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2003

Evaluation of AASHTO LRFD Fatigue Design with Weigh-in-Motion Data

by

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Thesis

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science in Engineering

The University of Texas at Austin
May, 2003

Evaluation of AASHTO LRFD Fatigue Design with Weigh-in-Motion Data

Approved by
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Karl H. Frank, Supervisor

Lance Manuel, Supervisor

Dedication

This thesis is dedicated with love to my mom, who taught me that education is second only to happiness, to my father, who learns something new everyday, and to my brother, who finally found his passion.

Acknowledgements

I would like to thank my advisor, Dr. Karl H. Frank for his guidance, but also for his patience throughout my time at The University of Texas. I would also like to thank Dr. Lance Manuel for his support and for being my second reader.

I would like to thank the employees at TxDOT, especially Richard Peters, for the data necessary to complete this project, and for the friendly answers to all my questions.

I wish to say a special thank you to all the friends I have made here in Austin, Texas. They have made my time here one of the most enjoyable experiences of my life, and will hopefully continue to make my world a brighter place.

Most importantly, I would like to thank my family for their love and encouragement, and especially my father, Dr. Paul J. Orgren, for contributing a computer program to this project, without which I would still be converting data files.

May 2, 2003

Abstract

Evaluation of AASHTO LRFD Fatigue Design with Weigh-in-Motion Data

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The University of Texas at Austin, 2003

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The current AASHTO *LRFD Bridge Design Specifications* lists a fatigue load factor of 0.75, and for finite life design, assumes that the maximum stress range experienced by a bridge is equal to two times the effective stress range on the bridge from the truck traffic. Using weigh-in-motion data from three sites in the state of Texas, the load factor was compared to the ratio of the effective truck moment to the moment caused by the AASHTO fatigue truck, and to the ratio of the effective gross vehicle weight to the AASHTO fatigue truck gross vehicle weight. Also using the weigh in motion data, the maximum moments and gross vehicle weights were compared to twice the effective moments and gross vehicle weights. Variables that were considered included the year of the data, the span length on which the moments were calculated, and local site characteristics.

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CHAPTER 1

Introduction

The current AASHTO *LRFD Bridge Design Specifications* lists a fatigue load factor of 0.75, and for finite life design, assumes that the maximum stress range experienced by a bridge is equal to two times the effective stress range on the bridge from the truck traffic. These assumptions are based on truck-load data collected with static scales, assuming the data from the static scales accurately represents the traffic data seen on a bridge, and that the gross-vehicle-weight accurately reflects the actual fatigue damage on a bridge. This project will use current weigh-in-motion data to develop a fatigue load factor based on both gross-vehicle-weights and moment ranges experienced by the bridge and compare these values to the AASHTO value of 0.75, and determine the maximum gross-vehicle-weight and moment due to the truck traffic compared to two times the effective gross-vehicle-weight and moment. The effect of span length, individual site characteristics, and date on the load factors and maximum values are also explained.

1.1 DEVELOPMENT OF THE AASHTO FATIGUE LOAD FACTOR

The American Association of State and Highway Transportation Officials (AASHTO) first published the *Standard Specifications for Highway Bridges* in 1931. In the late 1980s, a movement within the association pushed for new design standards incorporating a load and resistance factor design (LRFD) philosophy. Due to this movement, AASHTO published the first *LRFD Bridge Design Specifications* in 1994.

There are eleven load factor combinations listed in the AASHTO *LRFD Bridge Design Specifications (Table 3.4.1-1)*, including a fatigue combination. The fatigue combination applies a load factor of 0.75 to the live load, the vehicular dynamic load allowance, and the vehicular centrifugal force. While the centrifugal force only applies to curved bridges, the live load and dynamic load allowance must be used to evaluate every bridge. The specified fatigue live load consists of the standard AASHTO design truck, but with 30 ft spacing between the 32-kip axles (Table 1.1). The dynamic load allowance for fatigue is 15%, thus a factor of 1.15 is applied to the specified fatigue live load in order to account for the wheel load impact of moving vehicles.

Table 1.1: Axle Weight and Spacing of the AASHTO Fatigue Design Truck

Axle	Axle Weight (k)	Axle Spacing (ft)	Total GVW (k)	Total Wheelbase (ft)
A	8		72	44
		14		
B	32			
		30		
C	32			

The 0.75 fatigue load factor was developed using truck weight data obtained with static weigh stations in the 1970s. The static weigh station data comprised of the gross-vehicle-weight (GVW) for each truck in a certain period. The gross-vehicle-weight data was then sorted into load-frequency histograms. With the load-frequency histograms, an effective gross-vehicle-weight was calculated using a combination of Miners's Law of cumulative damage and a cube-root-mean-cube calculation (Laman & Nowak, 1996), which can be seen in equation 1.

$$GVW_{eff} = [\ \Sigma\ (\gamma_i * GVW_i^3)\ ]^{1/3} \qquad \text{eq. (1)}$$

where GVW_{eff} is equal to the effective gross-vehicle-weight, γ_i is equal to the frequency of the load range *i*, and GVW_i is the value of load range *i*.

The GVW_{eff} was then compared to the GVW of the AASHTO specified fatigue design truck. This ratio was found to be equal to 0.75.

1.2 AASHTO MAXIMUM STRESS RANGE ASSUMPTION

In section 6.6.1.2.5 of the AASHTO design code, it is assumed that for infinite life of a steel bridge, the nominal fatigue resistance should be greater than or equal to one-half the fatigue threshold. This is the infinite life design criteria, which is based upon the assumption that maximum stress from truck traffic is twice the stress produced by the effective stress of the truck traffic. If this criteria is met, it is assumed that all the live load stress ranges will be below the threshold.

1.3 CONCERNS WITH AASHTO FATIGUE DESIGN

There are many reasons that the AASHTO fatigue load factor may not accurately represent the current traffic, or the actual fatigue damage done to a bridge. Additionally, it is possible that with an increasing number of large permit loads and illegal overweight vehicles, that the code assumed maximum stress of two times the effective stress range may not be accurate.

Static scales do not often see the overweight traffic on a bridge. According to a study in Virginia, the maximum measured gross-vehicle-weight at a static weigh station is between 30% and 60% lower than the maximum measured by a weigh-in-motion system (Cottrell, 1992). Therefore, the fatigue load factor developed with data from static weigh stations may underestimate the load factor due to the lack of overweight truck data.

Another concern is that the current load factor does not take into account the impact that local traffic conditions may have. There are many different types of roads, ranging from dirt farm roads to busy interstates, each with their own traffic load pattern. A dirt farm road may experience a low ADTT consisting of tractors, while a busy interstate may experience a high ADTT of mostly fully loaded HS-20 trucks. However, every type of road includes bridges that have been designed with the same AASHTO fatigue load factor. It is possible that a different fatigue load factor could be used for sites with different loading characteristics.

The fatigue that a bridge may experience from a certain gross-vehicle-weight truck changes with different bridge span lengths, different axle spacing, or different weight distributions. Figure 1.1 illustrates the increase in the maximum mid-span moment caused by the AASHTO fatigue design truck as the span length of a simply supported bridge increases from 10 feet to 150 feet.

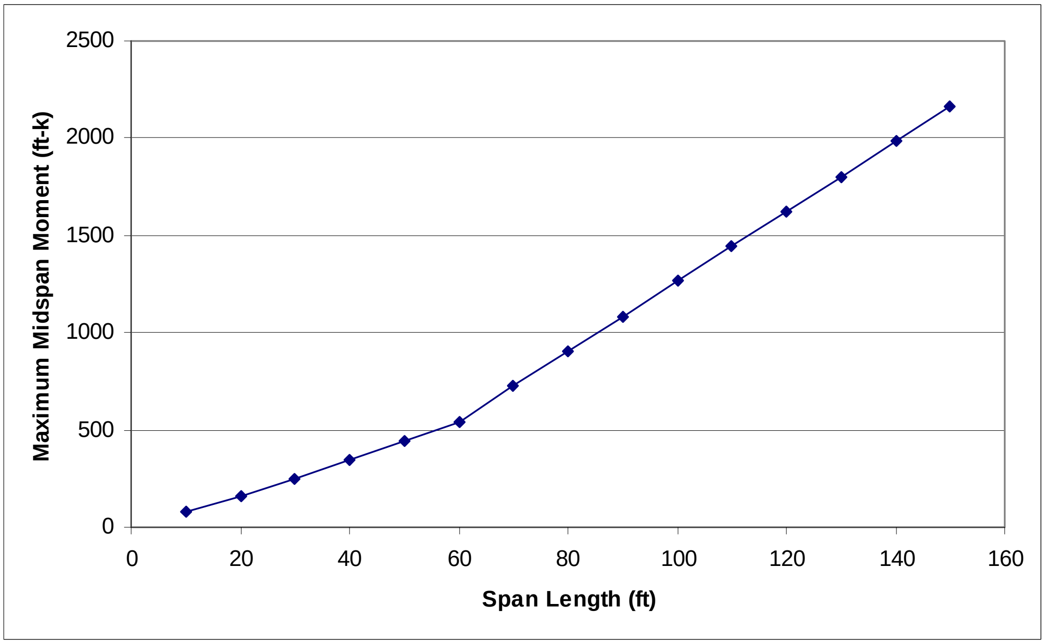

Figure 1.1: Maximum Mid-span Moment vs. Span Length for the AASHTO Fatigue Design Truck

In a similar manner, Figure 1.2 illustrates the increase in the maximum mid-span moment of a 100 ft simply-supported span as the rear axle spacing of the AASHTO fatigue truck decreases from 30 feet to 14 feet.

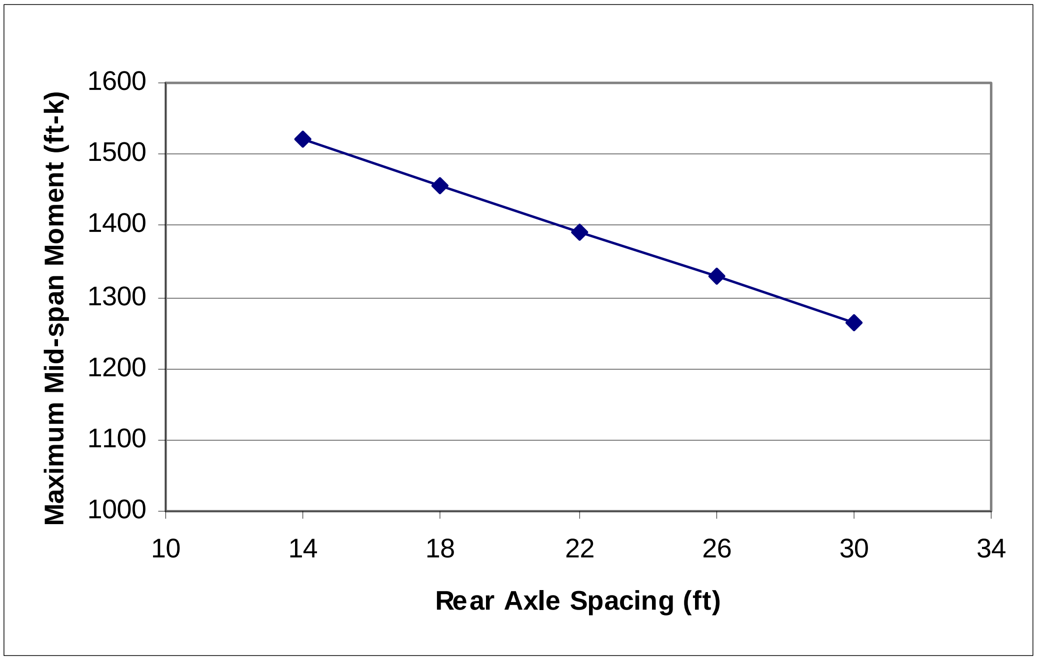

Figure 1.2: Maximum Mid-span Moment on 100 ft, Simply-supported Span Due to AASHTO Fatigue Truck with Variable Rear axle Spacing

Finally, Figure 1.3 shows the change in the maximum mid-span moment on a simply-supported 100 ft span as the weight distribution of the rear axles of the AASHTO fatigue truck is modified according to Table 1.2.

Table 1.2: Axle Weight and Spacing Distribution for Figure 1.3

Axle Weight (kips)			Axle Spacing (ft)	
Front	Middle	Rear	Front-Middle	Middle-Rear
8	0	64	14	30
8	8	56	14	30
8	16	48	14	30
8	24	40	14	30
8	32	32	14	30
8	40	24	14	30
8	48	16	14	30
8	56	8	14	30
8	64	0	14	30

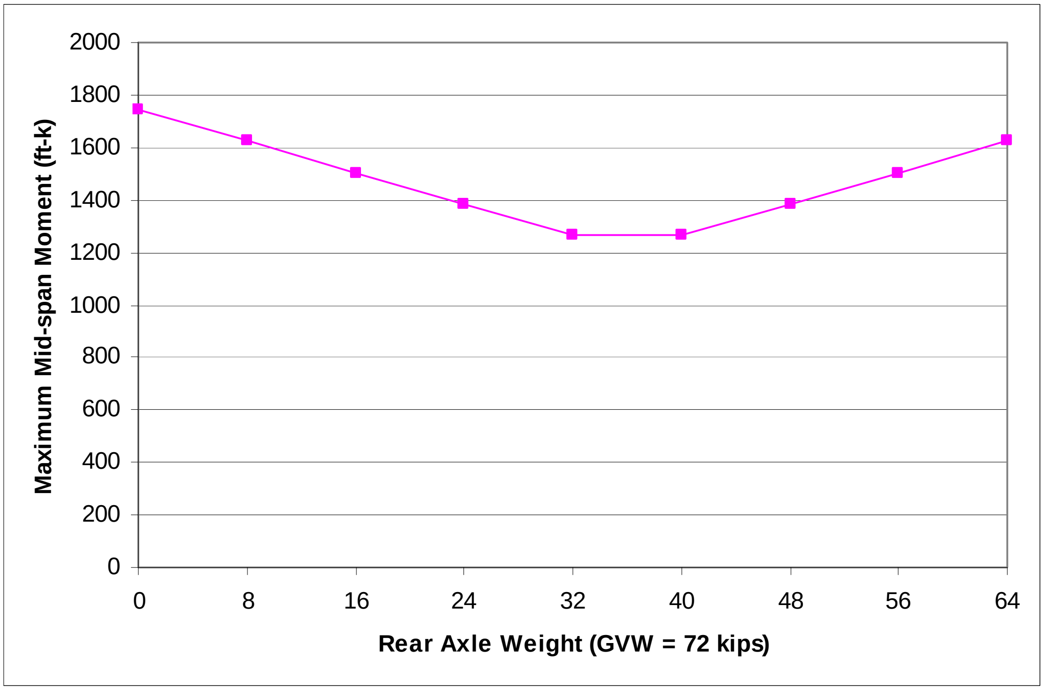

Figure 1.3: Maximum Mid-span Moment on a Simply-supported 100 ft Span vs. Axle Weight Distribution

Finally, the traffic loading patterns may have changed since 1975 due to increased truck traffic or changes in the types of trucks traveling on a certain road, which may bring about changes in the load factor.

1.4 DATA ACQUISITION

There is much available data containing axle weight information produced with weigh-in-motion systems, but there was no data including axle spacing. In order to compare the AASHTO fatigue load factor produced with gross-vehicle-weights to the fatigue load factor developed by vehicle moments on a bridge, data including axle spacing information was necessary.

TxDOT maintains weigh-in-motion data at various sites throughout Texas for use in the LTPP project. Upon request, TxDOT provided unprocessed weigh-in-motion data for use in this project.

The data from five weigh-in-motion sites was requested for analysis, spanning the state of Texas and including data from extremely rural areas as well as urban areas, and spanning 10 years of the most recent data. However, TxDOT did not begin implementing weigh-in-motion systems statewide until 1995, and since that time, not all the sites have been operating consistently. Therefore, a limited amount of data and collection sites were available. The earliest continuous data (two uninterrupted weeks of data collection) is from 1999 and only exists for three sites. Thus, these sites were selected for this project. Fortunately, the three sites represent a good range of ADTTs, with both rural and urban locations, and on interstates as well as highways. However, in the past Texas has focused their weigh-in-motion stations along routes coming to and from Mexico as a result of the NAFTA treaty, so the sites used in this project are focused in that general area, rather than the entire state of Texas.

1.5 SITES SELECTED FOR ANALYSIS

The sites used in this project include site number 513 in Jarrel, along I-35 between Austin and Waco, site number 522 in Falfurrias along US-281, and site number 516 in Lytle on I-35 just south of San Antonio. The location of these sites can be seen on the map of Texas in Figure 1.4.

Figure 1.4: Location of Selected Sites for Analysis

Site 513 is the most heavily trafficked of the three sites, with an ADTT in 2002 of about 11000. Site 516 is less heavily trafficked, with an ADTT in 2002 of approximately 8000. However, this site is in close proximity to the many armed forces bases, and experiences much larger loads due to military equipment than the other sites. Finally, site 522 is on a less-trafficked rural highway, with an ADTT in 2002 of around 4000. Figure 1.5 shows a histogram of the gross-vehicle-weight frequency over a two-week period in 2002 for each of the three sites.

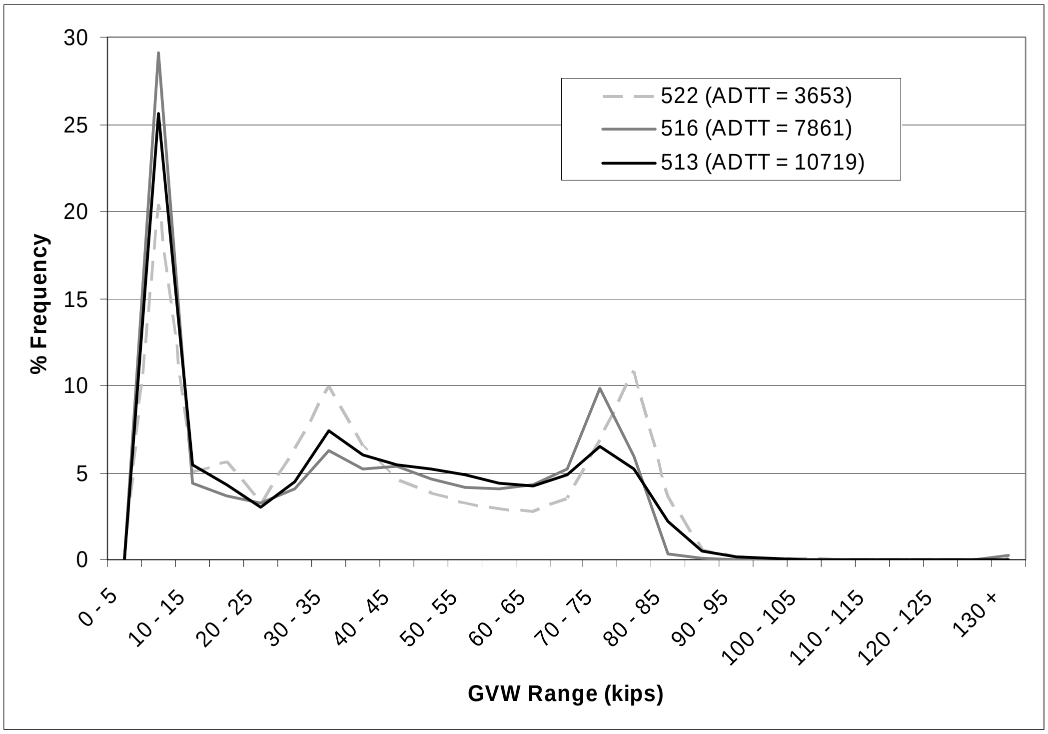

Figure 1.5: Gross-vehicle-weight Frequency

In order to test the effect of increasing traffic as a result of time, two weeks of data in three different years were chosen for analysis at site 513, the most heavily trafficked site. At site 516 it was decided that the same two-week period would be analyzed for both a 100 ft and 50 ft simply-supported span to monitor the effect span length may have on the fatigue load factor based on moment ranges rather than gross-vehicle-weights alone. This site was chosen because of the large gross-vehicle-weights at this site, which were thought to accentuate the effect span length would have on the fatigue load factor. At site 522 only one two-week period was selected for analysis, which would be used to compare the fatigue load factor to the load factors at site 513 and site 516 to determine any dependency on local traffic patterns.

Using a random number generator in the Microsoft Excel program, the two-week periods were selected, discounting holiday periods and periods where TxDOT had not supplied continuous raw data. The dates of the chosen data for site 513 were July 11 to July 24 in 1999, February 25 to March 10 in 2001, and April 14 to April 27 in 2002. For site 516, the two-week period selected was from May 5 to May 18 in 2002. And for site 522, the period selected was from February 3 to February 16 of 2002.

A 100 ft span was selected as the basis for analysis. However, to investigate the effect of span length on the fatigue load factor and the maximum moment assumption by AASHTO, a 50 ft span was analyzed as well.

1.6 RELATED RESEARCH

In Michigan, Laman and Nowak worked with weigh-in-motion data to update the AASHTO fatigue truck model, rather than the fatigue load factor for the current AASHTO fatigue truck, as was done in this project. To do this they measured the stress cycles at the mid-span of five steel girder bridges, along with the gross-vehicle-weight, axle weight, and axle spacing of each truck, and tried to develop a single truck that would produce the same effective stress cycles. Their study found that the fatigue caused by vehicles with 3-7 axles was better represented by a truck with 3 axles, while fatigue caused by vehicles with 10 or 11 axles was better represented with a 4 axle truck. They also found that vehicles with 2, 8, and 9 axles produced very little fatigue damage and could be excluded from consideration. From this they developed two fatigue trucks; one 3-axle truck for sites with mostly 2-6 axle vehicle traffic, and one 4-axle truck for sites with a significant amount of fatigue damage caused by vehicles with greater than 6 axles (Laman & Nowak, 1996). The axle weights and axle spacing of the vehicles they developed can be seen in Table 1.3.

Table 1.3: Axle Weight and Spacing of Laman and Nowak Fatigue Trucks

	Axle	Axle Weight (k)	Axle Spacing (ft)	Total GVW (k)	Total Wheelbase (ft)
Laman and Nowak 3-axle Truck	A	10 - 23	11.5 - 13	56 - 81	40.5 - 45
	B	23 - 29	29 - 32		
	C	23 - 29			
Laman and Nowak 4-axle Truck	A	10 - 22	11 - 14	110 - 202	39 - 46
	B	43 - 60	17 - 18		
	C	37 - 60	11 - 14		
	D	20 - 60			
AASHTO Fatigue Design Truck	A	8	14	72	44
	B	32	30		
	C	32			

CHAPTER 2

Weigh-in-Motion Equipment and Data Collection

2.1 BACKGROUND

Weigh-in-motion (WIM) systems were first developed in the 1960's and are defined as "the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle," (ASTM, 2002). When used without the knowledge of drivers, it measures true truck weights, unlike the measurements taken from static scales that do not include the overweight trucks that avoid the weigh stations. Additionally, WIM measurements provide axle weights and axle spacing, compared to a single static weight measured by traditional static scales.

2.1.1 Types of Weigh-in-Motion Systems

There are many different types of WIM systems, including bending plate, piezoelectric, load cells, and capacitive mats. Bending plate WIM systems measure the strains caused by the bending of a steel plate placed in the roadway and convert the strain measurement into a static axle weight (FHWA, n.d.).

Piezoelectric WIM systems use sensors embedded in the roadway that measure a change in voltage when pressure is applied to them by a vehicle axle. This pressure measurement is then converted into a static vehicle weight (FHWA, n.d.).

There are two types of load cell WIM systems; hydraulic systems and strain gauge systems. When a vehicle axle applies pressure to a hydraulic system, the pressure is measured and converted into a static weight. The strain gauge systems function in a similar manner to the bending plate WIM systems, where strain gauges measure the strain caused by a vehicle axle and convert the measurement into a static axle weight (FHWA, n.d.).

Capacitive mat systems also employ steel plates, but rather than measuring a strain from the bending action like the bending plate WIM system, it measures the change in capacitance of the steel plate from the bending with sensors on the bottom side of the plate. The measured change is capacitance is then converted into a static axle weight (FHWA, n.d.).

A study in the economics and performance of three major WIM systems done by Bushman and Pratt (1998) compared the accuracy, expected life, initial installation cost, and annual life cycle cost of these systems. Their results can be seen in Table 2.1. It is evident that as the accuracy and expected life of a system increase, the cost increases as well.

Table 2.1: Economics and Performance of Three Weigh-in-Motion Systems (Bushman & Pratt, 1998)

WIM System	Piezoelectric	Bending Plate	Load Cell
Accuracy (95% confidence)	+/- 15 %	+/- 10 %	+/- 6 %
Expected Life	4 years	6 years	12 years
Initial Installation Cost	$9,000	$21,500	$48,700
Annual Life Cycle Cost	$4,750	$6,400	$8,300

Weigh-in-motion systems are available in both permanent and portable models. In general, permanent installations are used in areas with high traffic volume and high speeds, and where accuracy is important. However, while permanent systems require a minimum installation time of a day, portable systems can be installed in minutes and can easily be transported in a car or truck (FHWA, n.d.).

2.1.2 Factors Affecting Weigh-in-Motion Accuracy

Many factors affect the accuracy of the data collected by a WIM system. These factors can be separated into two basic categories; intrinsic error and external factors (Scheuter, 2000).

Intrinsic error depends on the system technology, and may be affected by temperature, eccentric loading, creep and shringkage of the pavement, moisture surrounding the system, electromagnetic susceptibility, and accuracy of the weight determination algorithms (FHWA, n.d.). In order to minimize intrinsic error of any WIM system it is important to ensure that the system is installed according to manufacturer specifications and maintained regularly.

External factors affecting the accuracy of a WIM system include vehicle and roadway characteristics. Vehicle suspension, friction in the suspension, brake reaction forces, vehicle oscillation, and aerodynamic forces are all examples of vehicle characteristics that may affect the accuracy of a WIM system, while grade of the roadway, unevenness of the pavement, and the leveling of the sensor installation are examples of roadway characteristics (FHWA, n.d.).

Many of the external factors are related to each other. Uneven pavement, or a sensor installation that is not level causes vertical movement of a vehicle. As an axle is moving upward, the recorded weight will be lower than the static weight of the axle, whereas when the axle is moving downwards, the recorded weight will be higher than the static axle weight. Depending on the stiffness or the friction within the vehicle suspension, the reaction to the vertical movement will be different. A stiffer vehicle suspension will amplify the vertical movement, while greater friction will dampen it (Scheuter, 2000). However, if the roadway and the WIM system installation are level, there is no affect from the vehicle suspension. Therefore it is important to have a level roadway near the WIM installation, and ensure a level installation within the roadway of the WIM system.

While the roadway surface may excite vehicle oscillations at a high frequency, all vehicles also oscillate at a much lower frequency on the oder of 9 to 14 Hz (FHWA, n.d.). However, conventional WIM systems are not long enough to record the axle load during one complete period at the lower frequency, and thus introduces error into the weight measurement. While this is usually the largest external affect on accuracy, it can be offset by offsetting sensors for the left and right wheels (Scheuter, 2000).

As a vehicle brakes, angular momentum tilts the vehicle towards the front, creating a higher force on the front axles and a lower force on the rear axles. This effect is described as a brake reaction force above. If a vehicle passes over a WIM system while braking, the measured weight of the front axles will be high, while it will be low for the rear axles.

Similar to the effect of braking forces, a significant grade in the roadway will affect WIM accuracy by increasing the weight of the lower end of the vehicle while decreasing the weight of the higher end.

According to Scheuter, aerodynamic forces on a vehicle are relatively small in the vertical direction, compared to the vehicle weights (2000). However, he found that with a crosswind there is a significant load transfer to the wheels in the leeward direction. A WIM system that measures both sides of an axle can correct for this phenomenon, however, a system that only measures one side may have significant errors.

2.1.3 Current Weigh-in-Motion Applications

Weigh-in-motion systems have many applications, including truck weight enforcement, and for the collection of statistical data. Traditionally, truck weight enforcement has been done using static scales. However, many overweight vehicles bypass these scales, and there are often long lines, wasting time for the drivers. Using slow speed WIM systems as a vehicle sorter at static stations could eliminate much of the waiting time currently experienced by truck drivers, while the use of high speed WIM systems is ideal for enforcement officers monitoring overweight vehicles at any location and at any time of day (FHWA, n.d.).

The main purpose for the collection of statistical traffic data by TxDOT is for use in the Long Term Pavement Performance (LTPP) project, run by the FHWA. The LTPP project began in 1987 and collects truck axle weight data for purposes of pavement design and analysis (FHWA, n.d.). While TxDOT collects and stores 365 days of continuous data for all their sites, only 48 hours of every three months is actually submitted to LTPP (TxDOT, 2001). The rest is stored for possible future use.

2.2 PAT AMERICA BENDING PLATE WEIGH-IN-MOTION SYSTEM

The data in this project was collected by TxDOT using a PAT America bending plate with a DAW 200 Weigh-in-Motion and Classification System, also manufactured by PAT America, to function as the on-site computer that records and transmits the data.

2.2.1 Specifications

The PAT America Bending Plate is a high strength steel plate with dimensions of 69.6” length, 0.91”height, 20.0” width, and a weight of 265 pounds. The plate has two milled slots along the bottom side where seven-wire strain gauges are bonded to the steel plate along with optional temperature compensation resistors (PAT America, n.d.). As a truck passes over the plate, the DAW 200 WIM System measures the strain and converts it into a load. The measured displacement is approximately 2.3mm for a ten-ton load (PAT America, n.d.). Along with the vehicle weights, the DAW 200 records vehicle speed, time, and axle spacing. A typical set-up for a PAT America Bending Plate site consists of two inductive loop vehicle detectors (before and after the bending plates), two bending plates spaced together or slightly staggered that cover the entire traffic lane, and the DAW 200 to store or transmit the collected data to a central location (see Figure 2.1).

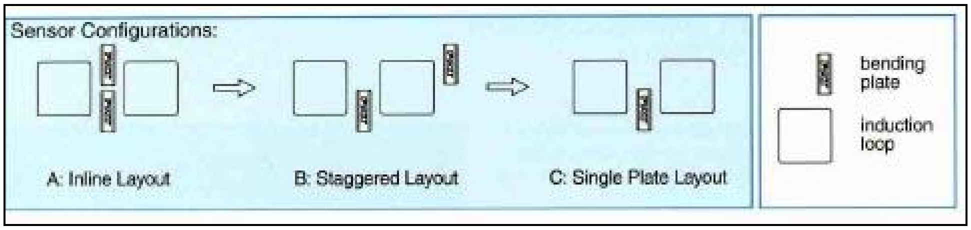

Figure 2.1: Configuration of Bending Plate and Induction Loop (taken from the PAT America website)

The sensors are placed within the pavement and can typically be installed within one day, minimizing the impact on traffic. A typical bending plate installation manufactured by PAT America can be seen in Figure 2.2.

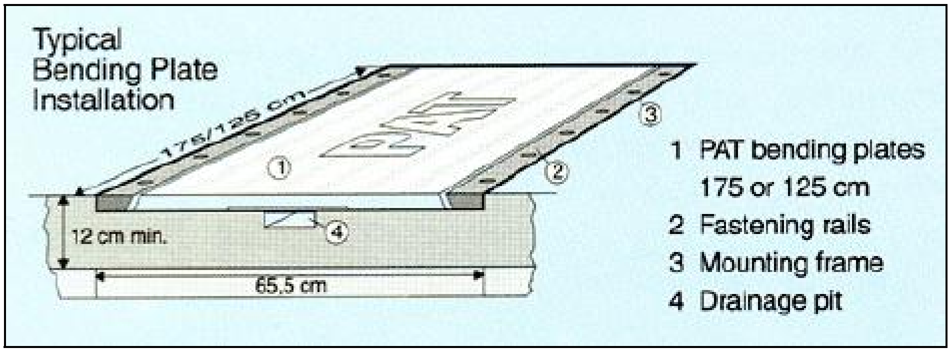

Figure 2.2: PAT Bending Plate Installation (taken from the PAT America website)

2.2.2 Accuracy

PAT America specifies that the Bending Plate must be used in an environment with temperatures between 14^{o}F and 122^{o}F, and a maximum water submersion time of 300 hours. In most parts of Texas, the temperature seldom drops below 14^{o}F. The capacity of the bending plate, when the load is evenly distributed on the steel plate, is 66,000 pounds. According to Richard Peters from TxDOT, the numerical accuracy of the weights measured with Bending Plate and DAW 200 used in this project is 8%.

2.2.3 Data Formatting

The data received from TxDOT was in the original format generated by the PAT DAW 200 weigh-in-motion recorder. In order to obtain the necessary information from this format, the raw data had to be processed using the PAT file processor called, "Reporter Program V 6.37." This processor was provided by TxDOT with the raw data and runs as a DOS-based program. It was used to create Type 7 reports according to the FHWA Traffic Monitoring Guide (TMG) data format specifications from the information generated by the PAT DAW 200 weigh-in-motion recorder (2003). These reports are data files containing a record of each truck passing the weigh-in-motion setup during a 24 hour period, including information such as site number, date, time of day, truck type, direction of travel, lane of travel, gross-vehicle-weight, weight of each axle, and axle spacing. Within the TMG Type 7 file, each truck record is listed in an 80-column row, with continuation records if necessary (for vehicles with more than ten axles) on the following line designated by the last character in the row. See Appendix A for a sample TMG Type 7 report and a listing of each column designation.

Due to the irregularity of the continuation files within the TMG Type 7 output, as well as the large size of the files (between 2000 and 15000 trucks), they are difficult to import into a Microsoft Excel spreadsheet in an automated way. Using a Perl program developed by Dr. Paul J. Orgren, the TMG Type 7 files were converted into a comma separated text file with each entire truck record on one line. Microsoft Excel automatically recognizes and opens this type of file, complete with column headings. For the code of the Perl program and an example of the converted TMG Type 7 file into a comma separated text file opened in Microsoft Excel, see Appendix B.

CHAPTER 3

Analysis Methods

3.1 CALCULATING VEHICLE MOMENTS

The first step in the analysis was to develop a spreadsheet with Microsoft Excel capable of finding the maximum moment at the quarter-, mid-, and three-quarter point along a simply supported span of variable length caused by a specified truck. In this spreadsheet, the user must enter the desired span length, the axle weights, and the total distance of each axle from the front of the vehicle (excluding the zero distance of the first axle). Using an influence line for the moment caused by each axle at the quarter-, mid- and three-quarter points along a span, and then summing the contribution of each axle, the spreadsheet creates the influence line for the specified truck. From this point, a simple Excel function finds the maximum moment of each influence line for the quarter-, mid-, and three-quarter span moments for the specified truck and span length. This spreadsheet does have limitations. In its original form, the spreadsheet was only able to analyze a vehicle with ten axles or fewer, and with a maximum wheelbase of 100 ft for a 100 ft span length. However, it became clear that there were a significant number of trucks in the files being analyzed in this project that surpassed these limitations. The spreadsheet was then edited to analyze a vehicle with thirteen axles or fewer, and a maximum wheelbase of 400 ft for a 100 ft span length.

Due to the large number of trucks contained within a single weigh-in-motion data file (where a data file contains a 24 hour period of continuous truck records), the process of inputting the truck axle weight and spacing, and recording the maximum moment at the quarter-, mid-, and three-quarter point along the span for each truck had to be automated. A macro written by the author with the Microsoft Visual Basic editor called “Find Moments” was created to execute the automation. The code for this macro can be found in Appendix C. Two worksheets were added to the original influence line spreadsheet described above: one for the data file, and one for the macro to record the maximum moments for each truck. With the macro, the used must simply paste the data file in the format created by the Perl program, “Convert,” enter the desired span length, and run the “Find Moments” macro. After the macro has finished running, the user has the maximum moment at the quarter-, mid-, and three-quarter point along the span, for every truck within the file. Depending on the number of trucks within the file size and the speed of the computer running the macro, the macro can take between 20 minutes to 3 hours to complete. For a file with 8000 trucks on a Pentium 4 computer, the macro takes 45 minute to complete.

Once the maximum moments had been determined for each truck within a file, a histogram for the frequency of each moment, as well as for the frequency of each gross-vehicle-weight was created. This was done using another Microsoft Excel spreadsheet with a macro written by the author in Visual Basic called “Create Histogram” for the moment histograms, and “Create GVW Histogram” for the GVW histograms. The code for these macros can be found in Appendix C. To use these macros the user copies the output of the “Find Moments” macro, as well as the column of the data file labeled, “Total Vehicle Weight,” into the spreadsheet containing the histogram macros. The histogram macros then count the number of moments or gross-vehicle-weights within a certain range and report that number in designated columns. An example of a gross-vehicle-weight histogram produced with this spreadsheet can be seen in Figure 3.1.

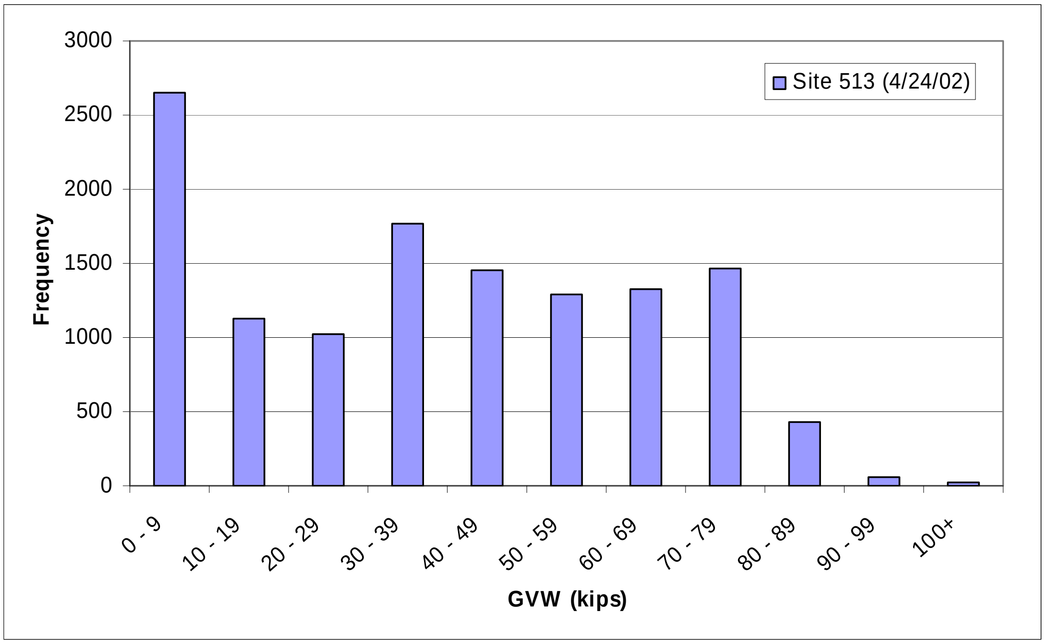

Figure 3.1: GVW Frequency Histogram for Site 513 on 4/24/02

With the histograms of both the moments and the gross-vehicle-weights for each truck it was possible to calculate an effective moment and an effective gross-vehicle-weight (see equation 1 in Chapter 1) for each file. These effective moments and gross-vehicle-weights were then divided by the corresponding moment and gross-vehicle-weight of the AASHTO fatigue truck to create load factors that were compared to the 0.75 load factor for fatigue used in the AASHTO code. In addition, the maximum moment within the file, as well as the maximum gross-vehicle-weight was identified for use in the comparison of the effective moment or gross-vehicle-weight to the maximum moment or gross-vehicle-weight.

For this project, the files from Site 513 and Site 522 were processed using a span length of 100 ft, while the files from Site 516 were processed using a span length of both 100 and 50 feet. The dates used from each file are identified in Chapter 1.

CHAPTER 4

Results

4.1 SUMMARY OF THE DATA

The ratio of the effective moment to the fatigue truck moment is referred to as the effective moment ratio, while the ratio of the effective gross-vehicle-weight to the fatigue truck weight is referred to as the effective gross-vehicle-weight ratio.

The effective moment ratios, maximum moments, effective gross-vehicle-weight ratios and maximum gross-vehicle-weights that were calculated for each site on the dates specified in Chapter 1, and the span lengths specified in Chapter 3 are listed in Appendix D, along with the daily truck traffic for those dates.

For each site, an effective moment ratio was calculated at the quarter-, mid-, and three-quarter point along the specified span. In every instance at site 513, the effective mid-span moment ratio was larger than both the quarter-span and three-quarter span ratios. This can be seen in Figure 4.1, where the quarter-span, mid-span, and three-quarter-span effective moment ratios are plotted versus the date of the truck data for site 513 in 2002. This was also true at site 522. However, at site 516 this was not always the case. For some days, for both the 50 ft and 100 ft span, the effective moment ratio was higher at the quarter- and the three-quarter-span than at the mid-span, as can be seen in Figures 4.2 and 4.3. This variation is due to changes in the daily traffic, with peaks occurring on days with a high proportion of heavy trucks with short wheelbases, and will be discussed in more depth later. However, it is important to note that despite this variation, it was decided that the mid-span effective moment was an accurate estimate to serve as the effective moment ratio for the comparisons in this project. It is also important to note that the effective moments are different at different places along a span, for a designer could take this into account when designing details of a bridge.

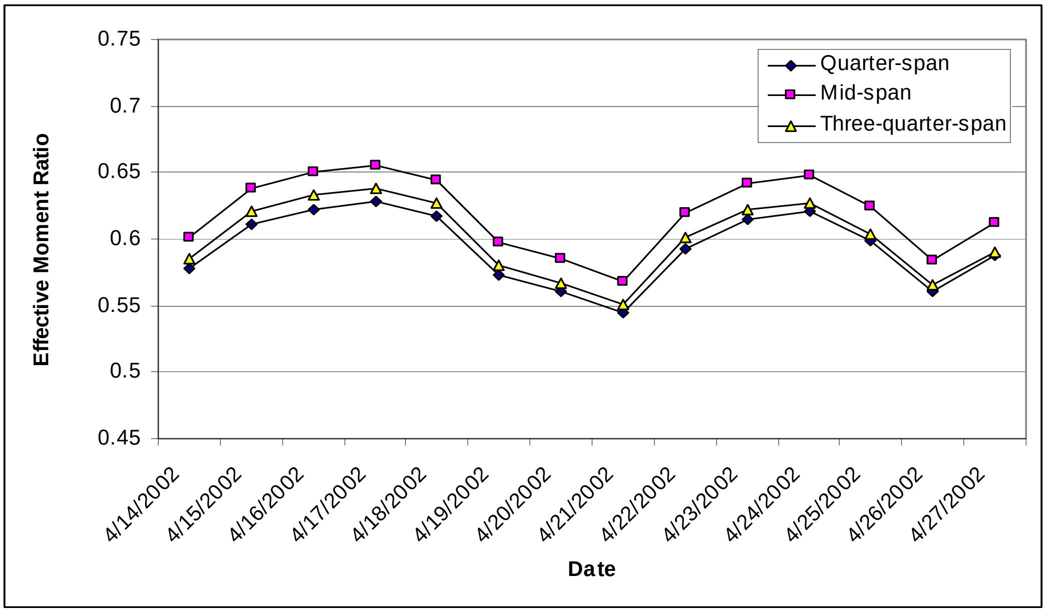

Figure 4.1: Effective Moment Ratio at Different Points Along a 100 ft Simply-Supported Span for Site 513

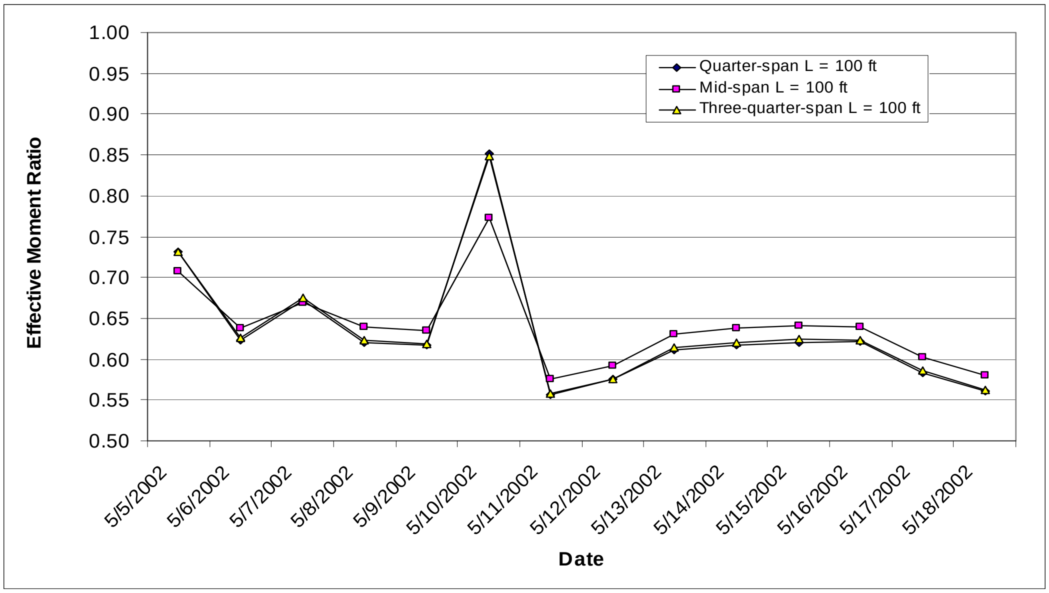

Figure 4.2: Effective Moment Ratio at Different Points Along a 100 ft Simply-Supported Span for Site 516

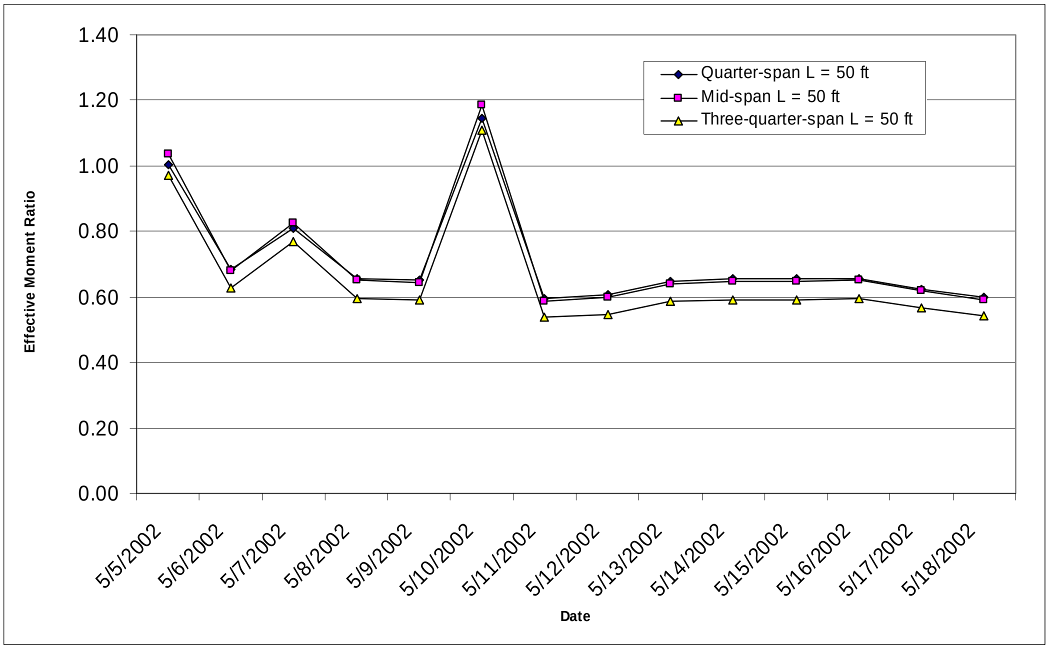

Figure 4.3: Effective Moment Ratio at Different Points Along a 50 ft Simply-Supported Span for Site 516

4.2 EVALUATION OF THE AASHTO FATIGUE LOAD FACTOR

In order to compare the ratios for each site with the AASHTO fatigue load factor, a root-mean-cube of the ratios taken over each two-week period was calculated for the effective moment ratios and the effective gross-vehicle-weight ratios. The results of this calculation for all the data is shown in Table 4.1.

Table 4.1: Root-mean-cube Values of All Data Taken Over a Two-week Period

Site Number	Year	Span Length (ft)	ADTT	Eff. Mid-span Moment Ratio	Effective GVW Ratio	Average Max Mid-span Moment (ft-k)	Average Max GVW (kip)
513	1999	100	8439	0.65	0.71	4608	267
513	2001	100	11137	0.64	0.71	1784	133
513	2002	100	11486	0.62	0.69	2338	161
522	2002	100	3653	0.67	0.73	2331	159
516	2002	100	7861	0.65	0.72	5112	276
516	2002	50	7861	0.76	0.72	1957	276

Figure 4.4 displays the value of the effective mid-span moment ratio on a 100 ft span and the effective gross-vehicle-weight ratio at each site from data taken in the year 2002. In this figure it is evident that the ratios change slightly between each site, but that the effective mid-span moment ratio is consistently lower than the gross-vehicle-weight ratio for a bridge span of 100 ft, and that the gross-vehicle-weight ratio is consistently lower than the code specified ratio of 0.75. Another interesting point illustrated by this comparison is that the large peak in effective ratios at site 516 seen in Figures 4.2 and 4.3 did not noticeably increase the two-week effective moment ratio value of 0.65, nor the effective gross-vehicle-weight ratio of 0.72.

Figure 4.4: Effective Mid-span Moment Ratio and Effective GVW Ratio Compared to the AASHTO Fatigue Load Factor for a 100 ft Span in 2002

While both the effective moment ratio and the effective gross-vehicle-weight ratio for all three sites are below the AASHTO fatigue load factor of 0.75, the inaccuracy of the weigh-in-motion system used to collect the data has not been accounted for. Figure 4.5 includes error bars for the effective moment ratios and the effective gross-vehicle-weight ratios of 8%, the same error of the PAT America Bending Plate and DAW 200 weigh-in-motion system. In this graph it is evident that the range of the effective gross-vehicle-weight ratio includes 0.75 for all three sites, meaning the AASHTO fatigue load factor is well-calibrated for current gross-vehicle-weight data at all three sites. However, the effective moment ratio is lower than 0.75 in all three cases, indicating that the AASHTO fatigue load factor may be overestimating the actual fatigue caused by truck traffic on bridges.

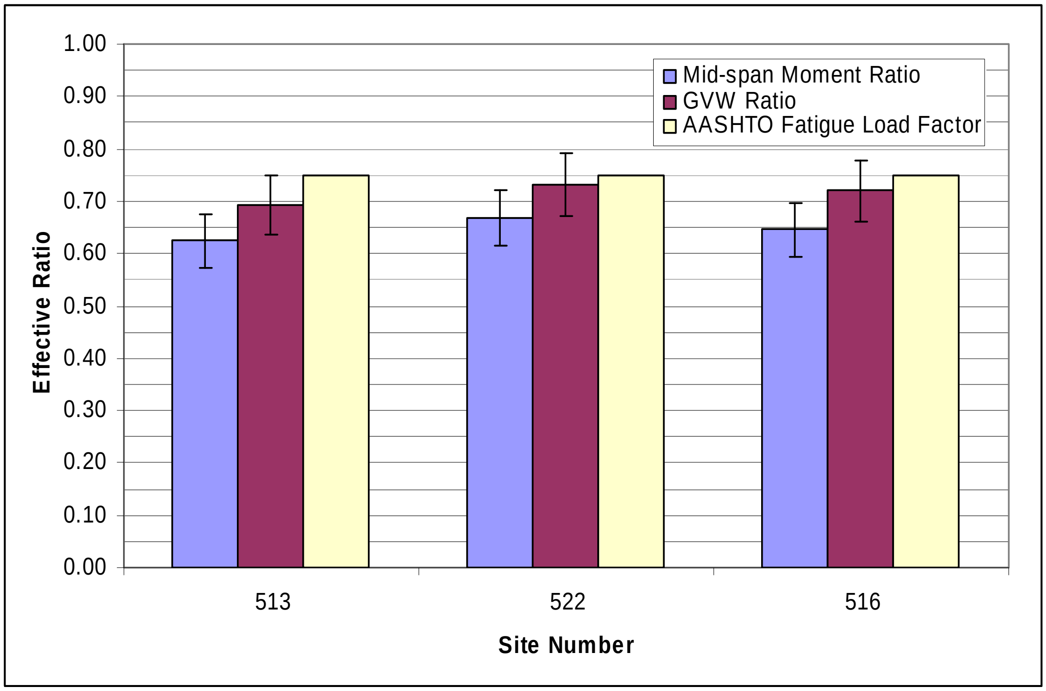

Figure 4.5: Effective Mid-span Moment Ratio and Effective GVW Ratio with 8 Percent Error Ranges Compared to the AASHTO Fatigue Load Factor for a 100 ft Span in 2002

In addition to the investigation of the effective moment ratio and the effective gross-vehicle-weight ratio at the three different sites, these quantities were tested for their dependence on time. Figure 4.6 shows the effective moment ratio and the effective gross-vehicle-weight ratio for Site 513 in the years 1999, 2001, and 2002, compared to the AASHTO fatigue load factor or 0.75. The ratios remain mostly constant over time, with variations that could be caused by the inaccuracies in the weigh-in-motion data, or by variations in the time of the year that the data was sampled from.

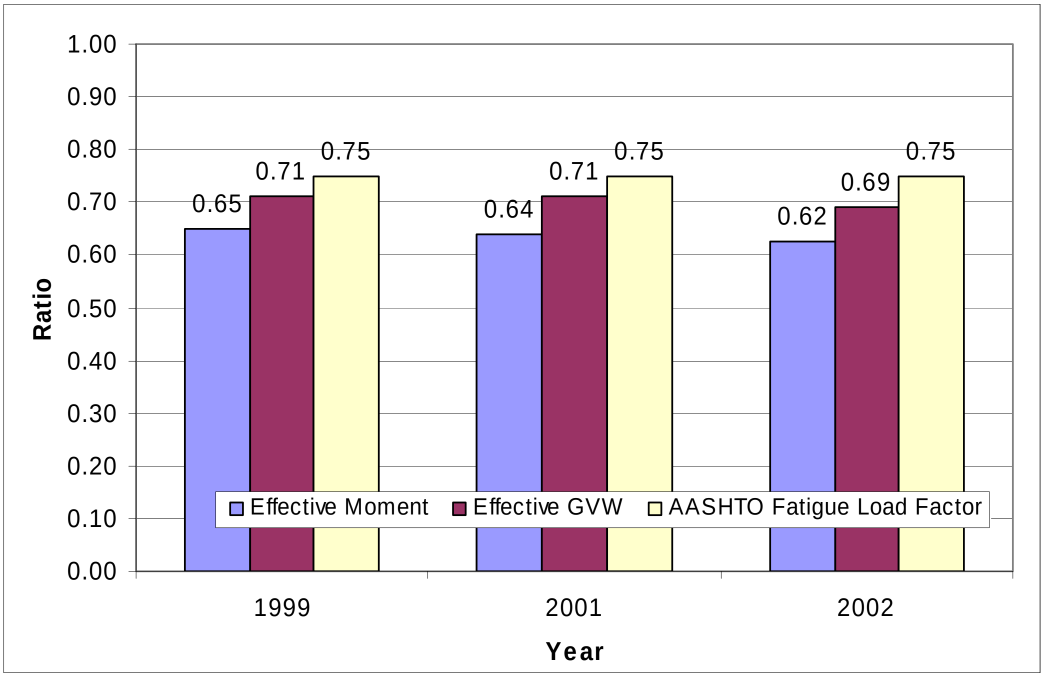

Figure 4.6: Effective Moment Ratio and Effective GVW Ratio Compared to the AASHTO Fatigue Load Factor at Site 513 for a 100 ft Simply-Supported Span

Finally, the variation in the moment ratio and the gross-vehicle-weight ratio was tested for a variation due to span length. It was expected that the moment ratios would decrease with decreasing span length due to the trend of the value of a moment caused by similar trucks to decrease with decreasing span lengths (see Figure 1.1 in Chapter 1), however in Figure 4.7 it is evident that this was not the case. The effective mid-span moment ratio for the two-week period analyzed at site 516 actually increases with the decrease in span length. An explanation for this behavior was studied in greater detail.

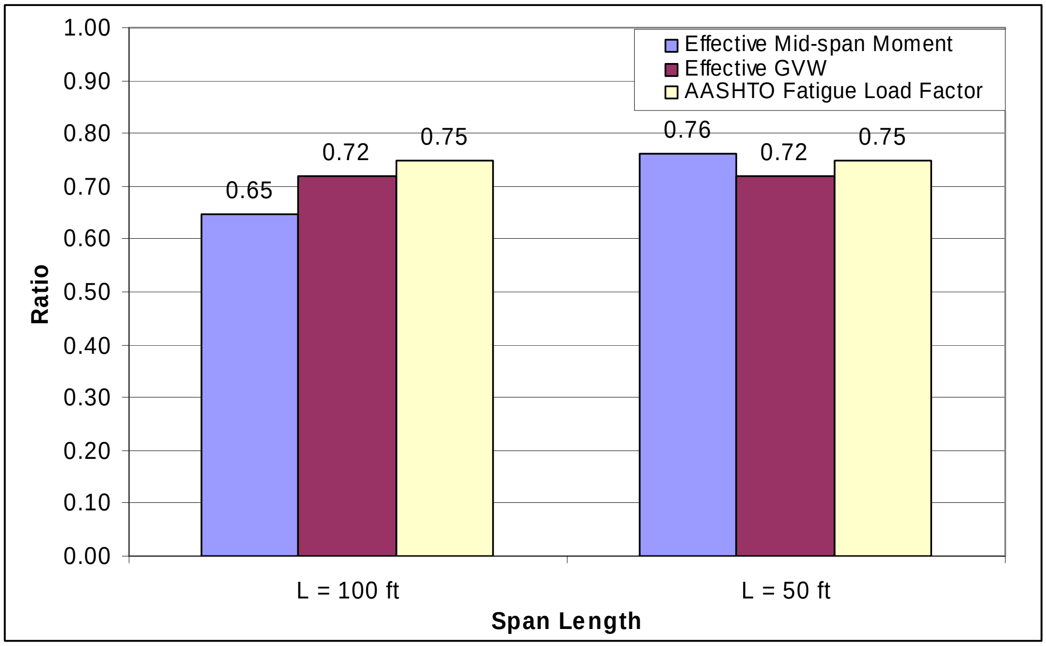

Figure 4.7: Effective Moment and GVW Ratios vs. Span Length at Site 516

An increase in the ratio of the effective moment to the fatigue moment with a decrease in span length is possible when the value of the moment caused by the fatigue truck decreases at a faster rate than the effective moment. This can be shown using a comparison between the moment of the fatigue truck and the moment caused by a truck recorded at site 516 on 5/10/2002, calculated at a span length of 50 ft and 100 ft. The axle weights and spacing of this vehicle can be seen in Table 4.2. While the actual moments caused by the fatigue truck and the design truck decrease at a shorter span length, the ratio between those moments increases because the moment caused by the fatigue truck has decreased more relative to the truck from site 516. The values of the moments in the two cases, along with the ratios between them can be seen in Table 4.3.

Table 4.2: Axle Weight and Spacing of a Sample Vehicle Recorded at Site 516

Axle Label	Axle Weight (k)	Distance from Front of Truck (ft)
A	20.9	0
B	20.8	3.7
C	21.2	7.1
D	30.5	10.8
E	28.8	14.2
F	31.4	17.9
G	28.1	21.6
H	30.2	25
I	30.2	28.7
J	28.5	32.1
K	30.2	35.8
L	27.6	39.5
M	29.7	42.9
Total	358.1	42.9

Table 4.3: Moments and Moment Ratios

	Maximum Mid-span Moment (ft-k)	
	L = 100 ft	L = 50 ft
Site 516 Truck	6971	2494
AASHTO Fatigue Design Truck	1264	444
Ratio of Site 516 Truck to the AASHTO Fatigue Design Truck	5.52	5.62

In general, any truck with a shorter wheelbase and higher gross-vehicle-weight will cause the ratio between the moment caused by that truck to the moment caused by the AASHTO fatigue truck to increase as the span length decreases. This is not to say that a longer truck could not produce the same effect, but it too would need a segment shorter than 44 ft with a weight larger than 72 kips (i.e. the dimensions and weight of the AASHTO fatigue truck) to cause the same effect. Therefore a site with heavier trucks on shorter wheelbases is more likely to have an increase in the effective moment ratio than a site with longer trucks that have lower gross-vehicle weights. The overall percentage of trucks recorded at site 516 between 5/5/2002 and 5/18/2002 that had a larger gross-vehicle-weight than the AASHTO fatigue truck (> 72 kips) and a wheelbase shorter than the AASHTO fatigue truck (< 44 ft) was 0.17%. However, if you look at the daily percentage of trucks exceeding the AASHTO fatigue truck gross-vehicle-weight with a shorter wheelbase, and compare that to the daily effective moment ratio, a trend of increasing ratios with shorter and heavier trucks is clear. This can be seen in Figure 4.8, where the effective moment ratio for each day of data analyzed is plotted against the percent of vehicles with a gross-vehicle-weight greater than 72 kips and a wheelbase shorter than 44 ft from that day.

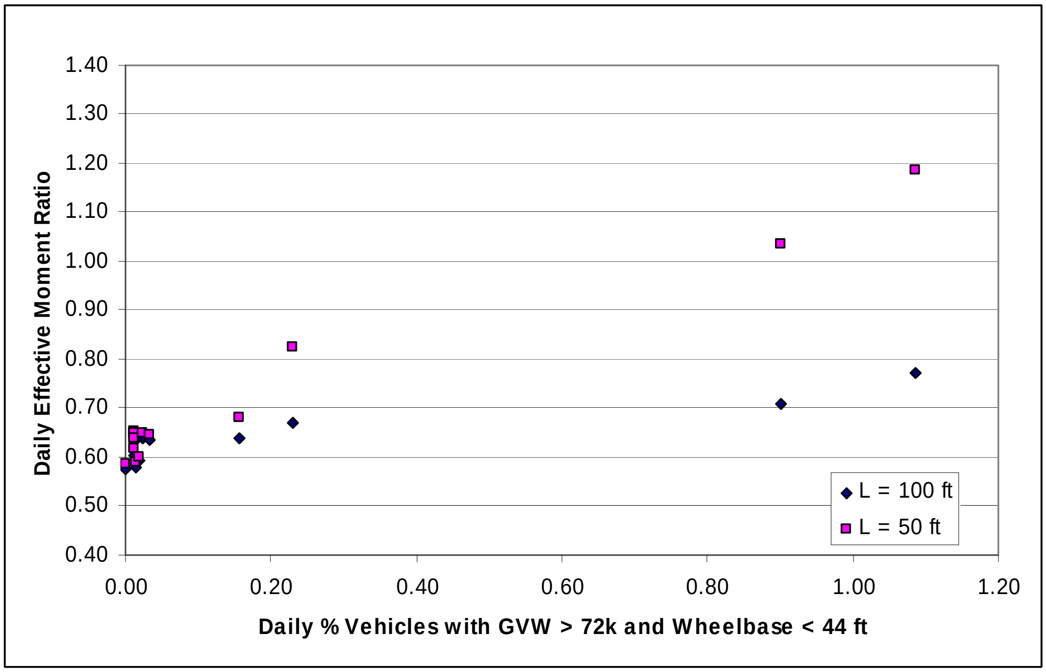

Figure 4.8: % Vehicles with GVW >72 k and Wheelbase < 44 ft at Site 516 Over a Two-week Period in 2002

While the relationship is not exactly linear, the effective moment ratio definitely increases with the percent of short and heavy vehicles for both the 100 ft and 50 ft spans. This gives a strong indication that traffic patterns at individual sites impact the fatigue damage done on a bridge. Additionally, shorter span lengths of a bridge will accentuate this increase.

4.3 EVALUATION OF AASHTO MAXIMUM STRESS RANGE ASSUMPTION

As stated in the AASHTO design code, the maximum stress range is assumed to be two times the effective stress range (or 1.5 times the fatigue truck stress range) for purposes of infinite life design. This assumption was checked with a comparison between two times the effective moment and the calculated maximum moment at each site, and a comparison between two times the effective gross-vehicle-weight and the recorded maximum gross-vehicle-weight.

At each site, there is significant variation in the maximum recorded moment and the maximum recorded gross-vehicle-weight, however at all three sites the maximum is larger than the AASHTO estimate for the maximum (two times the effective) by at least 40 percent in the case of the moments and 50 percent in the case of the gross-vehicle weights. Figure 4.9 graphically reports the maximum recorded moment compared with two times the effective moment calculated at that site, and Figure 4.10 graphically reports the maximum recorded gross-vehicle-weight compared to two times the effective gross-vehicle-weight at that site for a simply-supported span length of 100 ft . It should also be noted that the maximum recorded moment and gross-vehicle-weight at site 516 are significantly higher than the maximum recorded at site 513 and site 522. This is due to the heavy loads with short wheelbases observed at that site, as described previously in section 4.2.

Figure 4.9: Two times the Effective Moment Compared to the Recorded Maximum Moment on a Simply-Supported 100 ft Span in 2002

Figure 4.10: Two times the Effective Gross-Vehicle-Weight Compared to the Maximum Recorded Gross-Vehicle-Weight on a Simply-Supported 100 ft Span in 2002

The influence of time on the accuracy of the maximum stress range assumption by AASHTO was also investigated. Figure 4.11 compares the maximum measured moment to two times the effective moment at site 513 in the year 1999, 2001, and 2002. While the greatest difference is seen in 1999, and the least difference occurs in 2001, the maximum moment is underestimated in all three years by the AASHTO assumption of two times the effective moment. The same holds true for the variation in time of the maximum and estimated maximum gross-vehicle-weight (Figure 4.12).

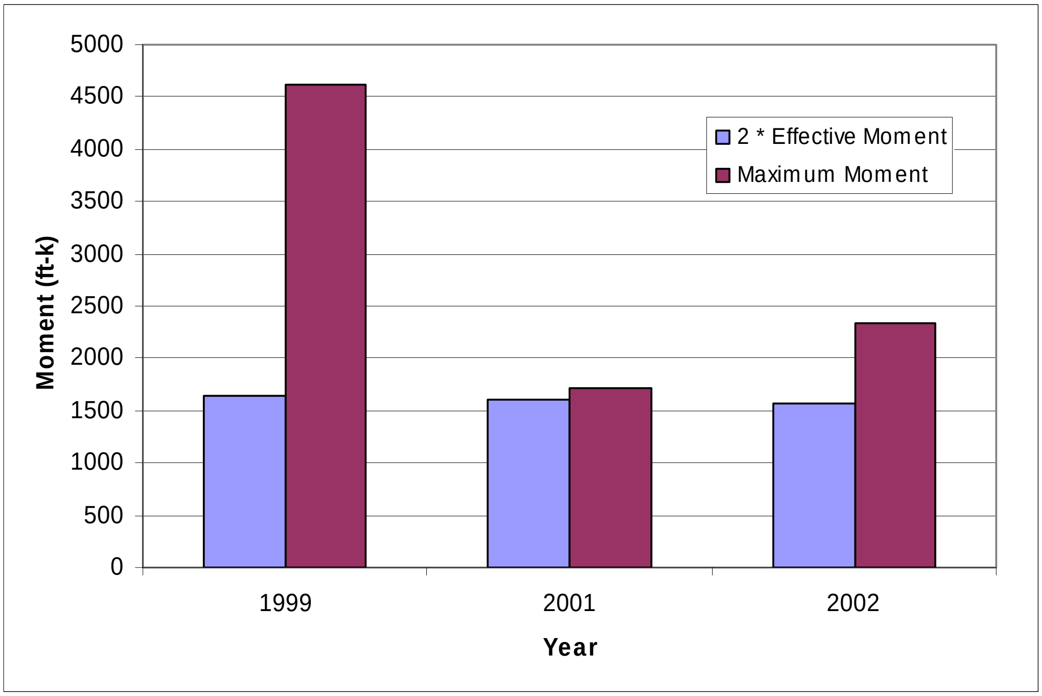

Figure 4.11: Two times the Effective Moment Compared to the Recorded Maximum Moment on a Simply-Supported 100 ft Span for Site 513

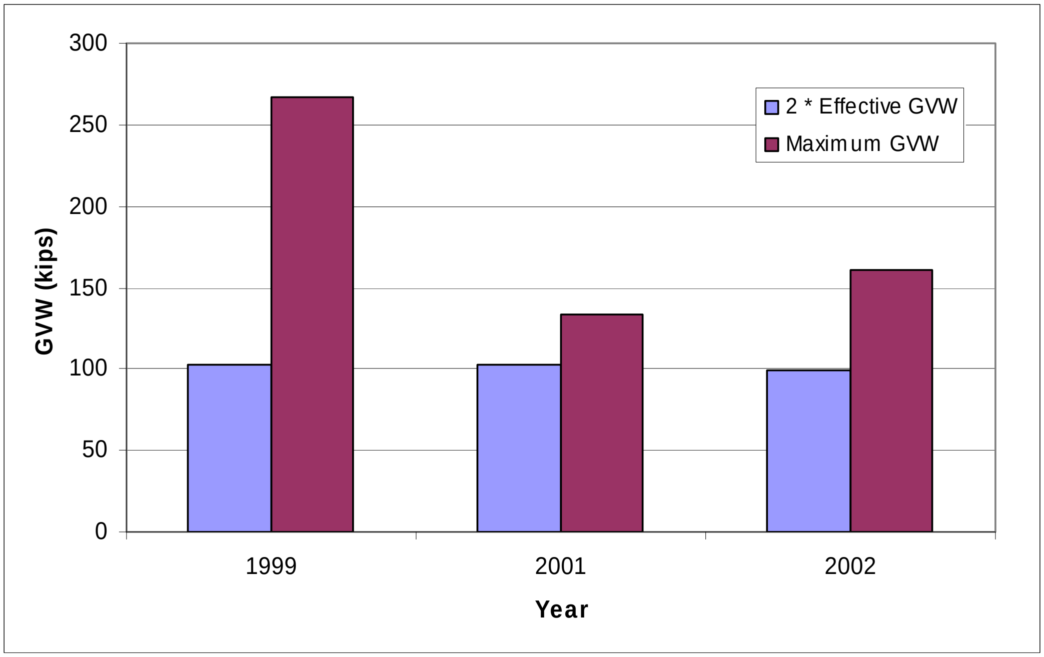

Figure 4.12: Two times the Effective Gross-Vehicle-Weight Compared to the Recorded Maximum Gross-Vehicle-Weight on a Simply-Supported 100 ft Span for Site 513

Finally, the validity of the AASHTO maximum stress range assumption was tested for variation among different span lengths using two times the effective moment compared to the measured maximum moment at Site 516 on a 50 ft and 100 ft span. The results of this comparison can be seen in Figure 4.13. The measured maximum moment is over 200% larger than two times the effective moment for the 100 ft span, while it is 190% larger for the 50 ft span. This indicates that as the span length decreases the percent error reduces as well, though only very slightly.

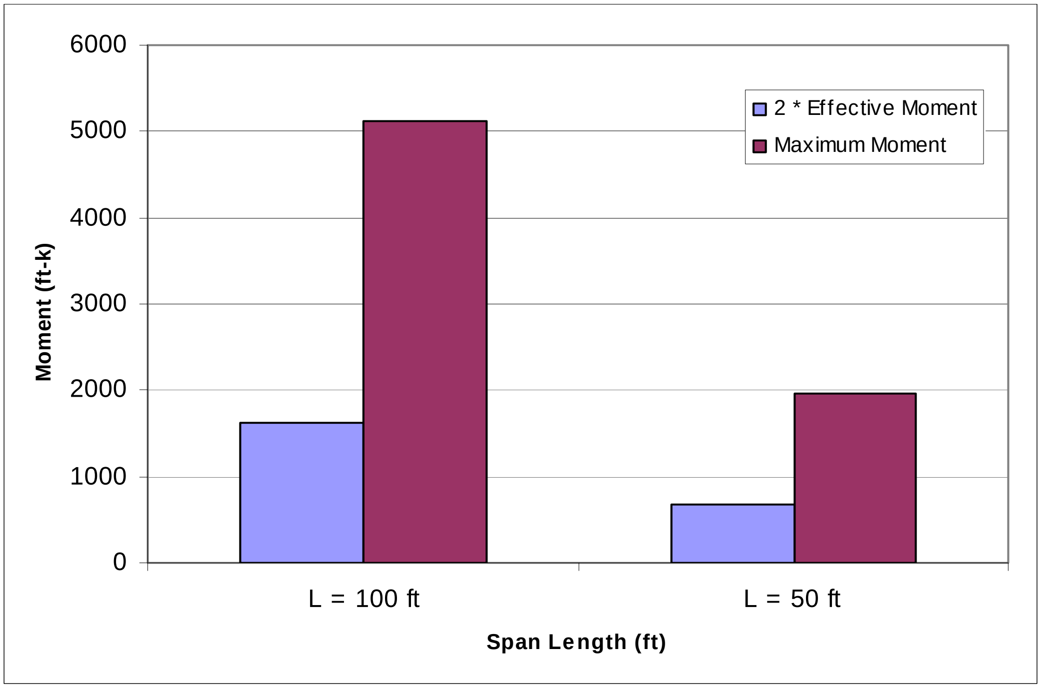

Figure 4.13: Two times the Effective Moment Compared to the Recorded Maximum Moment on a Simply-Supported Span for Site 516

4.4 OTHER TRENDS IN THE DATA

The effective moment ratio and the effective GVW ratio are not independent quantities. Figure 4.14 is a graph of all the effective mid-span moment ratios versus the effective GVW ratio calculated at each site with a 100 ft span length. It is evident in this graph that as the effective GVW ratio increases, the effective mid-span moment ratio increases as well.

This trend holds true for spans with different lengths as well. At site 516, effective mid-span moment ratios and effective GVW ratios were calculated for both a 100 ft span and a 50 ft span using the same weigh-in-motion data from 2002. These values are shown in Figure 4.15. It is evident that the relationship between the mid-span moment ratio and the GVW ratio is similar for a 100 ft and

50 ft span until the GVW ratio reaches 0.7. Beyond this point the moment and gross-vehicle-weight ratios increase at a faster rate for the 50 ft span than they do for the 100 ft span. However, the trend of an increase in the effective mid-span moment ratio as the effective GVW ratio increases remains true.

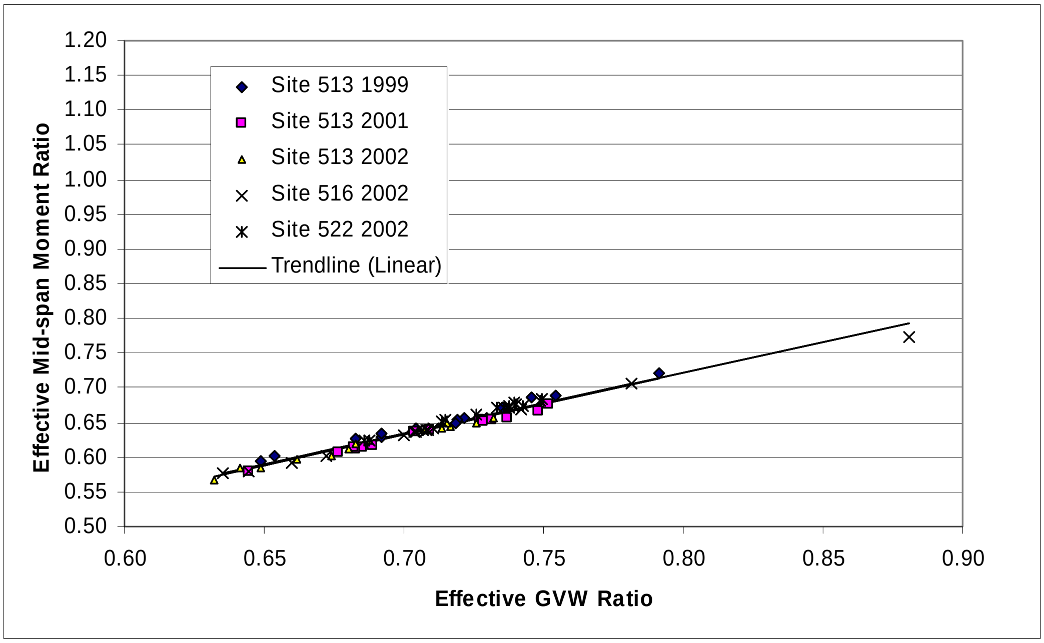

Figure 4.14: Effective Mid-span Moment Ratio vs. Effective GVW Ratio on a 100 ft Span

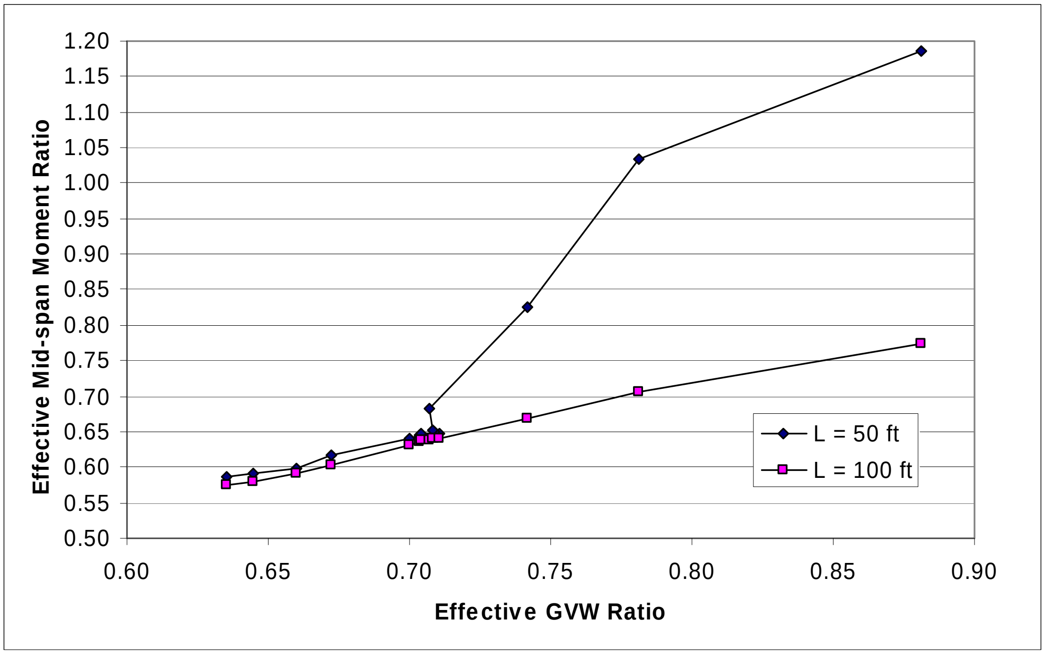

Figure 4.15: Effective GVW Ratio vs. Effective Mid-span Moment Ratio for Different Span Lengths at Site 516

The analysis done in this project does not indicate any correlation between ADTT and the effective moment ratio. As evidenced by the graph in Figure 4.16, there is significant scatter among the daily truck traffic and the effective moment ratio indicating no correlation between these values.

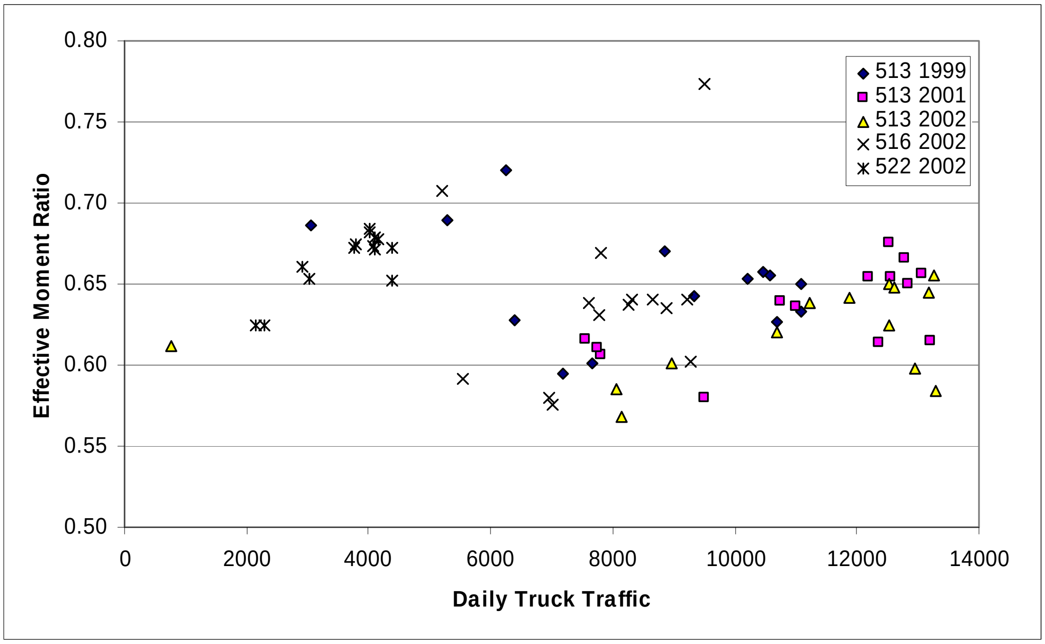

Figure 4.16: Effective Moment Ratio vs. Daily Truck Traffic for a 100 ft Simply-Supported Span

CHAPTER 5

Conclusions

The goal of this project was to compare the ratio of an effective moment and gross-vehicle-weight to the AASHTO fatigue design truck moment and gross-vehicle-weight in order to evaluate the accuracy of the AASHTO assumed ratio of 0.75. Additionally, the maximum moment and gross-vehicle-weight for each site was recorded for comparison to the AASHTO assumption that the maximum stress range seen by a bridge is equal to twice the effective stress range for the infinite life design criteria.

In almost every instance, the mid-span effective moment ratio was found to be larger than the quarter- and three-quarter-span effective moment ratio, and was used as the basis of comparison. However, the fact that the effective moment ratio was different along different points of the span may be useful information when considering design of a element subjected to fatigue at different points along a bridge.

Also, a root-mean-cube of the effective moment ratios, the effective gross-vehicle-weight ratios, and the maximum moments over each two-week period analyzed was computed in order to average out daily variation in the data and serve as a representative value for that site, date, and span length.

5.1 AASHTO FATIGUE LOAD FACTOR EVALUATION

For spans of 100 ft, the AASHTO fatigue load factor of 0.75 is an accurate representation of the gross-vehicle-weights carried by a bridge. At each of the three sites analyzed the effective gross-vehicle-weight ratio range, when the 8 percent error of the data was accounted for, included the 0.75 design value.

However, at all three locations, the effective moment ratio range was lower than 0.75, indicating that the AASHTO fatigue load factor may overestimate the actual damage done to a bridge by fatigue. Additionally, as the span length decreases, the effective moment ratio increases, especially for traffic containing heavy and short trucks. At site 516 it was found that changing the span length from 100 ft to 50 ft increased the effective mid-span moment ratio by 17 percent. Through comparison of the daily truck traffic at site 516, a correlation between the effective moment ratio and the percent of trucks heavier and shorter than the AASHTO fatigue design truck was found. As the percent of these short and heavy trucks increased, the effective moment ratio also increased, indicating that local traffic patterns at a bridge may significantly impact the effective moment ratio.

5.2 AASHTO MAXIMUM STRESS RANGE ASSUMPTION

For every site, for every year, and for every span length, the assumption by AASHTO that the maximum stress range seen by a bridge is equal to two times the effective stress range, was found to be inaccurate. In all cases, two times the effective stress range (taken as both the effective gross-vehicle-weight and the effective moment) underestimated the actual maximum moment by 7 to over 200 percent.

5.3 GENERAL TRENDS IN THE DATA

For all situations, the increase in the effective moment ratio correlated directly with the increase in the effective gross-vehicle-weight ratio, indicating that the effective gross-vehicle-weight ratio can effectively be used for estimating the fatigue damage to a bridge, as long as the relationship between the values is known.

Also, no correlation was found between the daily truck traffic at a site and the effective moment ratio, indicating that the amount of traffic at a site does not affect the fatigue load factor.

APPENDIX A

The PAT Reporter Program and the TMG Type 7 File Format

A.1 HOW TO USE THE PAT REPORTER PROGRAM

The files from the DAW 200, designed by PAT America, are data files that must be processed using the PAT Reporter software. The PAT Reporter software is a DOS-based program that can be run through the command prompt of a Windows-based computer. The files from the DAW 200 are labeled as D5130101.99, where D is the file type (specifying it's DAW origin), the next three digits (513) are the site number, the following two digits are the month of the data (01 for January), the next two digits are the day of the data (01 for 1), and the final two digits specify the year of the data (99 for 1999).

To create the TMG Type 7 reports from the DAW 200 files, the DAW 200 files are placed in the same folder as the reporter program. Although there is no official limit to the number of files that can be processed at once, it is recommended that no more than one hundred files be processed at one time. A command prompt is opened to run the PAT Reporter program, selecting the folder containing the program as the base directory. Once the program is running, the following characters are typed in succession to produce the TMG Type 7 reports. These characters are "1", "1", "A", "5", "A", "A".

After the program has completed the processing, the created files, labeled 75130505.02 with 7 for the file type, 513 for the site number of the file, 05 for the month of the file (May in this case), 05 for the day of the month, and 02 for the year of the file (2002), can be found in the folder with the reporter program.

A.2 TMG TYPE 7 FORMAT

A.2.1 Column Designation

Table A.1: Face Record

Columns	No. of Columns	Description
1	1	Truck weight record code
2-3	2	State code
4-5	2	Functional classification
6-8	3	Station identification number
9	1	Direction of travel
10-11	2	Year of data
12-13	2	Month of data
14-15	2	Date of month
16-17	2	Hour of day
18-23	6	Vehicle type code
24-41	18	
42-45	4	Total weight of truck or combination
46-48	3	A-axle weight (in hundreds of pounds)
49-51	3	B-axle weight
52-54	3	C-axle weight
55-57	3	D-axle weight
58-60	3	E-axle weight
61-63	3	A-B axle spacing (feet and tenths)
64-66	3	B-C axle spacing
67-69	3	C-D axle spacing
70-72	3	D-E axle spacing
73-76	4	Total wheelbase
77-79	3	Record serial number (same as continuation record)
80	1	Continuation indicator (0 = has no continuation, 1 = has a continuation)

Table A.2: Continuation Record

Columns	No. of Columns	Description
1-28	28	Same as columns 1-28 of the face record
29-31	3	F-axle weight (hundreds of pounds)
32-34	3	G-axle weight
35-37	3	H-axle weight
38-40	3	I-axle weight
41-43	3	J-axle weight
44-46	3	K-axle weight
47-49	3	L-axle weight
50-52	3	M-axle weight
53-55	3	E-F axle spacing (feet and tenths)
56-58	3	F-G axle spacing
59-61	3	G-H axle spacing
62-64	3	H-I axle spacing
65-67	3	I-J axle spacing
68-70	3	J-K axle spacing
71-73	3	K-L axle spacing
74-76	3	L-M axle spacing
77-79	3	Record serial number (same as face record)
80	1	Continuation indicator (2 = first continuation record for a vehicle with more than 13 axles, 9 = last continuation record)

A.2.2 Excerpt from a TMG Type 7 Output File (75160515.02)

```
748015166 2051500332000    4      4      0289097059059041033175043328041058700010
748015162 2051500332000    4      1      0559108096098129128193043308039058300020
748015162 2051500332000    4      1      0479095103086102093151041310037053900030
748015162 2051500332000    4      1      0723113156150159145174043395040065200040
748015162 2051500332000    4      1      0719103158134166158090043306074051300050
748015162 2051500337000    4      1      0704094140141158171141043305104059300060
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748015162 2051500337000    4      1      079311817316316817119004329209806230460
748015166 2051500332000    4      4      056509712712610111414404331503905410470
748015162 2051500332000    4      1      041710209108706407315504332304105620480
748015162 2051500332000    4      1      074010516215717314319604334904306310490
748015162 2051500322000    4      1      039408513609308000012334803900005100500
748015162 2051500332000    4      1      074011216916214115620804436104006530510
748015166 2051500332000    4      4      060911812012110214816404434403905910520
748015166 2051500332000    4      4      071111814014615615116904334203805920530
748015166 2051500332000    4      4      080611316216118918117004625608905610540
748015166 2051500337000    4      4      072910716917114613622404329110406620550
748015166 2051500332000    4      4      076112016316615915317304133104105860560
748015162 2051500332000    4      1      075911014215215619909004021808504330570
748015162 2051500332000    4      1      080210117616717618216104227103905130580
748015166 2051500332000    4      3      033109005606106206209204132803905000590
748015166 2051500220000    4      4      007204302900000000013400000000001340600
748015166 2051500332000    4      3      054509715014207907709204332603905000610
748015166 2051500332000    4      4      035810806506006605917004432804105830620
748015166 2051500521200    4      4      031608205406904107013120609522006520630
748015166 2051500332000    4      4      074511114514817516618604330504005740640
748015162 2051500332000    4      1      075512316314715816417604535104306150650
748015166 2051500337000    4      3      058310411103127138167042293098060006660
748015162 2051500332000    4      1      073611116616415414109804238404205660670
748015162 2051500220000    4      1      013803710100000000013200000000001320680
748015166 2051500332000    4      4      067412214112814314016604331503805620690

748015162 2051500337000    4      1      074910014614517618221104732810906950700
748015162 2051500332000    4      1      073011715414915615415804032003905570710
748015166 2051500332000    4      4      044808408408009710313504336104205810720
748015162 2051500332000    4      1      068211015014713713822104836004606750730
748015166 2051500332000    4      4      073610316115415216616704231204205630740
748015162 2051500332000    4      1      031909206605505005611404035804005520750
748015162 2051500332000    4      1      072710915514715516117804334603906060760
748015162 2051500332000    4      1      067211712912614615417404232304005790770
748015162 2051500332000    4      1      042511407507708207715004231103905420780
748015166 2051500337000    4      4      075810715915716317219205230310506520790
748015166 2051500332000    4      3      048610109709109210521704533204106350800
```

```
748015166 2051500332000    4      3      038409708407405507423104936504906940810
748015166 2051500332000    4      4      077911916416416616616404433104105800820
748015166 2051500332000    4      4      074310915515416416118104432804105940830
748015166 2051500332000    4      4      061211615115010109420104334804006320840
748015162 2051500332000    4      1      074710214314616918716404227907705620850
748015162 2051500332000    4      1      065310313613014314117504335804106170860
748015162 2051500332000    4      1      074311111920417313615704234504205860870
748015166 2051500521200    4      4      071408716217215613712521009822006530880
748015162 2051500332000    4      1      038111408107605705317804331703905770890
748015162 2051500332000    4      1      063311611511413914917304032304005760900
748015162 2051500220000    4      1      006804002800000000012400000000001240910
748015162 2051500332000    4      1      057911912412110710815904230903905490920
748015162 2051500332000    4      1      072010613612917117816104223808705280930
748015162 2051500332000    4      1      033711305906405105017104435504306130940
748015162 2051500333000    4      1      081411812912914414715904233404806310951
748015162 2051500333000     1470000000000000000000000480000000000000000000000000959
748015162 2051500332000    4      1      050411210208910409716704232804005770960
748015166 2051500332000    4      4      071812014314614816117204330003905540970
748015166 2051500332000    4      4      077311616316416216815204332603905600980
748015166 2051500322000    4      4      016004705902602800012521502900003690990
748015166 2051500230000    4      4      043713220110400000021304400000002571000
748015166 2051500230000    4      4      038611914012700000021804300000002611010
748015166 2051500332000    4      4      057209011011213612417004432003905731020
748015166 2051500337000    4      4      076411316415616216916104529610006021030
748015162 2051500332000    4      1      039309208608106606812204232304205291040
748015162 2051500332000    4      1      073110916015517313409804331404004951050
748015162 2051500332000    4      1      031009906006104704315704530304205471060
748015166 2051500332000    4      4      073312116014915215117403930803905601070
748015166 2051500332000    4      4      042010208007907508419404331303805881080
748015166 2051500337000    4      4      040911208107707306617504327510005931090
748015162 2051500332000    4      1      079211616416318316616704134504105941100
748015162 2051500220000    4      1      006703902800000000009300000000000931110
748015162 2051500332000    4      1      072411314814615915816404335203905981120
748015162 2051500332000    4      1      069011515215114912315704433804105801130
748015162 2051500332000    4      1      072710915015116115616404333103905771140
748015162 2051500332000    4      1      034210407106905704115803827103805051150
748015166 2051500332000    4      4      076111416616316115716204334103905851160
748015162 2051500332000    4      2      073411914914716615316904234504205981170
748015162 2051500332000    4      1      075511915815416316117704131503905721180
748015162 2051500332000    4      1      074611113813418417920304333304106201190
748015162 2051500332000    4      2      066711912011616215018504231704005841200
748015162 2051500332000    4      2      052011409409511510216804534403905961210
748015162 2051500332000    4      1      045110209309208507918403933403905961220
748015166 2051500230000    4      4      038110116411600000021504300000002581230
748015166 2051500431000    4      4      034910508408807200017104328100004951240
748015166 2051500333000    4      4      074711213713814212209703924604904831251
748015166 2051500333000     0960000000000000000000000520000000000000000000000001259
748015166 2051500332000    4      4      032010006106804904217104133504105881260
748015166 2051500332000    4      4      049510210309709110216704426004105121270
748015162 2051500332000    4      1      032108506705805805319604534403906241280
748015166 2051500332000    4      4      076911116516016416920304328104205691290
748015166 2051500521200    4      4      074710617316114915812021009321406371300
748015162 2051500332000    4      1      074810715916516015715404432804105671310
748015162 2051500332000    4      1      069611514813617412315404531803905561320
748015166 2051500230000    4      4      036710818107800000021504700000002621330
748015162 2051500521200    4      2      05460881301031111413021409721806591340
748015162 2051500220000    4      2      008003904100000000011200000000001121350
748015166 2051500220000    4      4      010904806100000000013600000000001361360
748015162 2051500220000    4      1      009204105100000000011300000000001131370
```

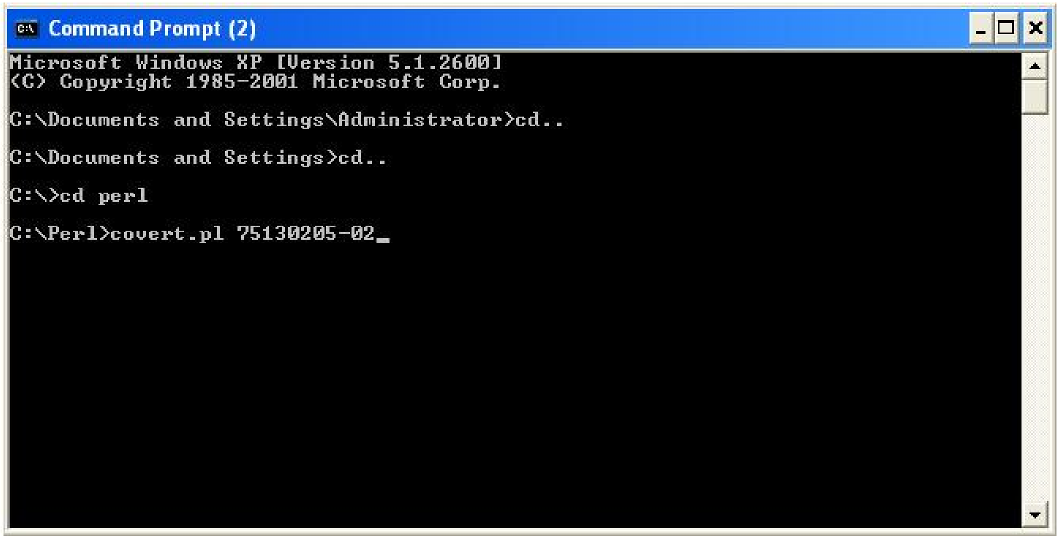
APPENDIX B

The Perl Conversion Program

B.1 PROGRAM FUNCTION

As discussed in Chapter 2, the eighty-column TMG Type 7 format is difficult to import into Microsoft Excel, due to the irregularity of the continuation files. To solve this problem, Dr. Paul J. Orgren, a computer scientist, was consulted. He developed a Perl program, "Convert.pl", that converted the TMG Type 7 files into comma-separated-text files, where the continuation records were attached to the end of their primary records in a long string, with each field separated by a comma, including labels for the meaning of each column. Microsoft Excel could then easily import and open this file-type as a spreadsheet.

Perl is a free compiler that specializes in text-based functions. It can be downloaded from the www.perl.org website. To run the program, the TMG Type 7 files should be placed in the same folder where Perl and the Perl program ("Convert.pl" in this case) are installed. From the command prompt available in Microsoft Windows operating systems, the program name is typed, followed by a space and then the name of the program to be converted. Figure B.1 shows a screenshot of this command in the command prompt.



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Administrator>cd..

C:\Documents and Settings>cd..

C:\>cd perl

C:\Perl>covert.pl 75130205-02_
```

Figure B.1: Screenshot of the Command Prompt Input for Perl "Convert" Program

B.2 CONVERT.PL PROGRAM TEXT

```
#!/usr/local/bin/perl

if (($#ARGV < 0) || ($#ARGV > 1)) {
        print STDOUT "Usage: perl LisaConv.pl input-file [ output-file ]\n";
        print STDOUT "\n";
        die "Exiting because of wrong number ($#ARGV) of arguments";
}

my $infile = $ARGV[0];
my $outfile = "";

if ($#ARGV == 0) {
        $outfile = $infile . ".csv";
} else {
        $outfile = $ARGV[1];
}

print STDOUT "Argv=$#ARGV ;  Input file: $infile ;  output file: $outfile\n";

if (!(-e $infile)) {
        print STDOUT "Input file $infile does not exist.\n";
        print STDOUT "\n";
        die "Exiting because input file $infile does not exist.";
```

```
    }

    if (!(-r $infile)) {
        print STDOUT "Input file $infile is not readable.\n";
        print STDOUT "\n";
        die "Exiting because input file $infile is not readable.";
    }

    if (-e $outfile) {
        print STDOUT "Output file $outfile already exists.\n";
        print STDOUT "\n";
        die "Exiting because output file $outfile already exists.";
    }

    open(IN,$infile) || die "cannot open $infile for reading";
    open(OUT,">$outfile") || die "cannot create $outfile";

    my @fac;
    my @con;
    my @cot;
    my $continuing = 0;
    my $num_of_elts = 0;
    my @cmt;
    my $count = 0;
    my $year = 0;

    print OUT "\"Truck weight record code\",\"State Code\"," .
        "\"Functional Classification\",\"Station ID Number\"," .
        "\"Direction of Travel\",\"Year of Data\",\"Month of Data\"," .
        "\"Date of Month\",\"Hour of Day\",\"Vehicle Type Code\",\"N/A\"," .
        "\"Total weight of truck or combination\",\"A-axle\",\"B-axle\"," .
        "\"C-axle\",\"D-axle\",\"E-axle\",\"AB spacing\",\"BC spacing\"," .
        "\"CD spacing\",\"DE spacing\",\"total wheelbase\"," .
        "\"record serial number\",\"continuation indicator\",\"F-axle\"," .
        "\"G-axle\",\"H-axle\",\"I-axle\",\"J-axle\",\"K-axle\",\"L-axle\"," .
        "\"M-axle\",\"EF spacing\",\"FG spacing\",\"GH spacing\"," .
        "\"HI spacing\",\"IJ spacing\",\"JK spacing\",\"KL spacing\"," .
        "\"LM spacing\",\"record serial number\",\"continuation indicator\"\n";
    while (<IN>) {
        if (length($_) == 81) {     # have to count the newline as a character
            if ($continuing == 0) {
                @fac = ();
                @fac                                                    =
/^(\d)(\d\d)(\d\d)(\d\d\d)(\d)(.\d)(\d\d)(\d\d)(\d\d)(\d\d\d\d\d\d)(..................)(\d\d\d\d)(\d\d\d)(\d\d\d
)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d\d)(\d\d\d)(\d)/;
                $num_of_elts = @fac;
                if ($num_of_elts < 24) {
                    chop($_);
```

```
                    print OUT "\"Skip line that didn't match pattern:
$_\"\n";
                } else {
                    $count = $fac[23] + 0;
                    $year = $fac[5] + 1900;
                    if ($year < 1961) {
                        $year = $year + 100;
                    }
    # NOTE:                 # if you want just 2-digit year, uncomment
                    # the next line by removing the "#":
                    # $year = $fac[5] + 0;
                    if ($count == 0) {
                        @cmt = $fac[10] =~ /^ *(\w+ +\w+) *$/;
                        print OUT "$fac[0],$fac[1],$fac[2]," .
                            "$fac[3],$fac[4],$year," .
                            "$fac[6],$fac[7],$fac[8]," .
                            "$fac[9],\"$cmt[0]\",$fac[11],".
                            "$fac[12],$fac[13],$fac[14]," .
                            "$fac[15],$fac[16],$fac[17]," .
                            "$fac[18],$fac[19],$fac[20]," .
                            "$fac[21],$fac[22],$fac[23]\n";
                    } elsif ($count == 1) {
                        $continuing = 1;
                    }
                }
            } elsif ($continuing == 1) {
                $continuing = 0;
                @con = ();
                @con                                                  =
/^(\d)(\d\d)(\d\d)(\d\d\d)(\d)(.\d)(\d\d)(\d\d)(\d\d)(\d\d\d\d\d\d)(.....)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\
d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d
)/;
                $num_of_elts = @con;
                if ($num_of_elts < 29) {
                    chop($_);
                    print OUT "\"Skip line that didn't match pattern:
$_\"\n";
                } else {
                    $count = $con[28] + 0;
                    if ($count == 9) {
                        @cmt = $fac[10] =~ /^ *(\w+ +\w+) *$/;
                        print OUT "$fac[0],$fac[1],$fac[2]," .
                            "$fac[3],$fac[4],$year," .
                            "$fac[6],$fac[7],$fac[8]," .
                            "$fac[9],\"$cmt[0]\",$fac[11],".
                            "$fac[12],$fac[13],$fac[14]," .
                            "$fac[15],$fac[16],$fac[17]," .
                            "$fac[18],$fac[19],$fac[20]," .
                            "$fac[21],$fac[22],$fac[23]," .
```

```
                            "$con[11],$con[12],$con[13]," .
                            "$con[14],$con[15],$con[16]," .
                            "$con[17],$con[18],$con[19]," .
                            "$con[20],$con[21],$con[22]," .
                            "$con[23],$con[24],$con[25]," .
                            "$con[26],$con[27],$con[28]\n";
                        if ($fac[22] != $con[27]) {
                            print OUT "Warning: Preceding ".
                                "line has serial " .
                                "numbers that do NOT " .
                                "match!\n";
                        }
                    } elsif ($count == 2) {
                        $continuing = 2;
                    }
                }
            } elsif ($continuing == 2) {
                $continuing = 0;
                @cot = ();
                @cot = /^(\d)(\d\d)(\d\d)(\d\d\d)(\d)(.\d)(\d\d)(\d\d)(\d\d)(\d\d\d\d\d)(.....)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d\d\d)(\d)/;
                $num_of_elts = @cot;
                if ($num_of_elts < 29) {
                    chop($_);
                    print OUT "\"Skip line that didn't match pattern: $_\"\n";
                } else {
                    $count = $cot[28] + 0;
                    if ($count == 9) {
                        @cmt = $fac[10] =~ /^ *(\w+ +\w+) *$/;
                        print OUT "$fac[0],$fac[1],$fac[2]," .
                            "$fac[3],$fac[4],$year," .
                            "$fac[6],$fac[7],$fac[8]," .
                            "$fac[9],\"$cmt[0]\",$fac[11],".
                            "$fac[12],$fac[13],$fac[14]," .
                            "$fac[15],$fac[16],$fac[17]," .
                            "$fac[18],$fac[19],$fac[20]," .
                            "$fac[21],$fac[22],$fac[23]," .
                            "$con[11],$con[12],$con[13]," .
                            "$con[14],$con[15],$con[16]," .
                            "$con[17],$con[18],$con[19]," .
                            "$con[20],$con[21],$con[22]," .
                            "$con[23],$con[24],$con[25]," .
                            "$con[26],$con[27],$con[28]," .
                            "$cot[11],$cot[12],$cot[13]," .
                            "$cot[14],$cot[15],$cot[16]," .
                            "$cot[17],$cot[18],$cot[19]," .
```

```
                        "$cot[20],$cot[21],$cot[22]," .
                        "$cot[23],$cot[24],$cot[25]," .
                        "$cot[26],$cot[27],$cot[28]\n";
                    if (($fac[22] != $con[27]) ||
                       ($fac[22] != $cot[27])) {
                        print OUT "Warning: Preceding ".
                            "line has serial " .
                            "numbers that do NOT " .
                            "match!\n";
                    }
                } elsif ($count == 2) {
                    $continuing = 2;
                }
            }
        }
    } else {
        if (length($_) > 2) {
            chop($_);
            print OUT "\"Skip line with wrong length " .
                length($_) . ": $_\"\n";
        } # silently skip extremely short lines
    }
}

close(IN);
close(OUT);
```

B.3 SAMPLE CONVERT.PL PROGRAM OUTPUT OPENED WITH EXCEL

Table B.1: Columns 1 - 9

Truck weight record code	State Code	Functional Classification	Station ID Number	Direction of Travel	Year of Data	Month of Data	Date of Month	Hour of Day
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	1	2001	4	14	0
7	48	1	513	5	2001	4	14	0
7	48	1	513	5	2001	4	14	0

Table B.2: Columns 10 - 17

Vehicle Type Code	N/A	Total weight of truck or combination	A-axle	B-axle	C-axle	D-axle	E-axle
220000	7 4	80	37	43	0	0	0
332000	7 3	666	105	196	190	109	66
220000	7 4	73	38	35	0	0	0
521200	7 4	732	101	195	178	129	129
220000	7 3	104	55	49	0	0	0
521200	7 4	552	109	152	123	89	79
220000	7 2	81	46	35	0	0	0
332000	7 1	571	102	110	107	125	127
332000	7 2	394	104	72	69	79	70
322000	7 4	146	45	49	15	37	0
220000	7 2	71	36	35	0	0	0
521200	7 1	532	98	134	96	116	88
220000	7 1	210	82	128	0	0	0
190300	7 1	279	85	158	36	0	0
190300	7 4	382	138	211	33	0	0
337000	7 1	704	104	140	133	159	168
531200	7 1	754	88	108	111	143	141
220000	7 4	124	43	81	0	0	0
220000	7 4	205	66	139	0	0	0
332000	7 4	341	109	61	64	60	47
332000	7 1	401	86	83	84	74	74
521200	7 1	379	86	106	80	62	45
521200	7 1	380	79	130	90	48	33
337000	7 2	587	101	134	135	108	109
521200	7 4	623	116	148	168	89	102
632100	7 4	715	117	101	110	123	136
332000	7 1	563	80	112	110	127	134
332000	7 1	443	87	94	90	102	70
521200	7 4	322	38	108	66	49	61
332000	7 4	361	107	78	75	51	50

Table B.3: Columns 18 - 24

AB spacing	BC spacing	CD spacing	DE spacing	total wheelbase	record serial number	continuation indicator
118	0	0	0	118	1	0
195	46	352	48	641	2	0
122	0	0	0	122	3	0
127	218	95	226	666	4	0
92	0	0	0	92	5	0
128	215	97	224	664	6	0
120	0	0	0	120	7	0
173	43	328	39	583	8	0
100	43	294	43	480	9	0
131	148	27	0	306	10	0
119	0	0	0	119	11	0
127	213	99	222	661	12	0
171	0	0	0	171	13	0
239	44	0	0	283	14	0
240	46	0	0	286	15	0
178	42	276	101	597	16	0
114	42	193	101	666	17	1
138	0	0	0	138	18	0
213	0	0	0	213	19	0
194	43	337	39	613	20	0
109	43	351	41	544	21	0
131	225	94	232	682	22	0
134	229	94	239	696	23	0
198	43	316	104	661	24	0
128	210	102	223	663	25	0
164	45	209	88	733	26	1
187	44	365	40	636	27	0
176	44	324	40	584	28	0
128	219	96	227	670	29	0
114	45	371	43	573	30	0

Table B.4: Columns 25 - 33

F-axle	G-axle	H-axle	I-axle	J-axle	K-axle	L-axle	M-axle	EF spacing
163	0	0	0	0	0	0	0	216
128	0	0	0	0	0	0	0	227

Table B.5: Columns 34 - 42

FG spacing	GH spacing	HI spacing	IJ spacing	JK spacing	KL spacing	LM spacing	record serial number	continuation indicator
0	0	0	0	0	0	0	17	9
0	0	0	0	0	0	0	26	9

APPENDIX C

Code for Excel Macros

C.1 CODE FOR "FIND MOMENTS"

```
Sub Find_Moments()
'
' Find_Moments Macro
' Macro recorded 1/8/2003 by Lisa F. Orgren
'
Dim count As Integer
count = 0

Do While count < 15000

'    Set axle weights
Dim x As Integer
x = count + 2

Sheets("Data File").Select
a = Cells(x, 13)
b = Cells(x, 14)
c = Cells(x, 15)
d = Cells(x, 16)
e = Cells(x, 17)
f = Cells(x, 25)
g = Cells(x, 26)
h = Cells(x, 27)
i = Cells(x, 28)
j = Cells(x, 29)
k = Cells(x, 30)
l = Cells(x, 31)
m = Cells(x, 32)

Sheets("Input Data").Select
Range("C3") = a * 100
Range("C4") = b * 100
Range("C5") = c * 100
Range("C6") = d * 100
Range("C7") = e * 100
Range("C8") = f * 100
Range("C9") = g * 100
Range("C10") = h * 100
```

```
Range("C11") = i * 100
Range("C12") = j * 100
Range("C13") = k * 100
Range("C14") = l * 100
Range("C15") = m * 100

'       Set axle spacing
Dim y As Integer
y = count + 2

Sheets("Data File").Select
AB = Cells(y, 18)
BC = Cells(y, 19)
CD = Cells(y, 20)
DE = Cells(y, 21)
EF = Cells(y, 33)
FG = Cells(y, 34)
GH = Cells(y, 35)
HI = Cells(y, 36)
IJ = Cells(y, 37)
JK = Cells(y, 38)
KL = Cells(y, 39)
LM = Cells(y, 40)

Sheets("Input Data").Select
Range("E3") = AB / 10
Range("E4") = (AB + BC) / 10
Range("E5") = (AB + BC + CD) / 10
Range("E6") = (AB + BC + CD + DE) / 10
Range("E7") = (AB + BC + CD + DE + EF) / 10
Range("E8") = (AB + BC + CD + DE + EF + FG) / 10
Range("E9") = (AB + BC + CD + DE + EF + FG + GH) / 10
Range("E10") = (AB + BC + CD + DE + EF + FG + GH + HI) / 10
Range("E11") = (AB + BC + CD + DE + EF + FG + GH + HI + IJ) / 10
Range("E12") = (AB + BC + CD + DE + EF + FG + GH + HI + IJ + JK) / 10
Range("E13") = (AB + BC + CD + DE + EF + FG + GH + HI + IJ + JK + KL) / 10
Range("E14") = (AB + BC + CD + DE + EF + FG + GH + HI + IJ + JK + KL + LM) / 10


'       Copy maximum moments
Dim z As Integer
z = count + 3

Sheets("Moment Ranges").Select
Range("B1").Select
Selection.Copy
Sheets("Moments for Each Truck").Select
Cells(z, 1).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
```

```
            :=False, Transpose:=False
Sheets("Moment Ranges").Select
Range("C1").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Moments for Each Truck").Select
Cells(z, 2).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
            :=False, Transpose:=False
Sheets("Moment Ranges").Select
Range("D1").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Moments for Each Truck").Select
Cells(z, 3).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
            :=False, Transpose:=False

count = count + 1
Loop

'
End Sub
```

C.2 CODE FOR "CREATE HISTOGRAM"

```
Sub Create_Histogram()
'
' Create_Histogram Macro
' Macro recorded 1/10/2003 by Lisa F. Orgren
'
Dim col As Integer
col = 5

Do While col <= 7


  Dim count As Integer
  count = 3

  one = 0
  two = 0
  three = 0
  four = 0
  five = 0
  six = 0
  seven = 0
```

```
eight = 0
nine = 0
ten = 0
eleven = 0
twelve = 0
thirteen = 0
fourteen = 0
fifteen = 0
sixteen = 0
seventeen = 0
eighteen = 0
nineteen = 0
twenty = 0
one2 = 0
two2 = 0
three2 = 0
four2 = 0
five2 = 0
six2 = 0
seven2 = 0
eight2 = 0
nine2 = 0
ten2 = 0
eleven2 = 0
twelve2 = 0
thirteen2 = 0
fourteen2 = 0
fifteen2 = 0
sixteen2 = 0
seventeen2 = 0
eighteen2 = 0
nineteen2 = 0
twenty2 = 0
one3 = 0
two3 = 0
three3 = 0
four3 = 0
five3 = 0
six3 = 0
seven3 = 0
eight3 = 0
nine3 = 0
ten3 = 0
eleven3 = 0
twelve3 = 0
thirteen3 = 0
fourteen3 = 0
fifteen3 = 0
sixteen3 = 0
```

```
seventeen3 = 0
eighteen3 = 0
nineteen3 = 0
twenty3 = 0
twentyone = 0

Sheets("MR").Select

Do Until Cells(count, col) = 0
   a = Cells(count, col)
      If a < 50 Then
         one = one + 1
      Else
      If a < 100 Then
         two = two + 1
      Else
      If a < 150 Then
         three = three + 1
      Else
      If a < 200 Then
         four = four + 1
      Else
      If a < 250 Then
         five = five + 1
      Else
      If a < 300 Then
         six = six + 1
      Else
      If a < 350 Then
         seven = seven + 1
      Else
      If a < 400 Then
         eight = eight + 1
      Else
      If a < 450 Then
         nine = nine + 1
      Else
      If a < 500 Then
         ten = ten + 1
      Else
      If a < 550 Then
         eleven = eleven + 1
      Else
      If a < 600 Then
         twelve = twelve + 1
      Else
      If a < 650 Then
         thirteen = thirteen + 1
      Else
```

```
If a < 700 Then
    fourteen = fourteen + 1
Else
If a < 750 Then
    fifteen = fifteen + 1
Else
If a < 800 Then
    sixteen = sixteen + 1
Else
If a < 850 Then
    seventeen = seventeen + 1
Else
If a < 900 Then
    eighteen = eighteen + 1
Else
If a < 950 Then
    nineteen = nineteen + 1
Else
If a < 1000 Then
    twenty = twenty + 1
Else
If a < 1050 Then
    one2 = one2 + 1
Else
If a < 1100 Then
    two2 = two2 + 1
Else
If a < 1150 Then
    three2 = three2 + 1
Else
If a < 1200 Then
    four2 = four2 + 1
Else
If a < 1250 Then
    five2 = five2 + 1
Else
If a < 1300 Then
    six2 = six2 + 1
Else
If a < 1350 Then
    seven2 = seven2 + 1
Else
If a < 1400 Then
    eight2 = eight2 + 1
Else
If a < 1450 Then
    nine2 = nine2 + 1
Else
If a < 1500 Then
```

```
    ten2 = ten2 + 1
Else
If a < 1550 Then
    eleven2 = eleven2 + 1
Else
If a < 1600 Then
    twelve2 = twelve2 + 1
Else
If a < 1650 Then
    thirteen2 = thirteen2 + 1
Else
If a < 1700 Then
    fourteen2 = fourteen2 + 1
Else
If a < 1750 Then
    fifteen2 = fifteen2 + 1
Else
If a < 1800 Then
    sixteen2 = sixteen2 + 1
Else
If a < 1850 Then
    seventeen2 = seventeen2 + 1
Else
If a < 1900 Then
    eighteen2 = eighteen2 + 1
Else
If a < 1950 Then
    nineteen2 = nineteen2 + 1
Else
If a < 2000 Then
    twenty2 = twenty2 + 1
Else
If a < 2050 Then
    one3 = one3 + 1
Else
If a < 2100 Then
    two3 = two3 + 1
Else
If a < 2150 Then
    three3 = three3 + 1
Else
If a < 2200 Then
    four3 = four3 + 1
Else
If a < 2250 Then
    five3 = five3 + 1
Else
If a < 2300 Then
    six3 = six3 + 1
```

```
Else
If a < 2350 Then
    seven3 = seven3 + 1
Else
If a < 2400 Then
    eight3 = eight3 + 1
Else
If a < 2450 Then
    nine3 = nine3 + 1
Else
If a < 2500 Then
    ten3 = ten3 + 1
Else
If a < 2550 Then
    eleven3 = eleven3 + 1
Else
If a < 2600 Then
    twelve3 = twelve3 + 1
Else
If a < 2650 Then
    thirteen3 = thirteen3 + 1
Else
If a < 2700 Then
    fourteen3 = fourteen3 + 1
Else
If a < 2750 Then
    fifteen3 = fifteen3 + 1
Else
If a < 2800 Then
    sixteen3 = sixteen3 + 1
Else
If a < 2850 Then
    seventeen3 = seventeen3 + 1
Else
If a < 2900 Then
    eighteen3 = eighteen3 + 1
Else
If a < 2950 Then
    nineteen3 = nineteen3 + 1
Else
If a < 3000 Then
    twenty3 = twenty3 + 1
Else
twentyone = twentyone + 1
End If
End If
End If
End If
End If
```

```
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
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End If
End If
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End If
End If
End If
End If
End If
End If
End If
End If
```

```
        End If
        End If
        End If
        End If
        End If
        End If

    count = count + 1

Loop

total1 = one + two + three + four + five + six + seven + eight + nine + ten + eleven +
        twelve + thirteen + fourteen + fifteen + sixteen + seventeen + eighteen +
        nineteen + twenty
total2 = one2 + two2 + three2 + four2 + five2 + six2 + seven2 + eight2 + nine2 + ten2
        + eleven2 + twelve2 + thirteen2 + fourteen2 + fifteen2 + sixteen2 + seventeen2
        + eighteen2 + nineteen2 + twenty2
total3 = one3 + two3 + three3 + four3 + five3 + six3 + seven3 + eight3 + nine3 + ten3
        + eleven3 + twelve3 + thirteen3 + fourteen3 + fifteen3 + sixteen3 + seventeen3
        + eighteen3 + nineteen3 + twenty3 + twentyone
total = total1 + total2 + total3

x = col + 6

Cells(5, x) = (one / total) * 100
Cells(6, x) = (two / total) * 100
Cells(7, x) = (three / total) * 100
Cells(8, x) = (four / total) * 100
Cells(9, x) = (five / total) * 100
Cells(10, x) = (six / total) * 100
Cells(11, x) = (seven / total) * 100
Cells(12, x) = (eight / total) * 100
Cells(13, x) = (nine / total) * 100
Cells(14, x) = (ten / total) * 100
Cells(15, x) = (eleven / total) * 100
Cells(16, x) = (twelve / total) * 100
Cells(17, x) = (thirteen / total) * 100
Cells(18, x) = (fourteen / total) * 100
Cells(19, x) = (fifteen / total) * 100
Cells(20, x) = (sixteen / total) * 100
Cells(21, x) = (seventeen / total) * 100
Cells(22, x) = (eighteen / total) * 100
Cells(23, x) = (nineteen / total) * 100
Cells(24, x) = (twenty / total) * 100
Cells(25, x) = (one2 / total) * 100
Cells(26, x) = (two2 / total) * 100
Cells(27, x) = (three2 / total) * 100
Cells(28, x) = (four2 / total) * 100
Cells(29, x) = (five2 / total) * 100
```

```
    Cells(30, x) = (six2 / total) * 100
    Cells(31, x) = (seven2 / total) * 100
    Cells(32, x) = (eight2 / total) * 100
    Cells(33, x) = (nine2 / total) * 100
    Cells(34, x) = (ten2 / total) * 100
    Cells(35, x) = (eleven2 / total) * 100
    Cells(36, x) = (twelve2 / total) * 100
    Cells(37, x) = (thirteen2 / total) * 100
    Cells(38, x) = (fourteen2 / total) * 100
    Cells(39, x) = (fifteen2 / total) * 100
    Cells(40, x) = (sixteen2 / total) * 100
    Cells(41, x) = (seventeen2 / total) * 100
    Cells(42, x) = (eighteen2 / total) * 100
    Cells(43, x) = (nineteen2 / total) * 100
    Cells(44, x) = (twenty2 / total) * 100
    Cells(45, x) = (one3 / total) * 100
    Cells(46, x) = (two3 / total) * 100
    Cells(47, x) = (three3 / total) * 100
    Cells(48, x) = (four3 / total) * 100
    Cells(49, x) = (five3 / total) * 100
    Cells(50, x) = (six3 / total) * 100
    Cells(51, x) = (seven3 / total) * 100
    Cells(52, x) = (eight3 / total) * 100
    Cells(53, x) = (nine3 / total) * 100
    Cells(54, x) = (ten3 / total) * 100
    Cells(55, x) = (eleven3 / total) * 100
    Cells(56, x) = (twelve3 / total) * 100
    Cells(57, x) = (thirteen3 / total) * 100
    Cells(58, x) = (fourteen3 / total) * 100
    Cells(59, x) = (fifteen3 / total) * 100
    Cells(60, x) = (sixteen3 / total) * 100
    Cells(61, x) = (seventeen3 / total) * 100
    Cells(62, x) = (eighteen3 / total) * 100
    Cells(63, x) = (nineteen3 / total) * 100
    Cells(64, x) = (twenty3 / total) * 100
    Cells(65, x) = (twentyone / total) * 100
    Cells(66, x) = total

 col = col + 1

Loop
'
End Sub
```

C.3 CODE FOR "CREATE GVW HISTOGRAM"

```
Sub GVW_Histogram()
'
' GVW_Histogram Macro
' Macro recorded 1/14/2003 by Lisa F. Orgren
'
 Dim count As Integer
    count = 2

    Dim one As Integer
    Dim two As Integer
    Dim three As Integer
    Dim four As Integer
    Dim five As Integer
    Dim six As Integer
    Dim seven As Integer
    Dim eight As Integer
    Dim nine As Integer
    Dim ten As Integer
    Dim eleven As Integer
    Dim twelve As Integer
    Dim thirteen As Integer
    Dim fourteen As Integer
    Dim fifteen As Integer
    Dim sixteen As Integer
    Dim seventeen As Integer
    Dim eighteen As Integer
    Dim nineteen As Integer
    Dim twenty As Integer
    Dim twentyone As Integer
    one = 0
    two = 0
    three = 0
    four = 0
    five = 0
    six = 0
    seven = 0
    eight = 0
    nine = 0
    ten = 0
    eleven = 0
    twelve = 0
    thirteen = 0
    fourteen = 0
    fifteen = 0
    sixteen = 0
    seventeen = 0
    eighteen = 0
```

```
nineteen = 0
twenty = 0
twentyone = 0

Sheets("GVW").Select

Do Until (Cells(count, 2)) = 0
   a = Cells(count, 2)
   If a < 10 Then
      one = one + 1
   Else
      If a < 20 Then
         two = two + 1
      Else
         If a < 30 Then
            three = three + 1
         Else
            If a < 40 Then
               four = four + 1
            Else
               If a < 50 Then
                  five = five + 1
               Else
                  If a < 60 Then
                     six = six + 1
                  Else
                     If a < 70 Then
                        seven = seven + 1
                     Else
                        If a < 80 Then
                           eight = eight + 1
                        Else
                           If a < 90 Then
                              nine = nine + 1
                           Else
                              If a < 100 Then
                                 ten = ten + 1
                              Else
                                 If a < 110 Then
                                    eleven = eleven + 1
                                 Else
                                    If a < 120 Then
                                       twelve = twelve + 1
                                    Else
                                       If a < 130 Then
                                          thirteen = thirteen + 1
                                       Else
                                          If a < 140 Then
                                             fourteen = fourteen + 1
```

```
                            Else
                              If a < 150 Then
                                fifteen = fifteen + 1
                              Else
                                If a < 160 Then
                                  sixteen = sixteen + 1
                                Else
                                  If a < 170 Then
                                    seventeen = seventeen + 1
                                  Else
                                    If a < 180 Then
                                      eighteen = eighteen + 1
                                    Else
                                      If a < 190 Then
                                        nineteen = nineteen + 1
                                      Else
                                        If a < 200 Then
                                          twenty = twenty + 1
                                        Else
                                          twentyone = twentyone + 1
                                        End If
                                      End If
                                    End If
                                  End If
                                End If
                              End If
                            End If
                          End If
                        End If
                      End If
                    End If
                  End If
                End If
              End If
            End If
          End If
        End If
      End If
    End If
  End If

  count = count + 1

Loop

total = one + two + three + four + five + six + seven + eight + nine + ten + eleven +
     twelve + thirteen + fourteen + fifteen + sixteen + seventeen + eighteen +
     nineteen + twenty + twentyone
```

```
    Range("K5") = (one / total)
    Range("K6") = (two / total)
    Range("K7") = (three / total)
    Range("K8") = (four / total)
    Range("K9") = (five / total)
    Range("K10") = (six / total)
    Range("K11") = (seven / total)
    Range("K12") = (eight / total)
    Range("K13") = (nine / total)
    Range("K14") = (ten / total)
    Range("K15") = (eleven / total)
    Range("K16") = (twelve / total)
    Range("K17") = (thirteen / total)
    Range("K18") = (fourteen / total)
    Range("K19") = (fifteen / total)
    Range("K20") = (sixteen / total)
    Range("K21") = (seventeen / total)
    Range("K22") = (eighteen / total)
    Range("K23") = (nineteen / total)
    Range("K24") = (twenty / total)
    Range("K25") = (twentyone / total)
    Range("K27") = total
'

End Sub
```

APPENDIX D

Complete Data Tables

Table E.1: Site 513 in 1999 (span length = 100ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
7/11	78.4	3067	0.66	0.69	0.67	2198	3090	2289	0.75	169
7/12	79.3	5276	0.66	0.69	0.67	1946	2585	1918	0.75	123
7/13	95.6	8852	0.64	0.67	0.65	1593	2202	1675	0.74	147
7/14	184.4	6247	0.71	0.72	0.72	5587	7466	5624	0.79	358
7/15	152.7	10573	0.63	0.66	0.64	1782	2413	1901	0.72	132
7/16	241.1	10702	0.60	0.63	0.61	1612	2208	1674	0.68	175
7/17	92.5	7193	0.57	0.60	0.58	1658	2218	1614	0.65	130
7/18	313.5	6392	0.62	0.63	0.62	6119	7822	5776	0.69	502
7/19	333.9	9340	0.62	0.64	0.63	2376	3112	2247	0.70	263
7/20	78.3	10211	0.63	0.65	0.64	2175	3080	2282	0.72	168
7/21	276.2	10455	0.63	0.66	0.64	1786	2285	1745	0.73	222
7/22	360.6	11090	0.63	0.65	0.63	1456	1888	1471	0.72	220
7/23	280.4	11099	0.61	0.63	0.62	5446	7308	5532	0.69	354
7/24	235.5	7653	0.58	0.60	0.58	2166	2821	2124	0.65	214

Table E.2: Site 513 in 2001 (span length = 100 ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
2/25	80.8	7556	0.59	0.62	0.60	1492	1802	1477	0.69	115
2/26	102.5	10746	0.61	0.64	0.62	1470	1740	1362	0.71	148
2/27	78.7	12525	0.65	0.68	0.66	1426	1664	1356	0.75	114
2/28	120.5	12796	0.64	0.67	0.65	1603	1874	1324	0.75	149
3/1	105.8	13066	0.63	0.66	0.64	1539	1798	1393	0.74	124
3/2	138.6	12373	0.59	0.61	0.60	1302	1586	1253	0.69	112
3/3	93.4	7809	0.58	0.61	0.59	1283	1481	1229	0.68	95
3/4	78.6	7758	0.59	0.61	0.59	1297	1711	1387	0.68	103
3/5	80.6	11009	0.61	0.64	0.62	1739	2052	1496	0.70	136
3/6	91.6	12195	0.63	0.65	0.64	1544	2006	1586	0.73	144
3/7	125.6	12555	0.63	0.65	0.64	1507	1929	1436	0.73	126
3/8	113.3	12833	0.62	0.65	0.63	1416	1836	1561	0.73	165
3/9	112.2	13196	0.59	0.61	0.60	1303	1638	1351	0.68	138
3/10	84.7	9502	0.56	0.58	0.56	1164	1489	1161	0.64	130

Table E.3: Site 513 in 2002 (span length = 100 ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
4/14	84.4	8957	0.58	0.60	0.58	1679	2029	1732	0.67	169
4/15	78.8	11228	0.61	0.64	0.62	2173	2903	2145	0.71	137
4/16	113.2	12518	0.62	0.65	0.63	1495	1930	1537	0.73	158
4/17	107.1	13251	0.63	0.66	0.64	1439	1847	1388	0.73	149
4/18	168.5	13178	0.62	0.64	0.63	2404	2813	2295	0.72	206
4/19	224	12955	0.57	0.60	0.58	1668	1999	1506	0.66	182
4/20	192.2	8053	0.56	0.59	0.57	2154	2885	2138	0.65	151
4/21	170.3	8153	0.54	0.57	0.55	1363	1783	1293	0.63	133
4/22	213.1	10704	0.59	0.62	0.60	1465	1884	1490	0.68	130
4/23	218.6	11886	0.61	0.64	0.62	1729	2312	1840	0.71	192
4/24	206.7	12607	0.62	0.65	0.63	1981	2438	1755	0.72	167
4/25	233.1	12522	0.60	0.62	0.60	1955	2545	1867	0.69	123
4/26	232.4	13305	0.56	0.58	0.57	1678	2225	1612	0.64	137
4/27	152.1	752	0.59	0.61	0.59	1336	1716	1232	0.68	102

Table E.4: Site 522 in 2002 (span length = 100 ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
2/3	82.3	2143	0.61	0.62	0.61	1610	1560	1589	0.69	124
2/4	89.6	4115	0.66	0.68	0.66	1998	1965	1704	0.74	170
2/5	75.3	3804	0.66	0.67	0.66	1802	2023	1914	0.74	145
2/6	106.1	3749	0.65	0.67	0.65	1882	1837	1561	0.74	180
2/7	80.8	4065	0.66	0.67	0.66	1763	1710	1647	0.74	161
2/8	76.8	4397	0.65	0.67	0.65	1805	1684	1734	0.73	152
2/9	75.7	2902	0.65	0.66	0.64	1537	1462	1405	0.73	115
2/10	74.3	2280	0.61	0.62	0.61	1462	1450	1428	0.69	106
2/11	73.4	4165	0.66	0.68	0.66	2107	2389	2255	0.74	169
2/12	79.8	4014	0.67	0.68	0.66	2221	2147	1939	0.75	172
2/13	101.7	4010	0.67	0.68	0.66	2205	2160	1824	0.75	169
2/14	100.4	4092	0.65	0.67	0.65	2128	2017	1904	0.74	199
2/15	78.4	4380	0.63	0.65	0.63	1469	1351	1365	0.71	115
2/16	90.1	3028	0.64	0.65	0.64	1473	1482	1428	0.71	144

Table E.5: Site 516 in 2002 (span length = 100 ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
5/5	305.3	5213	0.73	0.71	0.73	6402	8562	6346	0.78	433
5/6	111.4	7614	0.62	0.64	0.63	5023	6703	4984	0.71	332
5/7	197.4	7817	0.67	0.67	0.67	6404	8463	6169	0.74	458
5/8	74	8329	0.62	0.64	0.62	2130	2840	2096	0.71	135
5/9	108.1	8893	0.62	0.64	0.62	1622	1892	1447	0.70	121
5/10	315.5	9491	0.85	0.77	0.85	5509	7346	5503	0.88	397
5/11	80.9	7011	0.56	0.58	0.56	1629	1922	1665	0.64	153
5/12	76	5547	0.58	0.59	0.58	1237	1623	1277	0.66	102
5/13	85	7785	0.61	0.63	0.61	1468	1931	1522	0.70	142
5/14	77.1	8245	0.62	0.64	0.62	1222	1529	1244	0.70	98
5/15	157.8	8647	0.62	0.64	0.62	1196	1512	1215	0.71	99
5/16	136.7	9215	0.62	0.64	0.62	1458	1721	1347	0.71	112
5/17	121	9290	0.58	0.60	0.59	1781	2312	1814	0.67	233
5/18	101.4	6958	0.56	0.58	0.56	1343	1744	1348	0.64	155

Table E.6: Site 516 in 2002 (span length = 50 ft)

Date	Max Wheel-base (ft)	ADTT	Effective Moment Ratio			Maximum Moment (ft-k)			GVW	
			1/4	1/2	3/4	1/4	1/2	3/4	Eff. Ratio	Max (k)
5/5	305.3	5213	1.01	1.03	0.97	6977	9141	6923	0.78	433
5/6	111.4	7614	0.68	0.68	0.63	5829	7622	5737	0.71	332
5/7	197.4	7817	0.81	0.83	0.77	6852	8733	6483	0.74	458
5/8	74	8329	0.66	0.65	0.60	2496	3270	2418	0.71	135
5/9	108.1	8893	0.65	0.64	0.59	1639	2133	1643	0.70	121
5/10	315.5	9491	1.15	1.19	1.11	6445	8407	6447	0.88	397
5/11	80.9	7011	0.59	0.59	0.54	1693	2118	1688	0.64	153
5/12	76	5547	0.61	0.60	0.55	1462	1906	1432	0.66	102
5/13	85	7785	0.65	0.64	0.59	1437	1719	1407	0.70	142
5/14	77.1	8245	0.65	0.65	0.59	1420	1757	1242	0.70	98
5/15	157.8	8647	0.65	0.65	0.59	1389	1712	1267	0.71	99
5/16	136.7	9215	0.66	0.65	0.60	1536	1767	1424	0.71	112
5/17	121	9290	0.62	0.62	0.56	1859	2191	1916	0.67	233
5/18	101.4	6958	0.60	0.59	0.54	1826	2261	1822	0.64	155

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