94.2 | 110.3 | 109.0 | 92.4 | 95.4 | 103.2 | 98.2 |
| 64 | 150.7 | 65.5 | 79.5 | 95.5 | 101.9 | 95.2 | 102.9 | 56.0 | 61.9 | 56.0 | 71.2 | 77.6 | 83.1 | 73.8 | 89.7 | 92.3 | 101.5 | 98.2 | 113.6 | 112.6 | 96.0 | 99.6 | 107.1 | 102.1 |
| 68 | 158.3 | 66.0 | 81.4 | 98.6 | 106.3 | 97.3 | 106.1 | 58.8 | 63.3 | 58.8 | 72.1 | 79.4 | 85.8 | 75.1 | 91.8 | 94.8 | 103.8 | 101.7 | 116.5 | 115.8 | 99.8 | 103.2 | 110.6 | 105.5 |
| 72 | 164.9 | 66.4 | 83.0 | 101.4 | 110.1 | 99.1 | 109.1 | 61.5 | 64.5 | 61.5 | 72.9 | 81.0 | 88.3 | 76.3 | 93.7 | 97.1 | 105.9 | 104.7 | 119.0 | 118.5 | 103.6 | 106.3 | 113.6 | 108.5 |
| 76 | 170.7 | 66.8 | 84.4 | 103.7 | 113.5 | 100.7 | 111.9 | 63.9 | 65.5 | 63.9 | 73.7 | 82.4 | 90.4 | 77.3 | 95.3 | 99.0 | 107.7 | 107.3 | 121.2 | 120.9 | 106.9 | 109.0 | 116.2 | 111.1 |
| 80 | 175.9 | 67.1 | 85.7 | 105.8 | 116.5 | 102.1 | 114.3 | 66.0 | 66.5 | 66.0 | 74.3 | 83.6 | 92.3 | 78.2 | 96.7 | 100.7 | 109.3 | 109.7 | 123.1 | 123.1 | 109.8 | 111.4 | 118.5 | 113.9 |
| 84 | 180.6 | 67.4 | 86.8 | 107.7 | 119.1 | 106.0 | 116.5 | 67.9 | 67.3 | 67.9 | 74.9 | 84.7 | 94.0 | 79.0 | 98.0 | 102.2 | 110.7 | 111.8 | 124.9 | 125.0 | 112.4 | 114.4 | 120.6 | 117.1 |
| 88 | 184.7 | 67.6 | 87.8 | 109.4 | 121.5 | 111.0 | 118.4 | 69.5 | 68.0 | 69.5 | 75.4 | 85.7 | 95.5 | 79.7 | 99.1 | 103.6 | 111.9 | 113.7 | 126.4 | 126.7 | 114.7 | 117.2 | 122.4 | 119.8 |
| 92 | 188.4 | 67.9 | 88.7 | 110.9 | 123.6 | 115.6 | 120.1 | 71.1 | 68.7 | 71.1 | 75.9 | 86.5 | 96.8 | 80.3 | 100.1 | 104.8 | 113.1 | 115.3 | 127.8 | 128.2 | 116.8 | 119.7 | 124.1 | 122.3 |
| 96 | 191.8 | 68.1 | 89.5 | 112.3 | 125.6 | 119.8 | 121.6 | 72.4 | 69.3 | 72.4 | 76.3 | 87.3 | 98.0 | 80.9 | 101.0 | 105.9 | 114.1 | 116.8 | 129.0 | 129.6 | 118.6 | 122.0 | 125.6 | 124.6 |
| 100 | 194.8 | 68.3 | 90.3 | 113.5 | 127.3 | 124.3 | 124.9 | 73.7 | 69.9 | 73.7 | 76.7 | 88.0 | 99.1 | 81.4 | 101.9 | 106.9 | 115.0 | 118.2 | 130.2 | 130.8 | 120.3 | 124.0 | 126.9 | 126.7 |
| 104 | 197.6 | 68.4 | 90.9 | 114.6 | 128.9 | 128.5 | 128.9 | 74.8 | 70.4 | 74.8 | 77.0 | 88.7 | 100.1 | 81.9 | 102.6 | 107.8 | 115.9 | 119.4 | 131.2 | 131.9 | 121.9 | 125.9 | 128.2 | 128.5 |
| 108 | 200.1 | 68.6 | 91.6 | 115.6 | 130.3 | 132.3 | 133.5 | 75.8 | 70.8 | 75.8 | 77.3 | 89.3 | 101.0 | 82.3 | 103.3 | 108.6 | 116.6 | 120.6 | 132.2 | 133.0 | 123.3 | 127.6 | 129.3 | 130.2 |
| 112 | 202.5 | 68.7 | 92.1 | 116.5 | 131.7 | 135.8 | 138.4 | 76.8 | 71.2 | 76.8 | 77.6 | 89.8 | 101.9 | 82.7 | 103.9 | 109.4 | 117.3 | 121.6 | 133.0 | 133.9 | 124.6 | 129.1 | 130.3 | 131.8 |
| 116 | 204.6 | 68.9 | 92.6 | 117.4 | 132.9 | 139.0 | 143.0 | 77.6 | 71.6 | 77.6 | 77.9 | 90.3 | 102.6 | 83.1 | 104.5 | 110.1 | 118.0 | 122.6 | 133.8 | 134.8 | 125.8 | 130.6 | 131.3 | 133.2 |
| 120 | 206.6 | 69.0 | 93.1 | 118.2 | 134.0 | 142.0 | 147.2 | 78.4 | 72.0 | 78.4 | 78.1 | 90.8 | 103.3 | 83.5 | 105.0 | 110.7 | 118.6 | 123.5 | 134.5 | 135.6 | 126.9 | 131.9 | 132.1 | 134.5 |
| 124 | 208.4 | 69.1 | 93.5 | 118.9 | 135.0 | 144.7 | 151.7 | 79.2 | 72.3 | 79.2 | 78.4 | 91.2 | 104.0 | 83.8 | 105.5 | 111.3 | 119.1 | 124.3 | 135.2 | 136.3 | 127.9 | 133.1 | 132.9 | 135.7 |
| 128 | 210.0 | 69.2 | 93.9 | 119.6 | 136.0 | 147.3 | 155.9 | 79.8 | 72.6 | 79.8 | 78.6 | 91.6 | 104.6 | 84.1 | 106.0 | 111.9 | 119.6 | 125.0 | 135.8 | 137.0 | 128.8 | 134.2 | 133.7 | 136.9 |
| 132 | 211.6 | 69.3 | 94.3 | 120.2 | 136.9 | 149.7 | 159.8 | 80.5 | 72.9 | 80.5 | 78.8 | 92.0 | 105.2 | 84.3 | 106.4 | 112.4 | 120.1 | 125.7 | 136.4 | 137.7 | 129.7 | 135.3 | 134.4 | 137.9 |
| 136 | 213.1 | 69.4 | 94.7 | 120.8 | 137.7 | 151.9 | 163.5 | 81.1 | 73.1 | 81.1 | 79.0 | 92.3 | 105.7 | 84.6 | 106.8 | 112.8 | 120.6 | 126.4 | 137.0 | 138.3 | 130.5 | 136.3 | 135.0 | 138.9 |
| 140 | 214.4 | 69.5 | 95.0 | 121.4 | 138.5 | 153.9 | 166.9 | 81.6 | 73.4 | 81.6 | 79.1 | 92.6 | 106.2 | 84.8 | 107.2 | 113.3 | 121.0 | 127.0 | 137.5 | 138.8 | 131.2 | 137.2 | 135.6 | 139.8 |

## Summary

The effects of the overloaded vehicles collected in the neighboring states were compared with those by the Wis-SPV. Wis-SPV has relatively short vehicle length compared with the vehicles with similar gross weights. Hence Wis-SPV cause larger positive moments in simply supported or continuous girders. Longer vehicles similar to the MnDOT Type P413 vehicle would cause larger negative moments for two- and three-span simply supported girders.
The maximum moments in the simply-supported girders considered in this Chapter were plotted against the gross vehicle weights in Figs. 11 through 13. Regression analyses showed that the maximum positive moments in the girders have a poor linear correlation with the vehicle weights (the coefficient of determination, $\mathrm{R}^{2}$, is around 0.6 ). This indicates that the current permitting fee schedule, which is solely dependent upon the vehicle weight, may not properly reflect the impact of overloaded vehicles on bridges. The correlation is somewhat improved for positive moments when the gross vehicle weight is normalized by the maximum weight defined by the Federal bridge formula. Meanwhile, the maximum negative moments by these permitting vehicles are closely related to the gross vehicle weight. The correlation is not improved for negative moments with the normalized gross vehicle weight.

The Wis-SPV was further studied in Chapter 4 using the trucks recorded in the Weigh-in-Motion (WIM) data.


Fig. 3.11 Maximum moment distribution in 1-span girders


Fig. 3.12 Maximum moment distribution in 2-span girders


Fig. 3.13 Maximum moment distribution in 3-span girders

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# Chapter 4 <br> Analysis of Wisconsin WIM Data 

## Introduction

Overweight loads, especially those with multi-trip permits, can be applied to bridges with uncontrolled frequency, potentially impacting and hurting the performance and safety of bridges. These vehicles were analyzed in this chapter using the Weigh-in-Motion (WIM) data. WIM records were used because the database for annual permits in Wisconsin is not inclusive: the information from only about three thousand vehicles out of more than fifteen thousand annual permits issued per year is available.

Similar to static weigh stations, WIM systems are designed to capture and record truck axle weights, axle spacings, and gross vehicle weights. ${ }^{30}$ WIM systems can record configurations of vehicles as they drive over the sensors. The recorded vehicle data are classified in terms of their configurations per Federal Highway Administration (FHWA) Traffic Monitoring Guide (TMG), ${ }^{31}$ and reported to FHWA in W-cards and E-cards. ${ }^{32-33} \mathrm{~W}$-cards are in metric units while the E-cards are in the same format but in English units. A sample W-card record is interpreted below:

W55250529310602010005 009502032040064
55: Federal Information Processing Standard (FIPS) state code - state of Wisconsin. 250529: Station identification number (see Fig. 4.1 for the stations in Wisconsin).
3: Direction of travel
1: Lane of travel
06020100: Travel date and time, in yy-mm-dd-hr
05: Vehicle class (see the analysis section for details)
0095: Total weight of vehicle to the nearest tenth of a metric ton (100 kilograms) without a decimal point.
02: Total number of axles
032: The axle weight from the front to the nearest tenth of a metric ton without a decimal point. 040: (A-B) The axle spacing from the front to the nearest tenth of a meter ( 100 mm ) without a decimal point.
032040: The axle weight and axle spacing pair repeated for (the number of axles - 1)
064: The axle weight of the last axle to the nearest tenth of a metric ton without a decimal point.
There are seventeen WIM stations in Wisconsin as listed in Table 4.1. ${ }^{34}$ The positions of the stations are illustrated in Fig. 4.1 using Google ${ }^{\circledR}$ map service. The FHWA Traffic Monitoring Guide recommends classifying the vehicles into 13 different categories. Another two categories were also used in Wisconsin WIM systems, including a class for system errors or unrecognized vehicles. Representative overloaded vehicles for each class were created based on statistical analysis of the WIM records for Year 2007 (note that not all stations have 12 month operation schedule). The effect of these vehicles was analyzed in this chapter and the results were used to examine the Wisconsin standard permit vehicle(s).

Table 4.1 WIM stations in Wisconsin


Fig. 4.1 Locations of Wisconsin WIM stations using Google ${ }^{\circledR}$ Map

## Overview of Wisconsin Weigh-in-Motion (WIM) data

## Data Quality check

AASHTO Guidelines for Traffic Data Programs recommends that WIM data can be subjected to three different data-quality checks: ${ }^{35} 1$ ) comparing the daily volume of cars (Class 2) to that of 2axle, 4-tire single units (Class 3); 2) comparing the combined daily volume of cars (Class 2), 2axle, 4-tire single units (Class 3) and 5-axle single trailers (Class 9) to historical volumes; and 3) checking whether the weight distribution of 5-axle single trailers (Class 9) is a bimodal (i.e., two peaks are expected in the weight distribution). WIM data collected in this study excluded the Class 2 and Class 3 units; hence the WIM records were subjected to the last data-quality check. The weight distribution of Class 9 vehicles is shown in Fig. 4.2. Three peaks were observed: the first peak around 40,000 pounds for unloaded vehicles, the second around 70,000 pounds for loaded vehicles, and the third peak around 130,000 pounds for overweight vehicles. The above observation indicates that the WIM records in Wisconsin are reliable.


Fig. 4.2 Weight distribution of Class 9 semi-trailers
A Matlab ${ }^{\circledR}$ program (WIMan) was coded to process the WIM records. WIMan conducts three additional internal consistency checks: 1) compares the gross vehicle weight to the summation of individual axle weights. The gross weight was replaced by the summation of individual axle weights if they were different; (2) compares the total length (close to the vehicle length) to the summation of individual axle-spacings. The vehicle length was replaced by the summation of individual axle weights if it were smaller; (3) filters out records with errors. For example, some records contain the character '-' that disturbed the partition of W-cards.

Over six million truck records (including buses) are available for year 2007 from all seventeen stations in Wisconsin. Note that not all stations collect data for the entire 12 month. An overview of all the 6 million recorded vehicles is shown in Fig. 4.3, including the distribution of gross weight, vehicle classification and the total axle numbers. Note that the zero-kip minimum weight
was caused by rounding off some erroneous recorded values. The distribution of vehicle classes and total axles numbers of the vehicles indicate that over sixty percent of the vehicles have five axles, indicating large number of Class 9 semi-trailers on the road. In addition, $32 \%$ of the vehicles have two or three axles, indicating Class 4 (likely busses), Class 5 and Class 6 (likely utility trucks and small delivery trucks). In addition, four-axle concrete trucks and other 4-axle trucks take up another 5\% of the total vehicles. Class 10 vehicles' share is about $1.3 \%$ while vehicles in Classes 10 through 15 contribute around $5 \%$ of total records. In addition, over 50 percent of the total vehicles have gross weight less than 50kips, which may be small trucks and empty trucks.



Fig. 4.3 Overview of vehicles recorded in WIM data
The light vehicles will unlikely have an impact on highway bridges, thus can excluded from the study. WIMan divides the vehicles into three categories according to the criteria shown in Table 4.2. The criteria were established per Wisconsin Statute Chapter $348^{3}$ and WisDOT Bridge Manual. ${ }^{6}$

Table 4.2 Overweight criteria per Wisconsin Statute 0348

| Axle configurations | Legal weight | Vehicles likely with <br> annual permit | Vehicles likely with <br> single-trip permit |
| :--- | :--- | :--- | :--- |
| Leading axle | $\leq 13 \mathrm{kips}$ | $\leq 20 \mathrm{kips}$ | $>20 \mathrm{kips}$ |
| Single axle | $\leq 20 \mathrm{kips}$ | $\leq 30 \mathrm{kips}$ | $>30 \mathrm{kips}$ |
| 2-axle tandem | $\leq 40 \mathrm{kips}$ | $\leq 55 \mathrm{kips}$ | $>55 \mathrm{kips}$ |
| 3-axle tandem | $\leq 60 \mathrm{kips}$ | $\leq 70 \mathrm{kips}$ | $>70 \mathrm{kips}$ |
| 4-axle tandem | $\leq 73 \mathrm{kips}$ | $\leq 80 \mathrm{kips}$ | $>80 \mathrm{kips}$ |
| 5+-axle tandem | The gross weight of vehicles with permits likely exceeds the limits |  |  |
| Gross Weight | $\leq 80 \mathrm{kips}$ | $\leq 170 \mathrm{kips}$ | $>170 \mathrm{kips}$ |

Note that the tandem axles are defined as groups of axles with spacing smaller than 6 ft .
The distribution of the WIM records per vehicle type is shown in Fig. 4.4. The vehicles likely having permits are about $22 \%$ of the total truck records, which is slightly higher than the reported ratio - the number of the records caused by vehicles potentially with permits should be below $20 \% .^{35}$ The difference was believed reasonable because trucks could be loaded unevenly such that these vehicles may have one or multiple overloaded axles, thus being classified to those with permits.
Note that one truck may pass multiple WIM stations during its travel, creating multiple records in WIM data. Among the overweight records, around 1 million records are likely from the vehicles with multi-trip permits. Considering the fifteen thousand annual permits WisDOT issues every year, the classification indicates that each vehicle with annual permits may travel (pass) 65 station-times per year. Meanwhile, Fig. 4.4 also indicates that each vehicle with single-trip
permits may pass 25 stations per trip considering the forty five thousand permits issued per year. This seemed unreasonable because the longest route from Minnesota border to Illinois border only contains seven WIM stations. This error was caused by the strict application of the criteria shown in Table 4.2. For example, a 100-kip truck (likely with an annual permit) might have a $35-$ kip axle weight record due to an uneven load, in which case the truck would be classified as a record for single-trip permits. Such variation in both axle weights and gross vehicle weights may also have been caused by inaccurate recording. It is not uncommon to have recoding variations from $10 \%$ to $15 \% .^{30,} 35-36$ In addition, Wisconsin Statute Chapter 348 allows $10 \sim 15 \%$ increase in gross vehicle weights for seasonal loads. ${ }^{3}$ Hence, a sensitivity analysis was conducted, in which the upper limits for vehicles likely with annual permits were increase by $32 \%$ while the lower limits remained the same. This analysis resulted in $1,216,626$ records for annual permits and 123,581 records for single-trip permits, which seemed to be the lowest (i.e., 2.7 WIM stations on average per trip).


Fig. 4.4 Distribution of overweight type of vehicles in WIM data
All overweight vehicle records were included in this study due to the lack of a clear criteria for differentiating the vehicle with annual permits from vehicles with single-trip permits. The records for vehicles likely with single-trip permits were included because these vehicles are not necessarily heavier than the vehicles with annual permits as shown in Chapter 5. On the other hand, this also inevitably brought in superheavy vehicle records (i.e., vehicles with gross weight larger than 250 kips ) to the data sets that were subjected to the statistical analyses shown below. The inclusion of super heavy vehicles was deemed insignificant for the statistical analysis due to the small percentage of such records as shown in Fig. 4.5. This hypothesis was partly proved in Appendix 3.

The majority of the total 1.4 million overweight records indicate that the total vehicle weight is below 170kips, the maximum gross weight of vehicles that is listed in the annual permit fee table. Specifically 1782 vehicles have gross weights that are larger than 170 kips, and only thirty three vehicles have gross vehicle weight larger than 250 kips. In addition, over $99 \%$ of the
records show that the overall vehicle length is less than 75 ft , the upper limit for vehicles that can apply for annual permits. This indicates that the probability-based analysis adopted in this study is appropriate. The effect of small quantity of superheavy vehicles is illustrated in Appendix 3.


Fig. 4.5 Distribution of overweight vehicles recorded in WIM data

## Analysis of Overloaded WIM Records

The fundamentals of the statistical analysis used in this chapter are briefly summarized in Appendix 3. Vehicle records in each class were divided into groups based upon the total number
of axles, and analyzed separately. The vehicles in each group are called data population. A statistical modeling of the vehicle population is described in Appendix 4 while a descriptive statistical analysis was used in this chapter. The characteristic values (e.g., the maximum, the minimum, the mean values, and the standard deviation) are calculated for each vehicle group. A representative vehicle was created to represent the approximate upper bound of the responses in simply-supported girders caused by the vehicles in the group. The representative vehicles were then compared with the Wis-SPV. The axle weights corresponding to $95^{\text {th }}$ percentile of all axle weights in the group are used in the representative vehicles in each class. Axle spacings were analyzed individually: most axle spacings in a representative vehicle were taken as the average axle spacings; the spacings for tandem axles were taken as 4 ft rather than the average spacings; and one axle spacing was taken as a variable spacing defined by the $5^{\text {th }}$ percentile and $95^{\text {th }}$ percentile values. Only one variable axle spacing is allowed because the program for the moving load analysis, SAP2000, can only take one variable axle spacing per vehicle.
The analysis of each vehicle is shown below. All pictures are modified from the pictures in http://onlinemanuals.txdot.gov/txdotmanuals/tda/fhwavehicleclassificationfigures.htm

## Class 4 Vehicles

Class 4 vehicles are for traditional passenger carrying buses with two axles or three axles.


Two-axle buses: The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.6. The axles weights are in lbs and the axle spacings in ft .

| 21064 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 13448 | 99208 | 34588.28 | 8358.67 | 22046.23 | 50265.40 |
| Axle weight 1 | 441 | 43872 | 15615.52 | 4216.87 | 9700.34 | 23589.47 |
| Axle spacing 1 | 20 | 40 | 22.85 | 2.72 | 20.34 | 27.56 |
| Axle weight 2 | 220 | 64155 | 18972.95 | 6905.49 | 3968.32 | 29762.41 |



Fig. 4.6 Representative vehicle for Class 4 vehicles (2-axle)
Three-axle buses: The statistical characteristics are shown below, and a representative vehicle was created as shown in Fig. 4.7. Note that the last two axles likely form a tandem axle because the axle spacing 2 ranges from 2 ft to 6 ft with an average of 4 ft .

| 20351 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 13669 | 113979 | 49878.51 | 12861.58 | 34392.12 | 76941.34 |
| Axle weight 1 | 441 | 39904 | 17053.33 | 4642.62 | 12786.81 | 26675.94 |
| Axle spacing 1 | 20 | 40 | 25.56 | 3.41 | 20.34 | 33.46 |
| Axle weight 2 | 220 | 39904 | 18132.89 | 5760.93 | 9700.34 | 29321.49 |
| Axle spacing 2 | 2 | 6 | 4.05 | .30 | 3.61 | 4.59 |
| Axle weight 3 | 220 | 43431 | 14691.73 | 5399.50 | 6613.87 | 24691.78 |



Fig. 4.5 Representative vehicle for Class 4 vehicles (3-axle)

## Class 5 Vehicles

Class 5 vehicles are for two-axle, six-tire, single-unit trucks, including camping and recreational vehicles, and motor homes.


The statistical characteristics are shown below, and a representative vehicle was created as shown in Fig. 4.8. For the variable axle spacing, a smaller integer than the $5^{\text {th }}$ percentile value was used as the lower bound while a larger integer than the $95^{\text {th }}$ percentile value was used for the upper bound.

| $20069$ <br> vehicles | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 13228 | 78485 | 33339.49 | 7719.48 | 21164.38 | 47399.39 |
| Axle weight 1 | 220 | 40786 | 14441.25 | 4106.92 | 8157.11 | 21605.31 |
| Axle spacing 1 | 7 | 23 | 16.58 | 2.18 | 13.12 | 19.69 |
| Axle weight 2 | 220 | 49604 | 18898.82 | 6761.30 | 4629.71 | 29101.02 |
| Class 5-2 axle GVW=52 k |  |  |  |  |  |  |

Fig. 4.8 Representative vehicle for Class 5 vehicles

## Class 6 Vehicles

Class 6 vehicles are for three-axle single-unit trucks, including camping and recreational vehicles, motor homes, etc.


The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.9. The spacing 1 in this class are affected by the wheelbase of the trucks, hence a variable spacing is used for axle spacing 1 . The axle spacing 2 is dominated by length around 4.5 ft , hence tandem axle spacing was used for axle spacing 2 though the recorded values varies from 2 ft to 81 ft .

| 78523 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 14110 | 119931 | 42419.32 | 12201.99 | 26896.40 | 64815.92 |
| Axle weight 1 | 220 | 41888 | 15613.52 | 3812.44 | 10582.19 | 23148.54 |
| Axle spacing 1 | 4 | 41 | 17.33 | 2.70 | 12.47 | 21.65 |
| Axle weight 2 | 220 | 46518 | 12729.35 | 5328.61 | 5952.48 | 22707.62 |
| Axle spacing 2 | 2 | 81 | 4.38 | 1.82 | 3.94 | 4.59 |
| Axle weight 3 | 220 | 51809 | 14075.93 | 6923.83 | 5291.10 | 27116.86 |



Fig. 4.9 Representative vehicle for Class 6 vehicles

## Class 7 Vehicles

Class 7 vehicles are for all trucks on a single frame with four or more axles.


Four-axle trucks: The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.10. The vehicle configuration was determined based upon the sample vehicle show above, where the rear three axles form a tandem axle. Hence the first spacing was set as the variable spacing while the other two axles were set as 4 ft . Note that the gross weight of the representative vehicle is 99 kips , which is larger than the $95^{\text {th }}$ percentile of the gross weight ( 85 kips ) and smaller than the maximum gross weight ( 187 kips ).

| 15988 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 20944 | 187172 | 60172.07 | 13355.22 | 41226.45 | 84657.52 |
| Axle weight 1 | 220 | 40345 | 17045.27 | 4078.27 | 11904.96 | 24691.78 |
| Axle spacing 1 | 6 | 23 | 14.01 | 3.84 | 8.20 | 20.01 |
| Axle weight 2 | 0 | 65698 | 10917.38 | 4881.32 | 4409.25 | 19621.14 |
| Axle spacing 2 | 2 | 9 | 4.88 | 1.12 | 3.94 | 7.22 |
| Axle weight 3 | 220 | 55336 | 16410.82 | 5480.89 | 8157.11 | 26235.01 |
| Axle spacing 3 | 2 | 12 | 4.50 | .75 | 3.94 | 5.91 |
| Axle weight 4 | 220 | 59304 | 15797.90 | 6755.95 | 5070.63 | 27557.79 |



Fig. 4.10 Representative vehicle for Class 7 vehicles (4-axle)

Five-axle trucks: Similarly the statistical characteristics for the five-axle trucks are shown below, based on which a representative vehicle was created as shown in Fig. 4.11. The last three axle spacings are dominantly around 4 ft , hence they were set as tandem axle spacing. Note that the middle two axles might be the lift axle, which are put in action when the truck is heavily loaded.

| 36234 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 20503 | 171961 | 71689.29 | 13614.29 | 55115.58 | 96782.95 |
| Axle weight 1 | 220 | 45856 | 16860.91 | 3388.76 | 13007.28 | 22928.08 |
| Axle spacing 1 | 3 | 23 | 9.87 | 1.88 | 7.87 | 13.78 |
| Axle weight 2 | 220 | 39683 | 8126.03 | 2858.46 | 4188.78 | 13227.74 |
| Axle spacing 2 | 2 | 9 | 4.16 | .46 | 3.61 | 5.25 |
| Axle weight 3 | 220 | 44533 | 11540.57 | 5890.71 | 4850.17 | 22707.62 |
| Axle spacing 3 | 2 | 9 | 4.15 | .25 | 3.94 | 4.59 |
| Axle weight 4 | 220 | 44092 | 18014.21 | 4511.80 | 12345.89 | 26675.94 |
| Axle spacing 4 | 2 | 9 | 4.35 | .38 | 3.94 | 4.92 |
| Axle weight 5 | 220 | 44974 | 17147.96 | 5863.93 | 7275.26 | 27337.33 |
|  |  |  |  |  |  |  |

Fig. 4.11 Representative vehicle for Class 7 vehicles (5-axle)

## Class 8 Vehicles

Class 8 vehicles are for four or fewer axle single-trailer trucks -- All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.



Three-axle trucks: These trucks are likely AASHTO type 2 S1. Their statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.12. An average spacing of all vehicles was used for the steering spacing while a variable spacing is used for the second axle spacing to accommodate trailers in different sizes.

| 5789 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 14991 | 145285 | 47056.99 | 12938.70 | 29431.72 | 72862.79 |
| Axle weight 1 | 220 | 39683 | 14340.07 | 4793.76 | 6613.87 | 22266.69 |
| Axle spacing 1 | 6 | 23 | 12.97 | 2.23 | 9.19 | 16.40 |
| Axle weight 2 | 220 | 72312 | 18542.33 | 6059.67 | 9369.65 | 28660.10 |
| Axle spacing 2 | 11 | 40 | 25.04 | 6.57 | 15.91 | 37.40 |
| Axle weight 3 | 220 | 72312 | 14173.91 | 7483.40 | 2425.09 | 26455.48 |



Fig. 4.12 Representative vehicle for Class 8 vehicles (Type 2S1)
Four-axle trucks (a): These trucks are AASHTO type 3S1. The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.13. Again, an average spacing for the axle spacing of the truck power unit was used.

| 18469 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 14771 | 153001 | 64889.60 | 17772.36 | 36376.28 | 93255.55 |
| Axle weight 1 | 220 | 39242 | 15352.84 | 4166.36 | 9479.88 | 22707.62 |
| Axle spacing 1 | 4 | 38 | 16.21 | 2.31 | 11.81 | 19.36 |
| Axle weight 2 | 220 | 39904 | 15635.57 | 5473.72 | 6834.33 | 24250.85 |
| Axle spacing 2 | 1 | 6 | 4.27 | .32 | 3.94 | 4.92 |
| Axle weight 3 | 220 | 72312 | 17763.37 | 6586.90 | 7275.26 | 29541.95 |
| Axle spacing 3 | 3 | 52 | 30.28 | 7.03 | 10.66 | 38.06 |
| Axle weight 4 | 220 | 40786 | 16137.15 | 6963.89 | 4188.78 | 26896.40 |



Class 8-4 axle a
GVW=104 k

Fig. 4.13 Representative vehicle for Class 8 vehicles (Type 3S1)
Four-axle trucks (b): These trucks are AASHTO type 2S2. The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.14.

| 9813 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 16535 | 150576 | 61545.31 | 17194.59 | 39683.21 | 97730.94 |
| Axle weight 1 | 220 | 38581 | 14106.31 | 4614.69 | 7275.26 | 21825.77 |
| Axle spacing 1 | 3 | 38 | 13.44 | 2.26 | 11.48 | 16.73 |
| Axle weight 2 | 220 | 42990 | 20002.38 | 5948.90 | 9920.80 | 29762.41 |
| Axle spacing 2 | 4 | 59 | 31.98 | 6.16 | 18.70 | 38.71 |
| Axle weight 3 | 220 | 39683 | 12937.70 | 5754.70 | 5511.56 | 24912.24 |
| Axle spacing 3 | 2 | 6 | 3.98 | .40 | 3.61 | 4.59 |
| Axle weight 4 | 220 | 61509 | 14498.61 | 6866.19 | 5511.56 | 27778.25 |

Fig. 4.14 Representative vehicle for Class 8 vehicles (Type 2S2)

## Class 9 Vehicles

Class 9 vehicles are for five-axle single-trailer trucks -- All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.


Due to the importance of this class ( 76 percent of the vehicles are in this class), the $2.5^{\text {th }}$ and $97.5^{\text {th }}$ percentile values were used to construct the representative vehicles. This is also justified by the distribution of gross vehicle weight: a small hump exists after 120kips, indicating considerably large number of vehicles. In addition, an average spacing for the axle spacing of the truck power unit was used. The distribution of axle spacing 4 shows two spikes: one near 4 ft and the other at 10ft, indicating two distinguished vehicle types as show above Type 3S2 and Type 3S2 split. They were considered individually

Five-axle trucks (a): The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.15.

| 889230 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $2.5^{\text {th }}$ <br> percentile | $97.5^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 17637 | 242509 | 84500.69 | 24627.43 | 44092.46 | 144843.73 |
| Axle weight 1 | 220 | 47399 | 15663.98 | 4350.63 | 9038.95 | 25794.09 |
| Axle spacing 1 | 2 | 31 | 16.28 | 2.16 | 11.15 | 20.01 |
| Axle weight 2 | 220 | 46297 | 17063.44 | 5664.01 | 7716.18 | 30644.26 |
| Axle spacing 2 | 2 | 46 | 4.19 | .67 | 3.94 | 4.59 |
| Axle weight 3 | 220 | 70548 | 1828.68 | 6093.33 | 7936.64 | 32187.50 |
| Axle spacing 3 | 2 | 93 | 32.76 | 3.61 | 27.23 | 37.07 |
| Axle weight 4 | 0 | 57100 | 16120.09 | 6089.37 | 5732.02 | 29982.87 |
| Axle spacing 4 | 2 | 6 | 3.97 | .21 | 3.61 | 4.59 |
| Axle weight 5 | 0 | 70768 | 17372.47 | 6595.37 | 5952.48 | 31526.11 |

Fig. 4.15 Representative vehicle for Class 9 vehicles (Type 3S2)
Five-axle trucks (b): The statistical characteristics are shown below, based on which a representative vehicle is created as shown in Fig. 4.16. Note that the gross weight of this vehicle is similar to the Type 3 S 2 representative vehicle. Not that the split axle spacing was set to be 10 ft , close to the average spacing.

| 133972 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $2.5^{\text {th }}$ <br> percentile | $97.5^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 20062 | 217596 | 85501.24 | 25551.90 | 41667.37 | 145284.66 |
| Axle weight 1 | 220 | 39904 | 15413.54 | 4240.16 | 9038.95 | 25353.16 |
| Axle spacing 1 | 3 | 44 | 17.94 | 2.09 | 13.12 | 21.33 |


| Axle weight 2 | 220 | 39904 | 17160.95 | 5503.02 | 7936.64 | 29982.87 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Axle spacing 2 | 2 | 45 | 4.24 | .87 | 3.94 | 4.59 |
| Axle weight 3 | 220 | 69005 | 18186.18 | 5824.22 | 7936.64 | 31085.18 |
| Axle spacing 3 | 2 | 82 | 28.79 | 4.51 | 12.47 | 34.12 |
| Axle weight 4 | 0 | 72312 | 17305.22 | 6902.23 | 4629.71 | 31746.57 |
| Axle spacing 4 | 6 | 59 | 10.23 | 1.63 | 8.86 | 15.09 |
| Axle weight 5 | 220 | 72312 | 17435.00 | 7061.48 | 4629.71 | 32187.5 |



Class 9-5 axle b
$G V W=150 \mathrm{k}$

Fig. 4.14 Representative vehicle for Class 9 vehicles (Type 3S2 split)

## Class 10 Vehicles

Class 10 vehicles are for six or more axle single-trailer trucks -- All vehicles with six or
 more axles consisting of two units, one of which is a tractor or straight truck power unit..

$\underline{\text { Six-axle trucks: The statistical characteristics are shown below, based on which a representative }}$ vehicle is created as shown in Fig. 4.17. The last three axles likely form a tandem axle; hence the last two spacings were set to be 4 ft though the average values were different. The third spacing, which dictates the size of the trailer, varies from 4 ft to 37 ft , indicating that some single-unit trucks were included in this class. The heavy axle weight combined with the short spacing would likely cause large positive moment in simply supported girders.

| 27574 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 18078 | 267200 | 91073.17 | 23019.53 | 54895.11 | 136025.24 |
| Axle weight 1 | 220 | 39463 | 13182.49 | 4188.96 | 7936.64 | 21605.31 |
| Axle spacing 1 | 0 | 93 | 15.77 | 2.94 | 11.48 | 20.01 |
| Axle weight 2 | 220 | 57100 | 16232.44 | 4895.11 | 9038.95 | 25353.16 |
| Axle spacing 2 | 0 | 89 | 4.76 | 2.86 | 3.94 | 6.23 |
| Axle weight 3 | 220 | 72312 | 17697.65 | 5775.52 | 9700.34 | 29101.02 |
| Axle spacing 3 | 0 | 45 | 24.77 | 9.50 | 4.59 | 37.07 |
| Axle weight 4 | 0 | 65257 | 12609.14 | 5481.83 | 4629.71 | 22266.69 |
| Axle spacing 4 | 0 | 99 | 5.71 | 4.74 | 3.94 | 13.45 |
| Axle weight 5 | 220 | 57982 | 15920.13 | 6282.96 | 5732.02 | 27116.86 |
| Axle spacing 5 | 0 | 89 | 5.23 | 4.07 | 3.94 | 9.19 |
| Axle weight 6 | 220 | 72312 | 15429.95 | 6862.19 | 3747.86 | 27557.79 |



Fig. 4.17 Representative vehicle for Class 10 vehicles (Type 3S3)
Seven-axle trucks: The statistical characteristics for these trucks are shown below, based on which a representative vehicle was created as shown in Fig. 4.18. Similar to Type 3S3 vehicles, the third axle spacing varies from 4 ft to 38 ft . Hence, the short trucks would cause large positive moments in the simply-supported girder as shown later. Meanwhile, the total number of these vehicles is small, indicating a potentially insignificant impact to bridges.

| $2552$ <br> vehicles | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\mathrm{th}} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 17857 | 235674 | 95229.00 | 30635.63 | 55556.50 | 157928.17 |
| Axle weight 1 | 220 | 35054 | 13933.96 | 4074.49 | 8818.49 | 21384.84 |
| Axle spacing 1 | 6 | 22 | 15.77 | 2.49 | 10.17 | 19.36 |
| Axle weight 2 | 220 | 39904 | 15928.83 | 5435.96 | 8377.57 | 26235.01 |
| Axle spacing 2 | 3 | 6 | 4.27 | . 23 | 3.94 | 4.59 |
| Axle weight 3 | 441 | 39463 | 17124.27 | 6005.44 | 9259.42 | 29178.19 |
| Axle spacing 3 | 3 | 40 | 28.24 | 9.68 | 3.94 | 37.40 |
| Axle weight 4 | 220 | 35494 | 11183.80 | 5921.75 | 3968.32 | 22928.08 |
| Axle spacing 4 | 3 | 13 | 5.02 | 1.59 | 3.61 | 8.86 |
| Axle weight 5 | 220 | 39242 | 12413.44 | 6562.46 | 4409.25 | 24691.78 |
| Axle spacing 5 | 3 | 12 | 4.23 | . 66 | 3.94 | 4.92 |
| Axle weight 6 | 220 | 39904 | 12640.56 | 6457.33 | 4629.71 | 25132.70 |
| Axle spacing 6 | 3 | 11 | 4.62 | 1.24 | 3.94 | 8.86 |
| Axle weight 7 | 220 | 39022 | 12003.01 | 6183.32 | 4409.25 | 24250.85 |
| Class 10-7 axl GVW=173 k |  |  |  |  |  |  |

Fig. 4.18 Representative vehicle for Class 10 vehicles (Type 3S4)

## Class 11 Vehicles

Class 11 vehicles are for five or fewer axle multi-trailer trucks -- All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.


The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.19. The trailers might have similar dimensions; hence, the representative vehicle does not have any variable spacing. The spacing between the trailers was set to the average value - 9 ft . The wheelbases of the trailers are close (around 21 ft ).

| $\begin{aligned} & \hline 28618 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 18739 | 181000 | 90554.27 | 23032.07 | 59304.36 | 132718.30 |
| Axle weight 1 | 882 | 38140 | 16205.44 | 3948.83 | 10582.19 | 22928.08 |
| Axle spacing 1 | 6 | 17 | 12.38 | . 45 | 11.81 | 13.12 |
| Axle weight 2 | 441 | 39904 | 22814.27 | 5756.00 | 14550.51 | 33510.27 |
| Axle spacing 2 | 11 | 25 | 20.98 | . 54 | 20.34 | 21.98 |
| Axle weight 3 | 882 | 39683 | 18786.93 | 5812.25 | 10141.27 | 29101.02 |
| Axle spacing 3 | 6 | 19 | 9.30 | . 39 | 8.86 | 9.84 |
| Axle weight 4 | 220 | 39242 | 17325.68 | 5852.00 | 8598.03 | 27998.71 |
| Axle spacing 4 | 11 | 25 | 21.87 | . 51 | 21.33 | 22.64 |
| Axle weight 5 | 220 | 38140 | 15422.11 | 5227.66 | 7716.18 | 24912.24 |
| Class 11-5 axleGVW=139 k |  |  |  |  |  |  |

Fig. 4.19 Representative vehicle for Class 11 vehicles

## Class 12 Vehicles

Class 12 vehicles are for six-axle multi-trailer Trucks -- All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.


These vehicles are the combination of a semi-trailer and a trailer. Hence the configurations of the semi-trailers should be similar to those of Class 8 vehicles. The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.20. The second axle spacing ranges from 3 ft to 6 ft for all eleven thousand Class 12 vehicles, indicating that the number of type 2S2-2 vehicles seem rare in the WIM records. Hence the representative vehicle was created only for Type 3S1-2 vehicles. In addition, the dimension and weight of the trailers were same as those trailers in Class 11.

| 11011 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 34392 | 205250 | 96193.94 | 25863.89 | 61068.06 | 144182.34 |
| Axle weight 1 | 1323 | 36597 | 16525.42 | 4204.99 | 10361.73 | 24250.85 |
| Axle spacing 1 | 10 | 22 | 15.59 | 2.48 | 10.83 | 19.03 |
| Axle weight 2 | 220 | 37258 | 14270.70 | 4310.195 | 8157.11 | 22266.69 |
| Axle spacing 2 | 3 | 6 | 4.14 | .235 | 3.94 | 4.27 |
| Axle weight 3 | 220 | 39022 | 14678.29 | 4299.667 | 8377.57 | 22266.69 |
| Axle spacing 3 | 3 | 25 | 19.24 | 3.746 | 4.59 | 21.33 |


| Axle weight 4 | 1984 | 39022 | 17772.89 | 5728.475 | 9479.88 | 27998.71 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Axle spacing 4 | 6 | 18 | 9.22 | 1.198 | 8.20 | 11.15 |
| Axle weight 5 | 1102 | 39242 | 17049.24 | 5698.778 | 8598.03 | 27557.79 |
| Axle spacing 5 | 11 | 25 | 21.75 | 1.645 | 18.04 | 22.97 |
| Axle weight 6 | 2425 | 39683 | 15897.63 | 5427.705 | 7936.64 | 26014.55 |



Fig. 4.20 Representative vehicle for Class 12 vehicles

## Class 13 Vehicles

Class 13 vehicles are for seven or more axle multi-trailer trucks -- All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.


Class 13 includes both combination of trailers and nondivisible trucks potentially with permits. As a result, the distributions of the axle spacings were significantly scattered. In addition, 4579 out of 5105 Class 13 vehicles in the category are seven axle vehicles. Hence, the representative vehicles created below represents the 7-axle nondivisable trucks rather than Type 3S2-2 vehicles.

Seven-axle trucks (a): The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.21. The vehicle shown in Fig. 4.21 is the representative of total 1116 trucks. The distribution of axle spacing 1 shows two peaks, indicating two distinctive vehicle types. However, considering the small total number of this category, an average spacing is used for the first axle spacing.

| 1116 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 22708 | 219580 | 89124.65 | 23196.26 | 52183.43 | 129984.57 |
| Axle weight 1 | 220 | 36376 | 12581.96 | 4268.67 | 7054.79 | 20315.60 |
| Axle spacing 1 | 3 | 27 | 13.26 | 5.58 | 5.91 | 21.98 |
| Axle weight 2 | 220 | 34613 | 12406.73 | 5930.91 | 3527.40 | 22928.08 |
| Axle spacing 2 | 0 | 105 | 7.69 | 9.09 | 3.94 | 15.14 |
| Axle weight 3 | 220 | 39683 | 14905.50 | 5859.51 | 5511.56 | 25132.70 |
| Axle spacing 3 | 3 | 45 | 16.50 | 14.51 | 3.94 | 41.99 |
| Axle weight 4 | 220 | 30865 | 13123.63 | 5519.14 | 3527.40 | 21384.84 |
| Axle spacing 4 | 3 | 6 | 4.42 | .58 | 3.61 | 5.91 |
| Axle weight 5 | 220 | 48722 | 10162.40 | 7325.10 | 1543.24 | 22046.23 |
| Axle spacing 5 | 3 | 106 | 21.56 | 15.19 | 3.94 | 41.99 |
| Axle weight 6 | 220 | 39683 | 13369.18 | 6901.66 | 1763.70 | 22928.08 |
| Axle spacing 6 | 2 | 45 | 6.54 | 4.64 | 3.61 | 14.76 |
| Axle weight 7 | 220 | 46077 | 12554.50 | 7375.30 | 1322.77 | 23589.47 |



Class 13-7 axle a
GVW=158 k

Fig. 4.21 Representative vehicle for Class 13 vehicles
Seven-axle trucks (b): The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.22. The vehicle represents 3463 trucks. Note that the forth spacing ranges from 7 ft to 39 ft , and the short truck would likely cause large positive moments in simply-supported girders.

| $3463$ <br> vehicles | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 23589 | 248241 | 102497.72 | 25361.47 | 80027.81 | 154852.72 |
| Axle weight 1 | 661 | 34613 | 11554.69 | 3433.36 | 7319.35 | 18077.91 |
| Axle spacing 1 | 2 | 42 | 13.85 | 4.01 | 6.56 | 19.69 |
| Axle weight 2 | 220 | 37699 | 12697.11 | 4793.58 | 5952.48 | 20502.99 |
| Axle spacing 2 | 3 | 38 | 5.46 | 2.55 | 3.94 | 11.48 |
| Axle weight 3 | 220 | 72312 | 17226.11 | 5045.03 | 11464.04 | 26896.40 |
| Axle spacing 3 | 3 | 37 | 5.54 | 4.04 | 3.94 | 11.15 |
| Axle weight 4 | 220 | 52470 | 15796.76 | 6395.99 | 5952.48 | 27293.23 |
| Axle spacing 4 | 6 | 64 | 27.43 | 9.83 | 7.55 | 38.39 |
| Axle weight 5 | 220 | 36817 | 15335.66 | 5654.44 | 3086.47 | 23986.30 |
| Axle spacing 5 | 2 | 94 | 6.85 | 6.78 | 3.94 | 24.28 |
| Axle weight 6 | 220 | 39904 | 16395.38 | 5993.86 | 3747.86 | 25794.09 |
| Axle spacing 6 | 3 | 86 | 4.96 | 2.91 | 3.94 | 8.86 |
| Axle weight 7 | 220 | 42108 | 13477.61 | 7615.91 | 1984.16 | 24912.24 |
| Class 13-7 axle GVW=168 k |  |  |  |  |  |  |

Fig. 4.22 Representative vehicle for Class 13 vehicles

## Class 14 Vehicles

Class 14 vehicles are for five-axle truck-trailer combinations-- vehicles with five axles consisting of two units, one of which is a truck and the other is a trailer.


The statistical characteristics are shown below, based on which a representative vehicle was created as shown in Fig. 4.23. The total number of Class 14 vehicles is small compared with other classes; hence the statistical analysis should be treated with caution. With all four scattered spacing distributions, the axle spacing three was chosen to be the variable spacing only to separate the two relatively large load groups.

| $115$ <br> vehicles | Minimum | Maximum | Mean | Standard deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 37699 | 101192 | 64233.13 | 16762.16 | 39903.68 | 88273.10 |
| Axle weight 1 | 10141 | 21605 | 14932.01 | 2284.46 | 11419.95 | 19753.42 |
| Axle spacing 1 | 8 | 26 | 19.80 | 2.07 | 16.93 | 22.05 |
| Axle weight 2 | 5291 | 24692 | 14167.10 | 4685.64 | 7936.64 | 22222.60 |
| Axle spacing 2 | 4 | 6 | 4.52 | . 28 | 4.27 | 4.92 |
| Axle weight 3 | 6173 | 25574 | 13793.27 | 4799.73 | 6613.87 | 21561.21 |
| Axle spacing 3 | 7 | 20 | 14.47 | 2.58 | 9.38 | 19.03 |
| Axle weight 4 | 1323 | 23810 | 10622.45 | 4568.02 | 2866.01 | 17901.54 |
| Axle spacing 4 | 12 | 27 | 16.70 | 3.03 | 12.47 | 22.11 |
| Axle weight 5 | 2425 | 22928 | 10689.55 | 4921.15 | 3703.77 | 19488.87 |
|  |  | $\left.20^{\prime}\right\|_{4^{\prime}} ^{22}$ | $\left.9^{\prime}\right\|_{1} ^{18} 17^{\prime}$ | Class 14-5 axle GVW=101 k |  |  |

Fig. 4.23 Representative vehicle for Class 14 vehicles

## Comparison of Representative Overloaded Vehicles with Wis-SPV

The effects of the above representative overweight vehicles were compared with those of the 250-kip Wis-SPV. The analysis and the comparison used the same method as in Chapter 3.

## One-span simply supported girders

The maximum positive moments and shear in simply-supported girders with various plan lengths by the 18 representative vehicles are shown in Fig. 4.24, and the R-values are shown in Fig. 4.25. Again, the effects of the Wisconsin Standard Permit Vehicle are shown in solid (blue) lines. The effects of the representative vehicles for Classes 10 and 13 exceed those of Wis-SPV, for spans form 40 to 80 ft as confirmed in Table 4.3. In addition, the R-values for the representative vehicles for Classes 10 and 13 exceed 1.0, indicating that the moment envelopes exceeds that of the Wis-SPV throughout the entire span of the girders (from 40 ft to 80 ft ).
This might have been due to the fact that these three representative vehicles had a variable axle spacing. The vehicle with heavy loads could have short length when the variable spacing took the lower bound. Such short vehicles would likely cause large positive moment for short- to medium-span girders, for which several axles of Wis-SPV had to be placed outside the girder to obtain the maximum girder responses.


Fig. 4.24 Peak moment/shear values for overweight vehicles on one-span girders


Fig. 4.25 R-values for overweight vehicles on one-span girders

Table 4.3(a) Peak positive moments in two-span girders by overweight vehicles (kips-ft)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class4 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{gathered} \text { Class7 } \\ \text { 5axle } \end{gathered}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle a } \end{aligned}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle b } \end{aligned}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle a } \end{gathered}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \end{gathered}$ | $\begin{gathered} \text { Class10 } \\ \text { 6axle } \end{gathered}$ | $\left\|\begin{array}{c} \text { Class10 } \\ 7 \text { axle } \end{array}\right\|$ | $\begin{array}{\|c} \text { Class11 } \\ \text { 5axle } \end{array}$ | $\begin{array}{\|c} \text { Class12 } \\ \text { 6axle } \end{array}$ | $\begin{array}{\|c\|c} \text { Class13 } \\ 7 \text { axle a } \end{array}$ | Class 13 <br> 7axle b | Class 14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 723. | 238.4 | 384.0 | 285.3 | 395.0 | 551.7 | 596.8 | 280.3 | 467.9 | 375.5 | 447.3 | 506.7 | 724.0 | 763.5 | 338.7 | 558.0 | 698.0 | 512.1 | 371.7 |
| 36 | 843.3 | 270.6 | 437.8 | 335.9 | 467.7 | 650.0 | 709.5 | 358.2 | 548.6 | 436.3 | 535.4 | 599.1 | 855.0 | 915.1 | 394.7 | 660.0 | 836.5 | 594.3 | 433.6 |
| 40 | 962.9 | 321.0 | 501.4 | 386.8 | 540.4 | 748.5 | 823.5 | 436.1 | 631.8 | 517.7 | 623.8 | 700.1 | 986.0 | 1066.8 | 450.9 | 762.0 | 975.0 | 687.7 | 495.5 |
| 44 | 1085.3 | 372.0 | 580.7 | 437.9 | 613.1 | 847.1 | 937.5 | 514.1 | 735.5 | 599.5 | 712.3 | 821.1 | 1117.0 | 1218.6 | 531.3 | 864.0 | 1121.2 | 781.1 | 57.5 |
| 48 | 1214.6 | 423.3 | 660.3 | 489.2 | 686.0 | 945.8 | 1051.5 | 592.0 | 839.1 | 681.4 | 800.8 | 942.8 | 1256.7 | 1370.4 | 621.2 | 986.2 | 1280.1 | 874.7 | 629.5 |
| 52 | 1344.2 | 475.0 | 740.0 | 540.5 | 758.8 | 1044.4 | 1165.5 | 670.0 | 942.7 | 763.6 | 889.5 | 1087.2 | 1409.2 | 1542.5 | 711.3 | 1112.2 | 1439.0 | 968.4 | 710.6 |
| 56 | 1473.7 | 526.9 | 819.9 | 592.0 | 831. | 1143.1 | 1279.5 | 748.0 | 1046.4 | 855.3 | 978.2 | 1238.0 | 1561.6 | 1715.4 | 801.4 | 1238.1 | 1598.0 | 1076.0 | 2.3 |
| 60 | 1603.2 | 579.0 | 899.8 | 643. | 904.6 | 1242.0 | 1393.5 | 825.9 | 1150.2 | 956.9 | 1078.9 | 1388.7 | 1714.1 | 1888.4 | 902.0 | 1364.1 | 1756.9 | 1236.9 | 903.3 |
| 64 | 1732.8 | 631.3 | 979.9 | 695.1 | 977. | 1340.8 | 1507.5 | 903.9 | 1254.1 | 1058.8 | 1227.7 | 1539.5 | 1866.5 | 2061.3 | 1012.5 | 1490.0 | 1915.8 | 1403.9 | 1004.2 |
| 68 | 1865.6 | 683.7 | 1060.0 | 746.8 | 1050.4 | 1439.7 | 1621.5 | 981.9 | 1357.9 | 1161.1 | 1376.5 | 1690.3 | 2019.1 | 2234.2 | 1123.6 | 1636.1 | 2074.8 | 1571.4 | 1105.2 |
| 72 | 2042.4 | 736.2 | 1140.2 | 798.4 | 1123.3 | 1538.5 | 1735.5 | 1059.8 | 1461.7 | 1263.7 | 1525.7 | 1841.0 | 2171.8 | 2407.2 | 1256.9 | 1788.1 | 2233.7 | 1739.0 | 1206.2 |
| 76 | 2267 | 788.8 | 1220.4 | 850.1 | 1196.1 | 1637.4 | 1849.5 | 1137.8 | 1565. | 1366.6 | 1675.2 | 1991.8 | 2324.6 | 2580.1 | 1395. | 1940.0 | 2392 | 1906.9 | 1307.1 |
| 80 | 2509.5 | 841.5 | 1300.7 | 901.8 | 1269.1 | 1736.2 | 1963.5 | 1215.8 | 1669.4 | 1469.5 | 1824.7 | 2142.5 | 2477.3 | 2753.0 | 1534.5 | 2092.0 | 2551.6 | 2075.2 | 1408 |
| 84 | 2753.1 | 894.2 | 1381.1 | 953.6 | 1342. | 1835.0 | 2077.5 | 1293.8 | 1773.2 | 1572.8 | 1974.2 | 2293.4 | 2630.1 | 2925. | 1673.2 | 2243.9 | 2710.5 | 2243.5 | 1509.0 |
| 88 | 2996.7 | 947.1 | 1461.5 | 1005.5 | 1415.0 | 1933.9 | 2191.5 | 1371.7 | 1877.1 | 1676.3 | 2124.1 | 2444. | 2782.9 | 3098.9 | 1812.0 | 2395.8 | 2869.5 | 2411.8 | 1610.0 |
| 92 | 3241.0 | 1000.0 | 1541. | 1057.3 | 1488. | 2032.8 | 2305.5 | 1449.7 | 1980.9 | 1779.8 | 2274.1 | 2595.3 | 2935.6 | 3271.8 | 1950.8 | 2547.8 | 3028.5 | 2580.3 | 1711.0 |
| 96 | 3486.1 | 1052.8 | 1622.3 | 1109.1 | 1561.0 | 2131.7 | 2419.5 | 1527.7 | 2084.9 | 1883.3 | 2424.1 | 2746.2 | 3088.4 | 3444.7 | 2089.6 | 2699.7 | 3187.5 | 2749.2 | 1812.0 |
| 100 | 3731.3 | 1105.7 | 1702. | 1160.9 | 1634.0 | 2230.7 | 2533.5 | 1605.6 | 2188.8 | 1987.2 | 2574.2 | 2897.2 | 3241.1 | 3617.7 | 2228. | 2851.7 | 3346.5 | 2918.2 | 1913.0 |
| 104 | 3976. | 1158.8 | 1783. | 1212.7 | 1706.9 | 2329.7 | 2647.5 | 1683.6 | 2292.8 | 2091.2 | 2724.2 | 3048.1 | 3393.9 | 3790.6 | 2367.1 | 3003.6 | 3505.5 | 3087.1 | 2014.0 |
| 108 | 4222. | 1211.8 | 1863. | 1264. | 1779. | 2428.6 | 2761.5 | 1761.6 | 2396.7 | 2195.2 | 2874 | 3199.0 | 3546.6 | 3963.5 | 2506.0 | 3155.5 | 3664.5 | 3256.0 | 2115.0 |
| 112 | 4469.2 | 1264.9 | 1944.0 | 1316.4 | 1852. | 2527.6 | 2875.5 | 1839.5 | 2500.7 | 2299.1 | 3024.5 | 3350.0 | 3699.4 | 4136.5 | 2644.9 | 3307.5 | 3823.5 | 3424.9 | 2216.0 |
| 116 | 4715.6 | 1318.0 | 2024.6 | 1368.3 | 1925 | 2626.5 | 2989.5 | 1917.5 | 2604.7 | 2403.1 | 3175.0 | 3500.9 | 3852.3 | 4309.4 | 2783.8 | 3459.4 | 3982.5 | 3593.8 | 2317.0 |
| 120 | 4962.0 | 1371.0 | 2105.2 | 1420.2 | 1998.8 | 2725.5 | 3103.5 | 1995.5 | 2708.6 | 2507.2 | 3325.4 | 3651.9 | 4005.3 | 4482.3 | 2922.8 | 3611.4 | 4141.5 | 3763.2 | 2418.0 |
| 124 | 5208.7 | 1424.1 | 2185.7 | 1472.1 | 2071. | 2824.5 | 3217.5 | 2073.5 | 2812.6 | 2611.6 | 3475.9 | 3802.8 | 4158.2 | 4655.3 | 3061.7 | 3763.3 | 4300.5 | 3932.5 | 2519.0 |
| 128 | 5456.2 | 1477.1 | 2266.3 | 1524.1 | 2144.7 | 2923.4 | 3331.5 | 2151.5 | 2916.5 | 2715.9 | 3626.3 | 3953.7 | 4311.2 | 4828.2 | 3200.7 | 3915.2 | 4459.5 | 4101.9 | 2620.0 |
| 132 | 5703.7 | 1530.3 | 2346.9 | 1576.0 | 2217.7 | 3022.4 | 3445.5 | 2229.5 | 3020.5 | 2820.2 | 3776.8 | 4104.7 | 4464.1 | 5001.1 | 3339.6 | 4067.2 | 4618.5 | 4271.3 | 2721.0 |
| 136 | 5951.3 | 1583.5 | 2427.4 | 1627.9 | 2290.7 | 3121.3 | 3559.5 | 2307.5 | 3124.4 | 2924.6 | 3927.3 | 4255.6 | 4617.0 | 5174.0 | 3478.6 | 4219.1 | 4777.5 | 4440.7 | 2822.0 |
| 140 | 6198.8 | 1636.7 | 2508.0 | 1679.8 | 2363.7 | 3220.3 | 3673.5 | 2385.5 | 3228.4 | 3028.9 | 4077.7 | 4406.6 | 4770.0 | 5347.0 | 3617.5 | 4371.1 | 4936.5 | 4610.1 | 2923.0 |

Table 4.3(b) Peak shear in two-span girders by overweight vehicles (kips)

| Span <br> (ft) | Wis. SPV | Class4 2axle | Class4 3axle | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | Class7 <br> 4axle | Class7 <br> 5axle | $\begin{aligned} & \text { Class8 } \\ & \text { 3axle } \end{aligned}$ | Class8 4axle a | Class8 <br> 4axle b | Class9 <br> 5axle a | Class 9 <br> 5axle b | Class 10 <br> 6axle | $\begin{array}{\|c\|c\|} \hline \text { Class10 } \\ 7 \text { axle } \end{array}$ | Class 11 <br> 5axle | $\begin{array}{\|c\|} \hline \text { Class12 } \\ \text { 6axle } \\ \hline \end{array}$ | Class13 <br> 7 axle a | Class13 <br> 7 axle b | Class14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 100.44 | 38.39 | 56.71 | 43.05 | 58.61 | 78.22 | 85.94 | 44.26 | 65.42 | 59.23 | 68.85 | 79.97 | 98.72 | 105.71 | 50.95 | 76.85 | 95.31 | 73.10 | 53.10 |
| 36 | 103.7 | 40.0 | 59.38 | 44.04 | 60. | 80.53 | 89.06 | 48.0 | 67.15 | 62.48 | 71.09 | 84.97 | 104.74 | 110.85 | 55.40 | 79.64 | 100.16 | 75.42 | 56.20 |
| 40 | 106.35 | 41.39 | 61.51 | 44.84 | 61.49 | 82.38 | 91.55 | 51.01 | 70.83 | 66.73 | 72.88 | 88.97 | 109.57 | 115.06 | 58.96 | 82.92 | 104.05 | 78.67 | 58.68 |
| 44 | 108.50 | 42.4 | 63.26 | 45.49 | 62.53 | 83.89 | 93.59 | 53.46 | 73.84 | 70.21 | 75.48 | 92.25 | 113.52 | 120.33 | 62.91 | 86.84 | 108.92 | 85.34 | 71 |
| 48 | 110.80 | 43.39 | 64.71 | 46.03 | 63.40 | 85.15 | 95.29 | 55.51 | 76.36 | 73.11 | 79.60 | 94.98 | 116.81 | 124.72 | 67.17 | 90.10 | 113.10 | 90.89 | 62.40 |
| 52 | 118.23 | 44.1 | 65.94 | 46.49 | 64.14 | 86.22 | 96.73 | 57.24 | 78.48 | 75.56 | 83.23 | 97.29 | 119.59 | 128.43 | 70.77 | 93.02 | 116.63 | 95.59 | 83 |
| 56 | 125.8 | 44.8 | 66.99 | 46.8 | 64.7 | 87.13 | 97.97 | 58.72 | 80.31 | 77.66 | 88.07 | 99.27 | 121.98 | 131.62 | 73.86 | 95.52 | 119.66 | 100.58 | 65.06 |
| 60 | 132.47 | 45.40 | 67.91 | 47.23 | 65.32 | 87.92 | 99.03 | 60.01 | 81.89 | 79.49 | 92.26 | 101.75 | 124.05 | 134.38 | 76.53 | 97.68 | 122.28 | 105.21 | 66.12 |
| 64 | 138.6 | 45.9 | 68.71 | 47.52 | 65.8 | 88.61 | 99.97 | 61.13 | 83.27 | 81.08 | 95.93 | 104.82 | 125.86 | 136.79 | 78.88 | 99.58 | 124.57 | 109.26 | 25 |
| 68 | 145.19 | 46.34 | 69.41 | 47.79 | 66.23 | 89.22 | 100.80 | 62.12 | 84.49 | 82.49 | 99.17 | 107.54 | 127.45 | 138.92 | 80.94 | 101.25 | 126.60 | 112.83 | 67.87 |
| 72 | 151 | 46.7 | 70.04 | 48.02 | 66.60 | 89.77 | 101.53 | 63.0 | 85.5 | 83.74 | 102.05 | 109.96 | 128.87 | 140.81 | 82.78 | 102.74 | 128.40 | 116.01 | 8.60 |
| 76 | 156 | 47.08 | 70.60 | 48.23 | 66.94 | 90.25 | 102.19 | 63.79 | 86.54 | 84.86 | 104.63 | 112.12 | 130.14 | 142.51 | 84.50 | 104.07 | 130.01 | 118.85 | 69.25 |
| 80 | 160.9 | 47.4 | 71.11 | 48.42 | 67.24 | 90.69 | 102.78 | 64.50 | 87.41 | 85.86 | 106.95 | 114.06 | 131.28 | 144.03 | 87.22 | 105.26 | 131.46 | 121.41 | 69.84 |
| 84 | 165.15 | 47.68 | 71.56 | 48.59 | 67.52 | 91.09 | 103.31 | 65.15 | 88.20 | 86.77 | 109.04 | 115.82 | 132.32 | 145.41 | 89.68 | 106.34 | 132.77 | 123.72 | 8 |
| 88 | 169.00 | 47.94 | 71.98 | 48.75 | 67.77 | 91.44 | 103.80 | 65.73 | 88.92 | 87.60 | 110.95 | 117.41 | 133.26 | 146.66 | 91.93 | 108.05 | 133.96 | 125.82 | 72.44 |
| 92 | 172.53 | 48.18 | 72.36 | 48.89 | 67.99 | 91.77 | 104.24 | 66.26 | 89.58 | 88.36 | 112.69 | 118.88 | 134.12 | 147.81 | 93.97 | 109.96 | 135.05 | 127.74 | 73.68 |
| 96 | 175.75 | 48.40 | 72.70 | 49.02 | 68.20 | 92.07 | 104.65 | 66.75 | 90.18 | 89.05 | 114.29 | 120.21 | 134.90 | 148.86 | 95.85 | 111.71 | 136.05 | 129.50 | 74.82 |
| 100 | 178.72 | 48.6 | 73.02 | 49.14 | 68.39 | 92.35 | 105.02 | 67.20 | 90.73 | 89.69 | 115.75 | 121.45 | 135.63 | 149.82 | 97.58 | 113.32 | 136.97 | 131.12 | 75.87 |
| 104 | 181.47 | 48.78 | 73.32 | 49.25 | 68.57 | 92.61 | 105.37 | 67.62 | 91.24 | 90.28 | 117.11 | 122.58 | 136.29 | 150.72 | 99.17 | 114.81 | 137.81 | 132.62 | 76.84 |
| 108 | 184.00 | 48.95 | 73.59 | 49.35 | 68.74 | 92.84 | 105.69 | 68.00 | 91.71 | 90.82 | 118.37 | 123.63 | 136.91 | 151.54 | 100.64 | 116.19 | 138.60 | 134.00 | 77.73 |
| 112 | 186.36 | 49.11 | 73.85 | 49.44 | 68.89 | 93.06 | 105.98 | 68.36 | 92.15 | 91.33 | 119.53 | 124.61 | 137.49 | 152.31 | 102.01 | 117.47 | 139.33 | 135.29 | 78.56 |
| 116 | 188.56 | 49.26 | 74.08 | 49.53 | 69.03 | 93.27 | 106.26 | 68.69 | 92.56 | 91.80 | 120.62 | 125.52 | 138.02 | 153.02 | 103.29 | 118.66 | 140.00 | 136.49 | 79.34 |
| 120 | 190.60 | 49.40 | 74.30 | 49.61 | 69.16 | 93.46 | 106.52 | 69.00 | 92.94 | 92.24 | 121.63 | 126.37 | 138.52 | 153.69 | 104.48 | 119.77 | 140.64 | 137.60 | 80.06 |
| 124 | 192.52 | 49.53 | 74.51 | 49.69 | 69.29 | 93.64 | 106.76 | 69.29 | 93.30 | 92.65 | 122.58 | 127.17 | 138.99 | 154.31 | 105.59 | 120.81 | 141.23 | 138.65 | 80.73 |
| 128 | 194.32 | 49.65 | 74.70 | 49.76 | 69.40 | 93.81 | 106.98 | 69.57 | 93.63 | 93.04 | 123.47 | 127.91 | 139.43 | 154.89 | 106.64 | 121.79 | 141.79 | 139.63 | 81.37 |
| 132 | 196.00 | 49.76 | 74.89 | 49.83 | 69.51 | 93.96 | 107.20 | 69.82 | 93.95 | 93.40 | 124.30 | 128.61 | 139.84 | 155.44 | 107.62 | 122.70 | 142.31 | 140.55 | 81.96 |
| 136 | 197.59 | 49.87 | 75.06 | 49.89 | 69.61 | 94.11 | 107.40 | 70.06 | 94.24 | 93.74 | 125.09 | 129.27 | 140.23 | 155.96 | 108.54 | 123.56 | 142.80 | 141.41 | 82.52 |
| 140 | 199.09 | 49.97 | 75.22 | 49.95 | 69.71 | 94.25 | 107.59 | 70.29 | 94.52 | 94.07 | 125.83 | 129.89 | 140.59 | 156.45 | 109.41 | 124.38 | 143.26 | 142.23 | 83.05 |

## Two-span simply supported girders

The maximum positive moments and shear in two-span simply-supported girders with various span lengths by the 18 representative vehicles are shown in Fig. 4.26, and the R-values in Fig. 4.27. Similarly as shown in Table 4.4, the effects of the Wis-SPV were exceeded by the three representative vehicles, whose variable axle spacing could cause short heavy vehicles.


Fig. 4.26 Peak moment/shear values for overweight vehicles on two-span girders


Fig. 4.27 R-values for overweight vehicles on two-span girders

Table 4.4(a) Peak positive moments in two-span girders by overweight vehicles (kips-ft)

| Span <br> (ft) | Wis. SPV | Class 4 <br> 2axle | $\begin{aligned} & \text { Class4 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{gathered} \text { Class6 } \\ \text { 3axle } \end{gathered}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{gathered} \text { Class } 7 \\ 5 \text { axle } \end{gathered}$ | $\begin{gathered} \text { Class8 } \\ \text { 3axle } \end{gathered}$ | Class8 <br> 4axle a | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle b } \end{aligned}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle a } \end{gathered}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \end{gathered}$ | $\begin{gathered} \text { Class } 10 \\ \text { 6axle } \end{gathered}$ | $\left\|\begin{array}{c} \text { Class10 } \\ 7 \text { axle } \end{array}\right\|$ | Class11 5axle | $\left\|\begin{array}{c} \text { Class12 } \\ \text { 6axle } \end{array}\right\|$ | Class 13 <br> 7 axle a | Class13 <br> 7 axle b | Class14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 577.2 | 197.9 | 313.8 | 233.8 | 316.9 | 441.6 | 480.0 | 228.9 | 375.2 | 306.7 | 367.7 | 407.4 | 565.6 | 596.3 | 273.8 | 438.1 | 548.0 | 412.7 | 297.4 |
| 36 | 675.0 | 229 | 358.3 | 274.0 | 374. | 520.8 | 569.5 | 282.1 | 440.4 | 358.7 | 436.0 | 481.2 | 672.0 | 717.9 | 319.2 | 520.5 | 658.8 | 485.3 | 347.7 |
| 40 | 774.3 | 267.7 | 415.1 | 314.8 | 433.4 | 600.5 | 660.0 | 341.8 | 509.3 | 421.3 | 505.5 | 570.2 | 778.8 | 840.5 | 364.9 | 603.3 | 770.6 | 559.2 | 398.2 |
| 4 | 878. | 306 | 476.2 | 355.9 | 492 | 680.8 | 751.4 | 402.9 | 590.0 | 48 | 575.9 | 663.5 | 890.8 | 963.8 | 429.1 | 692.7 | 885.6 | 634.0 | . 9 |
| 48 | 982.8 | 346.8 | 538.4 | 397.4 | 551.7 | 761.4 | 843.2 | 464.6 | 671.8 | 550.0 | 647.0 | 758.6 | 1010.8 | 1089.2 | 497.7 | 789.8 | 1011.8 | 709.3 | 512.2 |
| 52 | 1088.0 | 387. | 601 | 439.3 | 611. | 842. | 935. | 526.7 | 754. | 618.7 | 718.6 | 855.1 | 1132.0 | 1226.3 | 567.5 | 888.3 | 1138.9 | 785.2 | 575.6 |
| 56 | 1193. | 429 | 665 | 481 | 670. | 923. | 1028.0 | 589 | 837 | 696.0 | 790.5 | 968.3 | 1254.2 | 1364.5 | 64 | 987.8 | 1266.8 | 878.6 | 639.8 |
| 60 | 1299.5 | 470.6 | 729.1 | 523.6 | 730.5 | 1004.5 | 1120.8 | 652.1 | 921.1 | 774.7 | 869.6 | 1087.3 | 1377.0 | 1503.5 | 724.7 | 1088.1 | 1395.3 | 993.1 | 712.1 |
| 64 | 1405.7 | 512. | 793. | 565.9 | 790 | 1085. | 1213. | 715.2 | 1005 | 854 | 981.3 | 1207.1 | 1500.5 | 1643.1 | 809.7 | 1188.9 | 1524.2 | 1116.0 | 791.1 |
| 68 | 1528.5 | 554. | 858.2 | 608.3 | 850.3 | 1167.2 | 1307.3 | 778 | 1089.3 | 935.2 | 1094.9 | 1327.6 | 1624.3 | 1783.1 | 895.8 | 1300.8 | 1653.5 | 1241.3 | 871.2 |
| 72 | 1678. | 597 | 923.2 | 650.7 | 910. | 1248. | 1400.9 | 841.9 | 1173.8 | 1016.6 | 1210.0 | 1448.7 | 1748.7 | 1923. | 982.9 | 1419.8 | 1783.2 | 1370.3 | 951.7 |
| 76 | 1844.9 | 639. | 988.4 | 693.2 | 970.5 | 1330.3 | 1494.6 | 905.5 | 1258.5 | 1098.5 | 1326.3 | 1570.2 | 1873 | 2064.6 | 1081.0 | 1540.3 | 1913.1 | 1502.2 | 1032.5 |
| 80 | 2022.6 | 682.7 | 1053.8 | 735.8 | 1030.6 | 1412.0 | 1588.4 | 969.2 | 1343.4 | 1180.9 | 1443.6 | 1692.1 | 1998.0 | 2205.7 | 1189.3 | 1661.5 | 2043. | 1635.0 | 1113.7 |
| 8 | 2203 | 725 | 1119.3 | 778.4 | 1090.8 | 1493.6 | 1682.2 | 103 | 1428 | 1263.7 | 1561. | 1814.3 | 2123 | 23 | 1298.3 | 1783 | 2173 | 1768.6 | 1195 |
| 88 | 2386. | 769 | 1185.1 | 821.0 | 1151.0 | 1575.3 | 1776.1 | 1096.9 | 1513.6 | 1347.0 | 1680.6 | 1936.9 | 2248 | 2488. | 1407.8 | 1905.2 | 2303. | 1902. | 1276.7 |
| 92 | 2572.4 | 812.2 | 1251.0 | 863.6 | 1181 | 1657. | 1870.1 | 1160.8 | 1598.8 | 1430.9 | 1800.1 | 2059.7 | 2373. | 2630.5 | 1517.9 | 2027.6 | 2434.4 | 2037.8 | 1358.5 |
| 96 | 2760.0 | 855 | 1317.0 | 906.3 | 1271. | 1738.8 | 1964.1 | 1224. | 1684.1 | 1515.1 | 1920.1 | 2182.9 | 2499 | 2772. | 1628. | 2150 | 2565.0 | 2173. | 1440.5 |
| 100 | 2951.9 | 899 | 1383.0 | 949.1 | 1331.7 | 1820. | 2058.1 | 1289.0 | 1769.5 | 1599.5 | 2040.6 | 2306.0 | 2624.8 | 2914.3 | 1739.4 | 2273.5 | 2695.8 | 2309.1 | 1522.6 |
| 104 | 3146. | 942. | 1449.2 | 992.0 | 1392.0 | 1902.5 | 2152.2 | 1353.1 | 1855.0 | 1684.1 | 2161.5 | 2429.6 | 2750.7 | 3056.7 | 1850. | 2396.8 | 2826.7 | 2445.2 | 1604.9 |
| 108 | 3341.7 | 986.1 | 1515.4 | 1034.9 | 1452.4 | 1984.3 | 2246.4 | 1417.2 | 1940.6 | 1769.0 | 2282.8 | 2553.1 | 2876.5 | 3199. | 1962.3 | 2520.3 | 2957.6 | 2582.2 | 1687.2 |
| 112 | 3537.9 | 1029 | 1581. | 1077.8 | 1512. | 2066. | 2340.6 | 1481 | 2026.1 | 1853. | 2404.3 | 2676.8 | 3002.5 | 3341.4 | 2074. | 2644.0 | 3088.7 | 2719.3 | 1769.7 |
| 116 | 3734.9 | 1073 | 1648.0 | 1120.8 | 1573. | 2148.1 | 2434.8 | 1545.7 | 2111.8 | 1939.0 | 2526.3 | 2800.6 | 3128.5 | 3483.9 | 2186.1 | 2768.0 | 3219. | 2856.8 | 1852.3 |
| 120 | 3932.7 | 1116. | 1714.4 | 1163.7 | 1633.4 | 2230.0 | 2529.0 | 1610.0 | 2197.5 | 2024.2 | 2648.3 | 2924.5 | 3254.5 | 3626.4 | 2298.5 | 2892.0 | 3350.9 | 2994.5 | 1934.9 |
| 124 | 4131.0 | 1160.6 | 1780.8 | 1206.7 | 1693.8 | 2311.9 | 2623.2 | 1674.2 | 2283.1 | 2109.5 | 2770.7 | 3048.5 | 3380.6 | 3769.0 | 2411.1 | 3016.3 | 3482.1 | 3132.5 | 2017.7 |
| 128 | 4330.0 | 1204.3 | 1847.2 | 1249.6 | 1754. | 2393. | 2717.5 | 1738.5 | 2368.9 | 2194.9 | 2893.2 | 3172.6 | 3506.8 | 3911.7 | 2523.7 | 3140.5 | 3613.3 | 3270.6 | 2100.5 |
| 132 | 4529.5 | 1248.1 | 1913.7 | 1292.6 | 1814. | 2475.8 | 2811.7 | 1802.9 | 2454.7 | 2280.4 | 3015.9 | 3296.7 | 3632.9 | 4054.4 | 2636.6 | 3265.0 | 3744.6 | 3409.0 | 2183.3 |
| 136 | 4729.4 | 1291.8 | 1980.2 | 1335.6 | 1875.0 | 2557.7 | 2906.0 | 1867.3 | 2540.6 | 2366.0 | 3138.7 | 3420.8 | 3759.2 | 4197.2 | 2749.7 | 3389.5 | 3876.0 | 3547.5 | 2266.2 |
| 140 | 4929.8 | 1335.6 | 2046.7 | 1378.6 | 1935.4 | 2639.6 | 3000.3 | 1931.7 | 2626.4 | 2451.6 | 3261.7 | 3545.1 | 3885.5 | 4340.0 | 2862.8 | 3514.1 | 4007.3 | 3686.1 | 2349.2 |

Table 4.4(b) Peak negative moments in two-span girders by overweight vehicles (kips-ft)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class4 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & 5 \text { axle } \end{aligned}$ | $\begin{gathered} \text { Class8 } \\ \text { 3axle } \end{gathered}$ | Class8 <br> 4axle a | Class8 <br> 4axle b | $\begin{gathered} \text { Class9 } \\ \text { 5axle a } \end{gathered}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \end{gathered}$ | $\begin{gathered} \text { Class } 10 \\ \text { 6axle } \end{gathered}$ | $\left\|\begin{array}{c} \text { Class10 } \\ 7 \text { axle } \end{array}\right\|$ | Class 11 5axle | $\left\|\begin{array}{c} \text { Class12 } \\ \text { 6axle } \end{array}\right\|$ | Class 13 <br> 7axle a | Class 13 <br> 7axle b | Class14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -469.3 | -153.7 | -229.1 | -144.1 | -206.7 | -273.5 | -298.1 | -195.2 | -258.6 | -270.5 | -339.9 | -334.1 | -378.8 | -410.8 | -281.3 | -307.0 | -368.6 | -404.3 | -213.0 |
| 36 | -547.7 | -164.0 | -244.9 | -150.6 | -219.4 | -291.5 | -316.8 | -211.9 | -276. | -292.5 | -371.3 | -360.6 | -409.3 | -448.3 | -308.7 | -335.6 | -397.3 | -441.6 | -228.9 |
| 40 | -620.5 | -174.0 | -260.6 | -156.4 | -231 | -308.2 | -334.3 | -228 | -293. | -314.3 | -409.7 | -394.2 | -438.3 | -485.7 | -334.0 | -365.4 | -432.0 | -479.6 | -243.6 |
| 4 | -688.0 | -183.2 | -276.3 | -161.7 | -241.8 | -323. | -350.8 | -244.8 | -309.6 | -336.0 | -448.4 | -427.5 | -465.9 | -522.6 | -357 | -393.3 | -466.3 | -519.6 | -257.4 |
| 48 | -76 | -191 | -292.0 | -166 | -25 | -338 | -366 | -261 | -32 | -357. | -484.6 | -460.5 | -49 | -559 | -378.5 | -4 | -500.4 | -556.9 | -274.8 |
| 52 | -831.6 | -199.3 | -307.8 | -177.7 | -260.8 | -351.9 | -386.0 | -277. | -347. | -379.0 | -518.3 | -493.2 | -528.9 | -595.7 | -398.3 | -445.5 | -534.4 | -592.3 | -297.5 |
| 56 | -898.1 | -206.5 | -323.4 | -188. | -269 | -36 | -410 | -29 | -3 | -400 | -550.2 | -525.7 | -560.6 | -631.81 | -426.6 | -478.6 | -567 | -627 | . 1 |
| 60 | -960.5 | -213. | -338.3 | -199.6 | -278 | -384.6 | -434.3 | -309 | -391 | -421 | -581.5 | -558.0 | -592.2 | -667.7 | -455.7 | -510.5 | -601.4 | -662.3 | -339.6 |
| 64 | -1019.2 | -219. | -352.4 | -210.5 | -293.2 | -405.0 | -458.1 | -325 | -412.9 | -442.7 | -612.7 | -590.0 | -623.8 | -703.6 | -483.6 | -541.2 | -634.6 | -697.2 | -358.9 |
| 68 | -1074. | -224. | -365.5 | -221 | -30 | -425 | -481. | -340 | -43 | -463 | -643 | -621.9 | -655 | -739. | -509.9 | -570 | -6 | -731. | -377.2 |
| 72 | -1126.3 | -229.9 | -378.0 | -231.9 | -323. | -445.7 | -505.6 | -356.6 | -456.2 | -484.8 | -674.8 | -653.6 | -686.6 | -774.5 | -534.9 | -599.5 | -700.8 | -766.5 | -394.7 |
| 76 | -11 | -23 | -389. | -24 | -338 | -4 | -528 | -37 | -47 | -505 | -70 | -6 | -717 | -809 | -558 | -626 | - | -800 | . |
| 80 | -1221. | -239. | -400.8 | -253.2 | -353 | -485. | -552.3 | -386 | -499. | -526. | -736.1 | -716.4 | -748.6 | -845 | -581 | -653. | -765. | -835.1 | -426.7 |
| 84 | -126 | -247 | -411.3 | -263.8 | -368. | -505.8 | -575.5 | -401 | -519.6 | -547.0 | -765.3 | -747.2 | -779.4 | -880.0 | -602.6 | -679. | -798. | -869.3 | -441.5 |
| 88 | -13 | -2 | -42 | -274 | -383 | -5 | -59 | -4 | -5 | -5 | -79 | -776.6 | -809.4 | -915.0 | -623.0 | -704.5 | -830.8 | -903.5 | 6 |
| 92 | -134 | -270.5 | -430.6 | -284.9 | -398.0 | -545.7 | -621.9 | -427. | -558.2 | -584.7 | -819.5 | -804.6 | -837.7 | -949.5 | -642. | -728.9 | -863.2 | -937.4 | -469.1 |
| 96 | -1381. | -281 | -439.7 | -295 | -412. | -565. | -644. | -43 | -576 | -602.0 | -844.7 | -831.2 | -864.7 | -982 | -660. | -752. | -895 | -969.9 | -481.9 |
| 100 | -1417.0 | -293.3 | -448.2 | -305.8 | -427.5 | -585. | -667.8 | -450. | -593 | -618.5 | -868.4 | -856.5 | -890.2 | -1013.6 | -678 | -775 | -925 | -1000.9 | -49 |
| 104 | -1450. | -30 | -45 | -316. | -442. | -605 | -690 | -462.0 | -610. | -634.1 | -891.4 | -880.8 | -914.7 | -1043 | -695 | -798 | -955. | -1030.5 | -505.9 |
| 108 | -1482.2 | -315. | -474.8 | -326.6 | -456. | -624.7 | -713. | -472. | -626.9 | -648.9 | -912.8 | -903.9 | -937. | -1072.0 | -711.3 | -820. | -983.6 | -1058.6 | -517.2 |
| 112 | -1511.9 | -326 | -491.6 | -337. | -471 | -644. | -736 | -482 | -642 | -663.2 | -933.5 | -925.8 | -959. | -1099.4 | -726 | -841 | -1010 | -1085.3 | -527.9 |
| 116 | -1540. | -338. | -508.4 | -347 | -486. | -664. | -759.2 | -492. | -657. | -676.5 | -953.3 | -947.1 | -981.0 | -1125.1 | -741 | -862.9 | -1037.1 | -1111.0 | -548.5 |
| 120 | -1568.2 | -349.2 | -525.2 | -357. | -500 | -683 | -781. | -501 | -676 | -689 | -972.2 | -967.2 | -1007. | -1150.1 | -755.6 | -883 | -1062 | -1135.5 | -571.6 |
| 124 | -1594.4 | -360.2 | -541.9 | -368.1 | -515. | -703.3 | -804.6 | -516.2 | -698. | -701.7 | -990.2 | -986.4 | -1038. | -1173.9 | -771.6 | -903 | -1086 | -1158.9 | -594.6 |
| 128 | -1619.3 | -371.3 | -558.5 | -378.4 | -529.5 | -722.9 | -827.2 | -532.6 | -719.6 | -713.5 | -1007.6 | -1005.1 | -1069.8 | -1198.5 | -793.0 | -923. | -1110. | -1181.3 | -617.5 |
| 132 | -1643.3 | -382.2 | -575.2 | -388.7 | -544.0 | -742.4 | -849.8 | -548.8 | -741. | -724 | -1024 | -1022.8 | -1101. | -1234.2 | -814. | -957 | -1141 | -1203.0 | -640.1 |
| 136 | -1666.4 | -393.1 | -591.7 | -399.0 | -558.5 | -761.9 | -872.4 | -565.1 | -762.4 | -735.6 | -1040.3 | -1039.9 | -1132.1 | -1269.5 | -834.5 | -991.1 | -1173.5 | -1223.5 | -662.7 |
| 140 | -1688.3 | -404.0 | -608.2 | -409.2 | -573.0 | -781.4 | -895.0 | -581.2 | -783.8 | -752.2 | -1055. | -1063.0 | -1163.3 | -1304.8 | -854.9 | -1024.7 | -1205.9 | -1243.4 | -685.2 |

Table 4.4(c) Peak shear in two-span girders by overweight vehicles (kips)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \end{aligned}$ | Class4 3axle | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 5axle } \end{aligned}$ | $\begin{gathered} \text { Class8 } \\ \text { 3axle } \end{gathered}$ | Class8 4axle a | Class8 4axle b | Class9 <br> 5axle a | Class9 <br> 5axle b | Class 10 6axle | Class 10 <br> 7axle | Class 11 <br> 5axle | Class 12 6axle | Class 13 <br> 7axle a | Class 13 <br> 7axle b | Class14 <br> 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 105.01 | 39.09 | 57.90 | 44.57 | 60.98 | 82.20 | 90.62 | 46.66 | 70.65 | 60.84 | 71.84 | 84.64 | 106.05 | 114.48 | 53.40 | 83.53 | 103.49 | 78.03 | 55.64 |
| 36 | 107.45 | 40.25 | 59.72 | 45.16 | 61.94 | 83.53 | 92.48 | 47.72 | 71.69 | 62.62 | 73.92 | 88.15 | 108.24 | 117.68 | 55.74 | 85.23 | 106.47 | 80.23 | 57.86 |
| 40 | 109.5 | 41.26 | 61.30 | 45.68 | 62.76 | 84.68 | 94.08 | 50.01 | 72.5 | 64.16 | 75.94 | 91.18 | 110.38 | 120.43 | 58.65 | 86.68 | 109.05 | 82.30 | 59.79 |
| 44 | 111.81 | 42.14 | 62.68 | 46.12 | 63.48 | 85.67 | 95.48 | 52.01 | 73.33 | 66.26 | 77.69 | 93.81 | 113.36 | 122.82 | 61.20 | 87.93 | 111.28 | 84.07 | 61.47 |
| 48 | 113.7 | 42. | 63.8 | 46. | 64.12 | 86.5 | 96. | 53 | 75 | 68.8 | 79.21 | 96.12 | 116 | 12 | 63 | 90.22 | 113.23 | 85.60 | 62.95 |
| 52 | 115.88 | 43.59 | 64.97 | 46.86 | 64.68 | 87.33 | 97.79 | 55.33 | 76.88 | 71.16 | 80.52 | 98.16 | 118.34 | 126.75 | 65.42 | 92.72 | 114.95 | 86.92 | 64.26 |
| 56 | 117.73 | 44.20 | 65.93 | 47.17 | 65.17 | 88.0 | 98.7 | 56.73 | 78.5 | 73.22 | 81.67 | 99.96 | 120.42 | 128.56 | 67.18 | 94.93 | 116.94 | 88.41 | 65.41 |
| 60 | 119.71 | 44.74 | 66.79 | 47.44 | 65.61 | 88.63 | 99.62 | 57.9 | 80.0 | 75.0 | 82.78 | 101.56 | 122.30 | 131.12 | 70.05 | 96.92 | 119.38 | 92.16 | 6.44 |
| 64 | 121.46 | 45.23 | 67.57 | 47.69 | 66.01 | 89.18 | 100.39 | 59.10 | 81.34 | 76.75 | 85.26 | 103.00 | 123.98 | 133.43 | 72.65 | 98.69 | 121.57 | 95.56 | 67.36 |
| 68 | 123.03 | 45.6 | 68.2 | 47 | 66 | 89 | 101.0 | 60 | 82 | 78 | 87 | 104.29 | 12 | 13 | 0 | 100.29 | 123.55 | 98.63 | 9 |
| 72 | 124.4 | 46.06 | 68.91 | 48.11 | 66.70 | 90.1 | 101.73 | 61.03 | 83.6 | 79.65 | 89.54 | 105.46 | 126.90 | 137.42 | 77.14 | 101.7 | 125.35 | 101.44 | 68.94 |
| 76 | 126.3 | 46.42 | 69.48 | 48.30 | 67.00 | 90 | 102.3 | 61 | 84.6 | 80.9 | 91 | 106.51 | 128.16 | 139 | 79.08 | 103.05 | 126. | 103. | 69.62 |
| 80 | 130.9 | 46.75 | 70.01 | 48.47 | 67.2 | 90.9 | 102.8 | 62.6 | 85 | 82. | 93 | 107.4 | 129.3 | 140. | 80.86 | 10 | 128 | 106.33 | 70.23 |
| 84 | 135.2 | 47.06 | 70.50 | 48.62 | 67.52 | 91.28 | 103.33 | 63.34 | 86.37 | 83.11 | 94.95 | 108.34 | 130.37 | 142.18 | 82.49 | 105.33 | 129.86 | 109.20 | 70.79 |
| 88 | 139 | 47 | 70.9 | 48.76 | 67 | 91 | 103.7 | 63 | 87.1 | 84.08 | 97.44 | 109.5 | 13 | 143.52 | 83.99 | 106.33 | 13 | 111.89 | 30 |
| 92 | 142.8 | 47.59 | 71.35 | 48.89 | 67.96 | 91.90 | 104.19 | 64.58 | 87.8 | 84.97 | 99.74 | 111.27 | 132.25 | 144.75 | 85.36 | 107.24 | 132.29 | 114.39 | 71.77 |
| 96 | 146.2 | 47.8 | 71.73 | 49.01 | 68.16 | 92.17 | 104.57 | 65.1 | 88.5 | 85.80 | 101.88 | 112.92 | 133.0 | 145.90 | 86.64 | 108.09 | 133.37 | 116.70 | 72.21 |
| 100 | 149.9 | 48.05 | 72.09 | 49.13 | 68.34 | 92.4 | 104.9 | 65.6 | 89.1 | 86.57 | 103.86 | 114.44 | 133.86 | 146.95 | 87.82 | 108.8 | 13 | 118.85 | 72.61 |
| 104 | 15 | 48.25 | 72.41 | 49.23 | 68.5 | 92.66 | 105.26 | 66.1 | 89.6 | 87.28 | 105.7 | 115.86 | 134.58 | 147.94 | 88.91 | 109.59 | 135.31 | 120.85 | 72.98 |
| 108 | 157.4 | 48.44 | 72.72 | 49.33 | 68.67 | 92.88 | 105.56 | 66.55 | 90.20 | 87.95 | 107.44 | 117.18 | 135.25 | 148.86 | 89.93 | 110.26 | 136.17 | 122.71 | 73.32 |
| 112 | 160 | 48.62 | 73.00 | 49.42 | 68.82 | 93.0 | 105.85 | 66.96 | 90.69 | 88.57 | 109.05 | 118.42 | 135.87 | 149.71 | 90.87 | 110.8 | 136. | 124.46 | 73.63 |
| 116 | 164 | 48.78 | 73.27 | 49.50 | 68.96 | 93.28 | 106.12 | 67.35 | 91.15 | 89.15 | 110.55 | 119.57 | 136.46 | 150.52 | 91.76 | 111.47 | 137.7 | 126.08 | 73.93 |
| 120 | 167.02 | 48.94 | 73.52 | 49.58 | 69.0 | 93.46 | 106.37 | 67.7 | 91.5 | 89.69 | 111.97 | 120.65 | 137.01 | 151.27 | 92.58 | 112.01 | 138.46 | 127.62 | 74.20 |
| 124 | 169.8 | 49.08 | 73.75 | 49.66 | 69.21 | 93.63 | 106.61 | 68.05 | 91.98 | 90.20 | 113.30 | 121.67 | 137.53 | 151.98 | 93.36 | 112.51 | 139.12 | 129.05 | 74.95 |
| 128 | 172.50 | 49.22 | 73.97 | 49.73 | 69.32 | 93.79 | 106.83 | 68.36 | 92.36 | 90.68 | 114.55 | 122.62 | 138.01 | 152.64 | 94.35 | 113.00 | 139.75 | 130.41 | 75.81 |
| 132 | 175.00 | 49.35 | 74.18 | 49.80 | 69.43 | 93.95 | 107.04 | 68.66 | 92.72 | 91.13 | 115.72 | 123.52 | 138.47 | 153.27 | 95.79 | 114.25 | 140.34 | 131.68 | 76.62 |
| 136 | 177.36 | 49.47 | 74.37 | 49.86 | 69.53 | 94.09 | 107.24 | 68.95 | 93.06 | 91.56 | 116.84 | 124.37 | 138.90 | 153.86 | 97.14 | 115.42 | 140.90 | 132.88 | 77.38 |
| 140 | 179.60 | 49.59 | 74.56 | 49.92 | 69.63 | 94.22 | 107.43 | 69.21 | 93.38 | 91.96 | 117.88 | 125.18 | 139.31 | 154.41 | 98.43 | 116.53 | 141.42 | 134.01 | 78.10 |

## Three-span simply supported girders

The maximum moments and shear in three-span simply-supported girders with various span lengths by the 18 representative vehicles are shown in Fig. 4.28, and the R-values in Fig. 4.29. The three representative vehicles caused larger positive moments than Wis-SPV in almost all spans as shown in Table 4.5.


Fig. 4.27 Peak moment/shear values for overweight vehicles on three-span girders


Fig. 4.28 R-values for overweight vehicles on three-span girders

Table 4.5(a) Peak positive moments in three-span girders by overweight vehicles (kips-ft)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \\ & \hline \end{aligned}$ | $\begin{gathered} \text { Class4 } \\ \text { 3axle } \\ \hline \end{gathered}$ | $\begin{gathered} \text { Class5 } 5 \\ \text { 2axle } \\ \hline \end{gathered}$ | $\begin{gathered} \text { Class6 } 6 \\ \text { 3axle } \\ \hline \end{gathered}$ | $\begin{gathered} \text { Class7 } \\ \text { 4axle } \\ \hline \end{gathered}$ | $\begin{gathered} \text { Class7 } \\ \text { 5axle } \\ \hline \end{gathered}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 3axle } \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle a } \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle b } \end{aligned}$ | $\begin{aligned} & \text { Class9 } \\ & \text { 5axle a } \end{aligned}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline \text { Class } 10 \\ \text { 6axle } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline \text { Class10 } \\ \text { 7axle } \\ \hline \end{array}$ | $\begin{array}{\|c\|c\|} \hline \text { Class 11 } \\ \text { 5axle } \\ \hline \end{array}$ | $\begin{array}{\|c} \text { Class12 } \\ \text { 6axle } \\ \hline \end{array}$ | $\begin{array}{\|c\|c} \hline \text { Class13 } \\ \text { 7axle a } \\ \hline \end{array}$ | $\begin{array}{\|l} \hline \text { Class13 } \\ \text { 7axle b } \\ \hline \end{array}$ | $\begin{gathered} \text { Class } 14 \\ \text { 5axle } \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 528.0 | 183.3 | 287.9 | 211.0 | 283.9 | 396.4 | 429.2 | 206.4 | 337.6 | 287.2 | 335.6 | 365.3 | 503.9 | 526.8 | 247.6 | 390.7 | 484.8 | 383.0 | 268.3 |
| 36 | 575 | 195 | 309.8 | 230.5 | 312.1 | 435.1 | 472 | 225 | 369.5 | 307.4 | 362.7 | 401.2 | 556.1 | 586.2 | 269.9 | 431.1 | 538.9 | 410.7 | 293.0 |
| 40 | 622. | 209.2 | 331.7 | 250.3 | 340.6 | 473.9 | 516.6 | 248.5 | 401.6 | 326.5 | 396.0 | 437.4 | 608.5 | 646.0 | 292.3 | 471.6 | 593.3 | 442.6 | 317.8 |
| 44 | 667 | 227 | 353.7 | 270.2 | 369.2 | 513.0 | 560.9 | 277.2 | 433.7 | 353.8 | 42 | 473.9 | 661.0 | 706.1 | 314.7 | 512.3 | 8.0 | . 5 | 6 |
| 48 | 713. | 245.5 | 380.2 | 290.2 | 398.0 | 552.2 | 605.4 | 306.4 | 466.1 | 384.3 | 463.7 | 516.9 | 713.7 | 766.4 | 337.3 | 553.0 | 703.0 | 514.7 | 367.5 |
| 52 | 763 | 264 | 409.7 | 310.4 | 426.9 | 591.6 | 650.1 | 336.1 | 501. | 415.2 | 498.0 | 561.8 | 766.4 | 826.9 | 359.9 | 593.9 | 758.2 | 551.2 | 5 |
| 5 | 814 | 283 | 439 | 330. | 456.0 | 631 | 695.1 | 365.9 | 541.3 | 446.5 | 532.6 | 607.4 | 819.3 | 887.7 | 389.5 | 635.1 | 813.6 | 587.9 | 417.5 |
| 60 | 865. | 302.7 | 469.6 | 351.0 | 485.1 | 670.7 | 740.3 | 396.0 | 581.1 | 478.1 | 567.4 | 653.5 | 877.5 | 948.5 | 422.5 | 682.2 | 871.2 | 624.8 | 443.5 |
| 64 | 917. | 322. | 500.1 | 371. | 514.2 | 710.3 | 785.5 | 426.3 | 621.3 | 509.8 | 602.4 | 700.1 | 936.3 | 1009.5 | 455.9 | 729 | 933 | 661 | 9 |
| 68 | 968 | 342. | 530.8 | 392.0 | 543.5 | 750.1 | 830.9 | 456.7 | 661.6 | 541.8 | 637.5 | 747.1 | 995.5 | 1071.8 | 489.7 | 777. | 995.4 | 699.1 | 504.7 |
| 72 | 1020 | 361. | 561.7 | 412.5 | 57 | 789. | 876.4 | 487.2 | 702 | 574.0 | 672.6 | 794 | 1055.0 | 1139.0 | 523.8 | 826.2 | 105 | 736.4 | 535.8 |
| 76 | 1072 | 382 | 592. | 433 | 602.2 | 829.9 | 922.0 | 517.9 | 742.9 | 609.8 | 708.0 | 842.2 | 1114.8 | 1206.7 | 558.3 | 874 | 1120.5 | 773.9 | 567 |
| 80 | 112 | 402 | 624. | 453. | 631 | 869.9 | 967.7 | 548.6 | 783.8 | 647.5 | 743.4 | 893 | 1174.9 | 1274.6 | 593.0 | 923.8 | 1183.5 | 813.9 | 598.6 |
| 84 | 1176 | 422 | 655.5 | 474 | 661 | 909.9 | 1013.4 | 579.5 | 824.8 | 685.7 | 778.9 | 951.2 | 1235 | 1342.7 | 63 | 972 | 1246 | 866.0 | 630.3 |
| 88 | 1228. | 443 | 68 | 49 | 690.6 | 950.0 | 1059.2 | 610.4 | 866.0 | 724.2 | 814.5 | 1009 | 1295 | 1411.0 | 672.1 | 1022.2 | 1309.7 | 919.2 | 662 |
| 92 | 1280. | 463. | 718.7 | 516.2 | 720.1 | 990.1 | 1105.1 | 641.4 | 907.2 | 763.0 | 855.9 | 1068.2 | 1356 | 1479.5 | 713.4 | 1071.7 | 1373.1 | 978.4 | 00.0 |
| 96 | 1333.2 | 484 | 750. | 537 | 749.6 | 1030.2 | 1151.0 | 672 | 948.6 | 802.2 | 910.2 | 1127.1 | 1417 | 154 | 75 | 1121 | 1436.6 | 1038.2 | 739.0 |
| 100 | 13 | 505.3 | 782.2 | 558.0 | 779.2 | 1070.4 | 1151.0 | 703 | 990.0 | 841.5 | 965.2 | 1186.1 | 1478.0 | 1617.4 | 796.8 | 1171.0 | 1500.2 | 1098.8 | 778.2 |
| 104 | 1439. | 526. | 814.2 | 578 | 808.8 | 1110.5 | 1242.9 | 734.7 | 1031.6 | 881.2 | 1020.7 | 1245 | 1539 | 1686.5 | 839 | 1222 | 1563.8 | 1160.1 | 817.5 |
| 108 | 1507. | 547. | 84 | 59 | 838.4 | 1150.8 | 1288.9 | 765.9 | 1073.2 | 921.0 | 1076.5 | 1304. | 1600.2 | 1755.8 | 881.6 | 1280.7 | 1627.6 | 1221.8 | 856.9 |
| 112 | 1577.8 | 568.0 | 878.2 | 620. | 868.0 | 1191.0 | 1335.0 | 797.2 | 1114.8 | 961.0 | 1132.8 | 1364.7 | 1661.5 | 1825.2 | 924.3 | 1338.9 | 1691.5 | 1284.0 | 896.5 |
| 116 | 165 | 588. | 910 | 641 | 897 | 1231.3 | 1381.2 | 828.5 | 1156.5 | 1001.2 | 1189.5 | 1424 | 1722 | 1894.7 | 967.3 | 1397.3 | 1755 | 1347.4 | 936.1 |
| 120 | 17 | 609. | 94 | 662 | 927 | 1271.6 | 1427.3 | 85 | 1198.3 | 1041.5 | 1246.4 | 1484.5 | 1784.3 | 1964.2 | 1010.5 | 1456.2 | 1819.6 | 1412.1 | 975.9 |
| 124 | 1818.0 | 631.0 | 974.7 | 683.9 | 957.0 | 1311.9 | 1473.4 | 891. | 1240.2 | 1082.0 | 1303.7 | 1544.7 | 1845.8 | 2033.9 | 1061.2 | 1515.7 | 1883.8 | 1477.1 | 1015.7 |
| 128 | 1904.5 | 652.0 | 1006. | 704.9 | 986.7 | 1352.2 | 1519.6 | 922.8 | 1282.0 | 1122.6 | 1361.2 | 1604.8 | 1907.4 | 2103.6 | 1114.3 | 1575.2 | 1948.0 | 1542.4 | 1055.7 |
| 132 | 1991.9 | 673.2 | 1039.2 | 725.9 | 1016.4 | 1392.5 | 1565.8 | 954.3 | 1323.9 | 1163.3 | 1419.1 | 1665.2 | 1969.0 | 2173.3 | 1167.5 | 1635.0 | 2012.3 | 1607.9 | 1095.7 |
| 136 | 2080.0 | 694.3 | 1071.5 | 747.0 | 1046.1 | 1432.8 | 1612.1 | 985.8 | 1365.9 | 1204.1 | 1477.1 | 1725.5 | 2030.8 | 2243.1 | 1221.0 | 1694.8 | 2076.6 | 1673.6 | 1135.8 |
| 140 | 2169.0 | 715.5 | 1103.9 | 768.0 | 1075.8 | 1473.2 | 1658.4 | 1017.3 | 1407.8 | 1245.1 | 1535.4 | 1785.9 | 2092.5 | 2313.0 | 1274.6 | 1754.7 | 2141.0 | 1739.5 | 1175.9 |

Table 4.5(b) Peak negative moments in three-span girders by overweight vehicles (kips-ft)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class4 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { Class8 } \\ & \text { 3axle } \end{aligned}$ | Class8 <br> 4axle a | Class8 <br> 4axle b | $\begin{gathered} \text { Class9 } \\ \text { 5axle a } \end{gathered}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \end{gathered}$ | $\begin{gathered} \text { Class } 10 \\ \text { 6axle } \end{gathered}$ | $\left.\begin{array}{\|c} \text { Class10 } \\ 7 \text { axle } \end{array} \right\rvert\,$ | Class11 5axle | $\left\|\begin{array}{c} \text { Class12 } \\ \text { 6axle } \end{array}\right\|$ | Class13 <br> 7axle a | Class13 <br> 7 axle b | Class 14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -430 | -148 | -226.3 | -141.3 | -205.3 | -275.2 | -305.5 | -190.6 | -262.7 | -257.9 | -316.8 | -317.2 | -390.0 | -412.2 | -264.3 | -312.6 | -374.8 | -377.0 | . 8 |
| 36 | -504. | -157. | -241.9 | -148.2 | -218.9 | -294.4 | -325.8 | -207.3 | -282.3 | -278.7 | -348.1 | -342.5 | -422.8 | -452.3 | -290.9 | -338.8 | -409.6 | -414.1 | -230.7 |
| 40 | -574. | -167.8 | -257.5 | -154.5 | -231.3 | -312.4 | -345.1 | -223. | -300. | -299.3 | -384.8 | -375.4 | -454.2 | -490.7 | -315.7 | -368.4 | -443.1 | -451.2 | -246.6 |
| 44 | -640 | -177 | -273.0 | -165.7 | -242.9 | -329.3 | -363.2 | -240.0 | -318. | -319.7 | -424.0 | -407.9 | -484.1 | -527.6 | -338.7 | -398.0 | -47 | -490.9 | -261.5 |
| 48 | -708.6 | -186.2 | -288.6 | -177.6 | -253.7 | -345.1 | -385.5 | -256.2 | -334.7 | -340.1 | -460.9 | -440.1 | -512.9 | -563.1 | -360.1 | -426.2 | -505.9 | -528.8 | -275.6 |
| 52 | -7 | -194 | -304.2 | -189.4 | -263 | -366.0 | -411.5 | -27 | -350 | -360.5 | -495.6 | -472.2 | -540.7 | -597.6 | -379.9 | -452.8 | -535.8 | -564.3 | 0 |
| 56 | -839.3 | -201. | -319.6 | -201.1 | -279.9 | -388.1 | -437.3 | -288.1 | -368.1 | -380.7 | -528.1 | -504.0 | -567.3 | -630.6 | -404.7 | -487.0 | -564.6 | -598.3 | -313.7 |
| 6 | -90 | -208. | -335. | -212.8 | -296 | -410.0 | -46 | -30 | -390 | -400.8 | -559.1 | -535.4 | -593 | -662 | -434.4 | -521.2 | -595.3 | -632.1 | 8 |
| 64 | -959 | -215.2 | -350.0 | -224.4 | -312.6 | -431.8 | -488.4 | -319. | -412 | -420.8 | -589.5 | -566.7 | -618.3 | -694 | -462.9 | -554.2 | -628.6 | -665.7 | -353.2 |
| 68 | -1014. | -221.2 | -364.1 | -235.9 | -328. | -453.5 | -513.8 | -335 | -434 | -440.9 | -619.9 | -597.8 | -642.8 | -72 | -490.1 | -586.0 | -661 | -699.3 | -371.9 |
| 72 | -1067 | -226 | -377. | -247.3 | -344 | -475 | -539.0 | -35 | -456 | -460 | -650.2 | -628.8 | -666 | -754 | -516.2 | -616.9 | -694.8 | -732.7 | 1 |
| 76 | -1117.2 | -238 | -390.0 | -258.7 | -360.9 | -496.6 | -563.9 | -366.6 | -477.8 | -480.8 | -680.1 | -659.6 | -697.9 | -783.6 | -540.9 | -646.8 | -727.5 | -765.9 | -407.4 |
| 8 | -1164 | -25 | -402.1 | -270.0 | -376.9 | -518.0 | -588.8 | -382. | -499 | -500.6 | -710.0 | -690.1 | -733 | -814.7 | -564.4 | -675.8 | -760. | -799 | -424.4 |
| 8 | -120 | -26 | -413.4 | -281.3 | -392. | -539.4 | -613.7 | -397 | -520 | -520.4 | -739.8 | -720.6 | -767.7 | -852. | -586.9 | -704.0 | -792.6 | -832.1 | -440.8 |
| 88 | -125 | -276 | -424.2 | -292.6 | -408. | -560.7 | -638.4 | -411 | -542.0 | -539.9 | -768.8 | -750.7 | -802.4 | -891 | -608.4 | -731.4 | -827.9 | -865.1 | -456.8 |
| 92 | -1291. | -288.5 | -434.7 | -303.8 | -424. | -581.9 | -663.1 | -424.8 | -562.2 | -558.5 | -796.5 | -779.8 | -836.9 | -931.2 | -628.9 | -758. | -864. | -898.0 | -472.4 |
| 96 | -1330.0 | -300. | -451.7 | -315.0 | -440.1 | -603.1 | -687.6 | -437.9 | -581 | -576.2 | -822.8 | -807.5 | -871.1 | -970.3 | -648.6 | -784.0 | -900.1 | -930.8 | -487.5 |
| 10 | -1366. | -312. | -470.0 | -326.1 | -455.9 | -624.1 | -687.6 | -450.4 | -605 | -593.0 | -848.0 | -834.1 | -905.2 | -1009.4 | -667.3 | -809. | -935 | -962.8 | -502.3 |
| 104 | -1400.9 | -324. | -488.2 | -337.2 | -471 | -645.2 | -736.6 | -46 | -628 | -609.1 | -872.2 | -859.6 | -939 | -1048.4 | -685 | -83 | -971 | -993.5 | -516.8 |
| 108 | -1434.3 | -336. | -506.3 | -348.3 | -487.2 | -666.2 | -761.1 | -479.9 | -652.0 | -624.3 | -894.9 | -883.8 | -973.2 | -1087.0 | -704. | -858.3 | -1006.8 | -1022.8 | -534.8 |
| 112 | -1465.3 | -348.6 | -524.3 | -359.4 | -502. | -687.2 | -785.4 | -497.8 | -675 | -639.0 | -917.0 | -907.1 | -1006.9 | -1125.4 | -730.3 | -881.9 | -1042. | -1050.6 | -559.9 |
| 116 | -1495.7 | -360.5 | -542.2 | -370.5 | -518.3 | -708.2 | -809.6 | -515.4 | -698. | -657.4 | -938.1 | -929.6 | -1040.6 | -1163.8 | -755.4 | -905.1 | -1077.3 | -1077.5 | -584.9 |
| 120 | -1524.3 | -372. | -560.1 | -381.5 | -533.8 | -729.1 | -833.9 | -532.9 | -721.5 | -681.9 | -958.3 | -958.0 | -1074.2 | -1202.1 | -780.1 | -927.8 | -1112.3 | -1103.3 | -609.5 |
| 124 | -1551.8 | -384.2 | -577.9 | -392.5 | -549.3 | -750.0 | -858.1 | -550.5 | -744 | -706.2 | -977.6 | -993.6 | -1107.6 | -1240.2 | -804 | -950.3 | -1147.3 | -1127.8 | -634.1 |
| 128 | -1578.1 | -396.0 | -595.7 | -403.5 | -564.7 | -770.9 | -882.2 | -568.0 | -767.4 | -730.4 | -996.3 | -1028.9 | -1140.9 | -1278.2 | -827.7 | -984.8 | -1182.2 | -1151.5 | -658.5 |
| 132 | -1603.3 | -407.6 | -613.4 | -414.5 | -580.2 | -791.8 | -906.3 | -585.3 | -790.3 | -754.5 | -1014.2 | -1063.9 | -1174.2 | -1316.2 | -850.6 | -1021.0 | -1216.9 | -1174.3 | -682.7 |
| 136 | -1627.7 | -419.2 | -631.1 | -425.5 | -595.6 | -812.5 | -930.4 | -602.6 | -813.1 | -778.5 | -1031.5 | -1098.8 | -1207.4 | -1353.9 | -873.3 | -1057.0 | -1251.5 | -1196.1 | -706.8 |
| 140 | -1650.9 | -430.9 | -648.7 | -436.4 | -611.1 | -833.3 | -954.5 | -619.9 | -835.9 | -802.3 | -1048.1 | -1133.7 | -1240.6 | -1391.6 | -895.2 | -1092.9 | -1286.1 | -1217.2 | -730.8 |

Table 4.5(c) Peak shear in three-span girders by overweight vehicles (kips)

| Span <br> (ft) | Wis. SPV | $\begin{aligned} & \text { Class4 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class4 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class5 } \\ & \text { 2axle } \end{aligned}$ | $\begin{aligned} & \text { Class6 } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { Class7 } \\ & \text { 4axle } \end{aligned}$ | $\begin{gathered} \text { Class7 } \\ \text { 5axle } \end{gathered}$ | $\begin{gathered} \text { Class8 } \\ \text { 3axle } \end{gathered}$ | Class8 <br> 4axle a | $\begin{aligned} & \text { Class8 } \\ & \text { 4axle b } \end{aligned}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle a } \end{gathered}$ | $\begin{gathered} \text { Class9 } \\ \text { 5axle b } \end{gathered}$ | $\begin{array}{\|c} \text { Class10 } \\ \text { 6axle } \end{array}$ | $\begin{array}{\|c\|c} \hline \text { Class10 } \\ 7 \text { axle } \end{array}$ | Class11 <br> 5axle | $\left\|\begin{array}{c} \text { Class12 } \\ \text { 6axle } \end{array}\right\|$ | Class 13 <br> 7axle a | Class 13 <br> 7 axle b | Class 14 5axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 105.43 | 39.20 | 58.09 | 44.70 | 61.20 | 82.55 | 91.05 | 46.39 | 70.49 | 61.05 | 71.79 | 84.48 | 106.19 | 114.72 | 52.91 | 83.47 | 103.75 | 77.64 | 55.44 |
| 36 | 107.68 | 40.38 | 59.91 | 45.30 | 62.15 | 83.88 | 92.91 | 47.95 | 71.54 | 62.84 | 73.65 | 88.02 | 108.39 | 117.94 | 55.46 | 85.18 | 106.76 | 79.62 | 67 |
| 40 | 109.66 | 41.39 | 61.50 | 45.81 | 62.98 | 85.02 | 94.51 | 50.25 | 72.43 | 64.39 | 75.43 | 91.09 | 110.94 | 120.71 | 58.38 | 86.65 | 109.35 | 81.46 | 59.61 |
| 44 | 111.64 | 42.27 | 62.89 | 46.26 | 63.70 | 86.01 | 95.90 | 52.27 | 73.33 | 66.51 | 77.01 | 93.75 | 113.93 | 123.11 | 60.95 | 87.91 | 111.59 | 83.09 | 61.31 |
| 48 | 113.41 | 43.03 | 64.12 | 46.65 | 64.33 | 86.88 | 97.1 | 54.0 | 75 | 69.12 | 78.41 | 96.09 | 116.57 | 125.21 | 63.21 | 90. | 113.56 | 2 | 62.81 |
| 52 | 115.21 | 43.74 | 65.20 | 46.99 | 64.89 | 87.65 | 98.20 | 55.62 | 77.28 | 71.45 | 79.64 | 98.15 | 118.92 | 127.06 | 65.21 | 92.70 | 115.29 | 85.77 | 64.13 |
| 5 | 116.8 | 44 | 66.17 | 47.30 | 65 | 88.3 | 99 | 57.0 | 78. | 73.53 | 80.7 | 99.97 | 121.00 | 129 | 67 | 94 | 117.63 | 88.57 | 30 |
| 60 | 118.51 | 44.89 | 67.03 | 47.57 | 65.82 | 88.94 | 100.02 | 58.27 | 80.41 | 75.40 | 82.72 | 101.59 | 122.88 | 131.83 | 69.90 | 96.94 | 120.07 | 92.37 | 66.34 |
| 64 | 120.03 | 45.38 | 67.80 | 47.82 | 66.21 | 89.49 | 100.78 | 59.40 | 81.74 | 77.08 | 85.24 | 103.04 | 124.56 | 134.14 | 72.53 | 98.73 | 122.26 | 95.80 | 67.28 |
| 68 | 121.45 | 45. | 68.51 | 48.04 | 66. | 89.99 | 101.4 | 60.42 | 82.9 | 78.61 | 87.51 | 104.35 | 126 | 136.23 | 74. | 100.34 | 124.24 | 98.92 | 12 |
| 72 | 123.22 | 46.21 | 69.14 | 48.24 | 66.90 | 90.44 | 102.11 | 61.34 | 84.04 | 79.99 | 89.58 | 105.53 | 127.47 | 138.13 | 77.08 | 101.80 | 126.04 | 101.75 | 68.88 |
| 76 | 126.8 | 46.5 | 69.72 | 48.42 | 67.1 | 90.8 | 102 | 62.1 | 85 | 81.26 | 91 | 106.5 | 128.7 | 139.8 | 79 | 103. | 127. | 104 | 7 |
| 80 | 131.56 | 46.90 | 70.24 | 48.58 | 67.46 | 91.2 | 103.20 | 62.9 | 85.9 | 82.41 | 93.18 | 107.56 | 129.88 | 141.43 | 80.8 | 104.3 | 129.17 | 106.83 | 70.19 |
| 84 | 135.88 | 47.20 | 70.73 | 48.73 | 67.70 | 91.56 | 103.68 | 63.6 | 86.77 | 83.47 | 95.41 | 108.45 | 130.93 | 142.88 | 82.51 | 105.43 | 130.54 | 109.77 | 70.76 |
| 88 | 139 | 47.48 | 71.17 | 48.87 | 67.9 | 91.8 | 104.1 | 64.2 | 87 | 84. | 97.92 | 110.13 | 13 | 14 | 8 | 106 | 13 | 11 | 8 |
| 92 | 143.56 | 47.74 | 71.58 | 49.00 | 68.14 | 92.16 | 104.53 | 64.88 | 88.24 | 85.34 | 100.24 | 111.90 | 132.80 | 145.44 | 85.42 | 107.36 | 132.96 | 115.00 | 71.76 |
| 96 | 146.99 | 47.97 | 71.96 | 49.12 | 68.33 | 92.43 | 104.90 | 65.43 | 88.89 | 86.17 | 102.39 | 113.55 | 133.62 | 146.58 | 86.71 | 108.21 | 134.03 | 117.32 | 72.19 |
| 100 | 150.67 | 48.19 | 72.31 | 49.23 | 68.5 | 92.6 | 104.90 | 65.9 | 89.4 | 86.93 | 104.39 | 115.08 | 134.39 | 147.63 | 87.9 | 109. | 135.03 | 119.48 | 72.60 |
| 104 | 15 | 48.3 | 72.64 | 49.33 | 68.68 | 92.9 | 105.58 | 66.41 | 90.05 | 87.65 | 106.25 | 116.50 | 135.11 | 148.61 | 89.0 | 109.72 | 135.95 | 121.49 | 72.97 |
| 108 | 158.25 | 48.58 | 72.94 | 49.43 | 68.83 | 93.13 | 105.88 | 66.85 | 90.58 | 88.31 | 107.98 | 117.82 | 135.77 | 149.52 | 90.04 | 110.40 | 136.81 | 123.37 | 73.32 |
| 112 | 161.68 | 48.76 | 73.22 | 49.52 | 68.9 | 93.33 | 106.16 | 67.25 | 91.06 | 88.93 | 109.61 | 119.06 | 136.39 | 150.37 | 91.0 | 111.02 | 137.61 | 125.12 | 73.64 |
| 116 | 164.89 | 48.92 | 73.48 | 49.60 | 69.11 | 93.52 | 106.42 | 67.63 | 91.52 | 89.51 | 111.12 | 120.21 | 136.97 | 151.16 | 91.89 | 111.61 | 138.37 | 126.75 | 73.94 |
| 120 | 167.91 | 49.07 | 73.73 | 49.68 | 69.2 | 93.6 | 106.67 | 67.9 | 91.94 | 90.05 | 112.54 | 121.29 | 137.51 | 151.91 | 92.73 | 112.16 | 139.07 | 128.29 | 74.51 |
| 124 | 170.75 | 49.22 | 73.96 | 49.75 | 69.36 | 93.86 | 106.90 | 68.33 | 92.34 | 90.56 | 113.87 | 122.30 | 138.02 | 152.60 | 93.51 | 112.67 | 139.73 | 129.73 | 75.42 |
| 128 | 173.42 | 49.35 | 74.18 | 49.82 | 69.47 | 94.02 | 107.12 | 68.64 | 92.72 | 91.04 | 115.13 | 123.26 | 138.49 | 153.26 | 94.91 | 113.70 | 140.35 | 131.09 | 76.28 |
| 132 | 175.94 | 49.48 | 74.38 | 49.89 | 69.5 | 94.16 | 107.33 | 68.9 | 93.07 | 91.49 | 116.31 | 124.15 | 138.95 | 153.88 | 96.36 | 114.95 | 140.93 | 132.36 | 77.08 |
| 136 | 178.31 | 49.60 | 74.58 | 49.95 | 69.68 | 94.30 | 107.52 | 69.22 | 93.41 | 91.91 | 117.42 | 125.00 | 139.37 | 154.46 | 97.72 | 116.12 | 141.48 | 133.56 | 77.84 |
| 140 | 180.56 | 49.71 | 74.76 | 50.01 | 69.77 | 94.43 | 107.71 | 69.48 | 93.72 | 92.31 | 118.47 | 125.80 | 139.77 | 155.01 | 99.01 | 117.23 | 142.00 | 134.70 | 78.56 |

## Summary of the girder responses to representative vehicles

The positive moment / shear envelopes of the Wis-SPV were breached by the following three representative vehicles all three types of girders (i.e., simply supported, 2-sapn continuous and 3span continuous girders). This is due to the fact that the variable spacings in these representative vehicles all have a small lower bound (e.g., 4 ft ) such that the last five or six axles literally becomes a heavy axle group. Considering the definitions of the two classes, it was very likely that some nondivisable trucks had been recorded in Class 13 vehicles, and some single unit trucks, potentially with multiple lift axles, had been recorded in Class 10 vehicles.

Meanwhile, it should be noted that heavy vehicles in other classes, the representative vehicles of which did not show larger maximum girder response, could possibly cause large moments than Wis-SPV. This is due to the fact that the representative were established to only represent top $5 \%$ heavy vehicles in each class rather than representing the heaviest trucks. Hence, the representative vehicles were quantified before being used for estimating the probability of the heavy trucks cause larger bridge response than the Wis-SPV.


## Evaluation of representative overloaded vehicles

To determine how closely the proposed representative vehicles represents the overweight vehicles in the term of bridge girder responses. Fifty vehicles were randomly selected from the vehicles that have top $5 \%$ of gross vehicle weight in each vehicle class/group. It was deemed that heavier vehicles in a certain class/group would most likely produce larger girder responses because the vehicle configurations are similar in the class/group. Girder analyses were conducted for each randomly selected vehicle on two randomly selected girder spans. The representative vehicles could then be positioned within the top $5 \%$ heaviest vehicles in each class/group by comparing the obtained girder responses with that of the representative vehicle. The comparison for the representative vehicle in Class 9, Type 3S2 vehicles is shown below in details to illustrate the process. The comparison for other representative vehicles was tabulated in Table 4.6.

The girder responses of the randomly selected vehicles are plotted in Fig. 4.29, in which the responses by the representative vehicle as shown in Fig. 4.15 for Type 3S2 vehicles are shown in solid (blue) lines, the responses by the Wis-SPV are shown in black dashed lines, and the randomly selected vehicles are shown in various marks. Due to the random nature of the analyses, the selected vehicles covered the entire span range of interest though only two spans were calculated for each vehicle. The girder responses of the selected vehicles closely followed the responses of the representative vehicle, indicating that the representative vehicle had properly represented the top 5\% overweight vehicles.





Fig. 4.29 Comparison of randomly selected vehicles with the representative vehicle (Type 3S2)
The calculated responses for the randomly selected vehicles were divided by the responses of the representative vehicles for the selected span lengths to get the response ratios. The responses ratios for the maximum positive moments, the maximum negative moments, and the maximum shear are shown in Fig. 4.30, and the last bar chart in the figure shows the distribution of the total ratios. The mean ratios $(\mu)$ and the standard deviations $(\sigma)$ are listed in Table 4.6 and shown on the subfigures. Most distributions failed the Lilliefors normality tests, indicating that the randomly generated responses may not be modeled as a normal distribution. However, a normal distribution was shown in Fig. 4.30 for comparison purposes.
Similarly, the response distributions of the vehicles in the entire class/group may not be modeled using a normal distribution using the sample mean ratio of $\mu$ and the sample standard deviation of $\sigma$ listed in table 4.6. However, normal distributions with the mean ratios of $\mu$ and the standard deviations of $\sigma$ were assumed to describe the statistical characteristics of the vehicles of the entire class/group. An upper confidence bound (ucb in Fig. 4.30) for each representative vehicle was calculated for each distribution as the cumulative distribution function corresponding to the response ratio of 1.0. The upper confidence bound indicates that ucb\% of the vehicles within the top $5 \%$ gross vehicle weights in a class/group would cause girder responses less than that by the representative vehicles in the class/group. For example, the representative vehicle for Class 9 Type 3 S 2 vehicles had an upper confidence bound of $84.7 \%$, indicating that the representative vehicle would envelop the positive moments by $84.7 \%$ vehicles in the top $5 \%$ of this class/group. Note that an optimization procedure may be used to modify the representative vehicles such that the obtained upper confidence bound for each representative vehicle can maintain constant.


Fig. 4.30 Statistical evaluation of the representative vehicle for Class 9 (Type 3S2)
Table 4.6 summary of the statistical analysis of response ratios

| Vehicles | Positive moments |  | Negative moments |  | Maximum shear |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mu$ | $\sigma$ | ucb | $\mu$ | $\sigma$ | ucb | $\mu$ | $\sigma$ | ucb |
| Class 4 2-axle | 1.004 | 0.086 | 48.3 | 1.006 | 0.084 | 47.0 | 1.013 | 0.088 | 44.3 |
| Class 4 3-axle | 0.984 | 0.091 | 57.1 | 0.998 | 0.104 | 50.7 | 1.002 | 0.092 | 49.1 |
| Class 5 2-axle | 0.983 | 0.101 | 56.7 | 1.012 | 0.109 | 45.5 | 1.006 | 0.099 | 47.5 |
| Class 6 3-axle | 0.959 | 0.122 | 63.1 | 0.983 | 0.122 | 55.4 | 0.979 | 0.116 | 57.3 |
| Class 7 4-axle | 0.886 | 0.074 | 93.8 | 0.911 | 0.074 | 88.5 | 0.910 | 0.073 | 89.1 |
| Class 7 5-axle | 0.956 | 0.124 | 63.9 | 0.970 | 0.126 | 59.3 | 0.967 | 0.127 | 60.2 |
| Class 8 3-axle | 0.968 | 0.166 | 57.5 | 1.000 | 0.140 | 50.0 | 1.009 | 0.171 | 48.0 |
| Class 8 4-axle a | 0.885 | 0.122 | 82.7 | 0.962 | 0.138 | 60.8 | 0.919 | 0.126 | 74.1 |
| Class 8 4-axle b | 0.907 | 0.133 | 75.7 | 0.979 | 0.133 | 56.3 | 0.925 | 0.125 | 72.7 |
| Class 9 5-axle a | 0.924 | 0.078 | 83.5 | 0.934 | 0.062 | 85.7 | 0.928 | 0.068 | 85.7 |
| Class 9 5-axle b | 0.786 | 0.067 | 99.9 | 0.900 | 0.078 | 90.0 | 0.830 | 0.070 | 99.3 |
| Class 10 6-axle | 0.722 | 0.113 | 99.3 | 0.880 | 0.095 | 89.6 | 0.808 | 0.125 | 93.8 |
| Class 10 7-axle | 0.785 | 0.098 | 98.6 | 0.933 | 0.094 | 76.4 | 0.861 | 0.111 | 89.4 |
| Class 11 5-axle | 1.011 | 0.054 | 41.7 | 1.002 | 0.042 | 48.3 | 1.000 | 0.047 | 49.9 |
| Class 12 6-axle | 0.755 | 0.099 | 99.3 | 0.912 | 0.058 | 93.5 | 0.848 | 0.093 | 94.9 |
| Class 13 7-axle a | 0.662 | 0.147 | 98.9 | 0.847 | 0.203 | 77.5 | 0.745 | 0.158 | 94.7 |
| Class 13 7-axle b | 0.974 | 0.173 | 56.0 | 0.983 | 0.173 | 53.8 | 0.976 | 0.162 | 55.8 |
| Class 14 5-axle | 0.878 | 0.072 | 95.5 | 0.908 | 0.051 | 96.4 | 0.905 | 0.062 | 93.7 |

The mean response ratios and the corresponding standard deviations are not same for the girder internal forces (i.e., moments and shear). This indicates that some overloaded vehicles may cause large positive moments, and the others may cause large negative moments depending upon their configurations. To evaluate the representative vehicles, all responses ratios (including moment
and shear ratios) were used as shown in Table 4.7. The mean ratios and the standard deviations for the combined samples were calculated similar to the analysis for individual internal forces. The upper confidence bound is similar to those listed in Table 4.6. An ucb near 50\% indicates that the representative vehicles properly represent the top $5 \%$ overweight vehicles. The upper confidence bounds near $90 \%$ indicate that the representative vehicles may overestimate the top $5 \%$ overweight vehicles.

Table 4.7 Evaluation of the representative vehicles

| Vehicle <br> (Class/group) | $\mu$ | $\sigma$ | ucb (\%) | rep/spv <br> $(250 \mathrm{k})$ | poe (\%) | \# of <br> vehicles | \# of <br> exceeds | rep/spv <br> $(190 \mathrm{k})$ | poe (\%) | \# of <br> exceeds |
| :--- | :---: | :---: | ---: | :---: | :---: | ---: | ---: | ---: | ---: | ---: |
| Class 4 2-axle | 1.008 | 0.086 | 46.4 | 0.393 | 0.0 | 21064 | 0 | 0.517 | 0.0 | 0 |
| Class 4 3-axle | 0.994 | 0.095 | 52.4 | 0.585 | 0.0 | 20351 | 0 | 0.770 | 0.0 | 0 |
| Class 5 2-axle | 0.999 | 0.103 | 50.4 | 0.431 | 0.0 | 20069 | 0 | 0.567 | 0.0 | 0 |
| Class 6 3-axle | 0.973 | 0.120 | 59.0 | 0.585 | 0.0 | 78523 | 0 | 0.770 | 0.3 | 13 |
| Class 7 4-axle | 0.901 | 0.075 | 90.7 | 0.783 | 0.0 | 15988 | 0 | 1.030 | 17.6 | 141 |
| Class 7 5-axle | 0.964 | 0.125 | 61.4 | 0.870 | 7.0 | 36234 | 126 | 1.145 | 76.5 | 1385 |
| Class 8 3-axle | 0.991 | 0.163 | 52.1 | 0.526 | 0.0 | 5789 | 0 | 0.693 | 0.3 | 1 |
| Class 8 4-axle a | 0.917 | 0.131 | 73.7 | 0.728 | 0.0 | 18469 | 0 | 0.958 | 16.5 | 153 |
| Class 8 4-axle b | 0.932 | 0.133 | 69.6 | 0.660 | 0.0 | 9813 | 0 | 0.868 | 4.9 | 24 |
| Class 9 5-axle a | 0.928 | 0.070 | 84.7 | 0.747 | 0.0 | 889230 | 0 | 0.983 | 10.2 | 4536 |
| Class 9 5-axle b | 0.831 | 0.083 | 97.9 | 0.906 | 0.1 | 133972 | 2 | 1.192 | 46.4 | 3106 |
| Class 10 6-axle | 0.794 | 0.129 | 94.4 | 1.082 | 15.8 | 27574 | 217 | 1.424 | 76.1 | 1049 |
| Class 10 7-axle | 0.851 | 0.117 | 89.9 | 1.198 | 55.3 | 2552 | 71 | 1.576 | 96.7 | 123 |
| Class 11 5-axle | 1.005 | 0.049 | 46.1 | 0.626 | 0.0 | 28618 | 0 | 0.824 | 0.0 | 0 |
| Class 12 6-axle | 0.829 | 0.108 | 94.3 | 0.879 | 0.2 | 11011 | 1 | 1.156 | 37.0 | 204 |
| Class 13 7-axle a | 0.739 | 0.181 | 92.5 | 1.112 | 18.8 | 1116 | 11 | 1.463 | 62.1 | 35 |
| Class 13 7-axle b | 0.977 | 0.169 | 55.4 | 0.875 | 16.4 | 3463 | 28 | 1.152 | 74.0 | 128 |
| Class 14 5-axle | 0.896 | 0.065 | 94.6 | 0.593 | 0.0 | 115 | 0 | 0.780 | 0.0 | 0 |

Within a certain class/group, vehicles with a smaller gross vehicle weight than the representative vehicle would cause smaller girder responses. Assuming a normal distribution for girder responses by various vehicles, the probability of exceeding (poe) was calculated for the Wis-SPV for each vehicle class/group. Similar to the calculation of the ucb values, a target response ratio (i.e. the inverse of the tabulated values of rep/spv in Table 4.7) was needed for the probability of exceeding. This ratio was determined using the maximum moments/shear calculated for the representative vehicles listed in Tables 4.3 through 3.5 divided by the responses of the 250-kip Wis-SPV for various girders. Note that these response ratios were rather random; hence the maximum response ratios were used in the calculation of the probability of exceeding. Note that the probability of exceeding indicates that poe \% of top $5 \%$ over weight vehicles are likely to cause larger girder responses than the Wis-SPV. Finally the estimated number of vehicles was calculated by multiply the poe \% by $5 \%$ of the total number of the vehicles in the class/group (note that $2.5 \%$ was used for Class 9 vehicles). The total number of vehicles in each class/group is shown in the first cell in the table of the statistical characteristics of the vehicles class/group.

In addition to the Class 10 and Class 13 vehicles, for which the representative vehicles caused larger positive moments as shown in Tables 4.3 through 4.5, significant number of Class 7 vehicles (with 6 axles) may exceed the 250 -kip Wisconsin Standard Permit Vehicle. The random simulation for the Class 7 vehicles showed large variations. It is common that the exceeding probability increases with an increase in standard deviation as shown in Appendix 1. Meanwhile,
the estimated situation may have reflected the real situation because Class 7 vehicles are short single unit trucks: the representative is 26 ft long while has 113 kip gross weight. Hence, it is possible to create large positive moments, and sometimes large negative moments.

The total number of estimated vehicles (note that a vehicle may cause multiple records in the WIM data) was 456 , which corresponding to $0.035 \%$ of total overweight vehicles (records). These vehicles were examined next to reveal their common features.

The gross weight distribution of the randomly selected vehicles that caused larger responses than the representative vehicles is shown in Fig. 4.31. Sixteen vehicles (records) had a gross weight larger than 250 kips, and 266 vehicles (records) showed a gross weight larger than 170 kips. These heavy vehicles (records) took a slightly higher percentage than the actual data because a certain vehicle may be selected multiple times in the random process.


Fig. 4.31 gross weight distribution of the randomly selected vehicles

## Examination of randomly selected heavy vehicles

Fifty vehicles were randomly selected to conduct the above evaluation analysis for each representative vehicle on each simply-supported girder, resulting in 54 cases in total. Among the total 2,700 randomly selected vehicles in the 54 cases, 1,610 vehicles caused larger girder responses (i.e., positive moment, negative moment, or shear) than the representative vehicles. A close look at these vehicles indicated that the vehicle configurations were similar to the corresponding representative vehicles. Meanwhile almost all the 1,610 vehicles had a gross vehicle weight higher than the representative vehicles. In addition most axle spacings, especially the largest spacings were within the range of the variable spacings in the representative vehicles. This observation actually validated the methodology used in this study.

A list of heavy vehicles in each class/group was identified as shown in Fig. 4.32 to demonstrate the worst cases in permit vehicles in Wisconsin. Almost all these vehicles have a gross weight larger than 80 kips except the 2 -axle buses (trucks). Most vehicles have an outermost axle
spacing less than the legal length: trucks less than 50 ft and vehicle combinations less than 75 ft . Most single axle weights are blow 40 kips except for some Class 8 trucks with three axles, which have axle weights as large as 72 kips. The heavy rear axles actually reduced the load on the steering axle such that the steering axle was only 1kip. This seemed unreasonable; however there was no obvious evidence that they were error in the WIM records. The heaviest steering axle is 38 kips in single unit trucks while the steering axle weights were smaller in semi-trailers and vehicle combinations.

Some Class 7 vehicles with 5 axles were particularly heavy ( 170 kips ) and short, which would cause large girder responses in both positive moments and the negative moments. The worst Class 9 semi-trailers are slightly heavier than 170 kips , the upper limit for vehicles eligible for multi-trip permits. The worst Class 10 semi-trailers weighed close to 200 kips ; hence they may need single-trip permits. Meanwhile, there were short vehicles in this class which might have been due to a wrong vehicle classification though their axle configurations followed the same pattern as the Type 3S3 and Type 3S4 vehicles. These short trucks were captured in the representative vehicles, which were the major contributors to the large girders responses. Two such trucks are shown in Fig. 4.31 with 200-kip gross weight as the worst possible cases. The configuration of typical Type 3S2-2 vehicle combinations was not captured in the representative vehicles. This might have been due to the fact that Class 13 also includes non-divisible permit trucks/trailers, and the permit vehicles dominated the WIM records. Instead, the representative vehicles in Class 13 captured two typical non-divisible permit trucks/trailers as shown at the bottom of Fig. 4.31.



Fig. 4.31 gross weight distribution of the randomly selected vehicles
These occasional overloads might cause damage to highway bridges, ${ }^{37}$ especially on bridge decks. ${ }^{38}$ Some exceptionally high axle loads were recorded in WIM data such as the Class 8 example (with two 72-kip axles) in Fig. 4.31. Finite element analyses were conducted using ABAQUS ${ }^{\circledR}$ to investigate the potential local damage these high axle loads on bridge decks. The analysis results of a three-span slab bridge, which was used in Chapter 6 as permit rating example, are shown in Fig. 4.32. The slab bridge was subjected to a group of two 72-kip axle loads at two locations. Normal stresses in the longitudinal direction are examined.



Fig. 4.32 gross weight distribution of the randomly selected vehicles
In the model shown in Fig. 4.32, concrete slab was modeled using solid brick element with nonlinear concrete material model considering plastic damage. Haunch plates were used near the interior supports to represent the real design. Steel reinforcements were embedded in concrete elements. Both the reinforcements and the nonlinear plastic damage concrete model facilitated the convergence of the analyses, in which the vehicle load, combined with the self weight, can cause concrete cracking near peak moments. The axle loads, applied to the slab through four rubber blocks, were place at two locations to examine the potential local damage to the slab bridge. High stress concentration near the simulated tires was not observed in the analyzed two cases; however, the high axle loads did increase the normal stress distribution near the loads. Although the overloaded vehicle might have been considered in the design process, the increased stress may cause cracks, which may affect the durability of the bridge.

## Summary

The weigh-in-motion records in Wisconsin in 2007 were used to evaluate the WisDOT Standard Permit Vehicle. The recorded vehicles (records) in individual classes per FHWA definitions were further divided into groups, in which the vehicles had similar configuration patterns. Descriptive statistical analyses were conducted for the vehicles in each class/group to define representative vehicles that best describe the vehicles with top 5\% gross weights in that class/group. The representative vehicles were evaluated using randomly selected vehicles in the top $5 \%$ vehicles in the corresponding class/group. The girder responses by the randomly selected
vehicles on the girders with randomly selected span lengths were used to estimate the probability that the heavy vehicles in each class/group might cause larger girder response than Wis-SPV.

The analysis indicated that $0.035 \%$ of total overweight vehicles (records) may exceed the $250-$ kip Wis-SPV. Meanwhile about $1 \%$ of vehicle potentially with permits would cause larger girder responses than the 190 -kip Standard Permit Vehicle. A close examination of the selected overweight vehicles indicated that some short vehicles with 5 to 7 axles, currently on Wisconsin highway with annual permits, could generate severe bridge internal forces than the 250-kip Standard Permit Vehicle. These observations were similar to those obtained using multivariate statistical analyses of top 5\% heaviest vehicles shown in Appendix 4.
The 250-kip Standard Permit Vehicle was compared with the vehicles with single-trip permits in recent years in the next chapter. Recommendations to the current permitting practice are provided in the Chapter 6.

# Chapter 5 Analysis of Wisconsin Single-Trip Permit Vehicles 

## Introduction

The 250-kip Wis-SPV was intended to represent vehicles with single-trip permit in addition to enveloping all vehicles with multi-trip permits; ${ }^{6}$ In this chapter, the impact of Wis-SPV is compared with that by vehicles that applied for single-trip permits in recent years. Oversized (but not overloaded) vehicles that have single-trip permits are excluded from the vehicle data set.

## Overview of vehicles with single-trip permits

The single-trip permits issued between July 2004 and July 2007 were analyzed. Approximately forty nine thousand vehicle records were considered in the analysis (49,434 in total recorded during the period of time). The analyses excluded super-heavy vehicles, which in this study was defined as vehicles with gross weights of over 300kips. Vehicles with a gross weight of less than 40kips were also excluded because they are unlikely to be critical. This filtering process eliminated about $0.75 \%$ of the total records under consideration.

An overview of all the 49 thousand records is shown in Fig. 5.1, including the distribution of gross weight, vehicle length and the total axle numbers. The distribution of gross vehicle weight scatters with a peak at 90 kips . More than $75 \%$ of the vehicles have a gross weight above the legal weight - 80kips. Almost all vehicles have a length over 50 ft , and over fifty percent of the vehicles have a length more than 75 ft , the maximum vehicle length for vehicles eligible for multi-trip permits. In addition, less than $0.1 \%$ of the vehicles have two axles, and less than $0.3 \%$ of the vehicles have more than 13 axles. Hence the statistical analysis was performed for vehicles with three to thirteen axles.



Fig. 5.1 Overview of vehicles with single-trip permits

## Analysis of single-trip permit records

The same descriptive statistical analysis was used to analyze the permit trucks in this section. The histograms of axle weights and axle spacings are shown in Appendix 5. The characteristic values (e.g., the maximum, the minimum, and the mean values, and the standard deviations) were tabulated for each vehicle group based on axles (note that the permit trucks were classified based on their total number of axles). A representative vehicle was determined for each group. The axle weights corresponding to $95^{\text {th }}$ percentile were used for the representative vehicles in each group. The average spacing was used for the first spacing and 4 ft was used for all tandem axles (i.e., groups of axles with spacings less than 6 ft ). The values corresponding to $5^{\text {th }}$ percentile and $95^{\text {th }}$ percentile were used to define one variable spacing per vehicle. No vehicle combination was considered in the interpolation of the statistical analyses.

Note that the available population is relatively small; hence, the statistical analysis should be viewed with caution.

## Three-axle Vehicles

A representative vehicle was created as shown in Fig. 5.2. These vehicles are likely FHWA Class 4 three-axle buses and Class 6 three-axle trucks.

| $\begin{array}{\|l\|} \hline 1547 \\ \text { vehicles } \end{array}$ | Minimum | Maximum | Mean | Standard deviation | 5th percentile | 95th percentile | $\begin{array}{\|l\|} \hline 99 \text { th } \\ \text { percentile } \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 40500 | 90000 | 57972.53 | 4174.489 | 52980 | 64000 | 74000.00 |
| Axle weight 1 | 8000 | 32600 | 19292.57 | 1819.069 | 15000 | 20000 | 22500.00 |
| Axle spacing 1 | 8 | 37 | 16.33 | 1.728 | 14.117 | 19.417 | 21.00 |
| Axle weight 2 | 9000 | 35000 | 19365.08 | 1920.142 | 17016 | 22488 | 26880.00 |
| Axle spacing 2 | 3 | 30 | 4.77 | 3.383 | 4.08 | 4.75 | 25.72 |
| Axle weight 3 | 9000 | 35000 | 19314.87 | 1841.393 | 17080 | 22000 | 26630.00 |
| STP - 3 axle$\mathrm{GVW}=65 \mathrm{k}$ |  |  |  |  |  |  |  |

Fig. 5.2 Representative vehicle for 3-axle permit vehicles

## Four-axle Vehicles

Vehicles (a): A representative vehicle was created as shown in Fig. 5.3. These vehicles are likely FHWA Class 8, Type 3S1 trucks.

| $\begin{aligned} & 272 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $5^{5^{\text {th }}} \text { percentile }$ | $\begin{array}{\|l\|} \hline 95^{\text {th }} \\ \text { percentile } \\ \hline \end{array}$ | $\begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 40000 | 112000 | 64844.58 | 9594.493 | 54065.00 | 80700.00 | 112000.00 |
| Axle weight 1 | 6980 | 29000 | 18147.82 | 3294.010 | 12000.00 | 21000.00 | 29000.00 |
| Axle spacing 1 | 4 | 29 | 15.46 | 3.570 | 7.50 | 19.61 | 23.00 |
| Axle weight 2 | 0 | 29000 | 12907.46 | 4661.659 | 8000.00 | 20250.00 | 29000.00 |
| Axle spacing 2 | 0 | 10 | 5.15 | 1.457 | 4.08 | 7.53 | 10.00 |
| Axle weight 3 | 0 | 29584 | 16789.65 | 3131.732 | 13151.45 | 20250.00 | 27697.68 |
| Axle spacing 3 | 0 | 53 | 7.34 | 8.587 | 4.08 | 33.57 | 43.00 |
| Axle weight 4 | 2780 | 31000 | 16661.42 | 4421.767 | 8000.00 | 26400.00 | 29584.00 |
| STP - 4 axle a GVW=87 k |  |  |  |  |  |  |  |

Fig. 5.3 Representative vehicle for 4-axle permit vehicles (Type 3S1)
Vehicles (b): A representative vehicle was created as shown in Fig. 5.4. These vehicles are likely FHWA Class 8, Type 2 S2 trucks.
$\left.\begin{array}{|l|l|l|l|l|l|l|}\hline \begin{array}{l}856 \\ \text { vehicles }\end{array} & \text { Minimum } & \text { Maximum } & \text { Mean } & \begin{array}{l}\text { Standard } \\ \text { deviation }\end{array} & \begin{array}{l}5^{\text {th }} \\ \text { percentile }\end{array} & \begin{array}{l}95^{\text {th }} \\ \text { percentile }\end{array}\end{array} \begin{array}{l}99^{\text {th }} \\ \text { percentile }\end{array}\right]$

| Gross weight | 57320 | 130000 | 81351.19 | 10005.847 | 72000.00 | 97000.00 | 126430.00 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Axle weight 1 | 4000 | 31000 | 18790.81 | 2722.025 | 15750.00 | 22500.00 | 29000.00 |
| Axle spacing 1 | 4 | 18 | 5.93 | 1.398 | 4.08 | 7.50 | 10.62 |
| Axle weight 2 | 9000 | 31000 | 18879.94 | 2663.627 | 15794.00 | 22500.00 | 29430.00 |
| Axle spacing 2 | 10 | 42 | 15.79 | 3.037 | 12.83 | 19.67 | 31.17 |
| Axle weight 3 | 9750 | 35000 | 21840.39 | 3098.021 | 19000.00 | 28000.00 | 34000.00 |
| Axle spacing 3 | 4 | 11 | 4.40 | . 455 | 4.17 | 5.00 | 5.17 |
| Axle weight 4 | 9750 | 36000 | 21840.05 | 3106.667 | 19000.00 | 28000.00 | 34000.00 |
| STP - 4 axle bGVW=101 k |  |  |  |  |  |  |  |

Fig. 5.4 Representative vehicle for 4-axle permit vehicles (Type 2S2)

## Five-axle Vehicles

Non-split vehicles: A representative vehicle was created as shown in Fig. 5.5. These vehicles are likely FHWA Class 9 trucks (Type 3S2).

| $\begin{array}{\|l\|} \hline 5901 \\ \text { vehicles } \\ \hline \end{array}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{array}{\|l} 5^{\text {th }} \\ \text { percentile } \end{array}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{array}{\|l\|} \hline 99^{\mathrm{th}} \\ \text { percentile } \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 50000 | 152500 | 90817.72 | 7349.784 | 81000.00 | 100000.00 | 112000.00 |
| Axle weight 1 | 5860 | 31000 | 12164.64 | 1273.724 | 11000.00 | 13000.00 | 19500.00 |
| Axle spacing 1 | 2 | 29 | 17.67 | 2.963 | 12.00 | 21.00 | 22.50 |
| Axle weight 2 | 5850 | 32500 | 19222.22 | 2363.345 | 14000.00 | 22000.00 | 24000.00 |
| Axle spacing 2 | 4 | 44 | 4.63 | 1.627 | 4.17 | 5.00 | 13.58 |
| Axle weight 3 | 5850 | 32500 | 19203.85 | 2705.876 | 12500.00 | 22000.00 | 25000.00 |
| Axle spacing 3 | 3 | 97 | 36.81 | 9.542 | 25.50 | 54.00 | 68.16 |
| Axle weight 4 | 7690 | 50000 | 20165.18 | 2146.179 | 17500.00 | 23000.00 | 28500.00 |
| Axle spacing 4 | 1 | 6 | 4.42 | . 339 | 4.00 | 5.00 | 6.00 |
| Axle weight 5 | 7690 | 50000 | 20061.84 | 2132.427 | 17500.00 | 22500.00 | 28500.00 |
|  |  |  | $25 \sim 54^{\prime}$ | $\left.{ }_{\square}^{23} 4^{\prime}\right\|^{23}$ | $\begin{aligned} & \text { STP - } 5 \text { axle a } \\ & \text { GVW }=103 \mathrm{k} \end{aligned}$ |  |  |

Fig. 5.5 Representative vehicle for 5-axle permit vehicles (Type 3S2)
$\underline{\text { Split vehicles: A representative vehicle was created as shown in Fig. 5.6. These vehicles are }}$ likely FHWA Class 9 trucks (Type 3S2 split).

| 2091 <br> vehicles | Minimum | Maximum | Mean | landard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile | $l 9^{\text {th }}$ <br> percentile |
| :--- | ---: | ---: | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 48000 | 214000 | 91401.65 | 7417.666 | 82000.00 | 102000.00 | 118680.00 |
| Axle weight 1 | 0 | 23000 | 12036.05 | 1097.481 | 11000.00 | 13000.00 | 18000.00 |
| Axle spacing 1 | 0 | 25 | 17.66 | 2.837 | 12.00 | 20.83 | 22.75 |
| Axle weight 2 | 5500 | 27500 | 19204.29 | 2005.635 | 16000.00 | 22000.00 | 24000.00 |
| Axle spacing 2 | 3 | 19 | 4.54 | 1.381 | 4.17 | 4.58 | 14.67 |



Fig. 5.6 Representative vehicle for 5-axle permit vehicles (Type 3 S 2 split)

## Six-axle Vehicles

A representative vehicle was created as shown in Fig. 5.7. These vehicles are likely FHWA Class 10 trucks (Type 3S3).

| l4178 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile | $99^{\text {th }}$ <br> percentile |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Gross weight | 44000 | 200000 | 106498.75 | 13652.457 | 87000.00 | 135000.00 | 135700.00 |
| Axle weight 1 | 4000 | 25000 | 12287.89 | 1469.588 | 11000.00 | 14000.00 | 20000.00 |
| Axle spacing 1 | 3 | 26 | 17.00 | 3.254 | 12.00 | 20.75 | 22.42 |
| Axle weight 2 | 5380 | 5000 | 20418.66 | 3165.096 | 16000.00 | 27000.00 | 27000.00 |
| Axle spacing 2 | 3 | 44 | 4.58 | 1.280 | 4.00 | 5.00 | 13.42 |
| Axle weight 3 | 5428 | 50000 | 20436.01 | 3131.435 | 16000.00 | 27000.00 | 27000.00 |
| Axle spacing 3 | 1 | 117 | 37.10 | 12.647 | 11.96 | 59.00 | 85.00 |
| Axle weight 4 | 6000 | 50000 | 17761.33 | 2939.650 | 13300.00 | 23000.00 | 25000.00 |
| Axle spacing 4 | 1 | 96 | 5.41 | 5.396 | 4.00 | 6.00 | 37.04 |
| Axle weight 5 | 6000 | 41000 | 17811.86 | 2978.226 | 13000.00 | 23000.00 | 25000.00 |
| Axle spacing 5 | 3 | 16 | 4.76 | 1.423 | 4.00 | 5.50 | 14.08 |
| Axle weight 6 | 5000 | 41000 | 17783.01 | 2996.797 | 13000.00 | 23000.00 | 25000.00 |

Fig. 5.7 Representative vehicle for 6-axle permit vehicles (Type 3S3)

## Seven-axle vehicles

Vehicles (a): A representative vehicle was created as shown in Fig. 5.8. These vehicles are likely FHWA Class 10 trucks (Type 3S4).

| 1161 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile | $99^{\text {th }}$ <br> percentile |
| :--- | ---: | ---: | :--- | ---: | ---: | ---: | ---: |
| Gross weight | 78000 | 200000 | 124383.86 | 18168.319 | 96000.00 | 150000.00 | 185000.00 |
| Axle weight 1 | 8000 | 31500 | 15106.13 | 4485.624 | 12000.00 | 27000.00 | 27000.00 |
| Axle spacing 1 | 4 | 25 | 14.01 | 4.960 | 5.42 | 20.00 | 21.50 |
| Axle weight 2 | 0 | 31500 | 20275.49 | 2981.010 | 15410.00 | 25000.00 | 28000.00 |
| Axle spacing 2 | 0 | 16 | 5.21 | 2.003 | 4.17 | 6.75 | 14.67 |


| Axle weight 3 | 7000 | 33000 | 20356.83 | 2852.151 | 16349.70 | 25000.00 | 28000.00 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Axle spacing 3 | 4 | 121 | 32.53 | 23.490 | 5.00 | 79.00 | 91.00 |
| Axle weight 4 | 0 | 36200 | 17301.35 | 3495.736 | 12000.00 | 23000.00 | 25000.00 |
| Axle spacing 4 | 0 | 15 | 5.45 | 2.067 | 4.08 | 11.00 | 13.83 |
| Axle weight 5 | 7167 | 36200 | 17202.41 | 3616.101 | 12000.00 | 23000.00 | 25731.80 |
| Axle spacing 5 | 3 | 58 | 7.91 | 6.549 | 4.00 | 19.50 | 27.90 |
| Axle weight 6 | 7167 | 47000 | 17083.85 | 3754.708 | 12000.00 | 23000.00 | 26586.46 |
| Axle spacing 6 | 3 | 15 | 4.91 | 1.445 | 4.00 | 6.67 | 14.08 |
| Axle weight 7 | 7166 | 47000 | 17001.82 | 3825.604 | 11500.00 | 23000.00 | 26586.46 |



STP - 7 axle a $G V W=169 \mathrm{k}$

Fig. 5.8 Representative vehicle for 7 -axle permit vehicles
Vehicles (b): A representative vehicle was created as shown in Fig. 5.9. These vehicles are likely FHWA the Class 13 permit vehicles in Chapter 4.

| $\begin{aligned} & 6965 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{array}{\|l} 5^{\text {th }} \\ \text { percentile } \end{array}$ | $\left\lvert\, \begin{aligned} & 95^{\mathrm{th}} \\ & \text { percentile } \end{aligned}\right.$ | $\begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 81000 | 200000 | 122877.70 | 15583.952 | 95000.00 | 150000.00 | 162000.00 |
| Axle weight 1 | 7000 | 20200 | 12716.70 | 1484.404 | 11000.00 | 15000.00 | 18000.00 |
| Axle spacing 1 | 4 | 28 | 15.30 | 2.235 | 11.67 | 19.25 | 20.58 |
| Axle weight 2 | 4000 | 30000 | 17710.60 | 2989.662 | 12166.00 | 22000.00 | 25000.00 |
| Axle spacing 2 | 3 | 8 | 4.51 | . 264 | 4.17 | 5.00 | 5.50 |
| Axle weight 3 | 7867 | 30000 | 18181.66 | 2703.787 | 13333.00 | 22000.00 | 25000.00 |
| Axle spacing 3 | 4 | 15 | 4.54 | . 532 | 4.25 | 5.00 | 6.67 |
| Axle weight 4 | 7867 | 30000 | 18181.23 | 2698.615 | 13334.00 | 22000.00 | 25000.00 |
| Axle spacing 4 | 17 | 116 | 38.96 | 9.732 | 31.00 | 57.00 | 83.00 |
| Axle weight 5 | 7000 | 31000 | 18703.58 | 2730.326 | 14000.00 | 24000.00 | 25800.00 |
| Axle spacing 5 | 4 | 14 | 4.55 | . 363 | 4.17 | 5.00 | 5.59 |
| Axle weight 6 | 7700 | 31000 | 18704.40 | 2721.374 | 14000.00 | 24000.00 | 25800.00 |
| Axle spacing 6 | 4 | 14 | 4.77 | 1.447 | 4.17 | 5.00 | 14.08 |
| Axle weight 7 | 7700 | 31000 | 18679.54 | 2712.891 | 14000.00 | 24000.00 | 25556.44 |
|  |  |  |  |  | STP - 7 axle bGVW=153 k |  |  |

Fig. 5.9 Representative vehicle for 7 -axle permit vehicles

## Eight-axle vehicles

A representative vehicle was created as shown in Fig. 5.10. These vehicles are likely FHWA the WisDOT Standard Permit Vehicle.

| $\begin{array}{\|l\|} \hline 7323 \\ \text { vehicles } \\ \hline \end{array}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 80000 | 205000 | 160421.67 | 22933.351 | 120000.00 | 190000.00 | 193000.00 |


| Axle weight 1 | 4000 | 22000 | 14892.31 | 3012.295 | 12000.00 | 20000.00 | 21000.00 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Axle spacing 1 | 4 | 28 | 13.45 | 2.775 | 8.50 | 18.08 | 20.00 |
| Axle weight 2 | 6000 | 30000 | 20034.84 | 4363.146 | 12500.00 | 27000.00 | 27000.00 |
| Axle spacing 2 | 3 | 14 | 4.57 | .837 | 4.00 | 5.00 | 10.50 |
| Axle weight 3 | 5000 | 30000 | 22414.52 | 3926.847 | 16000.00 | 29960.00 | 30000.00 |
| Axle spacing 3 | 3 | 75 | 5.06 | 4.094 | 4.17 | 5.90 | 31.99 |
| Axle weight 4 | 6000 | 30000 | 22404.47 | 3954.900 | 16000.00 | 29200.00 | 30000.00 |
| Axle spacing 4 | 2 | 128 | 41.80 | 24.251 | 5.50 | 107.80 | 116.00 |
| Axle weight 5 | 6000 | 28000 | 20277.13 | 3061.095 | 15000.00 | 24000.00 | 26500.00 |
| Axle spacing 5 | 1 | 84 | 5.40 | 5.584 | 4.00 | 5.42 | 35.00 |
| Axle weight 6 | 5000 | 28700 | 20239.99 | 3123.612 | 14750.00 | 24278.00 | 26500.00 |
| Axle spacing 6 | 3 | 32 | 5.13 | 3.021 | 4.00 | 13.50 | 23.92 |
| Axle weight 7 | 5000 | 28000 | 20139.40 | 3027.797 | 14750.00 | 23750.00 | 25000.00 |
| Axle spacing 7 | 0 | 27 | 5.18 | 2.502 | 4.00 | 14.00 | 14.17 |
| Axle weight 8 | 0 | 28000 | 20016.93 | 3117.515 | 14500.00 | 23500.00 | 25000.00 |



Fig. 5.10 Representative vehicle for 8 -axle permit vehicles

## Nine-axle vehicles

Vehicles (a): A representative vehicle was created as shown in Fig. 5.11. These vehicles would be classified as Class 13 or as unrecognized in Class 15 in WIM records. Note that the two tandem axles could have a slightly different configuration: the two wheel groups may be spaced 14 ft rather than 4 ft . The shorter spacing ( 4 ft ) was used to be conservative in the following analysis.

| $\begin{aligned} & 1105 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $\sqrt{5^{\text {th }}}$ <br> percentile | $\left\lvert\, \begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}\right.$ | $\begin{aligned} & \hline 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 67000 | 229000 | 170984.47 | 19355.730 | 137342.00 | 195700.00 | 209880.00 |
| Axle weight 1 | 5000 | 20000 | 13145.07 | 1680.151 | 12000.00 | 17000.00 | 18940.00 |
| Axle spacing 1 | 11 | 28 | 17.90 | 2.675 | 12.17 | 21.75 | 23.83 |
| Axle weight 2 | 5000 | 30000 | 19548.25 | 2574.975 | 15000.00 | 22500.00 | 24477.50 |
| Axle spacing 2 | 2 | 6 | 4.51 | . 219 | 4.25 | 5.00 | 5.08 |
| Axle weight 3 | 5000 | 30000 | 19579.18 | 2563.781 | 15000.00 | 22500.00 | 24477.50 |
| Axle spacing 3 | 4 | 38 | 13.87 | 4.250 | 4.50 | 17.00 | 31.17 |
| Axle weight 4 | 6000 | 30000 | 19731.60 | 2557.778 | 15145.00 | 22500.00 | 25000.00 |
| Axle spacing 4 | 4 | 10 | 4.62 | . 755 | 4.25 | 5.00 | 10.08 |
| Axle weight 5 | 6000 | 30000 | 19704.81 | 2573.964 | 15145.00 | 22500.00 | 25000.00 |
| Axle spacing 5 | 21 | 99 | 38.23 | 8.665 | 29.33 | 57.08 | 72.83 |
| Axle weight 6 | 6150 | 27000 | 19842.32 | 2487.490 | 15000.00 | 23000.00 | 24000.00 |
| Axle spacing 6 | 4 | 5 | 4.55 | . 200 | 4.17 | 5.00 | 5.00 |
| Axle weight 7 | 6150 | 27000 | 19844.41 | 2485.940 | 15000.00 | 23000.00 | 24000.00 |
| Axle spacing 7 | 1 | 18 | 11.84 | 4.101 | 4.17 | 14.50 | 15.42 |
| Axle weight 8 | 6150 | 27000 | 19799.38 | 2468.964 | 15000.00 | 23000.00 | 24000.00 |
| Axle spacing 8 | 4 | 16 | 5.01 | 2.002 | 4.33 | 11.35 | 14.49 |



Fig. 5.11 Representative vehicle for 9-axle permit vehicles (Type a)
Vehicles (b): A representative vehicle was created as shown in Fig. 5.12.

| 1618 vehicles | Minimum | Maximum | Mean | Standard deviation | $\begin{array}{\|l} 5^{\text {th }} \\ \text { percentile } \\ \hline \end{array}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 87000 | 300000 | 167533.52 | 29428.268 | 102000.00 | 207000.00 | 220000 |
| Axle weight 1 | 6500 | 20000 | 15117.19 | 2395.242 | 12000.00 | 20000.00 | 20000 |
| Axle spacing 1 | 5 | 22 | 11.74 | 4.005 | 5.58 | 18.00 | 20.08 |
| Axle weight 2 | 2000 | 35000 | 18571.31 | 4248.955 | 12000.00 | 26000.00 | 27000 |
| Axle spacing 2 | 4 | 12 | 5.84 | 2.491 | 4.25 | 10.50 | 10.5 |
| Axle weight 3 | 6500 | 35000 | 20760.29 | 3555.155 | 14000.00 | 26000.00 | 27000 |
| Axle spacing 3 | 4 | 60 | 6.25 | 7.033 | 4.25 | 14.00 | 42.89 |
| Axle weight 4 | 6600 | 35000 | 20553.00 | 4031.203 | 12500.00 | 26000.00 | 27000 |
| Axle spacing 4 | 4 | 120 | 34.99 | 26.248 | 5.00 | 88.33 | 110 |
| Axle weight 5 | 6700 | 35000 | 19240.50 | 4458.718 | 10100.00 | 24000.00 | 26666 |
| Axle spacing 5 | 4 | 20 | 4.95 | 1.466 | 4.00 | 6.08 | 13.62 |
| Axle weight 6 | 6000 | 35000 | 19238.85 | 4496.292 | 10100.00 | 24000.00 | 27000 |
| Axle spacing 6 | 4 | 69 | 8.75 | 7.746 | 4.00 | 18.50 | 36 |
| Axle weight 7 | 6600 | 35000 | 18060.69 | 3915.999 | 10100.00 | 24000.00 | 27000 |
| Axle spacing 7 | 4 | 51 | 8.48 | 4.777 | 4.17 | 14.83 | 17 |
| Axle weight 8 | 5000 | 35000 | 18003.58 | 4041.870 | 10000.00 | 24000.00 | 27000 |
| Axle spacing 8 | 3 | 15 | 4.56 | . 918 | 4.00 | 5.00 | 6 |
| Axle weight 9 | 5000 | 35000 | 17988.13 | 4055.228 | 10000.00 | 24000.00 | 27000 |
|  |  | $\left.\int_{1}^{26}\right\|_{\mid} ^{26} 4^{26}$ | $5 \sim 89^{\prime}$ | $4^{\prime}\left\|4^{\prime} x^{4}\right\| 4^{\prime} 4^{\prime}$ | STP - 9 axle b GVW=218 k |  |  |

Fig. 5.12 Representative vehicle for 9-axle permit vehicles (Type b)

## Ten-axle vehicles

Vehicles (a): A representative vehicle was created as shown in Fig. 5.13.

| 692 <br> vehicles | Minimum | Maximum | Mean | Standard <br> deviation | $5^{\text {th }}$ <br> percentile | $95^{\text {th }}$ <br> percentile | $99^{\text {th }}$ <br> percentile |
| :--- | ---: | ---: | :--- | :--- | :--- | :--- | :--- |
| Gross weight | 85000 | 296000 | 188093.45 | 22504.109 | 152825.00 | 226000.00 | 241490.00 |
| Axle weight 1 | 8000 | 20000 | 12797.54 | 1460.332 | 12000.00 | 16000.00 | 20000.00 |
| Axle spacing 1 | 4 | 22 | 16.10 | 1.929 | 12.67 | 19.67 | 20.84 |
| Axle weight 2 | 6500 | 32500 | 16632.55 | 2910.458 | 12565.00 | 21600.00 | 25000.00 |
| Axle spacing 2 | 4 | 6 | 4.53 | .219 | 4.33 | 5.00 | 5.42 |


| Axle weight 3 | 6500 | 32500 | 16694.07 | 2860.584 | 12666.00 | 21677.90 | 25000.00 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Axle spacing 3 | 4 | 40 | 5.81 | 5.196 | 4.33 | 14.03 | 36.33 |
| Axle weight 4 | 6500 | 34000 | 16623.74 | 2882.248 | 12667.00 | 20000.00 | 25140.00 |
| Axle spacing 4 | 2 | 32 | 13.27 | 3.312 | 4.50 | 16.00 | 18.50 |
| Axle weight 5 | 8000 | 34000 | 20923.79 | 3184.720 | 15130.00 | 27000.00 | 27000.00 |
| Axle spacing 5 | 4 | 10 | 4.58 | .335 | 4.33 | 5.00 | 6.00 |
| Axle weight 6 | 8000 | 34000 | 20929.57 | 3180.960 | 15130.00 | 27000.00 | 27000.00 |
| Axle spacing 6 | 21 | 84 | 39.94 | 8.035 | 32.00 | 56.42 | 70.00 |
| Axle weight 7 | 8000 | 36000 | 20924.43 | 2716.401 | 17000.00 | 25000.00 | 25140.00 |
| Axle spacing 7 | 4 | 6 | 4.58 | .252 | 4.33 | 5.00 | 6.00 |
| Axle weight 8 | 8000 | 36000 | 20929.06 | 2712.702 | 17000.00 | 25000.00 | 25140.00 |
| Axle spacing 8 | 4 | 19 | 11.84 | 4.108 | 4.50 | 15.00 | 16.17 |
| Axle weight 9 | 8000 | 36000 | 20813.13 | 2704.452 | 17000.00 | 25000.00 | 25070.00 |
| Axle spacing 9 | 4 | 16 | 4.90 | 1.676 | 4.33 | 6.00 | 14.09 |
| Axle weight 10 | 8000 | 36000 | 20825.56 | 2715.307 | 17000.00 | 25000.00 | 25070.00 |



Fig. 5.13 Representative vehicle for 10-axle permit vehicles (Type a)
Vehicles (b): A representative vehicle was created as shown in Fig. 5.14. The variable spacing indicated that the vehicles would also include flatbed trailers with multiple evenly spaced axles.

| $\begin{array}{\|l\|} \hline 1480 \\ \text { vehicles } \\ \hline \end{array}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 99^{\mathrm{th}} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 88500 | 290000 | 191569.53 | 36274.807 | 107000.00 | 240000.00 | 241000.00 |
| Axle weight 1 | 5000 | 21000 | 16167.01 | 2832.925 | 12000.00 | 20000.00 | 20000.00 |
| Axle spacing 1 | 5 | 25 | 13.40 | 4.284 | 5.58 | 20.00 | 20.83 |
| Axle weight 2 | 8500 | 30000 | 19560.92 | 3924.445 | 14000.00 | 27000.00 | 27000.00 |
| Axle spacing 2 | 2 | 10 | 5.32 | 2.116 | 4.00 | 10.50 | 10.50 |
| Axle weight 3 | 8500 | 30000 | 20942.86 | 3695.340 | 14000.00 | 27000.00 | 27000.00 |
| Axle spacing 3 | 4 | 38 | 7.59 | 5.108 | 4.17 | 15.67 | 18.00 |
| Axle weight 4 | 8000 | 30000 | 21521.57 | 3829.703 | 14000.00 | 27000.00 | 27000.00 |
| Axle spacing 4 | 4 | 88 | 15.91 | 16.581 | 4.25 | 46.00 | 66.00 |
| Axle weight 5 | 6600 | 30000 | 19943.67 | 4111.165 | 9000.00 | 25000.00 | 25000.00 |
| Axle spacing 5 | 4 | 117 | 25.25 | 24.783 | 4.00 | 57.32 | 117.00 |
| Axle weight 6 | 5000 | 30000 | 19800.06 | 4344.118 | 8508.35 | 25000.00 | 25000.00 |
| Axle spacing 6 | 4 | 20 | 6.68 | 5.023 | 4.00 | 18.58 | 18.58 |
| Axle weight 7 | 5000 | 30000 | 18709.08 | 4492.831 | 8682.70 | 25000.00 | 25000.00 |
| Axle spacing 7 | 4 | 57 | 6.14 | 4.357 | 4.00 | 14.50 | 16.22 |
| Axle weight 8 | 5000 | 30000 | 18559.52 | 4608.262 | 8683.65 | 25000.00 | 25000.00 |
| Axle spacing 8 | 4 | 19 | 8.82 | 4.337 | 4.50 | 14.41 | 18.42 |
| Axle weight 9 | 5000 | 30000 | 18147.70 | 5497.941 | 8000.00 | 25000.00 | 25000.00 |
| Axle spacing 9 | 4 | 6 | 4.63 | . 323 | 4.00 | 5.08 | 5.08 |
| Axle weight 10 | 5000 | 30000 | 18217.14 | 5448.610 | 8000.00 | 25000.00 | 25000.00 |



Fig. 5.14 Representative vehicle for 10 -axle permit vehicles

## Eleven-axle vehicles

A representative vehicle was created as shown in Fig. 5.15. Note that the third and seventh spacing can be either 4 ft or 14 ft , reflecting two different arrangements of tandem axles. Though both spacing 6 and spacing 7 have large scattering, the spacing 7 was dominated by a short spacing near 4 ft , hence spacing 6 was selected as the variable spacing.

| $\begin{aligned} & 1041 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 78000 | 266000 | 200626.46 | 26752.097 | 165000.00 | 237000.00 | 254000.00 |
| Axle weight 1 | 8000 | 20000 | 13652.83 | 2032.584 | 11000.00 | 18000.00 | 20000.00 |
| Axle spacing 1 | 5 | 22 | 14.97 | 2.559 | 11.17 | 19.50 | 21.22 |
| Axle weight 2 | 5000 | 25000 | 17756.24 | 3130.528 | 12699.40 | 22500.00 | 25000.00 |
| Axle spacing 2 | 4 | 6 | 4.46 | . 248 | 4.00 | 5.00 | 5.08 |
| Axle weight 3 | 5000 | 25000 | 18056.84 | 3031.116 | 13030.00 | 22500.00 | 25000.00 |
| Axle spacing 3 | 4 | 37 | 7.39 | 6.386 | 4.17 | 27.92 | 28.00 |
| Axle weight 4 | 5000 | 25000 | 17413.82 | 3036.093 | 12667.10 | 22000.00 | 24596.86 |
| Axle spacing 4 | 4 | 38 | 14.00 | 8.345 | 4.08 | 32.00 | 36.00 |
| Axle weight 5 | 6000 | 31000 | 19151.70 | 3269.969 | 14000.00 | 24000.00 | 25000.00 |
| Axle spacing 5 | 4 | 54 | 7.11 | 9.066 | 4.08 | 36.50 | 45.80 |
| Axle weight 6 | 4600 | 31000 | 19034.39 | 3308.489 | 13667.10 | 24000.00 | 25000.00 |
| Axle spacing 6 | 4 | 116 | 32.93 | 23.665 | 4.17 | 88.25 | 105.00 |
| Axle weight 7 | 4600 | 25000 | 18270.64 | 2938.342 | 14000.00 | 22000.00 | 25000.00 |
| Axle spacing 7 | 4 | 113 | 18.56 | 31.524 | 4.00 | 107.00 | 111.00 |
| Axle weight 8 | 4800 | 27000 | 19050.74 | 3380.679 | 14000.00 | 24500.00 | 25000.00 |
| Axle spacing 8 | 4 | 20 | 5.33 | 2.737 | 4.00 | 14.08 | 15.50 |
| Axle weight 9 | 5000 | 28000 | 19049.90 | 3321.379 | 14000.00 | 24500.00 | 25000.00 |
| Axle spacing 9 | 4 | 36 | 11.46 | 4.319 | 4.17 | 15.00 | 16.50 |
| Axle weight 10 | 3000 | 28000 | 19623.11 | 3242.605 | 15000.00 | 24500.00 | 25000.00 |
| Axle spacing 10 | 4 | 15 | 4.60 | . 815 | 4.00 | 5.00 | 10.08 |
| Axle weight 11 | 3000 | 28000 | 19566.25 | 3318.997 | 15000.00 | 24500.00 | 25000.00 |



Fig. 5.15 Representative vehicle for 11 -axle permit vehicles

## Twelve-axle vehicles

A representative vehicle was created as shown in Fig. 5.16.

| $\begin{aligned} & 1590 \\ & \text { vehicles } \end{aligned}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\left\lvert\, \begin{aligned} & 99^{\text {th }} \\ & \text { percentile } \end{aligned}\right.$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 88000 | 295000 | 205544.20 | 29641.935 | 164000.00 | 246200.00 | 255000.00 |
| Axle weight 1 | 10000 | 20000 | 13859.54 | 1535.971 | 12000.00 | 16000.00 | 19000.00 |
| Axle spacing 1 | 5 | 22 | 13.42 | 2.709 | 10.50 | 19.00 | 20.25 |
| Axle weight 2 | 6500 | 27000 | 16513.18 | 2734.014 | 12000.00 | 20000.00 | 22000.00 |
| Axle spacing 2 | 0 | 6 | 4.43 | . 224 | 4.33 | 5.00 | 5.17 |
| Axle weight 3 | 6500 | 27000 | 17057.90 | 2625.704 | 13000.00 | 20000.00 | 22000.00 |
| Axle spacing 3 | 4 | 35 | 5.53 | 3.892 | 4.33 | 15.00 | 18.12 |
| Axle weight 4 | 6700 | 27000 | 16888.00 | 2730.999 | 12000.00 | 20000.00 | 21500.00 |
| Axle spacing 4 | 4 | 56 | 21.59 | 8.654 | 5.00 | 29.00 | 34.55 |
| Axle weight 5 | 6000 | 35000 | 16787.78 | 3010.505 | 12000.00 | 21000.00 | 22817.00 |
| Axle spacing 5 | 4 | 8 | 4.35 | . 417 | 4.08 | 5.00 | 5.75 |
| Axle weight 6 | 6000 | 35000 | 16787.74 | 3007.660 | 12000.00 | 21000.00 | 22817.00 |
| Axle spacing 6 | 2 | 78 | 7.77 | 11.482 | 4.08 | 39.00 | 59.67 |
| Axle weight 7 | 4300 | 35000 | 16710.74 | 3060.617 | 12000.00 | 21000.00 | 22600.00 |
| Axle spacing 7 | 1 | 124 | 72.04 | 39.383 | 5.00 | 120.67 | 124.00 |
| Axle weight 8 | 4300 | 35000 | 18095.60 | 3044.741 | 12000.00 | 21000.00 | 22760.00 |
| Axle spacing 8 | 4 | 71 | 4.87 | 4.909 | 4.00 | 5.00 | 34.08 |
| Axle weight 9 | 4400 | 35000 | 18115.12 | 3011.348 | 13500.00 | 21000.00 | 22760.00 |
| Axle spacing 9 | 4 | 30 | 5.21 | 3.094 | 4.00 | 14.25 | 15.52 |
| Axle weight 10 | 6000 | 25000 | 18121.49 | 2824.081 | 13500.00 | 21000.00 | 22760.00 |
| Axle spacing 10 | 4 | 17 | 11.80 | 2.665 | 5.00 | 14.50 | 15.00 |
| Axle weight 11 | 6700 | 25000 | 18303.67 | 2952.021 | 13000.00 | 22760.00 | 24000.00 |
| Axle spacing 11 | 4 | 14 | 4.31 | . 473 | 4.00 | 5.00 | 5.50 |
| Axle weight 12 | 6600 | 25000 | 18303.42 | 2950.536 | 13000.00 | 22760.00 | 24000.00 |



Fig. 5.16 Representative vehicle for 12 -axle permit vehicles

## Thirteen-axle vehicles

A representative vehicle was created as shown in Fig. 5.17.

| $\begin{array}{\|l\|} \hline 1102 \\ \text { vehicles } \\ \hline \end{array}$ | Minimum | Maximum | Mean | Standard deviation | $\begin{aligned} & 5^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 95^{\text {th }} \\ & \text { percentile } \end{aligned}$ | $\begin{aligned} & 99^{\mathrm{th}} \\ & \text { percentile } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 85000 | 300000 | 201808.56 | 64800.794 | 90000.00 | 270850.00 | 292000.00 |
| Axle weight 1 | 10000 | 20000 | 13836.31 | 2173.282 | 12000.00 | 18000.00 | 20000.00 |
| Axle spacing 1 | 11 | 22 | 15.29 | 1.775 | 12.25 | 18.00 | 20.81 |
| Axle weight 2 | 4300 | 23400 | 15569.66 | 5339.225 | 6250.00 | 21000.00 | 22600.00 |
| Axle spacing 2 | 4 | 5 | 4.60 | . 191 | 4.33 | 5.00 | 5.00 |
| Axle weight 3 | 4300 | 23300 | 15619.61 | 5352.360 | 6250.00 | 21000.00 | 22700.00 |
| Axle spacing 3 | 4 | 26 | 4.86 | 1.889 | 4.33 | 5.00 | 14.08 |
| Axle weight 4 | 4400 | 23300 | 15564.10 | 5371.536 | 6250.00 | 21000.00 | 22700.00 |
| Axle spacing 4 | 4 | 40 | 15.06 | 3.333 | 13.33 | 17.92 | 33.96 |
| Axle weight 5 | 6000 | 27000 | 15762.98 | 5257.973 | 6500.00 | 21500.00 | 23400.00 |


| Axle spacing 5 | 4 | 25 | 4.85 | . 865 | 4.50 | 5.00 | 5.25 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Axle weight 6 | 6000 | 27000 | 15762.79 | 5260.868 | 6500.00 | 21666.00 | 23300.00 |
| Axle spacing 6 | 4 | 34 | 4.92 | 1.547 | 4.50 | 5.00 | 5.25 |
| Axle weight 7 | 6000 | 27000 | 15771.13 | 5258.072 | 6500.00 | 21668.00 | 23300.00 |
| Axle spacing 7 | 4 | 131 | 48.39 | 20.076 | 24.00 | 78.00 | 131.00 |
| Axle weight 8 | 4600 | 26500 | 15496.61 | 5771.854 | 5000.00 | 21487.40 | 25425.00 |
| Axle spacing 8 | 4 | 47 | 4.92 | 1.754 | 4.50 | 5.00 | 5.25 |
| Axle weight 9 | 4600 | 26500 | 15493.10 | 5774.004 | 5000.00 | 21487.40 | 25425.00 |
| Axle spacing 9 | 4 | 14 | 4.84 | . 637 | 4.50 | 5.00 | 5.25 |
| Axle weight 10 | 4667 | 26000 | 15486.58 | 5757.669 | 5000.00 | 21405.40 | 24940.00 |
| Axle spacing 10 | 4 | 23 | 14.00 | 2.269 | 10.00 | 16.00 | 18.50 |
| Axle weight 11 | 3507 | 26000 | 15811.05 | 5237.982 | 6500.00 | 21320.55 | 24455.00 |
| Axle spacing 11 | 2 | 16 | 5.14 | 1.767 | 4.50 | 5.00 | 14.33 |
| Axle weight 12 | 3507 | 26000 | 15818.99 | 5286.196 | 6500.00 | 21416.00 | 24970.00 |
| Axle spacing 12 | 4 | 10 | 4.82 | . 405 | 4.50 | 5.00 | 5.25 |
| Axle weight 13 | 3507 | 26000 | 15815.65 | 5285.281 | 6500.00 | 21368.00 | 24970.00 |
| $\left.\right\|^{18}$ |  | $4^{2} \square_{\square}^{22} 4^{2}$ | 24~78' |  | $\begin{array}{l\|l\|} 12121 \\ 4^{\prime}\left\|4^{\prime}\right\| \\ \hline \end{array}$ | $\begin{aligned} & \text { STP }-13 \text { axle } \\ & \text { GVW }=273 \mathrm{k} \end{aligned}$ |  |

Fig. 5.17 Representative vehicle for 13 -axle permit vehicles

## Comparison of Wis-SPV with single-trip permit vehicles

The effects of the above representative permit vehicles were compared with those of the 250-kip Wisconsin Standard Permit Vehicle for simply supported girders.

## One-span simply supported girders

The maximum positive moments and shear in simply-supported girders with various plan lengths by the 16 representative permit vehicles are shown in Fig. 5.18, and the values are listed in Table 5.1. The effects of the Wisconsin Standard Permit Vehicle are shown in blue dark lines. Again, the legends for other vehicles were not shown to simplify the presentation.


Fig. 5.18 Peak moment/shear values for representative permit vehicles on one-span girders


Fig. 5.19 R-values for representative permit vehicles on one-span girders

Table5.1(a) Peak positive moments in one-span girders by representative permit vehicles (kips-ft)

| Span <br> (ft) | Wis SPV | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 6axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & 7 \text { 7axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 7axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 8axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | STP_ Oaxle_ | Oaxle | 1axle | 2axle | xle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 723.7 | 437.6 | 556.5 | 586.6 | 647.3 | 603.5 | 720.0 | 802.6 | 520.0 | 877.3 | 603.1 | 837.0 | 502.6 | 828.0 | 800.0 | 554.9 | 664.0 |
| 36 | 843 | 514 | 642. | 710.0 | 753.0 | 717.5 | 849.0 | 963.0 | 598.0 | 1068.2 | 702.8 | 1047.9 | 619.9 | 1007.0 | 975.0 | 646.5 | 783.0 |
| 40 | 962.9 | 591.2 | 736.0 | 833.9 | 858.9 | 831.5 | 978.0 | 1123.6 | 676.0 | 1259.1 | 802.4 | 1263.1 | 747.6 | 1186.0 | 1150.0 | 738.2 | 902.0 |
| 44 | 1085 | 668 | 84 | 9 | 96 | 94 | 11 | 1284.3 | 75 | 1450.1 | 902.3 | 1478.3 | 875.3 | 0 | . 0 | 1 | 1030.3 |
| 48 | 1214.6 | 744.9 | 962.3 | 1082.8 | 1083.3 | 1059.5 | 1236.0 | 1471.1 | 851.5 | 1641.0 | 1021.1 | 1693.6 | 1003.5 | 1544.0 | 1500.0 | 921.9 | 1183.6 |
| 52 | 1344.2 | 821 | 1075 | 12 | 1208.7 | 1188.8 | 1383.7 | 1658 | 943.9 | 1845. | 1139.9 | 1913.8 | 1142 | . 1 | 1675.0 | 1018.3 | 5 |
| 56 | 147 | 898 | 11 | 13 | 1334.2 | 1320.4 | 1532.2 | 1846.8 | 1036.6 | 2056.9 | 1258 | 2149.7 | 129 | 1927.8 | 1866.4 | . 0 | 6 |
| 60 | 1603.2 | 975. | 130 | 1457 | 145 | 1451.9 | 1680.7 | 2034.7 | 1146.0 | 2268.8 | 1377.5 | 2385.6 | 1440 | 2126.5 | 2061.1 | 1280.8 | 7 |
| 64 | 1732.8 | 1052.5 | 1417.7 | 1582.8 | 1585.1 | 1583.5 | 1829.1 | 2222.7 | 1302.7 | 2480.8 | 1496.4 | 2621.5 | 1589 | 2325.1 | 2255.8 | 1433.7 | 1928.5 |
| 68 | 1865.6 | 1129. | 1531.9 | 1708 | 1710.5 | 1715.2 | 1977.6 | 2410.6 | 1470.4 | 2692.7 | 1666.2 | 2857.5 | 1738 | 2523.8 | 2450.5 | 1586.9 | 2115.3 |
| 72 | 20 | 12 | 16 | 18 | 18 | 1847.0 | 2126 | 2598.5 | 1638.6 | 2904.6 | 18 | 3093.5 | 1887 | . 5 | . 2 | . 9 | 2302.1 |
| 76 | 226 | 128 | 1760 | 195 | 196 | 1978.8 | 2275 | 2786.4 | 1807. | 311 | 2066 | 3329.5 | 2036 | 2921 | 2839.9 | 896 | 4 |
| 80 | 2509. | 1360. | 187 | 2084 | 2086.9 | 2110.6 | 2423.7 | 2974.4 | 1975.6 | 3328.4 | 2276.2 | 3565.5 | 2185 | 3119.9 | 3034.6 | 58.6 | 2699.4 |
| 84 | 2753. | 1437 | 198 | 22 | 2212.3 | 2242.5 | 2572. | 3162.3 | 214 | 35 | 248 | 38 | 2334 | 3318.6 | 3229.2 | 2232.1 | 2 |
| 88 | 2996.7 | 1514. | 2104 | 2335 | 2337 | 2374.5 | 2721.2 | 3350.2 | 2313.8 | 3752.3 | 2700.0 | 4037.5 | 2524.5 | 3517. | 3423.9 | 2405.9 | 31 |
| 92 | 32 | 15 | 22 | 24 | 2463.2 | 2506.5 | 28 | 3538.1 | 2483 | 3964.2 | 2912.9 | 4273.5 | 2748.1 | 3716.3 | 3618.6 | 80.4 | , |
| 96 | 3486. | 1668. | 2333. | 2586. | 2588.7 | 2638.5 | 3018. | 3632.1 | 2652. | 4176.1 | 3126. | 4509.5 | 2971.8 | 3915.2 | 3813.5 | 2754.8 | 3525.2 |
| 100 | 373 | 17 | 24 | 27 | 2714.1 | 2770.5 | 3167.5 | 3914.0 | 28 | 4388.0 | 3339.8 | 5 | 3195.4 | . 1 | 4008.4 | 9.3 | 8 |
| 104 | 3976. | 1822 | 2562.3 | 2838. | 2839.6 | 2902.5 | 3316.3 | 4101.9 | 2991.5 | 4600.0 | 3553.5 | 4981.5 | 3419 | 4313.1 | 4203.4 | 3104.0 | 3940.5 |
| 108 | 4222. | 18 | 2676. | 2963. | 2965.0 | 3034.5 | 3465 | 4289.8 | 3161.4 | 4812.0 | 3767.1 | 5217.5 | 3642.7 | 4512. | 4398. | 3279.2 | 41 |
| 112 | 4469.2 | 1976. | 2791.6 | 3089. | 3090.5 | 3166.5 | 3613.8 | 4477.8 | 3331.3 | 5024.0 | 3980.7 | 5453.5 | 3866.3 | 4710.9 | 4593.2 | 3454.4 | 4355.8 |
| 116 | 4715. | 2053. | 2906. | 3215. | 3215.9 | 3298.5 | 3762. | 4665.7 | 3501.2 | 5236.0 | 4194.3 | 5689.5 | 4090 | 4909.8 | 4788. | 3629.7 | 4563.5 |
| 120 | 4962 | 2130 | 3021. | 3341 | 3341.4 | 3430.5 | 3911.5 | 4853.6 | 3671.1 | 5448.0 | 4408.0 | 5925.5 | 4313.7 | 5108.7 | 4983.1 | 3804.9 | 4771 |
| 124 | 5208.7 | 2207. | 3136.0 | 3467.1 | 3466.8 | 3562.5 | 4060.4 | 5041.5 | 3841.0 | 5660.0 | 4622.2 | 6161.5 | 4537.7 | 5307.7 | 5178.0 | 3980.1 | 4978.8 |
| 128 | 5456.2 | 2284. | 3250.8 | 3592.9 | 3592.3 | 3694.5 | 4209.3 | 5229.5 | 4010.9 | 5872.0 | 4836 | 6397.5 | 4761.6 | 5506.6 | 5372.9 | 4155.7 | 5186.5 |
| 132 | 5703.7 | 2360.9 | 3365.6 | 3718.7 | 3717.8 | 3826.5 | 4358.3 | 5417.4 | 4181.1 | 6084.0 | 5050.6 | 6633.5 | 4985.5 | 5705.5 | 5567.8 | 4331.6 | 5394.1 |
| 136 | 5951.3 | 2437.9 | 3480.5 | 3844.5 | 3843.3 | 3958.5 | 4507.2 | 5605.3 | 4351.5 | 6296.0 | 5264.9 | 6869.5 | 5209.4 | 5904.4 | 5762.7 | 4507.5 | 5601.8 |
| 140 | 6198. | 2514. | 3595.3 | 3970.3 | 3968.8 | 4090.5 | 4656.2 | 5793.2 | 4521.9 | 6508.0 | 5479.1 | 7105.5 | 5433.3 | 6103.3 | 5957.7 | 4683.4 | 5809.5 |

Table 5.1(b) Peak shear in two-span girders by representative permit vehicles (kips)

| Span <br> (ft) | Wis SPV | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | STP <br> 5axle | STP <br> 5axle | $\begin{aligned} & \text { STP } \\ & \text { 6axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 7axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 7axle } \end{aligned}$ | STP <br> 8axle | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | STP <br> 9axle | $\begin{aligned} & \text { STP_1 } \\ & \text { Oaxle_ } \end{aligned}$ | $\begin{aligned} & \text { STP_1 } \\ & \text { Oaxle_ } \end{aligned}$ | $\begin{aligned} & \begin{array}{l} \text { STP_1 } \\ \text { 1axle } \end{array} \end{aligned}$ | $\begin{array}{\|l} \hline \text { STP_1 } \\ \text { 2axle } \end{array}$ | $\begin{aligned} & \text { STP_1 } \\ & 3 \text { 3axle } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 100.4 | 62.8 | 80.7 | 90.9 | 89.0 | 84.4 | 97.5 | 111.1 | 70.7 | 122.1 | 82.4 | 118.9 | 80.8 | 112.1 | 109.3 | 74.7 | 91.4 |
| 36 | 103.7 | 64.4 | 84.5 | 94.8 | 93.0 | 87.7 | 101.3 | 117.3 | 73.1 | 129.8 | 86.5 | 129.7 | 86.1 | 119.5 | 116.6 | 77.9 | 98.3 |
| 40 | 106.3 | 65. | 87. | 97 | 96.3 | 90.4 | 106.1 | 124 | 76.4 | 135.9 | 89.7 | 138.3 | 90.4 | 126.5 | 123.0 | 82.6 | 106.1 |
| 44 | 108.5 | 66.7 | 90.1 | 100.5 | 98.9 | 92.5 | 110.0 | 130.2 | 82.8 | 140.9 | 92.4 | 146.8 | 93.9 | 133.1 | 129.5 | 88.4 | 113.6 |
| 48 | 110 | 67. | 92. | 102.6 | 101.2 | 95.8 | 113.2 | 135.0 | 88.7 | 145 | 98.0 | 154.2 | 96.9 | 138.5 | 135.0 | 94.2 | 119.8 |
| 52 | 118.2 | 68.3 | 93.9 | 104.4 | 103.0 | 98.6 | 116.0 | 139.1 | 93.6 | 150.8 | 105.0 | 160.5 | 100.8 | 143.2 | 139.6 | 99.1 | 125.0 |
| 56 | 125.9 | 68.9 | 95. | 105.9 | 104.6 | 101.0 | 118.3 | 142.6 | 97.9 | 155.2 | 111.5 | 165.9 | 104.3 | 147.2 | 143.5 | 103.3 | 130.6 |
| 60 | 132.5 | 69 | 96 | 107 | 106 | 103. | 120.4 | 145 | 102 | 159 | 117.2 | 170.6 | 107.4 | 150.6 | 14 | 108.2 | 135.7 |
| 64 | 138.6 | 69.9 | 97.9 | 108.5 | 107.2 | 104.8 | 122.2 | 148.3 | 107.0 | 162.3 | 122.1 | 174.6 | 113.1 | 153.7 | 150.0 | 112.5 | 140.3 |
| 68 | 145.2 | 70. | 98. | 109 | 108.3 | 106.4 | 123.7 | 150.6 | 110.8 | 165.2 | 126.4 | 178.3 | 118.4 | 156.3 | 152.6 | 116.3 | 144.2 |
| 72 | 151.0 | 70.7 | 99.8 | 110.4 | 109.3 | 107.9 | 125.1 | 152.7 | 114.1 | 167.8 | 130.3 | 181.5 | 123.2 | 158.7 | 155.0 | 119.7 | 147.8 |
| 76 | 156.2 | 71 | 100. | 111.2 | 110 | 109. | 126.4 | 154 | 117 | 17 | 134.1 | 184 | 127. | 160.8 | 157.1 | 122.7 | 1.0 |
| 80 | 160.9 | 71.3 | 101. | 112. | 110.9 | 110.3 | 127.5 | 156.2 | 119.8 | 172.2 | 138.1 | 186.9 | 131.3 | 162.7 | 159.0 | 125.4 | 153.8 |
| 84 | 165.1 | 71. | 101.9 | 112.6 | 111.6 | 111.3 | 128.6 | 157.7 | 122.2 | 174. | 141.8 | 189.2 | 134.7 | 164.5 | 160.7 | 127.9 | 156.4 |
| 88 | 169.0 | 71. | 102. | 113. | 112.2 | 112 | 129 | 159.1 | 124.4 | 175.8 | 145.1 | 191.4 | 137 | 166.0 | 162.3 | 130.1 | 158.7 |
| 92 | 172.5 | 72.1 | 103. | 113 | 112.8 | 113.1 | 130.3 | 160.4 | 126.5 | 177.4 | 148.1 | 193.3 | 140.7 | 167.5 | 163.7 | 132.2 | 160.9 |
| 96 | 175.8 | 72.3 | 103.6 | 114.3 | 113.3 | 113.9 | 131.1 | 160.9 | 128.3 | 178.9 | 150.9 | 195.1 | 143.4 | 168.8 | 165.0 | 134.0 | 162.8 |
| 100 | 178.7 | 72.5 | 104. | 114.8 | 113.8 | 114.6 | 131.8 | 162.6 | 130.0 | 180.2 | 153.5 | 196.7 | 145.8 | 170.0 | 166.2 | 135.7 | 164.6 |
| 104 | 181.5 | 72. | 104.5 | 115.2 | 114.3 | 115.3 | 132.5 | 163.5 | 131 | 181.4 | 155.9 | 198.2 | 148.0 | 171.1 | 167.3 | 137.3 | 166. |
| 108 | 184.0 | 72.8 | 104.8 | 115.6 | 114.7 | 115.9 | 133.1 | 164.4 | 133.1 | 182.5 | 158.0 | 199.6 | 150.1 | 172.1 | 168.3 | 138.8 | 167.9 |
| 112 | 186.4 | 72.9 | 105.2 | 11 | 115.1 | 116.5 | 133.7 | 165.3 | 134.4 | 183.6 | 160.1 | 200.9 | 152.0 | 173.1 | 169.3 | 140.2 | 169.3 |
| 116 | 188.6 | 73. | 105.5 | 116.3 | 115.4 | 117.0 | 134.2 | 166.1 | 135.7 | 184.6 | 162.0 | 202.1 | 153.8 | 174.0 | 170.2 | 141.4 | 170.6 |
| 120 | 190.6 | 73.2 | 105.9 | 116.6 | 115.8 | 117.5 | 134.7 | 166.8 | 136.9 | 185.5 | 163.7 | 203.3 | 155.9 | 174.8 | 171.0 | 142.6 | 171.9 |
| 124 | 192.5 | 73. | 106.2 | 11 | 11 | 11 | 135.2 | 167.5 | 138.0 | 186.3 | 165.4 | 204.3 | 158.1 | 175.6 | 171.8 | 143.7 | 173.0 |
| 128 | 194.3 | 73.5 | 106.4 | 117.2 | 116.4 | 118.4 | 135.6 | 168.1 | 139.0 | 187.1 | 166.9 | 205.3 | 160.2 | 176.3 | 172.5 | 144.8 | 174.1 |
| 132 | 196.0 | 73.6 | 106.7 | 117.5 | 116.6 | 118.8 | 136.0 | 168.7 | 140.0 | 187.9 | 168.4 | 206.2 | 162.1 | 177.0 | 173.2 | 145.7 | 175.2 |
| 136 | 197.6 | 73.7 | 106.9 | 117.7 | 116.9 | 119.2 | 136.4 | 169.3 | 140.9 | 188.6 | 169.8 | 207.1 | 163.9 | 177.7 | 173.8 | 146.7 | 176.1 |
| 140 | 199.1 | 73.8 | 107.2 | 118.0 | 117.2 | 119.6 | 136.7 | 169.8 | 141.7 | 189.3 | 171.1 | 207.9 | 165.6 | 178.3 | 174.4 | 147.5 | 177.0 |

## Two-span simply supported girders

The maximum moments and shear in simply-supported girders with various plan lengths by the 16 representative permit vehicles are shown in Fig. 5.20, and the values are listed in Table 5.2.


Fig. 5.20 Peak moment/shear values for representative permit vehicles on two-span girders


Fig. 5.21 R-values for representative permit vehicles on two-span girders

Table 5.2(a) Peak positive moments in two-span girders by representative permit vehicles (kips-ft)

| Span <br> (ft) | Wis SPV | STP <br> 3axle | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | 5axle | 6axle | STP <br> 7axle | 7axle | $\begin{aligned} & \text { STP } \\ & \text { 8axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | 9axle | Oaxle | Oaxle | 1axle | $2 \mathrm{a}$ | 3axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 577.2 | 351.2 | 445.5 | 472.2 | 517.0 | 474.3 | 563.8 | 626.8 | 417.6 | 681.5 | 481.0 | 648.2 | 411.7 | 636.2 | 613.6 | 442.5 | 520.0 |
| 36 | 675.0 | 412.9 | 516.8 | 568.7 | 603 | 565.8 | 668.6 | 755.4 | 481.9 | 830.2 | 562.5 | 813.4 | 495.6 | 778.2 | 752.1 | 517.5 | 616.7 |
| 40 | 774 | 475. | 603.1 | 666. | 690 | 658.0 | 773.9 | 885.1 | 546.2 | 980.9 | 644.3 | 982.1 | 589.7 | 922.1 | 892.7 | 592.7 | 716.9 |
| 44 | 878 | 53 | 69 | 76 | 781.4 | 75 | 880.4 | 10 | 5 | 11 | 72 | 1153.2 | 690.3 | 1066.9 | 1034.2 | 2 | 7.4 |
| 48 | 982.8 | 600.4 | 780.8 | 866.8 | 879.0 | 850.1 | 997.0 | 1164.8 | 690.7 | 1294.8 | 822.9 | 1325.7 | 792.1 | 1216.3 | 1176. | 743.8 | 951.3 |
| 52 | 108 | 66 | 87 | 96 | 977 | 95 | 1114.9 | 13 | 765.4 | 146 | 917 | 1504.3 | 894.8 | 1373.6 | 1329. | . 1 | , |
| 56 | 1193.6 | 726 | 962.6 | 1069.2 | 1077 | 1059 | 1233.8 | 146 | 840.5 | 163 | 10 | 1689.6 | 1010.8 | 1532.2 | 148 | 932 | 1231.8 |
| 60 | 1299.5 | 78 | 105 | 1171.1 | 1177 | 116 | 1353.3 | 1615 | 935.0 | 1801 | 1109.0 | 1876. | 1128.9 | 1691.8 | 1640.4 | 10 | 2 |
| 64 | 1405 | 85 | 1146.7 | 12 | 12 | 12 | 1473.4 | 17 | 1051.9 | 1972. | 1209.2 | 2064.8 | 1247.7 | . 2 |  | 23.1 | 5.9 |
| 68 | 1528.5 | 916.3 | 1239.3 | 1375.7 | 1379. | 1378.0 | 1594.0 | 1919.7 | 1175.3 | 2143.6 | 1345.2 | 2254.0 | 1367.1 | 2013.0 | 1954.5 | 1281 | 1674.8 |
| 72 | 167 | 97 | 13 | 14 | 14 | 14 | 1715.0 | 2072.5 | 1301.0 | 23 | 14 | 24 | 1487.0 | 6 | 5 | 1401.2 | 1832.1 |
| 76 | 1844 | 1043 | 1425 | 1581. | 158 | 1592 | 1836.3 | 2225.7 | 1428.5 | 2488 | 1655.5 | 263 | 1607 | 2336. | 2270.8 | 1522.3 | 1993.2 |
| 80 | 2022 | 110 | 15 | 1684. | 1684 | 1699.8 | 1957.8 | 2379.1 | 1557.4 | 266 | 1815.7 | 2826.7 | 1728.0 | 2498.6 | 2429.5 | 1650.2 | 6 |
| 84 | 2203 | 117 | 161 | 1787.3 | 178 | 18 | 2079.5 | 2532.8 | 1687.7 | 283 | 1977.8 | 3019.2 | 186 | 266 | 2588.6 | 178 | 2319.0 |
| 88 | 23 | 12 | 170 | 18 | 18 | 19 | 2201.5 | 2686.8 | 1821.4 | 3007 | 21 | 3212.1 | 2011.4 | 2823.9 | 2747.9 | 1916.9 | 3 |
| 92 | 2572 | 1297. | 1800.2 | 1994. | 1993 | 20 | 2323.5 | 2840.9 | 1956.0 | 3181 | 2306.6 | 3405.2 | 2174.4 | 2986.9 | 2907.5 | 2052.1 |  |
| 96 | 2760. | 136 | 1894.3 | 2098. | 2096 | 2131.7 | 2445.7 | 2995.2 | 2091.2 | 3354. | 2473 | 3598.6 | 2339. | 3150 | 3067 | 2190 | 2814.0 |
| 100 | 295 | 142 | 1988.7 | 22 | 2199 | 2240.0 | 2568.0 | 3149.6 | 2227.0 | 3528.7 | 2640.4 | 3792.1 | 2506 | 3313.1 | 3226.9 | 2330.0 | 2980 |
| 104 | 3146. | 1488.3 | 2083.1 | 2305.5 | 2302 | 2348.4 | 2690.5 | 3304.3 | 2363.2 | 3703. | 2808 | 3985.9 | 2675.0 | 3476.7 | 3387.0 | 2470.1 | 3147.0 |
| 108 | 3341. | 1552 | 21 | 24 | 240 | 24 | 281 | 345 | 2500. | 3877.3 | 2977. | 4179.8 | 2844.8 | 3640.3 | 3547.3 | 2610 | 3314.1 |
| 112 | 3537.9 | 1615.7 | 2272.2 | 2513.3 | 2509. | 2565.5 | 2935.7 | 3613.8 | 2637.0 | 4051.7 | 3147. | 4373.8 | 3015.9 | 3804.1 | 3707.6 | 2751.7 | 3481.7 |
| 116 | 3734.9 | 1679.4 | 2366.8 | 2617.2 | 2613.2 | 2674.2 | 3058.4 | 3768.7 | 2774.4 | 4226.2 | 3317.9 | 4568.0 | 3191.6 | 3967.8 | 3868.0 | 2893 | 3649.6 |
| 120 | 3932. | 1743.1 | 2461.5 | 2721.2 | 2716.7 | 2782.8 | 3181.1 | 3923.6 | 2912.0 | 4400.7 | 3488.8 | 4762.3 | 3370.0 | 4131.7 | 4028.5 | 3034.8 | 3817.7 |
| 124 | 4131.0 | 1806.8 | 2556.2 | 2825.2 | 2820.3 | 2891.5 | 3303.9 | 4078.6 | 3049.9 | 4575. | 3660.3 | 4956.6 | 3549.0 | 4295.7 | 4189.1 | 3176.9 | 3986.1 |
| 128 | 4330.0 | 1870.5 | 2651.0 | 2929.3 | 2923.9 | 3000.3 | 3426.8 | 4233.7 | 3188.3 | 4750.1 | 3832.1 | 5151.1 | 3728.5 | 4459.7 | 4349 | 3319.3 | 4154.7 |
| 132 | 4529.5 | 1934.2 | 2745.8 | 3033.3 | 3027.5 | 3109.2 | 3549.6 | 4388.8 | 3327.0 | 4924.9 | 4004.3 | 5345.6 | 3908.2 | 4623.8 | 4510.5 | 3462.0 | 4323.6 |
| 136 | 4729.4 | 1998.0 | 2840.7 | 3137.5 | 3131.2 | 3218.0 | 3672.6 | 4543.9 | 3465.9 | 5099.8 | 4176.9 | 5540.2 | 4088.5 | 4787.9 | 4671.2 | 3604.8 | 4492.8 |
| 140 | 4929.8 | 2061.7 | 2935.5 | 3241 | 3234.9 | 3326.9 | 3795.6 | 4699.1 | 3604.9 | 5274.8 | 4349.9 | 5734 | 4269.1 | 4952.1 | 4832.1 | 3747.9 | 4662.5 |

Table 5.2(b) Peak negative moments in two-span girders by representative permit vehicles (kips-ft)

| Span <br> (ft) | Wis SPV | 3axle | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | 4axle | 5axle | 5axle | 6axle | STP <br> 7axle | STP <br> 7axle | 8axle | $9 \text { axle }$ | 9axle | Oaxle | Oaxle | 1axle | 2axle | axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -547.7 | -229.6 | -322.7 | -376.2 | -352.9 | -339.2 | -400.6 | -491.8 | -433.9 | -552.8 | -503.5 | -610.7 | -369.4 | -518.1 | -481.9 | -442.9 | -518, |
| 36 | -688. | -25 | -354 | -425 | -396 | -390.6 | -457 | -572.6 | -512 | -643 | -613 | -71 | -483.0 | -603.2 | -555.2 | -528.1 | -606 |
| 40 | -831.6 | -270. | -381.9 | -475.5 | -435.9 | -444.0 | -513.2 | -652.1 | -592.2 | -732.5 | -708.1 | -813.1 | -608.6 | -687.2 | -629. | -608.8 | -682.2 |
| 44 | -960.5 | -298.5 | -413.8 | -524 | -483.1 | -499.8 | -575.1 | -730.2 | -663.5 | -820.6 | -799.6 | -911.7 | -720.8 | 769.9 | . 6 | -679.1 | -748.1 |
| 48 | -1074.3 | -330.2 | -451. | -569.8 | -534.8 | -554.8 | -636.5 | -807.6 | -733.5 | -907.7 | -890.4 | -1009.2 | -820.9 | -851.8 | -795. | -740 | -805.9 |
| 52 | -1175.1 | -361. | -496 | -609 | -586 | -609.3 | -697.2 | -884.3 | -803.1 | -994 | -979.6 | 1105.9 | -917.7 | -933.0 | -876.9 | -794.9 |  |
| 56 | -1264.7 | -392.9 | -546.1 | -643.8 | -636.9 | -663.5 | -757.6 | -960.4 | -872.2 | -1080.1 | -1068.0 | -1201.6 | -1017.2 | -1013.7 | -957.9 | -842.9 | -903.3 |
| 60 | -1344. | -423.9 | -594. | -674 | -687.6 | -717.1 | -817.6 | -1036.1 | -940.9 | -1165.4 | -1155.9 | -1296.9 | -1114.3 | -1093.7 | -1038.3 | -886 | -975.1 |
| 6 | -1417.0 | -454.8 | -642. | -723 | -738 | -770.4 | -877.3 | -1111.4 | -1009.4 | -1250.5 | -1243.3 | -1391.5 | -1210.6 | -1173.7 | -1118.1 | -925.6 | 10 |
| 68 | -1482.2 | -485. | -690.4 | -775.3 | -788.0 | -823.5 | -936.8 | -1186.3 | -1077.6 | -1335.1 | -1330.3 | -1485.8 | -1305.6 | -1253.2 | -1197 | -961. | -1158. |
| 72 | -1540. | -516 | -737 | -826 | -838 | -875 | -996.1 | -1260.9 | -1145 | -1419.2 | -1416.6 | -1579.7 | -1399.8 | -1332.1 | -12 | -995.8 | -1248.5 |
| 76 | -1594.4 | -546 | -784 | -877 | -887.9 | -923.7 | -1055.2 | -1335.3 | -1213.0 | -1503.2 | -1502.7 | -1673.3 | -1493.3 | -1410.9 | -1354.9 | -1027.3 |  |
| 80 | -1643.3 | -576. | -831. | -927. | -937.6 | -967.9 | -1114.1 | -1409.6 | -1280.5 | -1587.0 | -1588. | -1766.7 | -1586.1 | -1489.5 | -1433.2 | -1103.8 | -1426.0 |
| 84 | -1688.3 | -607. | -878.2 | -978. | -987.1 | -1008.8 | -1172.9 | -1483.6 | -1347.9 | -1670.6 | -1674.2 | -1859.7 | -1678.4 | -1568.1 | -1511.2 | -1183. | -1513.7 |
| 88 | -1729.5 | -637. | -9 | -1028 | -1036.5 | -1047.2 | -1231.5 | -1557.4 | -1415.1 | -1753.9 | -1759.5 | -1952.6 | -1770.2 | -1646.3 | -1588.9 | -1261.4 | -1600. |
| 92 | -1767.5 | -667.9 | -970.8 | -1078.5 | -1085.7 | -1100.8 | -1290.2 | -1631.3 | -1482.2 | -1837.1 | -1844.6 | -2045.3 | -1861.7 | -1724.5 | -1666. | -1339.1 | -1687.3 |
| 96 | -1803.4 | -698 | -1016.9 | -1128 | -1132 | -1154.4 | -1348.8 | -1705.1 | -1549.2 | -1920.4 | -1929.6 | -2138 | -1952.7 | -1801 | -1744. | -1416.1 |  |
| 100 | -1882.8 | -728. | -1062.9 | -1178.7 | -1176.1 | -1207.8 | -1407.2 | -1778.9 | -1616.3 | -2003.6 | -2014.6 | -2230.7 | -2043.3 | -1874.1 | -1821.3 | -1492. | -1859.0 |
| 104 | -1996.6 | -758 | -1108. | -1228. | -1216.7 | -1260.7 | -1465.5 | -1852.2 | -1683.2 | -2086.4 | -2099.2 | -2322.8 | -2133.6 | -1941.3 | -1898.2 | -1567.9 | -1944.1 |
| 108 | -2110.2 | -788 | -1154. | -1277. | -1262.2 | -1313.4 | -1523.6 | -1925.5 | -1749.9 | -2169.1 | -2181.2 | -2414.9 | -2222.2 | -2004.7 | -1974.9 | -1643 | -2029.0 |
| 112 | -2222.7 | -818.2 | -1200.1 | -1327.4 | -1311.8 | -1366.1 | -1581.7 | -1998.8 | -1816.5 | -2251.8 | -2258.5 | -2507.0 | -2307.5 | -2064.9 | -2051.6 | -1717.9 |  |
| 116 | -2333. | -848 | -1245.7 | -1376.9 | -136 | -1418.9 | -1638.7 | -2072.0 | -1880.7 | -2334.4 | -2331.7 | -2599. | -2388.5 | -2136.4 | -2128.2 | -1792.3 |  |
| 120 | -2444.4 | -878. | -1291.1 | -1426.2 | -1410.8 | -1471.3 | -1693.1 | -2145.1 | -1941.4 | -2416.9 | -2400.8 | -2690.9 | -2465.4 | -2215.6 | -2204. | -1866.1 | -2281.6 |
| 124 | -2554. | -908. | -1336. | -1475.6 | -1460.2 | -1523.8 | -1744.5 | -2217.9 | -1998.9 | -2499.5 | -2466.5 | -2782.7 | -2538.6 | -2294. | -2281. | -1939.8 | -2365.3 |
| 128 | -2662.9 | -938.3 | -1381.7 | -1524.9 | -1509.7 | -1576.0 | -1793.2 | -2288.2 | -2053.7 | -2582.0 | -2528.6 | -2874.5 | -2608.8 | -2373.6 | -2357.6 | -2013.0 | -24 |
| 132 | -2770.9 | -968.1 | -1427.0 | -1574.2 | -1559.1 | -1628.1 | -1845.6 | -2355.1 | -2105.7 | -2664.4 | -2587.8 | -2966.3 | -2675.8 | -2452.6 | -2433.9 | -2085.9 | -2532 |
| 136 | -2878.4 | -998.0 | -1472.2 | -1623.6 | -1608.3 | -1680.3 | -1904.2 | -2418.8 | -2155.0 | -2746.8 | -2643.8 | -3058.0 | -2739.6 | -2531.3 | -2510.1 | -2158.6 | -2615.2 |
| 140 | -2985.5 | -1027.9 | -1517.4 | -1672.9 | -1657.5 | -1732.4 | -1962.7 | -2479.4 | -2202.0 | -2829.0 | -2697.3 | -3149.6 | -2801.3 | -2609.6 | -2586.1 | -2231.0 | -2698.2 |

Table 5.2(c) Peak shear in two-span girders by representative permit vehicles (kips)

| Span <br> (ft) | $\begin{aligned} & \text { Wis_ } \\ & \text { SPV } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{array}{\|l\|} \hline \text { STP } \\ \text { Saxle_ } \end{array}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 6axle } \end{aligned}$ | STP <br> 7axle | STP <br> 7axle | $\begin{aligned} & \text { STP } \\ & \text { 8axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | 9axle | Oaxle | Oaxle | 1axle | $2 \mathrm{ax} \mathrm{l}$ | $\begin{aligned} & \text { STP_1 } \\ & \text { 3axle } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 107.4 | 66.4 | 86.1 | 97.8 | 95.2 | 92.9 | 107.4 | 124.3 | 77.1 | 136.6 | 90.2 | 131.8 | 89.4 | 125.4 | 122.7 | 82.8 | 102.1 |
| 36 | 111 | 67 | 90 | 101 | 99 | 96 | 110.8 | 129.8 | 81.2 | 144.5 | 95.9 | 143.9 | 95.3 | 133.2 | 130.4 | 85.7 | 106.8 |
| 40 | 115.9 | 69.0 | 93.3 | 104.8 | 102.7 | 98.6 | 114.8 | 136.0 | 84.4 | 150.7 | 100.8 | 153.3 | 99.9 | 139.2 | 136.3 | 88.3 | 115.6 |
| 44 | 119.7 | 69 | 95 | 107 | 105 | 100.5 | 118.7 | 141.9 | 88.4 | 155.5 | 104.8 | 161.8 | 105.1 | 145.8 | 14 | . 0 | 9 |
| 48 | 123.0 | 70.6 | 97.8 | 109.2 | 107. | 103.8 | 121.8 | 146.8 | 95.3 | 159.8 | 107.9 | 169.6 | 111.0 | 151.4 | 147.5 | 101.6 | 130.7 |
| 52 | 126.4 | 71. | 99 | 110 | 109 | 106.5 | 124.5 | 150.8 | 100.9 | 164.9 | 115.1 | 176.1 | 115.9 | 156.1 | 152.1 | 107.2 | 3 |
| 56 | 135 | 71 | 100 | 112 | 110 | 108 | 126 | 154 | 105. | 169 | 122 | 181.6 | 119.9 | 159.9 | 156.0 | 1.8 | 142.3 |
| 60 | 142.9 | 72.1 | 102.0 | 113.3 | 111. | 110.8 | 128.5 | 157.0 | 111.3 | 172.7 | 128.9 | 186.1 | 123.2 | 163.2 | 159.2 | 117.3 | 147.9 |
| 6 | 149 | 72 | 103 | 11 | 11 | 11 | 13 | 15 | 11 | 17 | 134.4 | 19 | 126.0 | 166.0 | 16 | 122.1 | 2. |
| 68 | 157.4 | 72.8 | 103.9 | 115.1 | 113.8 | 113.9 | 131.5 | 161.5 | 120.2 | 178.5 | 139.1 | 193.5 | 129.8 | 168.4 | 164.5 | 126.2 | 156.8 |
| 72 | 164 | 73 | 104 | 11 | 114. | 11 | 132 | 163 | 123.8 | 180 | 143 | 196 | 135.1 | 170.5 | 166 | 29.80 | 160.5 |
| 76 | 169.8 | 73 | 105 | 116. | 115 | 116 | 133 | 164 | 127 | 182 | 146 | 199.0 | 139.8 | 172.4 | 168.4 | 33.0 | 6 |
| 80 | 17 | 73 | 10 | 11 | 11 | 11 | 13 | 166.3 | 129.8 | 18 | 150.8 | 201.4 | 144.0 | 174.0 | 170. | 135. | 166.5 |
| 84 | 179.6 | 73 | 106 | 117 | 116 | 118 | 135 | 167 | 132 | 186 | 154.8 | 20 | 147.7 | 175.5 | 171.5 | 138.3 | 169.0 |
| 88 | 183.7 | 73 | 106 | 118 | 116 | 11 | 136 | 168.7 | 134. | 187. | 158.3 | 205.2 | 151.0 | 176.8 | 172.8 | 140.6 | 171.2 |
| 92 | 187 | 74 | 10 | 11 | 117 | 119 | 136. | 169.7 | 136.6 | 188.9 | 161.4 | 206.9 | 154.0 | 178.0 | 174.0 | 142.6 | 2 |
| 96 | 190.8 | 74. | 107. | 118. | 117. | 120. | 137.5 | 170.7 | 138.5 | 190 | 164.3 | 208.4 | 156.7 | 179.0 | 175. | 144. | 175.0 |
| 100 | 193.8 | 74 | 10 | 11 | 11 | 120.7 | 138.0 | 171 | 140.1 | 191.2 | 166.9 | 209.7 | 159.2 | 180.0 | 176.0 | 146.1 | 176.7 |
| 104 | 196.6 | 74. | 108. | 119. | 118. | 121 | 138.5 | 172.3 | 141. | 192 | 169.3 | 210.9 | 161.4 | 180.9 | 176. | 147. | 178.2 |
| 108 | 199.1 | 74. | 108. | 119. | 118 | 121.7 | 139. | 172.9 | 143.0 | 193 | 171.4 | 212.1 | 163.4 | 181.7 | 177.7 | 149.0 | 79.6 |
| 112 | 201.4 | 74 | 10 | 12 | 11 | 12 | 139.4 | 173.6 | 14 | 193 | 173.4 | 213.1 | 165.7 | 182.4 | 178.5 | 150.2 | 180.8 |
| 116 | 203.6 | 74. | 109. | 120. | 119. | 12 | 139.8 | 174.2 | 145.4 | 194 | 175.2 | 214.1 | 168.3 | 183.1 | 179.1 | 151. | 182.0 |
| 120 | 205.6 | 74. | 109. | 12 | 11 | 12 | 140. | 174.7 | 146. | 195.3 | 176.9 | 214.9 | 170.6 | 183.7 | 179.8 | 152.5 | 183.1 |
| 124 | 207.4 | 74. | 109.6 | 120.6 | 119.8 | 123.3 | 140.5 | 175.2 | 147.5 | 195.9 | 178.5 | 215.7 | 172.9 | 184.3 | 180. | 153.4 | 184.1 |
| 128 | 209.1 | 75. | 109.8 | 120.8 | 120.0 | 123.6 | 140.8 | 175.7 | 148.4 | 196.5 | 179.9 | 216.5 | 174.9 | 184.9 | 180.9 | 154.4 | 185.0 |
| 132 | 210.6 | 75.0 | 110. | 121.0 | 120.2 | 123.9 | 141.1 | 176.1 | 149.3 | 197.0 | 181.3 | 217.2 | 176.8 | 185.4 | 181.4 | 155.2 | 185.8 |
| 136 | 212.1 | 75.1 | 110.2 | 121.2 | 120.4 | 124.2 | 141.4 | 176.5 | 150.1 | 197.6 | 182.5 | 217.9 | 178.6 | 185.8 | 181.9 | 156.0 | 186.6 |
| 140 | 213.5 | 75.2 | 110.3 | 121.3 | 120.5 | 124.4 | 141.6 | 176.9 | 150.8 | 198.0 | 183.7 | 218.5 | 180.2 | 186.3 | 182.3 | 156.8 | 187.4 |

## Three-span simply supported girders

The maximum moments and shear in 3-span simply-supported girders by the 16 representative permit vehicles are shown in Fig. 5.22, and the values are listed in Table 5.3.


Fig. 5.22 Peak moment/shear values for representative permit vehicles on three-span girders


Fig. 5.23 R-values for representative permit vehicles on three-span girders

Table 5.3(a) Peak positive moments in three-span girders by representative permit vehicles (kips-ft)

| Span <br> (ft) | Wis SPV | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 6axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & 7 \text { 7axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 7axle } \end{aligned}$ | STP <br> 8axle | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | STP_1 | STP_ <br> Oaxle_ | 1axle | 2axic | 3axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | 575.6 | 345.9 | 438.9 | 464.9 | 509.1 | 466.6 | 554.4 | 616.1 | 437.2 | 670.3 | 503.4 | 636.4 | 429.1 | 624.3 | 602.0 | 437.0 | 511.3 |
| 36 | 667.4 | 406.8 | 509.9 | 559.7 | 594.5 | 556.7 | 657. | 742.8 | 505.4 | 816.6 | 588.3 | 798.8 | 513.6 | 764.7 | 739.0 | 509.6 | 606.6 |
| 40 | 763. | 468.1 | 594.6 | 656.4 | 680.1 | 647.5 | 761.6 | 870.7 | 573.6 | 965.1 | 673.4 | 965.0 | 610.7 | 906.4 | 877.4 | 583.9 | 706.1 |
| 44 | 865 | 5 | 681.3 | 75 | 7 | 738.8 | 86 | 10 | 641.9 | 1115.3 | 758.5 | 1133.4 | 712.9 | 1 | 8 | . 4 | 815.3 |
| 48 | 968.8 | 591.7 | 769.5 | 853.4 | 866.7 | 837.3 | 982.1 | 1145.7 | 709.9 | 1274.2 | 835.5 | 1303.4 | 814.2 | 1197.2 | 1157. | 733.1 | 936.9 |
| 52 | 107 | 653 | 85 | 95 | 96 | 939.9 | 10 | 12 | 773.7 | 14 | 91 | 1479.2 | 913.0 | 2 | 8 | . 8 | 1068.8 |
| 56 | 1176 | 716.2 | 948 | 1053 | 1062.2 | 1043 | 121 | 1440.6 | 832.1 | 1605 | 998.5 | 166 | 1015.8 | 508.4 | 146 | 919.6 | 1211.0 |
| 60 | 128 | 77 | 103 | 115 | 11 | 11 | 133 | 158 | 921.5 | 1773.2 | 1093.2 | 1845.7 | 1115.4 | 1665.7 | 1615.0 | 1031.5 | 9 |
| 64 | 138 | 84 | 11 | 12 | 12 | 1252.3 | 1451.6 | 1739.8 | 1036.2 | , | 1192.1 | 2031.1 | 227 | 8 | 5 | 1145.8 | 1500.4 |
| 68 | 1507.7 | 903.7 | 1221.7 | 1355.9 | 1360.3 | 1357.5 | 1570.5 | 1890.3 | 1157.1 | 2110.7 | 1324.1 | 2217.6 | 1344.7 | 1982.5 | 1924.7 | 1262. | 1647.0 |
| 72 | 16 | 96 | 13 | 14 | 146 | 14 | 1689.9 | 2041.3 | 1280.4 | 2280.5 | 14 | 24 | 462.9 | 8 | 2080.5 | 1379.9 | 1803.2 |
| 76 | 1818 | 1029 | 140 | 155 | 1560. | 156 | 1809 | 219 | 1405.7 | 245 | 1628 | 25 | 1581.5 | 2301.5 | 2236.7 | 1499.1 | 1961.7 |
| 80 | 199 | 1091. | 1497.8 | 166 | 1661 | 1675.1 | 1929.4 | 2344.2 | 1532.5 | 2621.2 | 17 | 278 | 1700.6 | 2461.6 | 2393.4 | 162 | 2121.6 |
| 84 | 2169 | 115 | 1590. | 1762 | 17 | 1781.4 | 2049.6 | 2496.1 | 1660.6 | 27 | 19 | 29 | 1834 | 2622.1 | 2550.3 | . 3 | 282.6 |
| 88 | 23 | 12 | 1682.7 | 18 | 18 | 18 | 2170.0 | 2648.2 | 1791.0 | 2963.3 | 2105.7 | 31 | , | 2782.7 | 2707.6 | 1887.1 | 24 |
| 92 | 25 | 128 | 1775 | 19 | 19 | 1994 | 229 | 2800.4 | 1923.6 | . 7 | 2268.0 | 3352.1 | 2141 | 2943.6 | 2865.1 | 2020.2 | 2607.2 |
| 96 | 2715. | 1343. | 1868 | 2068.5 | 2067.7 | 2101.5 | 2411 | 2952.8 | 2056.8 | 3306 | 2431 | 3542. | 2303.7 | 3104.7 | 3022.8 | 2155.1 | 2770. |
| 100 | 29 | 14 | 1961.2 | 217 | 2169.7 | 2208.4 | 2532 | 3105.2 | 2190.8 |  | 2596.6 | 37 | 2467.8 | 3265.8 | 3180.6 | 2 | , |
| 104 | 3093. | 1468. | 2054.2 | 2272.9 | 2271.8 | 2315.4 | 2652.9 | 3258.1 | 2325.1 | 3650.1 | 2762 | 3925.1 | 2633.4 | 3427.4 | 3338.7 | 2430 | 3099 |
| 108 | 3285 | 1531. | 214 | 237 | 2373. | 2422 | 27 | 3410.9 | 2460.1 | 3822.2 | 29 | 41 | 2800.4 | 3589.0 | 3497.0 | 2569 |  |
| 112 | 3478. | 1594.6 | 2240.5 | 2478.1 | 2476.2 | 2529.9 | 2895.1 | 3563.8 | 2595.3 | 3994.5 | 3096.2 | 4308.3 | 2968.7 | 3750.7 | 3655.3 | 2708.2 | 3429.6 |
| 116 | 3673. | 1657.6 | 2333.6 | 2580.8 | 2578.4 | 2637.2 | 3016.3 | 3716.8 | 2730 | 4166.8 | 3264 | 4500.2 | 3138.1 | 3912.4 | 3813.7 | 2847.6 | 3595. |
| 120 | 3868. | 1720.5 | 2427.2 | 2683.5 | 2680.7 | 2744.5 | 3137.6 | 3869.8 | 2866.8 | 4339.2 | 3432.7 | 4692.1 | 3310.8 | 4074.2 | 3972.2 | 2987.5 | 3761 |
| 124 | 4063.5 | 1783.5 | 2520.8 | 2786.3 | 2783.1 | 2851.9 | 3258.8 | 4022.9 | 3002.9 | 4511.8 | 3601.8 | 4884.1 | 3487 | 4236.3 | 4130.9 | 3127.7 | 3927.7 |
| 128 | 4259. | 1846.5 | 2614.4 | 2889.1 | 2885.4 | 2959.3 | 3319.5 | 4176.1 | 3139.3 | 4684.4 | 3771.3 | 5076.2 | 3663.7 | 4398.3 | 4289.6 | 3268.3 | 4094.3 |
| 132 | 4456. | 1909.4 | 2708.0 | 2991. | 2987.7 | 3066.9 | 3501.6 | 4329.4 | 3275.9 | 4857.1 | 3941.2 | 5268.4 | 3840.7 | 4560.4 | 4448.3 | 3409.1 | 4261.1 |
| 136 | 4653.8 | 1972.4 | 2801.7 | 3094.7 | 3090.2 | 3174.4 | 3623.0 | 4482.6 | 3412.7 | 5029.9 | 4111.6 | 5460.7 | 4018.5 | 4722.5 | 4607.1 | 3550.1 | 4428.1 |
| 140 | 4851.5 | 2035.4 | 2895.5 | 3197.7 | 3192.7 | 3282.0 | 3744.5 | 4636.0 | 3549.7 | 5202.7 | 4282.3 | 5653.0 | 4196.9 | 4884.8 | 4766.1 | 3691 | 4595.4 |

Table 5.3(b) Peak negative moments in three-span girders by representative permit vehicles (kips- ft )

| Span <br> (ft) | Wis SPV | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 5axle } \end{aligned}$ | STP <br> 5axle | $\begin{aligned} & \hline \text { ГP } \\ & \text { xxle } \end{aligned}$ | $\begin{aligned} & \text { IP } \\ & \text { ixle_ } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & 7 \text { 7axle } \end{aligned}$ | STP <br> 8axle | STP <br> 9axle | 9axle | Oaxle | Oaxle | laxle | 2axie | 3axle |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -504 | -230.5 | -329.0 | -360.3 | -364 | -350.0 | -414 | -486.1 | -405.1 | -527.1 | -465.6 | -589.8 | -354.7 | -498.7 | -478.1 | -421.9 | -505.1 |
| 36 | -640.8 | -254.6 | -363.5 | -408.0 | -411.7 | -405.5 | -475.2 | -563.5 | -482.2 | -611.6 | -573.2 | -687.7 | -450.3 | -578.4 | -561.3 | -503.9 | -589.7 |
| 40 | -775 | -28 | -394.1 | -455 | -45 | -456 | -531 | -63 | -560 | -701 | -667.5 | -78 | -574.7 | -6 | -646.3 | . 6 | -665.1 |
| 44 | -900. | -318.2 | -423.1 | -502. | -495.4 | -504.7 | -584 | -703 | -631.4 | -786.7 | -756.9 | -879.4 | -688.0 | -739.3 | -725. | -650.9 | 2.0 |
| 48 | -1014.7 | -352.1 | -476.9 | -548 | -533.4 | -549.8 | -634 | -77 | -698 | -867.4 | -848.0 | -973 | -790. | -81 | -801.5 | -712.6 |  |
| 52 | -1117.2 | -385 | -529.8 | -604 | -585.1 | -592.8 | -681.6 | -851 | -766.0 | -944.8 | -934.3 | -1066.8 | -888.0 | -891 | -876. | -767.5 | -844 |
| 56 | -1209. | -418.9 | -582.3 | -660 | -641.6 | -646.4 | -74 | -924 | -832.7 | -1034.7 | -1019.8 | -1159 | -990.9 | -96 | -958 | -816.5 | -892.0 |
| 60 | -1291 | -452.0 | -634.0 | -716.5 | -697.4 | -706.9 | -816.0 | -1010 | -898 | -1132.5 | -1104.8 | -1251.5 | -1087.8 | -1060.5 | -1040 | -860.5 | -972.6 |
| 64 | -1366. | -484.9 | -685.3 | -771 | -753.0 | -766.9 | -882.5 | -1095.3 | -964.8 | -1229.0 | -1189.2 | -1342.9 | -1183.6 | -1151. | -1120. | -900.7 | -106 |
| 68 | -1434 | -517. | -736.3 | -826 | -808.2 | -826 | -948 | -1179 | -1030.5 | -1324 | -1273.2 | -1437.2 | -1278.2 | , | 9 | 937.8 | -1159.1 |
| 72 | -1495.7 | -550.3 | -786.7 | -881 | -862.8 | -885.2 | -1014.2 | -1263.5 | -1095.7 | -1419.4 | -1356.6 | -1544.5 | -1371.9 | -1330.1 | -1296 | -972. | -1250.6 |
| 76 | -1551 | -582.8 | -836.9 | -935 | -917 | -943.5 | -1079.3 | -1346 | -1160.8 | -1513.6 | -1439.7 | -1651.0 | -1464.9 | -1418 | -1383.3 | -1052.2 | -1341.2 |
| 80 | -160 | -615. | -886. | -989 | -971.6 | -1001.7 | -1144 | -1429 | -1225 | -1607.0 | -1522.6 | -1756.6 | -1557.1 | -1506.2 | -1469.5 | -1135.8 | -1431.0 |
| 84 | -1650.9 | -647.7 | -936.6 | -1043.2 | -1025.6 | -1059.5 | -1208.7 | -1511 | -1290.7 | -1699.9 | -1605.2 | -1861.5 | -1648.8 | -1593 | -1555.2 | -1218.2 | -1520. |
| 88 | -169 | -680.0 | -986.1 | -1096.8 | -1079.4 | -1116.9 | -1273.0 | -1593 | -1355.3 | -1792.2 | -1687.6 | -1965.7 | -1739.9 | -1680.2 | -1640.5 | -1299.8 | -1608.3 |
| 92 | -1758.6 | -712.3 | -1035 | -1150.2 | -1133.0 | -1174.1 | -1337.0 | -1674.6 | -1419.8 | -1884.2 | -1769.6 | -2069.4 | -1830.7 | -1766. | -1725 | -1380.5 | 1696.2 |
| 96 | -1884. | -744.4 | -1084.5 | -1203.7 | -1186.6 | -1231.2 | -1400.9 | -1755 | -1484.2 | -1976.0 | -1851.5 | -2172.6 | -1921.0 | -1852. | -1809 | -1460.6 | -1790.8 |
| 100 | -2008.1 | -776. | -1133.6 | -1257 | -1240.1 | -1288.1 | -1464 | -1837 | -1548.7 | -2067.7 | -1933.5 | -2275.1 | -2010.9 | -1938 | -1894 | -1540.1 | -1886 |
| 104 | -2129. | -808.6 | -1182.7 | -1310.0 | -1293 | -1344.6 | -1528 | -1917.2 | -1613.0 | -2158.2 | -2015.0 | -2377.2 | -2100.4 | -2023 | -1977.9 | -1618.4 | 19 |
| 108 | -2250.7 | -840.6 | -1231.4 | -1362.9 | -1346.2 | -1400.8 | -1591.2 | -1997.4 | -1677.1 | -2248.7 | -2096.5 | -2479.1 | -2189.6 | -2108 | -2061.5 | -1698. | -2073 |
| 112 | -2370.6 | -872. | -1280.0 | -1415 | -1399 | -1457.1 | -1654 | -2077.3 | -1741.2 | -2339.2 | -2176.6 | -2580.6 | -2278.2 | -2194 | -2145 | -1780.0 | -2166.2 |
| 116 | -2489.3 | -904.7 | -1328.6 | -1468.5 | -1452.0 | -1513.3 | -1717 | -2157 | -1805.3 | -2429.4 | -2252.6 | -2681.9 | -2363.8 | -2278.6 | -2228.1 | -1860.7 | 22 |
| 120 | -2607.2 | -936.8 | -1377.0 | -1521.2 | -1504.7 | -1569.3 | -1780.2 | -2237.0 | -1868.1 | -2519.4 | -2324.8 | -2782.7 | -2445.5 | -2363.1 | -2311.1 | -1941.0 | -2350.8 |
| 124 | -2724.2 | -968.8 | -1425.4 | -1573.9 | -1557.5 | -1625.2 | -1843.1 | -2316.6 | -1943.6 | -2609.2 | -2393.4 | -2883.4 | -2524.1 | -2447.4 | -2393.8 | -2020.8 | -2442.4 |
| 128 | -2840.3 | -1000.7 | -1473.7 | -1626.5 | -1610.2 | -1680.9 | -1874.5 | -2395.9 | -2020.8 | -2698.8 | -2467.9 | -2984.0 | -2599.2 | -2531.7 | -2476.5 | -2100.3 | -2533. |
| 132 | -2955.5 | -1032.6 | -1522.1 | -1679.1 | -1662.9 | -1736.6 | -1968.5 | -2475.2 | -2097.6 | -2788.4 | -2566.5 | -3084.3 | -2671.0 | -2615.9 | -2559.1 | -2179.4 | -2625.0 |
| 136 | -3070.2 | -1064.5 | -1570.3 | -1731.7 | -1715.4 | -1792.2 | -2031.0 | -2554.5 | -2173.8 | -2877.8 | -2664.2 | -3184.3 | -2740.3 | -2699.8 | -2641 | -2258.2 | -2715.7 |
| 140 | -3184.3 | -1096.4 | -1618.4 | -1784.3 | -1767.9 | -1847.8 | -2093.5 | -2633.4 | -2249.8 | -2967.0 | -2761.7 | -3284.2 | -2806.7 | -2783.4 | -2723.6 | -2336.4 | -2806.0 |

Table 5.3(c) Peak shear in three-span girders by representative permit vehicles (kips)

| Spa <br> (ft) | Wis SPV | $\begin{aligned} & \text { STP } \\ & \text { 3axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 4axle } \end{aligned}$ | STP <br> 5axle | STP <br> 5axle | STP <br> 6axle | STP <br> 7axle | $\begin{aligned} & \text { STP } \\ & \text { 7axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 8axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | $\begin{aligned} & \text { STP } \\ & \text { 9axle } \end{aligned}$ | $\begin{aligned} & \mathrm{STP} \_1 \\ & \text { Oaxle__ } \end{aligned}$ | $\begin{aligned} & \text { STP_1 } \\ & \text { Oaxle_ } \end{aligned}$ | $\begin{aligned} & \mathrm{STP} \\ & \text { 1axle } \end{aligned}$ | Zaxle | $\begin{aligned} & \text { STP_1 } \\ & \text { 3axle } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32 | -107.7 | -66.6 | -86.5 | -98.2 | -95.6 | -93.0 | -107.6 | -124.5 | -76.7 | -137.1 | -90.0 | -132.5 | -89.5 | -125.8 | -123.1 | -82.3 | -101.3 |
| 36 | -111.6 | -68.1 | -90.6 | -102.2 | -99.8 | -96.2 | -110.9 | -130.1 | -80.4 | -145.1 | -95.3 | -144.6 | -95.4 | -133.7 | -130.9 | -84.9 | -107.4 |
| 40 | -11 | -69.2 | -93 | -105 | -10 | -98.7 | -11 | -13 | -83.3 | -151.2 | -99.8 | -154.0 | -100.0 | -139.8 | -136.8 | 88.7 | 2 |
| 44 | -118.5 | -70.1 | -96.2 | -107.7 | -105.7 | -101.0 | -119.3 | -142.7 | -88.8 | -156.0 | -103.5 | -162.8 | -104.3 | -146.7 | -142.7 | -95.4 | -124.6 |
| 48 | -12 | -70 | -98 | -10 | -107 | -10 | -12 | -14 | -9 | -16 | -107 | -17 | -1 | -152.3 | -148.3 | -102.1 | -131.4 |
| 52 | -12 | -71.4 | -99. | -11 | -109.5 | -107 | -125. | -15 | -101 | -165.8 | -115 | -17 | -115. | -156.9 | -152.9 | -107.7 | -137.0 |
| 56 | -13 | -71 | -101.2 | -112.6 | -11 | -10 | -12 | -15 | -10 | -170 | -1 | -182.6 | -119.0 | -160.8 | -156.8 | -112.4 | 1 |
| 60 | -14 | -72 | -10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -129.3 | -187.2 | -1 | -1 | -1 | , | -148.7 |
| 64 | -150.7 | -72.7 | -103.4 | -114.6 | -113.2 | -112.9 | -130.6 | -160.1 | -116.7 | -176.7 | -134.9 | -191.1 | -125.2 | -166.8 | -162.8 | -122.7 | -153.5 |
| 68 | -158.3 | -7 | -10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -194.5 | -130.3 | -169.2 | -165.2 | -126.9 | -157.7 |
| 72 | -16 | -73.2 | -105 | -116.2 | -114.9 | -11 | -133 | -16 | -124 | -181 | -14 | -1 | -135 | -171.3 | -167.3 | -130.5 | -161.3 |
| 76 | -170 | -73 | -10 | -1 | -1 | -1 | -1 | -1 | -127 | -1 | -1 | -2 | -140.4 | -173.2 | -169.2 | 3 7 | -164.5 |
| 80 | -17 | -73.7 | -106.2 | -117.4 | -116.2 | -117.6 | -135 | -167 | -130.5 | -18 | -1 | -20 | -1 | -17 | -170.8 | -136.5 | -167.3 |
| 84 | -18 | -73 | -106. | -11 | -116.8 | -118 | -13 | -168.2 | -133.0 | -187 | -15 | -204 | -148.3 | -176.2 | -172.2 | -139.0 | -1 |
| 88 | -18 | -7 | -107 | -1 | -1 | -119.2 | -13 | -16 | -135.3 | -1 | -1 | -2 | -15 | -1 | -173.5 | -1 | -172.0 |
| 92 | -188. | -74.2 | -107 | -118.7 | -117.7 | -119.9 | -137.3 | -170 | -137.3 | -189.7 | -162. | -207 | -154.7 | -178.7 | -174.7 | -143.3 | -174.0 |
| 96 | -191.8 | -74.3 | -108. | -119.1 | -118. | -120.5 | -137. | -171.3 | -139.1 | -190.9 | -165 | -209.2 | -157.4 | -179.7 | -175.7 | -145.1 | -175.9 |
| 100 | -194. | -74. | -108. | -11 | -118 | -121 | -138 | -17 | -140.8 | -19 | -167 | -2 | -1 | -18 | -176 | -146 | -177.5 |
| 104 | -197. | -7 | -108.6 | -119.7 | -118.8 | -121. | -13 | -172 | -142.3 | -192. | -170.2 | -21 | -162.1 | -181.5 | -177.6 | -148.3 | -179.0 |
| 108 | -200. | -74.7 | -108.9 | -120. | -119.1 | -122.1 | -139.4 | -17 | -143.7 | -193 | -17 | -212.9 | -164.1 | -182.3 | -178.4 | -149.6 | -180.4 |
| 112 | -202.5 | -74.8 | -109.2 | -120.2 | -119.3 | -122.5 | -13 | -174.1 | -14 | -194.5 | -174.3 | -213.9 | -166.6 | -183.0 | -179.1 | -150.9 | -181.6 |
| 116 | -20 | -7 | -109.4 | -120.5 | -119.6 | -122.9 | -140. | -17 | -146.1 | -195.2 | -17 | -214.8 | -169.2 | -183.7 | -179.7 | -152.0 | -182.8 |
| 120 | -206.6 | -74.9 | -109.6 | -120.7 | -119.8 | -123.3 | -140.5 | -175.3 | -147.1 | -195.9 | -177.8 | -215.7 | -171.6 | -184.3 | -180.4 | -153.1 | -183.8 |
| 124 | -208. | -75. | -109.8 | -120.9 | -120.0 | -123. | -140 | -175. | -148.1 | -196.5 | -179.4 | -216.5 | -173.8 | -184.9 | -180.9 | -154.1 | -184. |
| 128 | -210.0 | -75.1 | -110.0 | -121.1 | -120.2 | -123.9 | -141.0 | -176.2 | -149.0 | -197.1 | -180.8 | -217.2 | -175.9 | -185.4 | -181.5 | -155.0 | -185.7 |
| 132 | -211.6 | -75. | -110.2 | -121.2 | -120.4 | -124.2 | -141.4 | -176.6 | -149.9 | -197.7 | -182. | -217.9 | -177.8 | -185.9 | -182.0 | -155.8 | -186.6 |
| 136 | -213.1 | -75. | -110.4 | -121.4 | -120.6 | -124.5 | -141.7 | -177.0 | -150.7 | -198.2 | -183.4 | -218.6 | -179.6 | -186.4 | -182.4 | -156.6 | -187.3 |
| 140 | -214.4 | -75.3 | -110.5 | -121.6 | -120.8 | -124.7 | -141.9 | -177.4 | -151.4 | -198.6 | -184.5 | -219.2 | -181.2 | -186.8 | -182.8 | -157.4 | -188.1 |

## Summary

The 250-kip Wisconsin Standard Permit Vehicle is reasonably positioned within the single-trip permit vehicles as far as load impacts on simply supported, 2 -span, and 3-span continuous girders. Specifically, Wis-SPV may envelope almost all single-unit trucks with less than 9 total axles, which attrbutes $80 \%$ of the total permit records. The representative vehicles with 7 axles and 8 axles could cause larger girder responses than the Wis-SPV. A close look at these vehicles indicated that the potential worst vehicles are short vehicles with distributed multiple axles likely FHWA the vehicle in Fig. 5.24. This observation is likely FHWA that obtained in the analysis of WIM records in Chapter 4.


Fig. 5.24 Example of short trucks with lift axles
Many permit vehicles with 9+ axles may cause larger girder responses than Wis-SPV. The permit vehicles with $9+$ axles are about $20 \%$ of the total permit records. The representative vehicles indicated that these vehicles may likely be heavier than the Wis-SPV. Two typical vehicles, represented by the proposed vehicles in this chapter, are shown in Fig. 5.24.


Fig. 5.25 Permit vehicles with more than 9 axles

# Chapter 6 Suggested Modifications to Wis-SPV 

## Introduction

The Wisconsin Standard Permit Vehicle (Wis-SPV) is 63-ft long with a gross weight of 250 kips; hence Wis-SPV would control the internal force responses in long-span simply-supported girders ( $\mathrm{L}>100 \mathrm{ft}$ ). Meanwhile Wis-SPV has a heavy axle group - the four-axle tandem weighs 140 kips; hence, Wis-SPV would also dominate the responses in short-span simply-supported girders ( $\mathrm{L}<40 \mathrm{ft}$ ). However, short trucks with five to seven axles, might cause larger forces in medium-span girders as shown in the analyses in Chapters 4 and 5 . In addition to positive moments, the configuration and the gross weight of the vehicles also have impact on negative moments in continuous girders. The analyses in the previous chapters indicated that some vehicles, especially long vehicles such as MnDOT Type P413, may cause larger negative moments. This was not deemed as a concern in this study because the overweight vehicles in Wisconsin that are eligible for annual permits should be shorter than 75 ft . Hence, a longer vehicle than the 63 ft Wis-SPV was not proposed to the standard permit vehicles.

Note that a short truck may cause large negative moments in many cases in addition to large positive moments. For example, both the long vehicle and the short vehicle in Fig. 6.1 (showing influence lines for the moment at the interior support) would produce similar negative moment in the two-span simply-supported girders because the two points corresponded to the same influence line values for the negative moment at the middle support. Hence, a short truck was proposed in this Chapter such that together with Wis-SPV, the standard permit vehicles would envelop most overloaded vehicles in Wisconsin.


Fig. 6.1 Demonstration of short vehicles causing the worst negative moments
The prototype vehicle for the proposed short vehicle was the specialized hauling vehicles (SHVs), such as dump trucks, transit mixers, and trash trucks as illustrated in Fig. 6.2. Note that the proposed short truck was based on the statistical analyses as shown below, and does not have any indication that the vehicles shown in Fig. 6.2 are overweight. SHVs represent more than forty percent of the single-unit trucks operating with three or more axles. ${ }^{1}$ The common commodities that SHVs haul are construction materials, gravel, ready-mix concrete, grain, and garbage or waste. These vehicles are usually three axle trucks with two to four lifting axles. When being fully loaded, all axles carry weight, resulting in short heavy trucks with five to seven axles. A fully loaded specialized hauling vehicle may be particularly heavy when the loaded materials are wet (or saturated).


Fig. 6.2 Examples of specialized hauling vehicles (SHVs) from various online sources

## Proposed Short Permit Truck

All 5-axle short vehicles with gross vehicle weight between 80 kips and 250 kips were selected from the WIM records and analyzed (out of 43,570 5-axle overload trucks). There were 8417 vehicles in total, including 6833 Class 7 trucks, 1418 Class 9 trailers, 166 Class 15 vehicles. The results of the descriptive statistical analysis of these vehicles are shown below. A representative vehicle was created with the first axle spacing as the mean value and all other spacings 4 ft . Axle weights in the proposed short vehicle were slightly higher than the $95 \%$ percentile values. The axle weights were slightly modified to create a 150-kip truck as illustrated in Fig. 6.3.

| 8417 <br> vehicles | Minimum | Maximum | Mean | Standard deviation | $5^{\mathrm{th}}$ <br> percentile | $\begin{gathered} 95^{\text {th }} \\ \text { percentile } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gross weight | 80028 | 242509 | 92551.45 | 13925.688 | 80468.74 | 122797.50 |
| Axle weight 1 | 4850 | 47399 | 19779.50 | 4612.622 | 12786.81 | 27998.71 |
| Axle spacing 1 | 4 | 21 | 10.72 | 2.175 | 8.20 | 14.44 |
| Axle weight 2 | 882 | 39683 | 10305.49 | 3792.207 | 5291.10 | 16755.13 |
| Axle spacing 2 | 3 | 7 | 4.36 | . 530 | 3.94 | 5.25 |
| Axle weight 3 | 220 | 55556 | 16624.59 | 7370.003 | 6613.87 | 30203.34 |
| Axle spacing 3 | 3 | 8 | 4.21 | . 274 | 3.94 | 4.59 |
| Axle weight 4 | 1323 | 57100 | 23482.84 | 5171.193 | 16534.67 | 33730.73 |
| Axle spacing 4 | 3 | 8 | 4.48 | . 449 | 3.94 | 5.25 |
| Axle weight 5 | 1764 | 57320 | 22359.15 | 6948.196 | 10361.73 | 34612.58 |
|  |  |  |  |  |  |  |

Fig. 6.3 The proposed 5-axle vehicle to supplement the Wis-SPV

The gross weight distribution of the selected 5-axle short overloaded trucks recorded in 2007 WIM data is shown in Fig. 6.4. The gross weight of the proposed short permit truck is 150 kips such that only 42 trucks ( $0.5 \%$ ) would exceed the gross weight of the proposed truck.


Fig. 6.4 Gross weight distribution of 5-axle short trucks in 2007 WIM records
To further qualify the proposed short truck, 50 vehicles were randomly selected from the heaviest $5 \%$ of all 5 -axle short trucks in WIM records. There were 421 trucks fell in the group, including the 42 truck with a gross weight over 150 kips . The randomly selected vehicles were analyzed for girders with two randomly selected span lengths, and the maximum moments and shear were compared with the proposed short truck in Fig. 6.5.



Fig. 6.5 Comparison of the proposed short truck with randomly selected 5-axle trucks
The peak moments by Wis-SPV were shown in dashed (black) lines and the proposed short truck was represented by solid (blue) lines in Fig. 6.5. The moments of randomly selected vehicles are shown in various marks. The ratios of peak moments or shear produced by the randomly selected vehicles over the proposed short truck are shown in Fig. 6.6. The distribution of the response ratios indicated an average value of 0.89 with a standard deviation of 0.083 . The normal distribution model predicted a probability of exceedance of roughly $10 \%$ with these two characteristic values. Hence, only $0.5 \%$ of the 8417 short five-axle trucks could cause larger moments/shear than the proposed 150 -kip short truck. Therefore, the proposed short permit truck should well represent the overloaded 5-axle short trucks and trailers.


Fig. 6.6 Statistical analysis of randomly selected 5-axle trucks
A total of 135 overloaded vehicles with six axles were identified in the 2007 WIM records, including 50 Class 10 vehicles and 85 Class 15 vehicles. Most of these vehicles had a gross weight below 150 kips though a 200 kip short truck was captured in the analysis in Chapter 4. Hence no short 6 -axle vehicle was proposed. In addition, 120 seven-axle overloaded short vehicles were identified, including 96 Class 10 vehicles, 21 Class 13 vehicles, and 10 Class 15 vehicles. Again most of these vehicles were found to weigh less than 150kips. This indicates that the representative vehicles for Class 10 in Chapter 4 may have poorly interpolated the WIM records because short vehicles in Classes 10 and 13 seemed not as heavy as 160kips as shown by the corresponding representative vehicles in Chapter 4. No short 7 -axle vehicle was proposed.
The proposed short truck caused higher positive moments in simply supported girders with span lengths between 30 ft and 80 ft . In addition, the moments by the short truck are larger than those by HL-93 loading (the design truck plus the $0.64 \mathrm{k} / \mathrm{ft}$ lane load) for the studied girder spans. Consequently, many vehicles that caused larger positive moments than Wis-SPV would be enveloped by the proposed short truck (Wis-SPT). The statistical analysis in Chapter 4 (shown in Table 4.6) was repeated with the increased positive peak moments, as listed in Table 6.1.

Table 6.1 Evaluation of the proposed short permit truck

| Vehicle <br> (Class/group) | without proposed short <br> truck |  |  |  | with proposed short truck |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
|  | \# of <br> vehicles | rep/spv <br> $(250 \mathrm{k})$ | poe <br> $(\%)$ | \# of <br> exceeds | rep/spv <br> $(250 \mathrm{k})$ | poe (\%) | \# of <br> exceeds |
| Class 4 2-axle | 21064 | 0.393 | 0.0 | 0 | 0.354 | 0.0 | 0 |
| Class 4 3-axle | 20351 | 0.585 | 0.0 | 0 | 0.529 | 0.0 | 0 |
| Class 5 2-axle | 20069 | 0.431 | 0.0 | 0 | 0.399 | 0.0 | 0 |
| Class 6 3-axle | 78523 | 0.585 | 0.0 | 0 | 0.542 | 0.0 | 0 |
| Class 7 4-axle | 15988 | 0.783 | 0.0 | 0 | 0.741 | 0.0 | 0 |
| Class 7 5-axle | 36234 | 0.870 | 7.0 | 126 | 0.808 | 1.4 | 26 |


| Class 8 3-axle | 5789 | 0.526 | 0.0 | 0 | 0.481 | 0.0 | 0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Class 8 4-axle a | 18469 | 0.728 | 0.0 | 0 | 0.661 | 0.0 | 0 |
| Class 8 4-axle b | 9813 | 0.660 | 0.0 | 0 | 0.617 | 0.0 | 0 |
| Class 9 5-axle a | 889230 | 0.747 | 0.0 | 0 | 0.735 | 0.0 | 0 |
| Class 9 5-axle b | 133972 | 0.906 | 0.1 | 2 | 0.849 | 0.0 | 0 |
| Class 10 6-axle | 27574 | 1.082 | 15.8 | 217 | 0.981 | 4.1 | 56 |
| Class 10 7-axle | 2552 | 1.198 | 55.3 | 71 | 1.090 | 28.5 | 36 |
| Class 11 5-axle | 28618 | 0.626 | 0.0 | 0 | 0.614 | 0.0 | 0 |
| Class 12 6-axle | 11011 | 0.879 | 0.2 | 1 | 0.829 | 0.0 | 0 |
| Class 13 7-axle a | 1116 | 1.112 | 18.8 | 11 | 1.011 | 8.3 | 5 |
| Class 13 7-axle | 3463 | 0.875 | 16.4 | 28 |  |  |  |
| b |  |  |  |  | 0.875 | 16.4 | 28 |
| Class 14 5-axle | 115 | 0.593 | 0.0 | 0 | 0.558 | 0.0 | 0 |

The total number of estimated vehicles (note that a vehicle may cause multiple records in the WIM data) reduced to $0.011 \%$ of total overloaded vehicles (records). Hence the short 5 -alxe truck can be used as the secondary standard permit vehicle for permit rating in the WisDOT Bridge Manual. The detailed recommendations are shown below.

## Recommendations regarding the WisDOT Standard Permit Vehicle

## Moment/shear envelopes

The moment caused by the 250 -kip WisDOT Standard Permit Vehicle on simply supported girders are listed in Table 45.9 of the Bridge Manual. ${ }^{6}$ Instead of creating additional moment tables, empirical moment/shear envelope models were proposed to for possible use in the Bridge Manual. The empirical models considered peak girder responses (e.g., moment and shear) and quadric equations with various parameters for response distribution along the girders. The comparison of peak responses in Chapter 3 indicated that the peak moment values can be calculated using SAP2000 moving load analysis for Wis-SPV. However, the peak moments occur at different locations form that indicated in Table 45.9 ( 0.4 L or 0.5 L , where L is the girder span) of the WisDOT Bridge Manual. The calculated positions of peak moments, shown in Fig. 6.7 , varied from 0.36L to 0.48 L . Hence the empirical models described below considered both the accurate peak responses and the locations of the peak responses.


Fig. 6.7 Relative locations of peak moments in simply supported girders

## Moment and shear envelopes for one-span girders

The moment/shear envelop for one-span simply supported girders is illustrated in Fig. 6.8. The moment envelope consisted of three regions: two symmetric regions at girder ends and a constant moment region with the peak value, $M_{\max }$ near the mid-span. The shear envelope for one-span simply supported girders is symmetric with peak shear, $V_{\max }$, at the supports and the minimum shear, $V_{\min }$, at the mid-span.



Fig. 6.8 Moment/shear envelope for one-span simply supported girders
The equations for the moment envelope is (only half girder is shown below in the equations)

$$
M=\left\{\begin{array}{ll}
\frac{M_{\max }}{x_{1}^{2}}\left(2 x_{1} x-x^{2}\right) & 0<x<x_{1}  \tag{6.1}\\
M_{\max } & x_{1} \leq x \leq 0.5
\end{array},\right.
$$

where, $x_{1}$ defines the location of peak moments. Note that the variable $x$ in all empirical models in this section is the normalized location from 0 at left support and 1 at the right support.
The equation for the shear envelope is

$$
\begin{equation*}
V=V_{\max }-2\left(V_{\max }-V_{\min }\right) x \quad 0<x \leq 0.5 . \tag{6.2}
\end{equation*}
$$

The characteristic values in the above models (e.g., $M_{\max }$ and $x_{1}$ ) for both Wis-SPV and the proposed short permit truck (SPT) are shown in Table 6.2 for the selected span lengths. Note that the models of the girder responses are for half wheel line to be comparable with the current Bridge Manual. No impact factors were included in the models because a dynamic allowance factor (IM) is used in the rating examples in the WisDOT Bridge Manual.

1. WisDOT Standard Permit Vehicle. The peak moment positions, $x_{1}$ values, are tabulated in Table 6.2. Note that $x_{1}$ for spans from 60 ft to 72 ft (near the length of Wis-SPV) were reduced from that shown in Fig. 6.7(a) to better fit the real moment envelopes. An average value of 0.44, or a lower bound ( 0.4 ) could be used for $x_{1}$ to simplify the model. The maximum moments can also be determined using two regression equations as shown in Fig. 6.9,

$$
M_{\max }=\left\{\begin{array}{ll}
15.6 L-136 & 20 \mathrm{ft} \leq L \leq 70 \mathrm{ft}  \tag{6.3}\\
30.7 L-1182 & 70 \mathrm{ft}<L \leq 250 \mathrm{ft}
\end{array} .\right.
$$

Regression analyses were also conducted for the maximum and minimum shear in the girders, leading to the following two peak shear equations,

$$
\begin{align*}
& V_{\max }=6.1 L^{3}-0.004 L^{2}+1.1 L+19.1 \\
& V_{\min }=-2.5 L^{3}+0.001 L^{2}+0.09 L+16.1 . \tag{6.4}
\end{align*}
$$

The $3^{\text {rd }}$ polynomials were needed to such that the peak shear values approaches to a fixed value as the girder span increases. Note that the regression models were for girders with a span between 20 ft and 250 ft while the tabulated values are from 32 ft to 140 ft .

Table 6.2 Characteristic values for the moment/shear envelope models in one-span girders

| Span (ft) | Wis-SPV |  |  |  |  | Wis-SPT |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $M_{\max }$ | $x_{1}$ | $V_{\max }$ | $V_{\min }$ | $M_{\max }$ | $x_{1}$ | $V_{\max }$ | $V_{\min }$ |  |
| 20 | 192.50 | 0.50 | 41.98 | 15.75 | 196.02 | 0.47 | 44.48 | 15.50 |  |
| 24 | 245.00 | 0.50 | 45.29 | 17.50 | 255.82 | 0.48 | 47.68 | 17.10 |  |
| 28 | 302.11 | 0.46 | 48.11 | 18.75 | 315.73 | 0.48 | 51.59 | 18.93 |  |
| 32 | 361.87 | 0.47 | 50.22 | 19.69 | 375.63 | 0.48 | 54.51 | 20.31 |  |
| 36 | 421.66 | 0.47 | 51.86 | 20.42 | 439.12 | 0.43 | 56.79 | 21.39 |  |
| 40 | 481.44 | 0.47 | 53.17 | 21.00 | 513.00 | 0.44 | 58.61 | 22.25 |  |
| 44 | 542.67 | 0.46 | 54.25 | 21.82 | 587.72 | 0.49 | 60.10 | 22.95 |  |
| 48 | 607.32 | 0.47 | 55.40 | 22.66 | 662.69 | 0.49 | 61.34 | 23.85 |  |
| 52 | 672.08 | 0.47 | 59.12 | 23.41 | 737.66 | 0.49 | 62.39 | 24.90 |  |
| 56 | 736.85 | 0.47 | 62.93 | 24.06 | 812.63 | 0.49 | 63.29 | 25.80 |  |
| 60 | 801.62 | 0.45 | 66.23 | 24.63 | 887.60 | 0.49 | 64.07 | 26.58 |  |
| 64 | 866.38 | 0.42 | 69.32 | 25.12 | 962.57 | 0.49 | 64.76 | 27.27 |  |
| 68 | 932.78 | 0.40 | 72.60 | 25.55 | 1037.5 | 0.49 | 65.36 | 27.87 |  |
| 72 | 1021.18 | 0.40 | 75.51 | 25.94 | 1112.5 | 0.49 | 65.89 | 28.40 |  |
| 76 | 1133.68 | 0.41 | 78.11 | 26.28 | 1187.5 | 0.49 | 66.37 | 28.88 |  |
| 80 | 1254.75 | 0.42 | 80.46 | 26.59 | 1262.5 | 0.49 | 66.80 | 29.31 |  |
| 84 | 1376.55 | 0.42 | 82.57 | 26.88 | 1337.5 | 0.49 | 67.19 | 29.70 |  |
| 88 | 1498.35 | 0.42 | 84.50 | 27.13 | 1412.5 | 0.49 | 67.55 | 30.06 |  |
| 92 | 1620.52 | 0.43 | 86.26 | 27.36 | 1487.5 | 0.49 | 67.87 | 30.38 |  |
| 96 | 1743.07 | 0.43 | 87.88 | 27.71 | 1562.5 | 0.49 | 68.17 | 30.68 |  |
| 100 | 1865.63 | 0.43 | 89.36 | 28.50 | 1637.5 | 0.49 | 68.44 | 30.95 |  |
| 104 | 1988.20 | 0.44 | 90.73 | 29.57 | 1712.5 | 0.49 | 68.70 | 31.20 |  |
| 108 | 2111.40 | 0.44 | 92.00 | 30.56 | 1787.5 | 0.49 | 68.93 | 31.44 |  |
| 112 | 2234.60 | 0.44 | 93.18 | 31.47 | 1862.5 | 0.49 | 69.15 | 31.65 |  |
| 116 | 2357.80 | 0.44 | 94.28 | 32.33 | 1937.5 | 0.49 | 69.35 | 31.85 |  |
| 120 | 2481.00 | 0.44 | 95.30 | 33.13 | 2012.5 | 0.49 | 69.54 | 32.04 |  |
| 124 | 2604.37 | 0.45 | 96.26 | 33.87 | 2087.5 | 0.49 | 69.71 | 32.22 |  |
| 128 | 2728.12 | 0.45 | 97.16 | 34.67 | 2162.5 | 0.49 | 69.88 | 32.38 |  |
| 132 | 2851.87 | 0.45 | 98.00 | 35.51 | 2237.5 | 0.49 | 70.03 | 32.54 |  |
| 136 | 2975.63 | 0.45 | 98.80 | 36.31 | 2312.5 | 0.49 | 70.18 | 32.68 |  |
| 140 | 3099.38 | 0.45 | 99.54 | 37.05 | 2387.5 | 0.49 | 70.32 | 32.82 |  |
|  |  |  |  |  |  |  |  |  |  |



Fig. 6.9 Regression analysis of the peak responses under Wis-SPV in 1-span girders with the calculated moment/shear envelopes in Fig. 6.10, in which the moment envelopes are shown in solid lines while the proposed empirical models are shown in dashed lines. The moment envelopes were fit closely with occasional overestimation of the moments. The shear envelopes were also slightly overestimated for several spans.


Fig. 6.10 Models of the peak responses under Wis-SPV in 1-span girders
2. WisDOT Short Permit Truck (SPT). The peak moment and shear location ( $x_{1}$ ) were mostly from $0.48 L$ to $0.5 L$ except for girders with 36 ft to 40 ft spans (F9g. 6.7(b)). Hence a value of 0.48 could be used for $x_{1}$ in the models. The peak responses could be determined using the following regression equations as shown in Fig. 6.11. The peak moment equation is for girder spans less than $80 f \mathrm{ft}$ such that the peak moments can be better represented in the critical region.

$$
\begin{align*}
& M_{\max }=18.1 L-196 \quad L \leq 80 \mathrm{ft}, \text { and }  \tag{6.5}\\
& V_{\max }=\frac{-634}{L}+0.002 L+75 \\
& V_{\min }=\frac{-407}{L}+0.02 L+33 \tag{6.6}
\end{align*}
$$

Again the regression equations ensure bounded peak shear values. The regression models are compared with the calculated envelopes for selected spans in Fig. 6.12.


Fig. 6.11 Regression analysis of the peak responses under Wis-SPV in 1-span girders


Fig. 6.12 Models of the peak responses under Wis-SPT in 1-span girders

Moment and shear envelope for two equal span girders.
The moment/shear envelops for two-span simply supported girders is illustrated in Fig. 6.13. The moment/shear envelopes are symmetric in the two spans. The peak positive moment, $M_{\max }$ in each span is located close to the exterior supports. The peak shear, $V_{\max }$, is located at the supports and the minimum shear, $V_{\text {min }}$, is located near mid-span close to the exterior supports. The shear at exterior supports is slightly smaller than the shear at the interior support; however the same maximum shear was used in the model to simplify the presentations.


Fig. 6.13 Moment/shear envelope for one-span simply supported girders
The models were developed for the left span of the two-span girders. Hence, $x=1$ is located at the interior supports. The equation for the positive moment envelope, $M_{\text {pos }}$, is

$$
M_{\mathrm{pos}}=\left\{\begin{array}{ll}
\frac{M_{\max }}{x_{1}^{2}}\left(2 x_{1} x-x^{2}\right) & 0<x \leq x_{1}  \tag{6.7}\\
\frac{M_{\max }}{\left(1-x_{1}\right)^{2}}\left(1-2 x_{1}+2 x_{1} x-x^{2}\right) & x_{1}<x<1
\end{array} .\right.
$$

The negative moment envelope ( $M_{\text {neg }}$ ) was modeled as a straight line from zero at the exterior supports to $M_{\min }$ at the interior support,

$$
\begin{equation*}
M_{\mathrm{neg}}=x M_{\min } \quad 0 \leq x \leq 1 . \tag{6.8}
\end{equation*}
$$

The shear envelope was modeled as two segments of straight lines within the each span as illustrated in Fig. 6.13,

$$
V=\left\{\begin{array}{ll}
V_{\max }-\left(V_{\max }-V_{\min }\right) \frac{x}{x_{1}} & 0<x \leq x_{1}  \tag{6.9}\\
V_{\min }+\left(V_{\max }-V_{\min }\right)\left(\frac{x-x_{1}}{1-x_{1}}\right) & x_{1}<x<1
\end{array} .\right.
$$

The characteristic values for the above models are shown in Table 6.3 for the selected span lengths followed by empirical models from regression analyses of peak values.

1. WisDOT Standard Permit Vehicle. The locations of peak positive moments varies from 0.38 L to 0.44 L as shown in Fig 6.7(a); hence the average location ( $x_{1}=0.4$ ) could be used in the moment model. The minimum shear location in the exterior spans varies from 0.38 L to 0.44 L . The average location ( $x_{1}=0.42$ ) could be used in the shear model. The regression analyses are shown in Fig. 6.14.
The regression equations for the peak positive moments are,

$$
M_{\max }=\left\{\begin{array}{ll}
12.9 L-120 & L \leq 70 \mathrm{ft}  \tag{6.10}\\
25 L-1023 & L>70 \mathrm{ft}
\end{array} .\right.
$$

The regression equations for the peak negative moments are,

$$
M_{\min }=\left\{\begin{array}{ll}
0.11 L^{2}-23.6 L+357 & L<100 \mathrm{ft}  \tag{6.11}\\
-13 L+330 & L \geq 100 \mathrm{ft}
\end{array} .\right.
$$

The equations for the maximum and minimum shear are,

$$
\begin{align*}
& V_{\max }=7.7 L^{3}-0.005 L^{2}+1.2 L+19.3 .  \tag{6.12}\\
& V_{\min }=0.13 L+16.7
\end{align*}
$$

Table 6.3 Characteristic values for the moment/shear envelope models in two-span girders

| Span (ft) | Wis-SPV |  |  |  |  | Wis-SPT |  |  |  |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: |
|  | $M_{\max }$ | $M_{\min }$ | $V_{\max }$ | $V_{\min }$ | $M_{\max }$ | $M_{\min }$ | $V_{\max }$ | $V_{\min }$ |  |
| 20 | 152.1 | -112.37 | 45.86 | 15.62 | 155.1 | -120.24 | 48.0 | 15.34 |  |
| 24 | 194.9 | -136.84 | 48.71 | 17.90 | 203.2 | -150.76 | 51.3 | 17.12 |  |
| 28 | 240.0 | -192.60 | 51.35 | 20.36 | 251.7 | -176.43 | 55.5 | 18.63 |  |
| 32 | 288.6 | -283.5 | 53.72 | 21.56 | 300.6 | -198.7 | 58.6 | 19.8 |  |
| 36 | 337.5 | -350.0 | 55.90 | 22.58 | 357.3 | -218.4 | 60.9 | 20.8 |  |
| 40 | 387.2 | -412.6 | 57.94 | 23.26 | 415.4 | -241.7 | 62.6 | 21.6 |  |
| 44 | 439.1 | -471.4 | 59.85 | 24.01 | 474.4 | -274.0 | 64.0 | 22.7 |  |
| 48 | 491.4 | -526.4 | 61.51 | 23.63 | 533.9 | -306.0 | 65.2 | 23.7 |  |
| 52 | 544.0 | -577.6 | 63.18 | 24.27 | 593.8 | -337.6 | 66.1 | 24.5 |  |
| 56 | 596.8 | -625.0 | 67.63 | 24.85 | 654.1 | -368.9 | 66.9 | 25.3 |  |
| 60 | 649.8 | -668.6 | 71.44 | 24.92 | 714.6 | -399.9 | 67.6 | 26.0 |  |
| 64 | 702.9 | -708.4 | 74.96 | 24.94 | 775.4 | -430.6 | 68.1 | 26.6 |  |
| 68 | 764.3 | -744.3 | 78.72 | 25.07 | 836.2 | -461.2 | 68.6 | 27.1 |  |
| 72 | 839.2 | -776.5 | 82.01 | 25.27 | 897.3 | -491.5 | 69.0 | 27.6 |  |
| 76 | 922.4 | -804.9 | 84.92 | 25.66 | 958.4 | -521.8 | 69.4 | 28.1 |  |
| 80 | 1011.3 | -829.4 | 87.50 | 26.04 | 1019.8 | -551.9 | 69.8 | 28.5 |  |
| 84 | 1101.7 | -850.1 | 89.80 | 26.38 | 1081.3 | -581.8 | 70.1 | 28.9 |  |
| 88 | 1193.4 | -867.1 | 91.86 | 26.87 | 1142.9 | -611.7 | 70.3 | 29.3 |  |
| 92 | 1286.2 | -880.2 | 93.72 | 27.77 | 1204.5 | -641.6 | 70.6 | 29.7 |  |
| 96 | 1380.0 | -889.5 | 95.39 | 28.62 | 1266.2 | -671.4 | 70.8 | 30.1 |  |
| 100 | 1475.9 | -945.0 | 96.92 | 28.95 | 1327.9 | -701.1 | 71.0 | 30.4 |  |
| 104 | 1573.2 | - | 98.30 | 29.16 | 1389.7 | -730.7 | 71.2 | 30.7 |  |
| 108 | 1670.8 | - | 99.56 | 29.37 | 1451.5 | -760.2 | 71.3 | 31.0 |  |
| 112 | 1768.9 | -100.72 | 30.15 | 1513.3 | -789.6 | 71.5 | 31.2 |  |  |
| 116 | 1867.4 | -101.79 | 31.06 | 1575.2 | -819.1 | 71.6 | 31.5 |  |  |
| 120 | 1966.3 | -102.78 | 32.05 | 1637.0 | -848.5 | 71.7 | 31.7 |  |  |
| 124 | 2065.5 | -103.69 | 32.93 | 1699.0 | -878.0 | 71.9 | 31.9 |  |  |
| 128 | 2165.0 | -104.53 | 33.61 | 1760.9 | -907.4 | 72.0 | 32.1 |  |  |
| 132 | 2264.7 | -105.32 | 34.27 | 1822.8 | -936.7 | 72.1 | 32.3 |  |  |
| 136 | 2364.7 | -106.05 | 34.90 | 1884.7 | -966.0 | 72.2 | 32.4 |  |  |
| 140 | 2464.9 | -106.73 | 35.50 | 1946.7 | -995.2 | 72.3 | 32.6 |  |  |



Fig. 6.14 Regression analysis of the peak responses under Wis-SPV in 2-span girders
The empirical models with parameters in Table 6.3 were compared with the calculated response envelopes in Fig. 6.15. The positive moment envelopes were fit closely up to 0.7 L . The empirical models overestimate the positive moments near the interior support, indicating the need for a higher order polynomial model. This was not further pursued because the positive moments near support would not be critical. The negative moment envelops were overestimated by the linear model in Eq. (6.8), especially in short span girders. In addition, the shear envelopes were slightly underestimated for short-span girders.


Fig. 6.15 Models of the peak responses under Wis-SPV in 2-span girders
2. WisDOT Short Permit Truck (SPT). The peak moment location varies slightly from 0.4 L to 0.44 L . Hence $x_{1}=0.42$ (or 0.4 to be conservative) could be used in the empirical model for
moments. Similarly $x_{1}=0.42$ could be used for shear. The peak moments/shear may be determined using the following equations from the regression analyses in Fig. 6.16,

$$
\begin{align*}
& M_{\max }=14.6 L-160 \quad 20 \leq L \leq 80 \mathrm{ft}  \tag{6.13}\\
& M_{\min }=-7.3 L+34.8 \quad 20 \leq L \leq 80 \mathrm{ft} \\
& V_{\max }=-\frac{616}{L}-0.01 L+78 \quad 20 \leq L \leq 250 \mathrm{ft}  \tag{6.14}\\
& V_{\min }=-\frac{390}{L}+0.02 L+32 \quad 20 \leq L \leq 250 \mathrm{ft}
\end{align*} .
$$

Note that the peak moment equations are only for short span girders, for which the Wis-SPT would be critical in design. The models were compared with the calculated response envelopes in Fig. 6.17. The low $\mathrm{R}^{2}$ values for the moments were due to the poor fit near the interior support. This was deemed acceptable because the models are conservative and the fact that positive moments near the interior supports are usually not critical in practice.


Fig. 6.16 Regression analysis of the peak responses under Wis-SPV in 2-span girders


Fig. 6.17 Models of the peak responses under Wis-SPT in 2-span girders

Moment and shear envelope for three equal span girders.
The moment/shear envelop for three-span simply supported girders is illustrated in Fig. 6.18. The moment envelopes for two exterior spans are symmetric with the peak positive moment, $M_{\max }$ and the peak negative moment $M_{\min }$ at the supports. The shear envelope for the exterior spans is
also symmetric with peak shear, $V_{\max }$, at the supports and the minimum shear, $V_{\min }$, near the mid span. The positive moments and the shear in the interior span are similar to those in a one-span girder.


Fig. 6.18 Moment/shear envelope for one-span simply supported girders
The equation for the moment envelopes for the exterior spans is

$$
\begin{align*}
& M_{\mathrm{pos}}=\left\{\begin{array}{ll}
\frac{M_{\max }}{x_{1}^{2}}\left(2 x_{1} x-x^{2}\right) & 0<x \leq x_{1} \\
\frac{M_{\max }}{\left(1-x_{1}\right)^{2}}\left(1-2 x_{1}+2 x_{1} x-x^{2}\right) & x_{1}<x<1
\end{array},\right. \text { and }  \tag{6.15}\\
& M_{\mathrm{neg}} \tag{6.16}
\end{align*}=x M_{\min } \quad 0 \leq x \leq 1 . \quad .
$$

The moment equations for the interior span are

$$
\begin{align*}
& M_{\text {pos }}^{\prime}=\left\{\begin{array}{ll}
\frac{M_{\max }^{\prime}}{x_{1}^{2}}\left(2 x_{1} x-x^{2}\right) & 0<x \leq x_{1} \\
M_{\max }^{\prime} & x_{1}<x<0.5
\end{array},\right. \text { and }  \tag{6.17}\\
& M_{\text {neg }}^{\prime}=M_{\min }^{\prime}+2\left(M_{\max }^{\prime}-M_{\min }^{\prime}\right) x \quad 0 \leq x \leq 0.5 . \tag{6.18}
\end{align*}
$$

The negative moment models may overestimate the real moments near the spike at the interior support for sort span girders. In addition, there are small positive moments near the interior supports, which were not considered in Eqs. (6.17) and (6.18).
The shear envelope was modeled as segments of straight lines within each span as illustrated in Fig. 6.15. The peak shear at the exterior supports was smaller than that at the interior support; however, the same maximum shear was used in the model to simplify the presentation. The equations for the shear envelopes were defined for the exterior spans and interior spans as

$$
\begin{align*}
& V=\left\{\begin{array}{ll}
V_{\max }-\left(V_{\max }-V_{\min }\right) \frac{x}{x_{1}} & 0<x \leq x_{1} \\
V_{\min }+\left(V_{\max }-V_{\min }\right)\left(\frac{x-x_{1}}{1-x_{1}}\right) & x_{1}<x<1
\end{array},\right. \text { and }  \tag{6.19}\\
& V^{\prime}=V_{\max }-2\left(V_{\max }-V_{\min }\right) x \quad 0<x \leq 0.5 . \tag{6.20}
\end{align*}
$$

The characteristic values for the above models are shown in Table 6.4 for the selected span lengths. Regression models were proposed for the peak values.

1. WisDOT Standard Permit Vehicle. The locations of peak positive moments for the exterior spans varies from $0.38 L$ to $0.42 L$ as shown in Fig 6.7(a); hence the average location ( $x_{1}=0.4$ ) could be used in the model. The peak moment position for the interior span varies from $0.44 L$ to $0.48 L$, hence ( $x_{1}=0.45$ ) could be used in the model. The minimum shear location in the exterior spans varies from $0.38 L$ to 0.44 L with an average at $\left(x_{1}=0.42\right)$, which could used in the model to simplify the presentation.

The regression equations for the peak positive moments are shown in Fig. 6.19,

$$
\begin{align*}
& M_{\max }=\left\{\begin{array}{ll}
12.5 L-110 & 20 \leq L \leq 70 \mathrm{ft} \\
24.7 L-1013 & 70 \leq L \leq 250 \mathrm{ft}
\end{array},\right. \text { and }  \tag{6.21}\\
& M_{\max }^{\prime}=0.027 L^{2}+11.5 L-223 . \tag{6.22}
\end{align*}
$$

The regression equations for the peak negative moments are,

$$
\begin{align*}
& M_{\min }=\left\{\begin{array}{ll}
0.074 L^{2}-20 L+285 & 20 \leq L \leq 90 \mathrm{ft} \\
-13.8 L+352 & 90 \leq L \leq 250 \mathrm{ft}
\end{array},\right. \text { and }  \tag{6.23}\\
& M_{\min }^{\prime}=-5.1 L+123 . \tag{6.24}
\end{align*}
$$

The equations for the maximum and minimum shear are,

$$
\begin{align*}
& V_{\max }=7.8 L^{3}-0.005 L^{2}+1.2 L+18.9  \tag{6.25}\\
& V_{\min }=0.13 L+16.5
\end{align*} .
$$

Table 6.4 Characteristic values for the moment/shear envelope models in three-span girders

| Span (ft) | Wis-SPV |  |  |  |  |  | Wis-SPT |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $M_{\text {max }}$ | $M_{\text {min }}$ | $M_{\text {max }}$ | $M_{\text {min }}$ | $V_{\text {max }}$ | $V_{\text {min }}$ | $M_{\text {max }}$ | $M_{\text {min }}$ | $M_{\text {max }}^{\prime}$ | $M_{\text {min }}$ | $V_{\text {max }}$ | $V_{\text {min }}$ |
| 20 | 160.0 | -114.0 | 122.4 | -71.0 | 46.0 | 15.8 | 152.7 | -121.1 | 122.9 | -37.3 | 48.2 | 15.1 |
| 24 | 199.4 | -140.4 | 157.7 | -85.2 | 49.0 | 17.8 | 200.1 | -153.8 | 161.9 | -47.9 | 51.5 | 16 |
| 28 | 241.2 | -177.1 | 193.4 | -86.8 | 51.6 | 19.6 | 248.0 | -181.7 | 201.8 | -58.2 | 55.7 | 1.9 |
| 32 | 287.8 | -252.2 | 230.3 | -83.4 | 53.8 | 24.8 | 296.2 | -206.1 | 242. | -70.1 | 58.8 | 19. |
| 36 | 333.7 | -320. | 270.7 | -89.2 | 55.8 | 26.6 | 352.1 | -228.0 | 282. | -83.5 | 61.1 | 20. |
| 40 | 381.7 | -387.8 | 311.4 | -90.8 | 57.6 | 27. | 409.3 | -257.6 | 329.5 | -96.8 | 62.9 | 21. |
| 44 | 432.9 | -450.0 | 353.9 | -97.9 | 59.3 | 27.8 | 467.4 | -292.1 | 377. | -109.7 | 64.3 | 22. |
| 48 | 484. | -507. | 397.0 | -108.8 | 60.7 | 27.9 | 526.1 | -326. | 426. | -122.5 | 65.4 | 23. |
| 52 | 536.2 | -558.6 | 440.5 | -119.5 | 63.4 | 27.7 | 585.2 | -360.0 | 475. | -135.1 | 66.4 | 24 |
| 56 | 588.2 | -604.5 | 484.2 | -130.2 | 67.9 | 27. | 644.7 | -393.3 | 525. | -147.6 | 67.1 | 24 |
| 60 | 640. | -645 | 528.1 | -140.8 | 71.8 | 26.8 | 704.5 | -426.4 | 575. | -160.0 | 67.8 | 25.6 |
| 64 | 692. | -683.2 | 572.3 | -163.3 | 75.3 | 26.5 | 764.4 | -459.2 | 625. | -172.3 | 68.4 | 26 |
| 68 | 753.9 | -717.2 | 616.5 | -186.0 | 79.1 | 26.2 | 824.6 | -491.8 | 676. | -184.5 | 68.8 | 27. |
| 72 | 827.6 | -747.8 | 666.8 | -208.3 | 82.5 | 26.1 | 884.9 | -524.1 | 728.3 | -196.7 | 69.3 | 27 |
| 76 | 909.0 | -775.9 | 723.0 | -232.6 | 85.4 | 25.9 | 945.3 | -556.4 | 779.7 | -208.8 | 69.6 | 28.2 |
| 80 | 995. | -801.7 | 784.2 | -257.5 | 88.0 | 26.0 | 1005.8 | -588.5 | 831. | -220.8 | 70.0 | 28 |
| 84 | 1084.5 | -825.5 | 850.8 | -282.0 | 90.3 | 26.1 | 1066.4 | -620.5 | 882. | -232.8 | 70.2 | 29.2 |
| 88 | 1174.5 | -847.3 | 921.9 | -306.1 | 92.4 | 26.4 | 1127.0 | -652.4 | 934.5 | -244.7 | 70.5 | 29. |
| 92 | 1265.6 | -879.3 | 994.1 | -329.9 | 94.2 | 26.6 | 1187.7 | -684.2 | 986.3 | -256.7 | 70.7 | 30. |
| 96 | 1357.8 | -942.1 | 1068.5 | -353.4 | 95.9 | 26.9 | 1248.4 | -716.1 | 1038. | -268.6 | 71.0 | 30.4 |


| 100 | 1450.9 | - | 1145.0 | -376.6 | 97.4 | 27.4 | 1309.2 | -747.8 | 1089.9 | -280.5 | 71.1 | 30.7 |
| :--- | :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 104 | 1546.6 | -1222.5 | -399.4 | 98.8 | 28.2 | 1370.3 | -779.3 | 1141.9 | -292.3 | 71.3 | 30.7 |  |
| 108 | 1642.8 | -1300.6 | -422.1 | 100.1 | 29.0 | 1431.3 | -810.8 | 1193.9 | -304.1 | 71.5 | 30.9 |  |
| 112 | 1739.4 | -1379.2 | -444.6 | 101.2 | 29.8 | 1492.4 | -842.2 | 1245.9 | -315.9 | 71.6 | 31.1 |  |
| 116 | 1836.5 | -1458.4 | -466.8 | 102.3 | 30.6 | 1553.5 | -873.6 | 1298.0 | -327.7 | 71.8 | 31.3 |  |
| 120 | 1934.0 | -1538.2 | -488.9 | 103.3 | 31.3 | 1614.6 | -905.0 | 1350.1 | -339.4 | 71.9 | 31.5 |  |
| 124 | 2031.8 | -1618.3 | -510.9 | 104.2 | 32.0 | 1675.8 | -936.4 | 1402.1 | -351.2 | 72.0 | 31.7 |  |
| 128 | 2129.9 | -1698.8 | -532.6 | 105.0 | 32.7 | 1737.0 | -967.8 | 1454.3 | -363.0 | 72.1 | 31.9 |  |
| 132 | 2228.2 | -1779.7 | -554.2 | 105.8 | 33.4 | 1798.2 | -999.1 | 1506.4 | -374.7 | 72.2 | 32.0 |  |
| 136 | 2326.9 | -1861.0 | -575.7 | 106.5 | 34.2 | 1859.4 | -1558.6 | -386.4 | 72.3 | 32.2 |  |  |
| 140 | 2425.7 | -1942.6 | -597.1 | 107.2 | 34.9 | 1920.6 | -1610.8 | -398.1 | 72.4 | 32.3 |  |  |



Fig. 6.19 Regression analysis of the peak responses under Wis-SPV in 3-span girders
The empirical model with parameters in Table 6.4 was compared with the calculated response envelopes in Fig. 6.20. Again, the moment envelopes at the exterior spans were fit closely up to 0.7 L . The positive moments at the interior spans were overestimated by using the fixed $x_{1}$ value ( 0.45 ). The small positive moments at the supports were not captured by the model. The empirical model overestimated the negative moments near the interior support due to the sharp spike in the negative moments. The shear envelopes were closely followed except the shear in the exterior spans, which were overestimated by using the same peak shear along the entire span.


Fig. 6.20 Models of the peak responses under Wis-SPV in 3-span girders
2. WisDOT Short Permit Truck (SPT). The locations of peak positive moments for the exterior spans are around $0.4 L$ as shown in Fig 6.7(b); hence the location ( $x_{1}=0.4$ ) was used in the model. Similar to Wis-SPV, the location $\left(x_{1}=0.45\right)$ could be used for the peak positive moments in interior spans. The minimum shear location in the exterior spans is close to ( $x_{1}=0.42$ ), which could used in the model to simplify the presentation. Meanwhile the minimum shear is located at the mid-span of the interior spans.

The regression equations for the peak positive moments are,

$$
\begin{align*}
& M_{\max }=14.5 L-159 \quad 20 \leq L \leq 80 \mathrm{ft} \\
& M_{\max }^{\prime}=12.0 L-138 \tag{6.26}
\end{align*}
$$

The regression equations for the peak negative moments are,

$$
\begin{align*}
& M_{\min }=-7.9 L+45.7 \quad 20 \leq L \leq 80 \mathrm{ft}  \tag{6.27}\\
& M_{\min }^{\prime}=-3.1 L+27.7
\end{align*}
$$

The equations for the maximum and minimum shear are,

$$
\begin{array}{ll}
V_{\max }=-615 / L-0.01 L+78.4 & 20 \leq L \leq 250 \mathrm{ft} \\
V_{\min }=-390 / L+0.02 L+31.3 & 20 \leq L \leq 250 \mathrm{ft} \tag{6.10}
\end{array} .
$$



Fig. 6.21 Regression analysis of the peak responses under Wis-SPT in 3-span girders
The models for Wis-SPT were compared with the calculated response envelopes in Fig. 6.22. Again the positive moments are fit well except near the interior supports. The small positive moments at the interior supports are ignored. The negative moments are generally over estimated because the linear models use peak negative moment at the interior supports, where moment spikes exist as shown in Fig. 6.22.


Fig. 6.22 Models of the peak responses under Wis-SPT in 3-span girders

## Impact on Permit Load Rating processes in WisDOT Bridge Manual

The Permit Load Rating in the WisDOT Bridge Manual may be impacted by the proposed short permit truck (Wis-SPT). The short permit truck will likely impact the moment/shear in short-
span girders, hence, the rating of a slab bridge in Chapters 18 and 45 of the WisDOT Bridge Manual for permit vehicles is examined below.

The three-span continuous example slab bridge has two 38 ft spans and one 51 ft interior span. The slab width is 42.5 ft with a clear roadway width of 40 ft . The slab ( $4-\mathrm{ksi}$ concrete) has been designed to be 17 in thick with a $1 / 2$-in wearing surface. The slab thickness is increased to 28 in within 8 ft at the interior supports. The reinforcement of the slab is \#9 @ $7 \mathrm{in}\left(1.71 \mathrm{in}^{2}\right.$ per foot slab) at 0.4 L and \#8 @ 5in (1.88 in ${ }^{2}$ per foot slab) at the interior supports. The concrete cover is 1.5 in for the bottom rebars and 2.0 in for top rebars. The moment envelops of the three-span bridge under the 190k Wis-SPV and 114k Wis-SPT is shown in Fig. 6.23. Note that the short permit truck was scaled down following the current permit rating practice for slab bridges.


Fig. 6.23 Moment envelops of a 3-span slab bridge under permit vehicles
The permit vehicle load rating in Chapter 45 of the WisDOT Bridge Manual was conducted for the peak negative moment at the interior supports. The rating considers 1) single-lane load distribution with future wearing surface and 2) multiple-lane distribution without future wearing surface. The permit vehicle rating using the $190-\mathrm{k}$ Wis-SPV and $114-\mathrm{k}$ WisSPT is compared as follows.

1. Single-lane distribution with future wearing surface (FWS).

The rating equation is $R F_{\text {permit }}=\frac{\phi_{c} \phi_{s} \phi M_{n}-\gamma_{D C} M_{D C}-\gamma_{D W} M_{D W}}{\gamma_{L} M_{L L_{-} I M}}$. The parameters used in the rating are listed in Table 6.5, and the calculation is shown in Table 6.6.

Table 6.5 Parameters in permit vehicle load rating

| Item | Values | References |
| :--- | :--- | :--- |
| Equivalent strip width $(\mathrm{E})$ | 178 in | LRFD [4.6.2.1.2, 4.6.2.3] |
| Distribution factor $(\mathrm{DF})$ | 0.0562 lanes/ft-slab | LRFR [6.4.5.4.2.2] |
| Dynamic load allowance $(\mathrm{IM})$ | 0.33 | LRFR [6.4.5.5] |
| Condition Factor $\left(\varphi_{\mathrm{c}}\right)$ | 1.0 | WisDOT [45.3.2.4] |
| System Factor $\left(\varphi_{\mathrm{s}}\right)$ | 1.0 | WisDOT [45.3.2.5] |
| Resistance Factor $(\varphi)$ | 0.9 | LRFD [5.7.2.1] |
| Load factor $\left(\gamma_{\mathrm{DC}}\right)$ | 1.25 | WisDOT [45.3-1] |
| Load factor $\left(\gamma_{\mathrm{DW}}\right)$ | 1.5 | WisDOT [45.3-1] |
| Load factor $\left(\gamma_{\mathrm{L}}\right)$ | 1.5 | WisDOT [45.3-3] |

Table 6.6 Permit vehicle load rating for single-lane distribution with FWS

| Position | Item | Wis-SPV | Wis-SPT |
| :--- | :--- | :--- | :--- |
| Support | Dead load moment $\left(\mathrm{M}_{\mathrm{DC}}\right)$ | $59.2 \mathrm{k}-\mathrm{ft}$ |  |
|  | FWS moment $\left(\mathrm{M}_{\mathrm{DW}}\right)$ | $4.9 \mathrm{k}-\mathrm{ft}$ |  |
|  | Nominal moment capacity | $226.7 \mathrm{k}-\mathrm{ft}$ | $34.6 \mathrm{k}-\mathrm{ft}$ |
|  | Live moment for 1-ft slab | $51.2 \mathrm{k}-\mathrm{ft}$ | 2.46 |
|  | RF | 1.66 |  |
| 0.4 L | Dead load moment $\left(\mathrm{M}_{\mathrm{DC}}\right)$ | $18.1 \mathrm{k}-\mathrm{ft}$ |  |
|  | FWS moment $\left(\mathrm{M}_{\mathrm{DW}}\right)$ | $1.5 \mathrm{k}-\mathrm{ft}$ |  |
|  | Nominal moment capacity | $116.6 \mathrm{k}-\mathrm{ft}$ | $49.4 \mathrm{k}-\mathrm{ft}$ |
|  | Live moment for 1-ft slab | $45.9 \mathrm{k}-\mathrm{ft}$ | 1.08 |
|  | $\mathrm{RF}_{\text {permit }}$ | 1.16 |  |

2. Multiple-lane distribution without future wearing surface (FWS).

The rating equation is $R F_{\text {permit }}=\frac{\phi_{c} \phi_{s} \phi M_{n}-\gamma_{D C} M_{D C}}{\gamma_{L} M_{L L_{-} I M}}$. The parameters used in the rating are listed in Table 6.7, and the calculation is shown in Table 6.8.

Table 6.7 Parameters in permit vehicle load rating

| Item | Values | References |
| :--- | :--- | :--- |
| Equivalent strip width (E) | 141 in | LRFD [4.6.2.1.2, 4.6.2.3] |
| Distribution factor $(\mathrm{DF})$ | 0.0709 lanes/ft-slab | LRFR [6.4.5.4.2.2] |
| Dynamic load allowance (IM) | 0.33 | LRFR [6.4.5.5] |
| Condition Factor $\left(\varphi_{\mathrm{c}}\right)$ | 1.0 | WisDOT [45.3.2.4] |
| System Factor $\left(\varphi_{\mathrm{s}}\right)$ | 1.0 | WisDOT [45.3.2.5] |
| Resistance Factor $(\varphi)$ | 0.9 | LRFD [5.7.2.1] |
| Load factor $\left(\gamma_{\mathrm{DC}}\right)$ | 1.25 | WisDOT [45.3-1] |
| Load factor $\left(\gamma_{\mathrm{L}}\right)$ | 1.3 | WisDOT [45.3-3] |

Table 6.8 Permit vehicle load rating for multiple-lane distribution without FWS

| Position | Item | Wis-SPV | Wis-SPT |  |
| :--- | :--- | :--- | :--- | :---: |
| Support | Dead load moment $\left(\mathrm{M}_{\mathrm{DC}}\right)$ | $59.2 \mathrm{k}-\mathrm{ft}$ |  |  |
|  | Nominal moment capacity | $226.7 \mathrm{k}-\mathrm{ft}$ | $43.6 \mathrm{k}-\mathrm{ft}$ |  |
|  | Live moment for 1-ft slab | $64.6 \mathrm{k}-\mathrm{ft}$ | 2.29 |  |
|  | RF $_{\text {permit }}$ | 1.55 |  |  |
|  | Dead load moment $\left(\mathrm{M}_{\mathrm{DC}}\right)$ | $18.1 \mathrm{k}-\mathrm{ft}$ | $62.3 \mathrm{k}-\mathrm{ft}$ |  |
|  | Nominal moment capacity | $116.6 \mathrm{k}-\mathrm{ft}$ | 1.02 |  |
|  | Live moment for 1-ft slab | $57.9 \mathrm{k}-\mathrm{ft}$ |  |  |
|  | RF $_{\text {permit }}$ | 1.09 |  |  |

Note that if the effect of multiple-presence factor were not removed in the calculation of the distribution factors in this rating, the DF would become 0.0851 lanes/ft. The live load moment caused by the permit vehicles would be $69.5 \mathrm{k}-\mathrm{ft}$ (SPV) and $74.8 \mathrm{k}-\mathrm{ft}$ (SPT). The rating factors would be then reduced to 0.91 and 0.85 , respectively. This indicates that the slab design is not adequate in the positive moment design. Roughly $15 \%$ more reinforcement (e.g., \#9 @ 6in) is needed for the mid-spans, especially in the interior span.

Instead of the peak moments and shear used in rating calculations, especially for girders with spans less than 80ft, the following impacts are expected in the bridge design:

1. Moments and shear used at critical sections different from the peak response locations, which are generally located from $0.4 L$ to $0.5 L$. For example, a moment value different form $M_{\max }$ should be used for checking moment capacity of a prestressed concrete girder with draped strands at the draping points. The proposed moment/shear envelope models can be used in these cases.
2. Capacity check with varied rebar configurations and varied transverse reinforcement along the span. Again, the proposed envelope models can be used.

# Chapter 7 <br> Summary and Conclusions 

## Summary

This study evaluated the impact of the 250-kip Wisconsin Standard Permit Vehicle against the overloaded vehicles operating on Wisconsin roads in recent years. The evaluation was conducted using three sets of data: 1) overloaded vehicle records within weigh-in-motion data collected in 2007; 2) the single-trip permit application records from 2004 to 2007; and 3) overloaded vehicles in neighboring states, including Minnesota, Iowa, Michigan, and Illinois.
The weigh-in-motion records were categorized into legal loads and overloads per Wisconsin Statute 348 and WisDOT Bridge manual. A total of 1.4 million overloaded vehicle records out of over 6 million total truck records were used to evaluate the WisDOT Standard Permit Vehicle. The recorded overloads in individual classes (per FHWA definitions) were further divided into groups, in which the vehicles had similar axle configurations. Descriptive statistical analyses were conducted for the vehicles in each class/group to define representative vehicles that best describe the heaviest 5\% vehicles in the class/group. The representative vehicles were evaluated using randomly selected vehicles within the heaviest $10 \%$ vehicles in the corresponding class/group. The girder responses (i.e., moments and shear) due to loading from the randomly selected vehicles were calculated for randomly selected span lengths to assess whether the heavy vehicles in each class/group might cause larger girder responses than Wis-SPV.
The application records for single-trip permits from July 2004 to July 2007 were used to further evaluate the 250 -kip Wisconsin Standard Permit Vehicle. Only the overloaded vehicle records were used, resulting in roughly 50 thousand records in total. The number of axles in over $99 \%$ of the records was from three to thirteen. Hence, the recorded vehicles were classified based upon their total number of axles. The configurations for each class/group were determined such that representative vehicles can be configured. The trucks in the WIM records were checked against the configuration patterns of the single-trip permit vehicles in order to properly define the configurations of the representative vehicles. The pattern comparison was conducted for the permit vehicles with less than 9 axles, which contributes about $80 \%$ of the total records. Multiple tandem axles were assumed for vehicles with more axles because only nondivisible vehicles are eligible for permits in Wisconsin. The responses in simply-supported girders with various span lengths by the representative vehicles were then compared with those by the Wis-SPV.

The Standard Permit Vehicle in Wisconsin is being used for permit rating of new bridges and for posting bridges. Hence the impact of the representative overloaded vehicles utilized in the neighboring states was compared with that by the WisDOT Standard Permit Vehicle. Again, the comparison was made using the worst girder responses using the influence line concept.
Based upon the above analyses, modifications to the current permitting practice were proposed. Wis-SPV is a $63-\mathrm{ft}$ long tractor-trailer, which is longer than the length limits for single-unit vehicles eligible for permits. Hence, the recommended change focused on a supplementary and shorter 5-axle truck to the Wis-SPV to increase the positive moments (and potential negative moments) in short span girders.

## Conclusions

The analysis of WIM records indicated that $0.035 \%$ of total overloaded vehicles (records) may exceed the impact of the 250 -kip Wis-SPV. A close examination of the selected overloaded vehicles indicated that some short vehicles with 5 to 7 axles, currently on Wisconsin highway with annual permits, could exceed the maximum anticipated internal forces. These vehicles were likely Class 7 trucks with multiple lift axles as well as Class 9 short trailers. The representative vehicles for Classes 11 through 14 indicated that the Wis-SPV envelopes almost all truck-trailer combinations, except Class 13 vehicles. Class 13 records includes large portion of vehicles with permits, hence the representative vehicles did not address Type 3S2-2 truck-trailer combinations well.

The analysis of Wisconsin single-trip permit trucks indicated that Wis-SPV envelopes almost all single-unit trucks with less than 9 axles, which attributes $80 \%$ of the total permit records. Representative vehicles with 7 axles could cause larger girder responses than the Wis-SPV. A closer close look at these vehicles indicated that the potential worst vehicles are short vehicles with distributed multiple axles (oftentimes with lift axles). This observation was similar to that obtained in the analysis of WIM records in Chapter 4.

Comparison with the typical representative overloaded vehicles in the neighboring states indicated that longer vehicles, similar to the MnDOT Type P413 vehicle, could cause larger negative moments for two- and three-span simply supported girders. This situation was discussed in Chapters 4 and 5 of this report using representative vehicles and randomly selected vehicles. Specifically, some representative vehicles may have a variable spacing that ranges from 4 ft to over 70 ft . Hence the vehicle with the smaller spacing may cause severe positive moments (and likely shear) while the vehicle with greater spacing may cause severe negative moments. Nevertheless, the proposed Short Permit Truck (SPT) did not consider long vehicle option because most likely the vehicles are longer than 50 ft (for trucks) and 75 ft (for trailers and vehicle combinations), the limit for vehicles eligible for permits. In such cases the vehicles will need a single-trip permit, and would be rigorously examined before the permit is issued.

## Future studies

It is generally believed that heavy weights distributed on multiple axles that spaced far would cause less bridge damage than short closely spaced overloads. Hence, the permitting fee may be based upon the ration of the gross vehicle weight with the legal weight calculated using the Federal bridge formula. It was shown in Chapter 3 that plot of the maximum girder responses vs. this ratio showed less scattering than the gross vehicle weight. A simple yet reasonably accurate permitting fee base should be studied in details to reflect the level of damage overload vehicles may cause to bridges. The consideration should include damage to bridge decks and the related potential damage to durability of the bridges.

The gross weight distribution of Class 9 vehicles showed some deviation from the characteristics described in an NCHRP study. ${ }^{10}$ Specifically the low peak (representing the empty trailers) and the high peak (representing overloaded trailers) are higher. This might be due to the special freight transport needs in Wisconsin, or this might indicate larger variations in the WIM recording. The accuracy of the WIM records needs to be studied before these records can e used for other purposes.

The WIM records can be used to assess and predict the traffic patterns, especially for trucks and overloads. The number of the overloads recorded by each station is very uneven as shown below, indicating drastically different overloads on Wisconsin highway bridges. For example, Station \# 410240 on Interstate highway 94 near Tomah, WI captured nearly $50 \%$ of the total overloads. This might be duo to the fact that overloads on highway 90 captured by Station \#410253 near Sparta, WI would also pass Station \# 410240. Hence, highway bridges near Tomah, WI would be more likely subjected to accumulated overloads, leading to less service life or higher maintenance costs. The reasonably predicted truck and overload pattern would help the design to tailor to the specific loads to the bridges.


Fig. 7.1 The overloaded vehicles captured in various WIM stations in Wisconsin

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## References

1. Transportation Research Board, (2002). Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles, Special Report 267, National Academy Press, Washington, D.C. 2002.
2. Wisconsin Department of Transportation, (2006) Fact and Figures 2005, Oversize / Overweight Permit. http://www.dot.wisconsin.gov/drivers/docs/overs-wpermit.pdf.
3. Wisconsin, (2006) Statute Chapter 348: Vehicles - Size, Weight And Load. http://www.legis.state.wi.us/Statutes/Stat0348.pdf.
4. Wisconsin Department of Transportation, (2006) Oversize/Overweight Single Trip Permit Information. http://www.dot.wisconsin.gov/business/carriers/forms/mv2600.pdf
5. Wisconsin Department of Transportation, (2006) Multiple Trip Permit Information for Nondivisible Oversize/Overweight Vehicles/Loads. http://www.dot.wisconsin.gov /business/ carriers/forms/mv2614.pdf
6. Wisconsin Department of Transportation, (2009) Bridge Manual Part I and Part II.
7. McIlrath, D., Frank, K., Wood, S., and Yura, J. (2000) Improving Bridge Rating And Truck Permitting Procedures Through Finite Element Analysis, Report FWHA/TX-04/0-1746-2, Texas Department of Transportation. pp. 127.
8. Altay, A., Arabbo, D., Corwin, E., Dexter, R., and French, C. (2003) Effects of Increasing Truck Weight on Steel and Prestressed Bridges, Minnesota Department of Transportation Report MN/RC - 2003-16 pp. 129.
9. Barker, R. and Puckett, J ((2007) Design of Higway Bridges: an LRFD approach (2ed), Wiley.
10. Fu, G., Feng, J., and Dekelbab, W. (2003) "Effect of Truck Weight on Bridge Network Costs." NCHRP report 495, National Cooperative Highway Research Program, Washington, D.C.
11. Fu, G. and Fu, C. (2006) "Bridge Rating Practices and Policies for Overweight Vehicles." NCHRP Synthesis 359, National Cooperative Highway Research Program, Washington, D.C.
12. Turer, A., and Aktan, E. A. (1999) Issues in Superload Crossing of Three Steel Girder Bridges in Toledo, Ohio. Transportation Research Record 1688, pp. 87-96.
13. O. Hag-Elsafi and J. Kunin (2004) "Monitoring prestressed concrete box-beam bridge for superloads." Transportation Research Record 1892, 2004: 126-136.
14. M. P. Culmo, J. T. DeWolf, and M. R. DelGrego (2004) "Behavior of steel bridges under superload permit vehicles." Transportation Research Record 1892, 2004: 107-114.
15. American Association of State Highway Transportation Officials (AASHTO). LRFD Bridge Design Specifications. 3rd Edition, Washington, D.C., 2004.
16. US Department of Transportation (2000) Comprehensive Truck Size and Weight (CTS\&W) Study. http://www.fhwa.dot.gov/reports/tswstudy/TSWfinal.htm.
17. Truck Characteristics Analysis, Federal Highway Administration, Washington, DC July 1999
18. U.S. DOT Federal Highway Administration, Bridge Formula Weights, http://ops.fhwa.dot.gov/freight/publications/brdg_frm_wghts/index.htm.
19. American Association of State Highway and Transportation Officials (AASHTO), Manual for Condition Evaluation and Load Rating of Highway Bridges Using Load and Resistance Factor Philosophy, AASHTO, Washington, D.C., 2001.
20. Minnesota Department of Transportation. Limits for Oversize/Overweight Annual Permits. http://www.dot.state.mn.us/motorcarrier/permits/limits_os_ow_annual.pdf.
21. Minnesota Department of Transportation. LRFD Bridge Design Manual. http://www.dot.state.mn.us/bridge/Manuals/LRFD/LRFD-CoversAndTOC.pdf.
22. Iowa Code 2003, Chapter 321E: Vehicles of Excessive Size and Weight: http://www.legis.state.ia.us/IACODE/2003/321E/.
23. Iowa Highway Research Board 1998, Project HR - 239 Phase III, Load Ratings For Standard Bridges, Ames, IA 50010
24. Michigan Department of Transportation, (2005) Bridge Analysis Guide, 2005 Edition, Part 1.
25. Illinois Vehicle Code, http://www.ilga.gov/legislation/ilcs/ilcs.asp.
26. Illinois Department of transportation, Bureau of Structures and Bridges (1999) Structural service manual.
27. Computers and Structures, Inc., SAP2000 Analysis Reference - Volume 1, Version 7.04, 1998.
28. Wood, S. M. (2004). Effects of Superload Trucks on a Steel Girder Highway Bridge. M.S. Thesis, Purdue University, W. Lafayette, IN.
29. Montgomery, D. and Runger, G. (2004) Applied Statistics and Probability for Engineers, Wiley
30. McCall, B. and Vodrazka, W (1997) State's Successful Practices Wieigh-in-Motion Handbook,
31. FHWA Traffic Monitoring Guide, 3rd Edition, http://www.fhwa.dot.gov/ohim/tmgbook.pdf.
32. FHWA (2001) Guide to LTPP Traffic Data Collection and Processing. http://www.tfhrc.gov/pavement/ltpp/pdf/trfcol.pdf
33. Center for Transportation Analysis, Oak Ridge National Laboratory (1998). Analysis of Vehicle Classification and Truck Weight Data of the New England States, Final Report.
34. Pavement research by WHRP
35. American Association of State Highway and Transportation Officials (2009) AASHTO Guidelines for Traffic Data Programs.
36. Harvey, B. A., Champion, G. H., Ritchie, S. M., and Ruby, C. D. (1995) Accuracy of Traffic Monitoring Equipment, Georgia Technical Research Institute, A-9291.
37. Dicleli, M., and M. Bruneau. (1995). "Fatigue-Based Methodology for Managing Impact of Heavy-Permit Trucks on Steel Highway Bridges." Journal of Structural Engineering, Vol. 121, No. 11, pp. 1651-1659.
38. Kostem, C. N. (1978). Overloading of Highway Bridges - Initiation of Deck Damage. Transportation Research Record 664, pp. 212-220.
39. E. J., O’Brien, (1999) Bridge deck analysis, E\&FN SPON, London, UK
40. Lichtenstein Consulting Engineers, Inc. "NCHRP Web Document 28 (Project C12-46): Contractor's Final Report: "Manual for Condition Evaluation and Load Rating of Highway Bridges Using Load and Resistance Factor Philosophy." May 2001. http://gulliver.trb.org/publications/nchrp/nchrp_w28.pdf.

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## Appendix 1 <br> Line Girder Analysis Using SAP2000

## Introduction

Steps for doing line girder analysis using SAP2000 (Ver. 11.0.6 Advanced) are shown below.
This example shows the procedures used to obtain moment/shear envelops of a 2 -span bridge (with a span length of 100 ft ) loaded by the WisDOT Standard Permit Vehicle shown below:


## Analysis Procedures

1. File>New Model: create a new Beam model (two spans of 100 ft ). Note that the forces are in kips and dimensions are in inches.


2. Define>Frame Sections: use the default section for line girder analysis

3. Define>Bridge Loads>Lanes: define lanes that describe how vehicles move on the structure
a) Click Add New Lane from Frame, use the default lane name or a new name; select frame member 1, leave Centerline Offset and Lane Width zero, and click Add

b) Change to frame member 1, leave Centerline Offset and Lane Width zero, and click Add
c) Increase Additional Lane Load Discretization to smooth the solution (e.g. 1/50 span)

4. Define>Bridge Loads>Vehicles: define Vehicle loads (e.g., HS20-44)
a) Click Add General Vehicle to define the WisDOT Standard Permit Vehicle

b) Use a name for the vehicle (e.g., WisDOT Standard Permit Vehicle)
c) Select Leading Load from Loads>Load length Type, put 25(kips) in Axle Load, select Two Points from the next column, put 72 (inches) in the last column, and click Add

d) Select Fixed Length from Loads>Load length Type, put 156(inches) in Min. Distance, put 35(kips) in Axle Load, leave everything else intact, and click Add
e) Put 48(inches) in Min. Distance, put 35(kips) in Axle Load, leave everything else intact, and click Add, and click Add again to input the last middle axle
f) Put 360(inches) in Min. Distance, put 30(kips) in Axle Load, leave everything else intact, and click Add. Put 48(inches) in Min. Distance, and click Add three times

5. Define>Bridge Loads>Vehicle Classes: specify sets of one or more vehicles that can be assigned to act on lanes in a moving-load analysis case
a) Click Add New Class
b) Use the default name or a new name for the class
c) Select the vehicle name (e.g., WisDOT Standard Permit Vehicle), and click Add

6. Define>Bridge Loads>Vehicle Response Requests: specify the response categories to be analyzed and the calculation method to be used
a) Check the first three requests and uncheck all others

7. Define>Analysis Case: define one or more moving-load analysis cases that assign the vehicles classes to the traffic lanes
a) Click Add New Case

b) Select Moving Load in Analysis Case Type, and choose the Zero Initial Conditions: Unstressed State option in Stiffness to Use,

c) Select Vehicle Class as defined (e.g., VECL1), and click Add

8. Analyze>Run Analysis: define load cases to run
a) Highlight all load cases other than the defined moving load case, and click Run/Do Not Run Case

b) Click Run Now, SAP2000 prompt to save the model

9. Display>Show Forces/Stresses>Frames/Cables: watch the moment/shear envelopes
a) Select Moment 3-3 for bending moments of the beam, select Show Values on Diagram, and click OK

b) Select Shear 2-2 for shear of the beam
c) The values shown the peak points on the moment diagram


## Export Analysis Results

10. Display>Choose Tables for Display: output the results
a) Select ANALYSIS RESULTS>Element Output>Frame Output
b) Leave all others options intact because there is only one load case

c) On the displayed table, File>Export Current Table>To Excel

d) Column V2 shows the shear envelop, and M2 bending moment envelop. The moments are in kips-in.
e) Note that the ElemStation column shows the position of calculated values in each element starts from i-node to $j$-node. The correct plot shows when the length of Member 1 is added to each position of Member 2.


Note:

- Phrases such as "File>Export Current Table>To Excel" show the command tree.
- Underlined phrases (e.g., Click Run Now ) show buttons to be clicked.
- Italic phrases (e.g., select Show Values on Diagram) show items on the screens to be selected.


## Appendix 2 Introduction to the Matlab® Programs

## Introduction to Weigh-in-Motion analysis (WIMan) program

The program WIMan is introduced below. WIMan reads in and mines the WIM records in FHWA W-cards. The program plots histograms of vehicle configurations and output configuration data in text file for post processing. If vehicles have analyzed using WIM_PVEHICLES, the results can be checked using randomly selected vehicles.

## Operation procedures of WIMan

The program window is shown below. The window is divided into three regions as illustrated in the following figure: a plot region, an information region that is below the plot region, and a command region on the right side.


The analysis starts with loading vehicle configurations (either in W-cards or in a .mat file) as noted in the information region by clicking the list box on the upper right side of the window. The program asks for a spreadsheet file that contains the vehicle configurations as shown in the following figure.


To facilitate the batch reading, a text file containing the W-cards can be specified. The read-in process will produce a mat file named "ALLVEHS.mat,"which can be reloaded to speedup the data mining. The vehicles will be listed after the W-cards are loaded. The program automatically filters out records with errors. For example, some records contain '-' that disturbed the partition of W-cards. These records (about 2,300 ) have been filtered out from the obtained 6 million records. These records can be further studied next quarter. Another error has been identified in the obtained vehicle data. For example, this record, W55250529710703160105 045802032025032 , indicates that the vehicle is class 5 and has 2 axles in total. The two axle weights are $032+032=064(=14 \mathrm{kips})$ while the gross weight shows 0458 , which is equivalent to 101kips. The program replaces the recorded gross weight with the summation of axle weights when the two values are not equal.
The vehicle configuration can be plotted by highlighting the code of the vehicle as shown below.



The histogram of the configuration data can be plotted and the bin sized specified as follows


The axle number can be specified for axle weight distribution as total axle \# - axle \#


The data set can be refined by clicking the image of the WisDOT SPV, and an input window will show to allow refining requirements. The last input informs the program to save the refined dataset in a mat file. Note that 1 gigabyte of memory is required for every two million records. This option allows a closer examination of any data set of interest.


The distribution of the refined data set can be plotted individually by clicking report button, and saved by clicking save button.

## Introduction to Moving Load analysis (MLan) program

The program MLan is introduced below. The Matlab program provides interface between user inputs on vehicle configurations and girder geometry information and the SAP2000 line girder analysis. The program also controls the SAP2000 line girder analysis and collects the analysis results into a database, which can be saved as a spreadsheet. The results can be viewed immediately after the analysis is finished and can be compared with that of the Wisconsin Standard Permit Vehicle. The comparison can be reported in terms of peak moment/shear values and R-values as defined in Chapter 4.

## Operation Procedures of Mola

The program window is shown below. The window is divided into three regions as illustrated in the following figure: a plot region, an information region that is below the plot region, and a command region on the right side.


The analysis starts with loading vehicle configurations as noted in the information region by clicking the list box on the upper right side of the window. The program asks for a spreadsheet file that contains the vehicle configurations as shown in the following figure.


The spreadsheet contains a vehicle per sheet, the name of which is the vehicle name as shown in the list box of the following figure. The format of the vehicle configuration in spreadsheet is

| Load | Min. Spacing | Max. Spacing |
| :--- | :--- | :--- |
| Leading load (kips) | 0 | 0 |
| Axle weight (kips) | Spacing to leading load (in) | 0 |
| Axle weight (kips) | Spacing to previous load (in.) | Spacing to previous load (in.) |

Note that the maximum spacing to the previous load is zero for fixed axle spacing and has a value for variable axle spacing. For example the input for the AASHTO design truck is shown below: the third axle has a variable spacing from 13 ft to 30 ft . Note that the sheet name in the spreadsheet cannot contain '_'.

| ® Microsoft Excel - SELECTEDVEH.xls |  |  |  |  |  |  |  | $\square \square \times$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| : Eile Edit View Insert Format Iools Data Window Help - © $\times$ |  |  |  |  |  |  |  |  |  |
| D1 - for |  |  |  |  |  |  |  |  |  |
|  | A | B | C | D | E | F | G | H | - |
| 1 | 8 | 0 |  |  |  |  |  |  |  |
| 2 | 32 | 156 |  |  |  |  |  |  |  |
| 3 | 32 | 156 |  |  |  |  |  |  | $\checkmark$ |
|  |  |  |  |  |  |  |  |  |  |
| Rea |  |  |  |  |  |  |  |  |  |



The vehicle configurations can be viewed briefly by highlighting the vehicle name from the list box. An error message would be generated if the vehicle configuration were not input correctly.


Specify the number of spans the girder to be analyzed has and specify the range of the span length. The program assumes that SAP2000 (Ver. 11 in this study) is installed at the default locations: C:\Progra~1\Comput~1\SAP200~1\Sap2000.exe. The analysis results can be viewed by selecting the span length using the slide bar and clicking the plot button.


The analysis results can be save as Matlab mat file and spreadsheet file by clicking the save button. And the results can be reloaded to the program by clicking the program logo. The result file name follows the following format for appropriate interpolation of the analysis case: vehicle name_minmum span_maximum span_span numberspan.mat


Enable the check box before 'WI_SPV 30~140ft' to show the comparison between the effect of the selected vehicle with that of the WIsDOT Standard Permit Vehicle. Click Summary button to show the comparison of peak values. The effect of the WisDOT Standard Permit Vehicle will be in dashed lines (red) while the selected vehicle will be in solid lines (blue).


Click Report button to show the comparison of moment/shear envelops for a group of selected vehicles for the specified span length. Enable check box before 'WI_SPV 30~140ft' to show the effect of the selected vehicle with that of the WIsDOT Standard Permit Vehicle and to calculate R-values. Note that the vehicle names must be same as the names in the result files.


The following files must be in the same directory of the program:
SELECTVEH.xls
Singlespan.s2k
Twoeqspan.s2k
Threespan.s2k
WisDOT Standard_30-140_1span.mat
WisDOT Standard_30-140_2span.mat
WisDOT Standard_30-140_3span.mat

# Appendix 3 <br> Fundamentals of Statistical Analysis in this Project 

## Introduction

WisDOT has used the Standard Permit Vehicle (shown in Fig. A3.1) for many years to describe the maximum safe load carrying capacity of highway bridges. The Standard Permit Vehicle load also has been used as a design parameter because all newly designed bridges are required to safely carry this load. The Standard Permit Vehicle is also an important guide for issuing annual permits and/or single-trip permits.


Fig. A3.1 Wisconsin Standard Permit Vehicle
The Standard Permit Vehicle was created with intentions: 1) to envelope all vehicles with annual permits; and 2) to represent the non-divisible trucks with single-trip permits. This means that the internal forces (i.e., moments and shear) caused by the WisDOT SPV in bridge girders should be larger than those of most vehicles on Wisconsin highway bridges.

In statistics language, the objective of this study is to test the following hypothesis:
The load effects of the Standard Permit Vehicle on Wisconsin bridges are larger than those of most vehicles on Wisconsin highways, where,
The load effects are moments (both positive and negative moments, for continuous girders) and shear in bridge girders in this study. Although the load effects should also include deflections and local effects on decks, they are not included in the study. This is because these effects are usually controlled with serviceability checks of a bridge rather than permit rating of the bridge.
The details of bridges should be taken into consideration for the calculation of load effects. To serve general design and rating practices, the bridges in this study are general simply supported girders with one to three equal spans. The span length varies form 30 ft to 140 ft similar to those in Wisconsin Bridge Manual.
"Vehicles" should be the population, of which information s sought: all trucks and trailers on Wisconsin highways. However, due to the inevitable variability and limitations in data collection, the available vehicles are only a subset of the population. Nevertheless, the vehicle data available collected in all weigh-in-motion stations is treated as the population due to a large data body (i.e. over six million vehicles excluding passenger cars and motorcycles.
The comparison is performed using moment/shear envelopes in simply-supported girders with
various span lengths and the peak moment/shear values in the girders.
'Most' indicates that the comparison of load effects cannot be performed with the entire population of vehicles due to limited computation power. Hence a subset of vehicles (named a sample) are analyzed and compared with the Wisconsin Standard Permit Vehicle. Based on the limited number of comparison, the conclusion needs to be drawn with certain confidence level. For example, the exceeding probability should be less than $0.0233 \%$ (corresponding to a safety index of 3.5 as illustrated in Fig. A3.2).


Fig. A3.2 Structural safety in LRFD structural design
Similar to the probability based structural analysis, the distribution of the subject was assumed to be normal. Another assumption needed was that the statistical characteristics of the entire population, though unknown, were assumed to be the same as that of the samples (e.g., the sample mean values and the sample standard deviation). The probability of exceeding ('poe' as the failure probability in the structural design shown in Fig. A.2) is affected by both the mean value and the standard deviation. This was shown for standard normal distributions in Fig. A3.3.


Fig. A3.3 Standard normal distribution

If the hypothesis is rejected, a modification should be proposed to the standard permit vehicle should be created to ensure that the hypothesis is true with certain confidence level.

## Population mean

The population mean for a discrete random variable $(X)$ is given by
$\mu_{X}=\sum_{x} x P(X=x)$,
where $P(X=x)$ is the probability mass function. Often time The mean value is also calculated as $\mu_{X}=\frac{\sum x}{n}$, where n is the total number of values in the population.

In the above example, $P(X=x)=\frac{1}{10}$ because each number has one appearance in the population. Hence $\mu_{X}=\frac{(1+2+3+4+5+6+7+8+9+10)}{10}=5.5$

## Population standard deviation

The population standard deviation ( $\sigma_{X}$ ) for a discrete random variable $(X)$ is given by
$\sigma_{X}^{2}=\frac{\sum_{x}\left(x-\mu_{X}\right)^{2}}{n-1}$,
In the above example, $\sum_{x}\left(x-\mu_{X}\right)^{2}=82.5$, and the standard deviation is $\sqrt{82.5 /(10-1)}=3.03$

## Population percentiles

The median of a sample is defined as the middle number of the average of the two middle numbers when the sample values are arranged from smallest to largest. In terms of the probability density function, the median is the point at which half the area under the curve is to the left and half the area is to the right. Similarly, the pth percentile $(0<p<100)$ of a population is the value such that $\mathrm{p} \%$ of the population are less than or equal to the value. A median is $50^{\text {th }}$ percentile. For example, to find the $90^{\text {th }}$ percentile of the following population,

## $3,4,7,1,2,6,8,9,10,5$

Reordering the population from smallest to largest gives

## $1,2,3,4,5,6,7,8,9,10$.

Any value between 9 and 10 would ensure $90 \%$ of the population is smaller than the value. SPSS calculates the $90^{\text {th }}$ percentile as $9+(10-9) \times 90 \%=9.9$. For the $95^{\text {th }}$ percentile of the same population, there is actually not a value that can ensure $95 \%$ of the population is less than or equal to the value. This is because the total number of population is 10 such that $95 \%$ of the population would result in nine and half numbers, which is invalid. In this case, SPSS find the value such that 10 values $(100 \%)$ are less than or equal to the value. This indicates that the $95^{\text {th }}$ percentile is for the above population is 10 .

The sample used in this study included both vehicles with annual permits and vehicles with single-trip permits. This was due to lacking of reliable criteria to separate single-trip permit vehicles form all other vehicles in the WIM records. In addition, Chapter 5 indicated that many vehicles with single-trip permits have reasonable gross vehicle weights. The number of vehicles heavier than 250 -kips is small. It was demonstrated here that the inclusion of small quantities of the heavy trucks would not affect significantly the results of the descriptive statistical analyses used in this study.
Consider a value of 20 is included in the group of data such that the probability of this value is as large as $1 \%$

## $0.1,0.2,0.3 \ldots 1.1,1.2,1.3 \ldots 2.1,2.2,2.3 \ldots 10.0,20$

The $90^{\text {th }}$ percentile of the new data set would be 9.18 compared with 9.09 for the data set without the number 20. The $95^{\text {th }}$ percentile would 9.69 compared with 9.60 . The effect of the small number of high values would cause insignificant impact in the calculation of the percentile values.

# Appendix 4 <br> Multivariate Statistical Analysis of WIM data 

## Introduction

There are 17 Weigh-In-Motion (WIM) stations in Wisconsin that record truck weight information as vehicles pass over their sensors at normal speeds. These WIM data include all legal and illegal trucks that may cross the WIM sensors, and thus provide a reasonably complete picture of truck loads. Understanding the statistical variability of different classes of truck loads is considered important with respect to probabilistic evaluation of overweight truck impacts on bridges and pavements. This study is designed to collect and analyze WIM truck data from all stations in Wisconsin for the entire year of 2007. Approximately 6 million truck records (truck classes 5 through 15) were evaluated in this study. Statistical analyses were performed on the heaviest 5 percent of trucks in each class-axle grouping.
The objectives of this research were as follows:

- Analyze Wisconsin WIM data to obtain axle weight and spacing information for heavy trucks in various truck classes. This will provide detailed information on load characteristics of heavy trucks traveling on Wisconsin highways.
- Determine unimodal and multimodal statistical distributions for all axle loads and spacings for the heaviest $5 \%$ of all trucks in each truck class-axle group, and determine multivariate "copulas" that map relationships between different distributions.
- Conduct multivariate Monte-Carlo simulation studies using the statistical distributions and copulas.
W-card data from the Wisconsin WIM stations were obtained from WisDOT. W-cards refer to the WIM data in metric units. These data were exported into Microsoft Excel spreadsheets for analyses. Excel truck data were checked to ensure that all sets of data were valid. Data were then sorted based on truck class. Only records for truck classes 5 through 15 were retained. For each truck class-axle grouping, two sets of data were developed: A complete set as well as a partial set containing the heaviest 5 percent (H5P) of all trucks in each class-axle group. The H5P data are significant with respect to impact of heavy loads on bridges and pavements. By separating and analyzing the H5P data, the accuracy of predictions on heavy loads would be improved significantly. For example, fitting a statistical distribution to the H5P data would be more accurate that looking at the tail of a distribution fit to the entire dataset.
Srinivas, Menon, and Prasad ${ }^{(1)}$ describe an approach for determining multivariate statistical distributions of truck axle weights and spacing using copulas. This approach was used to determine relevant distributions in this study. It is believed that considering axle weight and axle spacing as independent variables would not be as accurate since the important interdependencies between various axle loads and spacings would be overlooked. Also, conducting multivariate analyses using linear correlation coefficients would not accurately describe the dependence for non-elliptical distributions ${ }^{(1),(4)}$. Therefore, multivariate analyses and simulations using copulas were used in this study.

The software used in the data analyses phase of this study included Crystal Ball ${ }^{(2)}$, which is a forecasting and Monte Carlo simulation program that runs within the MS Excel platform, and ModelRisk ${ }^{(3)}$, which is a quantitative risk analysis program that also runs within MS Excel. Both Crystal Ball and ModelRisk can fit statistical distributions to a given dataset. ModelRisk can also fit copulas or determine empirical copulas based on data. Crystal Ball and ModelRisk can be run together to perform Monte Carlo simulations involving the determined distributions and copulas.

## Weigh-in-Motion data

All data produced by Wisconsin WIM stations in 2007 were obtained from WisDOT. A total of nearly 6 million vehicle WIM records were obtained. A few stations did not record any data in 2007, while others were operating part of the year only. Table A4.1 shows the number of vehicle records (classes 2 through 15) obtained from all stations in 2007. There were some records with the station identified as " 0 ". Those records were included in the analyses.

For data analyses, only vehicle classes 5 through 15 (i.e. trucks) were considered (i.e. non-truck classes 2,3 , and 4 were removed). Truck data were first tested to make sure that they were valid, and invalid truck records were discarded (approximately $0.1 \%$ of all truck data). Three validity tests were performed on each data line (truck record):

1. Is the total weight reported on the W -card for each truck within $\pm 5 \%$ of the sum of all axle weights reported?
2. Does the number of axles reported on the card match the number of axle weights reported?
3. Are all axle spacings reported reasonable? Records that showed axle spacing of less than 20 inches were discarded.

Data that failed these tests were not included in further analyses. Of the total of 5,761,802 unfiltered records for classes 5 through 15, only 4,352 records (or $0.08 \%$ ) were discarded based on the above three criteria. Table A4.2 shows the number of unfiltered truck records as grouped within different classes for different months of 2007.

Some truck classes may have different number of axles. For example, class 7 trucks could have either 4 or 5 axles (designated as class-axle groups $07-04$ and $7-05$ ) while class 8 trucks could have 3 or 4 axles (class-axle groups $08-03$ and $08-04$ ). Table A4.3 breaks down the number of trucks based on class and number of axles. WIM data for class 13 and 15 trucks include a large number of axle variations within the same class.

Data associated with the same number of axles within each class had to be separated before calculating the best fit statistical distributions. For example, two sets of statistical distributions were determined for class 7 .

Table A4.3 also shows the number of filtered trucks in each class (and axle) category as a percentage of trucks in each class as well as percentage of all filtered trucks. Class 9 trucks make up over $61.7 \%$ of all WIM trucks. There were over 3.5 million class 9 vehicles in the 2007 data. The second and third most common trucks are classes 8 and 5 at $14.7 \%$ and $13.0 \%$, respectively.

The minimum, maximum, and 95 percentile values for the total weight of each truck class are also shown in Table A4.3. For example, the maximum recorded total weight for a class 9 was 242.5 kips and the 95 percentile weight was 104.9 kips.

It is extremely important that the heaviest trucks in each class are accurately represented in the analyses and simulations. Therefore, the heaviest 5 percent (H5P) of trucks in each class-axle category (i.e. trucks that weigh more than the $95^{\text {th }}$ percentile value) were separated and analyzed. This is considered preferable (more accurate) relative to fitting distributions to the entire data and estimating the worst effects from the distribution tails. Basic H5P information for each class-axle category is shown in Table A4.1.

Table A4.1. Number of Raw Vehicle Records from all WIM Stations in All Months of 2007

| Station | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathbf{0}$ | 21456 | 19122 | 22183 | 17186 | 31204 | 32899 | 35081 | 35617 | 30815 | 30399 | 21611 | 14416 |
| $\mathbf{T O T A L}$ |  |  |  |  |  |  |  |  |  |  |  |  |
| $\mathbf{3 0 0 1 0}$ | 12807 | 0 | 0 | 0 | 60055 | 66559 | 20478 | 22227 | 54777 | 32949 | 41365 | 35311 |
| $\mathbf{4 0 0 0 2}$ | 0 | 0 | 0 | 0 | 0 | 0 | 6050 | 29519 | 22726 | 24098 | 18394 | 13667 |
| $\mathbf{1 0 0 0 0 1}$ | 89409 | 39056 | 57911 | 27132 | 42302 | 17412 | 2041 | 17082 | 16896 | 24379 | 15069 | 0 |
| $\mathbf{2 2 0 0 0 1}$ | 27203 | 26492 | 35286 | 38605 | 70501 | 63663 | 67780 | 73481 | 61924 | 74553 | 61278 | 46063 |
| $\mathbf{2 5 0 5 2 9}$ | 88486 | 7479 | 83352 | 48932 | 51497 | 71679 | 35772 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{2 6 0 0 0 1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{3 6 0 0 0 2}$ | 8054 | 6208 | 0 | 249 | 34997 | 0 | 0 | 0 | 0 | 24775 | 80140 | 77903 |
| $\mathbf{3 7 0 0 0 6}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{3 9 0 1 0 5}$ | 61578 | 24319 | 8345 | 7591 | 35253 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{4 1 0 2 4 0}$ | 0 | 0 | 0 | 0 | 228030 | 215906 | 200444 | 222604 | 198999 | 234690 | 199252 | 177924 |
| $\mathbf{4 1 0 2 5 3}$ | 0 | 0 | 0 | 0 | 129640 | 126113 | 138187 | 148541 | 117502 | 136091 | 111740 | 97566 |
| $\mathbf{4 5 0 2 3 9}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{4 7 0 1 0 2}$ | 6087 | 4968 | 6073 | 3298 | 2641 | 0 | 6230 | 9115 | 7421 | 8761 | 6687 | 5047 |
| $\mathbf{5 3 0 0 0 1}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $\mathbf{5 7 6 0 5 1}$ | 7291 | 6772 | 5655 | 0 | 13174 | 13650 | 16876 | 15345 | 11252 | 11087 | 8102 | 6807 |
| $\mathbf{5 9 0 6 0 8}$ | 38395 | 27317 | 35086 | 41011 | 49887 | 47827 | 54562 | 57059 | 44703 | 53391 | 41148 | 33859 |
| $\mathbf{6 4 0 3 4 8}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $\mathbf{5 2 4 2 4}$ |
| Total | $\mathbf{3 6 0 7 6 6}$ | $\mathbf{2 2 9 0 5 1}$ | $\mathbf{2 5 3 8 9 1}$ | $\mathbf{1 8 4 0 0 4}$ | $\mathbf{7 4 9 1 8 1}$ | $\mathbf{6 5 5 7 0 8}$ | $\mathbf{5 8 3 5 0 1}$ | $\mathbf{6 3 0 5 9 0}$ | $\mathbf{5 6 7 0 1 5}$ | $\mathbf{6 5 5 1 7 3}$ |  |  |

Table A4.2. Number of Unfiltered Truck Records in Each Vehicle Class (Year 2007)

| Classification | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Class 05 | 61472 | 42417 | 44533 | 31252 | 87485 | 77963 | 70912 | 72290 | 64979 | 70679 | 68312 | 57115 | $\mathbf{7 4 9 4 0 9}$ |
| Class 06 | 15133 | 9470 | 12368 | 11901 | 31637 | 25314 | 23411 | 27597 | 26198 | 27075 | 24445 | 17365 | $\mathbf{2 5 1 9 1 4}$ |
| Class 07 | 1656 | 1257 | 3156 | 3041 | 9796 | 6952 | 8239 | 9915 | 7818 | 10315 | 7760 | 3267 | $\mathbf{7 3 1 7 2}$ |
| Class 08 | 25836 | 17226 | 22899 | 18617 | 124162 | 121046 | 117640 | 122218 | 101025 | 79634 | 60791 | 37978 | $\mathbf{8 4 9 0 7 2}$ |
| Class 09 | 204243 | 117930 | 124366 | 90877 | 442906 | 364234 | 323198 | 369110 | 336788 | 418136 | 403424 | 359488 | $\mathbf{3 5 5 4 7 0 0}$ |
| Class 10 | 5547 | 3778 | 4560 | 3024 | 9676 | 7498 | 6044 | 7877 | 6346 | 8574 | 8491 | 6349 | $\mathbf{7 7 7 6 4}$ |
| Class 11 | 3362 | 1625 | 1432 | 955 | 12768 | 10631 | 9091 | 11039 | 9798 | 12271 | 11348 | 10258 | $\mathbf{9 4 5 7 8}$ |
| Class 12 | 687 | 408 | 307 | 185 | 3977 | 3402 | 3004 | 3570 | 3164 | 4165 | 4016 | 3692 | $\mathbf{3 0 5 7 7}$ |
| Class 13 | 971 | 909 | 1399 | 734 | 1713 | 1533 | 1076 | 510 | 506 | 626 | 570 | 360 | $\mathbf{1 0 9 0 7}$ |
| Class 14 | 72 | 66 | 396 | 254 | 111 | 148 | 84 |  |  |  |  |  | $\mathbf{1 1 3 1}$ |
| Class 15 | 9730 | 8708 | 13921 | 7183 | 8430 | 10611 | 7167 | 512 | 601 | 721 | 649 | 345 | $\mathbf{6 8 5 7 8}$ |
| Total | $\mathbf{3 2 8 7 0 9}$ | $\mathbf{2 0 3 7 9 4}$ | $\mathbf{2 2 9 3 3 7}$ | $\mathbf{1 6 8 0 2 3}$ | $\mathbf{7 3 2 6 6 1}$ | $\mathbf{6 2 9 3 3 2}$ | $\mathbf{5 6 9 8 6 6}$ | $\mathbf{6 2 4 6 3 8}$ | $\mathbf{5 5 7 2 2 3}$ | $\mathbf{6 3 2 1 9 6}$ | $\mathbf{5 8 9 8 0 6}$ | $\mathbf{4 9 6 2 1 7}$ | $\mathbf{5 7 6 1 8 0 2}$ |

Table A4.3. Detailed Information on Different Truck Classes

| Class | Class - <br> Axles | Unfiltered Count | Filtered Truck Data |  |  |  |  |  | H5P |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Count | Count \% of <br> Total | Count \% of Class | Min Wt. <br> (Kips) | Max Wt. <br> (Kips) | 95th <br> \%ile <br> (Kips) | Count | Min Wt. <br> (Kips) | Max Wt. <br> (Kips) |
| Class 5 | 05-02 | 749409 | 748658 | 13.00\% | 100.00\% | 0.22 | 78.48 | 24.69 | 38565 | 24.69 | 78.48 |
| Class 6 | 06-03 | 251914 | 251795 | 4.37\% | 100.00\% | 0.66 | 119.93 | 53.35 | 12730 | 53.35 | 119.93 |
| Class 7 | Total | 73172 | 73138 | 1.27\% |  | 1.10 | 187.17 | 89.51 | 3674 | 89.51 | 187.17 |
|  | 07-04 |  | 25753 | 0.45\% | 35.21\% | 1.10 | 187.17 | 79.81 | 1313 | 79.81 | 187.17 |
|  | 07-05 |  | 47385 | 0.82\% | 64.79\% | 1.32 | 171.96 | 93.26 | 2386 | 93.26 | 171.96 |
| Class 8 | Total | 849072 | 848482 | 14.74\% |  | 0.66 | 153.00 | 46.30 | 42763 | 46.30 | 153.00 |
|  | 08-03 |  | 634745 | 11.02\% | 74.81\% | 0.66 | 145.28 | 26.01 | 32061 | 26.01 | 145.28 |
|  | 08-04 |  | 213738 | 3.71\% | 25.19\% | 0.88 | 153.00 | 68.34 | 10836 | 68.34 | 153.00 |
| Class 9 | 09-05 | 3554700 | 3553613 | $61.72 \%$ | 100.00\% | 1.10 | 242.51 | 104.94 | 177857 | 104.94 | 242.51 |
| Class 10 | Total | 77764 | 77185 | 1.34\% |  | 1.32 | 267.20 | 116.62 | 3883 | 116.62 | 267.20 |
|  | 10-06 |  | 72939 | 1.27\% | 94.50\% | 1.32 | 267.20 | 114.64 | 3662 | 114.64 | 267.20 |
|  | 10-07 |  | 4246 | 0.07\% | 5.50\% | 1.76 | 235.67 | 143.52 | 215 | 143.52 | 235.67 |
| Class 11 | 11-05 | 94578 | 94572 | 1.64\% | 100.00\% | 3.31 | 181.00 | 116.85 | 4747 | 116.85 | 181.00 |
| Class 12 | 12-06 | 30577 | 30576 | 0.53\% | 100.00\% | 1.76 | 205.25 | 129.85 | 1537 | 129.85 | 205.25 |
| Class 13 | Total | 10907 | 10595 | 0.18\% |  | 1.54 | 328.05 | 130.29 | 534 | 130.29 | 328.05 |
|  | 13-07 |  | 9738 | 0.17\% | 91.91\% | 1.54 | 328.05 | 128.75 | 490 | 128.75 | 328.05 |
|  | 13-08 |  | 680 | 0.01\% | 6.42\% | 28.66 | 160.94 | 122.14 | 35 | 122.14 | 160.94 |
|  | 13-09 |  | 75 | 0.00\% | 0.71\% | 37.70 | 177.25 | 162.99 | 5 | 162.92 | 177.25 |
|  | 13-10 |  | 65 | 0.00\% | 0.61\% | 38.36 | 200.62 | 161.51 | 4 | 162.92 | 200.62 |
|  | 13-11 |  | 10 | 0.00\% | 0.09\% | 66.80 | 169.76 | 167.28 | 1 | 169.76 | 169.76 |
|  | 13-12 |  | 8 | 0.00\% | 0.08\% | 65.04 | 209.22 | 207.60 | 1 | 209.22 | 209.22 |
|  | 13-13 |  | 19 | 0.00\% | 0.18\% | 88.41 | 246.26 | 227.41 | 1 | 246.26 | 246.26 |
| Class 14 | 14-05 | 1131 | 1128 | 0.02\% | 100.00\% | 12.13 | 101.19 | 71.21 | 58 | 71.21 | 101.19 |
| Class 15 | Total | 68578 | 67708 | 1.18\% |  | 1.76 | 423.95 | 97.89 | 3388 | 97.89 | 423.95 |
|  | 15-02 |  | 3071 | 0.05\% | 4.54\% | 4.63 | 49.60 | 34.61 | 157 | 34.61 | 49.60 |
|  | 15-03 |  | 13617 | 0.24\% | 20.11\% | 6.17 | 55.34 | 26.90 | 682 | 26.90 | 55.34 |
|  | 15-04 |  | 10013 | 0.17\% | 14.79\% | 7.50 | 93.04 | 57.10 | 507 | 57.10 | 93.04 |
|  | 15-05 |  | 9057 | 0.16\% | 13.38\% | 12.57 | 104.72 | 73.85 | 465 | 73.85 | 104.72 |
|  | 15-06 |  | 19507 | 0.34\% | 28.81\% | 13.23 | 135.80 | 93.04 | 987 | 93.04 | 135.80 |
|  | 15-07 |  | 4164 | 0.07\% | 6.15\% | 19.62 | 130.95 | 100.09 | 214 | 100.09 | 130.95 |
|  | 15-08 |  | 4781 | 0.08\% | 7.06\% | 1.76 | 266.32 | 162.70 | 242 | 162.70 | 266.32 |
|  | 15-09 |  | 1264 | 0.02\% | 1.87\% | 1.98 | 345.91 | 182.26 | 64 | 182.32 | 345.91 |
|  | 15-10 |  | 727 | 0.01\% | 1.07\% | 2.20 | 423.95 | 202.16 | 39 | 202.16 | 423.95 |
|  | 15-11 |  | 489 | 0.01\% | 0.72\% | 2.20 | 239.86 | 166.85 | 25 | 167.11 | 239.86 |
|  | 15-12 |  | 384 | 0.01\% | 0.57\% | 2.43 | 359.79 | 91.45 | 20 | 92.37 | 359.79 |
|  | 15-13 |  | 341 | 0.01\% | 0.50\% | 2.65 | 322.10 | 61.29 | 18 | 61.29 | 322.10 |
|  | 15-14 |  | 293 | 0.01\% | 0.43\% | 3.09 | 131.40 | 51.72 | 15 | 52.91 | 131.40 |

## Statistical Distributions for H5P Data

The H5P data for all class-axle groups were used to generate best-fit statistical distributions using the ModelRisk software. Data from all stations were combined. Limited Analysis of Variance (ANOVA) showed that truck weights in different WIM stations did not belong to the same distribution. Best fit distributions were determined for each axle weight, axle spacing and the total weight in each truck class-axle category. ModelRisk reportedly utilizes the following information criteria to find the best fit distribution for each parameter:

- SIC (Schwarz Information Criterion), also known as Bayesian Information Criterion (BIC)
- AIC (Akaike Information Criterion)
- HQIC (Hannan-Quinn Information Criterion)

The fitting options within ModelRisk cannot directly accommodate bimodal ("double hump") or multi-modal statistical distributions. However, many axle load and axle spacing distributions are in fact multi-modal. When data warranted such considerations, a semi-manual approach was used to determine multi-modal best fit distributions. The following approach was used:

- A histogram of data was generated in MS Excel.
- ModelRisk® was used to find the best fit single-mode distributions.
- If the histogram indicated multi-modal ("multi-hump") behavior, then the histogram data was manually separated into grouping around each peak. Best fit single-mode distributions for each group were determined using ModelRisk. The number of data points within each grouping divided by the total number of data points is the probability $(\mathrm{P})$ associated with the distribution in that grouping. For example, for a tri-modal distribution:


## 

- The resulting multi-modal distribution was plotted and compared with the histogram to make sure that the data agrees with the distribution.

All single-mode distributions for all class-axle groupings are shown in Appendix A (These include distributions for which a unimodal assumption is not appropriate). Table A4.4 shows the single-mode best fit distributions for class 09 ( 5 axle truck). As stated earlier, not all single-mode distributions are appropriate. When the histogram shape indicated multimodal response, the multimodal distributions were determined as well and used in simulations in lieu of single-mode distributions. Table A4.5 shows the multi-modal distributions fit to class 9 data that were considered multi-modal. Appendix B includes all such multi-modal data for all classes. For reference, Table A4.6 shows typical shapes associated with different unimodal distributions.
Selected histogram and distribution plot for class 9 are shown in Table A4.7. More such plots are provided in Appendix C. Table A4.8 shows the axle loads and spacings for the heaviest three trucks in each class-axle group obtained from the H5P data. Table A4.9 shows percentages of permit/illegal trucks within each class-axle groupings in H5P data. The criteria for classification as permit/illegal were: a) gross weight $>80$ kips, b) front axle $>13$ kips, and c) any axle $>20$ kips.

Table A4.4. Best Fit Single-Mode Distributions for Class 9 Trucks.

| Class 09-05 |  |  |
| :--- | :--- | :--- |
| Wt. or Spacing | Distribution | Parameters* |
| Total Wt | Beta4 | $1.199,6.460,475.618,1100.592$ |
| A axle Wt | Student3 | $96.110,18.620,15$ |
| A-B spacing** | Student3 | $51.296,7.023,3$ |
| B axle Wt | Student3 | $118.086,18.667,302$ |
| B-C spacing | Student3 | $12.761,0.658,5$ |
| C axle Wt | Student3 | $122.246,19.266,43$ |
| C-D spacing | Student3 | $100.460,8.277,6$ |
| D axle Wt | Student3 | $116.664,18.978,50$ |
| D-E spacing** | Student3 | $12.008,0.444,3$ |
| E axle Wt | Student3 | $121.745,19.450,34$ |

* Parameters are determined using W-Card units. W-Card load data are given in 100kg's. WCard spacing data are given in 100 mm 's. The parameters are used to generate the particular distributions, say beta4 or student3.
** The histogram is not unimodal. Use multi-mode distribution given in Table A4.4 instead.

Table A4.5. Best Fit Multi-Modal Distributions for Class 9 Spacings.
Class 09-05 AB spacing

| Distribution | Parameters* | Weight | \% otal <br> Tot |
| :--- | :--- | :--- | :--- | :--- |
| Student3 | $36.560,2.952,10$ | 13483 | $7.58 \%$ |
| Logistic | $50.746,1.740$ | 137860 | $77.51 \%$ |
| Student3 | $59.601,2.069,4$ | 26514 | $14.91 \%$ |


| Class 09-05 DE spacing |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Distribution | Parameters* | Weight | \% <br> Total |
| Gamma | $362.838,0.033$ | 153114 | $86.09 \%$ |
| Student3 | $30.143,0.943,3$ | 24743 | $13.91 \%$ |

* Parameters are determined using W-Card units. W-Card load data are given in 100 kg 's. WCard spacing data are given in 100 mm 's. The parameters are used to generate the particular distributions, say beta 4 or student 3 .

Table A4.6. Typical Single Mode Statistical Distributions ${ }^{(3)}$


Table A4.7-H5P Histograms and distributions for Class 9 trucks.

|  <br> Axle A |  <br> Axle B |  <br> Axle C |  <br> Axle D |
| :---: | :---: | :---: | :---: |
|  <br> Axle E |  <br> AB Spacing |  <br> BC Spacing | Combined Distribution <br> DE Spacing |

Table A4.8 - Axle loads and spacings for the three heaviest trucks in each class-axle.

|  | No. <br> of <br> Class | Total <br> WT <br> kips | A <br> axle <br> Wt <br> kips | A-B <br> sp. <br> (ft) | B <br> axle <br> Wt <br> kips | B-C <br> sp. <br> (ft) | C <br> axle <br> Wt <br> kips | C-D <br> sp. <br> (ft) | D <br> axle <br> Wt <br> kips | D-E <br> sp. <br> (ft) | Exle <br> Wt <br> kips |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | 2 | 78.5 | 28.9 | 18.0 | 49.6 |  |  |  |  |  |  |
| 5 | 2 | 75.4 | 39.5 | 13.5 | 36.2 |  |  |  |  |  |  |
| 5 | 2 | 74.5 | 38.4 | 13.5 | 36.2 |  |  |  |  |  |  |
| 6 | 3 | 119.9 | 34.0 | 12.1 | 46.5 | 4.6 | 39.5 |  |  |  |  |
| 6 | 3 | 116.8 | 39.7 | 18.0 | 38.1 | 4.3 | 39.0 |  |  |  |  |
| 6 | 3 | 115.5 | 38.6 | 14.1 | 37.9 | 4.3 | 39.0 |  |  |  |  |
| 7 | 4 | 187.2 | 39.2 | 17.1 | 33.1 | 4.6 | 55.3 | 4.6 | 59.3 |  |  |
| 7 | 4 | 149.3 | 38.6 | 13.1 | 34.8 | 6.6 | 37.5 | 4.3 | 38.4 |  |  |
| 7 | 4 | 141.3 | 40.3 | 16.1 | 20.9 | 4.9 | 35.7 | 4.6 | 44.1 |  |  |
| 7 | 5 | 172.0 | 36.4 | 14.8 | 21.8 | 4.9 | 37.5 | 4.3 | 39.5 | 4.6 | 36.8 |
| 7 | 5 | 172.0 | 45.9 | 9.5 | 28.9 | 4.3 | 27.6 | 4.3 | 36.8 | 4.3 | 32.8 |
| 7 | 5 | 170.0 | 38.1 | 14.8 | 20.5 | 4.9 | 38.6 | 4.3 | 39.7 | 4.9 | 33.1 |
| 8 | 3 | 145.3 | 0.9 | 10.8 | 72.3 | 24.6 | 72.3 | 0.0 | 0.0 |  |  |
| 8 | 3 | 127.6 | 5.7 | 8.9 | 56.7 | 36.7 | 65.0 | 0.0 | 0.0 |  |  |
| 8 | 3 | 121.5 | 1.3 | 7.5 | 54.5 | 31.8 | 65.7 | 0.0 | 0.0 |  |  |
| 8 | 4 | 153.0 | 38.6 | 17.4 | 37.9 | 4.6 | 39.2 | 33.1 | 37.3 |  |  |
| 8 | 4 | 151.9 | 34.6 | 17.1 | 39.2 | 4.3 | 39.9 | 29.9 | 38.1 |  |  |
| 8 | 4 | 150.6 | 34.0 | 16.7 | 39.9 | 4.3 | 39.9 | 31.5 | 36.8 |  |  |
| 8 | 4 | 150.6 | 34.8 | 14.4 | 39.7 | 36.4 | 36.8 | 3.9 | 39.2 |  |  |
| 9 | 5 | 242.5 | 47.4 | 13.1 | 39.5 | 4.9 | 52.9 | 4.6 | 56.9 | 4.9 | 45.6 |
| 9 | 5 | 229.7 | 44.8 | 12.8 | 28.9 | 4.9 | 55.6 | 4.6 | 57.1 | 4.9 | 43.4 |
| 9 | 5 | 217.6 | 15.2 | 26.6 | 25.6 | 13.5 | 67.5 | 23.3 | 37.3 | 15.1 | 72.3 |

Table A4.8 (Cont.) Axle loads and spacings for the three heaviest trucks in each class-axle.

| Class | No. of axles | $\begin{aligned} & \text { Total } \\ & \text { WT } \\ & \text { kips } \end{aligned}$ | A <br> axle <br> Wt <br> kips | $\begin{gathered} \text { A-B } \\ \text { sp. } \\ \text { (ft) } \end{gathered}$ | B <br> axle <br> Wt <br> kips | $\begin{gathered} \text { B-C } \\ \text { sp. } \\ \text { (ft) } \end{gathered}$ | C <br> axle <br> Wt <br> kips | $\begin{gathered} \text { C-D } \\ \text { sp. } \\ (\mathrm{ft}) \end{gathered}$ | D <br> axle <br> Wt <br> kips | $\begin{gathered} \text { D-E } \\ \text { sp. } \\ (\mathrm{ft}) \end{gathered}$ | E <br> axle <br> Wt <br> kips | $\begin{aligned} & \text { E-F } \\ & \text { sp. } \\ & (\mathrm{ft}) \end{aligned}$ | F <br> axle <br> Wt <br> kips | $\begin{gathered} \text { F-G } \\ \text { sp. } \\ (\mathrm{ft}) \end{gathered}$ | G <br> axle <br> Wt <br> kips | G- <br> H <br> sp. <br> (ft) | $\begin{gathered} \mathrm{H} \\ \text { axle } \\ \mathrm{Wt} \\ \text { kips } \end{gathered}$ | $\begin{aligned} & \text { H-I } \\ & \text { sp. } \\ & \text { (ft) } \end{aligned}$ | I <br> axle <br> Wt <br> kips | $\begin{aligned} & \text { I-J } \\ & \text { sp. } \\ & \text { (ft) } \end{aligned}$ | J <br> axle <br> Wt <br> kips | $\begin{aligned} & \text { J-K } \\ & \text { sp. } \\ & (\mathrm{ft}) \end{aligned}$ | K <br> axle <br> Wt <br> kips | K- <br> L <br> sp. <br> (ft) | L <br> axle <br> Wt <br> kips |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 10 | 6 | 267.2 | 26.0 | 16.1 | 54.2 | 4.3 | 53.8 | 30.2 | 17.0 | 4.3 | 58.0 | 4.3 | 58.2 |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | 6 | 264.3 | 23.4 | 15.7 | 57.1 | 4.3 | 57.3 | 31.5 | 29.1 | 4.3 | 47.4 | 4.3 | 50.3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | 6 | 227.7 | 22.3 | 24.3 | 34.8 | 6.2 | 72.3 | 6.2 | 42.1 | 57.7 | 26.9 | 34.1 | 29.3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | 7 | 235.7 | 33.1 | 13.8 | 38.6 | 3.9 | 38.8 | 38.1 | 29.5 | 3.9 | 30.9 | 3.9 | 31.7 | 4.3 | 33.1 |  |  |  |  |  |  |  |  |  |  |
| 10 | 7 | 217.6 | 26.5 | 14.4 | 32.2 | 4.3 | 32.4 | 24.3 | 27.8 | 5.9 | 29.8 | 3.9 | 34.0 | 3.9 | 35.1 |  |  |  |  |  |  |  |  |  |  |
| 10 | 7 | 206.1 | 33.7 | 17.1 | 27.3 | 4.3 | 34.6 | 33.1 | 25.4 | 4.3 | 27.6 | 4.3 | 30.4 | 4.3 | 27.1 |  |  |  |  |  |  |  |  |  |  |
| 11 | 5 | 181.0 | 27.3 | 12.5 | 39.5 | 21.0 | 39.7 | 9.2 | 37.9 | 22.0 | 36.6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 | 5 | 172.6 | 30.9 | 12.8 | 35.1 | 21.0 | 37.5 | 9.2 | 32.8 | 22.6 | 36.4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 | 5 | 172.6 | 34.2 | 13.1 | 37.5 | 22.6 | 37.0 | 10.2 | 35.9 | 23.6 | 28.0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 | 6 | 205.3 | 36.6 | 16.4 | 37.3 | 4.6 | 30.4 | 21.0 | 36.2 | 11.2 | 35.5 | 23.6 | 29.3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 | 6 | 185.6 | 24.5 | 18.4 | 28.7 | 3.9 | 24.7 | 22.3 | 36.8 | 8.9 | 35.7 | 24.0 | 35.3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 | 6 | 184.3 | 24.3 | 11.5 | 30.0 | 4.3 | 28.0 | 20.0 | 31.1 | 9.8 | 39.2 | 21.3 | 31.7 |  |  |  |  |  |  |  |  |  |  |  |  |
| 13 | 7 | 328.0 | 20.9 | 27.9 | 26.9 | 6.6 | 72.3 | 19.7 | 30.2 | 5.9 | 72.3 | 61.7 | 33.3 | 5.9 | 72.3 |  |  |  |  |  |  |  |  |  |  |
| 13 | 7 | 313.1 | 31.5 | 20.0 | 32.6 | 6.6 | 67.5 | 6.2 | 51.6 | 21.0 | 26.9 | 7.2 | 31.1 | 6.2 | 72.3 |  |  |  |  |  |  |  |  |  |  |
| 13 | 7 | 281.3 | 18.3 | 20.7 | 25.8 | 5.2 | 39.9 | 5.6 | 61.3 | 18.4 | 31.5 | 5.9 | 72.3 | 82.3 | 32.6 |  |  |  |  |  |  |  |  |  |  |
| 14 | 5 | 101.2 | 14.8 | 18.4 | 23.8 | 4.3 | 23.4 | 15.7 | 21.2 | 18.4 | 18.1 | 0.0 | 0.0 |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 | 5 | 95.7 | 20.7 | 22.0 | 17.6 | 4.6 | 18.5 | 14.4 | 18.5 | 16.7 | 20.3 | 0.0 | 0.0 |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 | 5 | 93.9 | 11.7 | 16.4 | 16.1 | 4.9 | 22.5 | 9.8 | 23.8 | 16.4 | 19.8 | 0.0 | 0.0 |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 | 10 | 423.9 | 20.7 | 19.0 | 14.3 | 6.2 | 65.0 | 5.9 | 72.3 | 20.0 | 28.7 | 5.6 | 51.4 | 50.9 | 28.4 | 5.9 | 61.9 | 5.9 | 55.3 | 18.7 | 25.8 |  |  |  |  |
| 15 | 12 | 359.8 | 37.3 | 17.7 | 30.4 | 4.6 | 30.4 | 16.4 | 22.5 | 4.3 | 27.6 | 4.3 | 28.0 | 18.7 | 30.4 | 4.3 | 30.6 | 4.3 | 34.0 | 13.8 | 30.0 | 4.3 | 30.2 | 4.3 | 28.4 |
| 15 | 9 | 345.9 | 17.4 | 19.7 | 15.7 | 6.2 | 58.6 | 5.9 | 56.4 | 21.0 | 19.8 | 64.3 | 25.8 | 6.9 | 53.1 | 6.9 | 72.3 | 21.0 | 26.5 |  |  |  |  |  |  |

Table A4.9 - Legal or illegal/permit trucks within H5P data.

| Class | Class-Axle | Count | Legal* Trucks (\% of H5P) | (a)GrossWeight $>80$ kips <br> of <br> H5P) | $\begin{gathered} \hline \text { (b) } \\ \text { Leading } \\ \text { Axle }>13 \mathrm{kips}(\% \\ \text { of } \mathbf{~ H 5 P}) \\ \hline \end{gathered}$ | (c) <br> Any Single Axle > 20 kips (\% of H5P) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | 05-02 | 38565 | 53.1\% | 0.0\% | 32.6\% | 27.5\% |
| 6 | 06-03 | 12730 | 0.0\% | 7.4\% | 87.4\% | 81.3\% |
| 7 | Total | 3674 |  |  |  |  |
|  | 07-04 | 1313 | 0.0\% | 97.9\% | 96.6\% | 99.1\% |
|  | 07-05 | 2386 | 0.0\% | 100.0\% | 94.8\% | 100.0\% |
| 8 | Total | 42763 |  |  |  |  |
|  | 08-03 | 32061 | 82.2\% | 0.4\% | 12.9\% | 9.2\% |
|  | 08-04 | 10836 | 0.8\% | 36.9\% | 82.7\% | 84.8\% |
| 9 | 09-05 | 177857 | 0.0\% | 100.0\% | 97.1\% | 100.0\% |
| 10 | Total | 3883 |  |  |  |  |
|  | 10-06 | 3662 | 0.0\% | 100.0\% | 68.8\% | 99.8\% |
|  | 10-07 | 215 | 0.0\% | 100.0\% | 54.9\% | 100.0\% |
| 11 | 11-05 | 4747 | 0.0\% | 100.0\% | 99.9\% | 100.0\% |
| 12 | 12-06 | 1537 | 0.0\% | 100.0\% | 100.0\% | 100.0\% |
| 13 | Total | 534 |  |  |  |  |
|  | 13-07 | 490 | 0.0\% | 100.0\% | 71.6\% | 99.8\% |
|  | 13-08 | 35 | 0.0\% | 100.0\% | 17.1\% | 88.6\% |
|  | 13-09 | 5 | 0.0\% | 100.0\% | 60.0\% | 100.0\% |
|  | 13-10 | 4 | 0.0\% | 100.0\% | 50.0\% | 100.0\% |
|  | 13-11 | 1 | 0.0\% | 100.0\% | 100.0\% | 100.0\% |
|  | 13-12 | 1 | 0.0\% | 100.0\% | 0.0\% | 100.0\% |
|  | 13-13 | 1 | 0.0\% | 100.0\% | 100.0\% | 100.0\% |
| 14 | 14-05 | 58 | 15.5\% | 36.2\% | 74.1\% | 24.1\% |
| 15 | Total | 3388 |  |  |  |  |
|  | 15-02 | 157 | 0.0\% | 0.0\% | 94.3\% | 45.9\% |
|  | 15-03 | 682 | 70.7\% | 0.0\% | 19.9\% | 13.2\% |
|  | 15-04 | 507 | 13.8\% | 1.6\% | 56.2\% | 57.2\% |
|  | 15-05 | 465 | 7.1\% | 40.4\% | 83.0\% | 73.1\% |
|  | 15-06 | 987 | 0.0\% | 100.0\% | 15.5\% | 93.2\% |
|  | 15-07 | 214 | 0.0\% | 100.0\% | 15.4\% | 91.1\% |
|  | 15-08 | 242 | 0.0\% | 100.0\% | 75.6\% | 100.0\% |
|  | 15-09 | 64 | 0.0\% | 100.0\% | 75.0\% | 100.0\% |
|  | 15-10 | 39 | 0.0\% | 100.0\% | 94.9\% | 100.0\% |
|  | 15-11 | 25 | 0.0\% | 100.0\% | 32.0\% | 68.0\% |
|  | 15-12 | 20 | 0.0\% | 100.0\% | 50.0\% | 35.0\% |
|  | 15-13 | 18 | 22.2\% | 44.4\% | 55.6\% | 27.8\% |
|  | 15-14 | 15 | 53.3\% | 26.7\% | 13.3\% | 20.0\% |

*"Legal" means that the limited criteria (columns $\mathbf{a}, \mathrm{b}, \mathbf{c}$ ) are not met. It does not check tandem limitations

## COPULAS

The motivation behind determining statistical distributions for each parameter in a truck classaxle group is to be able to run Monte Carlo simulations using those marginal distributions. One could perform such simulations assuming that the various axle loads and spacings are independent of each other. If such parameters were considered independent of each other, then the relationships between different axle loads and spacings, if any, would be ignored. Srinivas et al. ${ }^{(1)}$ suggest that copulas be used to model the interdependence of truck load information.
Copulas have been widely used in financial and insurance industries to assess risk in financial instruments such as derivatives. Copulas were first introduced by Sklar in $1959^{(1), ~(7)}$. Copula functions can completely describe the dependence between the variables involved. The multivariate distribution can be determined by linking the marginal distributions with the copula function. ${ }^{(1)}$ There are many types of functions that can serve as copulas. Two prominent groups of copulas are Elliptical Copulas and Archimedean Copulas. The Gaussian and Student's T copulas belong in the Elliptical group while Clayton, Gumbel and Frank copulas belong in the Archimedean group. ${ }^{(1)}$ Empirical copulas are based on actual data and are not fit to particular mathematical functions. ${ }^{(8)}$

The ModelRisk software can determine best fit standard copulas based on data entered into an Excel spreadsheet. Alternatively, it can determine empirical copulas. The empirical copulas employed within ModelRisk are proprietary. According to the developer of the software, the ModelRisk empirical copulas are "based on re-sampling paired Dirichlet distributions, where each Dirichlet represents the univariate uncertainty of the empirical percentiles based on order statistics theory." In this study, both approaches (standard and empirical copulas) were examined. Best fit standard couplas were determined (see Appendix D for results) and empirical copulas were utilized as well. Table A4.10 shows the 9-parameter ( 5 axle loads and 4 spacings) best fit copula correlation matrix for the Class 9 truck. However, based on simulations of axle weights and spacings for each truck class, it was determined that the empirical copulas (which utilize actual data each time) were best able to simulate total truck weight distributions when such simulations were compared with corresponding histograms. Therefore, empirical copulas were used for the Monte Carlo simulations. The Crystal Ball software was used for Monte Carlo simulations. Both Crystal Ball and ModelRisk conveniently run with MS Excel. So, copulas and distributions were determined in Excel using ModelRisk, and these were used by Crystal Ball to conduct simulations.

Table A4.10. The Best-Fit Student-T Coupla for Class 9 H5P Data

| Class 09-05 Student-T Copula |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Correlation Matrix | 1.000 | 0.075 | 0.456 | 0.155 | 0.283 | 0.111 | 0.321 | 0.161 | 0.183 |
|  | 0.075 | 1.000 | 0.073 | 0.193 | 0.054 | -0.042 | 0.080 | 0.399 | 0.026 |
|  | 0.456 | 0.073 | 1.000 | 0.139 | 0.697 | 0.072 | 0.596 | 0.167 | 0.472 |
|  | 0.155 | 0.193 | 0.139 | 1.000 | 0.240 | 0.177 | 0.163 | 0.448 | 0.194 |
|  | 0.283 | 0.054 | 0.697 | 0.240 | 1.000 | 0.059 | 0.491 | 0.176 | 0.546 |
|  | 0.111 | -0.042 | 0.072 | 0.177 | 0.059 | 1.000 | -0.047 | -0.037 | -0.052 |
|  | 0.321 | 0.080 | 0.596 | 0.163 | 0.491 | -0.047 | 1.000 | 0.251 | 0.770 |
|  | 0.161 | 0.399 | 0.167 | 0.448 | 0.176 | -0.037 | 0.251 | 1.000 | 0.252 |
|  | 0.183 | 0.026 | 0.472 | 0.194 | 0.546 | -0.052 | 0.770 | 0.252 | 1.000 |
| Parameter | 9 |  |  |  |  |  |  |  |  |

## MONTE CARLO Simulations

As a first step in the simulation effort, a MS Excel spreadsheet was setup to calculate bending moment and shear envelopes for any moving truck arrangements (up to 10 axles) using influence lines. A simple-span bridge condition with spans ranging from 20 ft to 250 ft was considered. Fig. A4.1 shows the primary sheet for this Excel workbook. The simulations were run in this spreadsheet. The distributions and copulas were applied to axle loads and spacings. In addition, the Wisconsin Permit Vehicles (250-WPV and 190-WPV) was run, and the maximum moments and shears due to WPV's were compared with the simulation results to determine the effect of WPV (as a percentile of the simulation results) for each truck class-axle grouping. Fig. A4.2 shows the 190-kip and 250-kip WPV trucks.

|  |  |  | Input Truck |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Input Cells |  | A Axle load | $A B$ spacing | B Axle load | $B C$ spacing | C Axle load | CD spacin | D Axle load | DE spacin | E Axle loa | EF spacin | F Axle load |
|  | Simulation Cells |  | Kips | FT | Kips | FT | Kips | FT | Kips | FT | Kips | FT | Kips |
|  |  |  | 8 | 10 | 32 | 14 | 32 | 14 | 10 | 4 | 20 | 4 | 30 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Maximum | Moments and Shears | s due to Input truck | on Simply S | Supported Brid | e Spans |  |  |  |  |  |  |  |  |
| Span (FT) | Max Moment (K-FT) | Max Shear (K) | WPV-Moment | WPV-Shear |  |  |  |  |  |  |  |  |  |
| 20.0 | 245.9 | 52.0 | 415.5 | 84.0 |  |  |  |  |  |  |  |  |  |
| 30.0 | 457.9 | 69.9 | 720.3 | 98.9 |  |  |  |  |  |  |  |  |  |
| 40.0 | 704.7 | 80.1 | 1043.0 | 106.3 |  | Total Length | h of Truck | 80 | FT (from Fro | ont axle to b | back axie) |  |  |
| 50.0 | 949.8 | 93.4 | 1380.7 | 114.0 |  | Total Weigh | ht of Truck | 221 | kips |  |  |  |  |
| 60.0 | 1221.8 | 104.2 | 1729.9 | 133.2 |  | No. of Axles |  | 10 |  |  |  |  |  |
| 70.0 | 1629.8 | 115.2 | 2081.3 | 149.0 |  | FHWA Bridg | ge Formula | 122.4 | kips (for the | e entire truck |  |  |  |
| 80.0 | 2185.3 | 128.5 | 2586.4 | 161.4 |  | Ratio FHWA | A WT/WT | 0.55 |  |  |  |  |  |
| 90.0 | 2756.1 | 139.1 | 3172.1 | 169.6 |  |  |  |  |  |  |  |  |  |
| 100.0 | 3341.1 | 146.5 | 3845.2 | 178.8 |  |  |  |  |  |  |  |  |  |
| 110.0 | 3936.4 | 153.7 | 4506.6 | 184.8 |  |  |  |  |  |  |  |  |  |
| 120.0 | 4506.1 | 159.1 | 5164.3 | 190.5 |  |  |  |  |  |  |  |  |  |
| 130.0 | 5113.8 | 163.7 | 5835.8 | 195.6 |  |  |  |  |  |  |  |  |  |
| 140.0 | 5706.7 | 167.5 | 6492.5 | 200.3 |  |  |  |  |  |  |  |  |  |
| 150.0 | 6271.0 | 170.5 | 7166.9 | 203.2 |  |  |  |  |  |  |  |  |  |
| 160.0 | 6890.0 | 175.2 | 7844.0 | 205.1 |  |  |  |  |  |  |  |  |  |
| 170.0 | 7445.9 | 176.4 | 8464.9 | 207.3 |  |  |  |  |  |  |  |  |  |
| 180.0 | 8062.3 | 179.6 | 9167.9 | 209.2 |  |  |  |  |  |  |  |  |  |
| 190.0 | 8640.1 | 180.9 | 9788.0 | 211.4 |  |  |  |  |  |  |  |  |  |
| 200.0 | 9243.2 | 183.8 | 10467.5 | 214.3 |  |  |  |  |  |  |  |  |  |
| 210.0 | 9796.6 | 184.6 | 11157.8 | 217.4 |  |  |  |  |  |  |  |  |  |
| 220.0 | 10420.5 | 186.6 | 11823.2 | 217.7 |  |  |  |  |  |  |  |  |  |
| 230.0 | 11018.5 | 189.3 | 12519.1 | 218.7 |  |  |  |  |  |  |  |  |  |
| 240.0 | 11570.1 | 189.7 | 13184.3 | 219.7 |  |  |  |  |  |  |  |  |  |
| 250.0 | 12178.1 | 191.9 | 13859.5 | 220.6 |  |  |  |  |  |  |  |  |  |

Fig. A4.1. Spreadsheets for determining moment and shear envelopes due to any truck arrangement.


Fig. A4.2. The 250-kip and 190-kip Wisconsin Permit Vehicles.

Each simulation consisted of 10,000 runs using the determined distributions and empirical copulas. The results were then analyzed and presented by Crystal Ball. The total computer run time for each simulation (for each class) was on the order of 80 minutes. Summary of results for Class 9 trucks are shown in Tables 14 and 15. Representative sheets from simulation report are shown in Fig. A4.3. Summaries and reports for different class-axle configurations are shown in Appendix E.

Table A4.11. Summary of Moments - Monte Carlo Simulation results for H5P Class 9 Trucks.

| Max <br> Moment | Forecast Percentile (K-FT) |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Span (FT) | $\mathbf{0}$ | $\mathbf{1 0}$ | $\mathbf{2 0}$ | $\mathbf{3 0}$ | $\mathbf{4 0}$ | $\mathbf{5 0}$ | $\mathbf{6 0}$ | $\mathbf{7 0}$ | $\mathbf{8 0}$ | $\mathbf{9 0}$ | $\mathbf{1 0 0}$ |
| $\mathbf{2 0}$ | 133.3 | 193.6 | 207.2 | 217.5 | 226.8 | 235.2 | 244.0 | 253.8 | $\mathbf{2 6 4 . 7}$ | 279.9 | 371.2 |
| $\mathbf{3 0}$ | 252.8 | 334.6 | 352.8 | 368.4 | 381.4 | 395.4 | 409.8 | 424.3 | 441.4 | 465.6 | 610.7 |
| $\mathbf{4 0}$ | 372.3 | 473.2 | 498.5 | 520.0 | 539.8 | 558.9 | 578.2 | 599.6 | 623.4 | 657.0 | 960.5 |
| $\mathbf{5 0}$ | 525.7 | 633.6 | 665.5 | 694.5 | 721.8 | 748.3 | 774.1 | 803.1 | 834.7 | 882.8 | 1318.5 |
| $\mathbf{6 0}$ | 685.0 | 799.1 | 839.3 | 876.6 | 910.7 | 944.5 | 977.4 | 1013.5 | 1054.9 | 1115.3 | 1847.5 |
| $\mathbf{7 0}$ | 848.0 | 977.1 | 1026.1 | 1074.8 | 1115.8 | 1156.0 | 1196.5 | 1241.2 | 1293.9 | 1364.4 | 2430.2 |
| $\mathbf{8 0}$ | 1003.9 | 1203.8 | 1268.0 | 1324.5 | 1374.3 | 1425.7 | 1477.4 | 1530.9 | 1600.7 | 1692.4 | 2999.0 |
| $\mathbf{9 0}$ | 1220.3 | 1481.8 | 1557.0 | 1623.4 | 1684.0 | 1749.7 | 1812.7 | 1880.9 | 1964.3 | 2076.5 | 3562.1 |
| $\mathbf{1 0 0}$ | 1471.8 | 1769.5 | 1854.1 | 1931.6 | 2003.7 | 2079.4 | 2156.5 | 2236.9 | 2336.6 | 2465.3 | 4164.7 |
| $\mathbf{1 1 0}$ | 1748.2 | 2057.7 | 2154.3 | 2241.0 | 2324.4 | 2413.1 | 2503.9 | 2597.2 | 2710.2 | 2857.8 | 4709.7 |
| $\mathbf{1 2 0}$ | 2026.3 | 2346.4 | 2451.7 | 2549.5 | 2643.6 | 2745.8 | 2849.8 | 2954.0 | 3084.0 | 3255.2 | 5277.5 |
| $\mathbf{1 3 0}$ | 2300.9 | 2637.2 | 2749.7 | 2857.7 | 2965.7 | 3081.0 | 3195.0 | 3316.3 | 3459.2 | 3650.7 | 5894.9 |
| $\mathbf{1 4 0}$ | 2587.6 | 2924.3 | 3047.4 | 3163.0 | 3284.2 | 3413.1 | 3540.8 | 3673.3 | 3832.4 | 4044.3 | 6478.3 |
| $\mathbf{1 5 0}$ | 2869.0 | 3214.5 | 3345.1 | 3473.5 | 3605.0 | 3744.6 | 3889.8 | 4036.1 | 4205.9 | 4444.0 | 7046.3 |
| $\mathbf{1 6 0}$ | 3139.5 | 3502.3 | 3643.5 | 3784.3 | 3925.7 | 4080.3 | 4238.7 | 4394.7 | 4580.0 | 4841.7 | 7588.5 |
| $\mathbf{1 7 0}$ | 3409.9 | 3790.8 | 3942.1 | 4089.6 | 4249.1 | 4413.0 | 4585.8 | 4756.7 | 4954.0 | 5239.6 | 8182.1 |
| $\mathbf{1 8 0}$ | 3695.7 | 4081.0 | 4239.6 | 4397.6 | 4568.9 | 4746.7 | 4932.4 | 5116.1 | 5333.0 | 5634.1 | 8746.4 |
| $\mathbf{1 9 0}$ | 3960.7 | 4368.5 | 4538.5 | 4710.8 | 4888.5 | 5084.0 | 5283.2 | 5478.9 | 5707.2 | 6030.8 | 9321.1 |
| $\mathbf{2 0 0}$ | 4244.5 | 4655.1 | 4835.5 | 5012.2 | 5215.2 | 5413.3 | 5627.3 | 5837.9 | 6083.8 | 6422.8 | 9904.0 |
| $\mathbf{2 1 0}$ | 4534.0 | 4940.7 | 5133.7 | 5320.8 | 5531.4 | 5744.9 | 5972.3 | 6194.0 | 6456.5 | 6816.8 | 10494.2 |
| $\mathbf{2 2 0}$ | 4806.4 | 5231.6 | 5432.3 | 5631.3 | 5853.9 | 6080.0 | 6319.6 | 6559.6 | 6828.6 | 7218.8 | 11046.7 |
| $\mathbf{2 3 0}$ | 5081.8 | 5518.7 | 5732.0 | 5938.3 | 6175.7 | 6414.2 | 6669.6 | 6919.8 | 7203.6 | 7615.4 | 11655.0 |
| $\mathbf{2 4 0}$ | 5333.9 | 5807.5 | 6029.6 | 6246.3 | 6496.6 | 6747.1 | 7013.7 | 7275.5 | 7576.8 | 8004.6 | 12161.8 |
| $\mathbf{2 5 0}$ | 5618.0 | 6093.8 | 6330.0 | 6556.4 | 6817.6 | 7083.4 | 7363.7 | 7639.3 | 7955.4 | 8403.0 | 12781.6 |

Table A4.12. Summary of Shears - Monte Carlo Simulation results for H5P Class 9 Trucks.

| Max Shear | Forecast Percentile (Kips) |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Span | 0\% | 10\% | 20\% | 30\% | 40\% | 50\% | 60\% | 70\% | 80\% | 90\% | 100\% |
| 20 | 27.8 | 41.4 | 43.7 | 45.6 | 47.4 | 49.1 | 50.9 | 52.8 | 54.9 | 58.0 | 78.3 |
| 30 | 39.4 | 47.1 | 49.6 | 51.8 | 53.9 | 55.8 | 57.8 | 60.0 | 62.3 | 65.9 | 95.6 |
| 40 | 43.5 | 50.9 | 53.6 | 56.0 | 58.1 | 60.3 | 62.4 | 64.8 | 67.5 | 71.2 | 105.8 |
| 50 | 48.2 | 55.2 | 57.9 | 60.1 | 62.3 | 64.6 | 66.7 | 69.3 | 72.0 | 75.9 | 124.8 |
| 60 | 51.9 | 60.2 | 62.9 | 65.3 | 67.6 | 70.2 | 72.6 | 75.3 | 78.5 | 83.1 | 138.9 |
| 70 | 55.0 | 66.0 | 68.7 | 71.4 | 74.0 | 76.8 | 79.7 | 82.7 | 86.3 | 91.3 | 151.1 |
| 80 | 60.3 | 71.2 | 73.9 | 76.7 | 79.5 | 82.6 | 85.8 | 89.2 | 92.9 | 98.2 | 158.2 |
| 90 | 64.7 | 75.3 | 78.1 | 81.0 | 84.0 | 87.3 | 90.7 | 94.2 | 98.3 | 103.7 | 164.3 |
| 100 | 69.0 | 78.5 | 81.4 | 84.5 | 87.6 | 91.1 | 94.7 | 98.2 | 102.4 | 108.1 | 169.6 |
| 110 | 72.0 | 81.2 | 84.1 | 87.2 | 90.6 | 94.2 | 97.9 | 101.7 | 106.0 | 111.7 | 174.0 |
| 120 | 74.6 | 83.4 | 86.4 | 89.6 | 93.0 | 96.7 | 100.6 | 104.4 | 108.8 | 114.7 | 176.6 |
| 130 | 76.8 | 85.3 | 88.3 | 91.6 | 95.1 | 98.9 | 102.9 | 106.8 | 111.2 | 117.4 | 180.1 |
| 140 | 78.5 | 86.9 | 90.0 | 93.3 | 96.9 | 100.7 | 104.8 | 108.8 | 113.3 | 119.5 | 183.6 |
| 150 | 80.1 | 88.3 | 91.4 | 94.8 | 98.5 | 102.3 | 106.5 | 110.6 | 115.1 | 121.5 | 185.4 |
| 160 | 82.0 | 89.5 | 92.7 | 96.1 | 99.8 | 103.8 | 108.0 | 112.1 | 116.7 | 123.2 | 186.7 |
| 170 | 82.7 | 90.5 | 93.8 | 97.2 | 101.0 | 105.0 | 109.3 | 113.5 | 118.2 | 124.7 | 188.4 |
| 180 | 83.7 | 91.5 | 94.8 | 98.2 | 102.1 | 106.1 | 110.4 | 114.7 | 119.4 | 126.1 | 189.3 |
| 190 | 84.8 | 92.4 | 95.6 | 99.2 | 103.1 | 107.2 | 111.5 | 115.8 | 120.5 | 127.3 | 191.9 |
| 200 | 85.9 | 93.1 | 96.4 | 100.0 | 103.9 | 108.0 | 112.3 | 116.7 | 121.6 | 128.3 | 192.8 |
| 210 | 86.8 | 93.8 | 97.1 | 100.7 | 104.7 | 108.9 | 113.2 | 117.5 | 122.4 | 129.3 | 194.1 |
| 220 | 87.4 | 94.4 | 97.8 | 101.4 | 105.4 | 109.5 | 114.0 | 118.4 | 123.3 | 130.2 | 195.0 |
| 230 | 87.9 | 95.0 | 98.3 | 102.0 | 106.1 | 110.3 | 114.7 | 119.1 | 124.0 | 131.0 | 195.9 |
| 240 | 89.0 | 95.5 | 98.9 | 102.6 | 106.7 | 110.8 | 115.3 | 119.8 | 124.6 | 131.8 | 195.9 |
| 250 | 89.6 | 96.0 | 99.4 | 103.1 | 107.2 | 111.4 | 115.9 | 120.4 | 125.3 | 132.4 | 197.2 |

Moments and shear effects of 250-WPV loads are compared with H5P simulation results in Tables 16 and 17. The $250-W P V$ percentiles (with respect to H5P) were determined by comparing moments and shear due to $250-$ WPV with the tabular percentile values for each class. However, to improve accuracy between 90 and 100 percentiles, analyses were run between 90 and 100 percentiles at 1 percentile increments. Therefore, interpolations were made within 1percentile increments. Tables 16 and 17 include percentiles of H5P and "total" data. The term "total" refers to all trucks within that class. Since H5P data have the heaviest overall weights in that class-axle group, it is reasonable to assume that the effects due to H 5 P vehicles will result in higher moments and shears compared to the remaining $95 \%$ of trucks in that class. Therefore, the "total" percentile is estimated through the following relationship:

$$
\text { Total percentile }=95+(\text { H5P percentile }) \times 0.05
$$

Figures 5 and 6 show plots of $250-\mathrm{WPV}$ results versus span length (in percentiles of H5P simulations). For moments, the 250-WPV results fall below 100 percentile of class 9 H5P results for span lengths 40 through 140 ft . The $250-\mathrm{WPV}$ shear results also fall below 100 percentile for spans 40 through 60 ft . However, in both cases, the H5P percentiles never reach below 99.7. Tables 18 and 19 (as well as Figures 7 and 8) compare results for all classes. For moments and shears, the lowest percentiles belong to classes 07-05, 13-07, 10-06 and 07-04. However, the lowest H5P percentiles do not go below 96 percentile.

Forecast: Max Moment (Span 100)
B18
Entire range is from 1387.9 to 4139.1
Base case is 1771.5
After 10,000 trials, the std. error of the mean is 2.7


|  | Forecast values |
| :--- | ---: |
| Trials | 10,000 |
| Mean | 2101.1 |
| Median | 2077.9 |
| Mode | --- |
| Standard Deviation | 266.5 |
| Variance | 71038.2 |
| Skewness | 0.4926 |
| Kurtosis | 3.18 |
| Coeff. of Variability | 0.1269 |
| Minimum | 1387.9 |
| Maximum | 4139.1 |
| Range Width | 2751.2 |
| Mean Std. Error | 2.7 |

Mean Std. Error
Forecast: Max Moment (Span 100) (cont'd)

| Percentiles: | Forecast values |
| :---: | ---: |
| $0 \%$ | 1387.9 |
| $10 \%$ | 1774.9 |
| $20 \%$ | 1857.6 |
| $30 \%$ | 1932.9 |
| $40 \%$ | 2004.3 |
| $50 \%$ | 2077.9 |
| $60 \%$ | 2153.0 |
| $70 \%$ | 2231.8 |
| $80 \%$ | 2327.4 |
| $90 \%$ | 2462.6 |
| $100 \%$ | 4139.1 |

Fig. A4.3. Selections from Simulation Report for H5P Class 9 Trucks.

Table A4.13. Summary of Moments - 250-WPV Data Compared With Monte Carlo Simulation Results for H5P Class 9 Trucks.

| Max Moment | 250-WPV |  |  |
| :---: | :---: | :---: | :---: |
| Span (FT) | Moment (k-ft) | Percentile of H5P | Percentile of Total |
| 20 | 415.5 | 100.00\% | 100.00\% |
| 30 | 720.3 | 100.00\% | 100.00\% |
| 40 | 1043.0 | 100.00\% | 100.00\% |
| 50 | 1380.7 | 100.00\% | 100.00\% |
| 60 | 1729.9 | 99.80\% | 99.99\% |
| 70 | 2081.3 | 99.61\% | 99.98\% |
| 80 | 2586.4 | 99.62\% | 99.98\% |
| 90 | 3172.1 | 99.68\% | 99.98\% |
| 100 | 3845.2 | 99.77\% | 99.99\% |
| 110 | 4506.6 | 99.86\% | 99.99\% |
| 120 | 5164.3 | 99.93\% | 100.00\% |
| 130 | 5835.8 | 99.97\% | 100.00\% |
| 140 | 6492.5 | 100.00\% | 100.00\% |
| 150 | 7166.9 | 100.00\% | 100.00\% |
| 160 | 7844.0 | 100.00\% | 100.00\% |
| 170 | 8464.9 | 100.00\% | 100.00\% |
| 180 | 9167.9 | 100.00\% | 100.00\% |
| 190 | 9788.0 | 100.00\% | 100.00\% |
| 200 | 10467.5 | 100.00\% | 100.00\% |
| 210 | 11157.8 | 100.00\% | 100.00\% |
| 220 | 11823.2 | 100.00\% | 100.00\% |
| 230 | 12519.1 | 100.00\% | 100.00\% |
| 240 | 13184.3 | 100.00\% | 100.00\% |
| 250 | 13859.5 | 100.00\% | 100.00\% |

Table A4.14. Summary of Shears - 250-WPV Data Compared With Monte Carlo Simulation Results for Class 9 Trucks.


Fig. A4.4. Wisconsin 250-WPV Moment Results Compared to H5P Class 9 Truck Simulations


Fig. A4.5. Wisconsin 250-WPV Shear Results Compared to H5P Class 9 Truck Simulations
For comparison, results for the 190-WPV loads are shown in Tables 20 and 21 and Figures 9 and 10. For moments and shears, the lowest percentiles belong to classes 07-05, 13-07, 10-06 and 0704. The H5P data for the $190-\mathrm{WPV}$ reached as low as 50 percentile.

Table A4.15. Moments (as Percentile of H5P Data) on Simply Supported Bridge Due to 250-WPV

| Span <br> (ft) | $\begin{gathered} \hline \text { Class } \\ 05-06 \\ \hline \end{gathered}$ | $\begin{aligned} & \hline \text { Class } \\ & 06-03 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 07-04 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 07-05 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 08-03 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 08-04 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 09-05 \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 10-06 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 11-05 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 12-06 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 13-07 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 3} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 4} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 5} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & 15-06 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 20 | 100.0 | 99.4 | 99.2 | 99.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 30 | 100.0 | 99.6 | 99.3 | 98.5 | 100.0 | 100.0 | 100.0 | 99.5 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 40 | 100.0 | 99.7 | 99.3 | 98.0 | 100.0 | 100.0 | 100.0 | 99.5 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 50 | 100.0 | 99.8 | 99.2 | 97.1 | 100.0 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 60 | 100.0 | 9.8 | 99.2 | 96.6 | 100.0 | 100.0 | 99.8 | 99.0 | 100.0 | 100.0 | 97.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 70 | 100.0 | 99.9 | 99.2 | 96.0 | 100.0 | 100.0 | 99.6 | 97.9 | 100.0 | 100.0 | 96.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 80 | 100.0 | 100.0 | 99.3 | 98.4 | 100.0 | 100.0 | 99.6 | 98.4 | 100.0 | 100.0 | 96.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| 90 | 100.0 | 100.0 | 99.5 | 99.3 | 100.0 | 100.0 | 99.7 | 99.0 | 100.0 | 100.0 | 97.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 100 | 100.0 | 100.0 | 99.7 | 99.8 | 100.0 | 100.0 | 99.8 | 99.2 | 100.0 | 100.0 | 97.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| 110 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.9 | 99.3 | 100.0 | 100.0 | 98.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 120 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | 99.9 | 99.4 | 100.0 | 100.0 | 98.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 130 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.5 | 100.0 | 100.0 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 140 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.5 | 100.0 | 100.0 | 98.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| 150 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.6 | 100.0 | 100.0 | 98.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| 160 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 98.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| 170 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 98.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| 180 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 190 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 200 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 210 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 220 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 230 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 240 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 250 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |



Fig. A4.6. Plot of 250-WPV moments as percentile of H5P data versus span length ( ft ) for each truck class-axle group.

Table A4.16. Shears (as Percentile of H5P Data) on Simply Supported Bridge Due to 250-WPV Loading

| Span <br> (ft) | $\begin{gathered} \text { Class } \\ 05-06 \\ \hline \end{gathered}$ | $\begin{gathered} \text { Class } \\ 06-03 \end{gathered}$ | $\begin{aligned} & \text { Class } \\ & 07-04 \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 07-05 \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 08-03 \\ & \hline \end{aligned}$ | $\begin{gathered} \text { Class } \\ 08-04 \\ \hline \end{gathered}$ | $\begin{aligned} & \text { Class } \\ & 09-05 \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 10-06 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \mathbf{1 1 - 0 5} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 2 - 0 6} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \text { 13-07 } \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 3} \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 4} \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 15-05 } \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 5 - 0 6} \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 20 | 100.0 | 99.4 | 99.1 | 98.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 30 | 100.0 | 99.7 | 99.2 | 97.8 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 40 | 100.0 | 99.8 | 99.2 | 96.6 | 100.0 | 100.0 | 100.0 | 98.7 | 100.0 | 100.0 | 98.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 50 | 100.0 | 100.0 | 99.2 | 97.2 | 100.0 | 100.0 | 99.7 | 97.8 | 100.0 | 100.0 | 97.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 60 | 100.0 | 100.0 | 99.5 | 99.5 | 100.0 | 100.0 | 99.9 | 99.1 | 100.0 | 100.0 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 70 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 99.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 80 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 90 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.5 | 100.0 | 100.0 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 100 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.6 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 110 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 120 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 130 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 140 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 150 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 160 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 170 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 180 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 190 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 200 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 210 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 220 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 230 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 240 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 250 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |



Fig. A4.7. Plot of 250-WPV shear as percentile of H5P data versus span length (ft) for each truck class-axle group.

Table A4.17. Moments (as Percentile of H5P Data) on Simply Supported Bridge Due to 190-WPV

| Span <br> (ft) | $\begin{aligned} & \text { Class } \\ & \text { 05-06 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 06-03 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 07-04 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 07-05 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 08-03 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 08-04 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 09-05 \end{aligned}$ | $\begin{aligned} & \hline \text { Class } \\ & \mathbf{1 0 - 0 6} \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 11-05 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \mathbf{1 2 - 0 6} \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 13-07 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 15-03 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 15-04 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \mathbf{1 5 - 0 5} \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 15-06 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 20 | 100.0 | 98.6 | 92.1 | 66.6 | 100.0 | 99.0 | 99.0 | 87.4 | 100.0 | 99.9 | 85.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| 30 | 100.0 | 99.1 | 94.1 | 64.0 | 100.0 | 99.3 | 99.3 | 91.4 | 100.0 | 99.7 | 82.9 | 100.0 | 100.0 | 100.0 | 99.9 |
| 40 | 100.0 | 99.1 | 93.6 | 60.4 | 100.0 | 99.4 | 99.2 | 92.2 | 100.0 | 99.5 | 82.5 | 100.0 | 100.0 | 100.0 | 99.8 |
| 50 | 100.0 | 99.1 | 92.3 | 53.6 | 100.0 | 99.3 | 99.2 | 83.0 | 100.0 | 99.4 | 80.6 | 100.0 | 100.0 | 100.0 | 99.7 |
| 60 | 100.0 | 99.1 | 91.2 | 50.4 | 100.0 | 99.3 | 99.1 | 69.9 | 100.0 | 99.2 | 76.9 | 100.0 | 100.0 | 100.0 | 99.5 |
| 70 | 100.0 | 99.1 | 90.2 | 48.1 | 100.0 | 99.2 | 99.0 | 56.4 | 100.0 | 98.8 | 71.1 | 100.0 | 100.0 | 100.0 | 99.5 |
| 80 | 100.0 | 99.3 | 94.8 | 63.7 | 100.0 | 99.3 | 99.0 | 62.0 | 99.9 | 98.9 | 76.0 | 100.0 | 100.0 | 100.0 | 99.8 |
| 90 | 100.0 | 99.5 | 97.5 | 76.1 | 100.0 | 99.4 | 99.1 | 71.3 | 99.8 | 99.1 | 80.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 100 | 100.0 | 99.7 | 98.8 | 87.0 | 100.0 | 99.7 | 99.1 | 80.8 | 100.0 | 99.2 | 83.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 110 | 100.0 | 99.9 | 99.1 | 93.1 | 100.0 | 99.8 | 99.1 | 85.6 | 100.0 | 99.4 | 84.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| 120 | 100.0 | 100.0 | 99.2 | 96.0 | 100.0 | 99.9 | 99.2 | 89.0 | 100.0 | 99.6 | 85.7 | 100.0 | 100.0 | 100.0 | 100.0 |
| 130 | 100.0 | 100.0 | 99.3 | 97.7 | 100.0 | 100.0 | 99.2 | 91.5 | 100.0 | 99.6 | 86.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 140 | 100.0 | 100.0 | 99.3 | 98.4 | 100.0 | 100.0 | 99.2 | 93.0 | 100.0 | 99.7 | 86.7 | 100.0 | 100.0 | 100.0 | 100.0 |
| 150 | 100.0 | 100.0 | 99.4 | 98.9 | 100.0 | 100.0 | 99.2 | 94.6 | 100.0 | 99.7 | 87.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 160 | 100.0 | 100.0 | 99.4 | 99.1 | 100.0 | 100.0 | 99.2 | 95.4 | 100.0 | 99.6 | 87.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| 170 | 100.0 | 100.0 | 99.5 | 99.2 | 100.0 | 100.0 | 99.2 | 95.6 | 100.0 | 99.6 | 87.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 180 | 100.0 | 100.0 | 99.5 | 99.3 | 100.0 | 100.0 | 99.3 | 96.4 | 100.0 | 99.7 | 87.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| 190 | 100.0 | 100.0 | 99.5 | 99.3 | 100.0 | 100.0 | 99.3 | 96.4 | 100.0 | 99.6 | 87.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| 200 | 100.0 | 100.0 | 99.5 | 99.4 | 100.0 | 100.0 | 99.3 | 96.7 | 100.0 | 99.6 | 87.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| 210 | 100.0 | 100.0 | 99.6 | 99.5 | 100.0 | 100.0 | 99.3 | 97.1 | 100.0 | 99.7 | 88.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 220 | 100.0 | 100.0 | 99.6 | 99.5 | 100.0 | 100.0 | 99.3 | 97.3 | 100.0 | 99.7 | 88.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| 230 | 100.0 | 100.0 | 99.6 | 99.6 | 100.0 | 100.0 | 99.3 | 97.6 | 100.0 | 99.7 | 89.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 240 | 100.0 | 100.0 | 99.6 | 99.6 | 100.0 | 100.0 | 99.3 | 97.8 | 100.0 | 99.7 | 89.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 250 | 100.0 | 100.0 | 99.7 | 99.7 | 100.0 | 100.0 | 99.3 | 97.8 | 100.0 | 99.7 | 89.5 | 100.0 | 100.0 | 100.0 | 100.0 |



Fig. A4.8. Plot of 190-WPV moments as percentile of H5P data versus span length (ft) for each truck class-axle group.

Table A4.18. Shears (as Percentile of H5P Data) on Simply Supported Bridge Due to 190-WPV Loading

| Span <br> (ft) | $\begin{aligned} & \text { Class } \\ & \text { 05-06 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 06-03 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 07-04 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 07-05 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 08-03 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 08-04 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 09-05 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 10-06 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 11-05 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \mathbf{1 2 - 0 6} \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 13-07 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \mathbf{1 5 - 0 3} \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 15-04 \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & \text { 15-05 } \end{aligned}$ | $\begin{aligned} & \text { Class } \\ & 15-06 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 20 | 100.0 | 98.6 | 88.3 | 56.9 | 100.0 | 99.0 | 98.4 | 85.1 | 100.0 | 99.6 | 81.0 | 100.0 | 100.0 | 100.0 | 99.8 |
| 30 | 100.0 | 99.1 | 91.4 | 58.6 | 100.0 | 99.1 | 99.0 | 84.3 | 100.0 | 99.9 | 82.4 | 100.0 | 100.0 | 100.0 | 99.9 |
| 40 | 100.0 | 99.0 | 89.8 | 51.0 | 100.0 | 99.1 | 99.0 | 65.7 | 100.0 | 99.7 | 79.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 50 | 100.0 | 99.1 | 91.9 | 56.5 | 100.0 | 99.2 | 99.0 | 55.9 | 100.0 | 99.5 | 76.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 60 | 100.0 | 99.5 | 97.9 | 80.3 | 100.0 | 99.8 | 99.2 | 74.5 | 100.0 | 100.0 | 85.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 70 | 100.0 | 99.9 | 99.1 | 92.5 | 100.0 | 100.0 | 99.2 | 84.4 | 100.0 | 100.0 | 88.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 80 | 100.0 | 100.0 | 99.2 | 97.0 | 100.0 | 100.0 | 99.3 | 90.3 | 100.0 | 100.0 | 89.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 90 | 100.0 | 100.0 | 99.3 | 98.3 | 100.0 | 100.0 | 99.3 | 92.1 | 100.0 | 100.0 | 89.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 100 | 100.0 | 100.0 | 99.4 | 99.1 | 100.0 | 100.0 | 99.3 | 95.0 | 100.0 | 100.0 | 90.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 110 | 100.0 | 100.0 | 99.5 | 99.3 | 100.0 | 100.0 | 99.3 | 95.9 | 100.0 | 100.0 | 90.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 120 | 100.0 | 100.0 | 99.5 | 99.4 | 100.0 | 100.0 | 99.3 | 96.7 | 100.0 | 100.0 | 90.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| 130 | 100.0 | 100.0 | 99.6 | 99.5 | 100.0 | 100.0 | 99.3 | 97.2 | 100.0 | 100.0 | 90.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| 140 | 100.0 | 100.0 | 99.6 | 99.7 | 100.0 | 100.0 | 99.4 | 97.7 | 100.0 | 100.0 | 91.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 150 | 100.0 | 100.0 | 99.7 | 99.7 | 100.0 | 100.0 | 99.4 | 97.9 | 100.0 | 100.0 | 91.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 160 | 100.0 | 100.0 | 99.7 | 99.7 | 100.0 | 100.0 | 99.4 | 98.0 | 100.0 | 100.0 | 90.5 | 100.0 | 100.0 | 100.0 | 100.0 |
| 170 | 100.0 | 100.0 | 99.7 | 99.8 | 100.0 | 100.0 | 99.4 | 98.0 | 100.0 | 100.0 | 90.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 180 | 100.0 | 100.0 | 99.7 | 99.8 | 100.0 | 100.0 | 99.4 | 98.1 | 100.0 | 100.0 | 90.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 190 | 100.0 | 100.0 | 99.7 | 99.9 | 100.0 | 100.0 | 99.4 | 98.2 | 100.0 | 100.0 | 90.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 200 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.3 | 100.0 | 100.0 | 90.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| 210 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 100.0 | 100.0 | 91.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| 220 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 100.0 | 100.0 | 90.7 | 100.0 | 100.0 | 100.0 | 100.0 |
| 230 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 100.0 | 100.0 | 90.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| 240 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 100.0 | 99.9 | 90.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| 250 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 100.0 | 99.9 | 90.3 | 100.0 | 100.0 | 100.0 | 100.0 |



Fig. A4.9. Plot of 190-WPV shear as percentile of H5P data versus span length (ft) for each truck class-axle group.

## Summary and Conclusions

This study involved statistical evaluation of heavy truck loads that were recorded using Weigh-In-Motion (WIM) stations located throughout the State of Wisconsin. All 2007 WIM records (approximately 6 million vehicles) were obtained from the Wisconsin Department of Transportation (WisDOT). Of those, only data associated with FHWA trucks Classes 5 through 15 were retained. Vehicle classes 4 (buses) or less represent smaller vehicles and buses, and were thus excluded from analyses.

When a truck class did not have a fixed number of axles (i.e. numbers of axles could vary within the same class), then that class was further sub-divided such that each sub-group contained only one particular number of axles. For example, sub-groups 08-03 and 08-04 contained class 08 vehicles with 3- and 4-axles, respectively. Data for each class-axle group were sorted based on gross vehicle weight, and the heaviest 5 percent (H5P) of truck records in each group were separated and analyzed. Statistical analyses were performed on the H5P data.
Using the H5P data, best-fit unimodal and/or multimodal probability distributions ("marginal" distributions) were determined for each axle weight and spacing in each truck class-axle group. Furthermore, copulas were determined to allow multivariate Monte Carlo simulations. Copulas help perform multivariate simulations while maintaining interdependence between various marginal distributions.

Multivariate Analyses of Variance (ANOVA) were performed on a few class-axle groupings based on different WIM station results. ANOVA indicated that the various WIM stations records did not belong to the same distributions. Therefore, data from all stations were combined in various class-axle groupings.

Multivariate Monte Carlo simulations on H5P data in each class-axle group were conducted using the Crystal Ball and ModelRisk software programs running within Microsoft Excel. A spreadsheet program was written to calculate maximum moments and shears in a simply supported beam with spans ranging from 20 ft to 250 ft . Each simulated vehicle was "marched" across the bridge to find maximum moment and shear effects. Each simulation analysis consisted of 10,000 runs (i.e. 10,000 trucks automatically generated from marginal distributions and copulas). The maximum moments and shear for each of the spans and each of the 10,000 runs were calculated, and the percentile values for the simulation results were determined. In addition, maximum moments and shears associated with the 190-kip and 250-kip Wisconsin Permit Vehicles (190-WPV and $250-\mathrm{WPV}$ ) were also calculated for each span length, and compared with simulation results.

The following observations are made regarding the results of these analyses:

1) Truck simulations for each class-axle grouping were performed and successfully tested for validity.
2) Some H5P axle loads and axle spacing distributions are multimodal, and therefore multimodal marginal distributions must be used in such cases for proper simulations.
3) Empirical copulas provide more accurate simulations when compared to conventional copula functions determined by data fitting. All simulation results reported here are based on empirical copulas determined using the ModelRisk software program.
4) The percentile results derived can be used to assess the relative impact of any truck arrangement compared to simulation results. Moments and shears due to the 250-kip

Wisconsin Permit Vehicle were, in all cases, above the 96 percentile mark for the H5P simulation data. This is approximately equivalent to the 99.8 percentile for all trucks in each class.
5) It is clear that the 250 -kip Wisconsin Permit Vehicle results completely envelope most of the longer span length results (at 100 percentile). However, at shorter spans and for some truck classes, the percentile mark is reduced. This indicates that the probability of exceeding the permit vehicle effects is not uniform across all span lengths in simply supported bridges.
6) The marginal distributions and copulas determined here can also be used to statistically assess heavy truck impact on bridges and pavements based any load-dependent metric.

The following recommendations are made for future studies:

1) Expand determinations of marginal distributions and copulas to the entire dataset of trucks (not just H5P data).
2) With data from the previous recommendation, perform detailed bridge fatigue studies. These data would help achieve much greater detail and precision that would otherwise be feasible without such information.
3) Conduct statistical analyses using the existing H5P information developed in this study as well as data from recommendation No. 1 to enhance understanding of degree of reliability and performance in Portland cement concrete and asphalt pavements.

## References

1. Srinivas, S., Menon, D., and Prasad, A.M., "Multivariate Simulation and Multimodal Dependence Modeling of Vehicle Axle Weights and Copulas," Journal of Transportation Engineering, ASCE, Vol. 132, No. 12, December 2006, pp. 945-955.
2. "Crystal Ball", Software by Oracle, http://www.oracle.com/crystalball/index.html
3. "ModelRisk", by Vose Software, http://www.vosesoftware.com/modelrisk.htm
4. Joe, H., "Multivariate Models and Dependence Concepts," Chapman and Hall Publishers, London, 1997.
5. "Traffic Monitoring Guide," Federal Highway Administration, available online at http://www.fhwa.dot.gov/ohim/tmguide/index.htm
6. Lu, Q., Harvey, J., Le, T., Lea, J., Quinley, R., Redo, D., and Avis, J., "Truck Traffic Analysis using Weigh-In-Motion (WIM) Data in California," Report by Pavement Research Center, University of California, Berkeley, June 2002, available online at http://www.its.berkeley.edu/pavementresearch/PDF/WIMreport.pdf
7. Sklar, A., "Fonctions de repa'rticion a' n dimensions et leurs marges," Publications de l'Institut de Statistiue del'Universit de Paris, Paris, 8, 1959, pp. 229-231.
8. Nelsen, R.B., "Introduction to Copulas", Springer, $2^{\text {nd }}$ edition, 2007.
