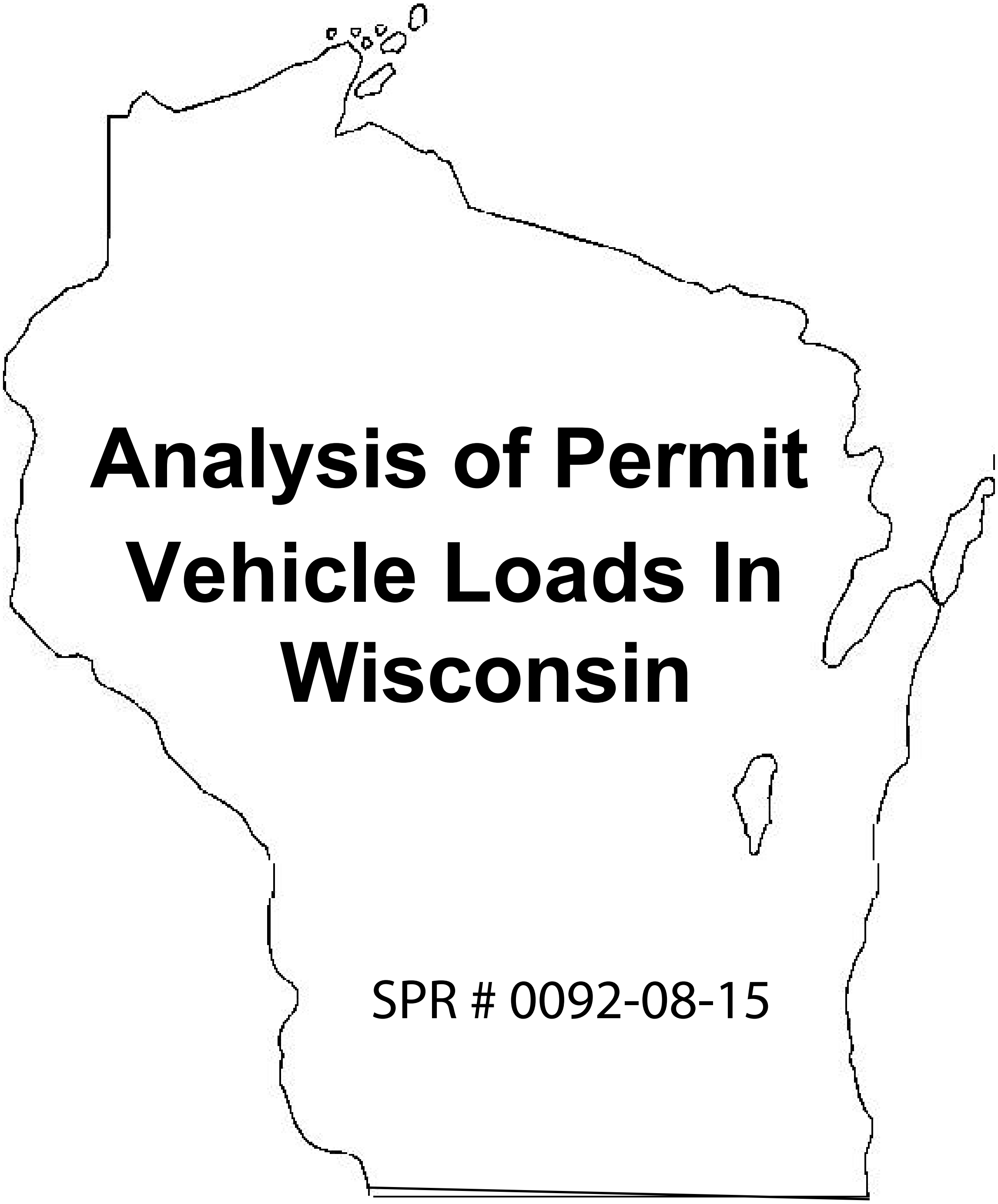
Wisconsin Highway Research Program



Analysis of Permit Vehicle Loads In Wisconsin

SPR # 0092-08-15

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September 2009

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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

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 3-span 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-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 4ft to over 70ft. 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 50ft (for trucks) and 75ft (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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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.

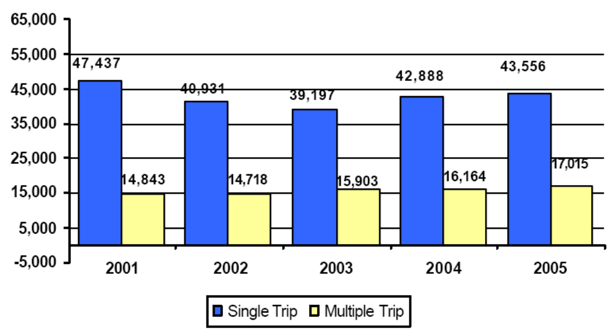

Fig. 1.1 Wisconsin OSOW permits in recent years

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 lbs up to 150,000 lbs.[4] For annual permits, the fee increase is $100 per 10,000 lbs up to 170,000 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 (Wis-SPV) 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 4ft – 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.

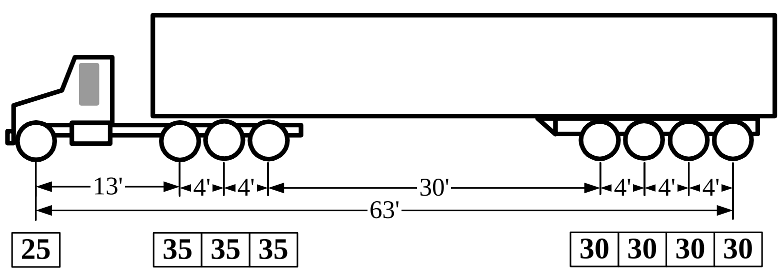

Fig. 1.2 Wisconsin Standard Permit Vehicle

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 Wis-SPV. 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® 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 lb;
- Tandem-axle weight limit of 32,000 lb;
- Gross Vehicle Weight (GVW) of 73,280 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 lb;
- Tandem-axle weight limit of 34,000 lb; and
- Gross Vehicle Weight (GVW) of 80,000 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]

$$W = 500\left(\frac{LN}{N-1} + 12N + 36\right), \tag{2.1}$$

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).

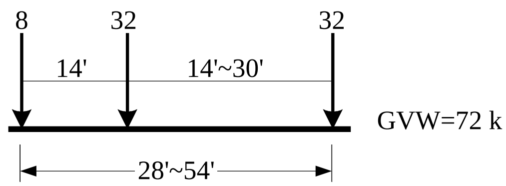


Fig. 2.1 Design truck in AASHTO LRFD and WisDOT Bridge Manual

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'-6" (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'
Semi trailer or trailer operated as part of a 2−vehicle combination	48'
Tractor − semi trailer combination	75'
Mobile homes, motor homes, and motorbuses.	45'
Mobile crane	48'

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 250-kip vehicle is used to estimate whether a bridge should be posted, and the rating is usually determined by

$$\frac{\text{Live load moment capacity}}{\text{Moment caused by the 250 - kip Standard Permit Vehicle load}} \times 250\,(\text{kips}). \tag{2.2}$$

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'
Each trailer or semi-trailer of a twin trailer combination	28'-6"
Trailer of two-vehicle combination	45'
Semi-trailer of two-vehicle combination	48'
Mobile crane	48'
Drive-away saddle mount combination	75'
Truck-tractor with semi-trailer combination,	75'

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', and the vehicle length limit is 60' for single motor vehicle and 85' for vehicle combinations. The maximum overall axle spacing is 75' while the minimum axle spacing between any two axles is 3'-9". 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 permits	GVW for 9+-axle vehicles	Not allowed for annual 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).

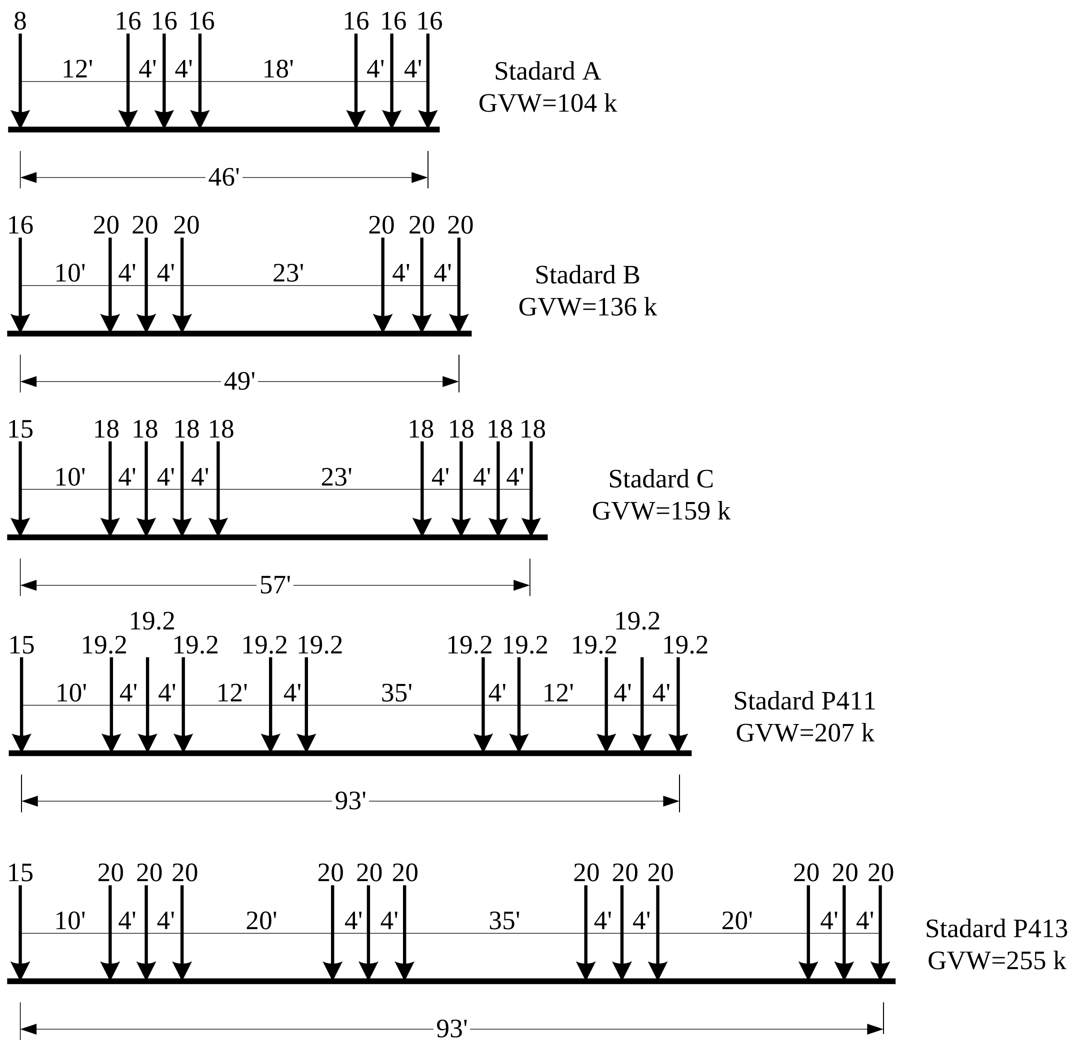


Fig. 2.2 Standard Mn/DOT Overload Permit Trucks

State of Iowa (IaDOT) 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'-6" (height), 8'-6" (width), and the length (inclusive of front and rear bumpers) should not exceed 40' for single trucks and 70' 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 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 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 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'-5", a maximum length of 120', a maximum overall height of 13'-10", and a total gross weight of 80,000 lbs.
- Vehicles with indivisible loads, or mobile homes including appurtenances, having a maximum width of 13'-5", a maximum length of 120', a maximum height of 15'-5", and a total gross weight not to exceed 156,000 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.

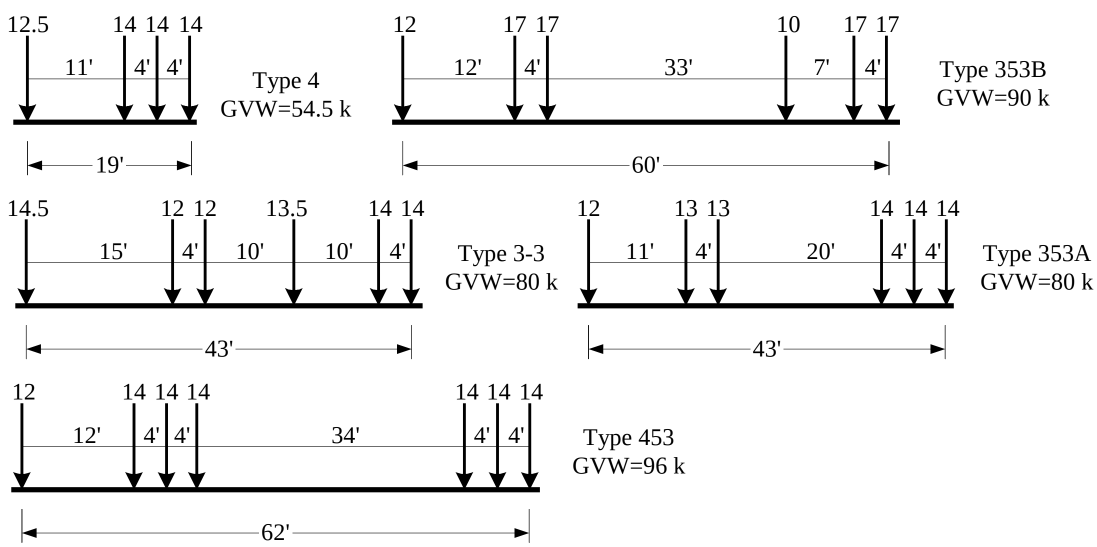


Fig. 2.3 Iowa rating vehicles

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 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:

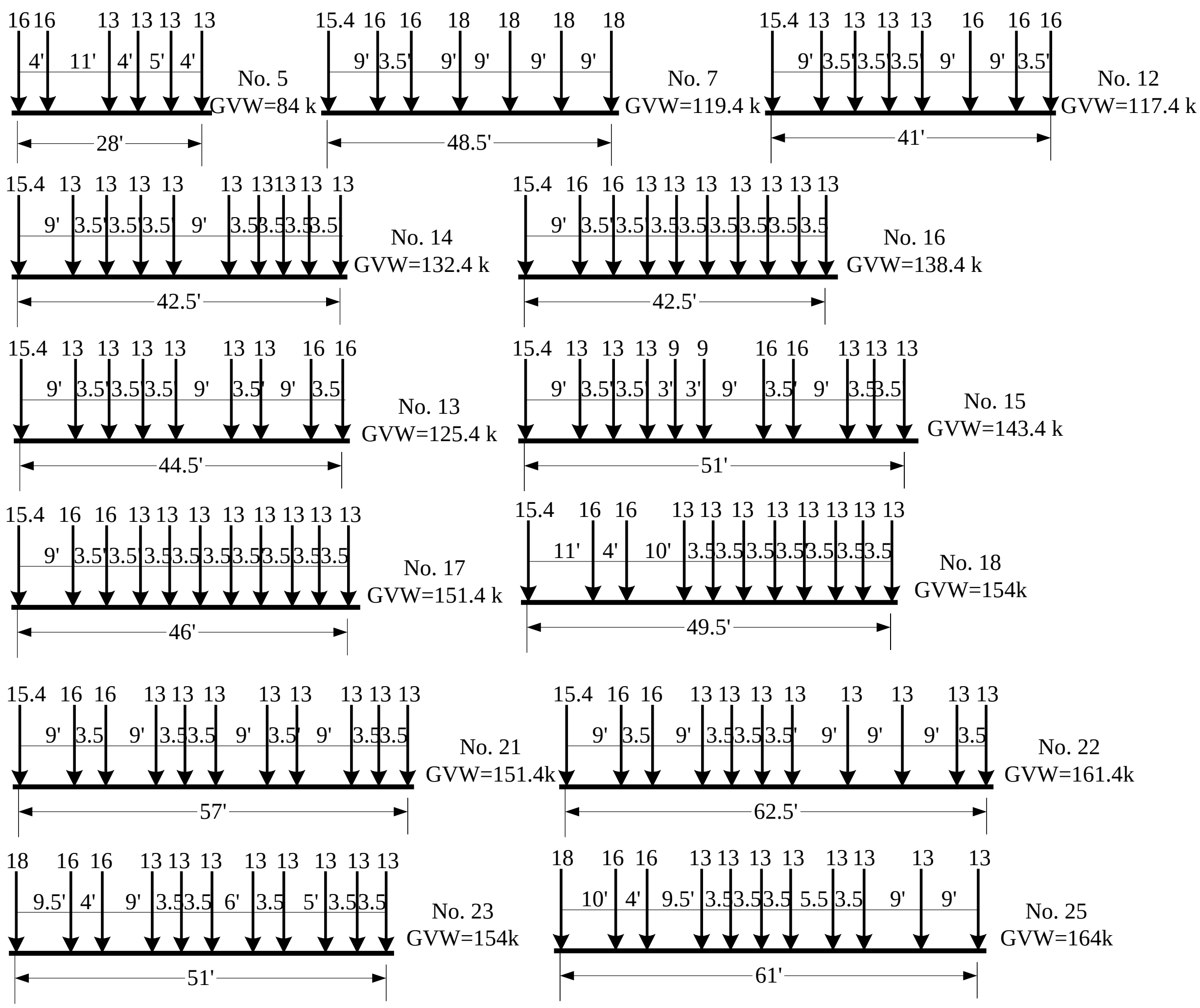


Fig. 2.4 Michigan Legal Vehicles with GVW larger than federal limit

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'-6", and the maximum width 8'-6". The Maximum legal weight of any vehicle in Illinois is 80,000 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.

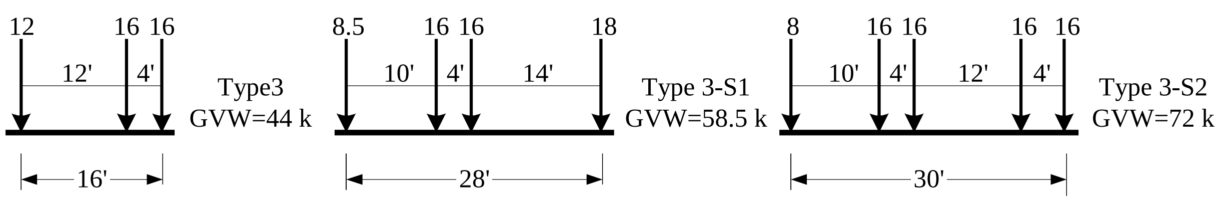


Fig. 2.5 Illinois load rating and posting trucks

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 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

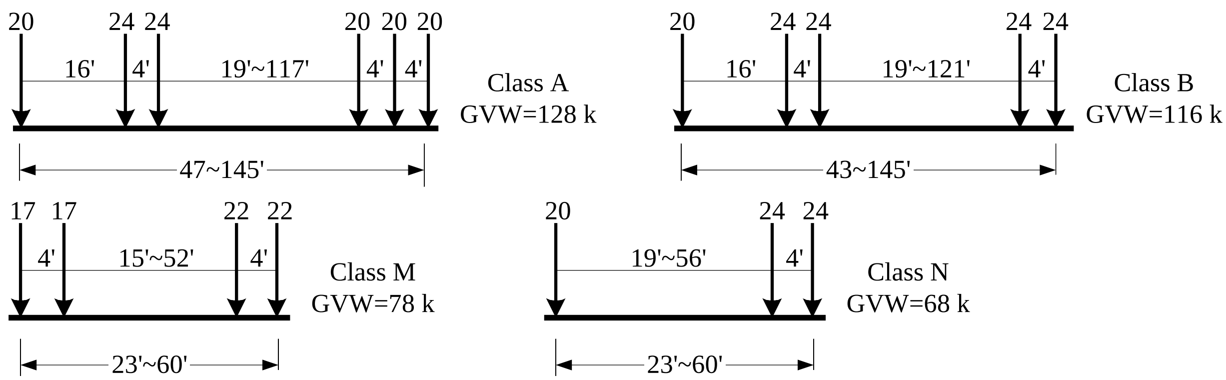


Fig. 2.6 Truck configurations for multi-trip permits in Illinois

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® 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,

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

where, M_{envelope} and V_{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® 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%.

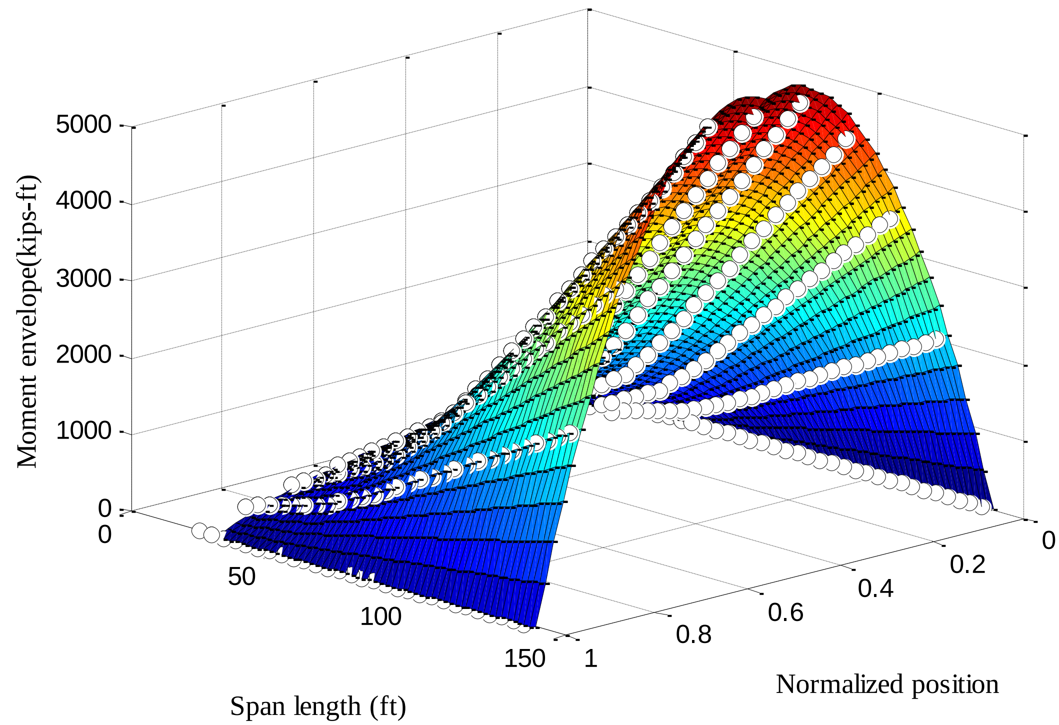


Fig. 3.1 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (one-span)

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.

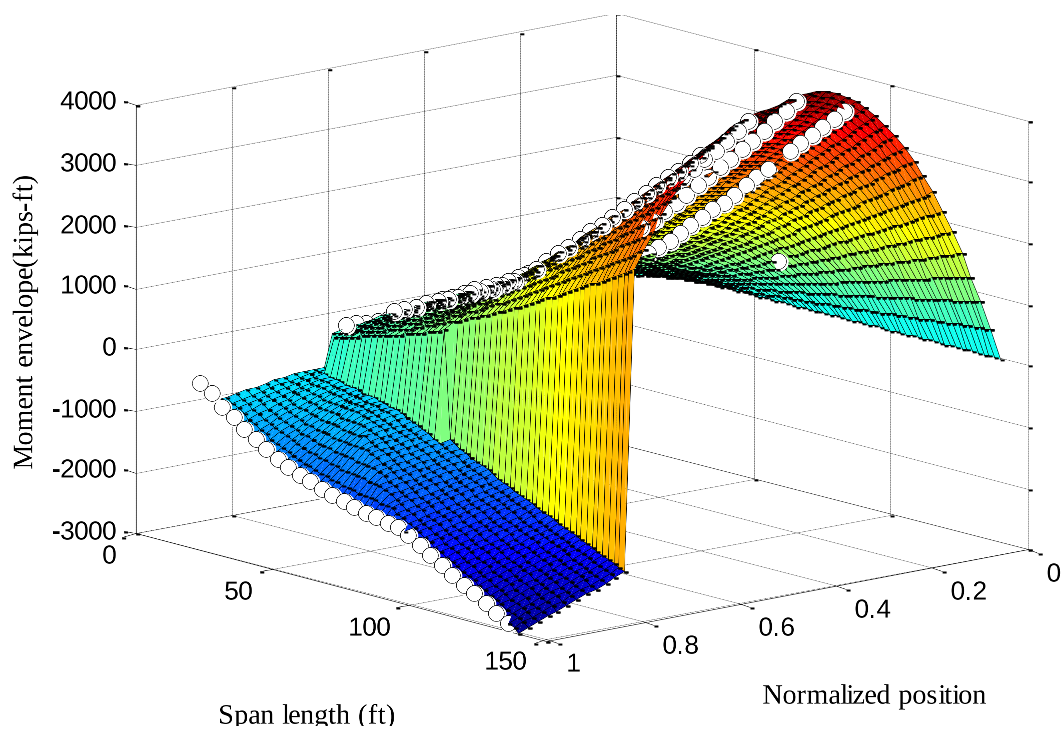


Fig. 3.2 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (two-span)

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, $1+\frac{50}{(L+125)} \le 1.3$, where L is span length, was considered in the comparison.

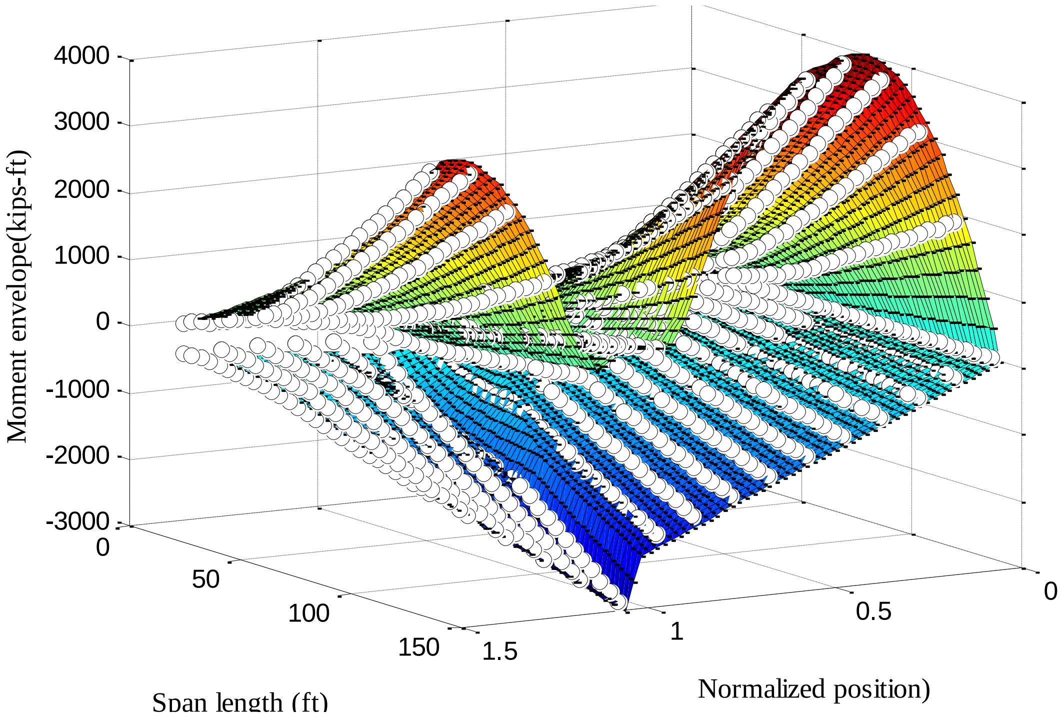


Fig. 3.3 Comparison of SAP2000 analysis results with WisDOT Bridge Manual (three-span)

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 60ft, 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.

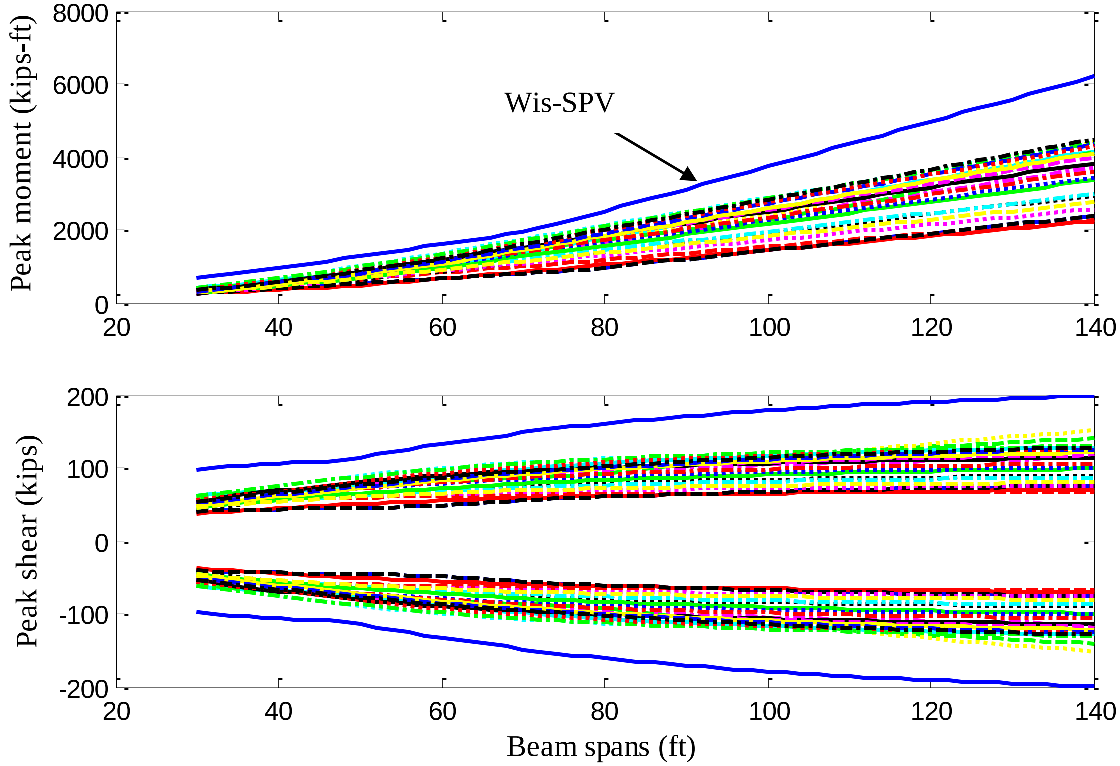


Fig. 3.4 Comparison of the maximum moments in simply-supported girders

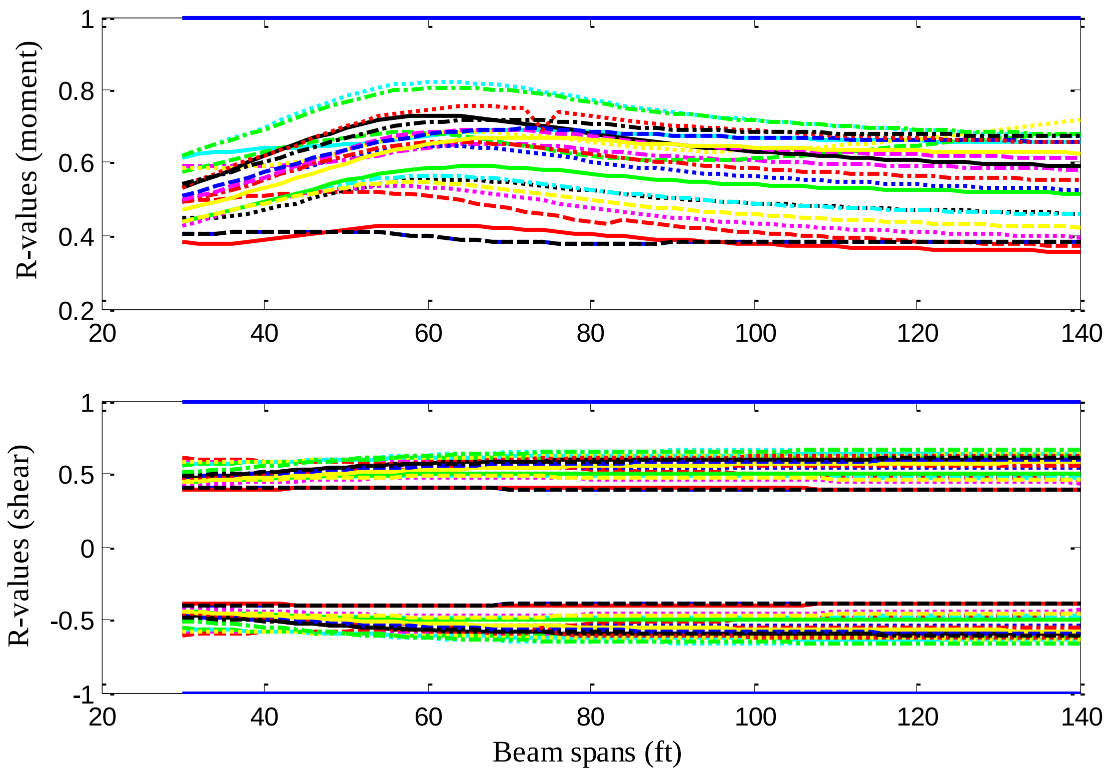


Fig. 3.5 R-values for the moment/shear envelopes in simply-supported girders

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)

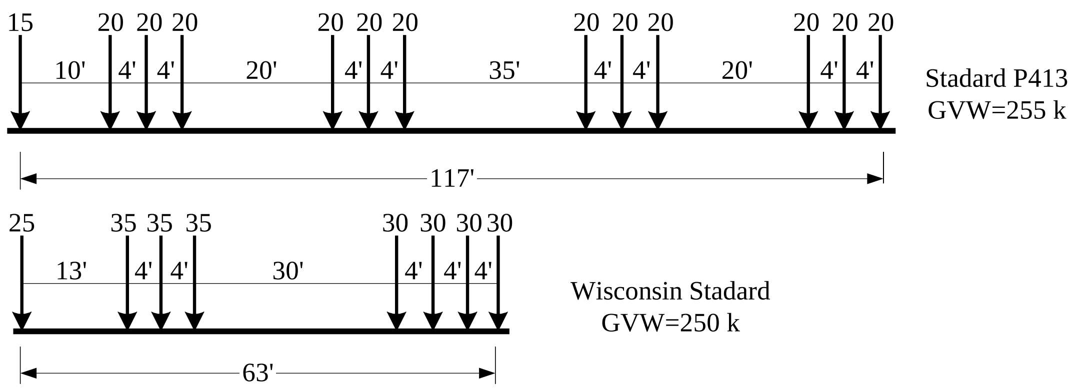
Span (ft)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
32	723.7	326.6	322.3	421.1	447.4	403.7	419.6	285.3	280.0	285.3	308.3	318.8	318.8	318.8	358.5	355.5	387.8	361.1	470.5	470.5	332.4	365.4	393.6	396.8
36	843.3	397.4	378.0	496.6	534.3	491.4	494.1	338.7	322.0	338.7	381.2	388.0	388.0	385.2	442.9	441.2	476.0	435.3	574.1	574.1	414.8	455.4	497.3	483.7
40	962.9	468.4	433.8	572.1	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	1214.6	611.0	568.8	723.4	795.2	815.3	719.0	499.5	458.5	499.5	631.4	638.1	638.1	645.2	727.7	722.3	809.5	743.6	938.5	919.1	712.5	762.8	825.3	815.8
52	1344.2	682.5	670.8	799.2	882.2	925.6	818.8	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	1473.7	754.0	773.3	886.6	969.2	1035.9	943.6	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	1603.2	825.6	875.8	1002.5	1057.4	1146.2	1076.6	660.8	660.0	660.8	883.3	941.8	970.5	917.3	1078.9	1089.3	1186.2	1119.1	1363.7	1326.5	1078.4	1150.5	1238.0	1205.8
64	1732.8	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	1865.6	969.0	1081.5	1270.2	1325.0	1368.0	1343.5	768.5	811.1	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	2042.4	1040.7	1184.5	1404.3	1478.9	1479.0	1477.2	822.3	889.5	822.3	1135.2	1245.8	1328.1	1190.1	1430.9	1464.2	1582.1	1547.3	1817.1	1779.7	1527.6	1587.9	1693.7	1682.8
76	2267.4	1112.4	1287.5	1538.8	1633.6	1590.0	1610.9	880.4	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	1184.2	1390.8	1673.4	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	2753.1	1255.9	1494.2	1808.0	1946.9	1812.0	1879.1	1058.6	1125.2	1058.6	1387.1	1549.9	1685.8	1463.3	1783.0	1839.8	1978.6	1976.4	2270.6	2240.1	1980.5	2071.9	2149.5	2174.8
88	2996.7	1327.7	1597.5	1942.7	2104.3	1923.0	2013.2	1151.8	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	3241.0	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	3486.1	1471.5	1804.2	2212.8	2419.6	2145.0	2281.5	1340.1	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	1543.4	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	3976.4	1615.2	2011.4	2483.0	2735.6	2416.7	2550.3	1529.3	1520.4	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	4222.8	1687.1	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)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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-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 71ft 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.



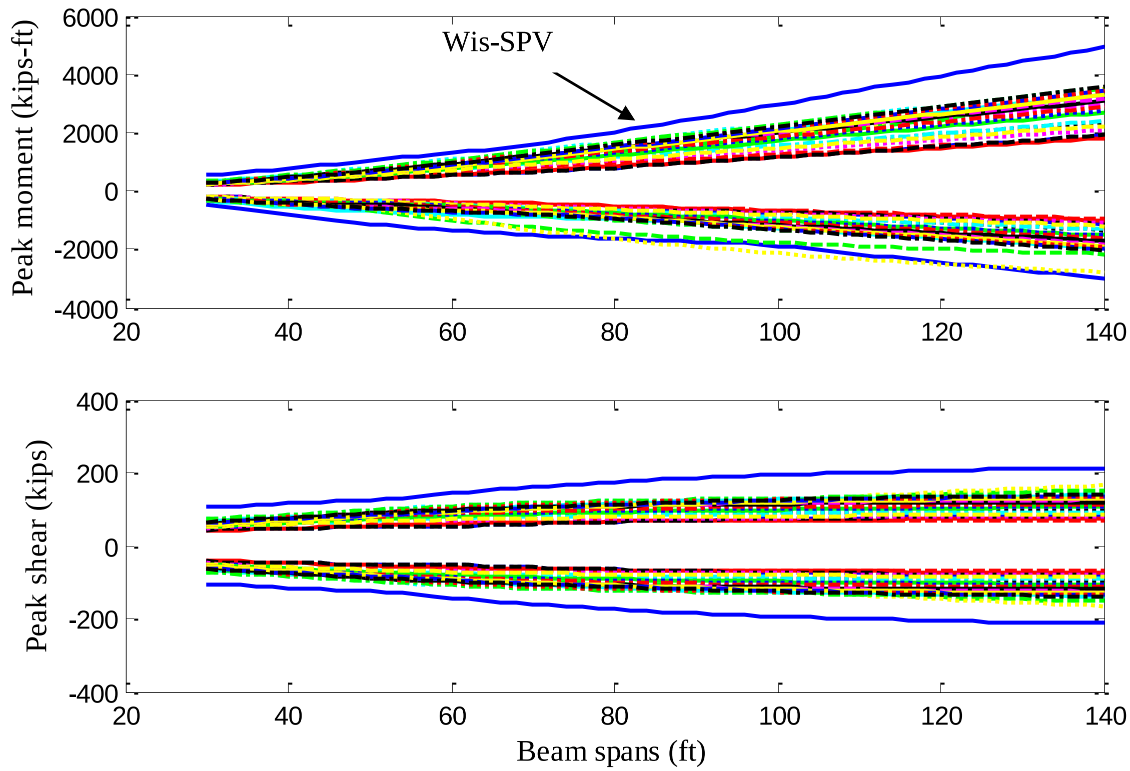


Fig. 3.6 Comparison of the peak moments in 2-span simply-supported girders

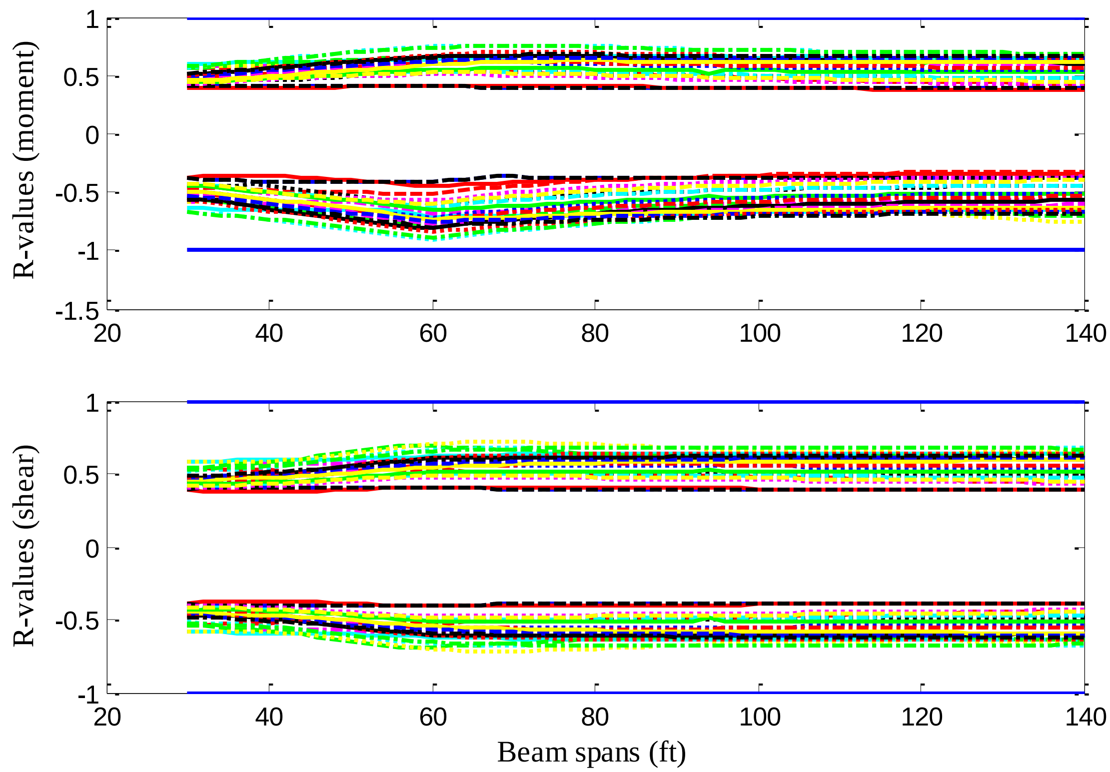


Fig. 3.7 R-values for the moment/shear envelopes in two-span girders

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

Span (ft)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
32	577.2	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	675.0	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	373.2	351.0	460.5	492.9	473.8	458.0	316.8	294.1	316.8	367.1	370.2	370.2	368.6	413.7	414.4	457.2	418.4	530.7	529.7	393.3	430.0	465.6	459.7
44	878.2	430.2	398.1	521.9	563.2	558.9	518.6	359.9	333.5	359.9	431.7	435.3	435.3	438.0	487.5	487.9	545.0	498.9	631.7	621.5	469.3	510.2	547.9	544.3
48	982.8	487.7	461.7	583.6	633.8	645.2	581.5	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	1088.0	545.5	533.2	645.5	704.6	732.5	665.3	446.9	428.8	446.9	563.6	582.4	582.4	580.0	664.7	661.5	725.4	669.1	843.0	831.1	640.6	689.8	747.9	727.4
56	1193.6	603.5	609.0	724.6	775.7	820.6	759.5	490.8	479.5	490.8	630.3	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	1299.5	661.7	687.5	816.6	857.8	909.2	858.3	534.8	531.1	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	1405.7	720.2	768.2	915.2	956.2	998.3	958.8	578.9	589.4	578.9	764.9	818.0	843.9	798.0	939.8	949.8	1033.0	981.5	1187.6	1161.7	951.8	997.7	1077.3	1055.9
68	1528.5	778.9	849.6	1015.5	1068.5	1087.8	1060.7	623.1	649.9	623.1	832.6	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	1678.4	837.7	931.7	1117.5	1185.2	1177.6	1163.8	667.3	711.3	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	1844.9	896.6	1014.1	1220.5	1303.7	1267.7	1267.8	726.3	773.3	726.3	969.0	1059.2	1127.7	1019.3	1220.8	1246.4	1349.4	1318.8	1550.3	1526.0	1304.1	1363.4	1438.5	1426.4
80	2022.6	955.6	1096.9	1324.5	1423.7	1358.0	1373.9	794.3	835.8	794.3	1037.4	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	2203.4	1014.7	1180.1	1429.4	1544.9	1448.5	1481.4	863.6	898.6	863.6	1105.9	1221.8	1319.1	1167.9	1410.1	1448.6	1562.6	1547.6	1794.5	1772.5	1543.8	1615.9	1682.2	1686.4
88	2386.8	1073.9	1263.6	1535.0	1667.3	1539.1	1589.3	933.9	961.8	933.9	1174.6	1303.8	1415.3	1242.4	1505.1	1550.1	1669.6	1662.6	1917.2	1896.4	1664.6	1743.4	1804.6	1818.0
92	2572.4	1133.0	1347.4	1641.5	1790.5	1629.8	1697.6	1005.1	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	2760.0	1192.3	1431.5	1749.6	1914.6	1738.5	1806.3	1077.0	1089.1	1077.0	1312.2	1469.4	1608.4	1391.8	1695.8	1753.8	1884.6	1893.8	2163.3	2145.3	1907.5	2000.1	2050.6	2082.2
100	2951.9	1251.6	1515.6	1858.4	2039.3	1850.8	1915.1	1149.5	1153.0	1149.5	1381.1	1552.3	1705.3	1466.6	1791.5	1856.0	1992.3	2009.9	2286.7	2270.2	2029.4	2129.1	2173.8	2214.9
104	3146.4	1310.9	1600.2	1967.4	2164.5	1964.2	2024.4	1222.7	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	3341.7	1370.2	1684.7	2077.0	2290.4	2078.5	2148.5	1296.3	1281.4	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	3537.9	1429.6	1769.4	2186.8	2416.6	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	3734.9	1489.0	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	3932.7	1548.4	1939.1	2407.1	2670.3	2407.9	2599.7	1519.5	1475.1	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)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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 84ft and 118ft. The R-values in Fig. 3.9 indicates that the breaches of the peak moments by Wis-SPV 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.

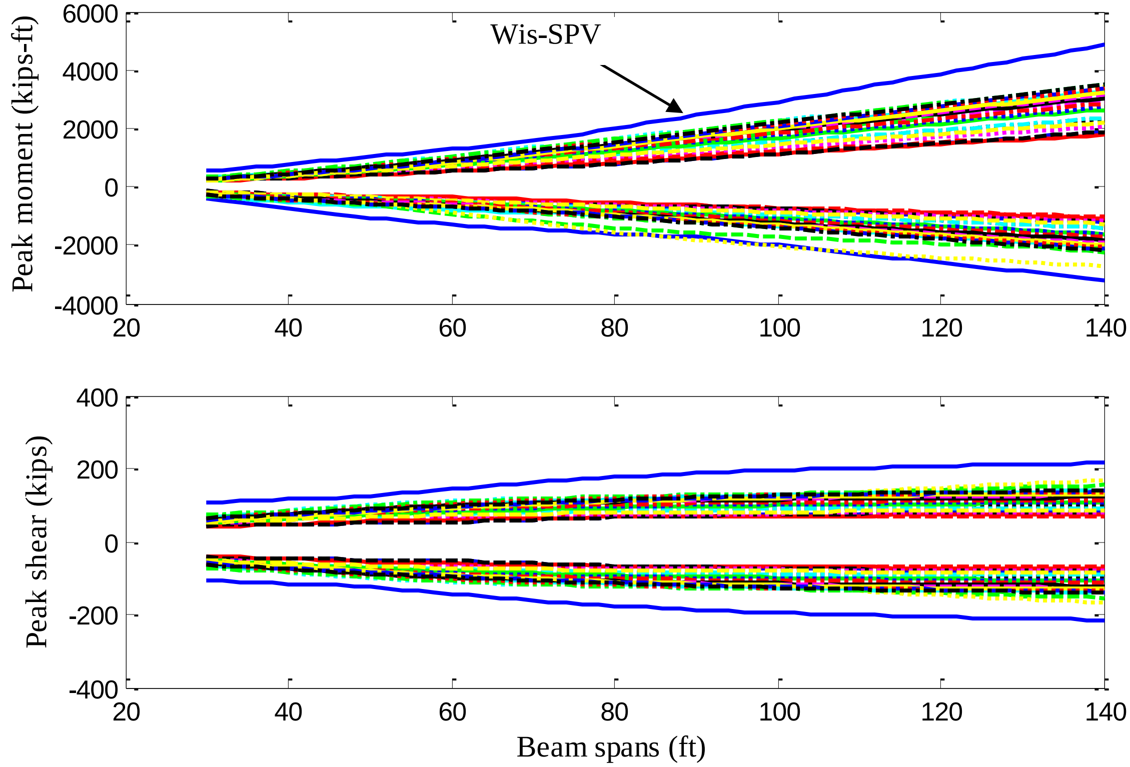


Fig. 3.8 Comparison of the peak moments in3-span simply-supported girders

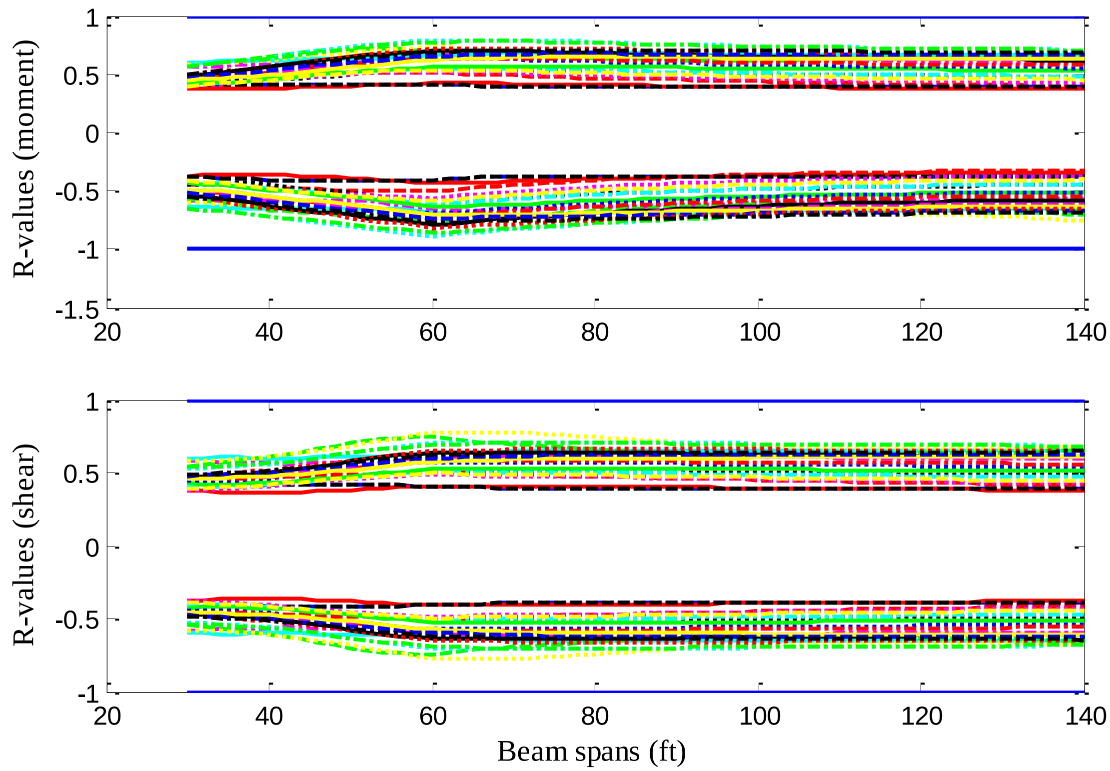


Fig. 3.9 R-values for the moment/shear envelopes in three-span girders

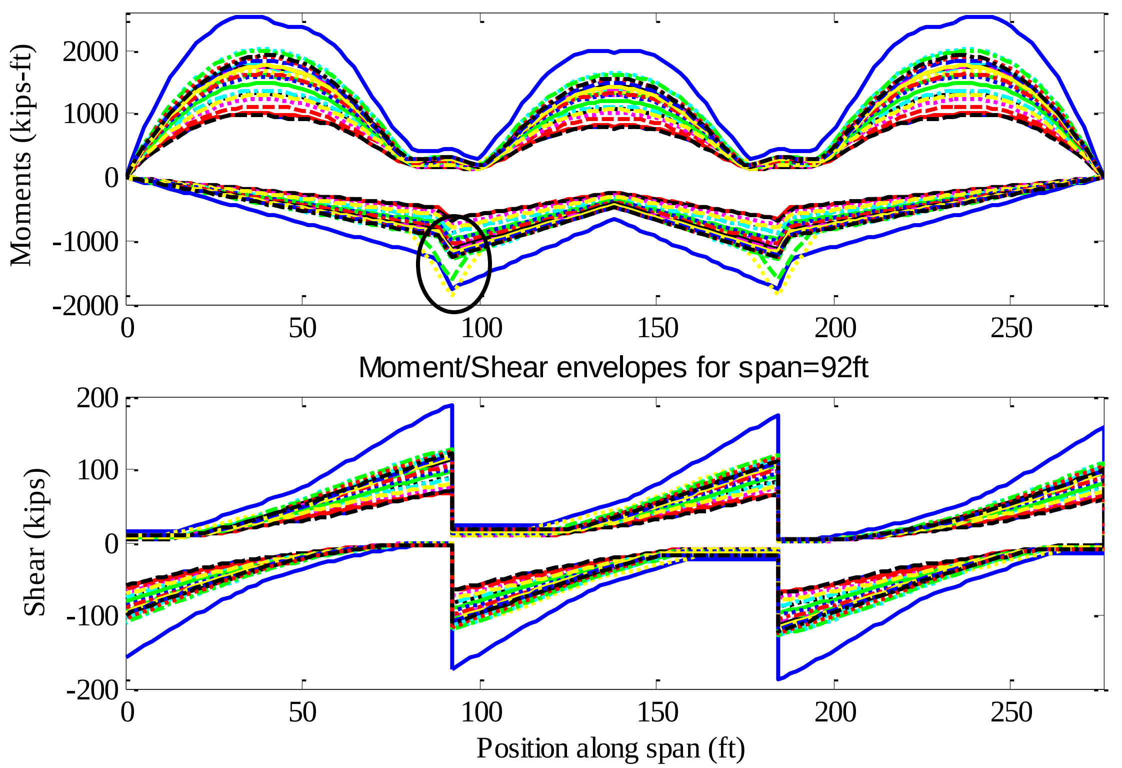


Fig. 3.10 Demonstration of breaching peak negative moment of Wis-SPV

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

Span (ft)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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	371.2
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	865.7	423.5	392.3	514.4	554.3	562.9	532.2	354.8	329.1	354.8	424.6	428.0	428.0	430.5	479.4	479.5	535.8	489.9	621.0	611.3	460.7	501.1	538.6	535.0
48	968.8	480.2	454.8	575.1	623.9	637.4	603.6	397.6	374.0	397.6	489.2	497.8	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	1072.3	537.2	525.1	636.1	693.9	720.3	685.6	440.6	422.7	440.6	554.5	572.8	572.8	570.2	653.2	650.5	713.2	657.6	828.7	817.2	629.4	677.9	734.7	713.8
56	1176.4	594.5	599.4	714.3	764.1	807.0	768.7	483.8	472.6	483.8	620.3	649.1	649.1	641.2	742.4	743.7	811.1	751.7	937.0	922.1	718.6	768.4	838.3	816.2
60	1280.8	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	709.7	755.2	901.2	941.7	982.2	943.6	570.6	580.3	570.6	753.1	804.7	828.4	784.9	923.8	934.0	1015.1	964.0	1167.6	1143.3	934.1	980.0	1057.8	1037.8
68	1507.7	767.6	835.4	999.8	1051.7	1070.4	1043.9	614.1	639.9	614.1	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	1655.1	825.5	916.2	1099.9	1166.3	1159.0	1145.3	657.8	700.2	657.8	887.1	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	883.6	997.5	1201.3	1282.6	1247.9	1247.8	716.5	761.1	716.5	954.3	1042.5	1107.6	1003.0	1200.6	1225.9	1326.7	1295.7	1525.2	1501.1	1281.1	1339.9	1413.2	1400.6
80	1991.9	941.7	1079.2	1303.7	1400.4	1337.0	1351.3	783.0	822.4	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	2169.0	999.9	1161.3	1407.1	1519.5	1426.3	1457.1	850.9	884.2	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	2349.0	1058.3	1243.6	1511.1	1639.6	1515.7	1563.5	919.9	946.5	919.9	1156.9	1283.5	1391.5	1223.2	1480.9	1525.1	1642.4	1634.5	1887.1	1866.1	1636.3	1713.8	1773.8	1786.7
92	2531.3	1116.7	1326.2	1615.8	1760.6	1605.4	1670.1	989.7	1009.1	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	2715.6	1175.2	1409.0	1721.7	1882.7	1713.6	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
100	2901.8	1233.8	1491.9	1829.0	2005.6	1823.8	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
104	3093.2	1292.4	1575.2	1936.6	2129.0	1935.2	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	2044.6	2253.1	2047.6	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
112	3478.8	1409.6	1741.9	2152.7	2377.6	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	2292.0	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	3868.0	1527.0	1909.1	2369.8	2627.9	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	2587.4	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 (ft)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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	-314	-407	-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	-344	-297	-344	-291	-330	-389	-294	-385	-411	-431	-470	-514	-531	-488	-506	-498	-491
48	-1015	-306	-403	-560	-649	-582	-542	-392	-318	-392	-332	-354	-421	-337	-413	-441	-459	-509	-557	-578	-538	-565	-547	-552
52	-1117	-339	-426	-600	-703	-705	-644	-435	-337	-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	-1292	-404	-471	-667	-795	-940	-901	-508	-369	-508	-450	-493	-516	-471	-562	-575	-636	-614	-714	-711	-660	-712	-671	-705
64	-1366	-436	-523	-696	-835	-1045	-1038	-539	-393	-539	-489	-542	-577	-514	-620	-637	-701	-678	-788	-770	-694	-761	-736	-757
68	-1434	-467	-574	-721	-870	-1144	-1177	-568	-432	-568	-527	-591	-636	-556	-676	-699	-764	-751	-861	-845	-736	-807	-812	-806
72	-1496	-499	-624	-747	-903	-1235	-1309	-594	-471	-594	-564	-638	-695	-598	-732	-759	-827	-822	-933	-920	-807	-850	-887	-868
76	-1552	-530	-674	-815	-932	-1320	-1434	-618	-510	-618	-602	-685	-753	-639	-787	-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	-1651	-592	-772	-948	-1044	-1472	-1664	-661	-585	-661	-676	-778	-867	-721	-895	-936	-1010	-1030	-1144	-1137	-1034	-1074	-1105	-1112
88	-1695	-622	-820	-1013	-1122	-1541	-1769	-679	-622	-679	-712	-824	-923	-762	-948	-994	-1070	-1098	-1212	-1208	-1107	-1153	-1175	-1192
92	-1759	-653	-867	-1078	-1200	-1605	-1868	-697	-659	-697	-749	-869	-978	-802	-1001	-1051	-1129	-1165	-1281	-1278	-1180	-1231	-1246	-1271
96	-1884	-684	-914	-1141	-1277	-1664	-1962	-713	-696	-713	-785	-914	-1033	-842	-1053	-1108	-1188	-1231	-1349	-1348	-1252	-1309	-1316	-1349
100	-2008	-714	-961	-1205	-1353	-1721	-2050	-757	-732	-757	-821	-959	-1087	-881	-1106	-1164	-1247	-1297	-1416	-1418	-1323	-1385	-1385	-1427
104	-2129	-745	-1008	-1268	-1428	-1773	-2134	-804	-768	-804	-857	-1004	-1142	-921	-1157	-1220	-1306	-1362	-1483	-1487	-1393	-1461	-1453	-1503
108	-2251	-775	-1054	-1330	-1503	-1823	-2212	-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	-1624	-1533	-1611	-1590	-1655
116	-2489	-836	-1146	-1453	-1650	-1913	-2358	-943	-875	-943	-964	-1137	-1302	-1039	-1312	-1386	-1479	-1556	-1683	-1692	-1602	-1685	-1657	-1730
120	-2607	-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	-2549	-1079	-980	-1079	-1071	-1268	-1460	-1156	-1464	-1551	-1651	-1746	-1880	-1894	-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)	Wis SPV	AASHTO	Mn A	Mn B	Mn C	Mn P411	Mn P413	IA Type4	IA 353A	IA 453	Mi No5	Mi No6	Mi No7	Mi No8	Mi No12	Mi No13	Mi No14	Mi No15	Mi No17	Mi No18	Mi No21	Mi No22	Mi No23	Mi No25
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, 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.

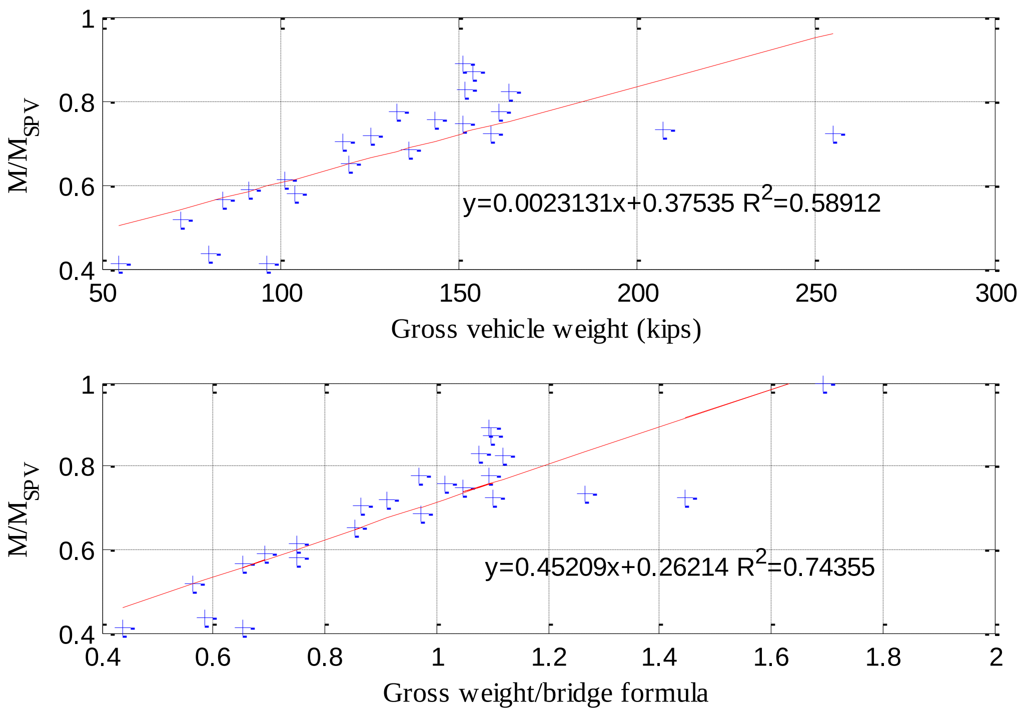


Fig. 3.11 Maximum moment distribution in 1-span girders

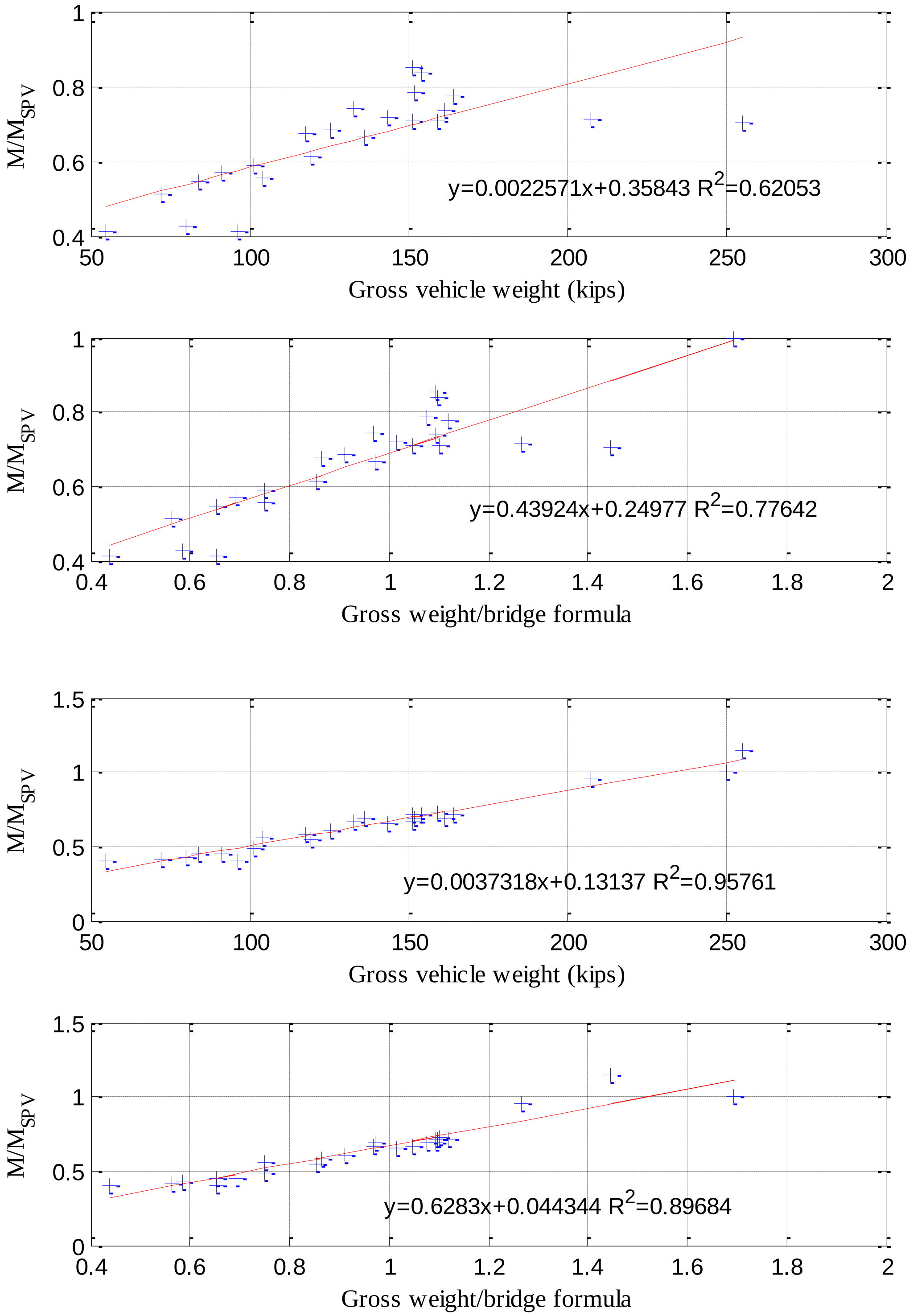


Fig. 3.12 Maximum moment distribution in 2-span girders

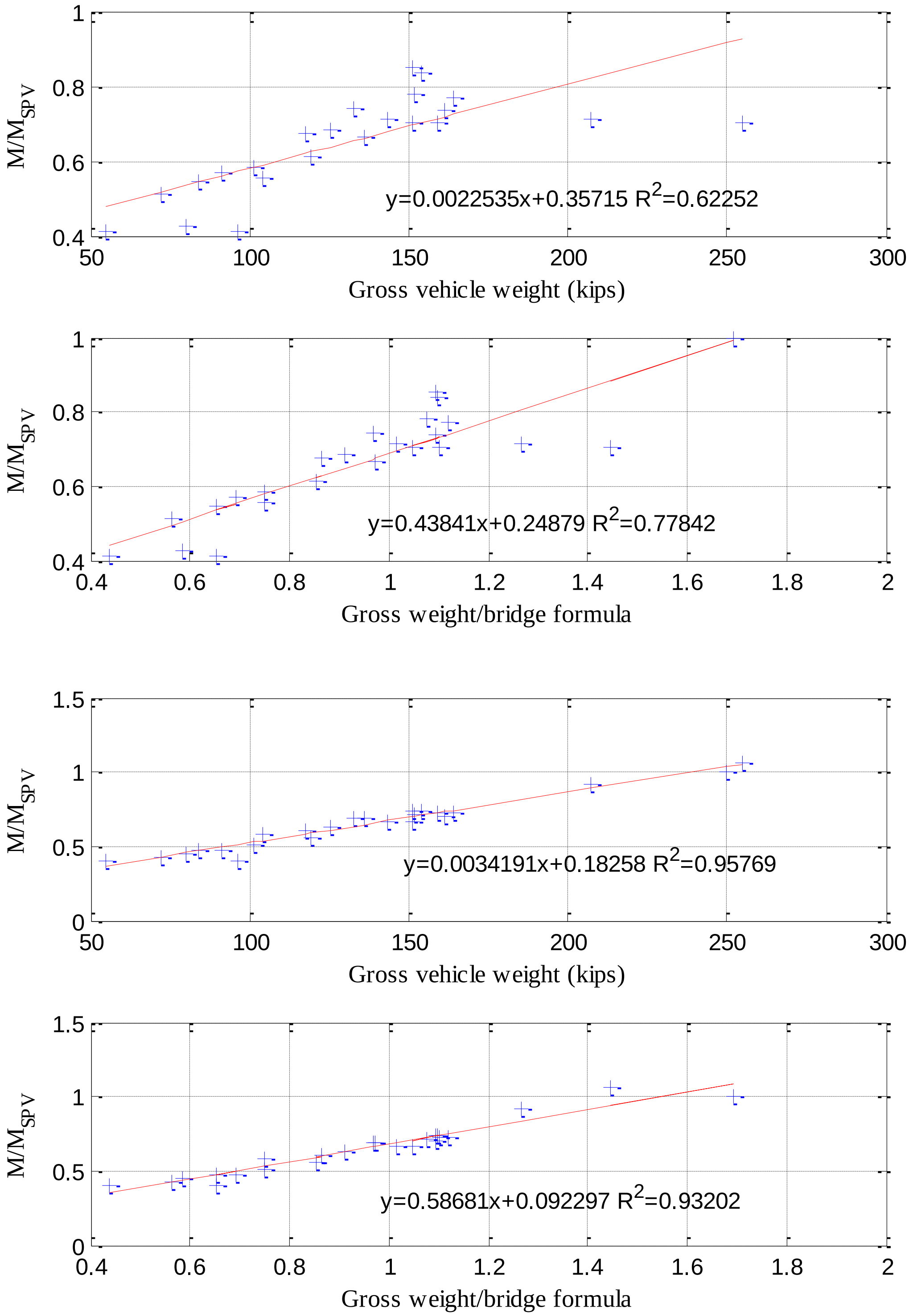


Fig. 3.13 Maximum moment distribution in 3-span girders

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Chapter 4
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] 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:

W552505293106020100005   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® 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

Station	Location	AADT
030010	USH 53, Cameron	10,057
040002	USH 2, Ino	3,842
100001	STH 29, Thorp	10,797
220001	USH 61/1 51, Dickeyville	7,511
250529	USH 18,151, Dodqeville	14,221
260001	USH 151, Mercer	2,332
360002	II I 43, Cooperstown	19,415
370006	STH 29, Hatley	9,437
390105	IH39, Edeavor	17,442
410240	IH94, Tomah	23,598
410253	IH 90, Sparta	16,430
450239	IH43, Port Washington	26,120
470102	STH 29 River Falls	3,535
530001	IH 39/90, Newville	46,301
576051	USH63,Hayward	1,156
590608	STH 23, Kohler	22,651
640343	IH 43 Delevan	13,477

Fig. 4.1 Locations of Wisconsin WIM stations using Google® 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 2-axle, 4-tire single units (Class 3); 2) comparing the combined daily volume of cars (Class 2), 2-axle, 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.

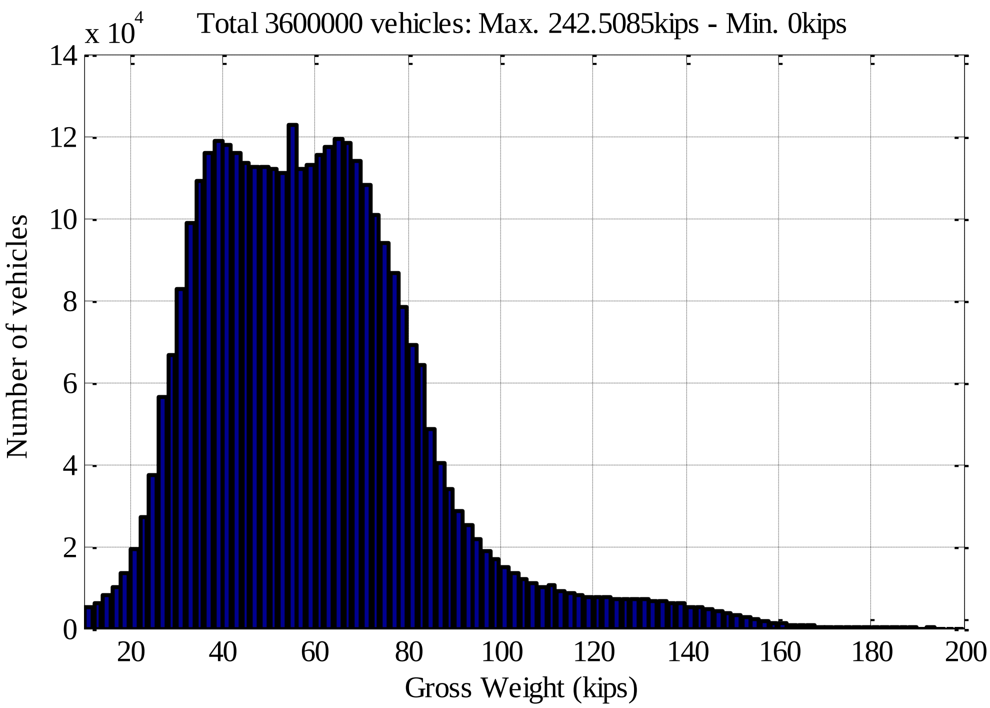
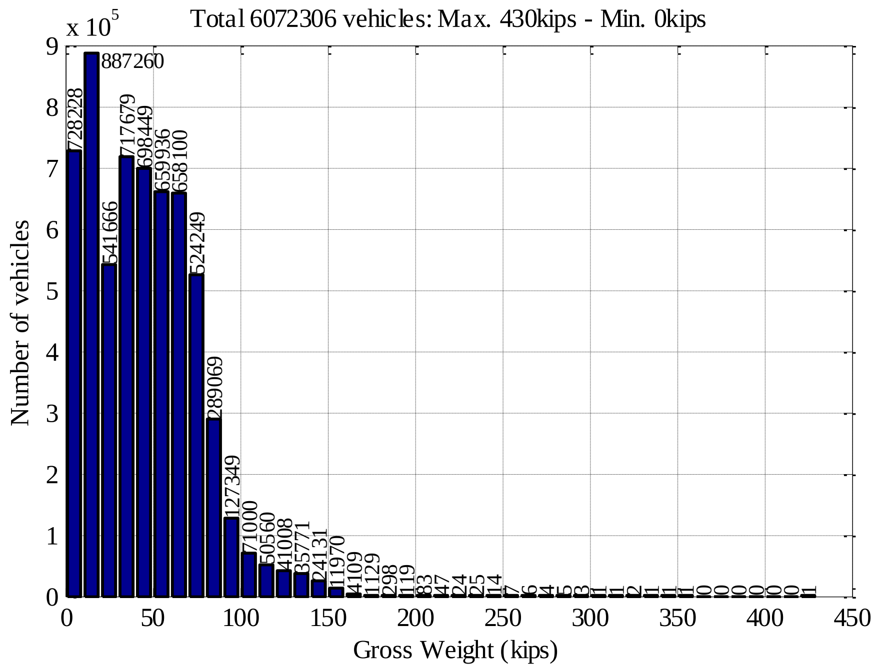
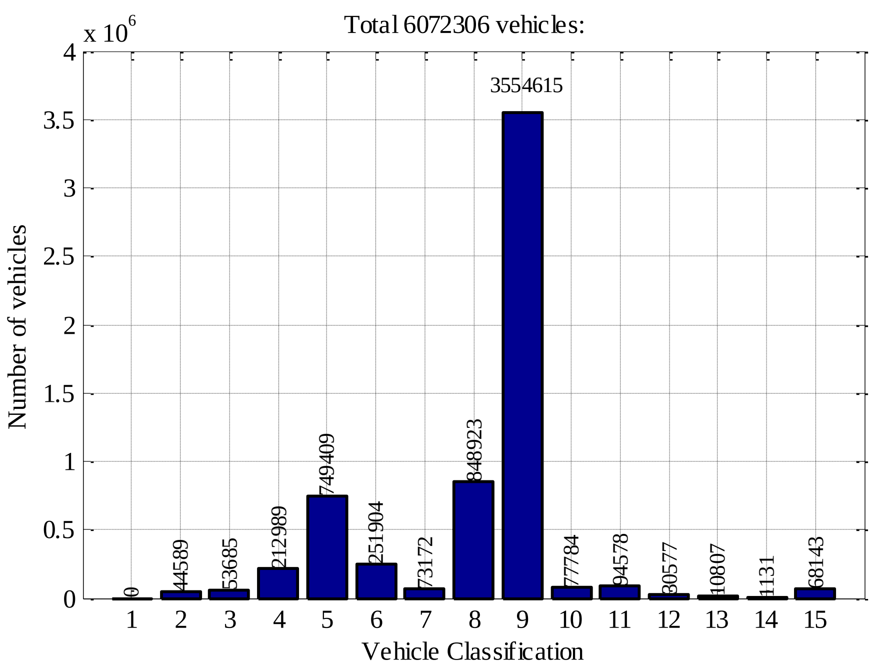


Fig. 4.2 Weight distribution of Class 9 semi-trailers

A Matlab® 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.





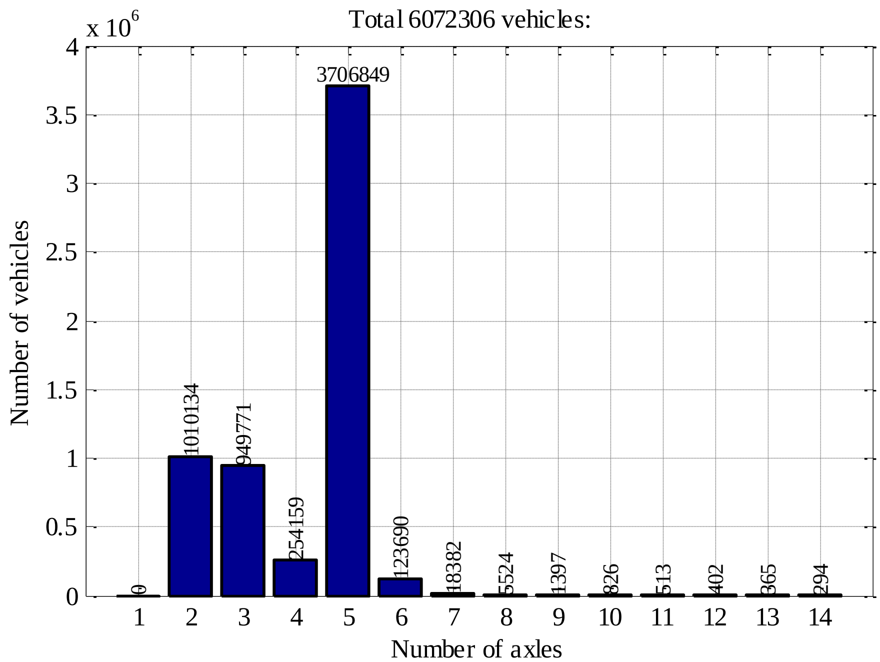


Fig. 4.3 Overview of vehicles recorded in WIM data

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 annual permit	Vehicles likely with single-trip permit
Leading axle	≤13kips	≤20kips	>20kips
Single axle	≤20kips	≤30kips	>30kips
2-axle tandem	≤40kips	≤55kips	>55kips
3-axle tandem	≤60kips	≤70kips	>70kips
4-axle tandem	≤73kips	≤80kips	>80kips
5+-axle tandem	The gross weight of vehicles with permits likely exceeds the limits		
Gross Weight	≤80kips	≤170kips	>170kips

Note that the tandem axles are defined as groups of axles with spacing smaller than 6ft.

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 10~15% 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).

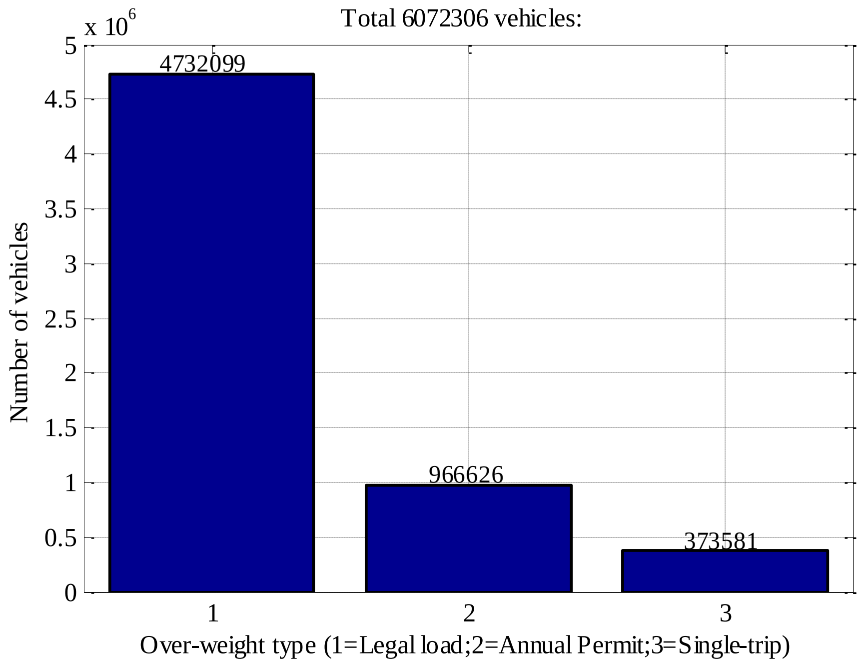


Fig. 4.4 Distribution of overweight type of vehicles in WIM data

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.

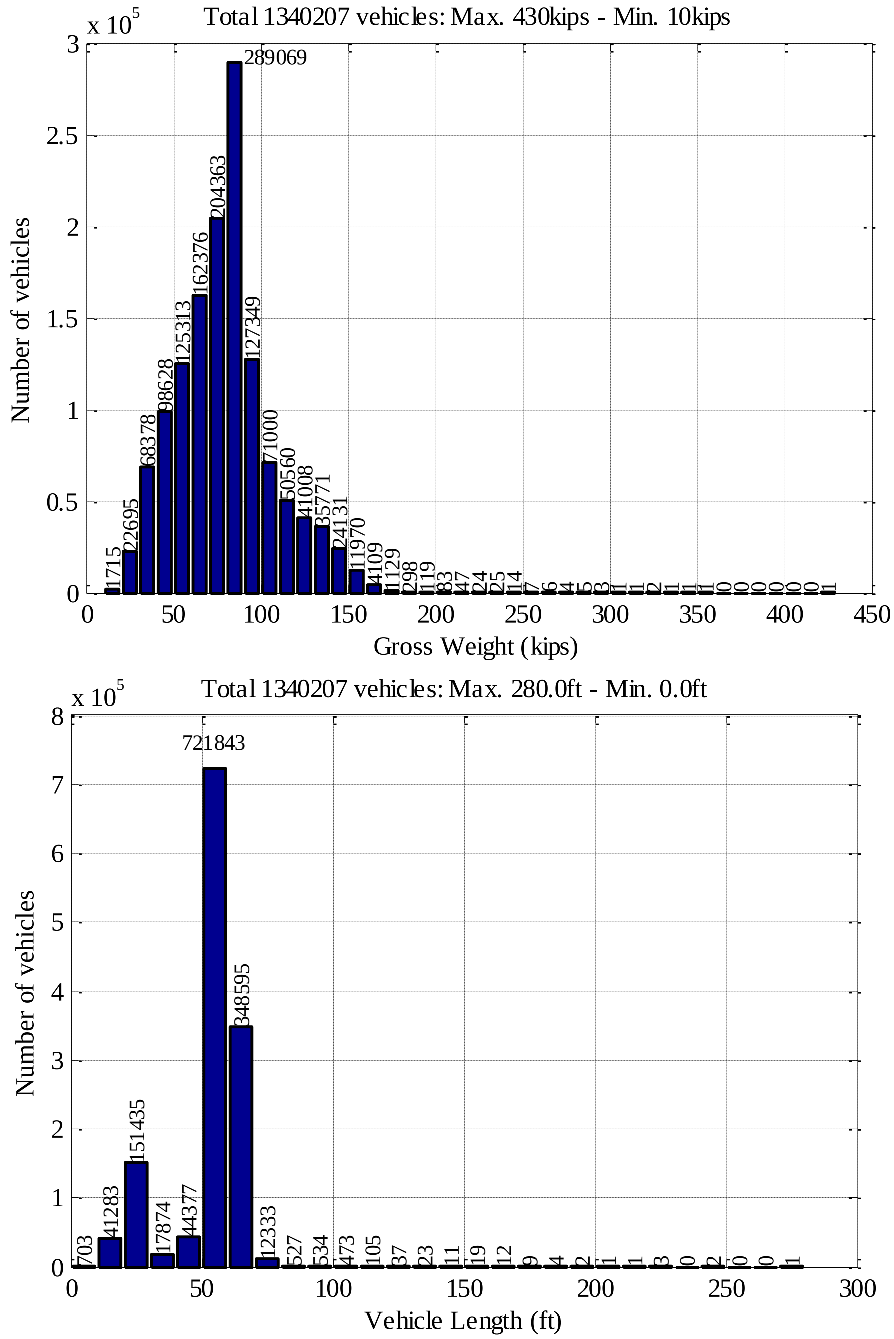


Fig. 4.5 Distribution of overweight vehicles recorded in WIM data

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^{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 4ft rather than the average spacings; and one axle spacing was taken as a variable spacing defined by the 5^{th} percentile and 95^{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 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} 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

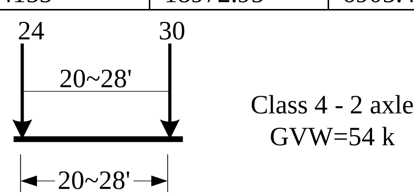


Fig. 4.6 Representative vehicle for Class 4 vehicles (2-axle)

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 2ft to 6ft with an average of 4ft.

20351 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} 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

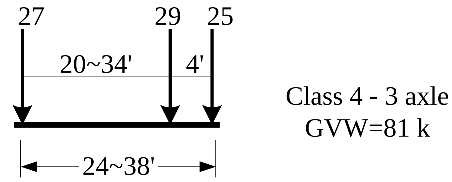


Fig. 4.5 Representative vehicle for Class 4 vehicles (3-axle)

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 5th percentile value was used as the lower bound while a larger integer than the 95th percentile value was used for the upper bound.

20069 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile
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

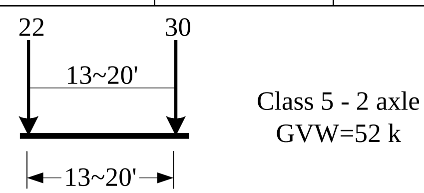


Fig. 4.8 Representative vehicle for Class 5 vehicles

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 4.5ft, hence tandem axle spacing was used for axle spacing 2 though the recorded values varies from 2ft to 81 ft.

78523 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

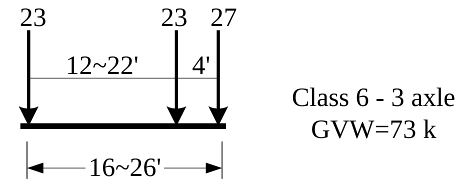
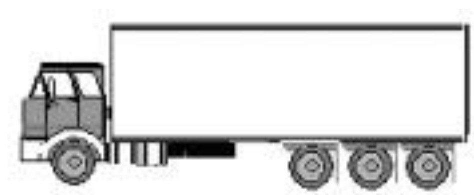


Fig. 4.9 Representative vehicle for Class 6 vehicles

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 4ft. Note that the gross weight of the representative vehicle is 99kips, which is larger than the 95th percentile of the gross weight (85kips) and smaller than the maximum gross weight (187kips).

15988 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

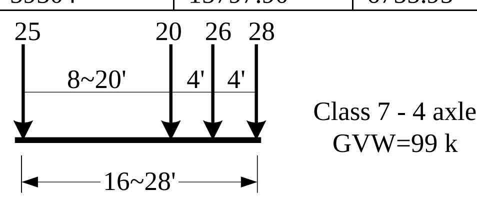


Fig. 4.10 Representative vehicle for Class 7 vehicles (4-axle)

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 4ft, 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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

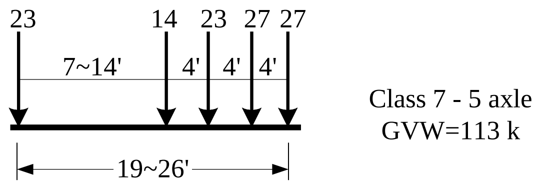
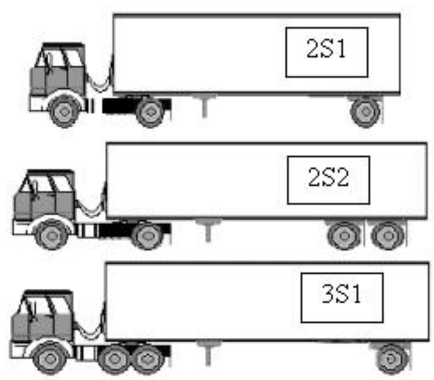


Fig. 4.11 Representative vehicle for Class 7 vehicles (5-axle)

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 2S1. 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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

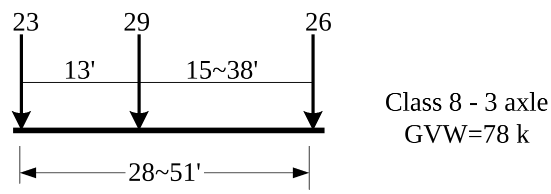


Fig. 4.12 Representative vehicle for Class 8 vehicles (Type 2S1)

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

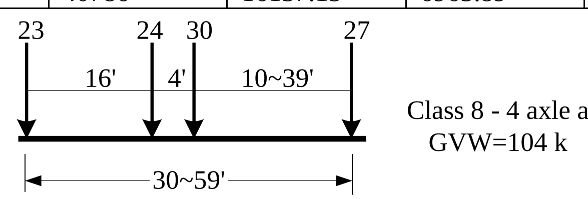


Fig. 4.13 Representative vehicle for Class 8 vehicles (Type 3S1)

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

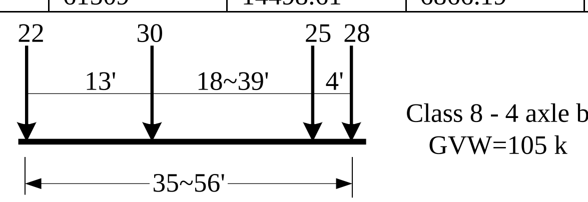


Fig. 4.14 Representative vehicle for Class 8 vehicles (Type 2S2)

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 2.5th and 97.5th 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 4ft 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 vehicles	Minimum	Maximum	Mean	Standard deviation	2.5th percentile	97.5th 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	18280.68	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

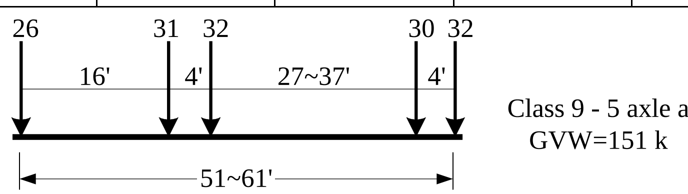


Fig. 4.15 Representative vehicle for Class 9 vehicles (Type 3S2)

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 3S2 representative vehicle. Not that the split axle spacing was set to be 10 ft, close to the average spacing.

133972 vehicles	Minimum	Maximum	Mean	Standard deviation	2.5th percentile	97.5th 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

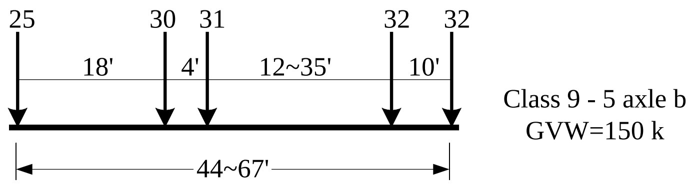
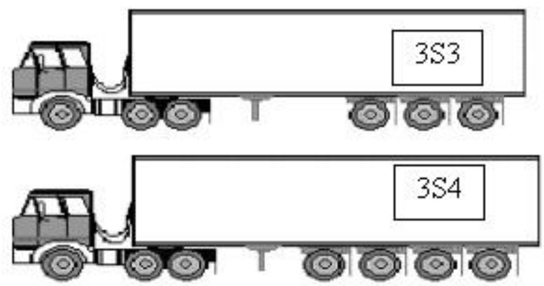


Fig. 4.14 Representative vehicle for Class 9 vehicles (Type 3S2 split)

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..



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 4ft though the average values were different. The third spacing, which dictates the size of the trailer, varies from 4ft to 37ft, 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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

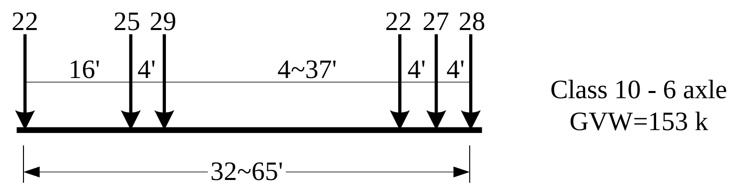


Fig. 4.17 Representative vehicle for Class 10 vehicles (Type 3S3)

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 4ft to 38ft. 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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile
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

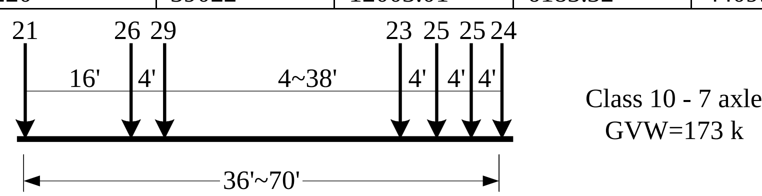
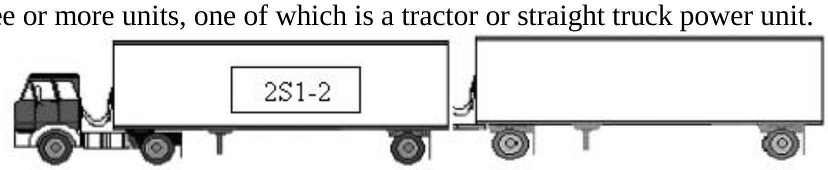


Fig. 4.18 Representative vehicle for Class 10 vehicles (Type 3S4)

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 - 9ft. The wheelbases of the trailers are close (around 21ft).

28618 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile
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

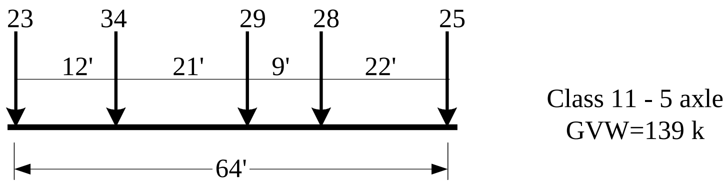
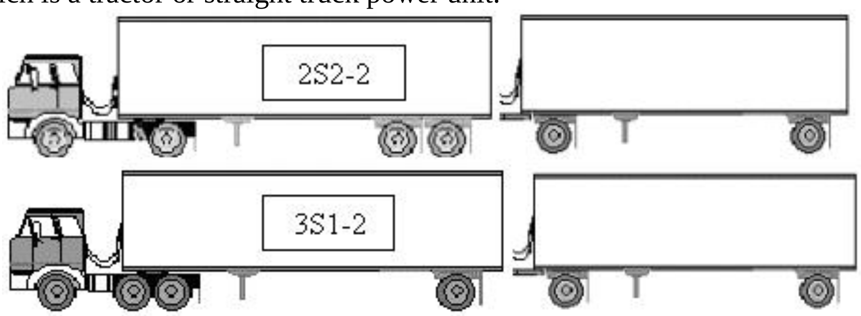


Fig. 4.19 Representative vehicle for Class 11 vehicles

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 3ft to 6ft 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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

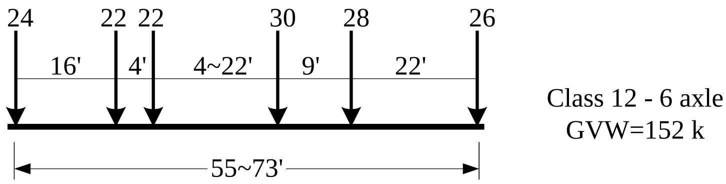
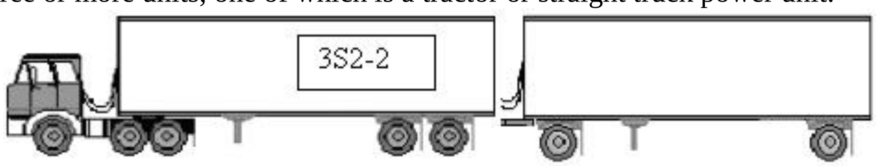


Fig. 4.20 Representative vehicle for Class 12 vehicles

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th 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

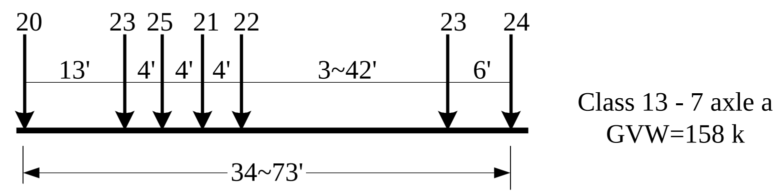


Fig. 4.21 Representative vehicle for Class 13 vehicles

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 7ft to 39ft, and the short truck would likely cause large positive moments in simply-supported girders.

3463 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} percentile
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

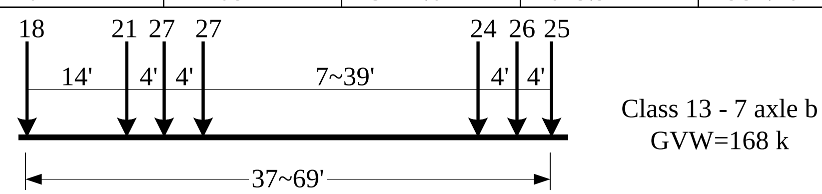
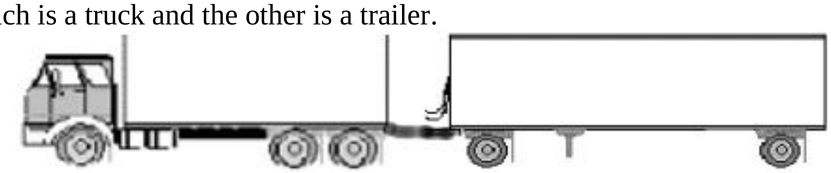


Fig. 4.22 Representative vehicle for Class 13 vehicles

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} 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

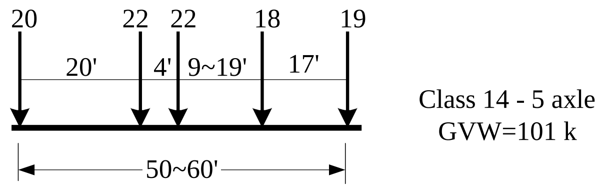


Fig. 4.23 Representative vehicle for Class 14 vehicles

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 40ft to 80ft).

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.

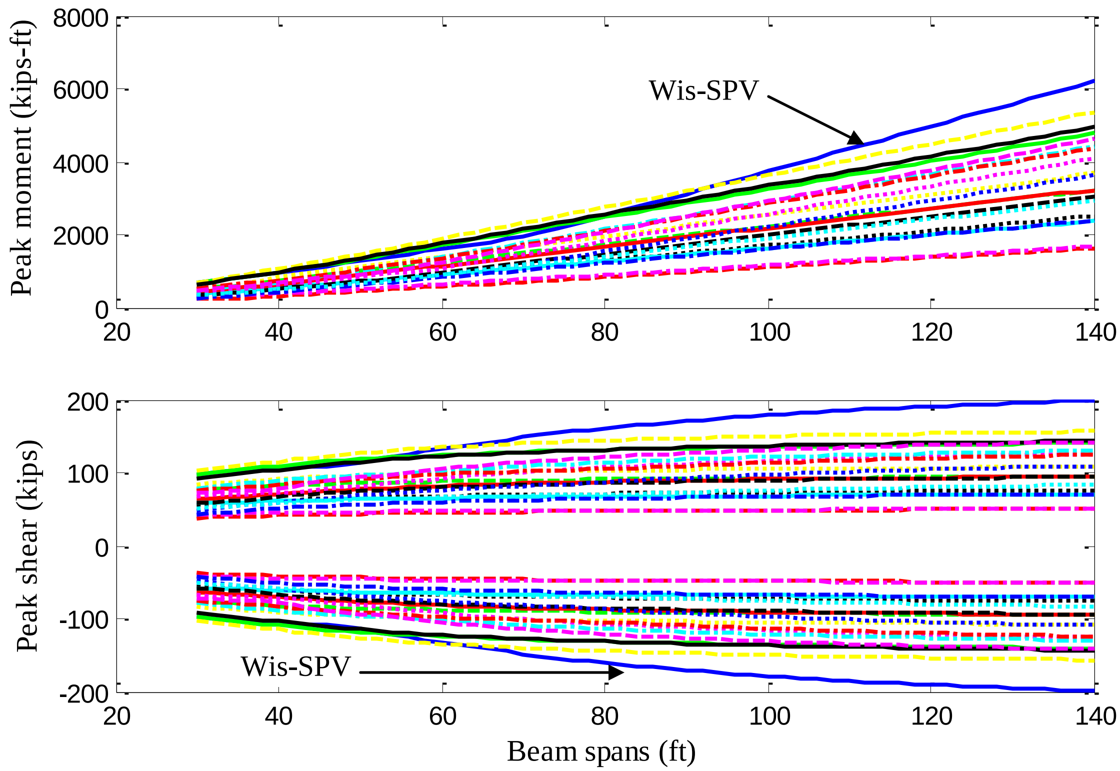


Fig. 4.24 Peak moment/shear values for overweight vehicles on one-span girders

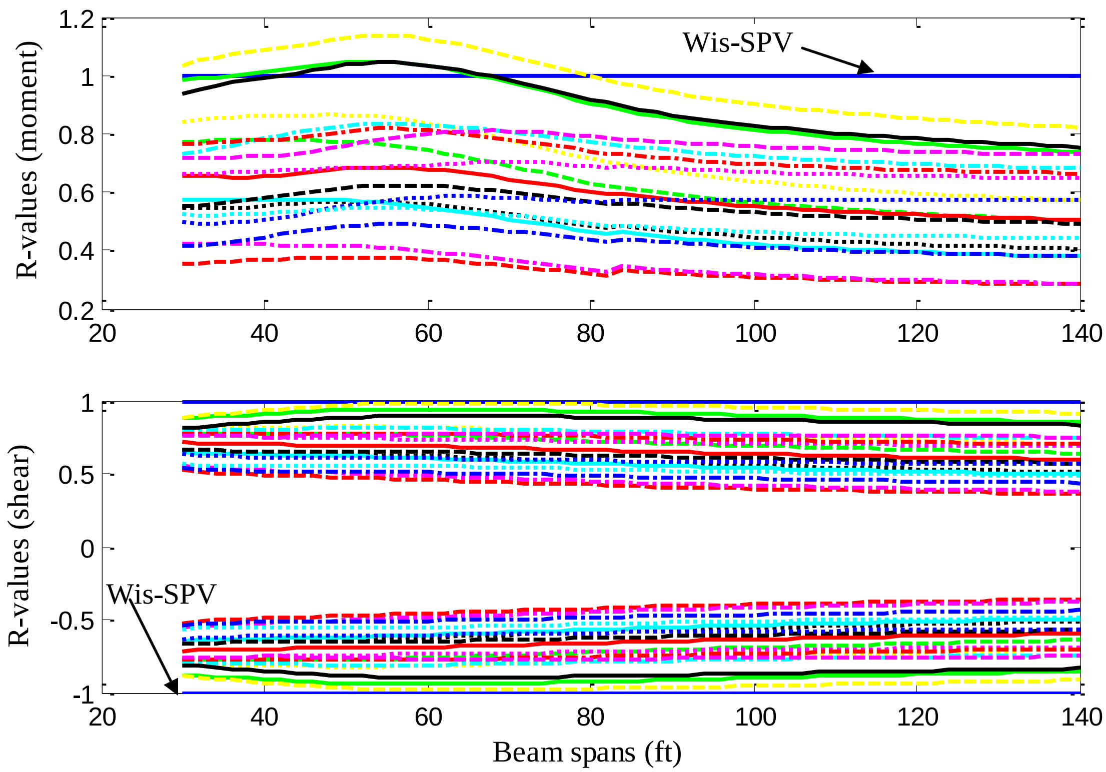


Fig. 4.25 R-values for overweight vehicles on one-span girders

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

Span (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle b	Class14 5axle
32	723.7	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	557.5
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	831.7	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	802.3
60	1603.2	579.0	899.8	643.5	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	977.5	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	2267.4	788.8	1220.4	850.1	1196.1	1637.4	1849.5	1137.8	1565.6	1366.6	1675.2	1991.8	2324.6	2580.1	1395.7	1940.0	2392.6	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	1408.1
84	2753.1	894.2	1381.1	953.6	1342.1	1835.0	2077.5	1293.8	1773.2	1572.8	1974.2	2293.4	2630.1	2925.9	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	2444.4	2782.9	3098.9	1812.0	2395.8	2869.5	2411.8	1610.0
92	3241.0	1000.0	1541.9	1057.3	1488.0	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	1702.7	1160.9	1634.0	2230.7	2533.5	1605.6	2188.8	1987.2	2574.2	2897.2	3241.1	3617.7	2228.4	2851.7	3346.5	2918.2	1913.0
104	3976.4	1158.8	1783.1	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	4222.8	1211.8	1863.5	1264.5	1779.9	2428.6	2761.5	1761.6	2396.7	2195.2	2874.2	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	1852.9	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	1925.8	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	2071.8	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 (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle 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	103.72	40.06	59.38	44.04	60.21	80.53	89.06	48.01	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	42.48	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	60.71
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	44.16	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	63.83
56	125.86	44.82	66.99	46.89	64.78	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	138.64	45.90	68.71	47.52	65.80	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	67.05
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	151.01	46.73	70.04	48.02	66.60	89.77	101.53	63.01	85.57	83.74	102.05	109.96	128.87	140.81	82.78	102.74	128.40	116.01	68.60
76	156.22	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	160.91	47.40	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	71.08
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	48.60	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.

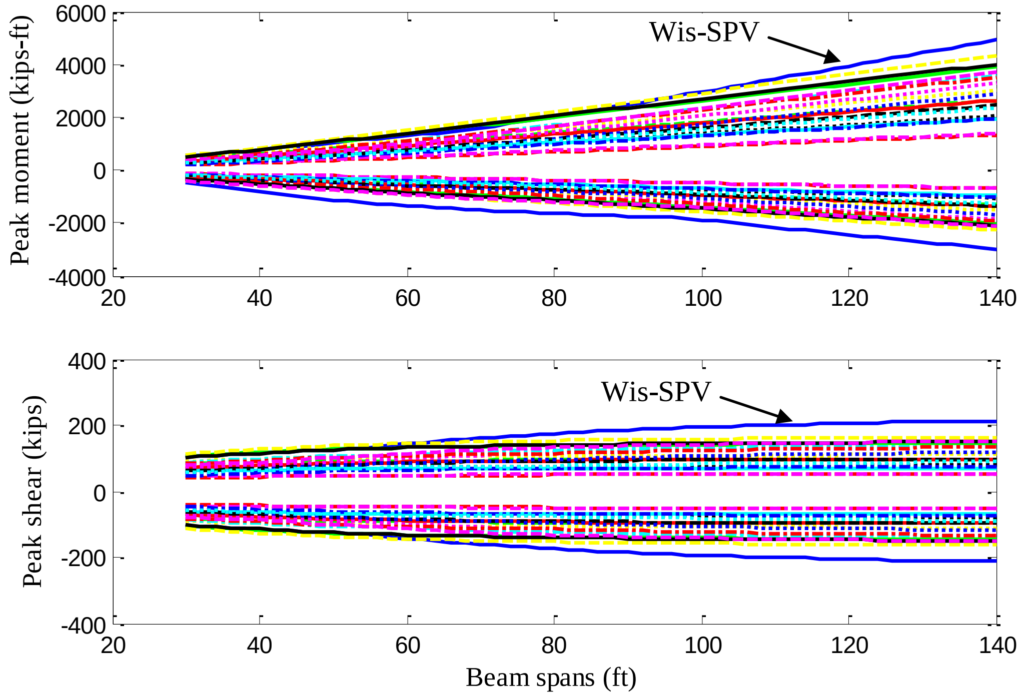


Fig. 4.26 Peak moment/shear values for overweight vehicles on two-span girders

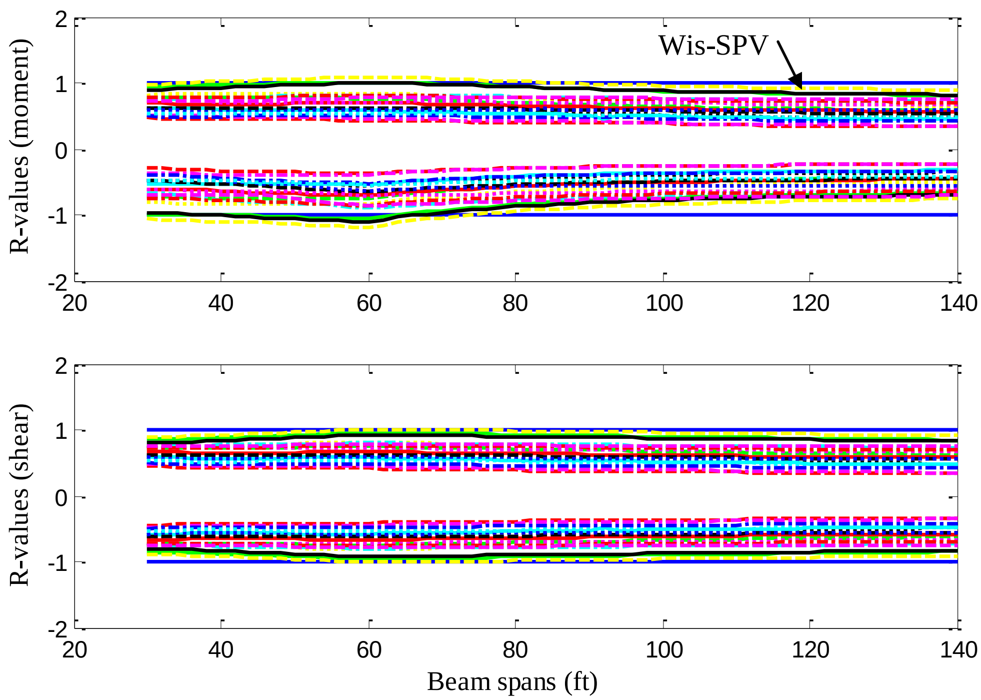


Fig. 4.27 R-values for overweight vehicles on two-span girders

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

Span (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle 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	229.8	358.3	274.0	374.9	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
44	878.2	306.8	476.2	355.9	492.4	680.8	751.4	402.9	590.0	485.2	575.9	663.5	890.8	963.8	429.1	692.7	885.6	634.0	449.9
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	387.7	601.4	439.3	611.1	842.3	935.5	526.7	754.3	618.7	718.6	855.1	1132.0	1226.3	567.5	888.3	1138.9	785.2	575.6
56	1193.6	429.0	665.0	481.4	670.8	923.3	1028.0	589.3	837.5	696.0	790.5	968.3	1254.2	1364.5	641.1	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	512.6	793.5	565.9	790.4	1085.8	1213.9	715.2	1005.1	854.5	981.3	1207.1	1500.5	1643.1	809.7	1188.9	1524.2	1116.0	791.1
68	1528.5	554.9	858.2	608.3	850.3	1167.2	1307.3	778.5	1089.3	935.2	1094.9	1327.6	1624.3	1783.1	895.8	1300.8	1653.5	1241.3	871.2
72	1678.4	597.3	923.2	650.7	910.4	1248.8	1400.9	841.9	1173.8	1016.6	1210.0	1448.7	1748.7	1923.7	982.9	1419.8	1783.2	1370.3	951.7
76	1844.9	639.9	988.4	693.2	970.5	1330.3	1494.6	905.5	1258.5	1098.5	1326.3	1570.2	1873.2	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	2043.1	1635.0	1113.7
84	2203.4	725.8	1119.3	778.4	1090.8	1493.6	1682.2	1033.0	1428.4	1263.7	1561.7	1814.3	2123.1	2347.1	1298.3	1783.1	2173.4	1768.6	1195.1
88	2386.8	769.0	1185.1	821.0	1151.0	1575.3	1776.1	1096.9	1513.6	1347.0	1680.6	1936.9	2248.4	2488.7	1407.8	1905.2	2303.8	1902.9	1276.7
92	2572.4	812.2	1251.0	863.6	1181.1	1657.1	1870.1	1160.8	1598.8	1430.9	1800.1	2059.7	2373.7	2630.5	1517.9	2027.6	2434.4	2037.8	1358.5
96	2760.0	855.6	1317.0	906.3	1271.5	1738.8	1964.1	1224.9	1684.1	1515.1	1920.1	2182.9	2499.3	2772.4	1628.4	2150.4	2565.0	2173.2	1440.5
100	2951.9	899.0	1383.0	949.1	1331.7	1820.6	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	3146.4	942.5	1449.2	992.0	1392.0	1902.5	2152.2	1353.1	1855.0	1684.1	2161.5	2429.6	2750.7	3056.7	1850.6	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	3199.0	1962.3	2520.3	2957.6	2582.2	1687.2
112	3537.9	1029.6	1581.7	1077.8	1512.7	2066.2	2340.6	1481.4	2026.1	1853.8	2404.3	2676.8	3002.5	3341.4	2074.1	2644.0	3088.7	2719.3	1769.7
116	3734.9	1073.3	1648.0	1120.8	1573.1	2148.1	2434.8	1545.7	2111.8	1939.0	2526.3	2800.6	3128.5	3483.9	2186.1	2768.0	3219.7	2856.8	1852.3
120	3932.7	1116.9	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	1754.2	2393.8	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	1814.6	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 (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 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	-276.7	-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	-231.1	-308.2	-334.3	-228.4	-293.6	-314.3	-409.7	-394.2	-438.3	-485.7	-334.0	-365.4	-432.0	-479.6	-243.6
44	-688.0	-183.2	-276.3	-161.7	-241.8	-323.8	-350.8	-244.8	-309.6	-336.0	-448.4	-427.5	-465.9	-522.6	-357.1	-393.3	-466.3	-519.6	-257.4
48	-760.7	-191.6	-292.0	-166.6	-251.7	-338.3	-366.5	-261.1	-324.8	-357.6	-484.6	-460.5	-496.7	-559.3	-378.5	-419.7	-500.4	-556.9	-274.8
52	-831.6	-199.3	-307.8	-177.7	-260.8	-351.9	-386.0	-277.2	-347.1	-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	-188.7	-269.5	-364.8	-410.3	-293.2	-369.1	-400.3	-550.2	-525.7	-560.6	-631.8	-426.6	-478.6	-567.9	-627.4	-319.1
60	-960.5	-213.0	-338.3	-199.6	-278.0	-384.6	-434.3	-309.1	-391.0	-421.5	-581.5	-558.0	-592.2	-667.7	-455.7	-510.5	-601.4	-662.3	-339.6
64	-1019.2	-219.0	-352.4	-210.5	-293.2	-405.0	-458.1	-325.1	-412.9	-442.7	-612.7	-590.0	-623.8	-703.6	-483.6	-541.2	-634.6	-697.2	-358.9
68	-1074.3	-224.7	-365.5	-221.2	-308.4	-425.4	-481.9	-340.9	-434.6	-463.8	-643.8	-621.9	-655.3	-739.1	-509.9	-570.7	-667.7	-731.9	-377.2
72	-1126.3	-229.9	-378.0	-231.9	-323.5	-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	-1175.1	-234.8	-389.6	-242.6	-338.5	-465.8	-528.9	-372.1	-477.7	-505.7	-705.5	-685.1	-717.6	-809.8	-558.7	-626.9	-733.4	-800.8	-411.0
80	-1221.2	-239.3	-400.8	-253.2	-353.5	-485.8	-552.3	-386.9	-499.0	-526.6	-736.1	-716.4	-748.6	-845.0	-581.1	-653.5	-765.9	-835.1	-426.7
84	-1264.7	-247.4	-411.3	-263.8	-368.4	-505.8	-575.5	-401.0	-519.6	-547.0	-765.3	-747.2	-779.4	-880.0	-602.6	-679.4	-798.4	-869.3	-441.5
88	-1305.9	-259.0	-421.1	-274.4	-383.2	-525.8	-598.7	-414.5	-539.3	-566.3	-793.1	-776.6	-809.4	-915.0	-623.0	-704.5	-830.8	-903.5	-455.6
92	-1344.9	-270.5	-430.6	-284.9	-398.0	-545.7	-621.9	-427.2	-558.2	-584.7	-819.5	-804.6	-837.7	-949.5	-642.4	-728.9	-863.2	-937.4	-469.1
96	-1381.9	-281.9	-439.7	-295.4	-412.8	-565.5	-644.8	-439.3	-576.3	-602.0	-844.7	-831.2	-864.7	-982.4	-660.9	-752.6	-895.1	-969.9	-481.9
100	-1417.0	-293.3	-448.2	-305.8	-427.5	-585.3	-667.8	-450.9	-593.8	-618.5	-868.4	-856.5	-890.2	-1013.6	-678.5	-775.6	-925.8	-1000.9	-494.1
104	-1450.2	-304.5	-457.8	-316.2	-442.2	-605.0	-690.8	-462.0	-610.6	-634.1	-891.4	-880.8	-914.7	-1043.7	-695.3	-798.2	-955.3	-1030.5	-505.9
108	-1482.2	-315.7	-474.8	-326.6	-456.9	-624.7	-713.7	-472.5	-626.9	-648.9	-912.8	-903.9	-937.8	-1072.0	-711.3	-820.1	-983.6	-1058.6	-517.2
112	-1511.9	-326.9	-491.6	-337.0	-471.4	-644.4	-736.4	-482.7	-642.5	-663.2	-933.5	-925.8	-959.9	-1099.4	-726.7	-841.8	-1010.9	-1085.3	-527.9
116	-1540.8	-338.1	-508.4	-347.4	-486.0	-664.1	-759.2	-492.5	-657.6	-676.5	-953.3	-947.1	-981.0	-1125.1	-741.4	-862.9	-1037.1	-1111.0	-548.5
120	-1568.2	-349.2	-525.2	-357.7	-500.6	-683.7	-781.9	-501.8	-676.5	-689.6	-972.2	-967.2	-1007.2	-1150.1	-755.6	-883.5	-1062.6	-1135.5	-571.6
124	-1594.4	-360.2	-541.9	-368.1	-515.1	-703.3	-804.6	-516.2	-698.1	-701.7	-990.2	-986.4	-1038.6	-1173.9	-771.6	-903.6	-1086.8	-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	-923.6	-1110.4	-1181.3	-617.5
132	-1643.3	-382.2	-575.2	-388.7	-544.0	-742.4	-849.8	-548.8	-741.1	-724.8	-1024.2	-1022.8	-1101.0	-1234.2	-814.1	-957.4	-1141.0	-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	-1055.6	-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 (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle b	Class14 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	109.56	41.26	61.30	45.68	62.76	84.68	94.08	50.01	72.57	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	113.78	42.91	63.89	46.51	64.12	86.55	96.71	53.77	75.03	68.85	79.21	96.12	116.00	124.91	63.44	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	88.01	98.75	56.73	78.53	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	57.98	80.00	75.08	82.78	101.56	122.30	131.12	70.05	96.92	119.38	92.16	66.44
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	45.66	68.27	47.91	66.37	89.69	101.09	60.11	82.54	78.27	87.50	104.29	125.51	135.52	75.00	100.29	123.55	98.63	68.19
72	124.41	46.06	68.91	48.11	66.70	90.14	101.73	61.03	83.63	79.65	89.54	105.46	126.90	137.42	77.14	101.74	125.35	101.44	68.94
76	126.35	46.42	69.48	48.30	67.00	90.56	102.31	61.87	84.62	80.90	91.39	106.51	128.16	139.14	79.08	103.05	126.99	103.99	69.62
80	130.98	46.75	70.01	48.47	67.27	90.93	102.84	62.64	85.53	82.05	93.08	107.47	129.31	140.73	80.86	104.24	128.49	106.33	70.23
84	135.25	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	139.21	47.33	70.94	48.76	67.75	91.60	103.77	63.98	87.14	84.08	97.44	109.50	131.35	143.52	83.99	106.33	131.13	111.89	71.30
92	142.87	47.59	71.35	48.89	67.96	91.90	104.19	64.58	87.84	84.97	99.74	111.27	132.25	144.75	85.36	107.24	132.29	114.39	71.77
96	146.27	47.83	71.73	49.01	68.16	92.17	104.57	65.13	88.50	85.80	101.88	112.92	133.09	145.90	86.64	108.09	133.37	116.70	72.21
100	149.93	48.05	72.09	49.13	68.34	92.43	104.92	65.64	89.11	86.57	103.86	114.44	133.86	146.95	87.82	108.87	134.38	118.85	72.61
104	153.81	48.25	72.41	49.23	68.51	92.66	105.26	66.11	89.67	87.28	105.71	115.86	134.58	147.94	88.91	109.59	135.31	120.85	72.98
108	157.44	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	160.84	48.62	73.00	49.42	68.82	93.09	105.85	66.96	90.69	88.57	109.05	118.42	135.87	149.71	90.87	110.88	136.99	124.46	73.63
116	164.03	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	137.74	126.08	73.93
120	167.02	48.94	73.52	49.58	69.09	93.46	106.37	67.71	91.58	89.69	111.97	120.65	137.01	151.27	92.58	112.01	138.46	127.62	74.20
124	169.84	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.

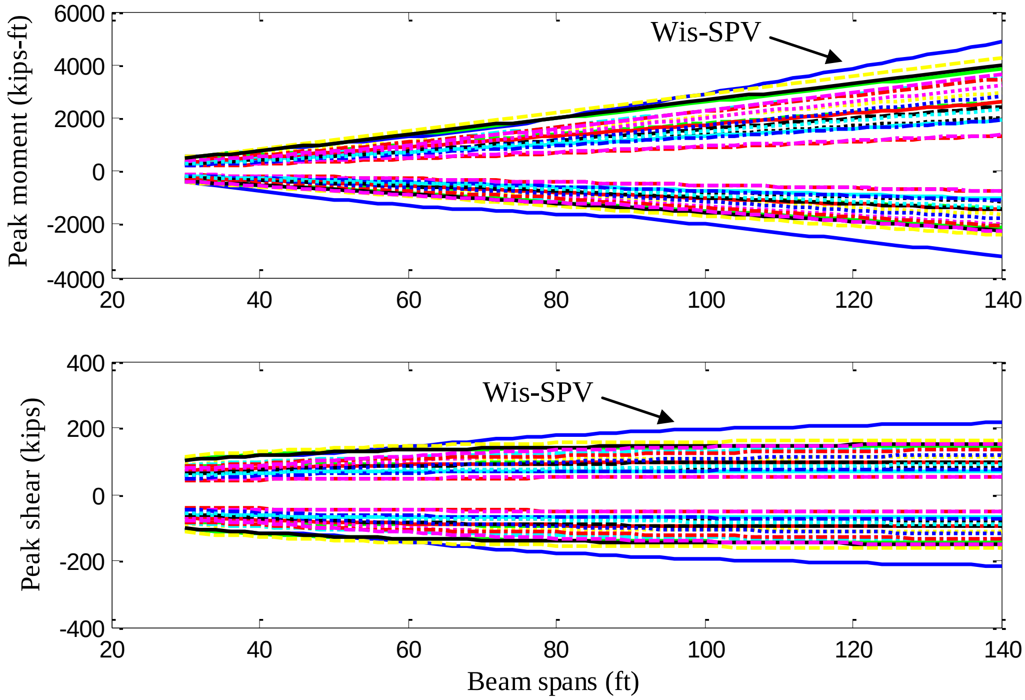


Fig. 4.27 Peak moment/shear values for overweight vehicles on three-span girders

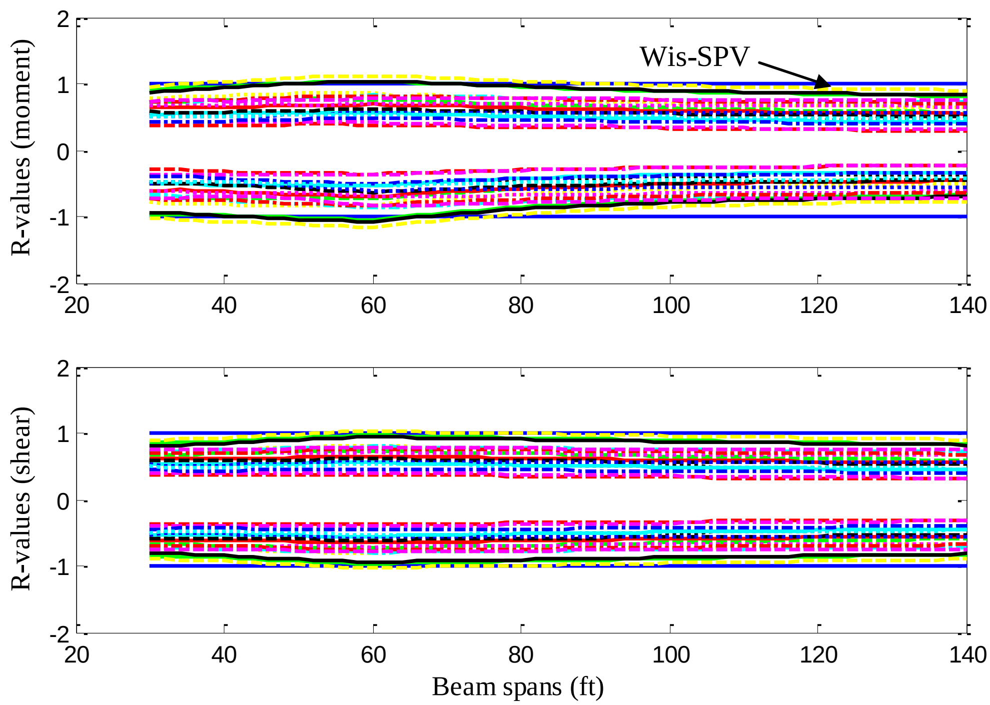


Fig. 4.28 R-values for overweight vehicles on three-span girders

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

Span (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle b	Class14 5axle
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	575.6	195.5	309.8	230.5	312.1	435.1	472.7	225.7	369.5	307.4	362.7	401.2	556.1	586.2	269.9	431.1	538.9	410.7	293.0
40	622.1	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	667.4	227.1	353.7	270.2	369.2	513.0	560.9	277.2	433.7	353.8	429.7	473.9	661.0	706.1	314.7	512.3	648.0	478.5	342.6
48	713.1	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	763.4	264.3	409.7	310.4	426.9	591.6	650.1	336.1	501.8	415.2	498.0	561.8	766.4	826.9	359.9	593.9	758.2	551.2	392.5
56	814.5	283.4	439.5	330.7	456.0	631.1	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	865.7	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	917.2	322.3	500.1	371.5	514.2	710.3	785.5	426.3	621.3	509.8	602.4	700.1	936.3	1009.5	455.9	729.9	933.1	661.9	473.9
68	968.8	342.0	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	777.9	995.4	699.1	504.7
72	1020.4	361.9	561.7	412.5	572.8	789.9	876.4	487.2	702.1	574.0	672.6	794.5	1055.0	1139.0	523.8	826.2	1057.8	736.4	535.8
76	1072.3	382.1	592.8	433.1	602.2	829.9	922.0	517.9	742.9	609.8	708.0	842.2	1114.8	1206.7	558.3	874.9	1120.5	773.9	567.1
80	1124.3	402.4	624.1	453.7	631.6	869.9	967.7	548.6	783.8	647.5	743.4	893.0	1174.9	1274.6	593.0	923.8	1183.5	813.9	598.6
84	1176.4	422.8	655.5	474.6	661.1	909.9	1013.4	579.5	824.8	685.7	778.9	951.2	1235.2	1342.7	631.4	972.9	1246.5	866.0	630.3
88	1228.5	443.3	687.1	495.4	690.6	950.0	1059.2	610.4	866.0	724.2	814.5	1009.6	1295.7	1411.0	672.1	1022.2	1309.7	919.2	662.1
92	1280.8	463.9	718.7	516.2	720.1	990.1	1105.1	641.4	907.2	763.0	855.9	1068.2	1356.3	1479.5	713.4	1071.7	1373.1	978.4	700.0
96	1333.2	484.6	750.4	537.1	749.6	1030.2	1151.0	672.4	948.6	802.2	910.2	1127.1	1417.1	1548.4	754.9	1121.3	1436.6	1038.2	739.0
100	1385.6	505.3	782.2	558.0	779.2	1070.4	1151.0	703.5	990.0	841.5	965.2	1186.1	1478.0	1617.4	796.8	1171.0	1500.2	1098.8	778.2
104	1439.0	526.2	814.2	578.9	808.8	1110.5	1242.9	734.7	1031.6	881.2	1020.7	1245.4	1539.0	1686.5	839.0	1222.9	1563.8	1160.1	817.5
108	1507.7	547.0	846.1	599.9	838.4	1150.8	1288.9	765.9	1073.2	921.0	1076.5	1304.9	1600.2	1755.8	881.6	1280.7	1627.6	1221.8	856.9
112	1577.8	568.0	878.2	620.9	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	1655.1	588.9	910.3	641.8	897.7	1231.3	1381.2	828.5	1156.5	1001.2	1189.5	1424.6	1722.9	1894.7	967.3	1397.3	1755.4	1347.4	936.1
120	1733.1	609.9	942.5	662.8	927.3	1271.6	1427.3	859.9	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	891.4	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	1006.9	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 (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle b	Class14 5axle
32	-430.7	-148.0	-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	-213.8
36	-504.5	-157.9	-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	-574.7	-167.8	-257.5	-154.5	-231.3	-312.4	-345.1	-223.7	-300.8	-299.3	-384.8	-375.4	-454.2	-490.7	-315.7	-368.4	-443.1	-451.2	-246.6
44	-640.8	-177.4	-273.0	-165.7	-242.9	-329.3	-363.2	-240.0	-318.2	-319.7	-424.0	-407.9	-484.1	-527.6	-338.7	-398.0	-475.0	-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	-775.6	-194.3	-304.2	-189.4	-263.7	-366.0	-411.5	-272.2	-350.5	-360.5	-495.6	-472.2	-540.7	-597.6	-379.9	-452.8	-535.8	-564.3	-293.0
56	-839.3	-201.8	-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
60	-900.1	-208.7	-335.1	-212.8	-296.3	-410.0	-463.0	-303.9	-390.3	-400.8	-559.1	-535.4	-593.2	-662.8	-434.4	-521.2	-595.3	-632.1	-333.8
64	-959.0	-215.2	-350.0	-224.4	-312.6	-431.8	-488.4	-319.7	-412.3	-420.8	-589.5	-566.7	-618.3	-694.1	-462.9	-554.2	-628.6	-665.7	-353.2
68	-1014.7	-221.2	-364.1	-235.9	-328.8	-453.5	-513.8	-335.4	-434.3	-440.9	-619.9	-597.8	-642.8	-724.7	-490.1	-586.0	-661.7	-699.3	-371.9
72	-1067.2	-226.8	-377.4	-247.3	-344.9	-475.2	-539.0	-351.1	-456.2	-460.9	-650.2	-628.8	-666.8	-754.7	-516.2	-616.9	-694.8	-732.7	-390.1
76	-1117.2	-238.9	-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
80	-1164.4	-251.4	-402.1	-270.0	-376.9	-518.0	-588.8	-382.1	-499.4	-500.6	-710.0	-690.1	-733.0	-814.7	-564.4	-675.8	-760.1	-799.0	-424.4
84	-1209.1	-263.8	-413.4	-281.3	-392.8	-539.4	-613.7	-397.1	-520.9	-520.4	-739.8	-720.6	-767.7	-852.1	-586.9	-704.0	-792.6	-832.1	-440.8
88	-1251.5	-276.1	-424.2	-292.6	-408.6	-560.7	-638.4	-411.3	-542.0	-539.9	-768.8	-750.7	-802.4	-891.8	-608.4	-731.4	-827.9	-865.1	-456.8
92	-1291.7	-288.5	-434.7	-303.8	-424.4	-581.9	-663.1	-424.8	-562.2	-558.5	-796.5	-779.8	-836.9	-931.2	-628.9	-758.0	-864.1	-898.0	-472.4
96	-1330.0	-300.6	-451.7	-315.0	-440.1	-603.1	-687.6	-437.9	-581.7	-576.2	-822.8	-807.5	-871.1	-970.3	-648.6	-784.0	-900.1	-930.8	-487.5
100	-1366.4	-312.7	-470.0	-326.1	-455.9	-624.1	-687.6	-450.4	-605.2	-593.0	-848.0	-834.1	-905.2	-1009.4	-667.3	-809.4	-935.8	-962.8	-502.3
104	-1400.9	-324.7	-488.2	-337.2	-471.6	-645.2	-736.6	-462.3	-628.6	-609.1	-872.2	-859.6	-939.2	-1048.4	-685.3	-834.2	-971.3	-993.5	-516.8
108	-1434.3	-336.6	-506.3	-348.3	-487.2	-666.2	-761.1	-479.9	-652.0	-624.3	-894.9	-883.8	-973.2	-1087.0	-704.4	-858.3	-1006.8	-1022.8	-534.8
112	-1465.3	-348.6	-524.3	-359.4	-502.8	-687.2	-785.4	-497.8	-675.4	-639.0	-917.0	-907.1	-1006.9	-1125.4	-730.3	-881.9	-1042.2	-1050.6	-559.9
116	-1495.7	-360.5	-542.2	-370.5	-518.3	-708.2	-809.6	-515.4	-698.5	-657.4	-938.1	-929.6	-1040.6	-1163.8	-755.4	-905.1	-1077.3	-1077.5	-584.9
120	-1524.3	-372.4	-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	-744.5	-706.2	-977.6	-993.6	-1107.6	-1240.2	-804.1	-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

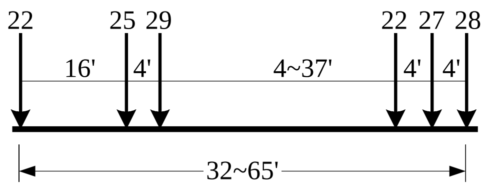
Table 4.5(c) Peak shear in three-span girders by overweight vehicles (kips)

Span (ft)	Wis. SPV	Class4 2axle	Class4 3axle	Class5 2axle	Class6 3axle	Class7 4axle	Class7 5axle	Class8 3axle	Class8 4axle a	Class8 4axle b	Class9 5axle a	Class9 5axle b	Class10 6axle	Class10 7axle	Class11 5axle	Class12 6axle	Class13 7axle a	Class13 7axle b	Class14 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	57.67
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	43.05	64.12	46.65	64.33	86.88	97.12	54.04	75.42	69.12	78.41	96.09	116.57	125.21	63.21	90.19	113.56	84.52	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
56	116.84	44.34	66.17	47.30	65.38	88.33	99.16	57.02	78.93	73.53	80.74	99.97	121.00	129.27	67.00	94.94	117.63	88.57	65.30
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	45.81	68.51	48.04	66.57	89.99	101.48	60.42	82.95	78.61	87.51	104.35	126.08	136.23	74.91	100.34	124.24	98.92	68.12
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	126.89	46.57	69.72	48.42	67.19	90.84	102.68	62.18	85.03	81.26	91.46	106.59	128.73	139.85	79.05	103.12	127.67	104.33	69.57
80	131.56	46.90	70.24	48.58	67.46	91.21	103.20	62.94	85.94	82.41	93.18	107.56	129.88	141.43	80.85	104.32	129.17	106.83	70.19
84	135.88	47.20	70.73	48.73	67.70	91.56	103.68	63.64	86.77	83.47	95.41	108.45	130.93	142.88	82.51	105.43	130.54	109.77	70.76
88	139.87	47.48	71.17	48.87	67.93	91.87	104.12	64.29	87.53	84.44	97.92	110.13	131.90	144.21	84.03	106.43	131.80	112.49	71.28
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	68.51	92.68	104.90	65.94	89.49	86.93	104.39	115.08	134.39	147.63	87.91	109.00	135.03	119.48	72.60
104	154.59	48.39	72.64	49.33	68.68	92.91	105.58	66.41	90.05	87.65	106.25	116.50	135.11	148.61	89.01	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	68.98	93.33	106.16	67.25	91.06	88.93	109.61	119.06	136.39	150.37	91.00	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	69.24	93.69	106.67	67.99	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	69.58	94.16	107.33	68.94	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

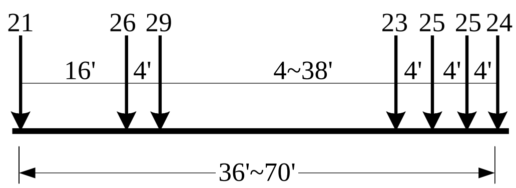
Summary of the girder responses to representative vehicles

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 3-span continuous girders). This is due to the fact that the variable spacings in these representative vehicles all have a small lower bound (e.g., 4ft) 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.

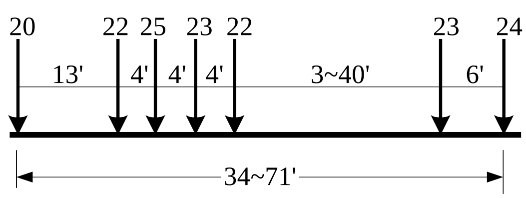
Meanwhile, it should be noted that heavy vehicles in other classes, the representative vehicles of which did not show larger maximum girder response, could possibly cause large moments than Wis-SPV. This is due to the fact that the representative were established to only represent top 5% heavy vehicles 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.



Class 10 - 6 axle
GVW=153 k



Class 10 - 7 axle
GVW=173 k

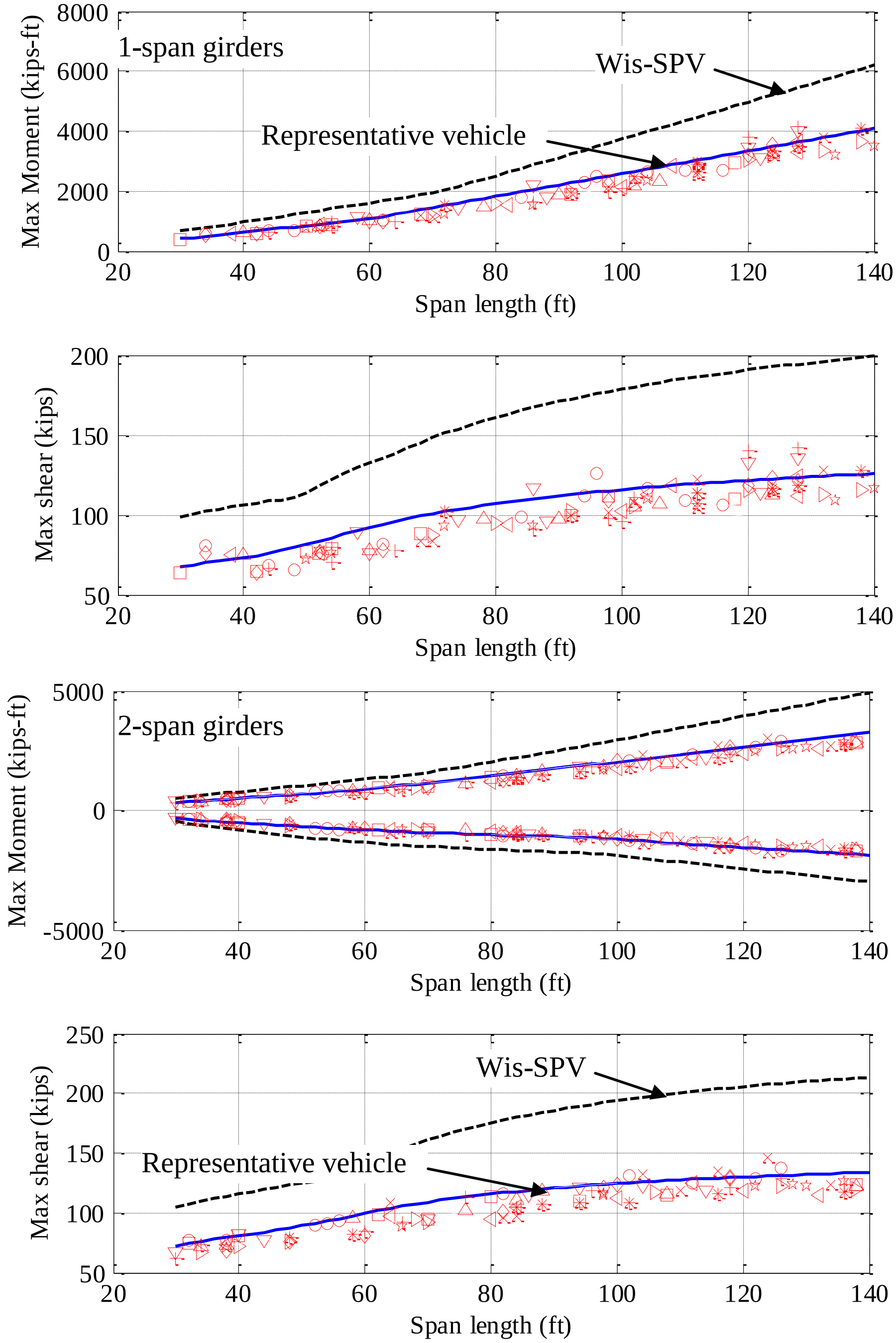


Class 13 - 7 axle a
GVW=159 k

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.



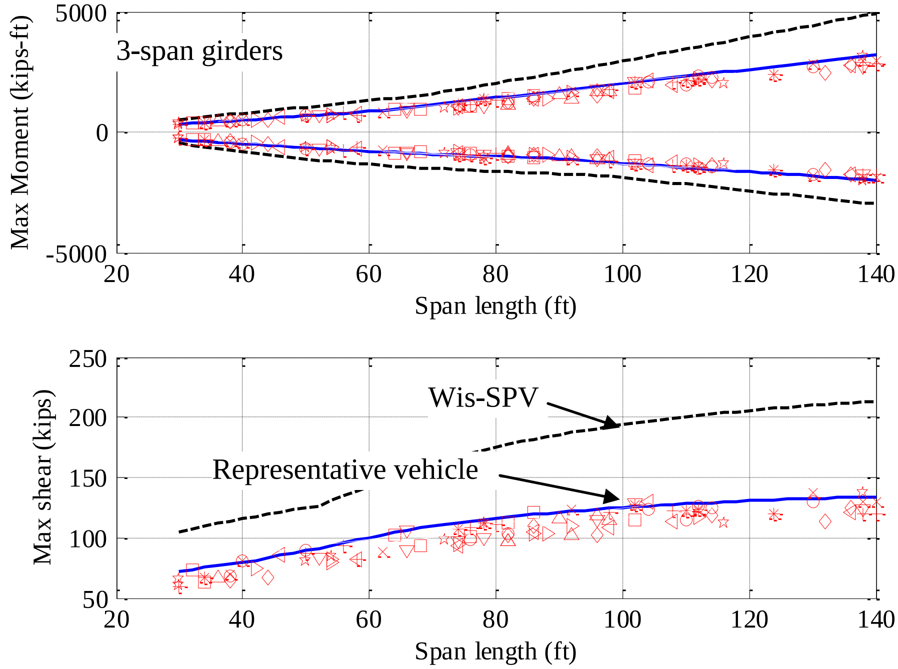


Fig. 4.29 Comparison of randomly selected vehicles with the representative vehicle (Type 3S2)

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 (μ) and the standard deviations (σ) 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 μ and the sample standard deviation of σ listed in table 4.6. However, normal distributions with the mean ratios of μ and the standard deviations of σ 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 3S2 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.

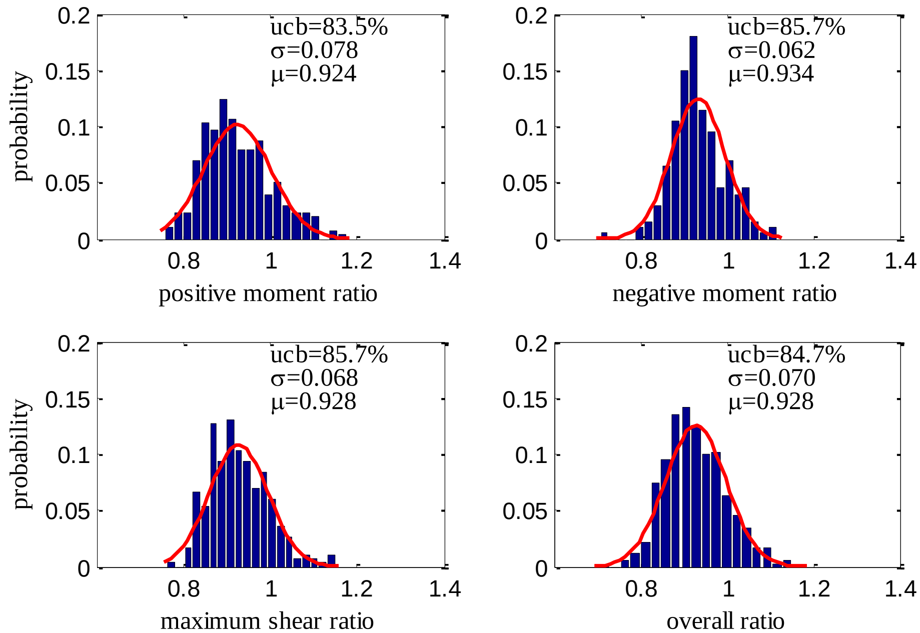


Fig. 4.30 Statistical evaluation of the representative vehicle for Class 9 (Type 3S2)

Table 4.6 summary of the statistical analysis of response ratios

Vehicles	Positive moments			Negative moments			Maximum shear		
	μ	σ	ucb	μ	σ	ucb	μ	σ	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 (Class/group)	μ	σ	ucb (%)	rep/spv (250 k)	poe (%)	# of vehicles	# of exceeds	rep/spv (190 k)	poe (%)	# of 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.

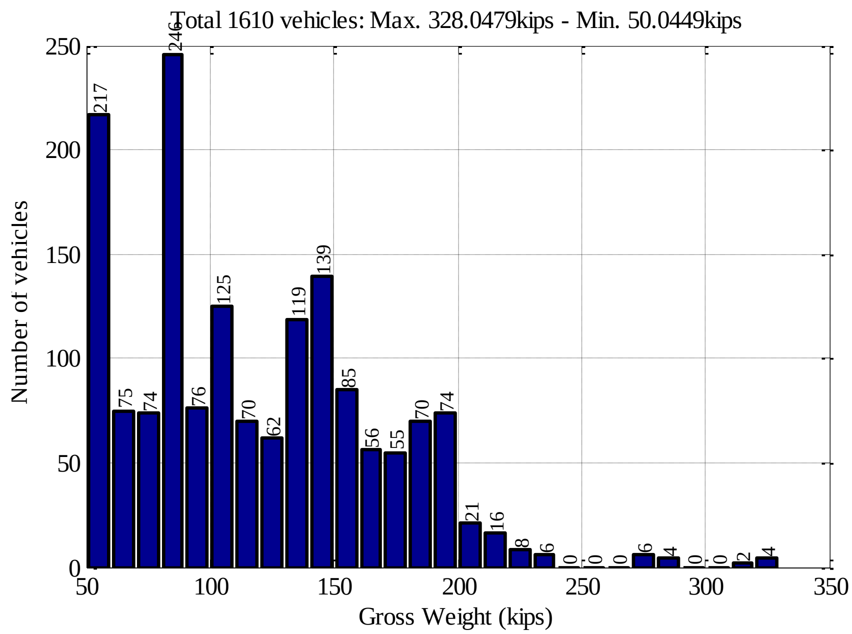


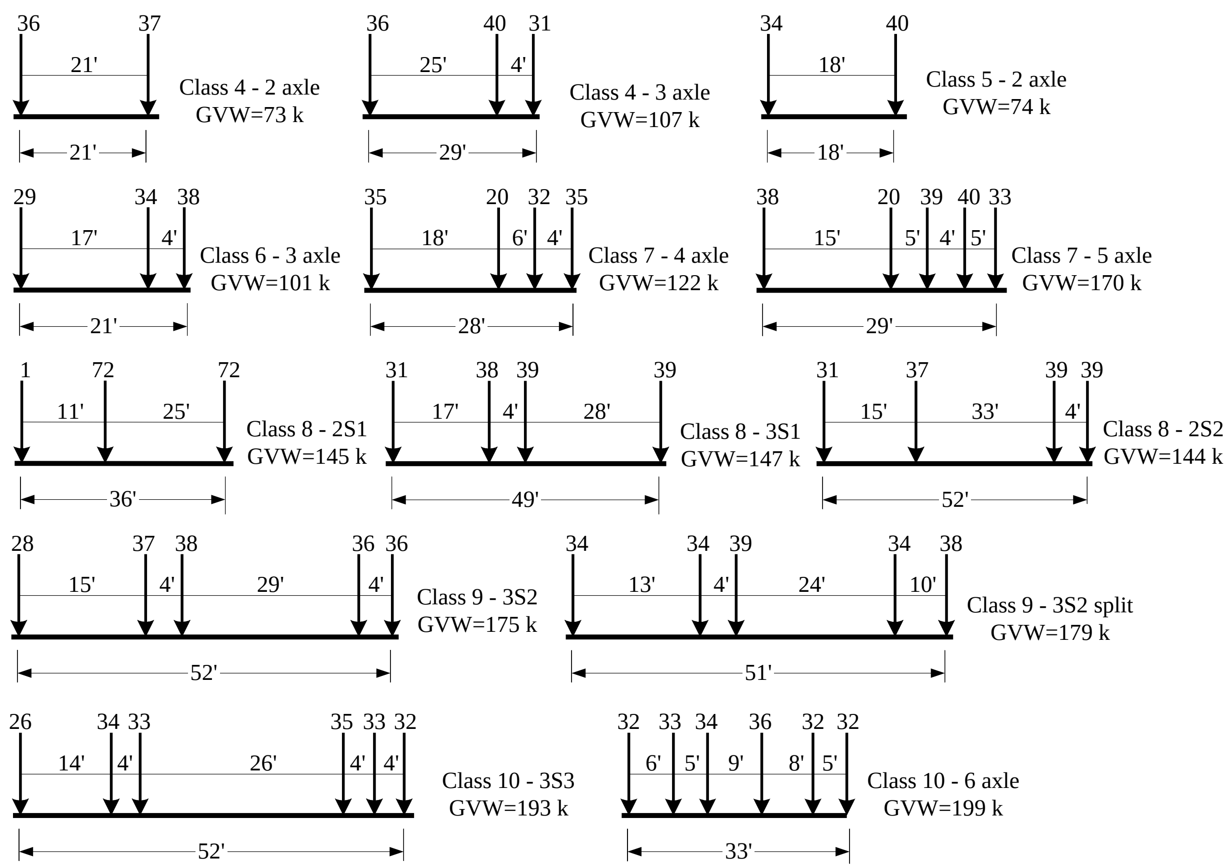
Fig. 4.31 gross weight distribution of the randomly selected vehicles

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.



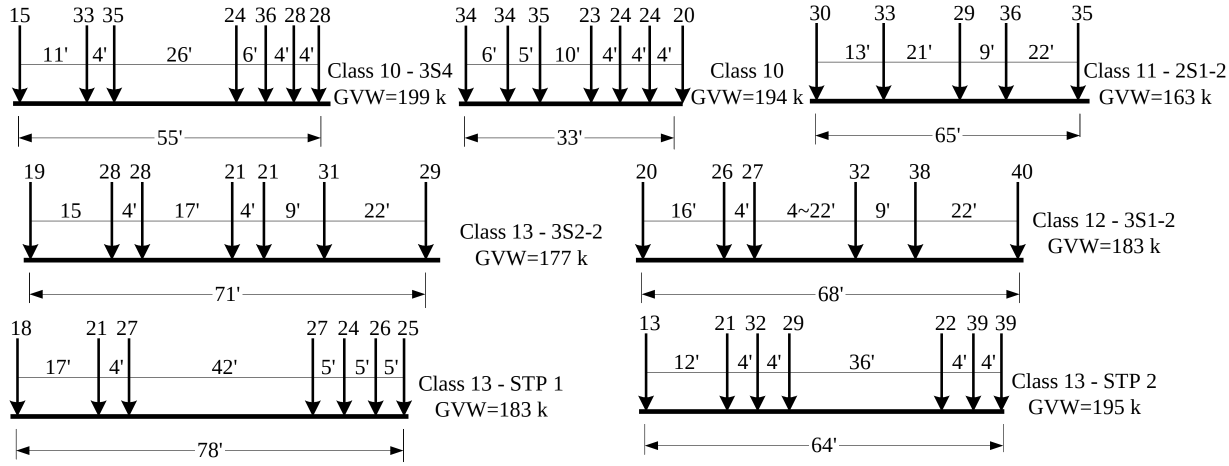
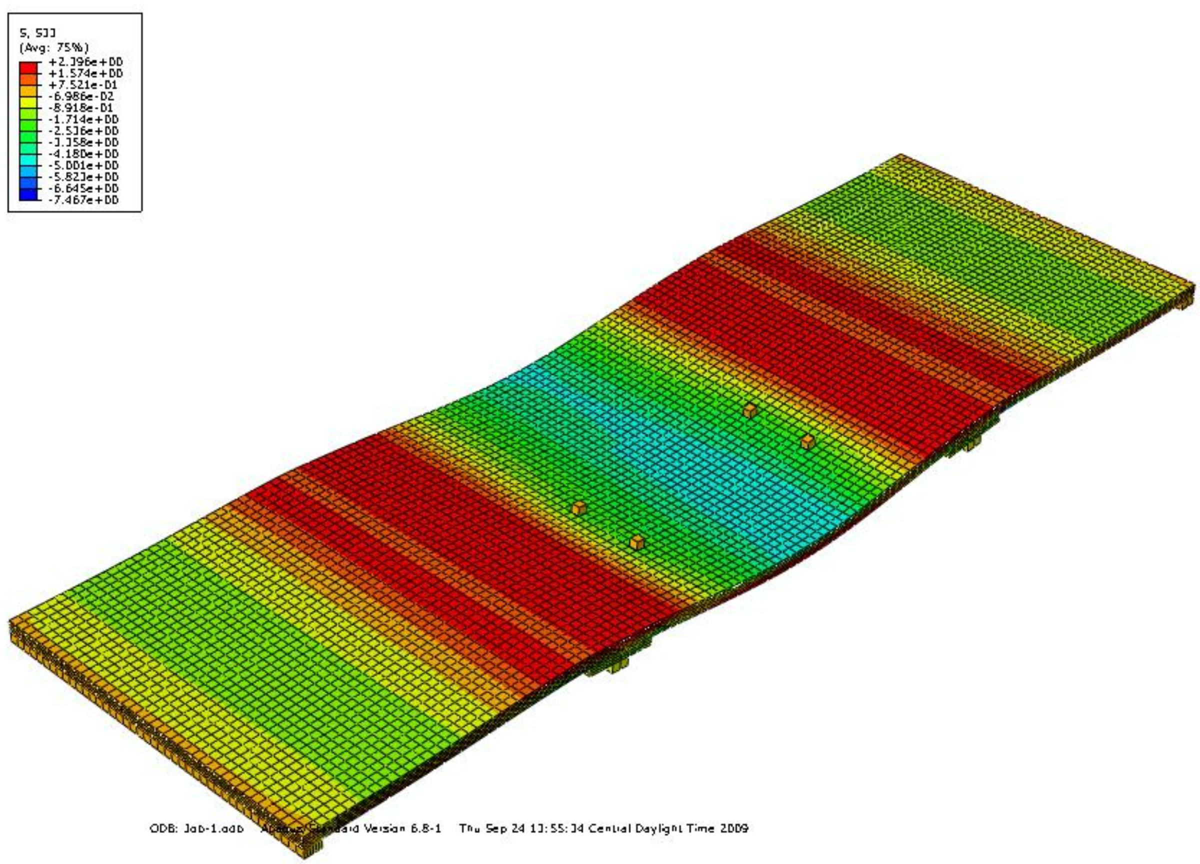


Fig. 4.31 gross weight distribution of the randomly selected vehicles

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® 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.



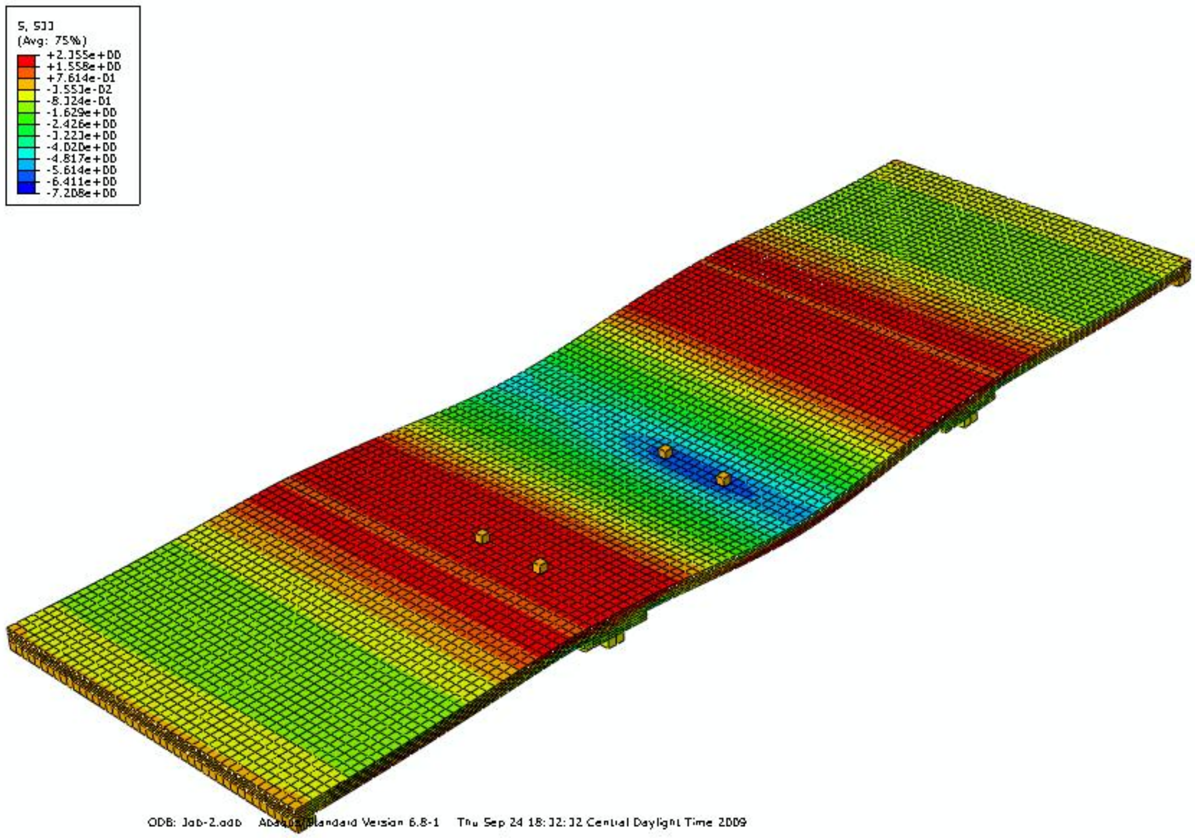


Fig. 4.32 gross weight distribution of the randomly selected vehicles

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

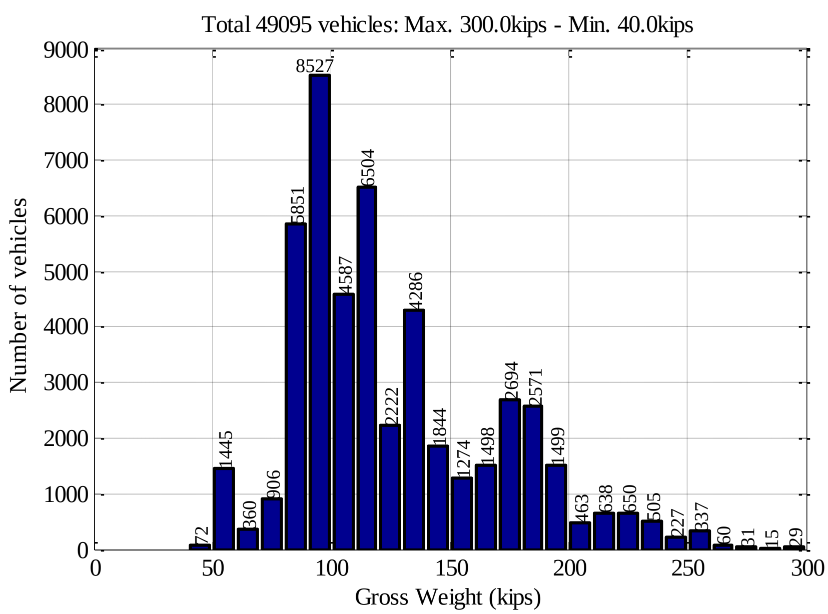
Introduction

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 90kips. 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.



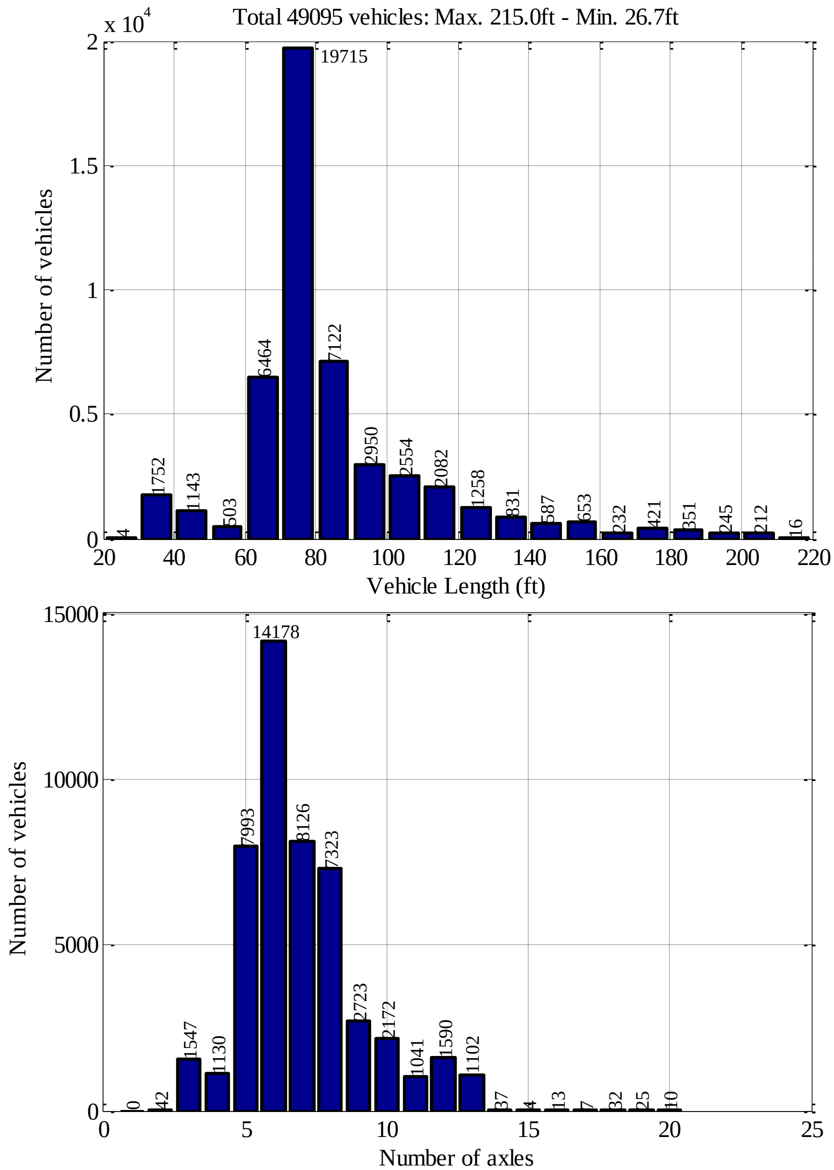


Fig. 5.1 Overview of vehicles with single-trip permits

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^{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 6ft). The values corresponding to 5^{th} percentile and 95^{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.

1547 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

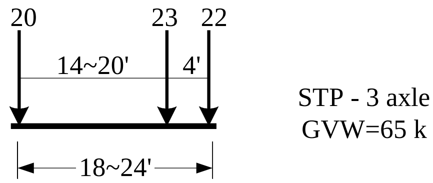


Fig. 5.2 Representative vehicle for 3-axle permit vehicles

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.

272 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} percentile	99^{th} percentile
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

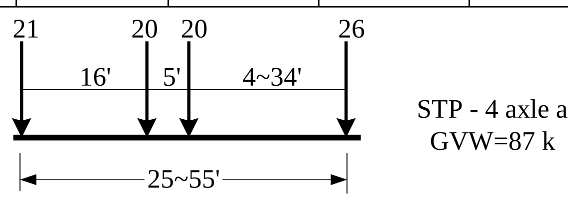


Fig. 5.3 Representative vehicle for 4-axle permit vehicles (Type 3S1)

Vehicles (b): A representative vehicle was created as shown in Fig. 5.4. These vehicles are likely FHWA Class 8, Type 2S2 trucks.

856 vehicles	Minimum	Maximum	Mean	Standard deviation	5^{th} percentile	95^{th} percentile	99^{th} percentile

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

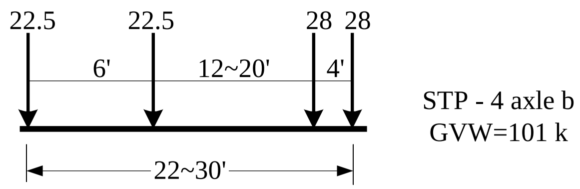


Fig. 5.4 Representative vehicle for 4-axle permit vehicles (Type 2S2)

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).

5901 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

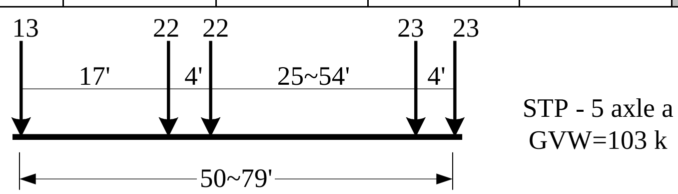


Fig. 5.5 Representative vehicle for 5-axle permit vehicles (Type 3S2)

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th 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

Axle weight 3	5500	33500	19237.76	2060.049	16000.00	22000.00	25000.00
Axle spacing 3	4	64	31.98	5.404	27.00	38.00	47.07
Axle weight 4	9000	35000	20457.98	2144.360	18000.00	24000.00	32500.00
Axle spacing 4	6	43	10.17	1.586	10.00	10.33	12.00
Axle weight 5	6500	35000	20410.57	2189.241	18000.00	24000.00	32500.00

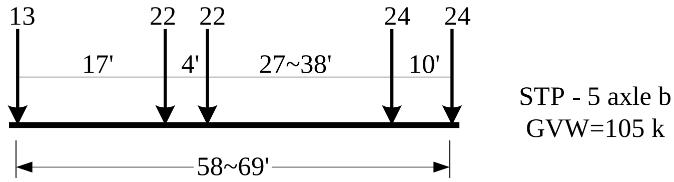


Fig. 5.6 Representative vehicle for 5-axle permit vehicles (Type 3S2 split)

Six-axle Vehicles

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

14178 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th 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	50000	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

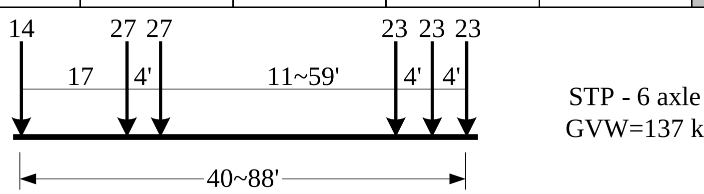


Fig. 5.7 Representative vehicle for 6-axle permit vehicles (Type 3S3)

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th 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

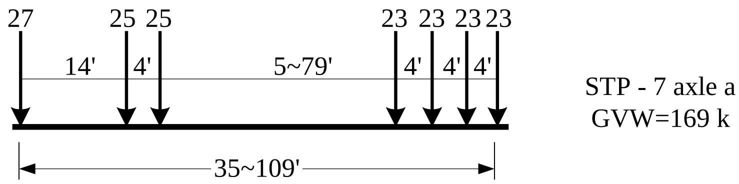


Fig. 5.8 Representative vehicle for 7-axle permit vehicles

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.

6965 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

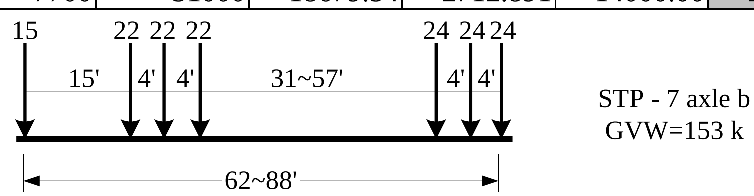


Fig. 5.9 Representative vehicle for 7-axle permit vehicles

Eight-axle vehicles

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

7323 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

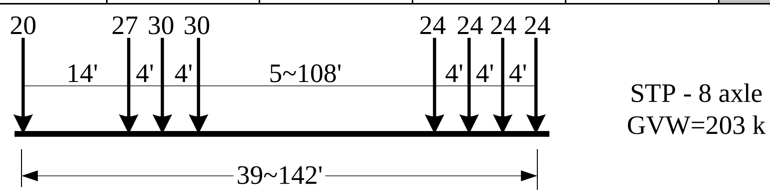


Fig. 5.10 Representative vehicle for 8-axle permit vehicles

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 14ft rather than 4 ft. The shorter spacing (4ft) was used to be conservative in the following analysis.

1105 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

Axle weight 9	6150	27000	19789.45	2521.420	15000.00	23000.00	24000.00

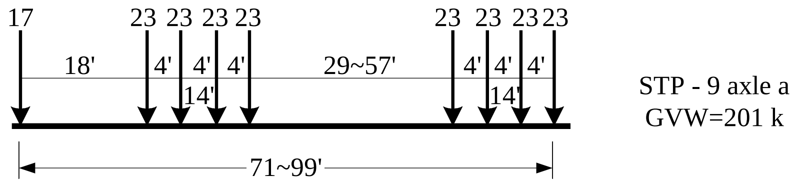


Fig. 5.11 Representative vehicle for 9-axle permit vehicles (Type a)

Vehicles (b): A representative vehicle was created as shown in Fig. 5.12.

1618 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

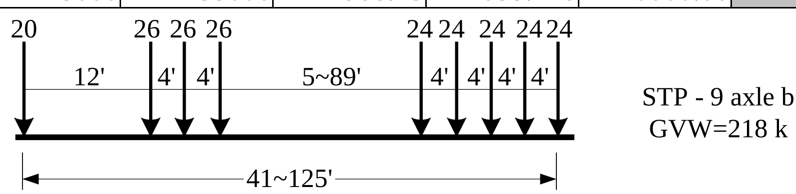


Fig. 5.12 Representative vehicle for 9-axle permit vehicles (Type b)

Ten-axle vehicles

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

692 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th 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

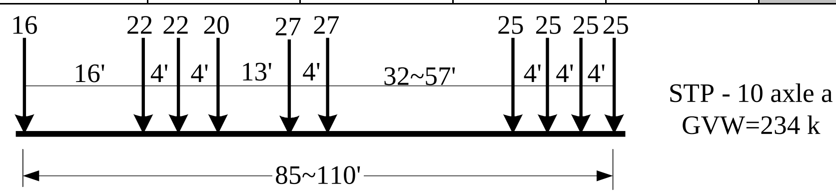


Fig. 5.13 Representative vehicle for 10-axle permit vehicles (Type a)

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.

1480 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

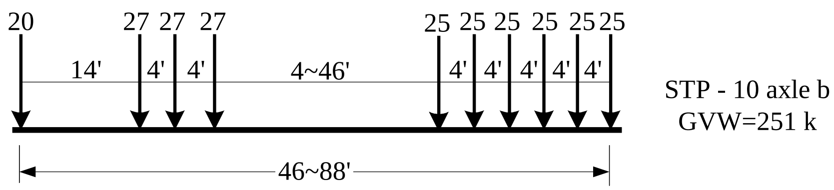


Fig. 5.14 Representative vehicle for 10-axle permit vehicles

Eleven-axle vehicles

A representative vehicle was created as shown in Fig. 5.15. Note that the third and seventh spacing can be either 4ft or 14ft, 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 4ft, hence spacing 6 was selected as the variable spacing.

1041 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

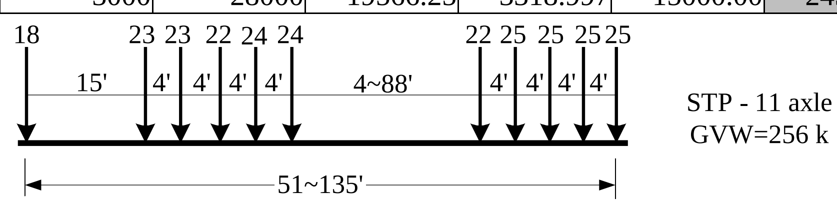


Fig. 5.15 Representative vehicle for 11-axle permit vehicles

Twelve-axle vehicles

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

1590 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

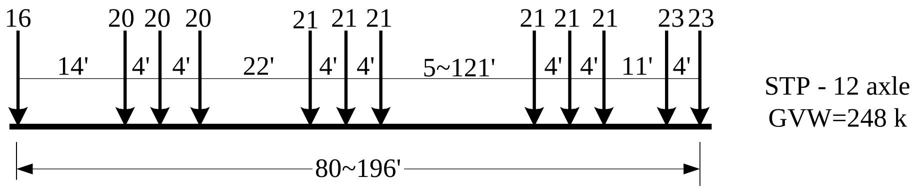


Fig. 5.16 Representative vehicle for 12-axle permit vehicles

Thirteen-axle vehicles

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

1102 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile	99th percentile
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

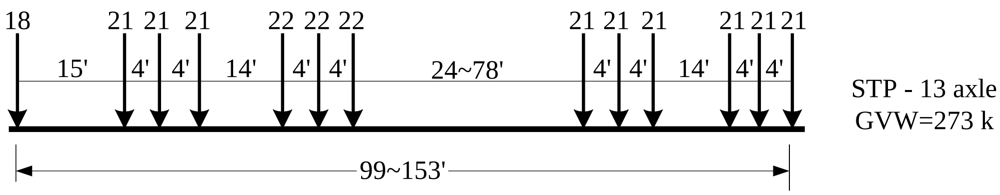


Fig. 5.17 Representative vehicle for 13-axle permit vehicles

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.

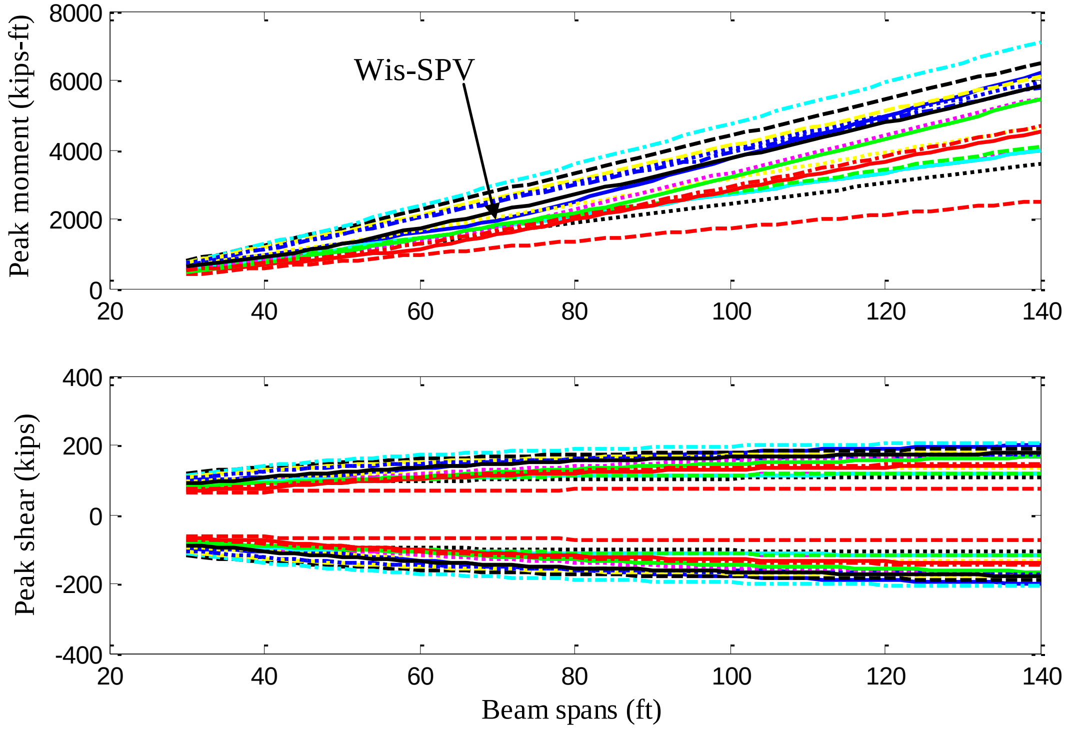


Fig. 5.18 Peak moment/shear values for representative permit vehicles on one-span girders

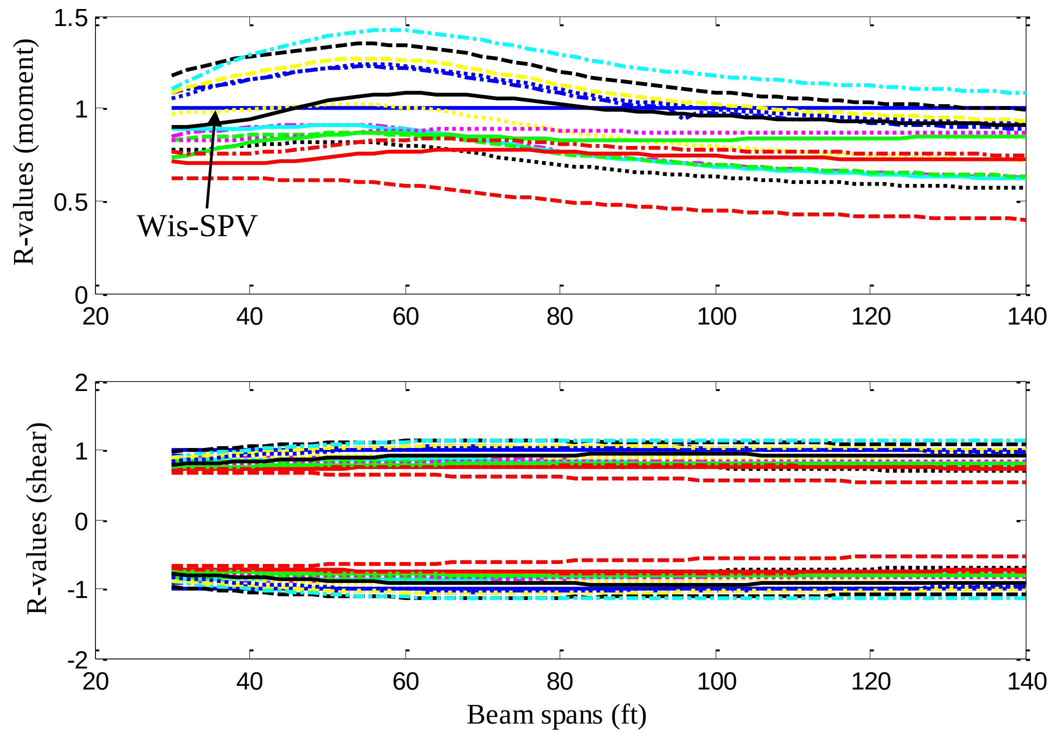


Fig. 5.19 R-values for representative permit vehicles on one-span girders

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

Span (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 3axle
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	843.3	514.4	642.5	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	1085.3	668.0	848.9	958.1	964.7	945.5	1107.0	1284.3	759.1	1450.1	902.3	1478.3	875.3	1365.0	1325.0	830.1	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	821.8	1075.8	1207.5	1208.7	1188.8	1383.7	1658.9	943.9	1845.0	1139.9	1913.8	1142.0	1729.1	1675.0	1018.3	1369.5
56	1473.7	898.7	1189.7	1332.4	1334.2	1320.4	1532.2	1846.8	1036.6	2056.9	1258.7	2149.7	1291.0	1927.8	1866.4	1140.0	1555.6
60	1603.2	975.6	1303.6	1457.6	1459.6	1451.9	1680.7	2034.7	1146.0	2268.8	1377.5	2385.6	1440.0	2126.5	2061.1	1280.8	1741.7
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	1589.0	2325.1	2255.8	1433.7	1928.5
68	1865.6	1129.4	1531.9	1708.0	1710.5	1715.2	1977.6	2410.6	1470.4	2692.7	1666.2	2857.5	1738.0	2523.8	2450.5	1586.9	2115.3
72	2042.4	1206.4	1646.2	1833.4	1836.0	1847.0	2126.2	2598.5	1638.6	2904.6	1857.6	3093.5	1887.0	2722.5	2645.2	1740.9	2302.1
76	2267.4	1283.4	1760.5	1958.9	1961.4	1978.8	2275.0	2786.4	1807.1	3116.5	2066.7	3329.5	2036.0	2921.2	2839.9	1896.2	2494.4
80	2509.5	1360.3	1874.8	2084.5	2086.9	2110.6	2423.7	2974.4	1975.6	3328.4	2276.2	3565.5	2185.0	3119.9	3034.6	2058.6	2699.4
84	2753.1	1437.3	1989.4	2210.0	2212.3	2242.5	2572.5	3162.3	2144.5	3540.3	2487.2	3801.5	2334.0	3318.6	3229.2	2232.1	2905.2
88	2996.7	1514.3	2104.0	2335.6	2337.8	2374.5	2721.2	3350.2	2313.8	3752.3	2700.0	4037.5	2524.5	3517.4	3423.9	2405.9	3111.1
92	3241.0	1591.2	2218.6	2461.1	2463.2	2506.5	2870.0	3538.1	2483.1	3964.2	2912.9	4273.5	2748.1	3716.3	3618.6	2580.4	3318.0
96	3486.1	1668.2	2333.1	2586.7	2588.7	2638.5	3018.8	3632.1	2652.4	4176.1	3126.2	4509.5	2971.8	3915.2	3813.5	2754.8	3525.2
100	3731.3	1745.2	2447.7	2712.3	2714.1	2770.5	3167.5	3914.0	2821.7	4388.0	3339.8	4745.5	3195.4	4114.1	4008.4	2929.3	3732.8
104	3976.4	1822.1	2562.3	2838.1	2839.6	2902.5	3316.3	4101.9	2991.5	4600.0	3553.5	4981.5	3419.0	4313.1	4203.4	3104.0	3940.5
108	4222.8	1899.1	2676.9	2963.9	2965.0	3034.5	3465.0	4289.8	3161.4	4812.0	3767.1	5217.5	3642.7	4512.0	4398.3	3279.2	4148.1
112	4469.2	1976.1	2791.6	3089.7	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	4715.6	2053.1	2906.4	3215.5	3215.9	3298.5	3762.6	4665.7	3501.2	5236.0	4194.3	5689.5	4090.0	4909.8	4788.1	3629.7	4563.5
120	4962.0	2130.0	3021.2	3341.3	3341.4	3430.5	3911.5	4853.6	3671.1	5448.0	4408.0	5925.5	4313.7	5108.7	4983.1	3804.9	4771.1
124	5208.7	2207.0	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	2284.0	3250.8	3592.9	3592.3	3694.5	4209.3	5229.5	4010.9	5872.0	4836.4	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	6198.8	2514.9	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 (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 3axle
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	65.7	87.6	97.9	96.3	90.4	106.1	124.4	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	110.8	67.5	92.1	102.6	101.2	95.8	113.2	135.0	88.7	145.7	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	95.4	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	69.4	96.7	107.3	106.0	103.0	120.4	145.6	102.7	159.0	117.2	170.6	107.4	150.6	147.0	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	70.3	98.9	109.5	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	71.0	100.6	111.2	110.1	109.1	126.4	154.5	117.1	170.1	134.1	184.3	127.4	160.8	157.1	122.7	151.0
80	160.9	71.3	101.3	112.0	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	71.6	101.9	112.6	111.6	111.3	128.6	157.7	122.2	174.1	141.8	189.2	134.7	164.5	160.7	127.9	156.4
88	169.0	71.8	102.5	113.2	112.2	112.2	129.5	159.1	124.4	175.8	145.1	191.4	137.9	166.0	162.3	130.1	158.7
92	172.5	72.1	103.1	113.8	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	104.0	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	72.6	104.5	115.2	114.3	115.3	132.5	163.5	131.6	181.4	155.9	198.2	148.0	171.1	167.3	137.3	166.3
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	116.0	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	73.1	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	73.3	106.2	116.9	116.1	118.0	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.

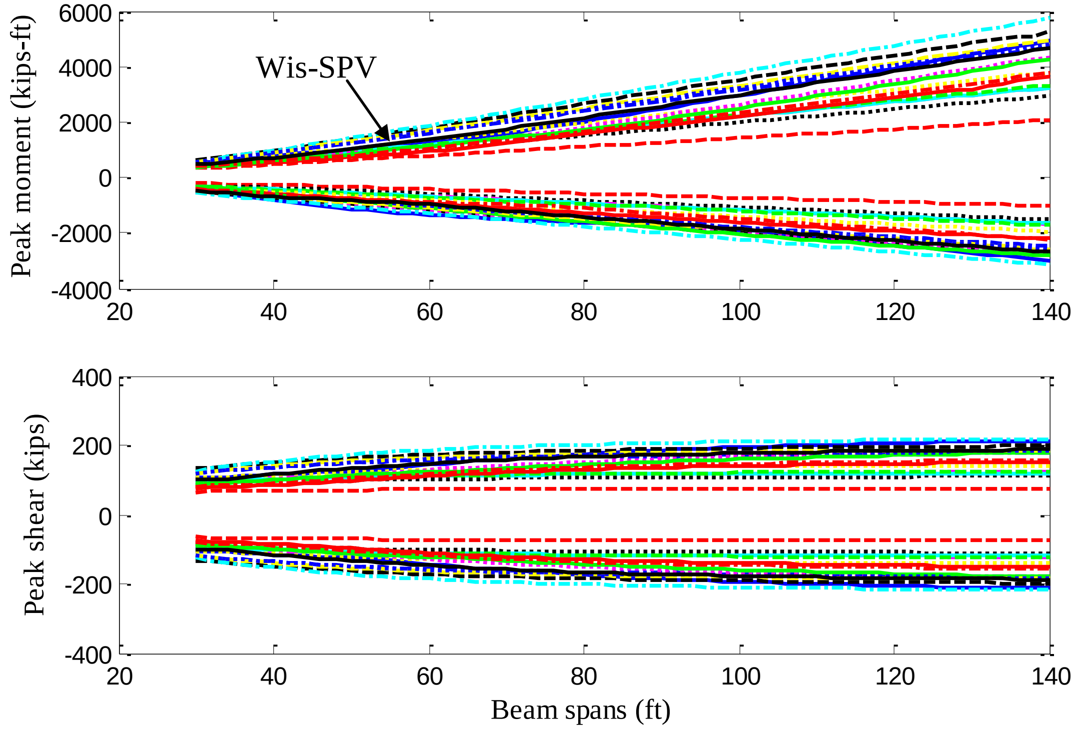


Fig. 5.20 Peak moment/shear values for representative permit vehicles on two-span girders

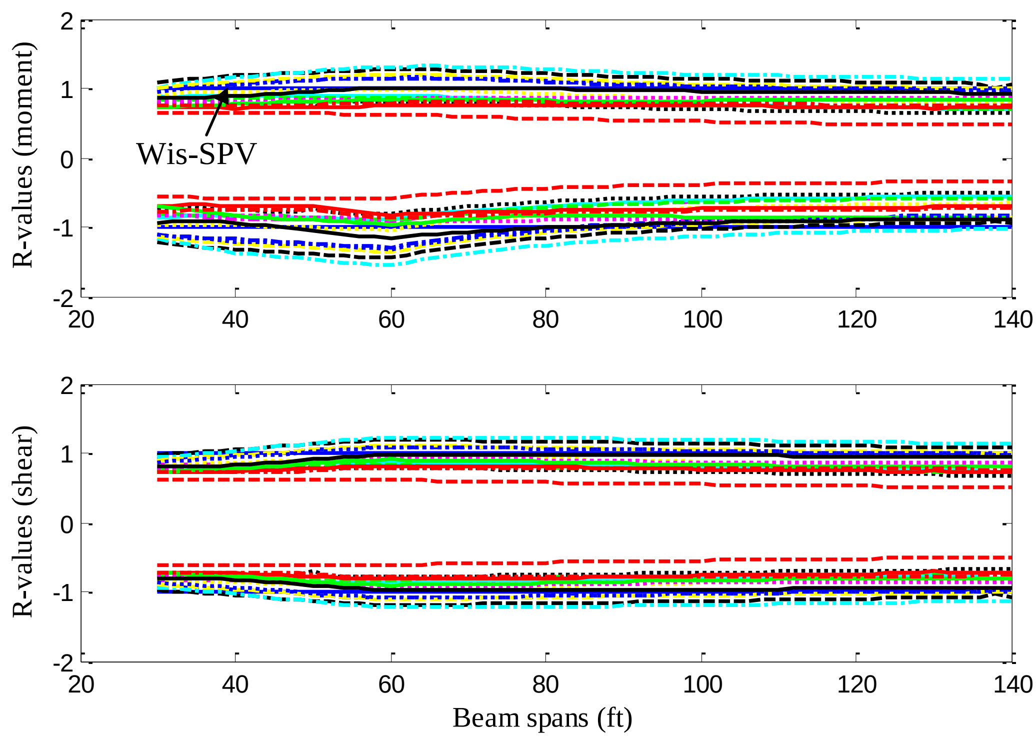


Fig. 5.21 R-values for representative permit vehicles on two-span girders

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

Span (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 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	603.5	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	774.3	475.1	603.1	666.9	690.3	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	878.2	537.6	691.3	766.4	781.4	750.6	880.4	1016.9	616.5	1133.7	729.1	1153.2	690.3	1066.9	1034.2	668.2	827.4
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	1176.2	743.8	951.3
52	1088.0	663.4	871.3	967.8	977.8	954.3	1114.9	1314.1	765.4	1462.4	917.6	1504.3	894.8	1373.6	1329.6	831.1	1087.0
56	1193.6	726.5	962.6	1069.2	1077.4	1059.4	1233.8	1464.4	840.5	1631.4	1013.0	1689.6	1010.8	1532.2	1484.5	932.4	1231.8
60	1299.5	789.7	1054.4	1171.1	1177.6	1165.1	1353.3	1615.6	935.0	1801.4	1109.0	1876.6	1128.9	1691.8	1640.4	1046.6	1378.2
64	1405.7	853.0	1146.7	1273.3	1278.3	1271.3	1473.4	1767.3	1051.9	1972.2	1209.2	2064.8	1247.7	1852.2	1797.1	1163.1	1525.9
68	1528.5	916.3	1239.3	1375.7	1379.4	1378.0	1594.0	1919.7	1175.3	2143.6	1345.2	2254.0	1367.1	2013.0	1954.5	1281.4	1674.8
72	1678.4	979.7	1332.3	1478.3	1480.9	1485.0	1715.0	2072.5	1301.0	2315.7	1497.7	2444.0	1487.0	2174.6	2112.5	1401.2	1832.1
76	1844.9	1043.2	1425.5	1581.1	1582.6	1592.3	1836.3	2225.7	1428.5	2488.1	1655.5	2634.6	1607.4	2336.4	2270.8	1522.3	1993.2
80	2022.6	1106.7	1518.8	1684.0	1684.5	1699.8	1957.8	2379.1	1557.4	2660.9	1815.7	2826.7	1728.0	2498.6	2429.5	1650.2	2155.6
84	2203.4	1170.3	1612.4	1787.3	1786.9	1807.6	2079.5	2532.8	1687.7	2834.1	1977.8	3019.2	1862.4	2661.1	2588.6	1782.9	2319.0
88	2386.8	1233.8	1706.0	1890.7	1889.9	1915.5	2201.5	2686.8	1821.4	3007.5	2141.5	3212.1	2011.4	2823.9	2747.9	1916.9	2483.3
92	2572.4	1297.4	1800.2	1994.4	1993.0	2023.6	2323.5	2840.9	1956.0	3181.1	2306.6	3405.2	2174.4	2986.9	2907.5	2052.1	2648.3
96	2760.0	1361.0	1894.3	2098.0	2096.1	2131.7	2445.7	2995.2	2091.2	3354.8	2473.0	3598.6	2339.6	3150.0	3067.1	2190.7	2814.0
100	2951.9	1424.7	1988.7	2201.6	2199.4	2240.0	2568.0	3149.6	2227.0	3528.7	2640.4	3792.1	2506.6	3313.1	3226.9	2330.0	2980.1
104	3146.4	1488.3	2083.1	2305.5	2302.8	2348.4	2690.5	3304.3	2363.2	3703.0	2808.6	3985.9	2675.0	3476.7	3387.0	2470.1	3147.0
108	3341.7	1552.0	2177.6	2409.4	2406.2	2457.0	2813.1	3459.0	2500.0	3877.3	2977.8	4179.8	2844.8	3640.3	3547.3	2610.6	3314.1
112	3537.9	1615.7	2272.2	2513.3	2509.7	2565.5	2935.7	3613.8	2637.0	4051.7	3147.6	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	2893.0	3649.6
120	3932.7	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	4575.4	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	4349.8	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	3241.6	3234.9	3326.9	3795.6	4699.1	3604.9	5274.8	4349.9	5734.9	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 (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 3axle
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	-518.7
36	-688.0	-251.8	-354.2	-425.9	-396.3	-390.6	-457.0	-572.6	-512.4	-643.3	-613.7	-712.8	-483.0	-603.2	-555.2	-528.1	-606.3
40	-831.6	-270.9	-381.9	-475.5	-435.9	-444.0	-513.2	-652.1	-592.2	-732.5	-708.1	-813.1	-608.6	-687.2	-629.1	-608.8	-682.2
44	-960.5	-298.5	-413.8	-524.7	-483.1	-499.8	-575.1	-730.2	-663.5	-820.6	-799.6	-911.7	-720.8	-769.9	-712.6	-679.1	-748.1
48	-1074.3	-330.2	-451.6	-569.8	-534.8	-554.8	-636.5	-807.6	-733.5	-907.7	-890.4	-1009.2	-820.9	-851.8	-795.2	-740.7	-805.9
52	-1175.1	-361.7	-496.9	-609.2	-586.1	-609.3	-697.2	-884.3	-803.1	-994.3	-979.6	-1105.9	-917.7	-933.0	-876.9	-794.9	-856.9
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	-1344.9	-423.9	-594.5	-674.4	-687.6	-717.1	-817.6	-1036.1	-940.9	-1165.4	-1155.9	-1296.9	-1114.3	-1093.7	-1038.3	-886.0	-975.1
64	-1417.0	-454.8	-642.7	-723.8	-738.0	-770.4	-877.3	-1111.4	-1009.4	-1250.5	-1243.3	-1391.5	-1210.6	-1173.7	-1118.1	-925.6	-1067.5
68	-1482.2	-485.5	-690.4	-775.3	-788.0	-823.5	-936.8	-1186.3	-1077.6	-1335.1	-1330.3	-1485.8	-1305.6	-1253.2	-1197.5	-961.8	-1158.4
72	-1540.8	-516.0	-737.7	-826.3	-838.0	-875.7	-996.1	-1260.9	-1145.3	-1419.2	-1416.6	-1579.7	-1399.8	-1332.1	-1276.3	-995.8	-1248.5
76	-1594.4	-546.5	-784.8	-877.2	-887.9	-923.7	-1055.2	-1335.3	-1213.0	-1503.2	-1502.7	-1673.3	-1493.3	-1410.9	-1354.9	-1027.3	-1337.6
80	-1643.3	-576.9	-831.5	-927.8	-937.6	-967.9	-1114.1	-1409.6	-1280.5	-1587.0	-1588.6	-1766.7	-1586.1	-1489.5	-1433.2	-1103.8	-1426.0
84	-1688.3	-607.3	-878.2	-978.2	-987.1	-1008.8	-1172.9	-1483.6	-1347.9	-1670.6	-1674.2	-1859.7	-1678.4	-1568.1	-1511.2	-1183.0	-1513.7
88	-1729.5	-637.6	-924.6	-1028.4	-1036.5	-1047.2	-1231.5	-1557.4	-1415.1	-1753.9	-1759.5	-1952.6	-1770.2	-1646.3	-1588.9	-1261.4	-1600.7
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	-1666.4	-1339.1	-1687.3
96	-1803.4	-698.0	-1016.9	-1128.6	-1132.2	-1154.4	-1348.8	-1705.1	-1549.2	-1920.4	-1929.6	-2138.0	-1952.7	-1801.4	-1744.0	-1416.1	-1773.3
100	-1882.8	-728.1	-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	-1492.6	-1859.0
104	-1996.6	-758.1	-1108.9	-1228.3	-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	-788.2	-1154.5	-1277.8	-1262.2	-1313.4	-1523.6	-1925.5	-1749.9	-2169.1	-2181.2	-2414.9	-2222.2	-2004.7	-1974.9	-1643.2	-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	-2113.4
116	-2333.9	-848.3	-1245.7	-1376.9	-1361.4	-1418.9	-1638.7	-2072.0	-1880.7	-2334.4	-2331.7	-2599.0	-2388.5	-2136.4	-2128.2	-1792.3	-2197.6
120	-2444.4	-878.3	-1291.1	-1426.2	-1410.8	-1471.3	-1693.1	-2145.1	-1941.4	-2416.9	-2400.8	-2690.9	-2465.4	-2215.6	-2204.7	-1866.1	-2281.6
124	-2554.1	-908.3	-1336.4	-1475.6	-1460.2	-1523.8	-1744.5	-2217.9	-1998.9	-2499.5	-2466.5	-2782.7	-2538.6	-2294.7	-2281.2	-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	-2448.9
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	-2532.1
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 (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 3axle
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	111.8	67.9	90.2	101.7	99.4	96.1	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	69.9	95.8	107.2	105.3	100.5	118.7	141.9	88.4	155.5	104.8	161.8	105.1	145.8	141.9	95.0	123.9
48	123.0	70.6	97.8	109.2	107.4	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	71.2	99.5	110.8	109.1	106.5	124.5	150.8	100.9	164.9	115.1	176.1	115.9	156.1	152.1	107.2	136.3
56	135.3	71.7	100.9	112.1	110.6	108.8	126.6	154.1	105.7	169.1	122.5	181.6	119.9	159.9	156.0	111.8	142.3
60	142.9	72.1	102.0	113.3	111.8	110.8	128.5	157.0	111.3	172.7	128.9	186.1	123.2	163.2	159.2	117.3	147.9
64	149.9	72.5	103.0	114.3	112.9	112.4	130.1	159.4	116.1	175.8	134.4	190.1	126.0	166.0	162.0	122.1	152.7
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	164.0	73.1	104.7	115.8	114.6	115.1	132.7	163.3	123.8	180.8	143.2	196.4	135.1	170.5	166.6	129.8	160.5
76	169.8	73.3	105.3	116.5	115.3	116.2	133.7	164.9	127.0	182.8	146.9	199.0	139.8	172.4	168.4	133.0	163.6
80	175.0	73.5	105.9	117.0	115.9	117.2	134.6	166.3	129.8	184.6	150.8	201.4	144.0	174.0	170.1	135.8	166.5
84	179.6	73.7	106.4	117.5	116.4	118.0	135.5	167.6	132.4	186.2	154.8	203.4	147.7	175.5	171.5	138.3	169.0
88	183.7	73.9	106.9	118.0	116.9	118.8	136.2	168.7	134.6	187.6	158.3	205.2	151.0	176.8	172.8	140.6	171.2
92	187.4	74.1	107.3	118.4	117.4	119.5	136.9	169.7	136.6	188.9	161.4	206.9	154.0	178.0	174.0	142.6	173.2
96	190.8	74.2	107.7	118.8	117.8	120.1	137.5	170.7	138.5	190.1	164.3	208.4	156.7	179.0	175.1	144.4	175.0
100	193.8	74.3	108.1	119.1	118.1	120.7	138.0	171.5	140.1	191.2	166.9	209.7	159.2	180.0	176.0	146.1	176.7
104	196.6	74.4	108.4	119.4	118.5	121.2	138.5	172.3	141.6	192.1	169.3	210.9	161.4	180.9	176.9	147.6	178.2
108	199.1	74.6	108.7	119.7	118.8	121.7	139.0	172.9	143.0	193.0	171.4	212.1	163.4	181.7	177.7	149.0	179.6
112	201.4	74.7	108.9	120.0	119.1	122.1	139.4	173.6	144.3	193.8	173.4	213.1	165.7	182.4	178.5	150.2	180.8
116	203.6	74.7	109.2	120.2	119.3	122.5	139.8	174.2	145.4	194.6	175.2	214.1	168.3	183.1	179.1	151.4	182.0
120	205.6	74.8	109.4	120.4	119.6	122.9	140.2	174.7	146.5	195.3	176.9	214.9	170.6	183.7	179.8	152.5	183.1
124	207.4	74.9	109.6	120.6	119.8	123.3	140.5	175.2	147.5	195.9	178.5	215.7	172.9	184.3	180.4	153.4	184.1
128	209.1	75.0	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	110.0	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.

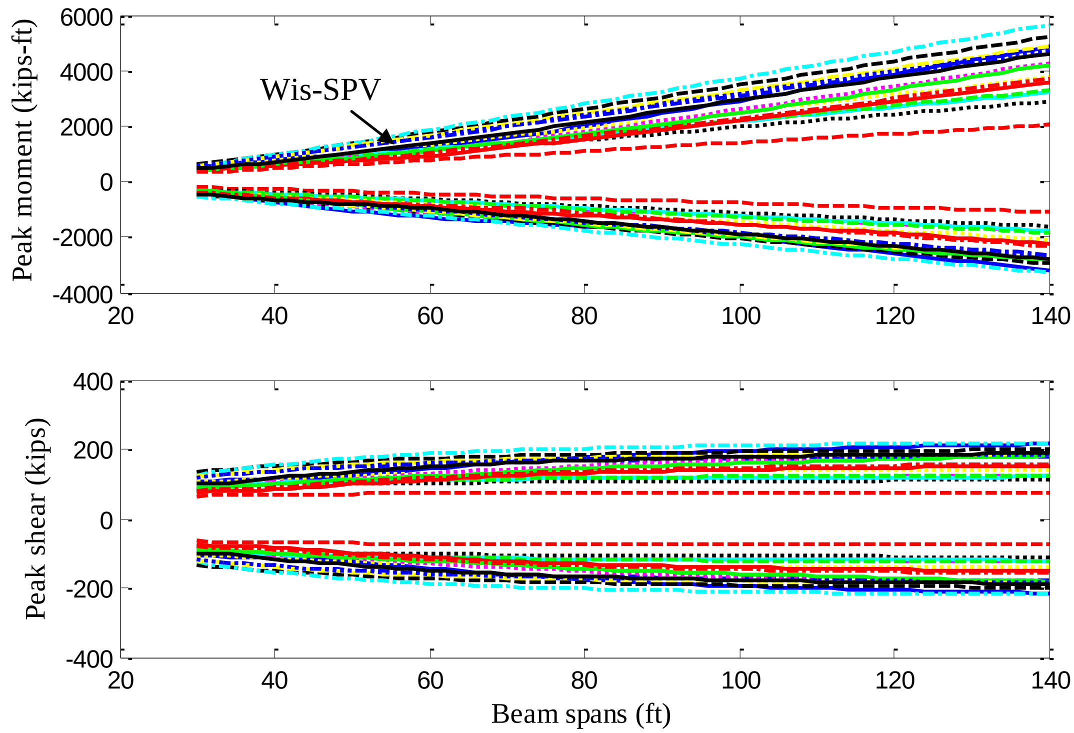


Fig. 5.22 Peak moment/shear values for representative permit vehicles on three-span girders

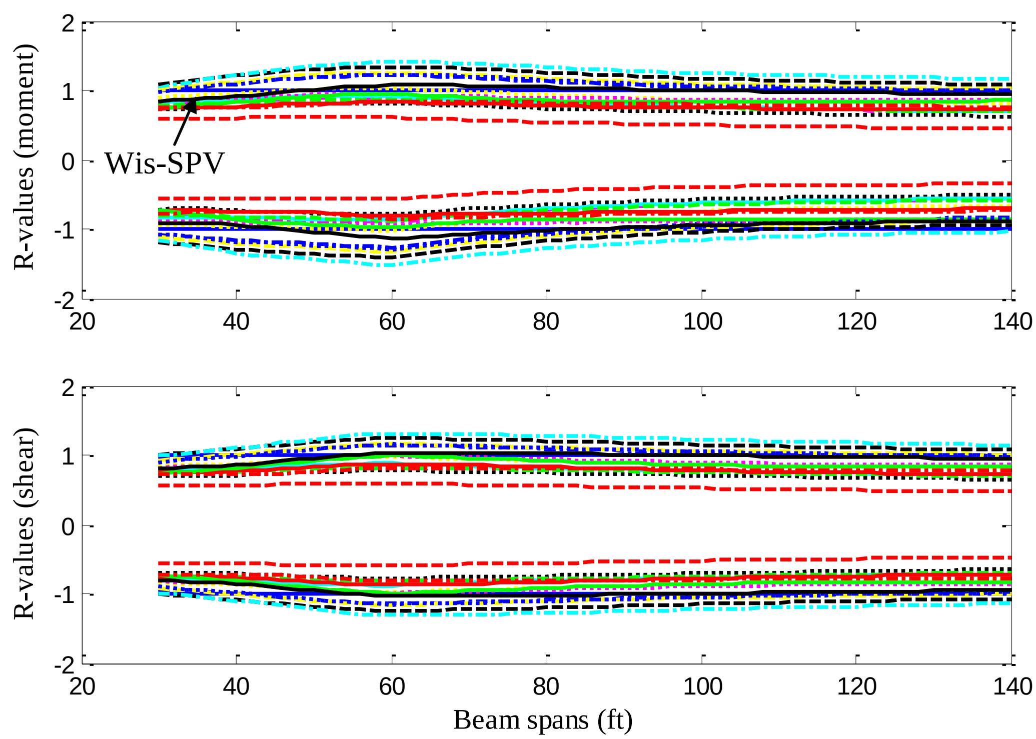


Fig. 5.23 R-values for representative permit vehicles on three-span girders

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

Span (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 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	657.8	742.8	505.4	816.6	588.3	798.8	513.6	764.7	739.0	509.6	606.6
40	763.4	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	865.7	529.8	681.3	754.5	770.5	738.8	867.4	1000.3	641.9	1115.3	758.5	1133.4	712.9	1049.1	1016.8	658.4	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	1157.7	733.1	936.9
52	1072.3	653.9	858.6	953.1	964.0	939.9	1098.2	1292.5	773.7	1439.2	914.8	1479.2	913.0	1352.2	1308.8	819.8	1068.8
56	1176.4	716.2	948.6	1053.3	1062.2	1043.4	1215.3	1440.6	832.1	1605.7	998.5	1661.6	1015.8	1508.4	1461.4	919.6	1211.0
60	1280.8	778.6	1039.2	1153.9	1161.1	1147.6	1333.1	1589.9	921.5	1773.2	1093.2	1845.7	1115.4	1665.7	1615.0	1031.5	1354.9
64	1385.6	841.1	1130.3	1254.8	1260.5	1252.3	1451.6	1739.8	1036.2	1941.7	1192.1	2031.1	1227.0	1823.8	1769.5	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	1262.0	1647.0
72	1655.1	966.3	1313.5	1457.3	1460.5	1463.1	1689.9	2041.3	1280.4	2280.5	1473.9	2404.9	1462.9	2141.8	2080.5	1379.9	1803.2
76	1818.0	1029.0	1405.5	1558.9	1560.9	1569.0	1809.5	2192.6	1405.7	2450.6	1628.5	2592.9	1581.5	2301.5	2236.7	1499.1	1961.7
80	1991.9	1091.7	1497.8	1660.6	1661.6	1675.1	1929.4	2344.2	1532.5	2621.2	1785.6	2781.6	1700.6	2461.6	2393.4	1624.9	2121.6
84	2169.0	1154.5	1590.2	1762.4	1762.5	1781.4	2049.6	2496.1	1660.6	2792.1	1944.8	2971.4	1834.6	2622.1	2550.3	1755.3	2282.6
88	2349.0	1217.3	1682.7	1864.4	1863.9	1888.0	2170.0	2648.2	1791.0	2963.3	2105.7	3161.6	1981.6	2782.7	2707.6	1887.1	2444.5
92	2531.3	1280.1	1775.5	1966.4	1965.8	1994.7	2290.6	2800.4	1923.6	3134.7	2268.0	3352.1	2141.6	2943.6	2865.1	2020.2	2607.2
96	2715.6	1343.0	1868.3	2068.5	2067.7	2101.5	2411.2	2952.8	2056.8	3306.3	2431.7	3542.8	2303.7	3104.7	3022.8	2155.1	2770.7
100	2901.8	1405.9	1961.2	2170.6	2169.7	2208.4	2532.0	3105.2	2190.8	3477.9	2596.6	3733.7	2467.8	3265.8	3180.6	2292.3	2934.5
104	3093.2	1468.8	2054.2	2272.9	2271.8	2315.4	2652.9	3258.1	2325.1	3650.1	2762.2	3925.1	2633.4	3427.4	3338.7	2430.5	3099.2
108	3285.5	1531.7	2147.3	2375.5	2373.9	2422.6	2774.0	3410.9	2460.1	3822.2	2928.8	4116.6	2800.4	3589.0	3497.0	2569.0	3264.1
112	3478.8	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	3673.0	1657.6	2333.6	2580.8	2578.4	2637.2	3016.3	3716.8	2730.9	4166.8	3264.2	4500.2	3138.1	3912.4	3813.7	2847.6	3595.4
120	3868.0	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	3761.4
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	3487.0	4236.3	4130.9	3127.7	3927.7
128	4259.8	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	4456.5	1909.4	2708.0	2991.9	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	3691.5	4595.4

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

Span (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_1 0axle_	STP_1 0axle_	STP_1 1axle	STP_1 2axle	STP_1 3axle
32	-504.5	-230.5	-329.0	-360.3	-364.6	-350.0	-414.3	-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	-775.6	-284.0	-394.1	-455.6	-455.1	-456.7	-531.7	-634.9	-560.1	-701.7	-667.5	-784.4	-574.7	-659.0	-646.3	-581.6	-665.1
44	-900.1	-318.2	-423.1	-502.9	-495.4	-504.7	-584.4	-703.4	-631.4	-786.7	-756.9	-879.4	-688.0	-739.3	-725.9	-650.9	-732.0
48	-1014.7	-352.1	-476.9	-548.8	-533.4	-549.8	-634.1	-777.7	-698.9	-867.4	-848.0	-973.5	-790.7	-815.6	-801.5	-712.6	-791.4
52	-1117.2	-385.6	-529.8	-604.5	-585.1	-592.8	-681.6	-851.4	-766.0	-944.8	-934.3	-1066.8	-888.0	-891.0	-876.9	-767.5	-844.4
56	-1209.1	-418.9	-582.3	-660.8	-641.6	-646.4	-748.8	-924.7	-832.7	-1034.7	-1019.8	-1159.4	-990.9	-968.8	-958.8	-816.5	-892.0
60	-1291.7	-452.0	-634.0	-716.5	-697.4	-706.9	-816.0	-1010.0	-898.9	-1132.5	-1104.8	-1251.5	-1087.8	-1060.5	-1040.0	-860.5	-972.6
64	-1366.4	-484.9	-685.3	-771.9	-753.0	-766.9	-882.5	-1095.3	-964.8	-1229.0	-1189.2	-1342.9	-1183.6	-1151.2	-1120.6	-900.7	-1066.6
68	-1434.3	-517.7	-736.3	-826.7	-808.2	-826.3	-948.4	-1179.9	-1030.5	-1324.8	-1273.2	-1437.2	-1278.2	-1241.0	-1208.9	-937.8	-1159.1
72	-1495.7	-550.3	-786.7	-881.2	-862.8	-885.2	-1014.2	-1263.5	-1095.7	-1419.4	-1356.6	-1544.5	-1371.9	-1330.1	-1296.4	-972.4	-1250.6
76	-1551.8	-582.8	-836.9	-935.5	-917.3	-943.5	-1079.3	-1346.7	-1160.8	-1513.6	-1439.7	-1651.0	-1464.9	-1418.4	-1383.3	-1052.2	-1341.2
80	-1603.3	-615.3	-886.8	-989.4	-971.6	-1001.7	-1144.2	-1429.4	-1225.9	-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	-1511.5	-1290.7	-1699.9	-1605.2	-1861.5	-1648.8	-1593.4	-1555.2	-1218.2	-1520.0
88	-1694.6	-680.0	-986.1	-1096.8	-1079.4	-1116.9	-1273.0	-1593.3	-1355.3	-1792.2	-1687.6	-1965.7	-1739.9	-1680.2	-1640.5	-1299.8	-1608.3
92	-1758.6	-712.3	-1035.4	-1150.2	-1133.0	-1174.1	-1337.0	-1674.6	-1419.8	-1884.2	-1769.6	-2069.4	-1830.7	-1766.6	-1725.4	-1380.5	-1696.2
96	-1884.1	-744.4	-1084.5	-1203.7	-1186.6	-1231.2	-1400.9	-1755.8	-1484.2	-1976.0	-1851.5	-2172.6	-1921.0	-1852.7	-1809.9	-1460.6	-1790.8
100	-2008.1	-776.5	-1133.6	-1257.1	-1240.1	-1288.1	-1464.7	-1837.0	-1548.7	-2067.7	-1933.5	-2275.1	-2010.9	-1938.5	-1894.3	-1540.1	-1886.1
104	-2129.5	-808.6	-1182.7	-1310.0	-1293.3	-1344.6	-1528.1	-1917.2	-1613.0	-2158.2	-2015.0	-2377.2	-2100.4	-2023.7	-1977.9	-1618.4	-1979.7
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	-2108.9	-2061.5	-1698.5	-2073.2
112	-2370.6	-872.7	-1280.0	-1415.7	-1399.2	-1457.1	-1654.3	-2077.3	-1741.2	-2339.2	-2176.6	-2580.6	-2278.2	-2194.0	-2145.0	-1780.0	-2166.2
116	-2489.3	-904.7	-1328.6	-1468.5	-1452.0	-1513.3	-1717.3	-2157.2	-1805.3	-2429.4	-2252.6	-2681.9	-2363.8	-2278.6	-2228.1	-1860.7	-2258.8
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	-2533.8
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	-2641.4	-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)

Span (ft)	Wis_ SPV	STP 3axle	STP 4axle_	STP 4axle_	STP 5axle_	STP 5axle_	STP 6axle	STP 7axle_	STP 7axle_	STP 8axle	STP 9axle_	STP 9axle_	STP_10axle_	STP_10axle_	STP_11axle	STP_12axle	STP_13axle
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	-115.2	-69.2	-93.7	-105.3	-103.1	-98.7	-115.4	-136.7	-83.3	-151.2	-99.8	-154.0	-100.0	-139.8	-136.8	-88.7	-116.2
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	-121.5	-70.8	-98.2	-109.6	-107.8	-104.3	-122.4	-147.6	-95.7	-160.7	-107.0	-170.7	-110.2	-152.3	-148.3	-102.1	-131.4
52	-126.9	-71.4	-99.9	-111.2	-109.5	-107.1	-125.0	-151.5	-101.4	-165.8	-115.3	-177.2	-115.0	-156.9	-152.9	-107.7	-137.0
56	-135.9	-71.9	-101.2	-112.6	-111.0	-109.3	-127.2	-154.9	-106.2	-170.1	-122.9	-182.6	-119.0	-160.8	-156.8	-112.4	-143.1
60	-143.6	-72.3	-102.4	-113.7	-112.2	-111.3	-129.0	-157.7	-111.8	-173.6	-129.3	-187.2	-122.4	-164.0	-160.0	-117.9	-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	-73.0	-104.2	-115.5	-114.1	-114.3	-132.0	-162.2	-120.8	-179.3	-139.6	-194.5	-130.3	-169.2	-165.2	-126.9	-157.7
72	-164.9	-73.2	-105.0	-116.2	-114.9	-115.6	-133.2	-164.0	-124.5	-181.6	-143.8	-197.4	-135.6	-171.3	-167.3	-130.5	-161.3
76	-170.7	-73.5	-105.6	-116.8	-115.6	-116.7	-134.2	-165.6	-127.7	-183.7	-147.5	-200.0	-140.4	-173.2	-169.2	-133.7	-164.5
80	-175.9	-73.7	-106.2	-117.4	-116.2	-117.6	-135.1	-167.0	-130.5	-185.4	-151.7	-202.3	-144.6	-174.8	-170.8	-136.5	-167.3
84	-180.6	-73.9	-106.7	-117.9	-116.8	-118.5	-135.9	-168.2	-133.0	-187.0	-155.6	-204.3	-148.3	-176.2	-172.2	-139.0	-169.8
88	-184.7	-74.0	-107.2	-118.3	-117.2	-119.2	-136.7	-169.4	-135.3	-188.4	-159.2	-206.1	-151.7	-177.5	-173.5	-141.3	-172.0
92	-188.4	-74.2	-107.6	-118.7	-117.7	-119.9	-137.3	-170.4	-137.3	-189.7	-162.3	-207.8	-154.7	-178.7	-174.7	-143.3	-174.0
96	-191.8	-74.3	-108.0	-119.1	-118.1	-120.5	-137.9	-171.3	-139.1	-190.9	-165.2	-209.2	-157.4	-179.7	-175.7	-145.1	-175.9
100	-194.8	-74.5	-108.3	-119.4	-118.4	-121.1	-138.5	-172.1	-140.8	-191.9	-167.8	-210.6	-159.8	-180.7	-176.7	-146.8	-177.5
104	-197.6	-74.6	-108.6	-119.7	-118.8	-121.6	-138.9	-172.8	-142.3	-192.8	-170.2	-211.8	-162.1	-181.5	-177.6	-148.3	-179.0
108	-200.1	-74.7	-108.9	-120.0	-119.1	-122.1	-139.4	-173.5	-143.7	-193.7	-172.3	-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	-139.8	-174.1	-144.9	-194.5	-174.3	-213.9	-166.6	-183.0	-179.1	-150.9	-181.6
116	-204.6	-74.9	-109.4	-120.5	-119.6	-122.9	-140.2	-174.7	-146.1	-195.2	-176.1	-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	-208.4	-75.0	-109.8	-120.9	-120.0	-123.6	-140.9	-175.7	-148.1	-196.5	-179.4	-216.5	-173.8	-184.9	-180.9	-154.1	-184.8
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	-75.1	-110.2	-121.2	-120.4	-124.2	-141.4	-176.6	-149.9	-197.7	-182.1	-217.9	-177.8	-185.9	-182.0	-155.8	-186.6
136	-213.1	-75.2	-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.

a) distribution beam b) hydraulic platform

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 (L > 100ft). 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 (L < 40ft). 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 75ft. Hence, a longer vehicle than the 63ft 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.

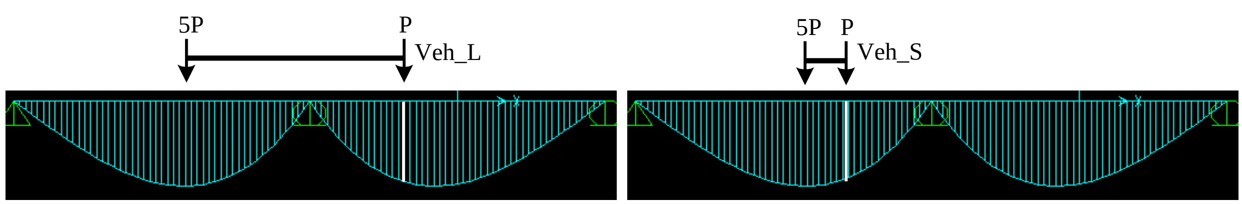


Fig. 6.1 Demonstration of short vehicles causing the worst negative moments

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 vehicles	Minimum	Maximum	Mean	Standard deviation	5th percentile	95th percentile
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

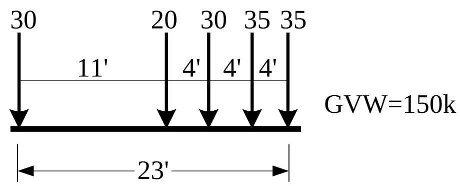


Fig. 6.3 The proposed 5-axle vehicle to supplement the Wis-SPV

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.

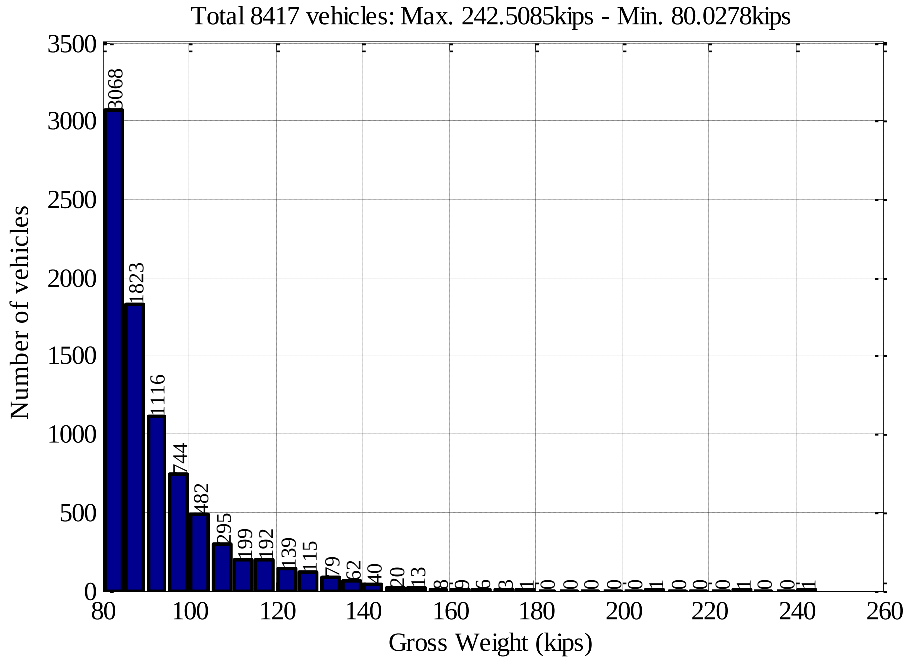
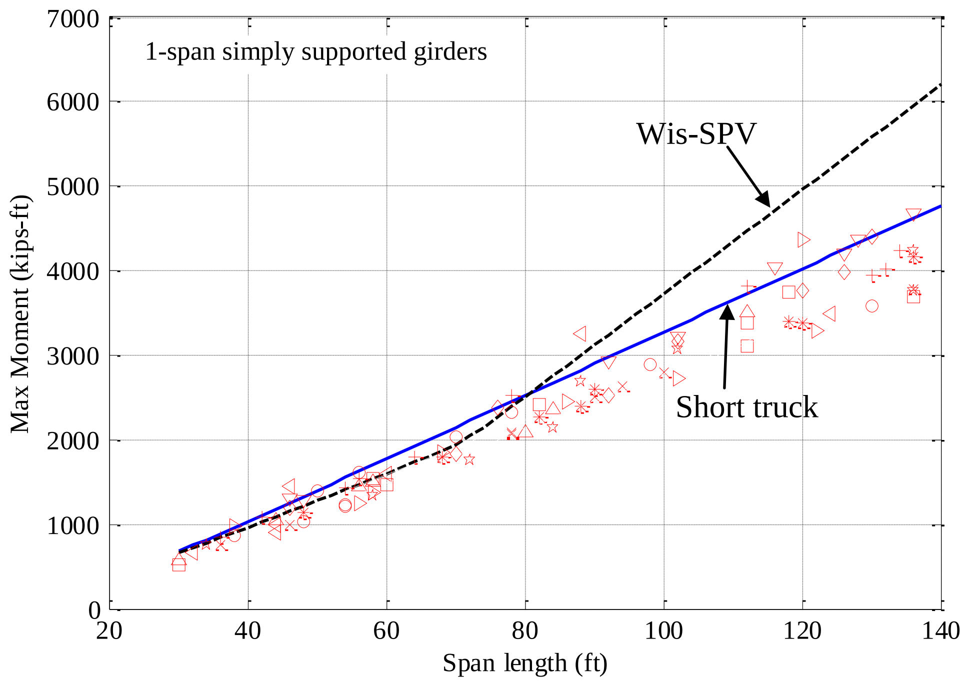


Fig. 6.4 Gross weight distribution of 5-axle short trucks in 2007 WIM records

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.



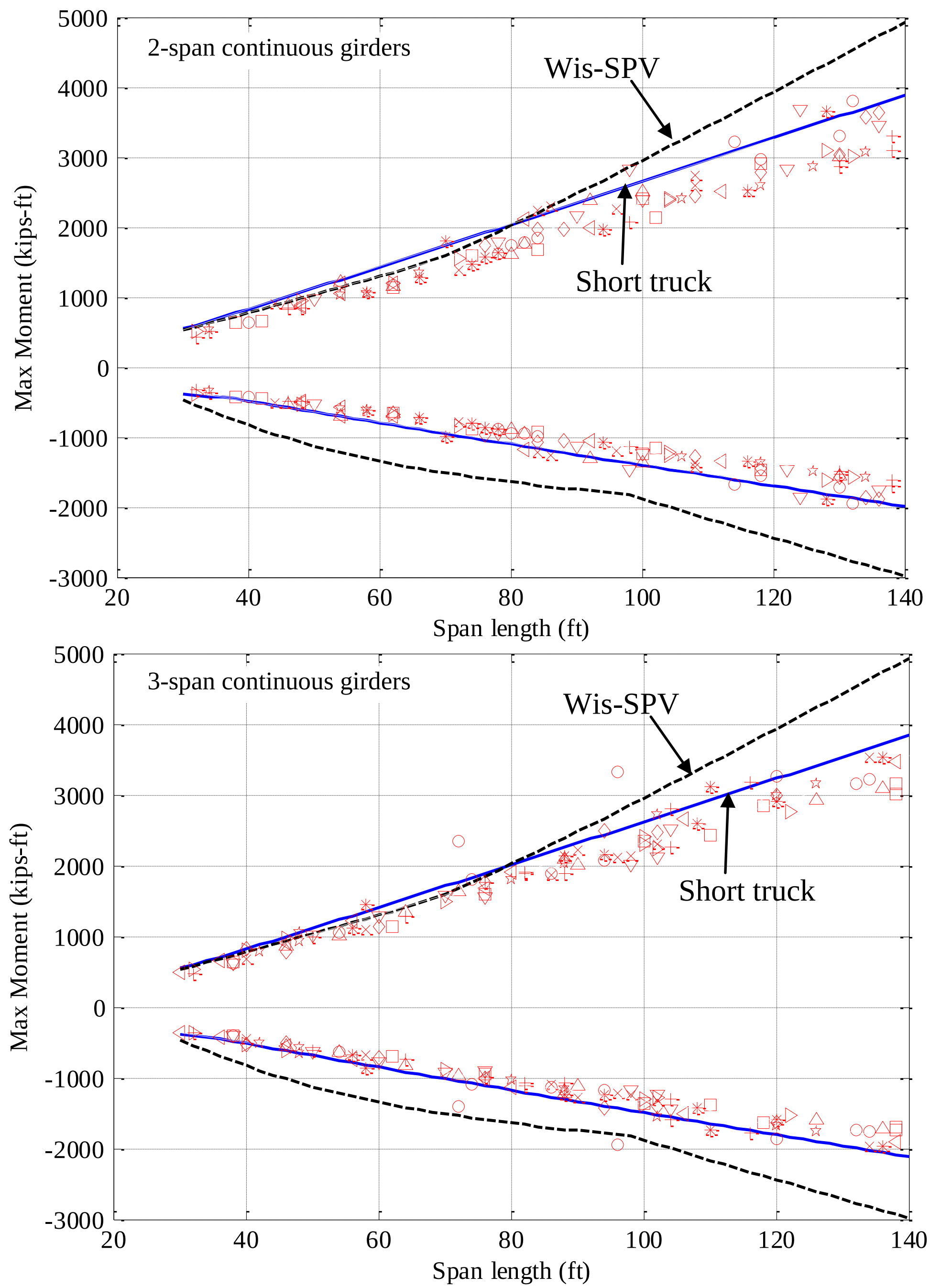


Fig. 6.5 Comparison of the proposed short truck with randomly selected 5-axle trucks

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.

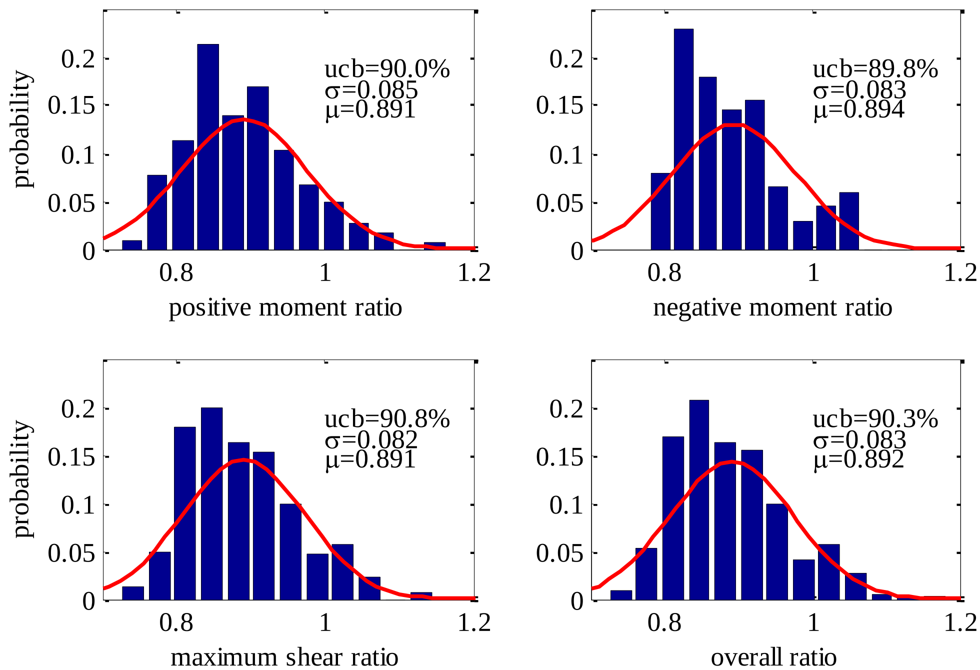


Fig. 6.6 Statistical analysis of randomly selected 5-axle trucks

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 30ft and 80ft. In addition, the moments by the short truck are larger than those by HL-93 loading (the design truck plus the 0.64k/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 (Class/group)		without proposed short truck			with proposed short truck		
	# of vehicles	rep/spv (250 k)	poe (%)	# of exceeds	rep/spv (250 k)	poe (%)	# of 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

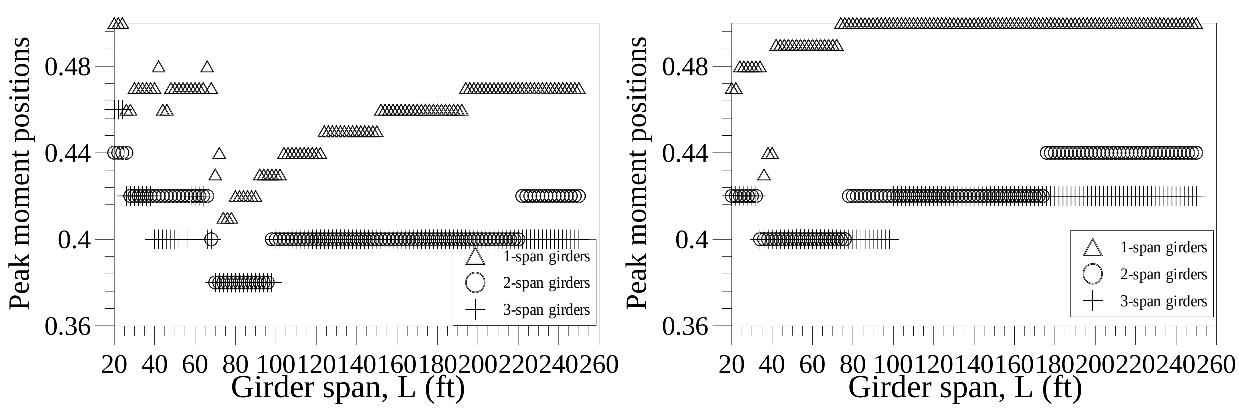
Class 8 3-axle	5789	0.526	0.0	0	0.481	0.0	0
Class 8 4-axle a	18469	0.728	0.0	0	0.661	0.0	0
Class 8 4-axle b	9813	0.660	0.0	0	0.617	0.0	0
Class 9 5-axle a	889230	0.747	0.0	0	0.735	0.0	0
Class 9 5-axle b	133972	0.906	0.1	2	0.849	0.0	0
Class 10 6-axle	27574	1.082	15.8	217	0.981	4.1	56
Class 10 7-axle	2552	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 b	3463	0.875	16.4	28	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 (0.4L or 0.5L, 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 0.48L. Hence the empirical models described below considered both the accurate peak responses and the locations of the peak responses.



(a) Wis-SPV (b) Wis-SPT

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.

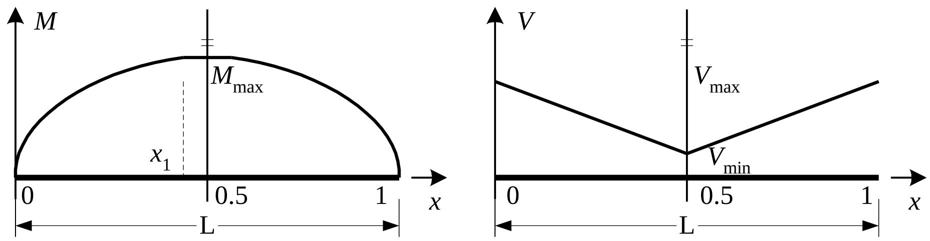


Fig. 6.8 Moment/shear envelope for one-span simply supported girders

The equations for the moment envelope is (only half girder is shown below in the equations)

$$M = \begin{cases} \dfrac{M_{max}}{x_1^2}\left(2x_1 x - x^2\right) & 0 < x < x_1 \\ M_{max} & x_1 \le x \le 0.5 \end{cases}, \tag{6.1}$$

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

$$V = V_{max} - 2\left(V_{max} - V_{min}\right)x \quad 0 < x \le 0.5. \tag{6.2}$$

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 60ft to 72ft (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,

$$M_{max} = \begin{cases} 15.6L - 136 & 20\text{ft} \le L \le 70\text{ft} \\ 30.7L - 1182 & 70\text{ft} < L \le 250\text{ft} \end{cases}. \tag{6.3}$$

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

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

The 3rd 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 20ft and 250ft while the tabulated values are from 32ft to 140ft.

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

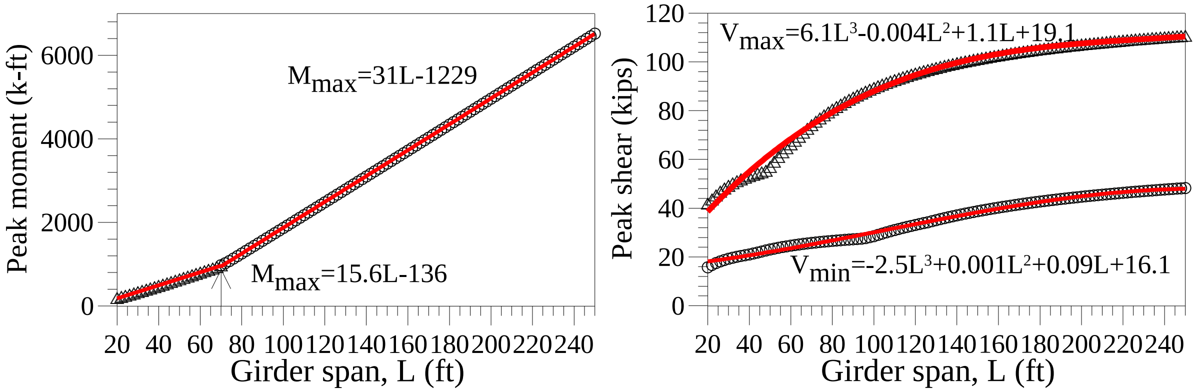


Fig. 6.9 Regression analysis of the peak responses under Wis-SPV in 1-span girders

The regression models shown in Eqs. (6.1) and (6.2) with parameters in Table 6.2 was compared 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.

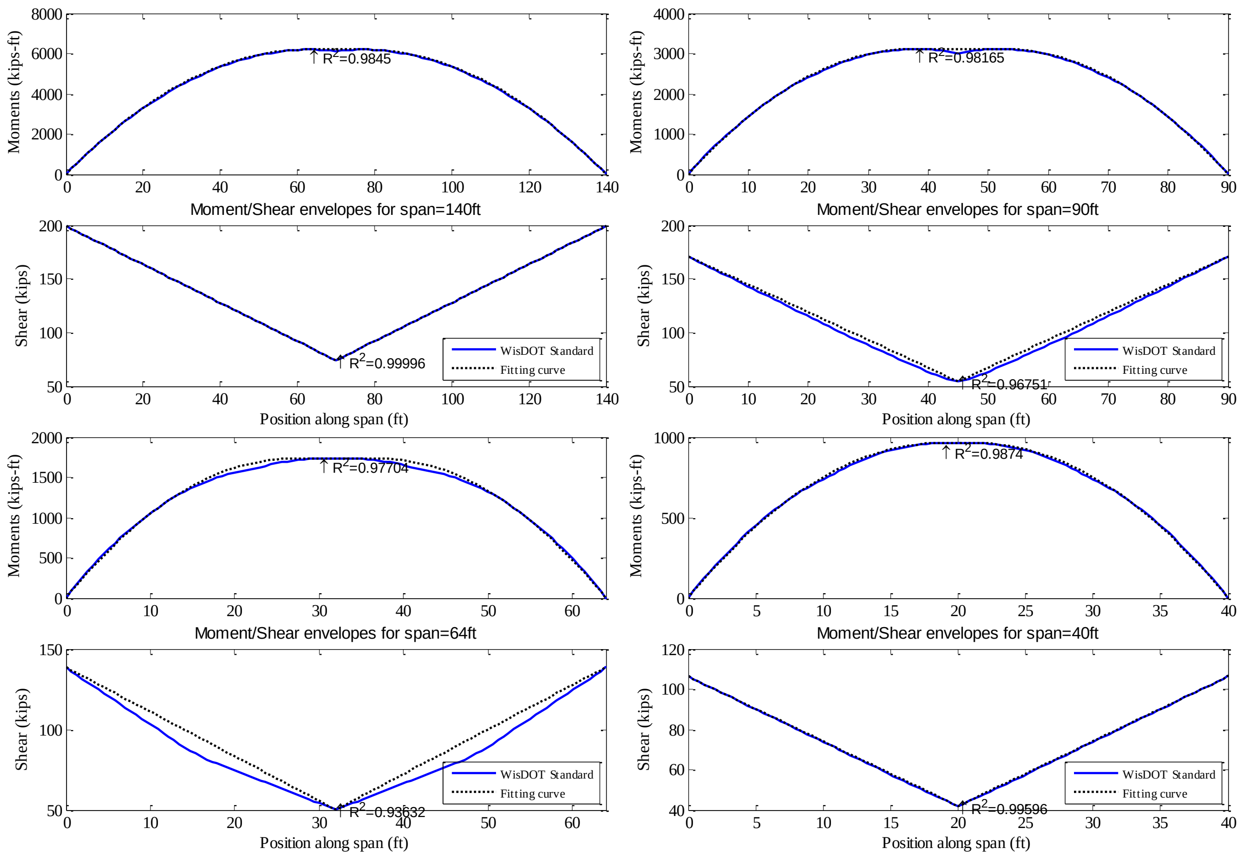


Fig. 6.10 Models of the peak responses under Wis-SPV in 1-span girders

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 36ft to 40ft 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 80ft such that the peak moments can be better represented in the critical region.

$$M_{max} = 18.1L - 196 \quad L \le 80\text{ft}, \text{ and} \tag{6.5}$$

$$\begin{aligned} V_{max} &= \frac{-634}{L} + 0.002L + 75 \\ V_{min} &= \frac{-407}{L} + 0.02L + 33 \end{aligned} . \tag{6.6}$$

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.

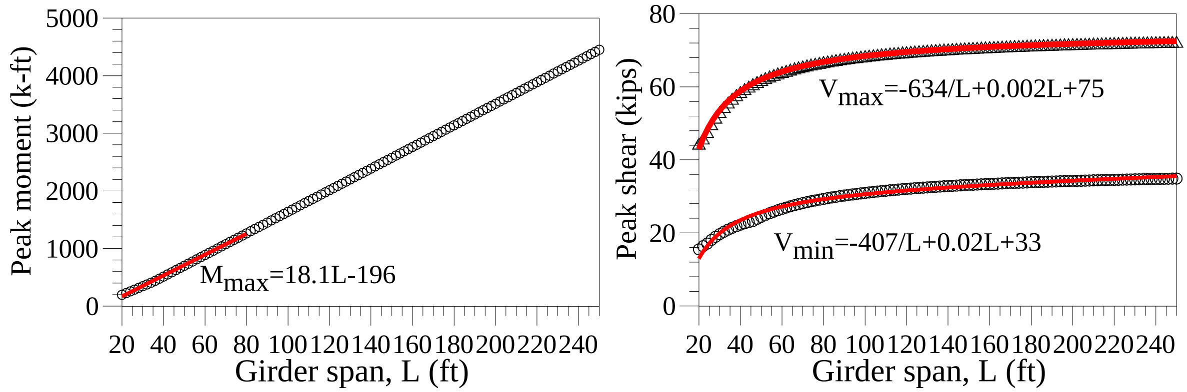


Fig. 6.11 Regression analysis of the peak responses under Wis-SPV in 1-span girders

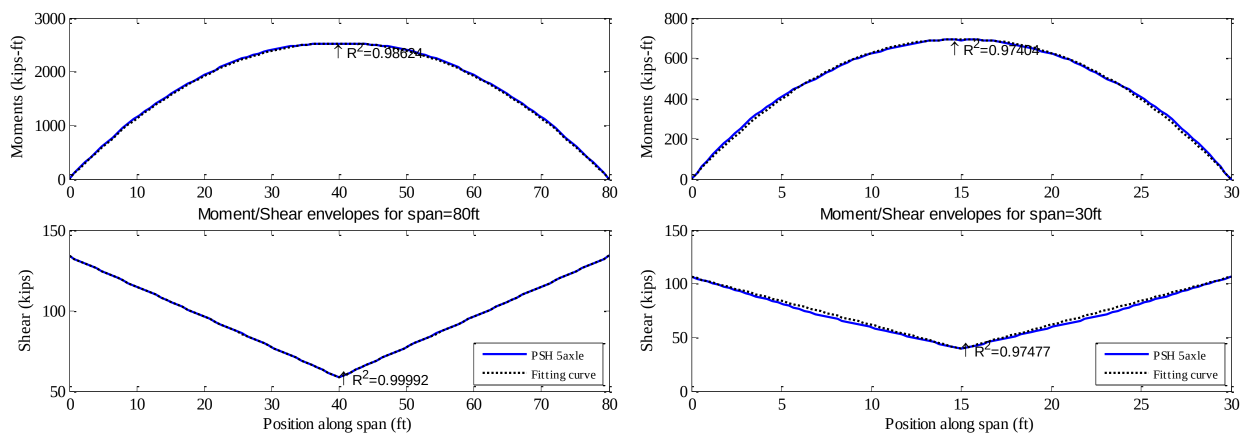


Fig. 6.12 Models of the peak responses under Wis-SPT in 1-span girders

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_{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.

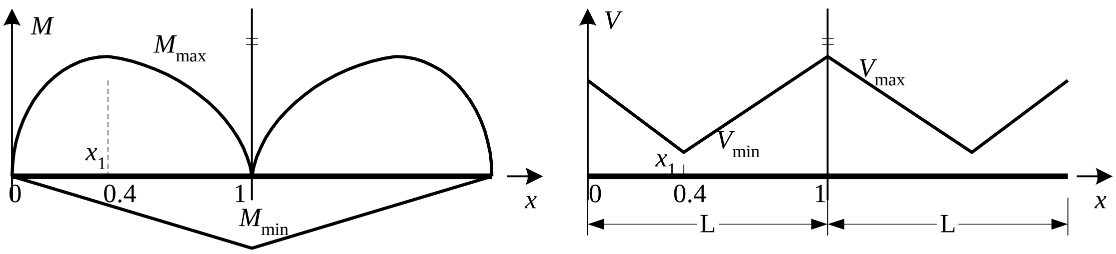


Fig. 6.13 Moment/shear envelope for one-span simply supported girders

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_{pos}, is

$$M_{pos} = \begin{cases} \frac{M_{max}}{x_1^2}\left(2x_1x - x^2\right) & 0 < x \le x_1 \\ \frac{M_{max}}{(1-x_1)^2}\left(1 - 2x_1 + 2x_1x - x^2\right) & x_1 < x < 1 \end{cases}. \tag{6.7}$$

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

$$M_{neg} = xM_{min} \quad 0 \le x \le 1. \tag{6.8}$$

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

$$V = \begin{cases} V_{max} - (V_{max} - V_{min})\frac{x}{x_1} & 0 < x \le x_1 \\ V_{min} + (V_{max} - V_{min})\left(\frac{x - x_1}{1 - x_1}\right) & x_1 < x < 1 \end{cases}. \tag{6.9}$$

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 0.38L to 0.44L 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 0.38L to 0.44L. 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,

$$M_{max} = \begin{cases} 12.9L - 120 & L \le 70\text{ft} \\ 25L - 1023 & L > 70\text{ft} \end{cases}. \tag{6.10}$$

The regression equations for the peak negative moments are,

$$M_{min} = \begin{cases} 0.11L^2 - 23.6L + 357 & L < 100\text{ft} \\ -13L + 330 & L \ge 100\text{ft} \end{cases}. \tag{6.11}$$

The equations for the maximum and minimum shear are,

$$V_{max} = 7.7L^3 - 0.005L^2 + 1.2L + 19.3$$
$$V_{min} = 0.13L + 16.7 \quad . \qquad (6.12)$$

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

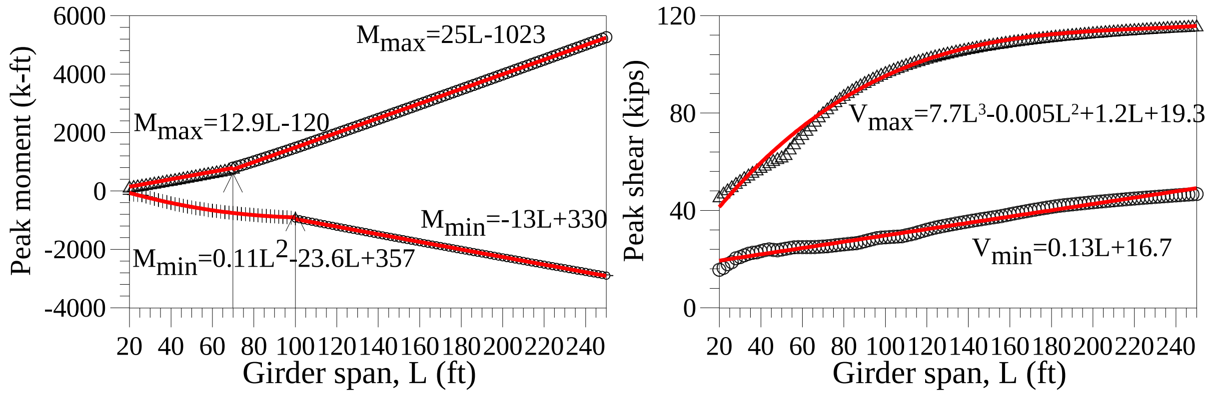


Fig. 6.14 Regression analysis of the peak responses under Wis-SPV in 2-span girders

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.

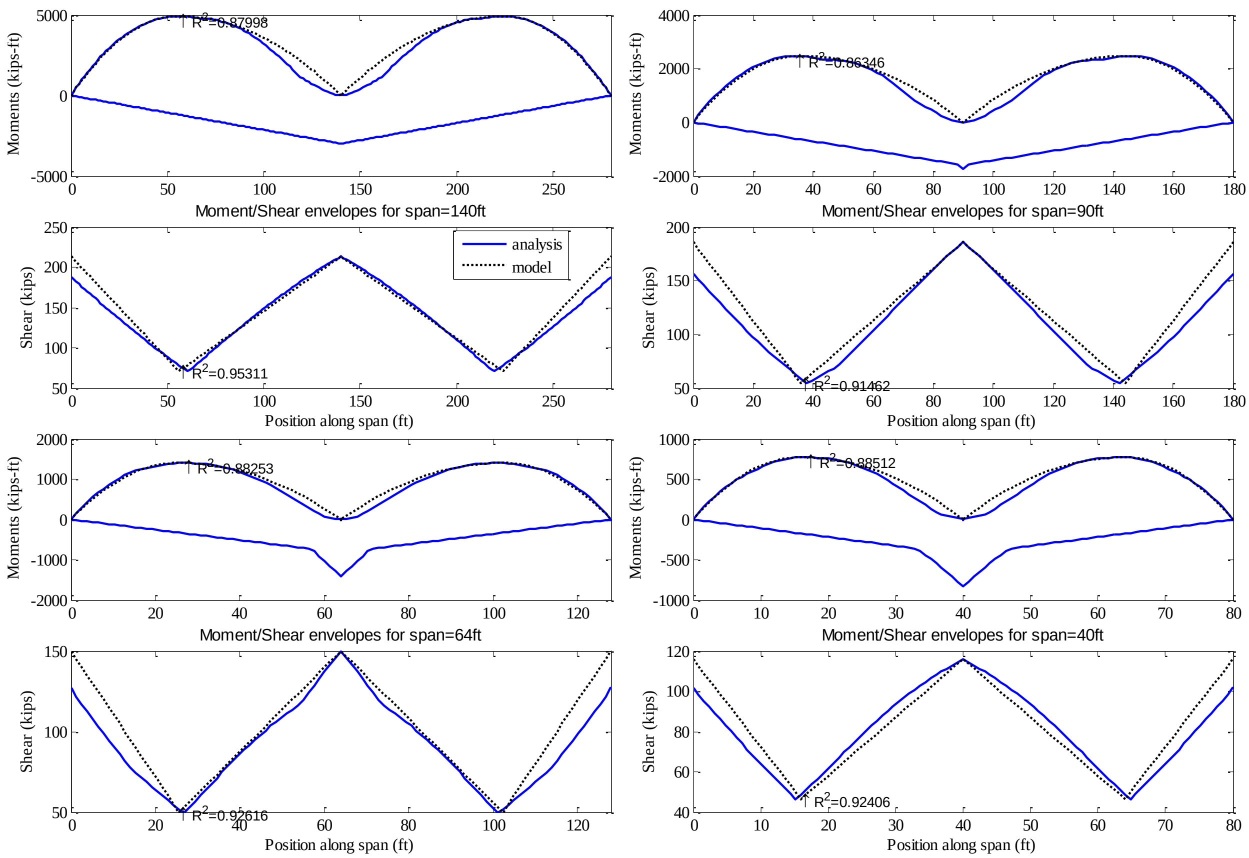


Fig. 6.15 Models of the peak responses under Wis-SPV in 2-span girders

2. *WisDOT Short Permit Truck* (*SPT*). The peak moment location varies slightly from 0.4L to 0.44L. 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,

$$\begin{aligned} M_{max} &= 14.6L - 160 \quad 20 \le L \le 80\text{ft} \\ M_{min} &= -7.3L + 34.8 \quad 20 \le L \le 80\text{ft} \end{aligned}, \text{ and} \tag{6.13}$$

$$\begin{aligned} V_{max} &= -\frac{616}{L} - 0.01L + 78 \quad 20 \le L \le 250\text{ft} \\ V_{min} &= -\frac{390}{L} + 0.02L + 32 \quad 20 \le L \le 250\text{ft} \end{aligned}. \tag{6.14}$$

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 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.

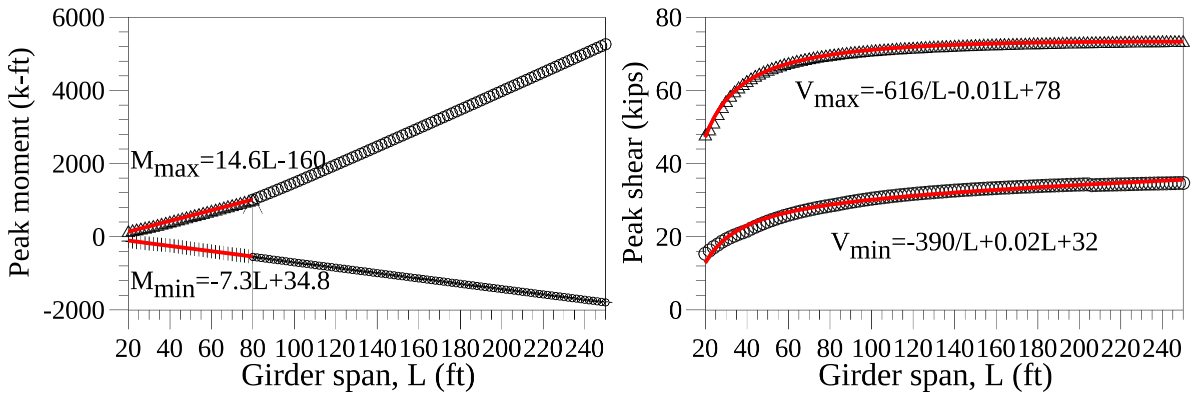


Fig. 6.16 Regression analysis of the peak responses under Wis-SPV in 2-span girders

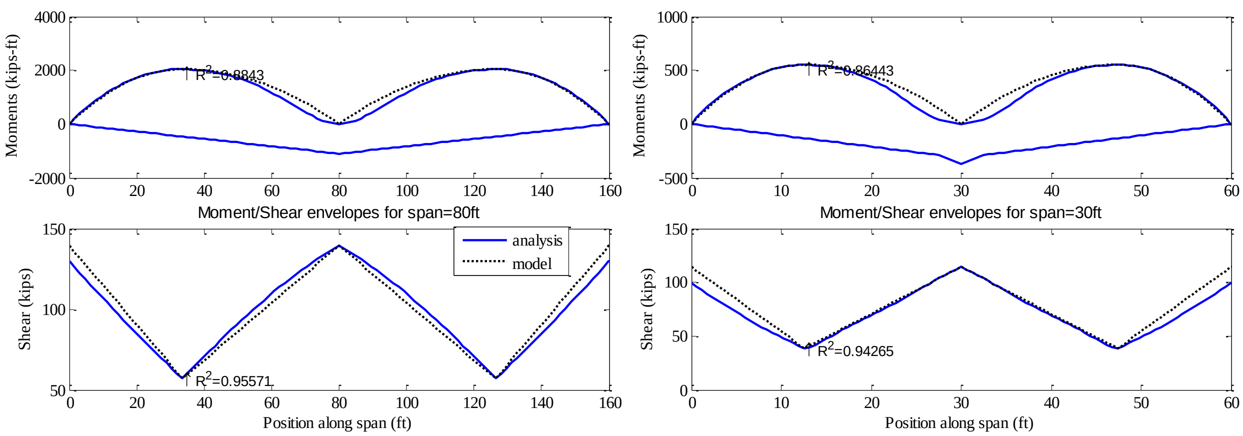


Fig. 6.17 Models of the peak responses under Wis-SPT in 2-span girders

<u>Moment and shear envelope for three equal span girders.</u>

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.

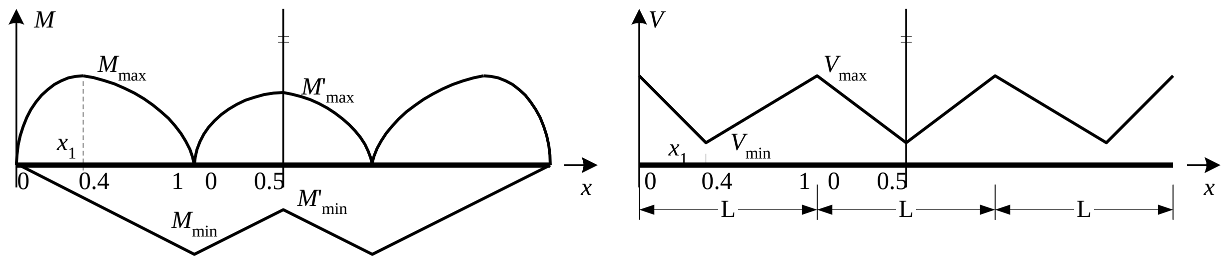


Fig. 6.18 Moment/shear envelope for one-span simply supported girders

The equation for the moment envelopes for the exterior spans is

$$M_{pos} = \begin{cases} \dfrac{M_{max}}{x_1^2}\left(2x_1 x - x^2\right) & 0 < x \le x_1 \\ \dfrac{M_{max}}{(1-x_1)^2}\left(1 - 2x_1 + 2x_1 x - x^2\right) & x_1 < x < 1 \end{cases}, \text{ and} \tag{6.15}$$

$$M_{neg} = xM_{min} \quad 0 \le x \le 1. \tag{6.16}$$

The moment equations for the interior span are

$$M'_{pos} = \begin{cases} \dfrac{M'_{max}}{x_1^2}\left(2x_1 x - x^2\right) & 0 < x \le x_1 \\ M'_{max} & x_1 < x < 0.5 \end{cases}, \text{ and} \tag{6.17}$$

$$M'_{neg} = M'_{min} + 2\left(M'_{max} - M'_{min}\right)x \quad 0 \le x \le 0.5. \tag{6.18}$$

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

$$V = \begin{cases} V_{max} - \left(V_{max} - V_{min}\right)\dfrac{x}{x_1} & 0 < x \le x_1 \\ V_{min} + \left(V_{max} - V_{min}\right)\left(\dfrac{x - x_1}{1 - x_1}\right) & x_1 < x < 1 \end{cases}, \text{ and} \tag{6.19}$$

$$V' = V_{max} - 2\left(V_{max} - V_{min}\right)x \quad 0 < x \le 0.5. \tag{6.20}$$

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 0.44L with an average at (x_1=0.42), which could used in the model to simplify the presentation.

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

$$M_{max} = \begin{cases} 12.5L - 110 & 20 \le L \le 70\text{ft} \\ 24.7L - 1013 & 70 \le L \le 250\text{ft} \end{cases}, \text{ and} \tag{6.21}$$

$$M'_{max} = 0.027L^2 + 11.5L - 223. \tag{6.22}$$

The regression equations for the peak negative moments are,

$$M_{min} = \begin{cases} 0.074L^2 - 20L + 285 & 20 \le L \le 90\text{ft} \\ -13.8L + 352 & 90 \le L \le 250\text{ft} \end{cases}, \text{ and} \tag{6.23}$$

$$M'_{min} = -5.1L + 123. \tag{6.24}$$

The equations for the maximum and minimum shear are,

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

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

Span (ft)	Wis-SPV						Wis-SPT					
	M_{max}	M_{min}	M'_{max}	M'_{min}	V_{max}	V_{min}	M_{max}	M_{min}	M'_{max}	M'_{min}	V_{max}	V_{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	16.3
28	241.2	-177.1	193.4	-86.8	51.6	19.6	248.0	-181.7	201.8	-58.2	55.7	17.9
32	287.8	-252.2	230.3	-83.4	53.8	24.8	296.2	-206.1	242.1	-70.1	58.8	19.5
36	333.7	-320.4	270.7	-89.2	55.8	26.6	352.1	-228.0	282.9	-83.5	61.1	20.5
40	381.7	-387.8	311.4	-90.8	57.6	27.4	409.3	-257.6	329.5	-96.8	62.9	21.5
44	432.9	-450.0	353.9	-97.9	59.3	27.8	467.4	-292.1	377.4	-109.7	64.3	22.4
48	484.4	-507.4	397.0	-108.8	60.7	27.9	526.1	-326.2	426.0	-122.5	65.4	23.3
52	536.2	-558.6	440.5	-119.5	63.4	27.7	585.2	-360.0	475.3	-135.1	66.4	24.1
56	588.2	-604.5	484.2	-130.2	67.9	27.4	644.7	-393.3	525.1	-147.6	67.1	24.9
60	640.4	-645.9	528.1	-140.8	71.8	26.8	704.5	-426.4	575.2	-160.0	67.8	25.6
64	692.8	-683.2	572.3	-163.3	75.3	26.5	764.4	-459.2	625.8	-172.3	68.4	26.2
68	753.9	-717.2	616.5	-186.0	79.1	26.2	824.6	-491.8	676.9	-184.5	68.8	27.0
72	827.6	-747.8	666.8	-208.3	82. 5	26.1	884.9	-524.1	728.3	-196.7	69.3	27.6
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	995.9	-801.7	784.2	-257.5	88.0	26.0	1005.8	-588.5	831.2	-220.8	70.0	28.8
84	1084.5	-825.5	850.8	-282.0	90.3	26.1	1066.4	-620.5	882.8	-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	29.7
92	1265.6	-879.3	994.1	-329.9	94.2	26.6	1187.7	-684.2	986.3	-256.7	70.7	30.1
96	1357.8	-942.1	1068.5	-353.4	95.9	26.9	1248.4	-716.1	1038.1	-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

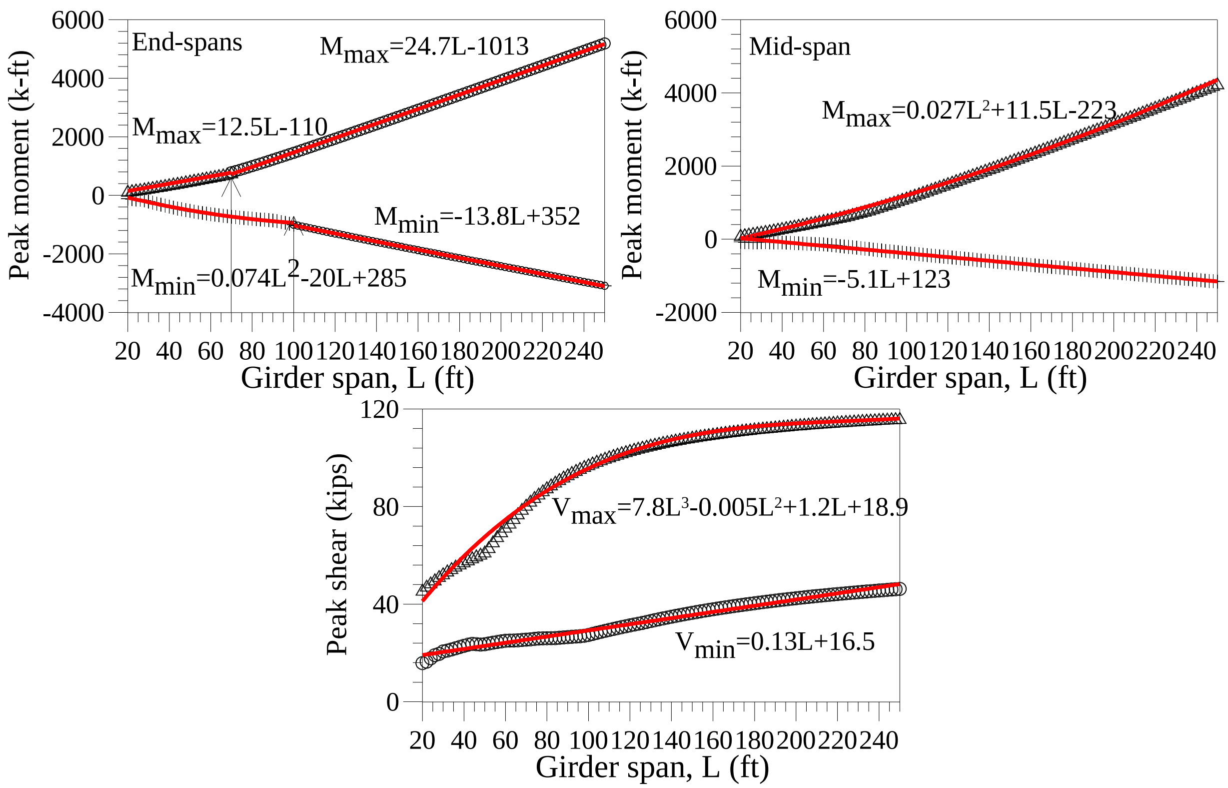


Fig. 6.19 Regression analysis of the peak responses under Wis-SPV in 3-span girders

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.

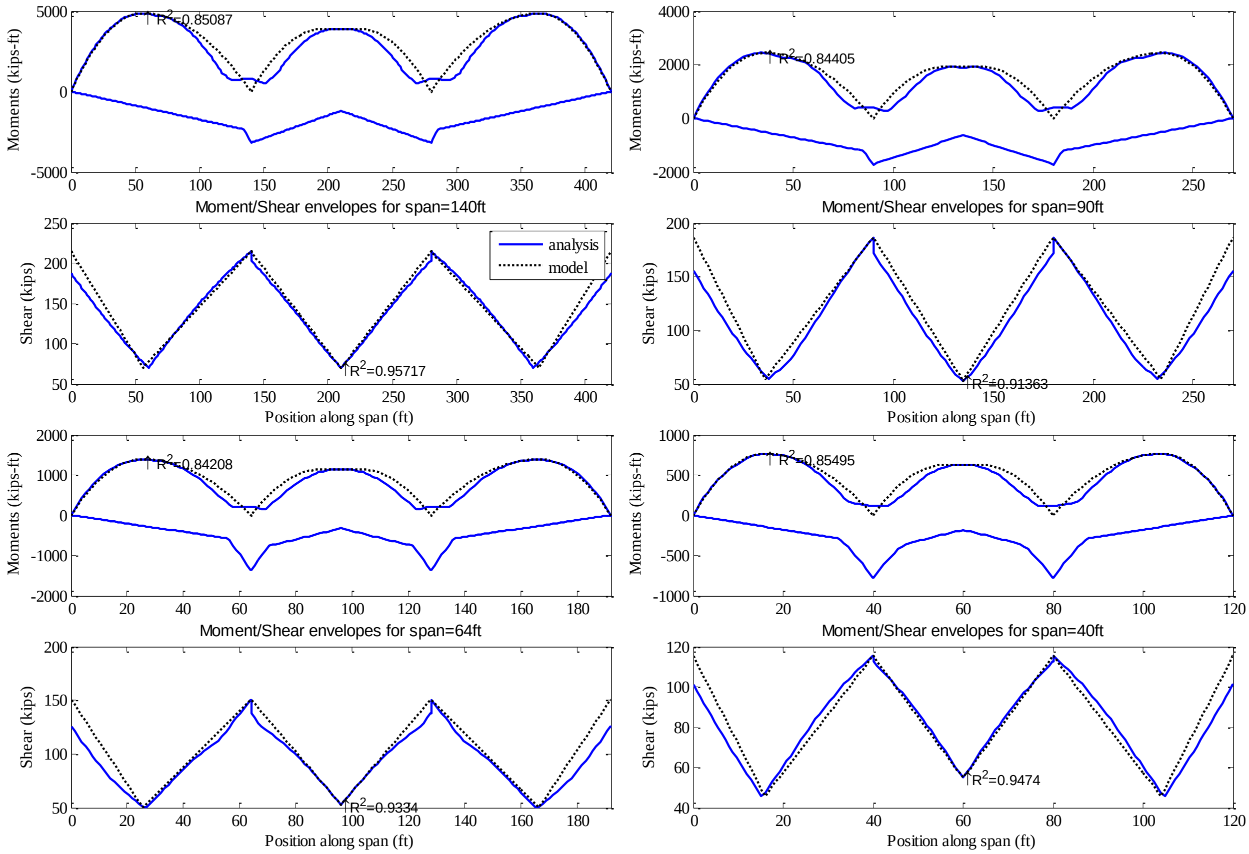


Fig. 6.20 Models of the peak responses under Wis-SPV in 3-span girders

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 (x_1=0.45) 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,

$$\begin{aligned} M_{\max} &= 14.5L - 159 \quad 20 \le L \le 80\text{ft} \\ M'_{\max} &= 12.0L - 138 \end{aligned} . \tag{6.26}$$

The regression equations for the peak negative moments are,

$$\begin{aligned} M_{\min} &= -7.9L + 45.7 \quad 20 \le L \le 80\text{ft} \\ M'_{\min} &= -3.1L + 27.7 \end{aligned} . \tag{6.27}$$

The equations for the maximum and minimum shear are,

$$\begin{aligned} V_{\max} &= -615/L - 0.01L + 78.4 \quad 20 \le L \le 250\text{ft} \\ V_{\min} &= -390/L + 0.02L + 31.3 \quad 20 \le L \le 250\text{ft} \end{aligned} . \tag{6.10}$$

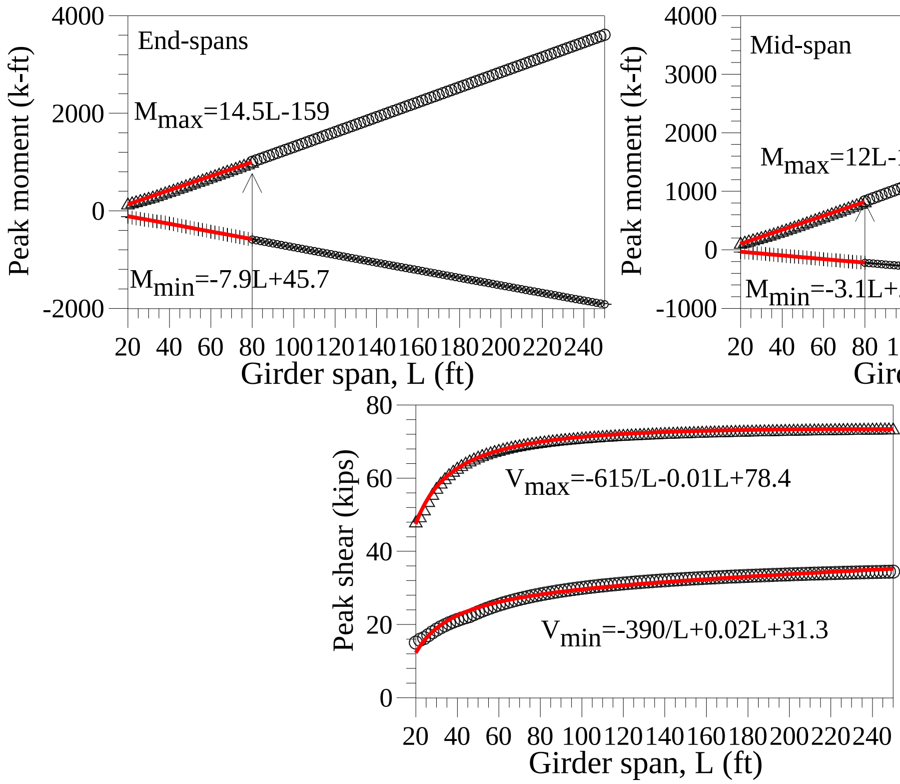


Fig. 6.21 Regression analysis of the peak responses under Wis-SPT in 3-span girders

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.

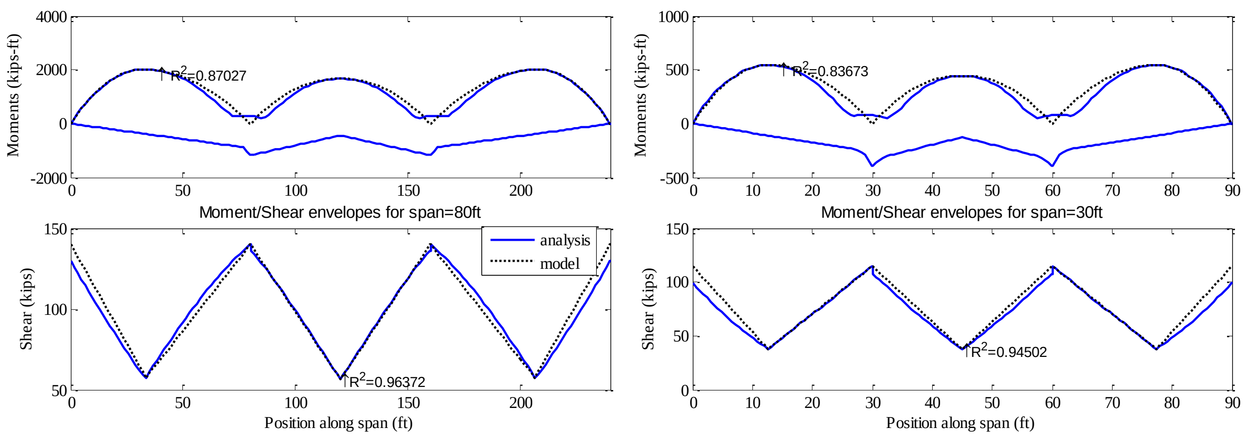


Fig. 6.22 Models of the peak responses under Wis-SPT in 3-span girders

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 51ft interior span. The slab width is 42.5 ft with a clear roadway width of 40 ft. The slab (4-ksi concrete) has been designed to be 17in thick with a ½-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 @ 7in (1.71 in^2 per foot slab) at 0.4L 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.

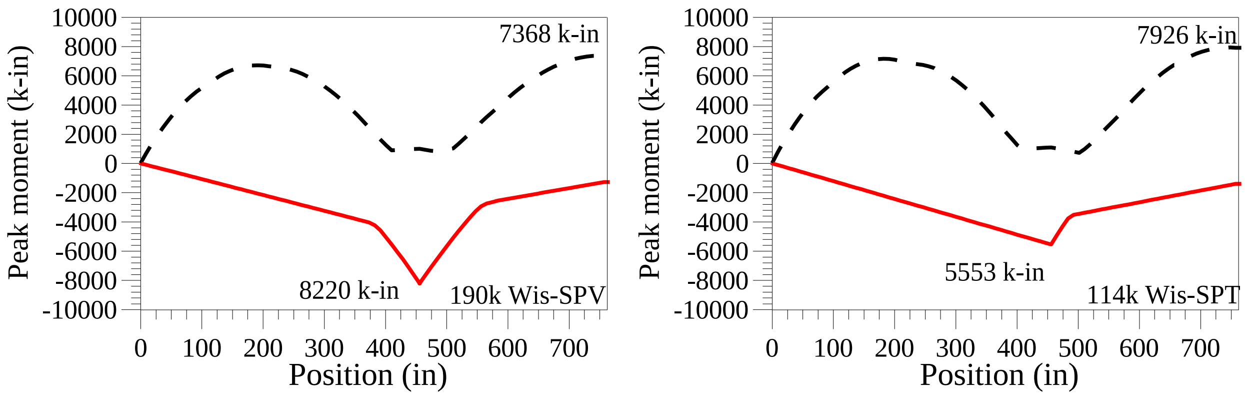


Fig. 6.23 Moment envelops of a 3-span slab bridge under permit vehicles

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-k Wis-SPV and 114-k WisSPT is compared as follows.

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

The rating equation is $RF_{\text{permit}} = \dfrac{\phi_c \phi_s \phi M_n - \gamma_{DC} M_{DC} - \gamma_{DW} M_{DW}}{\gamma_L M_{LL\_IM}}$. 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 (E)	178 in	LRFD [4.6.2.1.2, 4.6.2.3]
Distribution factor (DF)	0.0562 lanes/ft-slab	LRFR [6.4.5.4.2.2]
Dynamic load allowance (IM)	0.33	LRFR [6.4.5.5]
Condition Factor (φ_c)	1.0	WisDOT [45.3.2.4]
System Factor (φ_s)	1.0	WisDOT [45.3.2.5]
Resistance Factor (φ)	0.9	LRFD [5.7.2.1]
Load factor (γ_{DC})	1.25	WisDOT [45.3-1]
Load factor (γ_{DW})	1.5	WisDOT [45.3-1]
Load factor (γ_L)	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 (M_{DC})	59.2 k-ft	
	FWS moment (M_{DW})	4.9 k-ft	
	Nominal moment capacity	226.7 k-ft	
	Live moment for 1-ft slab	51.2 k-ft	34.6 k-ft
	RF_{permit}	1.66	2.46
0.4L	Dead load moment (M_{DC})	18.1 k-ft	
	FWS moment (M_{DW})	1.5 k-ft	
	Nominal moment capacity	116.6 k-ft	
	Live moment for 1-ft slab	45.9 k-ft	49.4 k-ft
	RF_{permit}	1.16	1.08

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

The rating equation is $RF_{\text{permit}} = \frac{\phi_c \phi_s \phi M_n - \gamma_{DC} M_{DC}}{\gamma_L M_{LL\_IM}}$. 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 (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 (φ_c)	1.0	WisDOT [45.3.2.4]
System Factor (φ_s)	1.0	WisDOT [45.3.2.5]
Resistance Factor (φ)	0.9	LRFD [5.7.2.1]
Load factor (γ_{DC})	1.25	WisDOT [45.3-1]
Load factor (γ_L)	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 (M_{DC})	59.2 k-ft	
	Nominal moment capacity	226.7 k-ft	
	Live moment for 1-ft slab	64.6 k-ft	43.6 k-ft
	RF_{permit}	1.55	2.29
0.4L	Dead load moment (M_{DC})	18.1 k-ft	
	Nominal moment capacity	116.6 k-ft	
	Live moment for 1-ft slab	57.9 k-ft	62.3 k-ft
	RF_{permit}	1.09	1.02

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 k-ft (SPV) and 74.8 k-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
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-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 4ft to over 70ft. 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 50ft (for trucks) and 75ft (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.

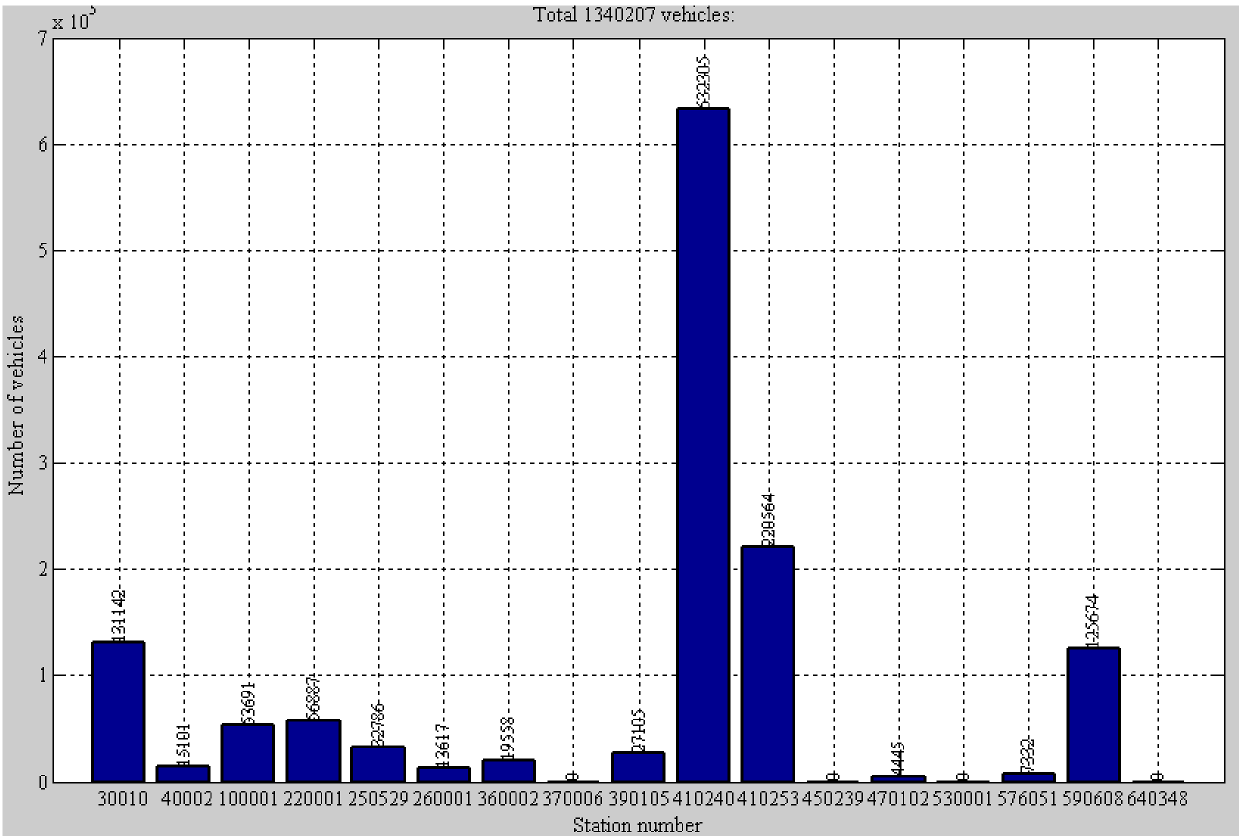


Fig. 7.1 The overloaded vehicles captured in various WIM stations in Wisconsin

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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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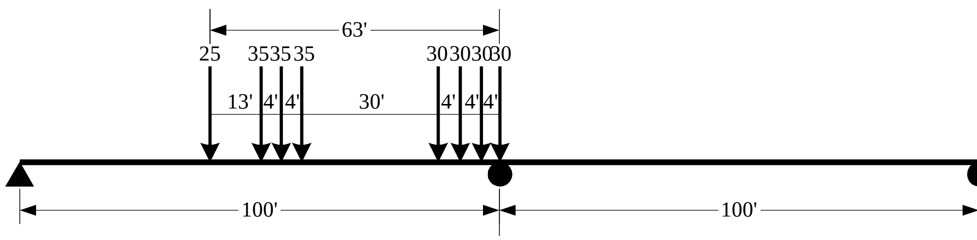
Appendix 1
Line Girder Analysis Using SAP2000

Introduction

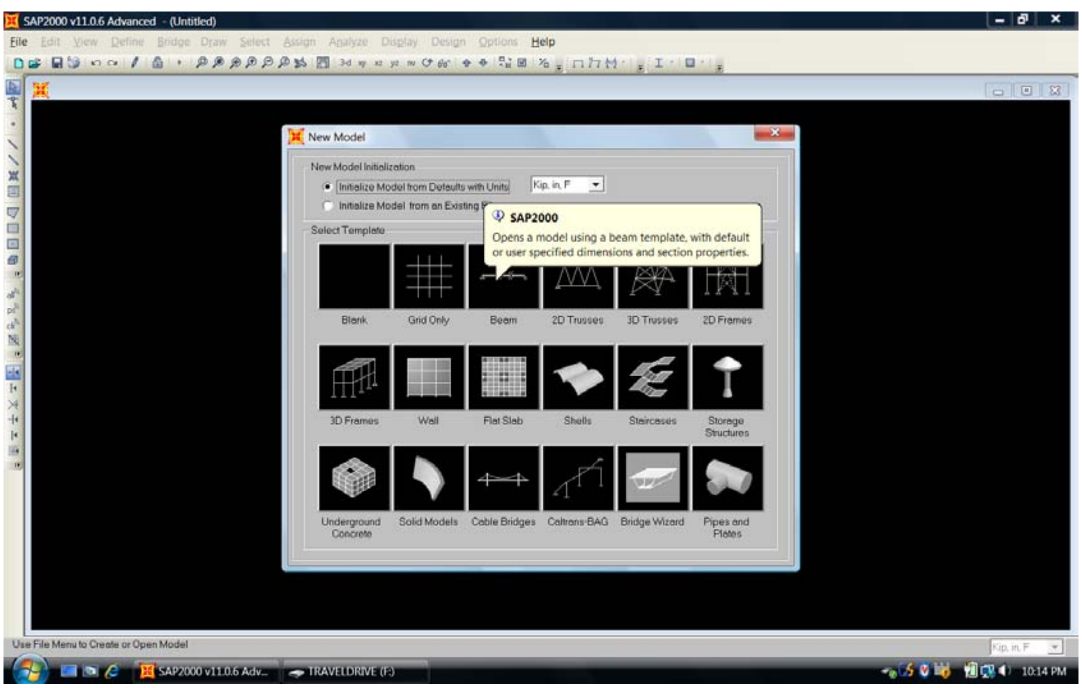
Steps for doing line girder analysis using SAP2000 (Ver. 11.0.6 Advanced) are shown below.

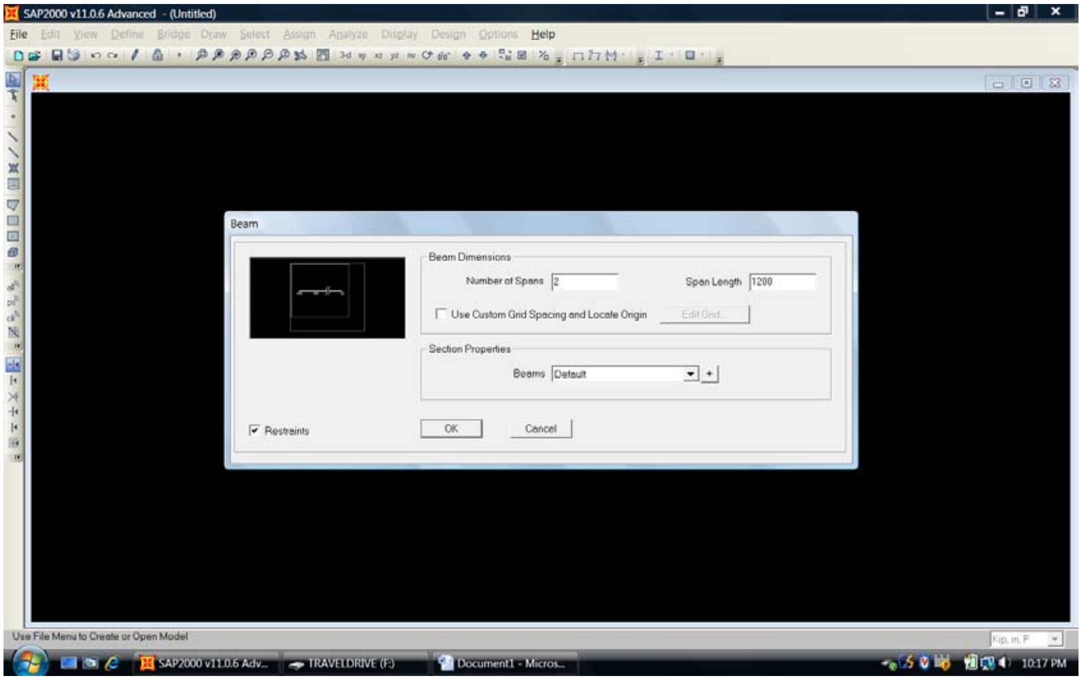
This example shows the procedures used to obtain moment/shear envelops of a 2-span bridge (with a span length of 100 ft) loaded by the WisDOT Standard Permit Vehicle shown below:



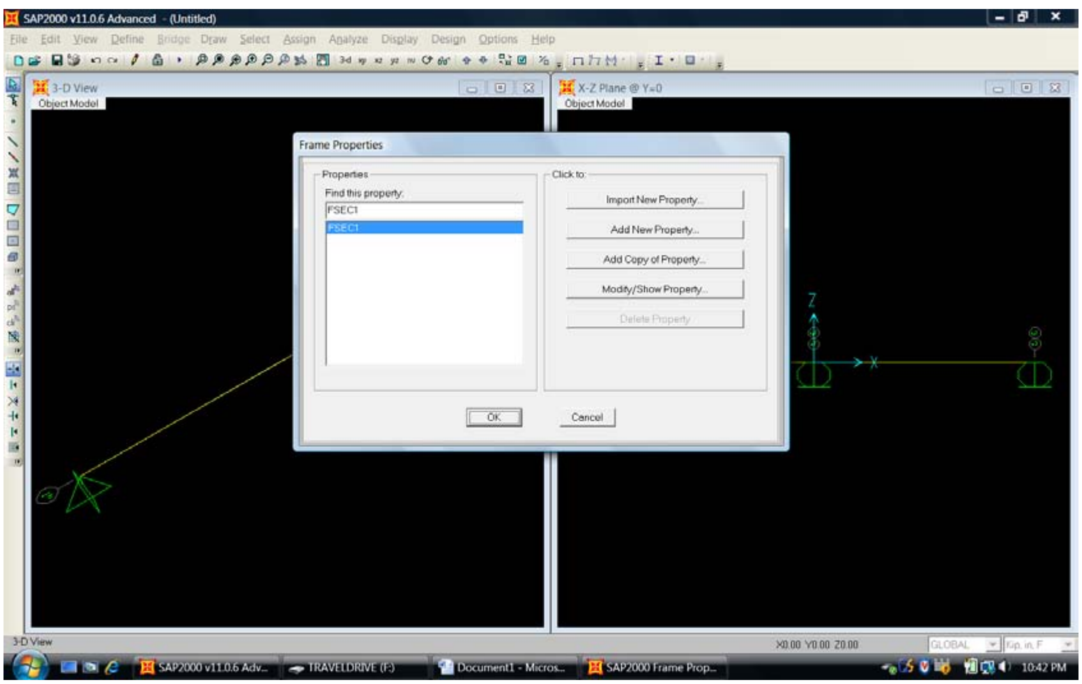
Analysis Procedures

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



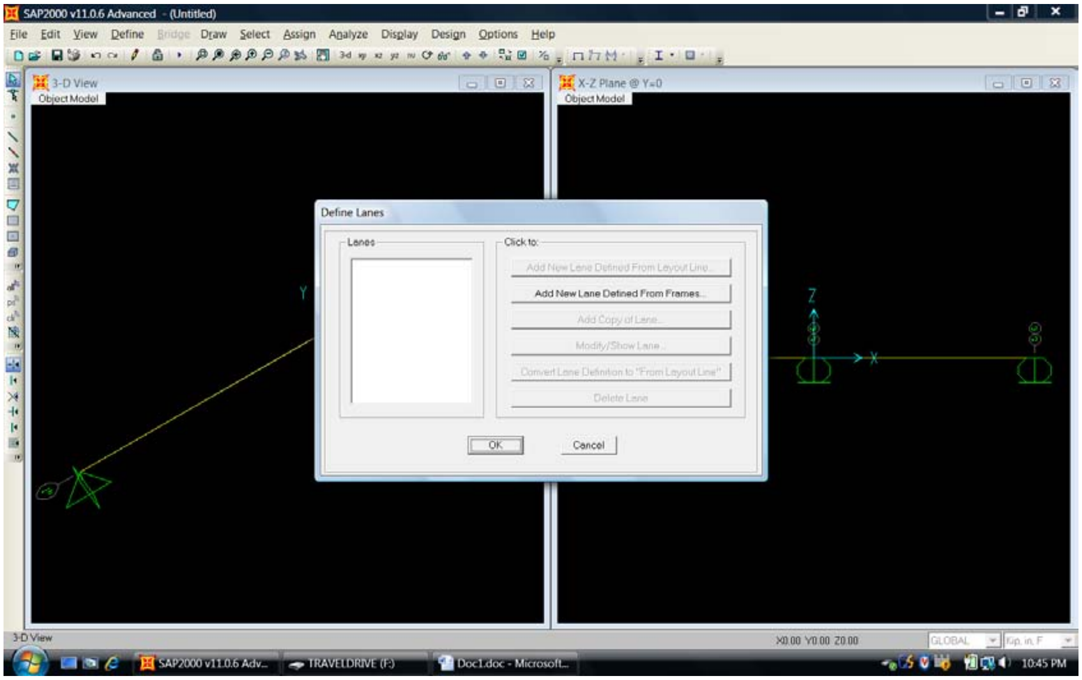


2. Define>Frame Sections: use the default section for line girder analysis



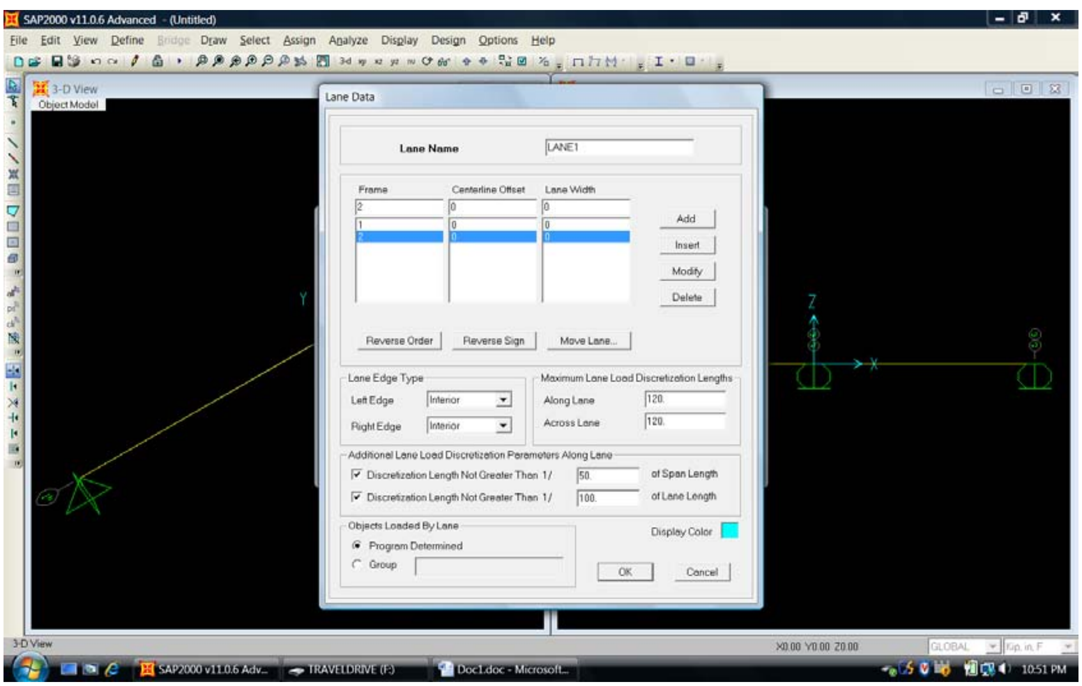
3. Define>Bridge Loads>Lanes: define lanes that describe how vehicles move on the structure

   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



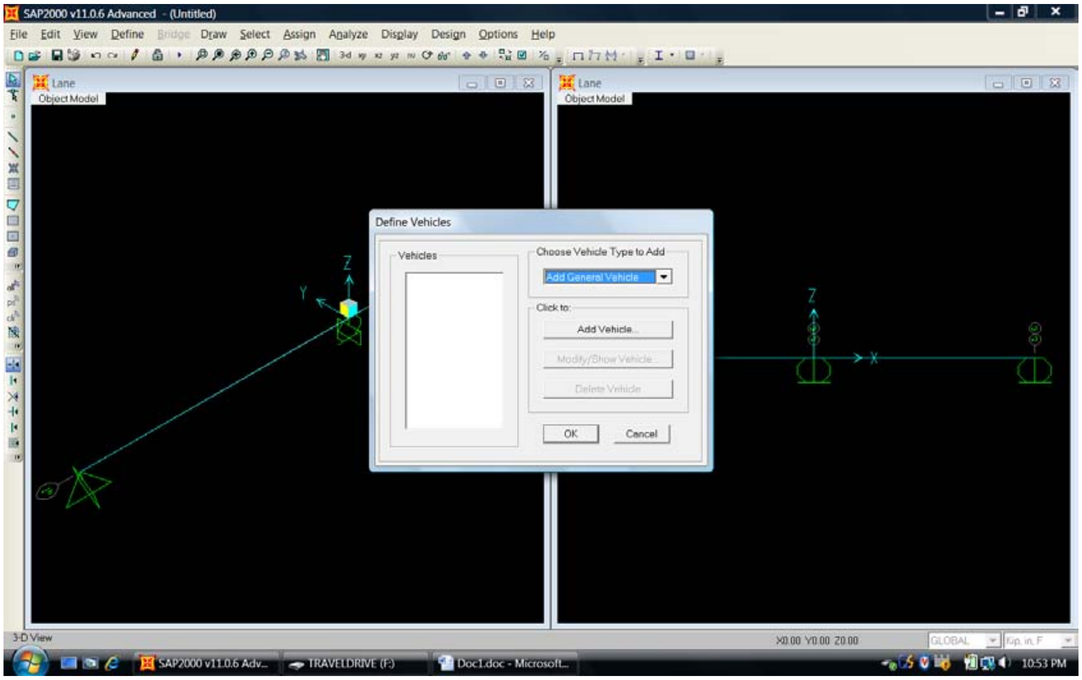
b) Change to frame member 1, leave *Centerline Offset and Lane Width* zero, and click <u>Add</u>

c) Increase *Additional Lane Load Discretization* to smooth the solution (e.g. 1/50 span)



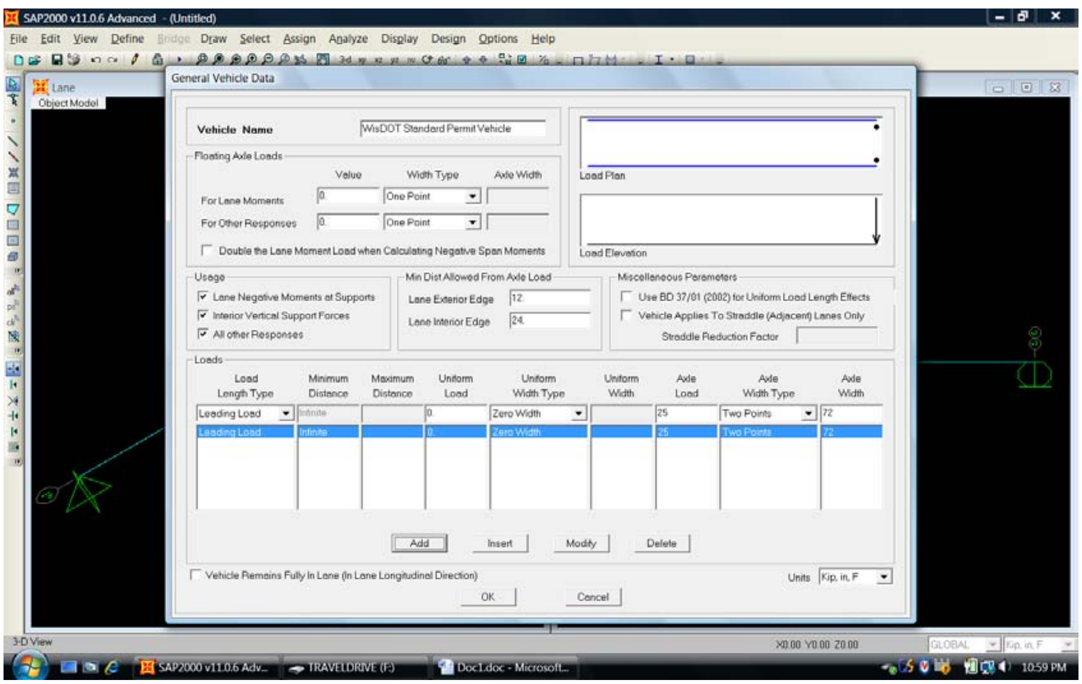
4. Define>Bridge Loads>Vehicles: define Vehicle loads (e.g., HS20-44)

   a) Click <u>Add General Vehicle</u> to define the WisDOT Standard Permit Vehicle



b) Use a name for the vehicle (e.g., WisDOT Standard Permit Vehicle)

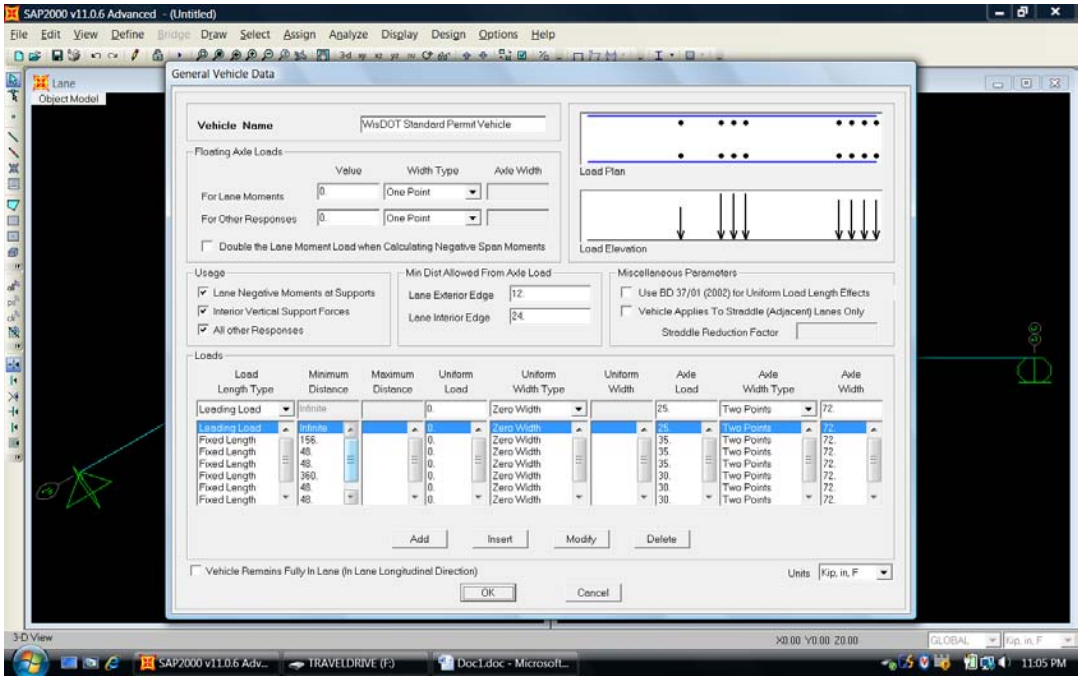
c) Select *Leading Load from Loads>Load length Type*, put 25(kips) in *Axle Load*, select *Two Points* from the next column, put 72 (inches) in the last column, and click Add



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

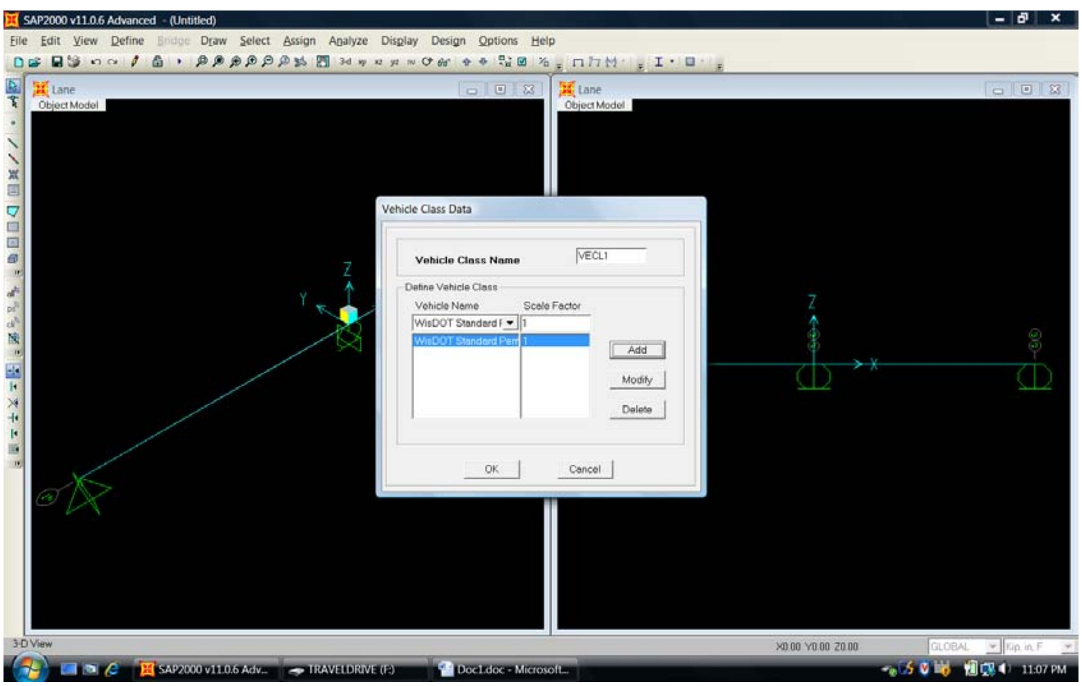


5. Define>Bridge Loads>Vehicle Classes: specify sets of one or more vehicles that can be assigned to act on lanes in a moving-load analysis case

a) Click Add New Class

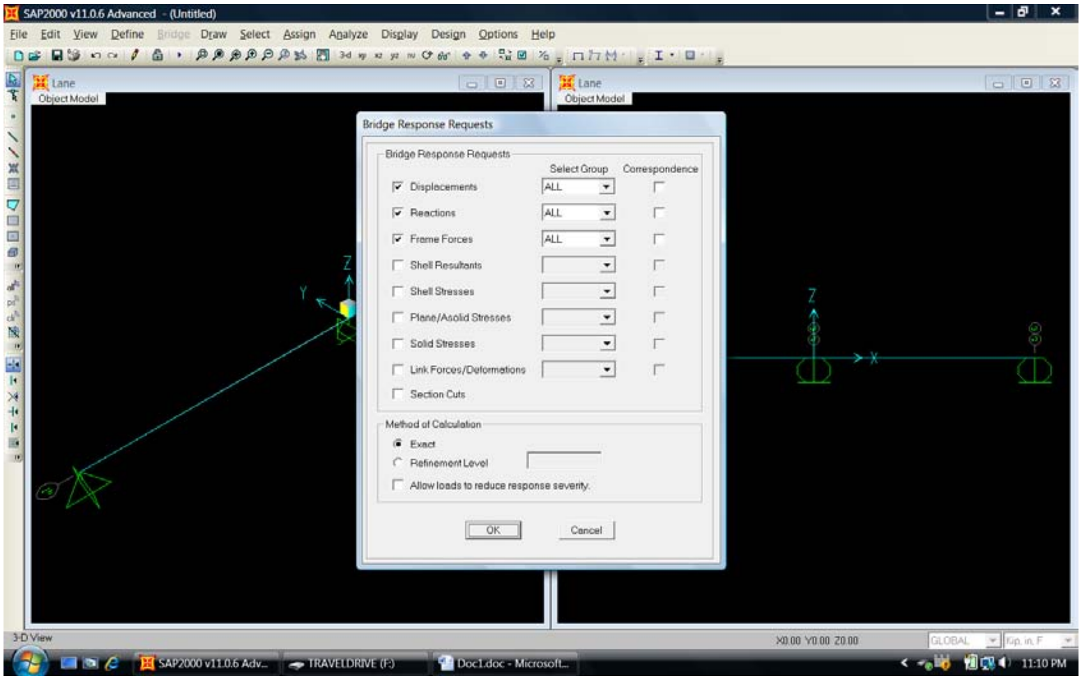
b) Use the default name or a new name for the class

c) Select the vehicle name (e.g., WisDOT Standard Permit Vehicle), and click Add



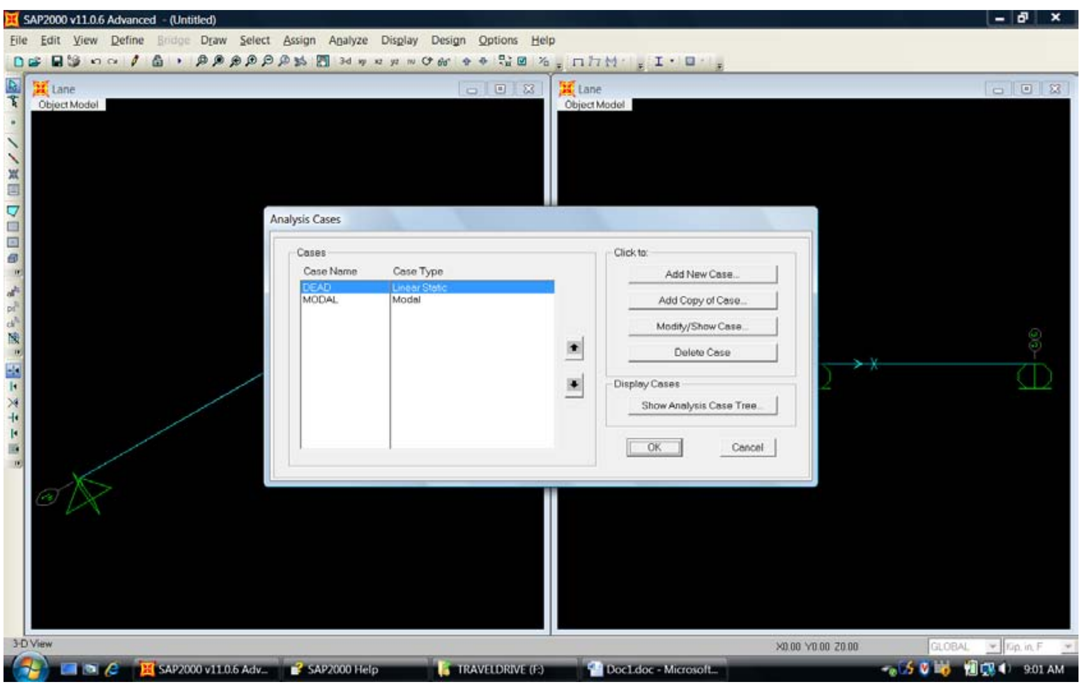
6. Define>Bridge Loads>Vehicle Response Requests: specify the response categories to be analyzed and the calculation method to be used

   a) Check the first three requests and uncheck all others

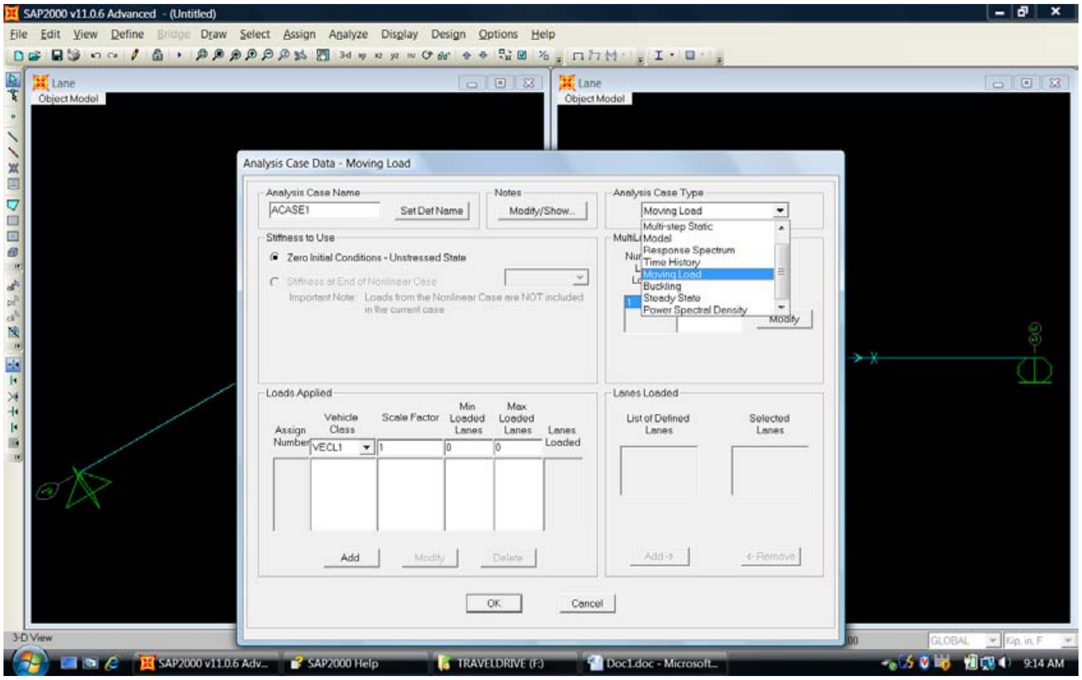


7. Define>Analysis Case: define one or more moving-load analysis cases that assign the vehicles classes to the traffic lanes

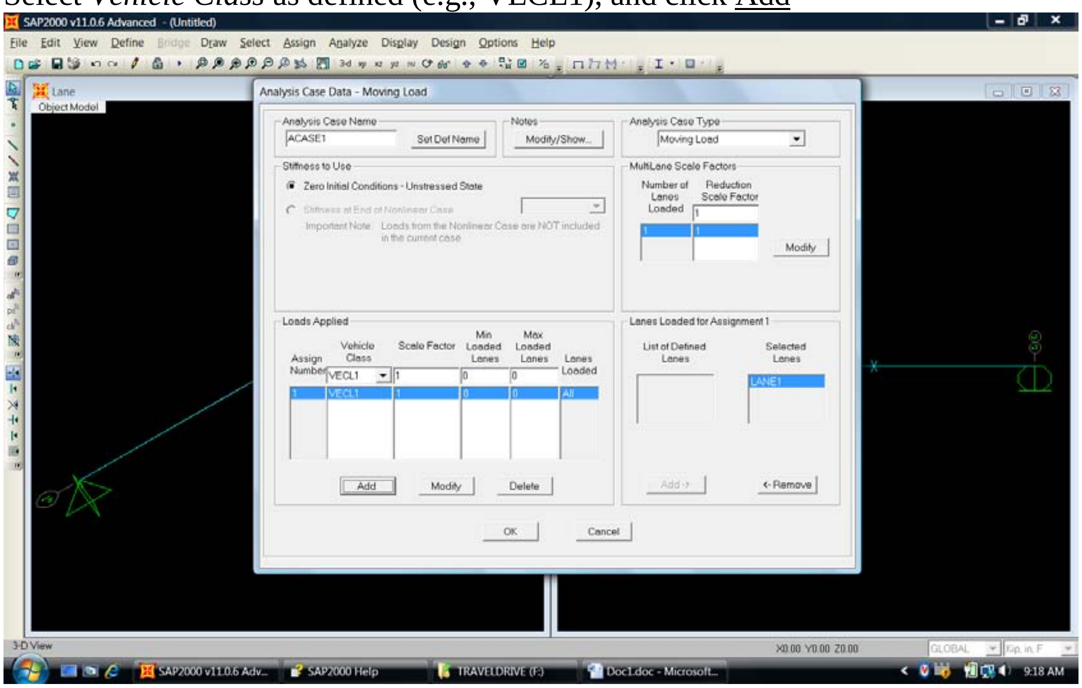
   a) Click Add New Case



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

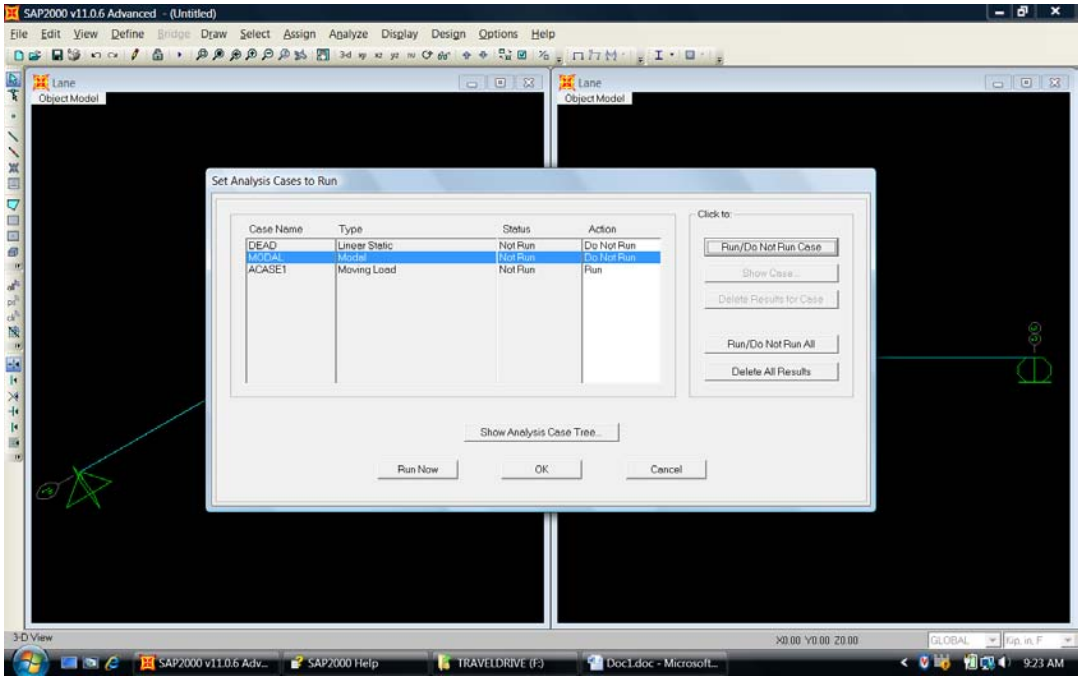


c) Select *Vehicle Class* as defined (e.g., VECL1), and click Add

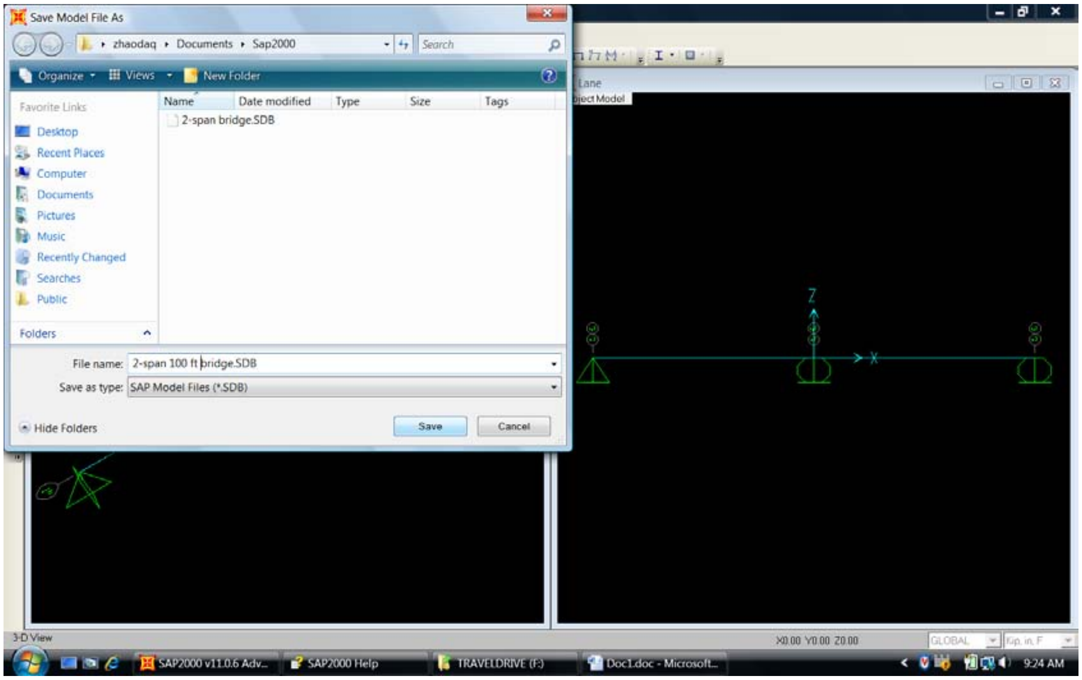


8. Analyze>Run Analysis: define load cases to run

a) Highlight all load cases other than the defined moving load case, and click Run/Do Not Run Case

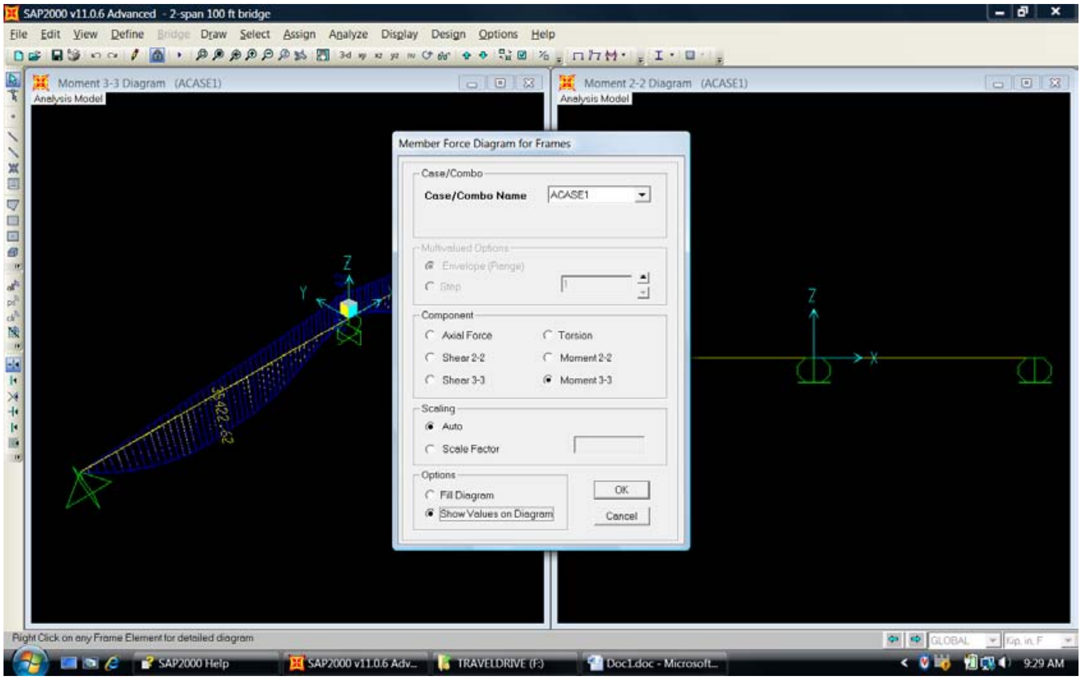


b) Click <u>Run Now</u>, SAP2000 prompt to save the model



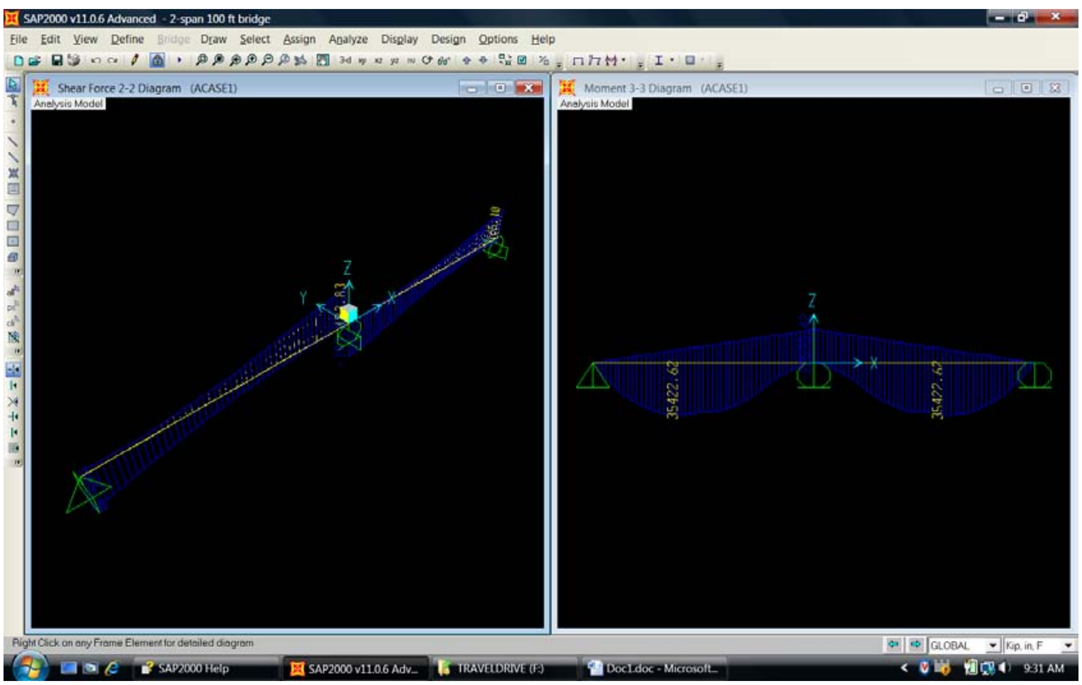
9. Display>Show Forces/Stresses>Frames/Cables: watch the moment/shear envelopes

   a) Select Moment 3-3 for bending moments of the beam, select *Show Values on Diagram*, and click <u>OK</u>



b) Select Shear 2-2 for shear of the beam

c) The values shown the peak points on the moment diagram

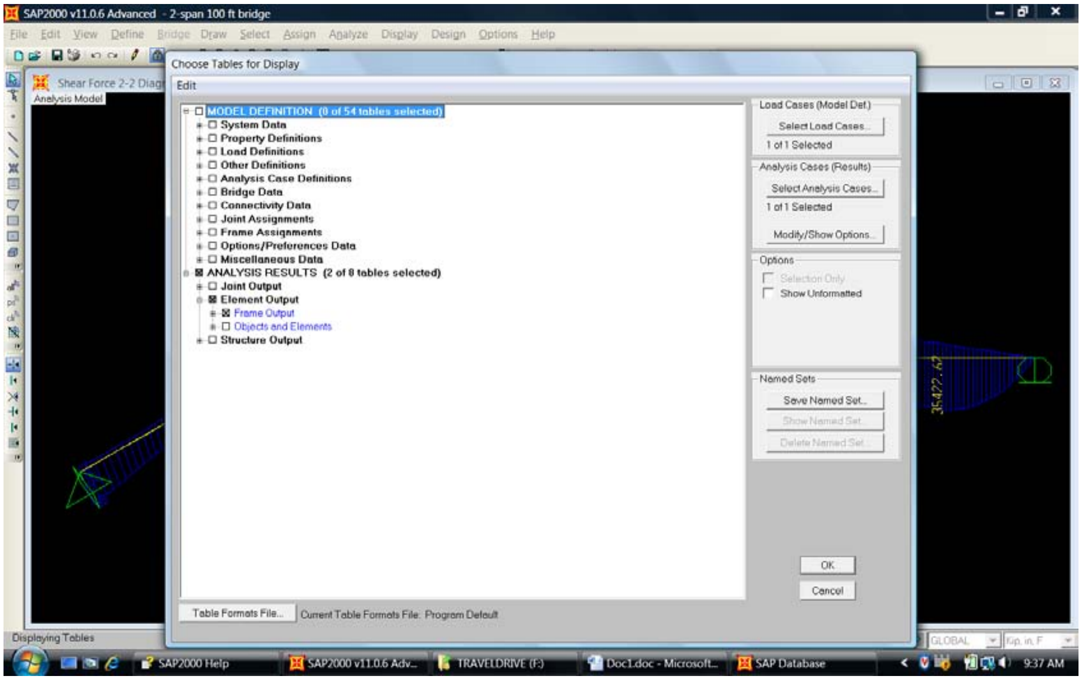


Export Analysis Results

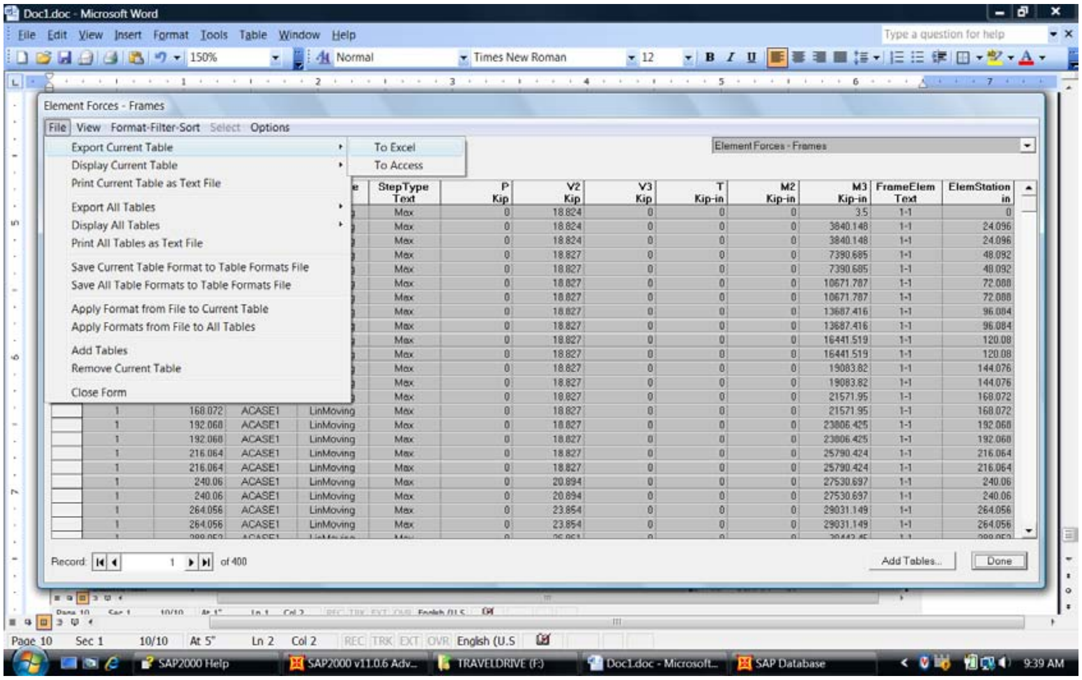
10. Display>Choose Tables for Display: output the results

a) Select ANALYSIS RESULTS>Element Output>Frame Output

b) Leave all others options intact because there is only one load case

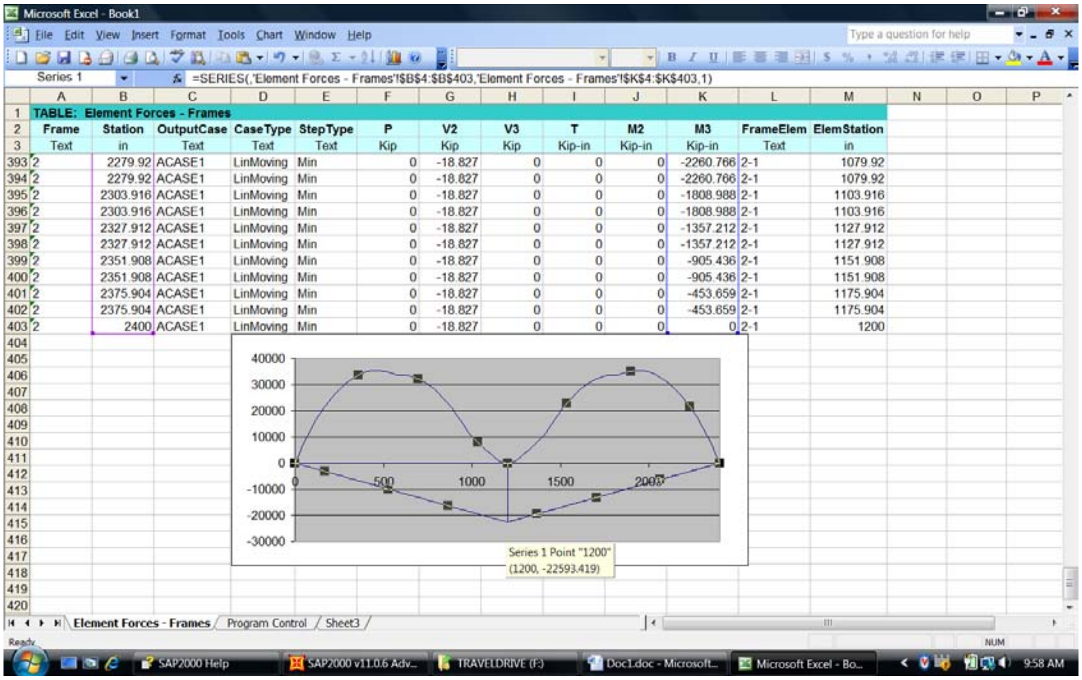


c) On the displayed table, File>Export Current Table>To Excel



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.



	Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem	ElemStation
1	TABLE: Element Forces - Frames												
2	Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem	ElemStation
3	Text	in	Text	Text	Text	Kip	Kip	Kip	Kip-in	Kip-in	Kip-in	Text	in
393	2	2279.92	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-2260.766	2-1	1079.92
394	2	2279.92	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-2260.766	2-1	1079.92
395	2	2303.916	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-1808.988	2-1	1103.916
396	2	2303.916	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-1808.988	2-1	1103.916
397	2	2327.912	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-1357.212	2-1	1127.912
398	2	2327.912	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-1357.212	2-1	1127.912
399	2	2351.908	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-905.436	2-1	1151.908
400	2	2351.908	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-905.436	2-1	1151.908
401	2	2375.904	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-453.659	2-1	1175.904
402	2	2375.904	ACASE1	LinMoving	Min	0	-18.827	0	0	0	-453.659	2-1	1175.904
403	2	2400	ACASE1	LinMoving	Min	0	-18.827	0	0	0	0	2-1	1200

Note:

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

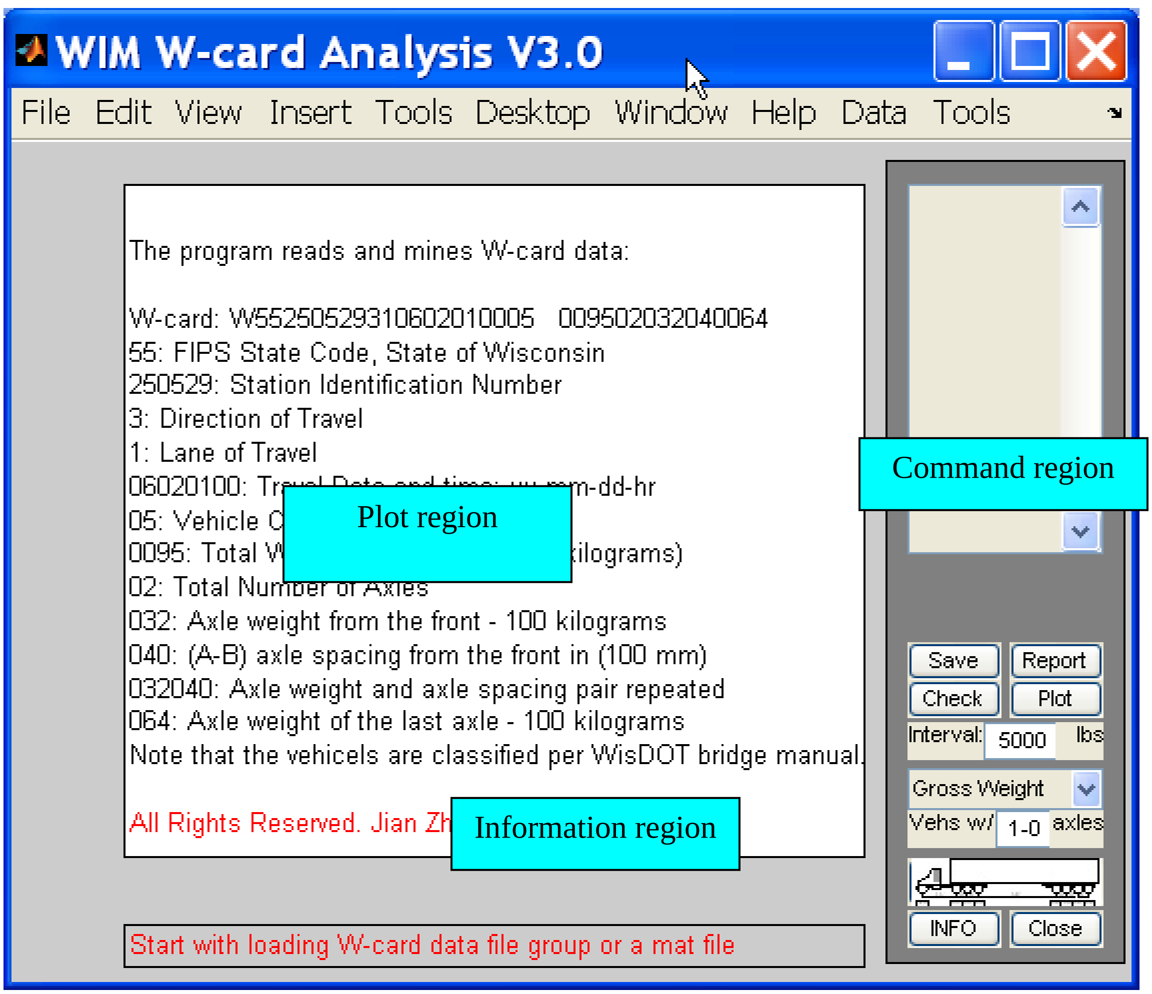
Appendix 2
Introduction to the Matlab® Programs

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

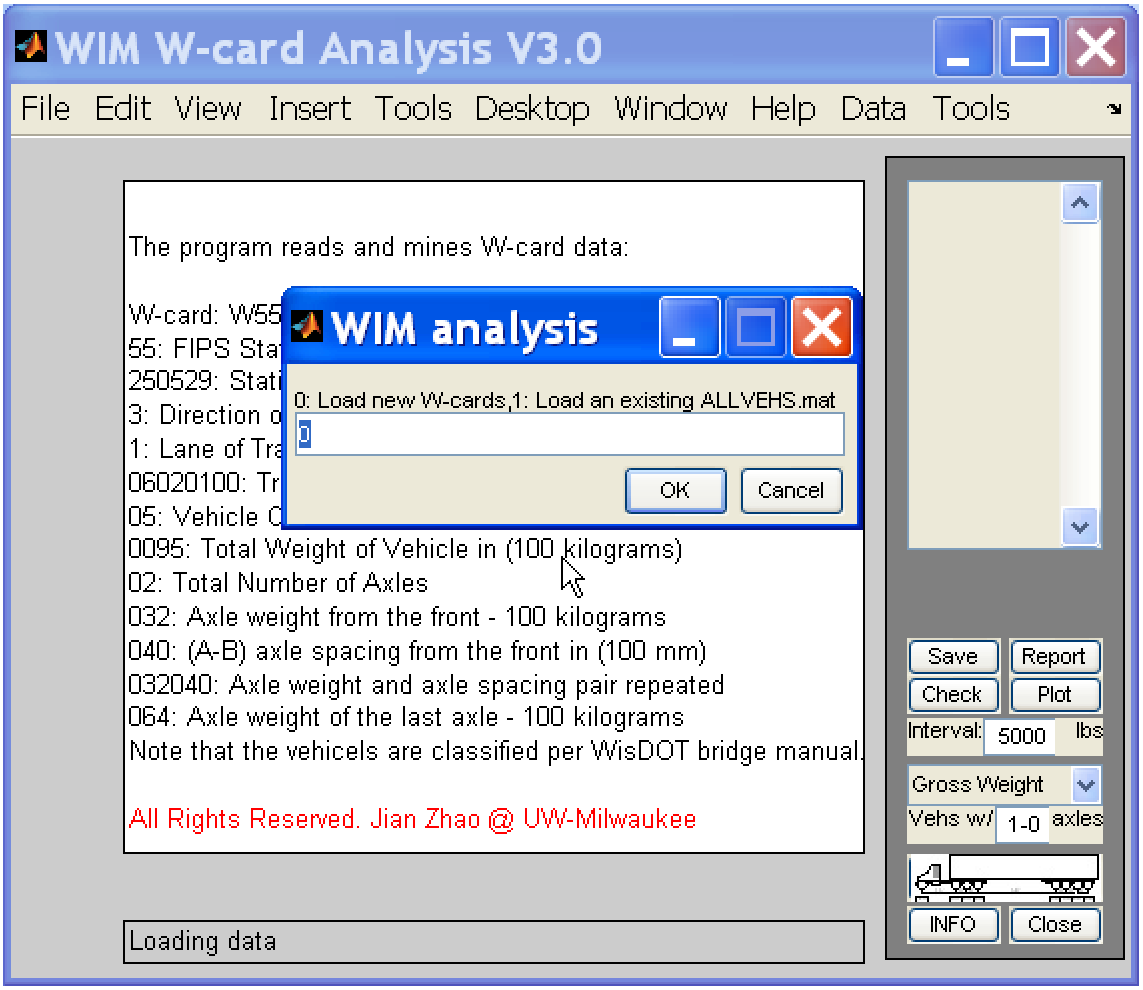
The program WIMan is introduced below. WIMan reads in and mines the WIM records in FHWA W-cards. The program plots histograms of vehicle configurations and output configuration data in text file for post processing. If vehicles have analyzed using WIM_PVEHICLES, the results can be checked using randomly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

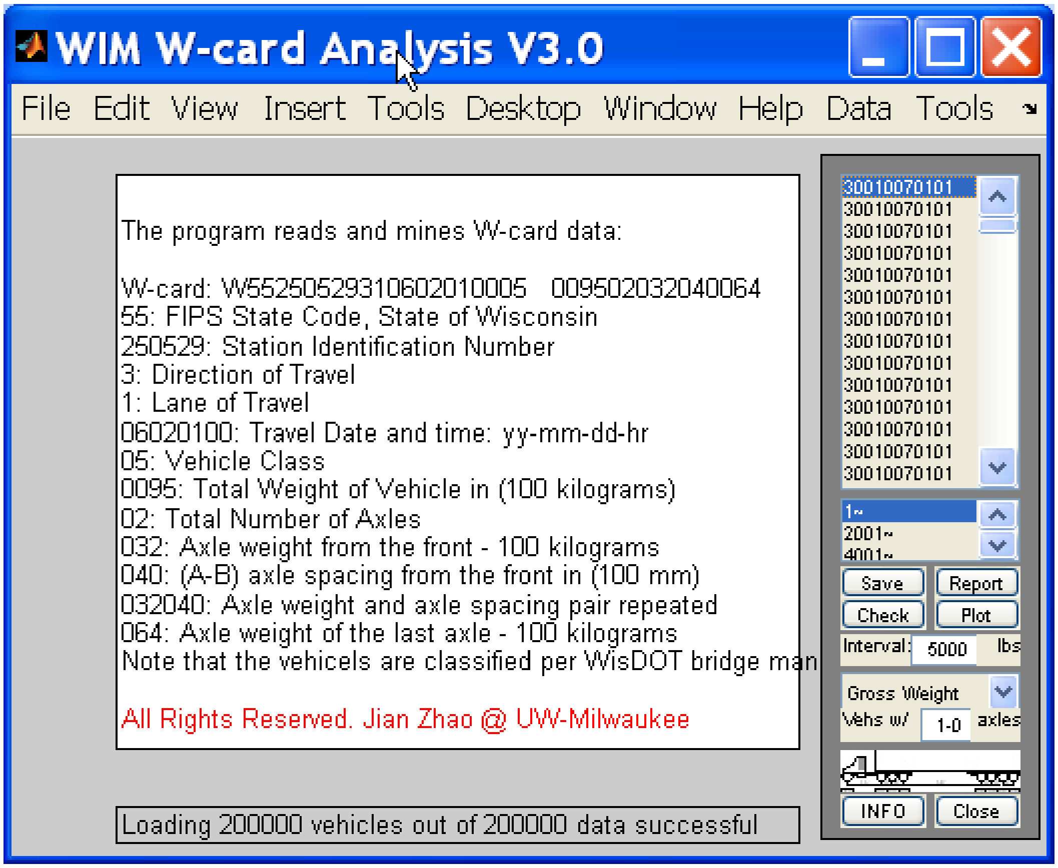


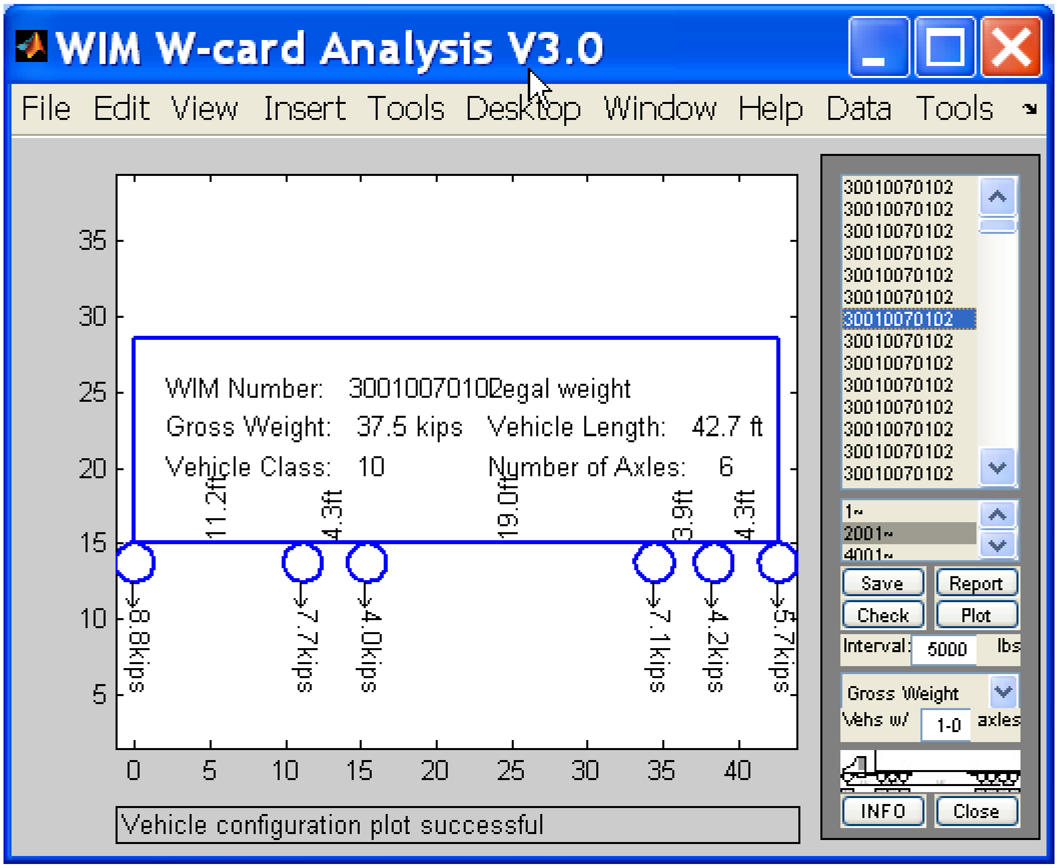
The analysis starts with loading vehicle configurations (either in W-cards or in a .mat file) as noted in the information region by clicking the list box on the upper right side of the window. The program asks for a spreadsheet file that contains the vehicle configurations as shown in the following figure.



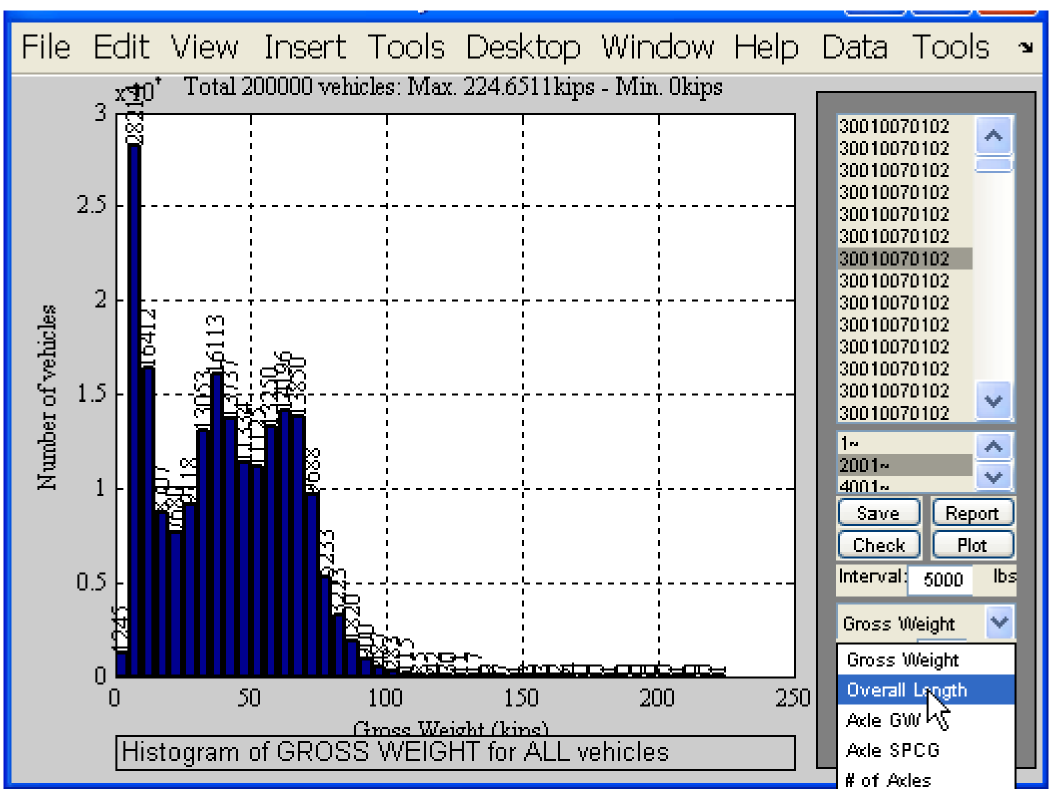
To facilitate the batch reading, a text file containing the W-cards can be specified. The read-in process will produce a mat file named "ALLVEHS.mat,"which can be reloaded to speedup the data mining. The vehicles will be listed after the W-cards are loaded. The program automatically filters out records 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, W552505297107031601050458020320250 32, indicates that the vehicle is class 5 and has 2 axles in total. The two axle weights are 032+032 = 064 (=14kips) 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.

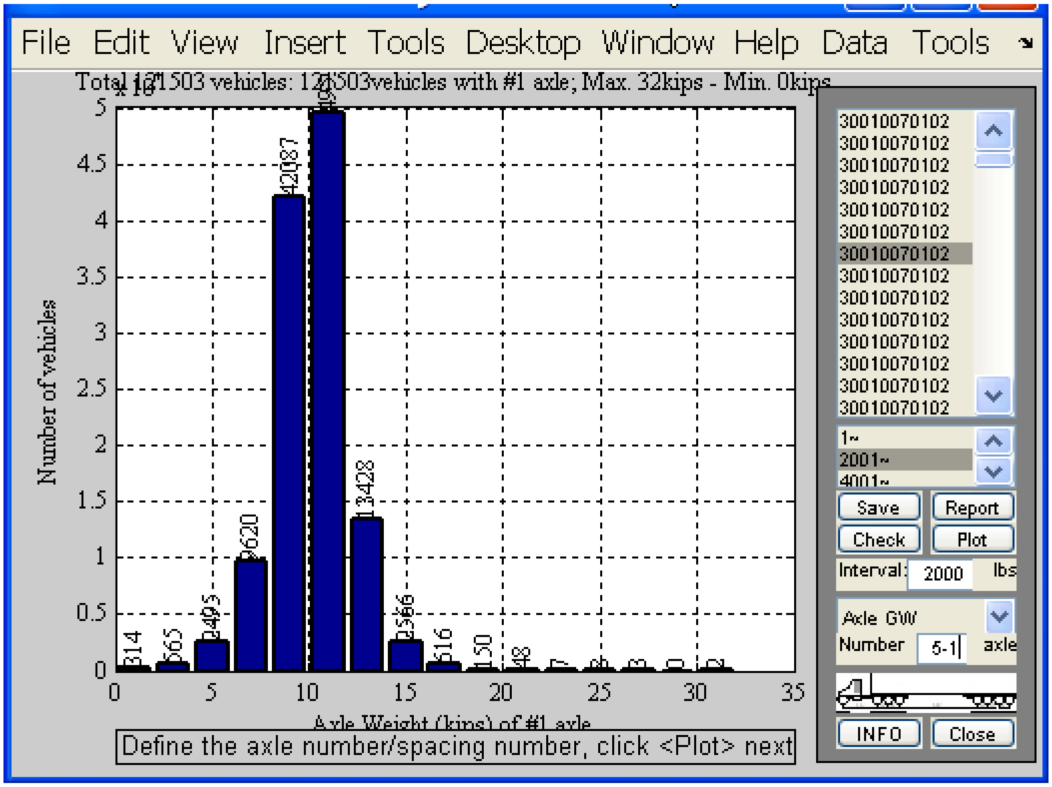

WIM W-card Analysis V3.0
File Edit View Insert Tools Desktop Window Help Data Tools
The program reads and mines W-card data:
W-card: W55250529310602010005 009502032040064
55: FIPS State Code, State of Wisconsin
250529: Station Identification Number
3: Direction of Travel
1: Lane of Travel
06020100: Travel Date and time: yy-mm-dd-hr
05: Vehicle Class
0095: Total Weight of Vehicle in (100 kilograms)
02: Total Number of Axles
032: Axle weight from the front - 100 kilograms
040: (A-B) axle spacing from the front in (100 mm)
032040: Axle weight and axle spacing pair repeated
064: Axle weight of the last axle - 100 kilograms
Note that the vehicels are classified per WisDOT bridge man
All Rights Reserved. Jian Zhao @ UW-Milwaukee
Loading 200000 vehicles out of 200000 data successful
30010070101
1~
2001~
4001~
Save
Report
Check
Plot
Interval:
5000
lbs
Gross Weight
Vehs w/
1-0
axles
INFO
Close



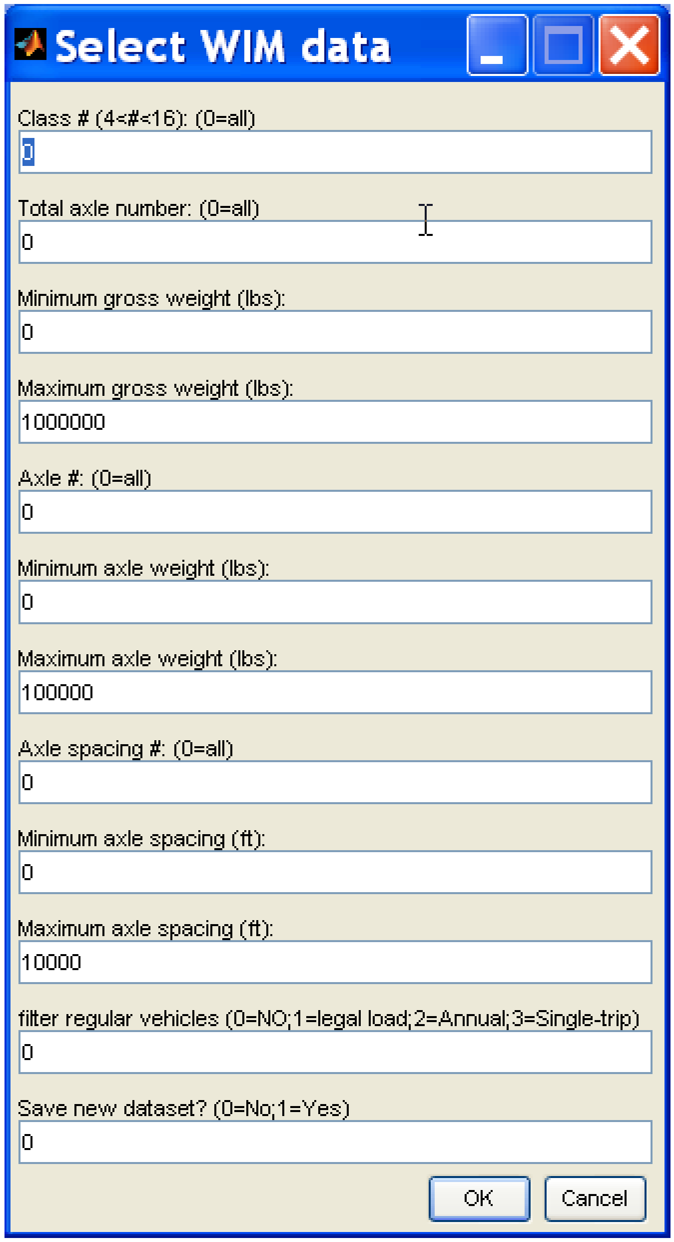
The histogram of the configuration data can be plotted and the bin sized specified as follows



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.



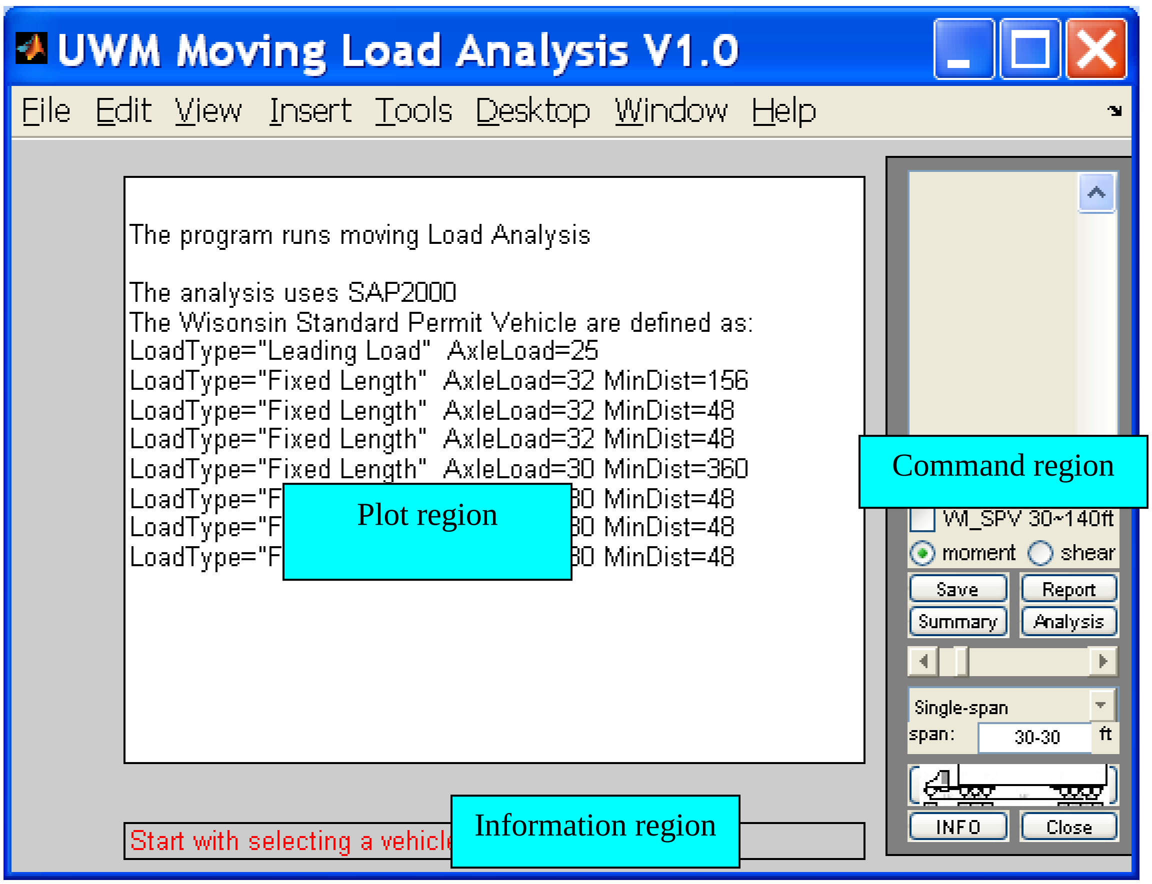
The distribution of the refined data set can be plotted individually by clicking *report button*, and saved by clicking *save button*.

Introduction to Moving Load analysis (MLan) program

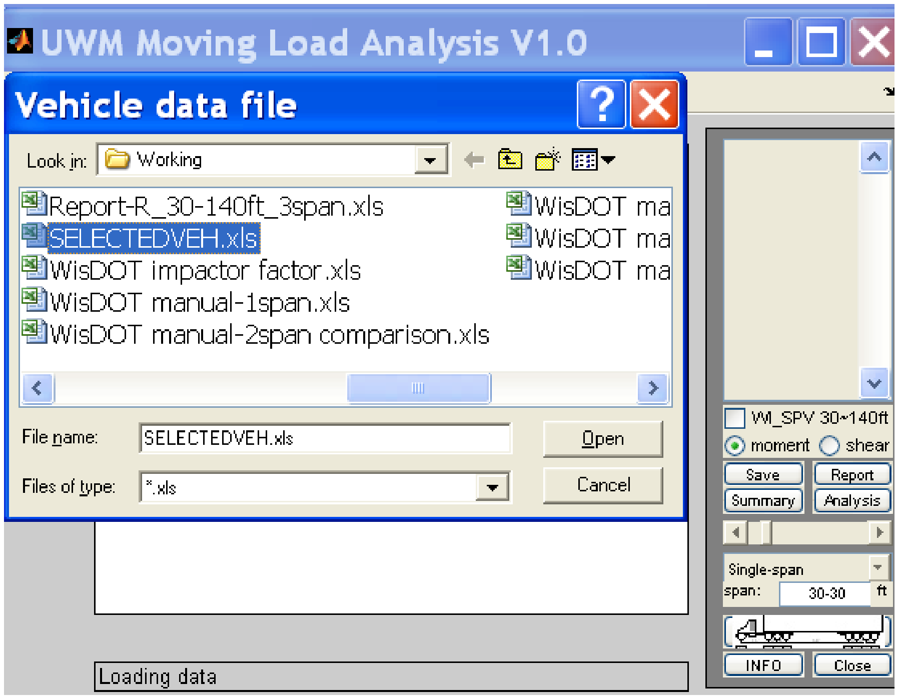
The program MLan is introduced below. The Matlab program provides interface between user inputs on vehicle configurations and girder geometry information and the SAP2000 line girder analysis. The program also controls the SAP2000 line girder analysis and collects the analysis results into a database, 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.



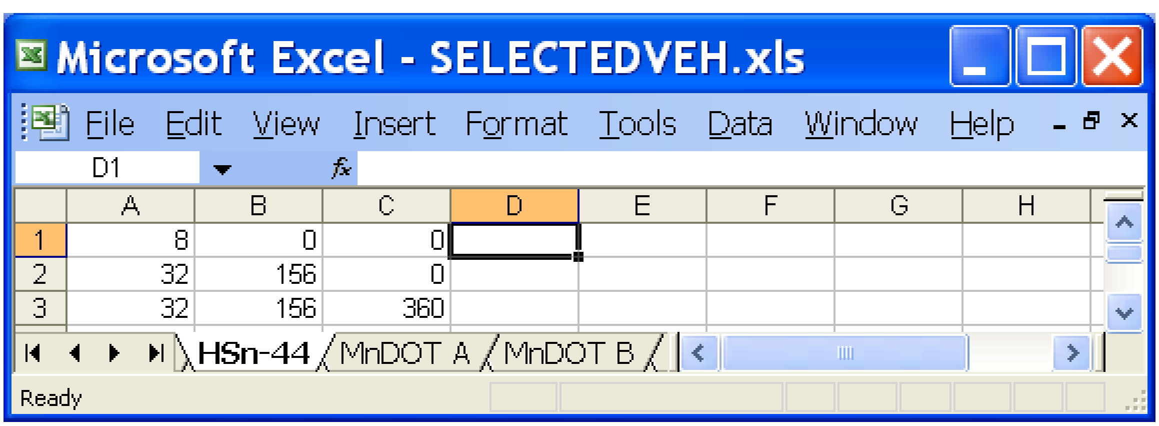
The analysis starts with loading vehicle configurations as noted in the information region by clicking the list box on the upper right side of the window. The program asks for a spreadsheet file that contains the vehicle configurations as shown in the following figure.

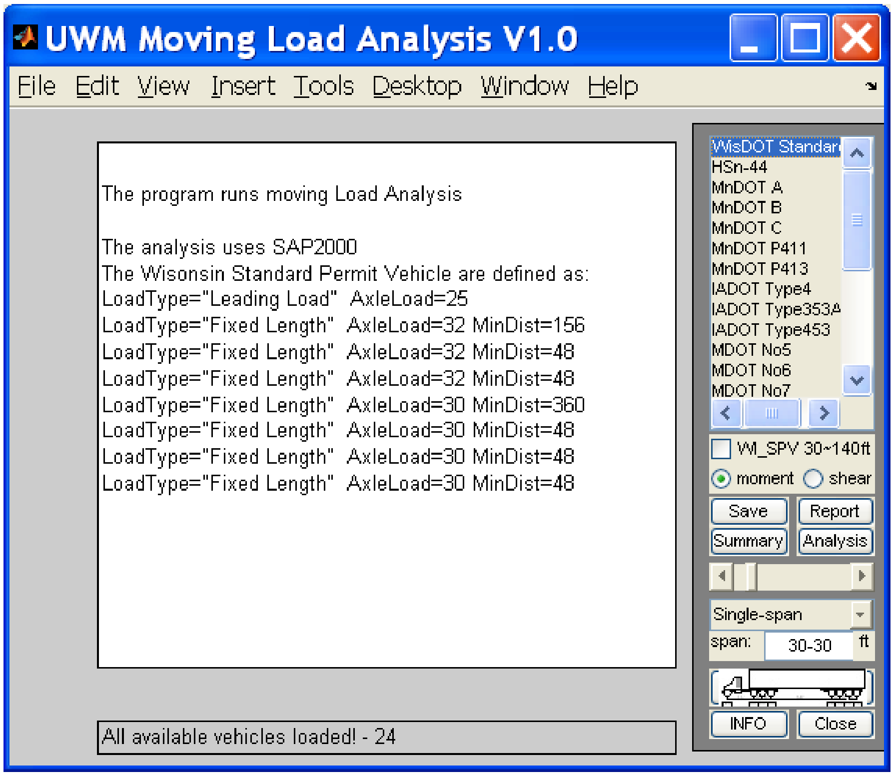


The spreadsheet contains a vehicle per sheet, the name of which is the vehicle name as shown in the list box of the following figure. The format of the vehicle configuration in spreadsheet is

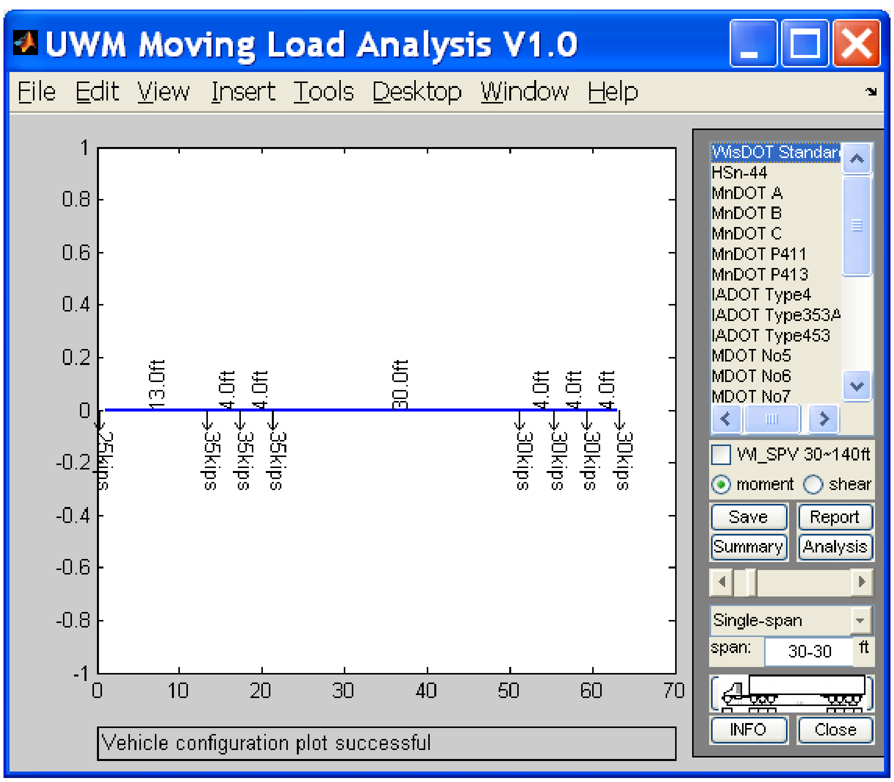
Load	Min. Spacing	Max. Spacing
Leading load (kips)	0	0
Axle weight (kips)	Spacing to leading load (in)	0
Axle weight (kips)	Spacing to previous load (in.)	Spacing to previous load (in.)

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 13ft to 30ft. Note that the sheet name in the spreadsheet cannot contain '_'.

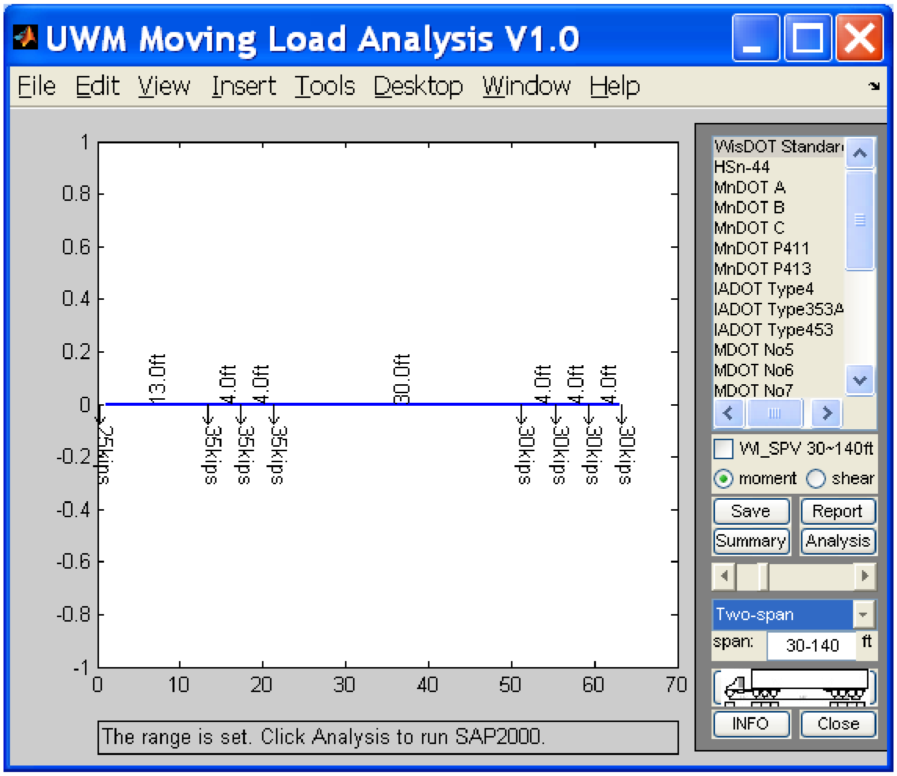


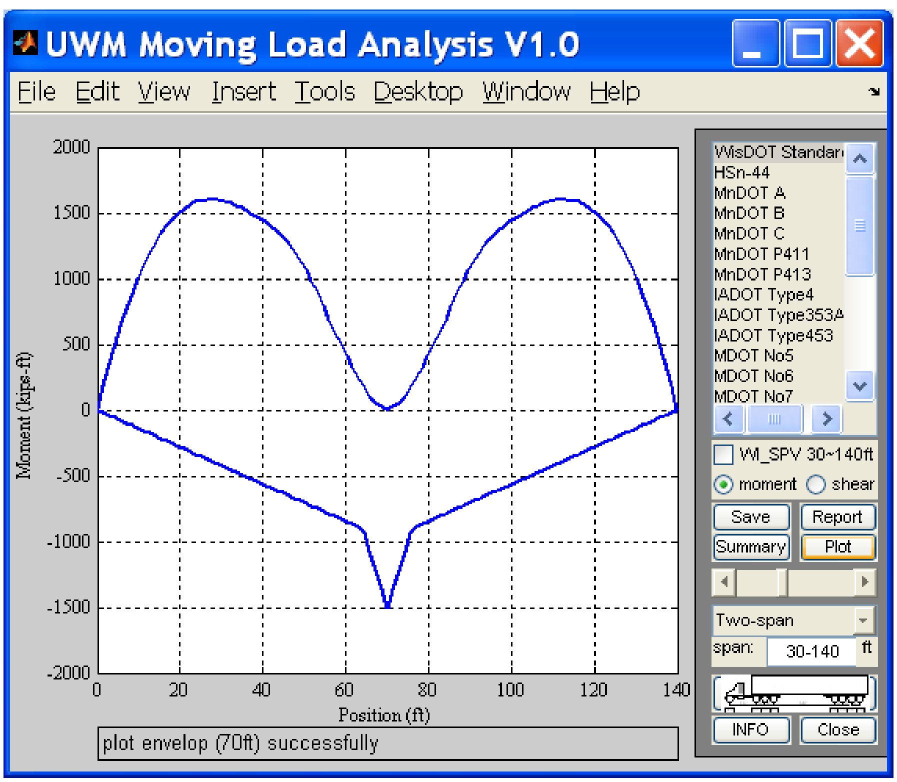


The vehicle configurations can be viewed briefly by highlighting the vehicle name from the list box. An error message would be generated if the vehicle configuration were not input correctly.

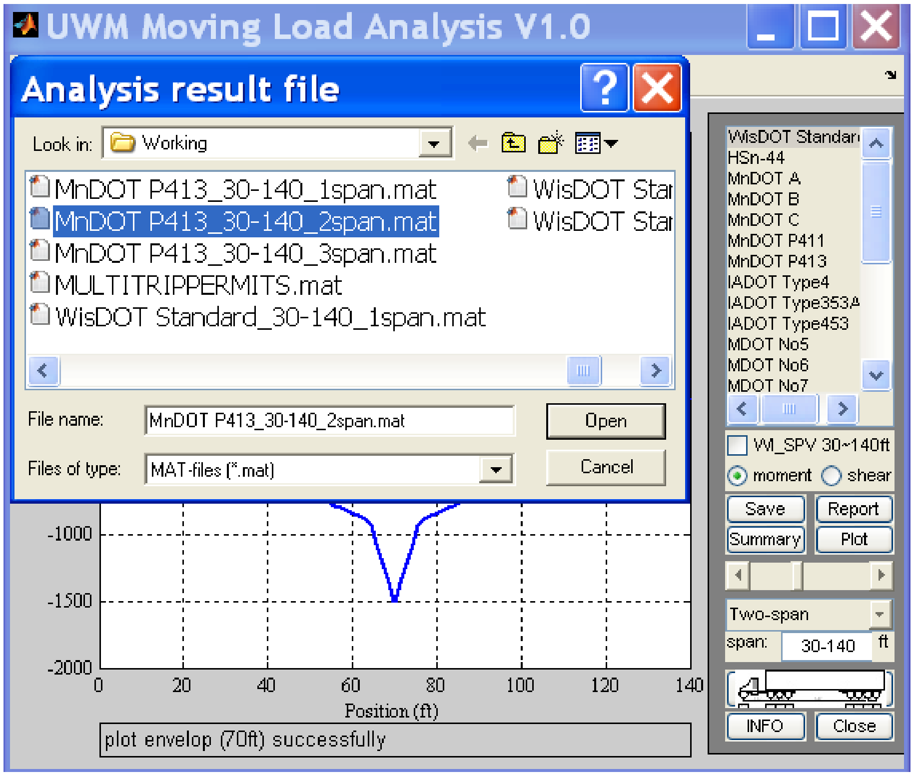


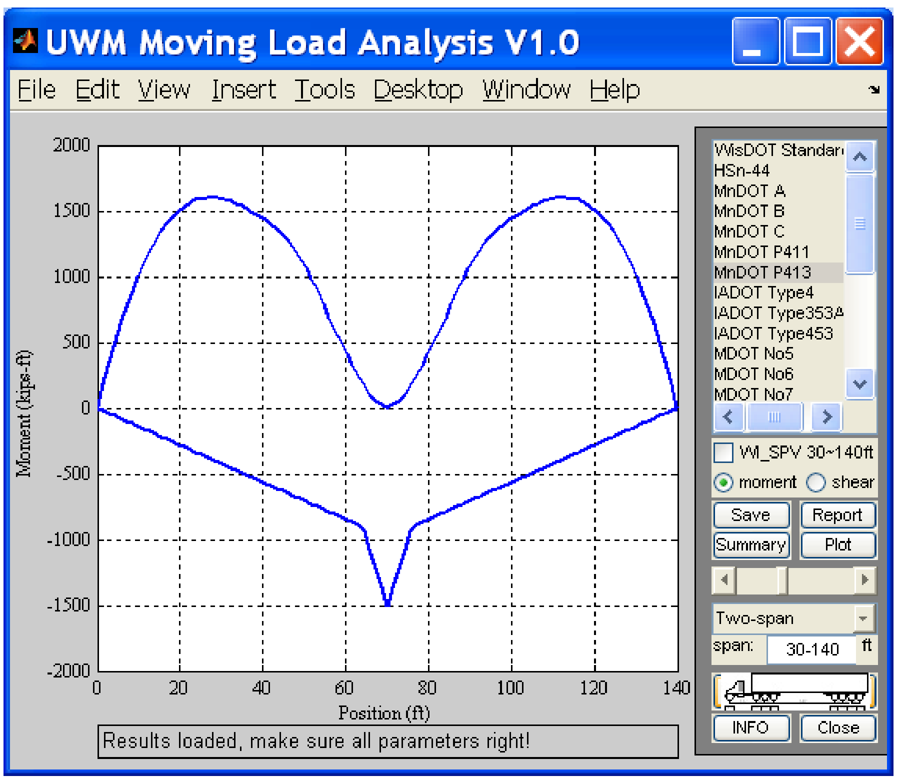
Specify the number of spans the girder to be analyzed has and specify the range of the span length. The program assumes that SAP2000 (Ver. 11 in this study) is installed at the default locations: C:\Progra~1\Comput~1\SAP200~1\Sap2000.exe. The analysis results can be viewed by selecting the span length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



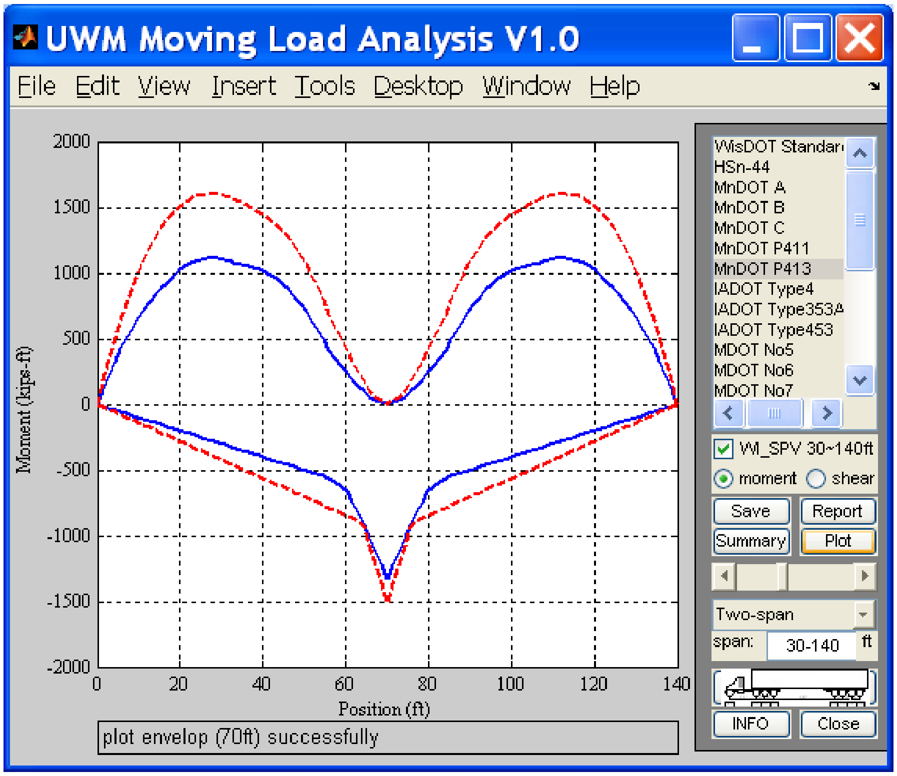


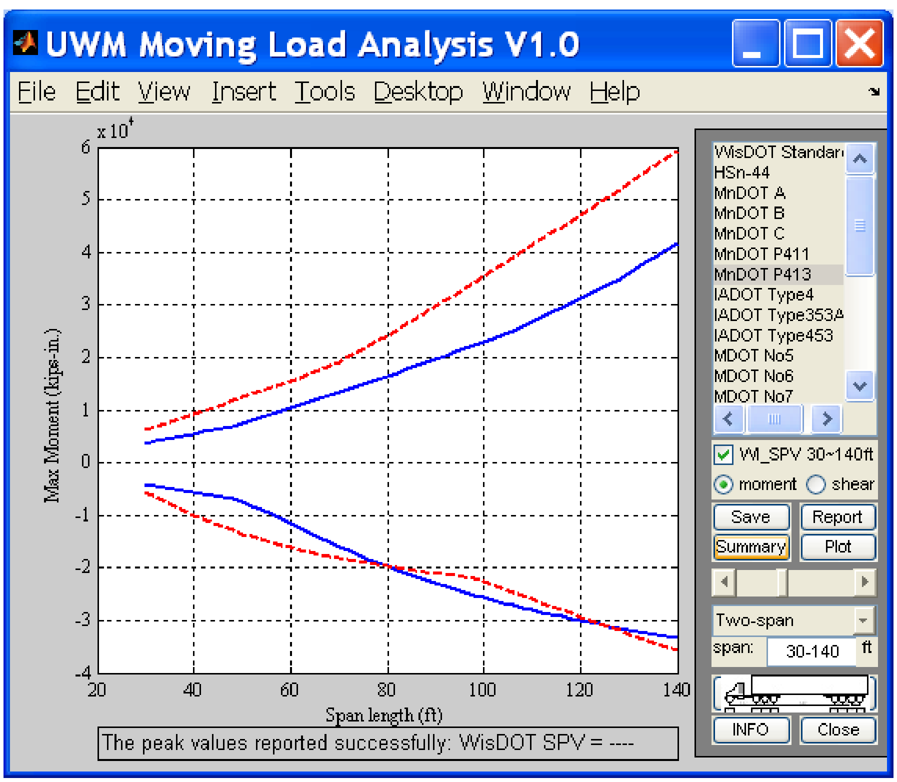
The analysis results can be save as Matlab mat file and spreadsheet file by clicking the save button. And the results can be reloaded to the program by clicking the program logo. The result file name follows the following format for appropriate interpolation of the analysis case: *vehicle name_minmum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



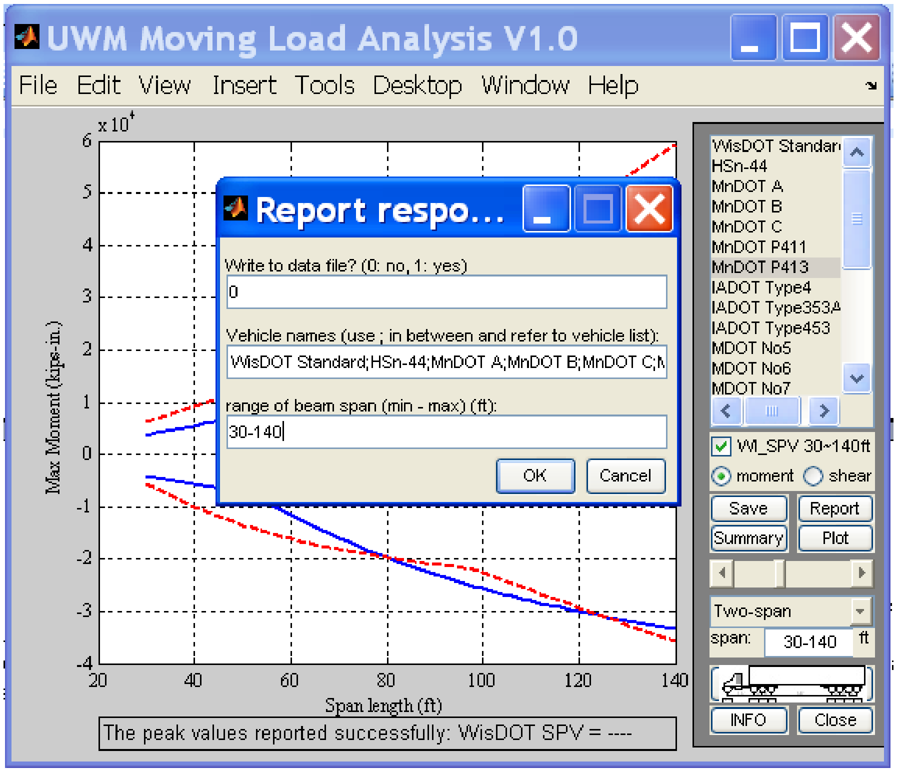


Enable the check box before 'WI_SPV 30~140ft" to show the comparison between the effect of the selected vehicle with that of the WIsDOT Standard Permit Vehicle. Click Summary button to show the comparison of peak values. The effect of the WisDOT Standard Permit Vehicle will be in dashed lines (red) while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

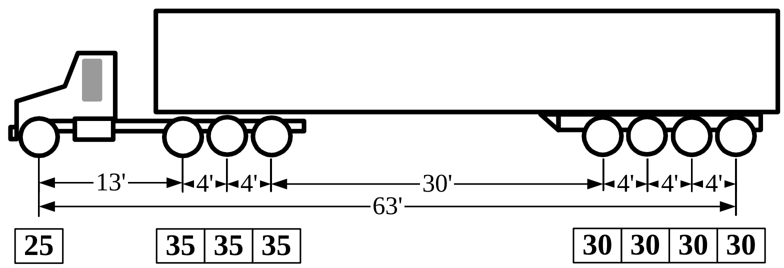


Fig. A3.1 Wisconsin Standard Permit Vehicle

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 30ft to 140ft 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).

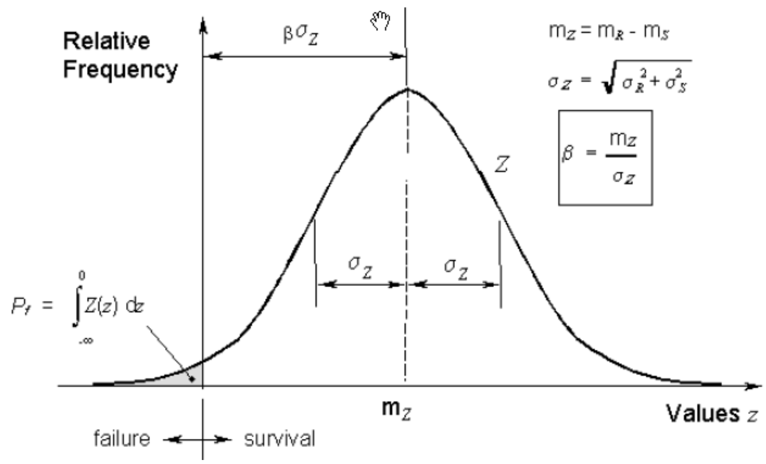


Fig. A3.2 Structural safety in LRFD structural design

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.

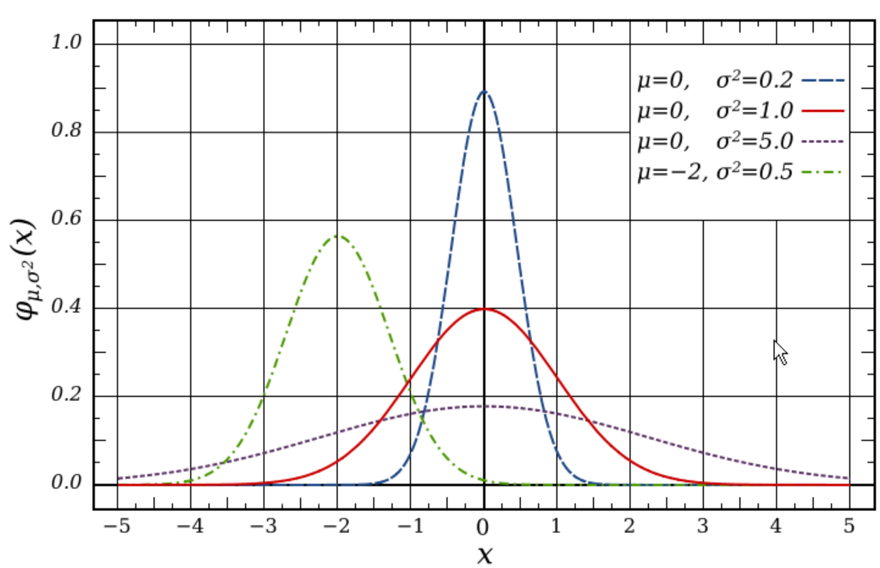


Fig. A3.3 Standard normal distribution

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

$$\mu_X = \sum_x xP(X = x),$$

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 (σ_X) for a discrete random variable (*X*) is given by

$$\sigma_X^2 = \frac{\sum_x (x - \mu_X)^2}{n-1},$$

In the above example, $\sum_x (x - \mu_X)^2 = 82.5$, 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 p% of the population are less than or equal to the value. A median is 50th percentile. For example, to find the 90th 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 90th percentile as $9 + (10-9) \times 90\% = 9.9$. For the 95th 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 95th 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 … 1.1, 1.2, 1.3 … 2.1, 2.2, 2.3 … 10.0, ***20***

The 90th percentile of the new data set would be 9.18 compared with 9.09 for the data set without the number 20. The 95th 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
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 ±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^{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.**	**TOTAL**
0	21456	19122	22183	17186	31204	32899	35081	35617	30815	30399	21611	14416	**311989**
30010	12807	0	0	0	60055	66559	20478	22227	54777	32949	41365	35311	**346528**
40002	0	0	0	0	0	0	6050	29519	22726	24098	18394	13667	**114454**
100001	89409	39056	57911	27132	42302	17412	2041	17082	16896	24379	15069	0	**348689**
220001	27203	26492	35286	38605	70501	63663	67780	73481	61924	74553	61278	46063	**646829**
250529	88486	74797	83352	48932	51497	71679	35772	0	0	0	0	0	**454515**
260001	0	0	0	0	0	0	0	0	0	0	0	0	**0**
360002	8054	6208	0	249	34997	0	0	0	0	24775	80140	77903	**232326**
370006	0	0	0	0	0	0	0	0	0	0	0	0	**0**
390105	61578	24319	8345	7591	35253	0	0	0	0	0	0	0	**137086**
410240	0	0	0	0	228030	215906	200444	222604	198999	234690	199252	177924	**1677849**
410253	0	0	0	0	129640	126113	138187	148541	117502	136091	111740	97566	**1005380**
450239	0	0	0	0	0	0	0	0	0	0	0	0	**0**
470102	6087	4968	6073	3298	2641	0	6230	9115	7421	8761	6687	5047	**66328**
530001	0	0	0	0	0	0	0	0	0	0	0	0	**0**
576051	7291	6772	5655	0	13174	13650	16876	15345	11252	11087	8102	6807	**116011**
590608	38395	27317	35086	41011	49887	47827	54562	57059	44703	53391	41148	33859	**524245**
640348	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**360766**	**229051**	**253891**	**184004**	**749181**	**655708**	**583501**	**630590**	**567015**	**655173**	**604786**	**508563**	**5982229**

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	**749409**
Class 06	15133	9470	12368	11901	31637	25314	23411	27597	26198	27075	24445	17365	**251914**
Class 07	1656	1257	3156	3041	9796	6952	8239	9915	7818	10315	7760	3267	**73172**
Class 08	25836	17226	22899	18617	124162	121046	117640	122218	101025	79634	60791	37978	**849072**
Class 09	204243	117930	124366	90877	442906	364234	323198	369110	336788	418136	403424	359488	**3554700**
Class 10	5547	3778	4560	3024	9676	7498	6044	7877	6346	8574	8491	6349	**77764**
Class 11	3362	1625	1432	955	12768	10631	9091	11039	9798	12271	11348	10258	**94578**
Class 12	687	408	307	185	3977	3402	3004	3570	3164	4165	4016	3692	**30577**
Class 13	971	909	1399	734	1713	1533	1076	510	506	626	570	360	**10907**
Class 14	72	66	396	254	111	148	84						**1131**
Class 15	9730	8708	13921	7183	8430	10611	7167	512	601	721	649	345	**68578**
Total	**328709**	**203794**	**229337**	**168023**	**732661**	**629332**	**569866**	**624638**	**557223**	**632196**	**589806**	**496217**	**5761802**

Table A4.3. Detailed Information on Different Truck Classes

Class	Class - Axles	Un-filtered Count	Filtered Truck Data						H5P		
			Count	Count % of Total	Count % of Class	Min Wt. (Kips)	Max Wt. (Kips)	95th %ile (Kips)	Count	Min Wt. (Kips)	Max Wt. (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 (P) associated with the distribution in that grouping. For example, for a tri-modal distribution:

$$\textit{Multi-Modal Distribution} = P_1 \times \textit{Distribution}_1 + P_2 \times \textit{Distribution}_2 + P_3 \times \textit{Distribution}_3$$

- 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. W-Card spacing data are given in 100mm'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**	**% of Total**
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**	**% of 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 100kg's. W-Card spacing data are given in 100mm's. The parameters are used to generate the particular distributions, say beta4 or student3.

Table A4.6. Typical Single Mode Statistical Distributions[3]

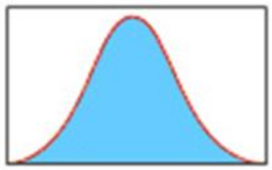
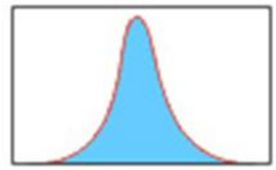
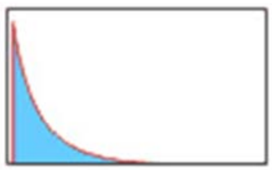
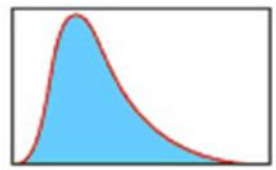
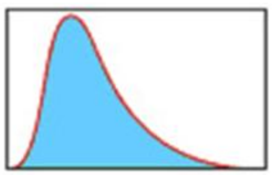
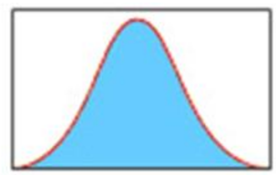
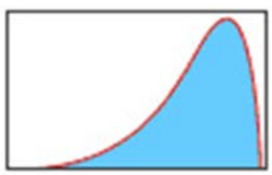
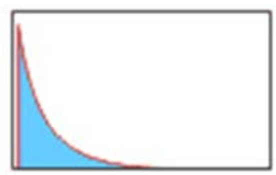
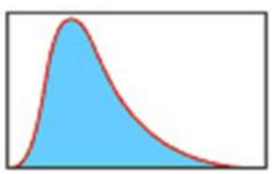
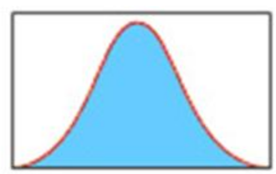
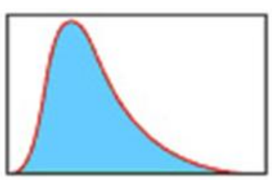
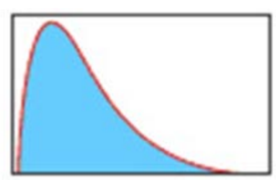
Distribution	Parameters	Chart	Distribution	Parameters	Chart
Beta4	a, b, min, max		**Logistic**	a, b	
Exponential	b		**Lognormal**	m, s	
Extreme Value Max	a, b		**Normal**	m, s	
Extreme Value Min	a, b		**Pareto**	q, a	
Gamma	a, b		**Student3**	m, s, n	
LogGamma	a, b, g		**Weibull**	a, b	

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

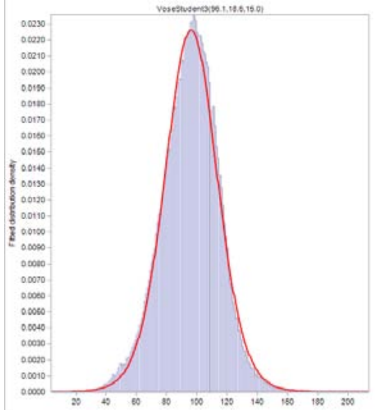
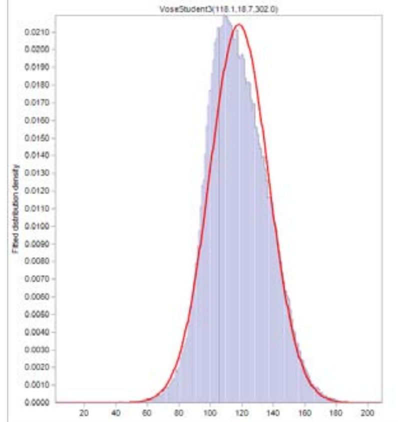
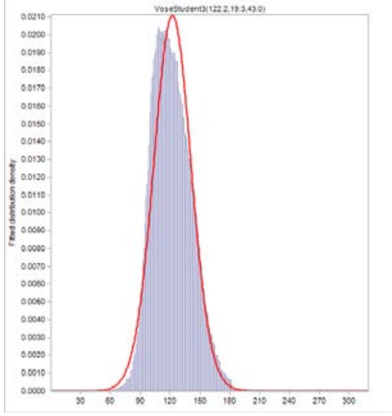
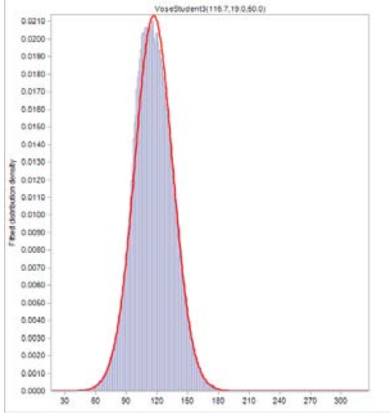
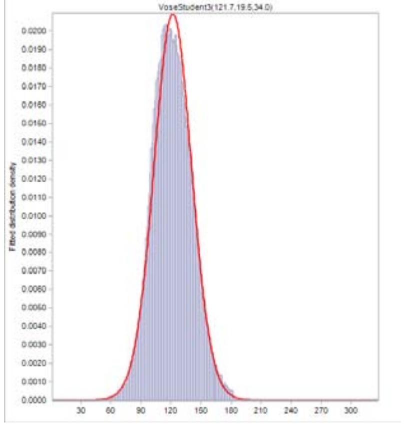
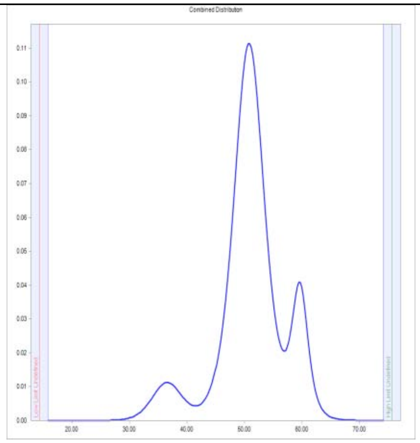
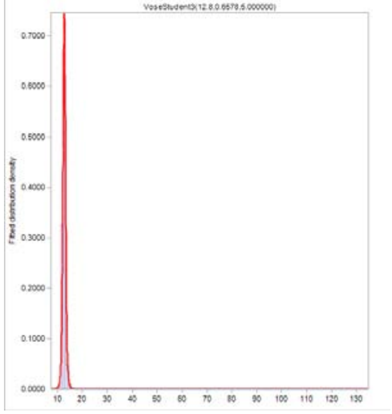
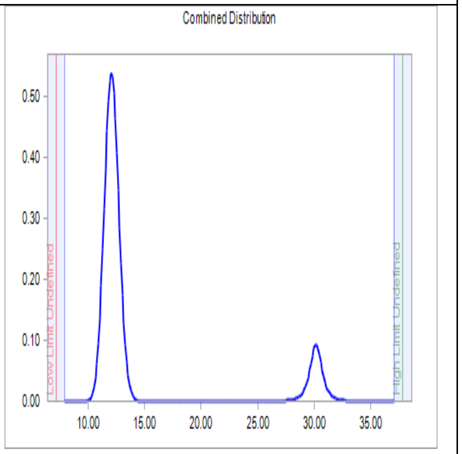
 Axle A	 Axle B	 Axle C	 Axle D
 Axle E	 AB Spacing	 BC Spacing	 DE Spacing

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

Class	No. of axles	Total WT kips	A axle Wt kips	A-B sp. (ft)	B axle Wt kips	B-C sp. (ft)	C axle Wt kips	C-D sp. (ft)	D axle Wt kips	D-E sp. (ft)	E axle Wt 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	Total WT kips	A axle Wt kips	A-B sp. (ft)	B axle Wt kips	B-C sp. (ft)	C axle Wt kips	C-D sp. (ft)	D axle Wt kips	D-E sp. (ft)	E axle Wt kips	E-F sp. (ft)	F axle Wt kips	F-G sp. (ft)	G axle Wt kips	G-H sp. (ft)	H axle Wt kips	H-I sp. (ft)	I axle Wt kips	I-J sp. (ft)	J axle Wt kips	J-K sp. (ft)	K axle Wt kips	K-L sp. (ft)	L axle Wt 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) Gross Weight > 80 kips (% of H5P)	(b) Leading Axle > 13 kips (% of H5P)	(c) 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 a, b, c) are not met. It does not check tandem limitations**

COPULAS

The motivation behind determining statistical distributions for each parameter in a truck class-axle 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	AB spacing	B Axle load	BC spacing	C Axle load	CD spacin	D Axle load	DE spacing	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 due to Input truck on Simply Supported Bridge 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
50.0	949.8	93.4	1380.7	114.0
60.0	1221.8	104.2	1729.9	133.2
70.0	1629.8	115.2	2081.3	149.0
80.0	2185.3	128.5	2586.4	161.4
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

Total Length of Truck	80	FT (from Front axle to back axle)
Total Weight of Truck	221	kips
No. of Axles	10	
FHWA Bridge Formula	122.4	kips (for the entire truck)
Ratio FHWA WT/WT	0.55	

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

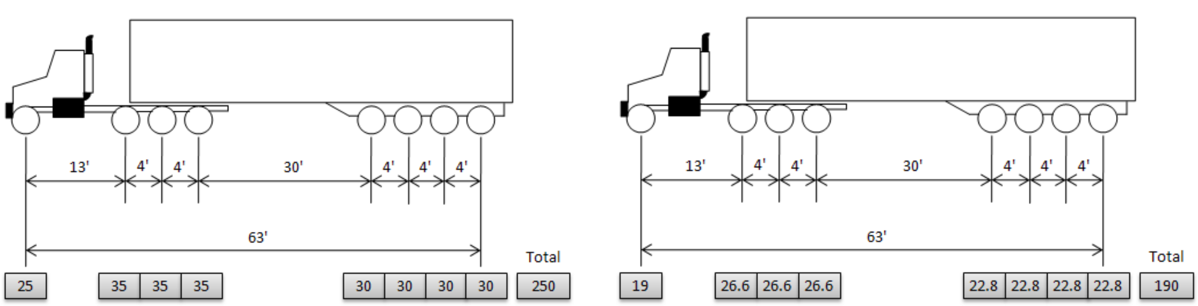


Fig. A4.2. The 250-kip and 190-kip Wisconsin Permit Vehicles.

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 Moment	Forecast Percentile (K-FT)										
Span (FT)	0	10	20	30	40	50	60	70	80	90	100
20	133.3	193.6	207.2	217.5	226.8	235.2	244.0	253.8	264.7	279.9	371.2
30	252.8	334.6	352.8	368.4	381.4	395.4	409.8	424.3	441.4	465.6	610.7
40	372.3	473.2	498.5	520.0	539.8	558.9	578.2	599.6	623.4	657.0	960.5
50	525.7	633.6	665.5	694.5	721.8	748.3	774.1	803.1	834.7	882.8	1318.5
60	685.0	799.1	839.3	876.6	910.7	944.5	977.4	1013.5	1054.9	1115.3	1847.5
70	848.0	977.1	1026.1	1074.8	1115.8	1156.0	1196.5	1241.2	1293.9	1364.4	2430.2
80	1003.9	1203.8	1268.0	1324.5	1374.3	1425.7	1477.4	1530.9	1600.7	1692.4	2999.0
90	1220.3	1481.8	1557.0	1623.4	1684.0	1749.7	1812.7	1880.9	1964.3	2076.5	3562.1
100	1471.8	1769.5	1854.1	1931.6	2003.7	2079.4	2156.5	2236.9	2336.6	2465.3	4164.7
110	1748.2	2057.7	2154.3	2241.0	2324.4	2413.1	2503.9	2597.2	2710.2	2857.8	4709.7
120	2026.3	2346.4	2451.7	2549.5	2643.6	2745.8	2849.8	2954.0	3084.0	3255.2	5277.5
130	2300.9	2637.2	2749.7	2857.7	2965.7	3081.0	3195.0	3316.3	3459.2	3650.7	5894.9
140	2587.6	2924.3	3047.4	3163.0	3284.2	3413.1	3540.8	3673.3	3832.4	4044.3	6478.3
150	2869.0	3214.5	3345.1	3473.5	3605.0	3744.6	3889.8	4036.1	4205.9	4444.0	7046.3
160	3139.5	3502.3	3643.5	3784.3	3925.7	4080.3	4238.7	4394.7	4580.0	4841.7	7588.5
170	3409.9	3790.8	3942.1	4089.6	4249.1	4413.0	4585.8	4756.7	4954.0	5239.6	8182.1
180	3695.7	4081.0	4239.6	4397.6	4568.9	4746.7	4932.4	5116.1	5333.0	5634.1	8746.4
190	3960.7	4368.5	4538.5	4710.8	4888.5	5084.0	5283.2	5478.9	5707.2	6030.8	9321.1
200	4244.5	4655.1	4835.5	5012.2	5215.2	5413.3	5627.3	5837.9	6083.8	6422.8	9904.0
210	4534.0	4940.7	5133.7	5320.8	5531.4	5744.9	5972.3	6194.0	6456.5	6816.8	10494.2
220	4806.4	5231.6	5432.3	5631.3	5853.9	6080.0	6319.6	6559.6	6828.6	7218.8	11046.7
230	5081.8	5518.7	5732.0	5938.3	6175.7	6414.2	6669.6	6919.8	7203.6	7615.4	11655.0
240	5333.9	5807.5	6029.6	6246.3	6496.6	6747.1	7013.7	7275.5	7576.8	8004.6	12161.8
250	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-WPV 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 1-percentile 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 H5P 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:

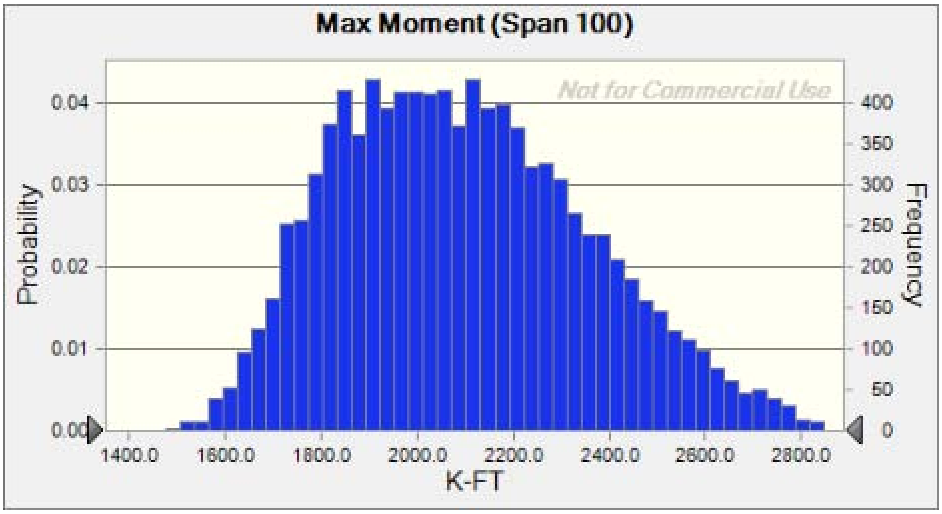
$$\text{Total percentile} = 95 + (\text{H5P percentile}) \times 0.05$$

Figures 5 and 6 show plots of 250-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-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.

Cell: B18

Forecast: Max Moment (Span 100)

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

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.

Max Shear	250-WPV		
Span	Shear (kips)	Percentile of H5P	Percentile of Total
20	84.0	100.00%	100.00%
30	98.9	100.00%	100.00%
40	106.3	100.00%	100.00%
50	114.0	99.73%	99.99%
60	133.2	99.87%	99.99%
70	149.0	99.96%	100.00%
80	161.4	100.00%	100.00%
90	169.6	100.00%	100.00%
100	178.8	100.00%	100.00%
110	184.8	100.00%	100.00%
120	190.5	100.00%	100.00%
130	195.6	100.00%	100.00%
140	200.3	100.00%	100.00%
150	203.2	100.00%	100.00%
160	205.1	100.00%	100.00%
170	207.3	100.00%	100.00%
180	209.2	100.00%	100.00%
190	211.4	100.00%	100.00%
200	214.3	100.00%	100.00%
210	217.4	100.00%	100.00%
220	217.7	100.00%	100.00%
230	218.7	100.00%	100.00%
240	219.7	100.00%	100.00%
250	220.6	100.00%	100.00%

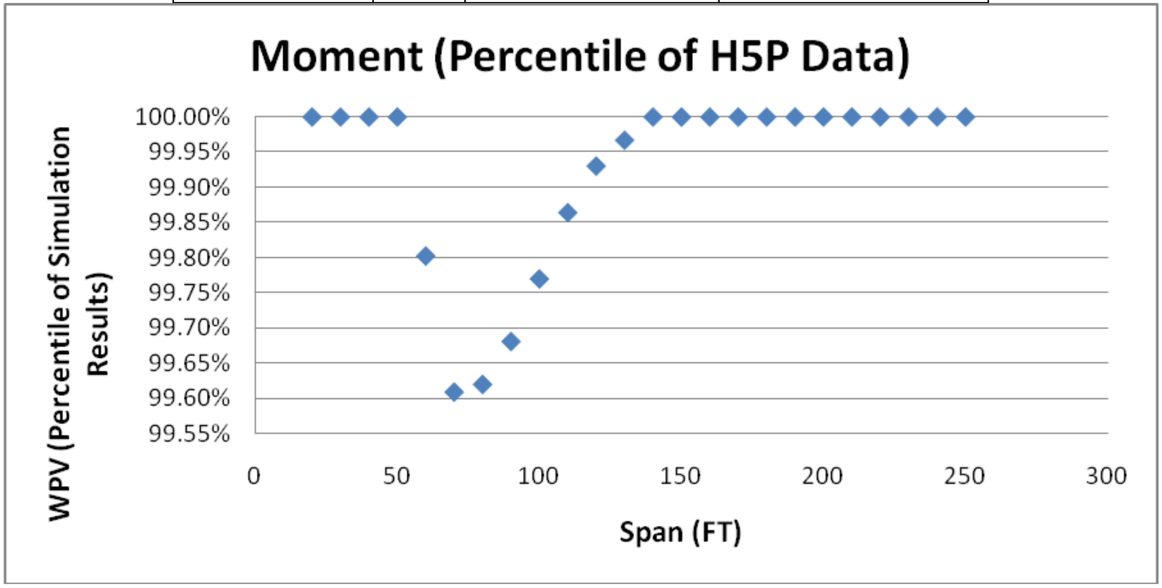


Fig. A4.4. Wisconsin 250-WPV Moment Results Compared to H5P Class 9 Truck Simulations

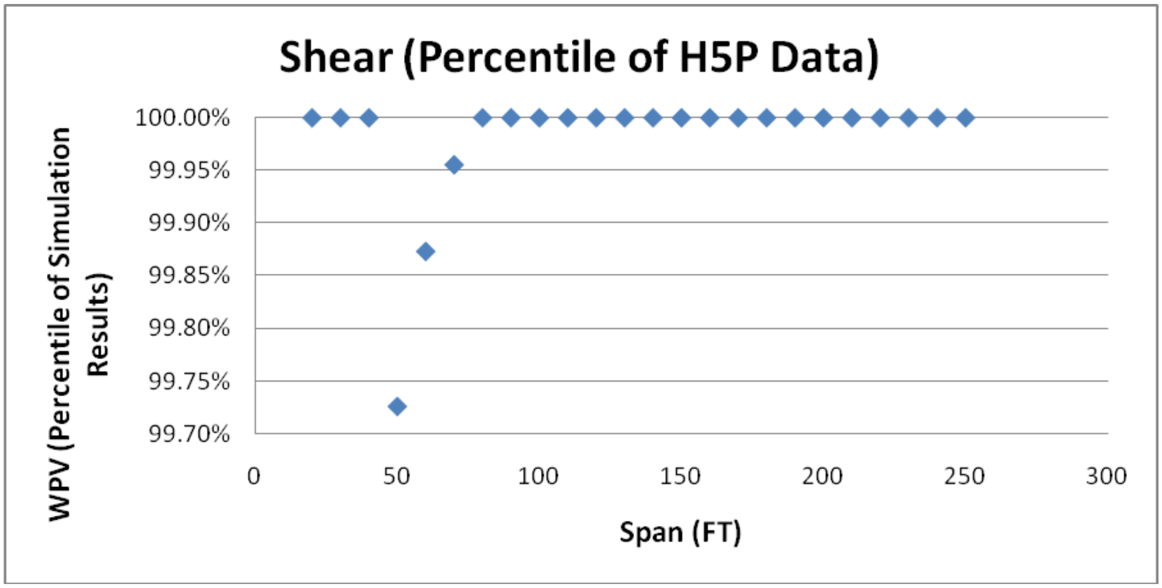


Fig. A4.5. Wisconsin 250-WPV Shear Results Compared to H5P Class 9 Truck Simulations

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 07-04. The H5P data for the 190-WPV reached as low as 50 percentile.

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

Span (ft)	Class 05-06	Class 06-03	Class 07-04	Class 07-05	Class 08-03	Class 08-04	Class 09-05	Class 10-06	Class 11-05	Class 12-06	Class 13-07	Class 15-03	Class 15-04	Class 15-05	Class 15-06
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	99.8	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

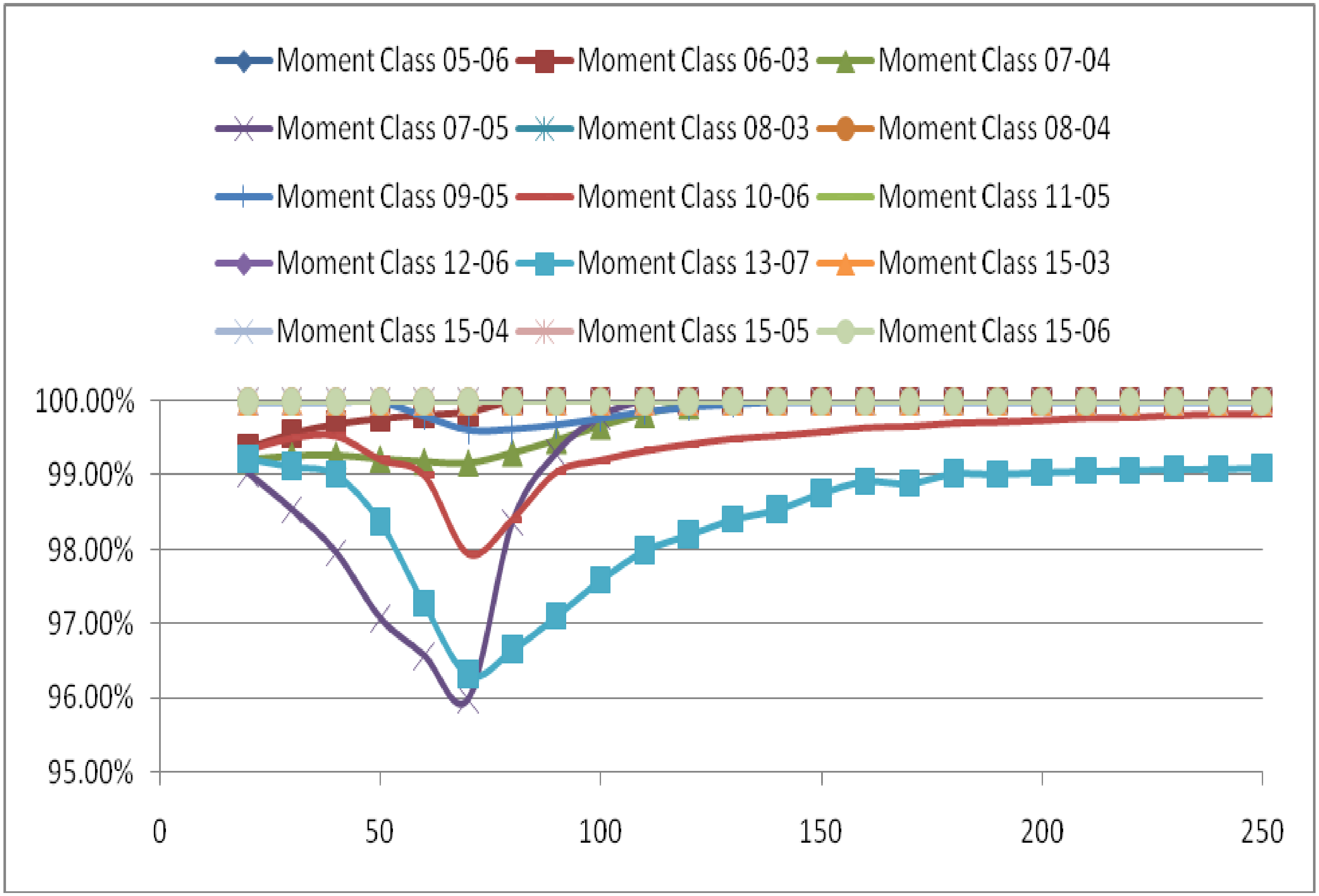


Fig. A4.6. Plot of 250-WPV moments as percentile of H5P data versus span length (ft) for each truck class-axle group.

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

Span (ft)	**Class 05-06**	**Class 06-03**	**Class 07-04**	**Class 07-05**	**Class 08-03**	**Class 08-04**	**Class 09-05**	**Class 10-06**	**Class 11-05**	**Class 12-06**	**Class 13-07**	**Class 15-03**	**Class 15-04**	**Class 15-05**	**Class 15-06**
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

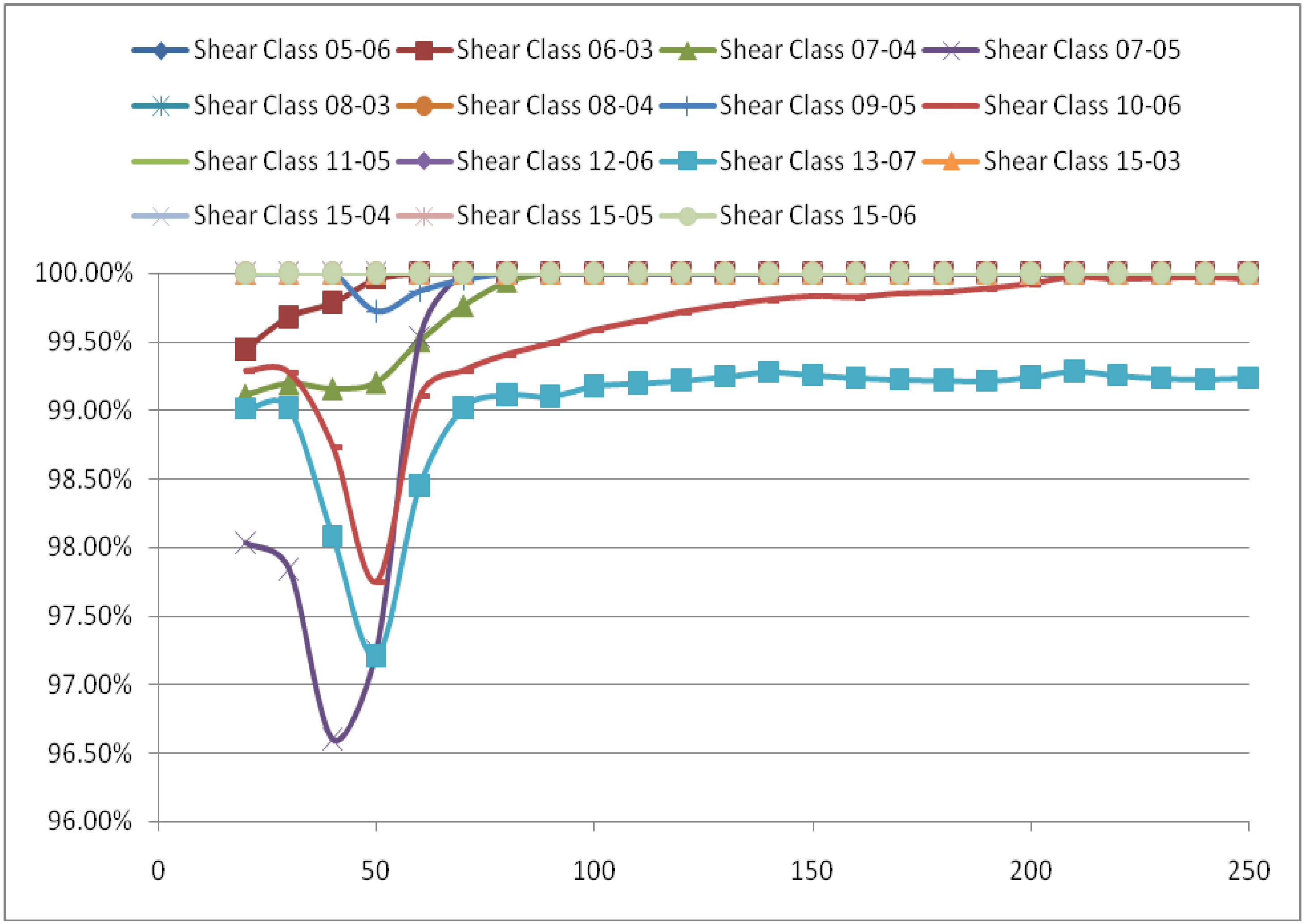


Fig. A4.7. Plot of 250-WPV shear as percentile of H5P data versus span length (ft) for each truck class-axle group.

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

Span (ft)	Class 05-06	Class 06-03	Class 07-04	Class 07-05	Class 08-03	Class 08-04	Class 09-05	Class 10-06	Class 11-05	Class 12-06	Class 13-07	Class 15-03	Class 15-04	Class 15-05	Class 15-06
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

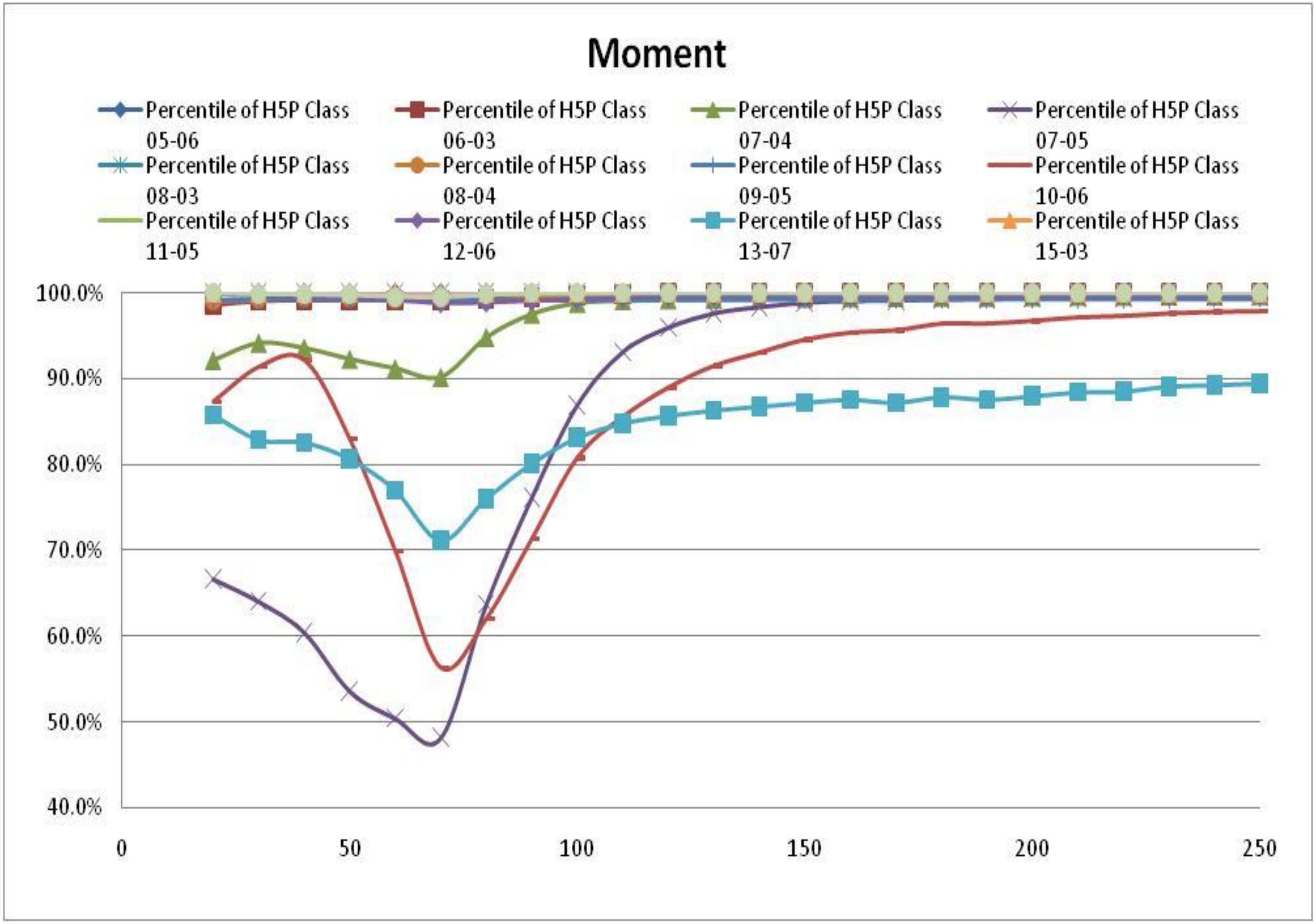


Fig. A4.8. Plot of 190-WPV moments as percentile of H5P data versus span length (ft) for each truck class-axle group.

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

Span (ft)	**Class 05-06**	**Class 06-03**	**Class 07-04**	**Class 07-05**	**Class 08-03**	**Class 08-04**	**Class 09-05**	**Class 10-06**	**Class 11-05**	**Class 12-06**	**Class 13-07**	**Class 15-03**	**Class 15-04**	**Class 15-05**	**Class 15-06**
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

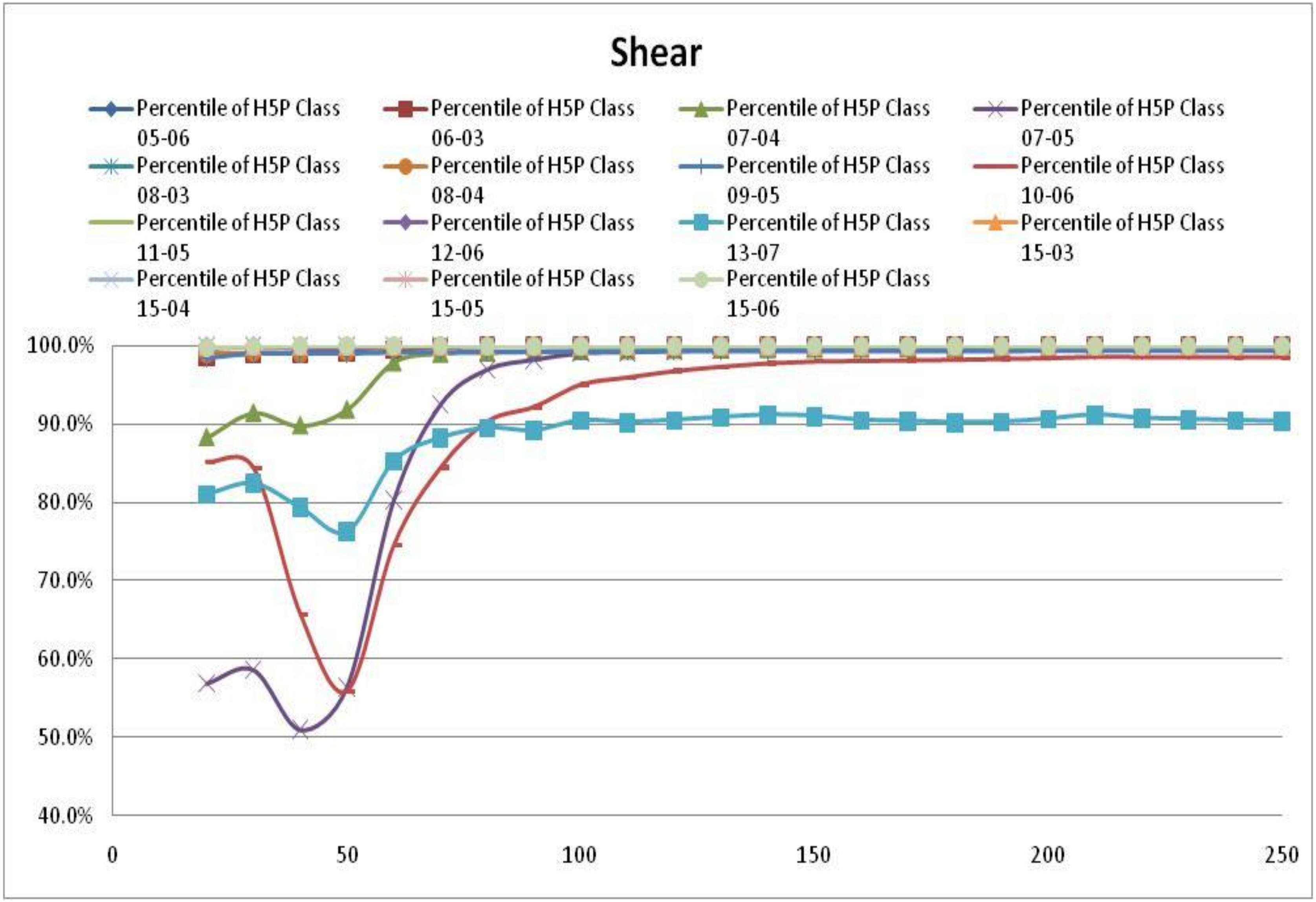


Fig. A4.9. Plot of 190-WPV shear as percentile of H5P data versus span length (ft) for each truck class-axle group.

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-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, 2nd edition, 2007.