

Chapter 4

Wheel Load Data Analysis

This chapter explains the methods used for analyzing the wheel load data. The analyses of the data in the time and frequency domains are addressed. The effects of various degrees of curvature, subgrade stiffness, and truck design on the wheel load are described, along with a short discussion on improving the data collection and reduction techniques in future tests.

4.1 Initial Data Reduction and Analysis

Before any meaningful results could be produced from the wheel load data, it was necessary to determine the exact nature of the data and devise a valid method of analysis. As stated in Chapter 3, the wheel load data was collected at the Transportation Technology Center, Inc. on the High Tonnage Loop (shown in Figure 3.1). Since the construction of the HTL, wheel load measurements have been collected and categorized regularly, based on the current level of accumulated traffic. The data that was made available for this study ranged from 100 Million Gross Tons (MGT) to more than 600 MGT of traffic. Each data file contained information relating to the wheel loads, distance traveled, vehicle speed, and time elapsed for one complete lap around the HTL.

The wheel load data was initially sampled at a rate of 512 Hz. Given that one loop on the HTL is 14405.1 feet long, the nominal consist speed for this study was 40 mph, and 16 separate measurements were recorded for each test; each of the resulting files contain approximately 2 million data points. Since the size of the data files was directly related to the amount of

analysis that could be performed within the time frame of this study, it was decided that some type of data reduction was needed in order to make the file sizes more manageable.

One way to reduce the number of points present in a data set is to decimate the data at a lower sampling rate. When using this method, it is necessary to first filter the data to prevent aliasing of any frequency content that is present above the new Nyquist frequency [28]. Of course, any information above the cut-off frequency of the low-pass filter will be lost with this process. In order to reduce the number of data points present in the file without affecting any of the useful information, it was necessary to first analyze the data and determine the maximum frequency of interest. When that was complete, a cut-off frequency was selected that would allow the data to be resampled and not eliminate any of the valuable frequency content.

The wheel load data for the complete HTL was initially analyzed in this study by determining the Power Spectrum Density (PSD) of the signal [28]. As shown in Figure 4.1, this analysis of the data indicated that there was not a significant amount of frequency content above 15 Hz. Since the data had already been digitized, we decided to use a digital filter to remove the frequency contents higher than 64 Hz. The 64 Hz cutoff frequency for the filter was selected to allow us to adequately capture the 15 Hz dynamic range that we had observed in the original data.

Accordingly, the signal was digitally low-pass filtered with a 64 Hz cut-off frequency and then resampled at 256 Hz. The cut-off frequency was selected as slightly higher than twice the highest frequency of interest. The new sampling frequency was selected to yield an over-sampling rate of four times the new cut-off frequency. Since the signal was digitally filtered, an over-sampling rate of four is conservative. Higher over-sampling rates are sometimes used to minimize the effect of aliasing that results from the roll-off rate associated with analog filters. Since a digital filter has no roll-off rate, an over-sampling rate of two would have been sufficient. The end result of this initial phase of the data reduction was a series of data files that were

significantly smaller, and easier to manage, while containing all of the useful frequency content of the original data.

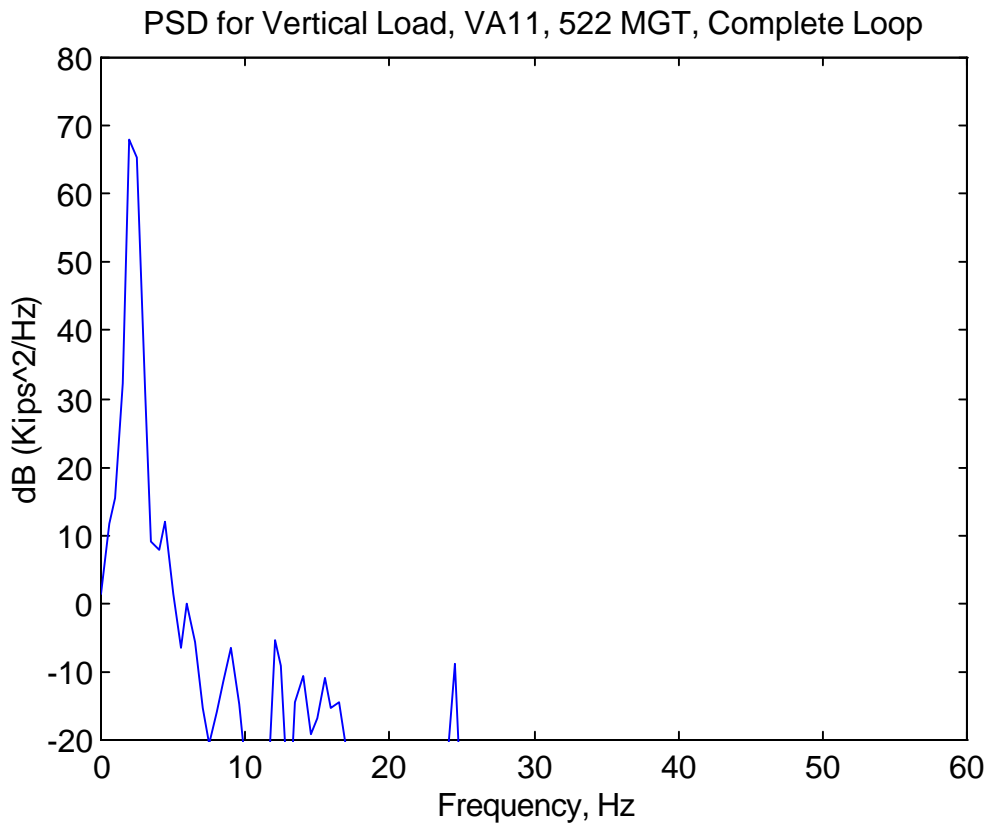


Figure 4.1. Sample Frequency Spectrum for Complete Loop Wheel Load Data Before Resampling

After the wheel load data was decimated, it was studied in three forms. The amplitude distributions of the data were analyzed by examining the histogram and exceedance plots of the loads. Spatial plots were used to look for trends and deterministic behavior occurring at specific locations on the track, while power spectral densities (PSD) were used to determine the frequency contents of the data.

4.2 Frequency Domain Analysis

After decimating the wheel load data as described in the previous section, the data was re-evaluated in the frequency domain to determine if any of the frequency contents had been affected. As indicated by the PSD plot in Figure 4.2, none of the significant frequency contents were affected by the decimating process.

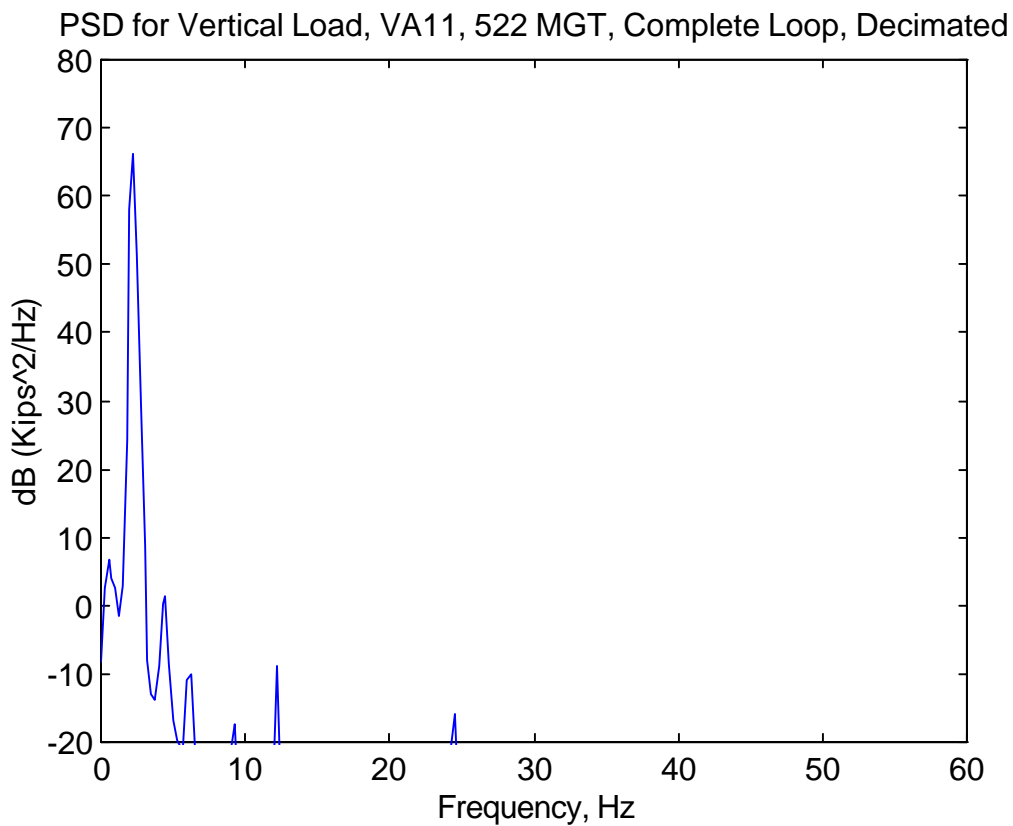
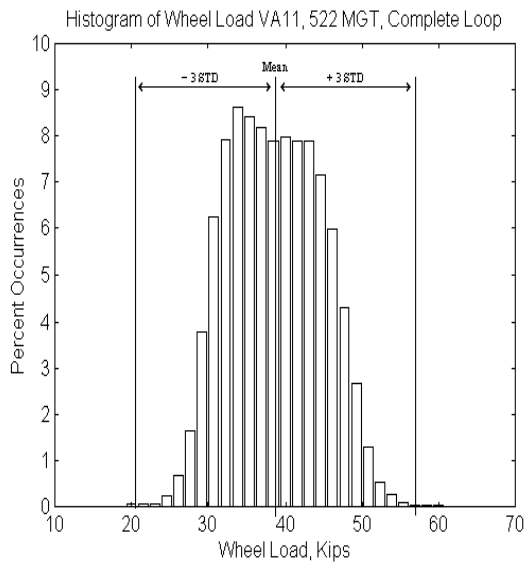


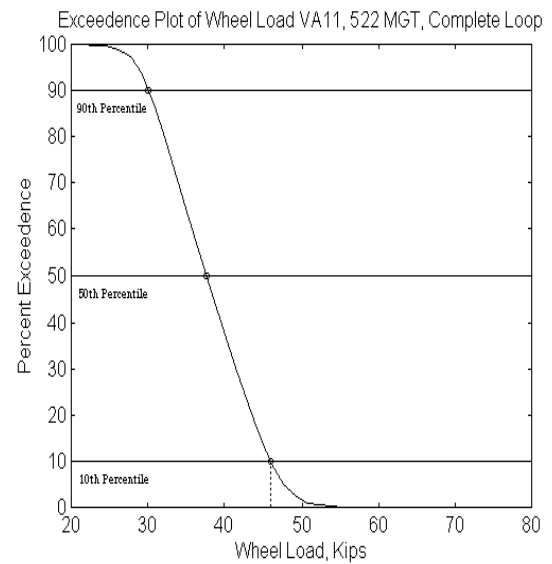
Figure 4.2. Typical Power Spectrum Density (PSD) for Complete Loop Wheel Load Data After Decimation

4.3 Full Loop Amplitude Analysis

As mentioned earlier, the amplitude distributions were analyzed using both histograms and exceedence plots. The histograms were useful for displaying information about the amplitude distributions of the data. The exceedence plots displayed the percentage of the total number of occurrences falling above a specific load. Further, the exceedence plots were used to determine the median or 50th percentile load and the 10th percentile load. The 10th percentile load is defined as the load at which 10 percent of the total number of measurements have forces greater than the 10th percentile load [26]. When an event is more sensitive to high loads, the 10th percentile load is a reasonable benchmark for determining if one system is more favorable than another. Exceedence plots have the added advantage that they do not require a normal distribution in order to make conclusions about the overall data set, whereas histograms typically use the standard deviation to produce uncertainty limits. The accuracy of these limits is significantly affected by the normality of the data. The less normal the data, the less accurate the uncertainty limits are. Examples of the histograms and exceedence plots for identical data are shown in Figure 4.3.



(a)



(b)

Figure 4.3. Sample Amplitude Distributions; Histogram (a) and Exceedence Plot (b)

Once the amplitude distributions were completed for all of the pertinent data, several trends became apparent. In particular, the amplitude distributions for the vertical wheel loads were approximately normal. As shown in Figure 4.4, the distributions for lateral wheel loads were bimodal in most cases. This was a particularly interesting discovery. A rail vehicle subjected to a continuous and consistent static and dynamic loading would have been expected to have a normal distribution. Since the lateral wheel loads did not display normal distributions, one can conclude that some aspect of the system was not consistent. Either the track parameters were not providing a normally distributed input, or the rail vehicle was not responding to the track inputs in a consistent (or linear) manner. In order to find the cause of this distribution, the data was analyzed in the spatial domain. Plots of the lateral wheel loads versus distance traveled showed the track locations where the two principal bimodal distributions occurred, as well as the reason for their occurrence.

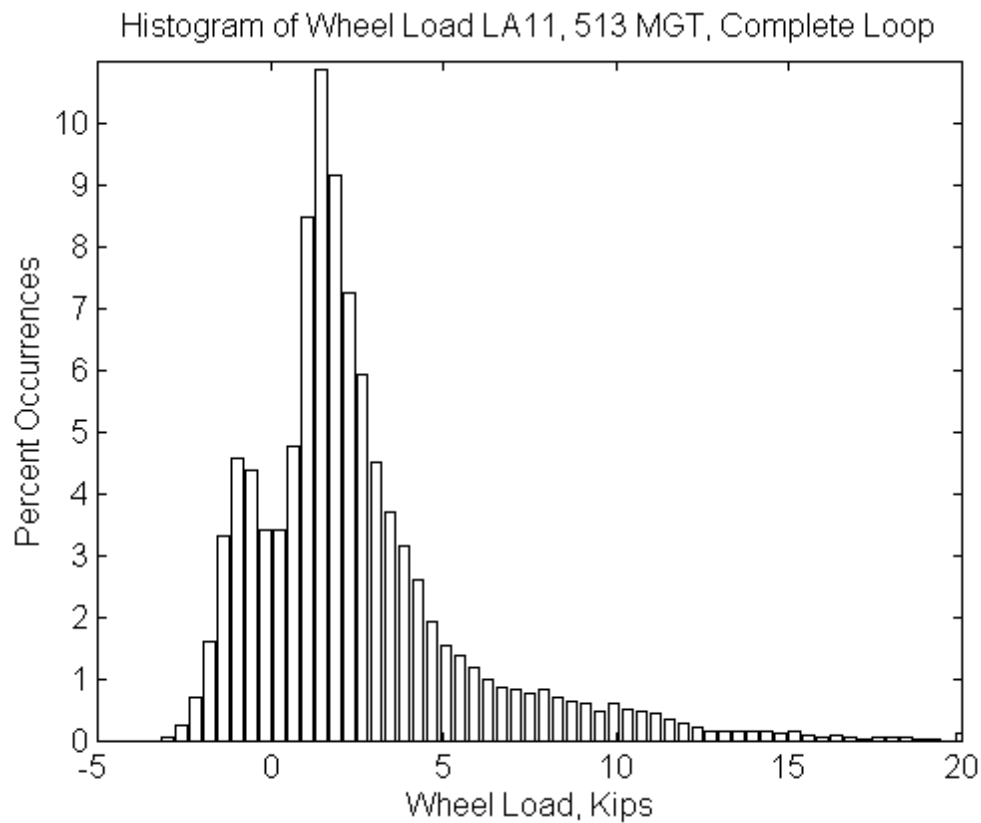


Figure 4.4. Bimodal Distribution of Lateral Wheel Loads

The complete loop amplitude distribution analysis was useful in displaying the overall shape and magnitude of the wheel load data. This information was used to determine the bin width and overall range used by the histograms and exceedence plots for the subsequent analysis. The lateral loads were analyzed from -20 kips to 30 kips with 0.5-kip-spaced non-overlapping bins. The vertical loads were analyzed using bins from 0 kips to 80 kips at intervals of 2 kips. The comparison of the effect of different track and vehicle parameters was not possible when using the complete loop analysis since neither the track geometry nor vehicle response appeared to be constant throughout the entire HTL. Ultimately, it was determined that the amplitude distributions must be analyzed separately for each significant section of the HTL to correctly characterize the statistical behavior of the wheel load data. This analysis is described in the following sections.

4.4 Spatial Domain Analysis

As mentioned in the previous section, the amplitude distributions for the lateral wheel loads were bimodal. Since the HTL is a loop, it was not possible to keep all of the track parameters constant along the entire length of the track. As discussed in Chapter 3, the HTL has various curved and tangent sections with different track geometries in each section. Given that the loads experienced by a rail vehicle are dependent on the track geometry (e.g., straight vs. curved track), it is logical to assume that the variation in track geometry from one section to another may create a non-normal distribution of the lateral wheel loads. By evaluating the lateral wheel load as a function of distance, it is possible to determine the general distributions of the lateral loads for various sections of the track.

As shown in Figure 4.5, the average lateral load on the front right wheel of the front axle of the front truck (LA11) is greater in sections 3, 25, and 31 than in other sections. Each of these sections corresponds to standard left-hand curves. In this situation, neither the track geometry nor the vehicle response are consistent. A curved track will naturally be designed with more crosslevel (also referred to as "cant") than a tangent track. At the same time, the lateral loads exerted on the vehicle will be greater since the track must supply enough force to turn the vehicle. The crosslevel of the track will reduce the lateral load that is exerted by the rail onto the vehicle by allowing the weight of the vehicle to supply some of the lateral load required to turn the vehicle. In some cases, the net lateral load exerted by the rails onto the vehicle will be zero or negative. For each curve, there is a speed that will result in this situation. The nominal 40 mph operating speed on the HTL is, however, above the balance speed for all of the curved sections, and this situation does not occur.

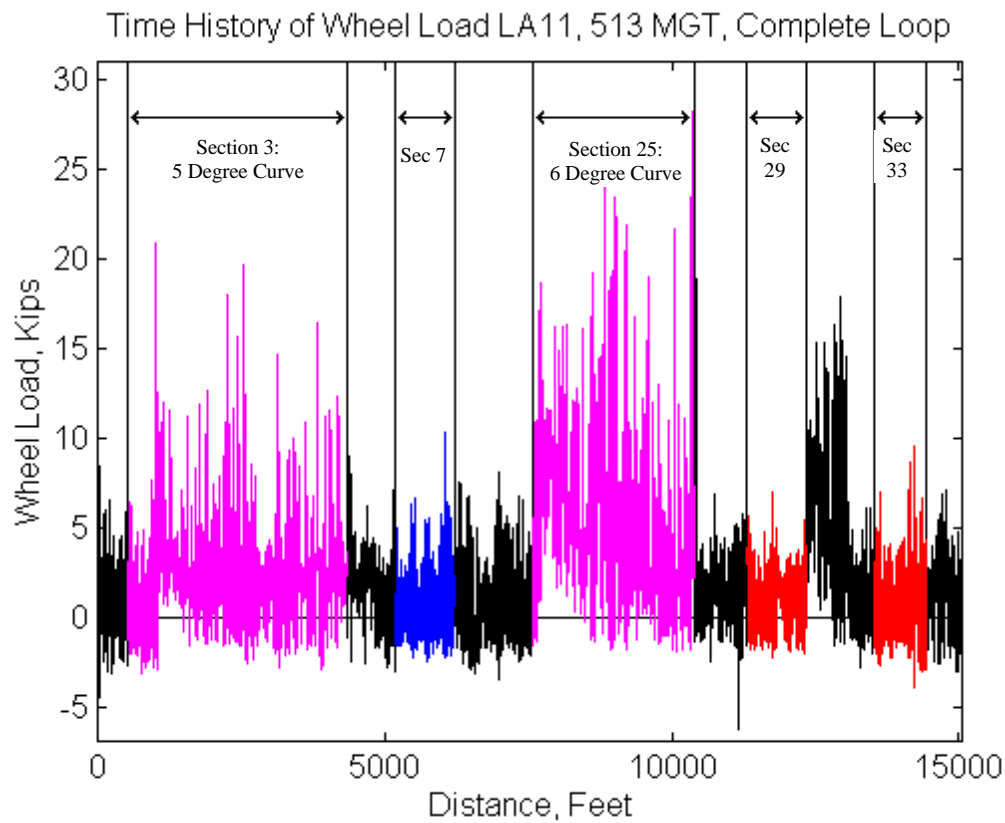


Figure 4.5. Spatial History of Lateral Wheel Load

The spatial plot shows an increase in the lateral loads during curved sections. Practical knowledge supports this observation. This increase in load, however, does present a problem. The lateral loads and, as will be shown in Chapter 5, some of the track parameters have non-normal distributions. It is difficult to relate information from a non-normal sample to an overall population. For this reason, we decided to analyze the data separately for the different sections of the HTL, fully recognizing that there is no guarantee that the distributions of the lateral loads will be normal for the individual sections selected.

4.5 Sectional Analysis

Since the complete loop analysis did not provide the information that was needed in order to proceed with the correlation analysis, it was necessary to subdivide the HTL into several sections for individual analysis. There are 22 sections on the main HTL loop. Each section has individual characteristics that make it significant for the many studies taking place at TTCL. In accordance with one of the objectives of this research, several sections were selected for individual study that would yield information about the effects of subgrade stiffness and degree of curvature on the vertical and lateral wheel loads. In particular, sections 3, 7, 25, 29, and 33, as specified in Table 4.1, were selected for study.

Table 4.1. Specification of Significant HTL Sections

HTL Track Sections		
Section	Curvature	Subgrade
3	5 Deg.	Standard
7	5 Deg. Rev.	Standard
25	6 Deg.	Standard
29	Straight	Soft
33	Straight	Standard

The five sections chosen for individual analysis account for approximately 65% of the entire HTL. None of the sections, however, were of the same length. Since the results from the sectional analysis would ultimately be manipulated and compared, it was important that each of the sections have approximately the same accuracy and weight. Therefore, approximately eight seconds of data centrally located in each section was used to represent the wheel load in that section. There were several advantages to selecting the data in this way: it allowed for the transient responses at the beginning and end of the section to be removed, each of the sections to be equally represented, and any error in the estimated start and

end locations of a section to be eliminated. The same methods that were used to analyze the complete loop data were also used for the sectional analysis.

4.6 Sectional Amplitude Analysis

A deciding factor in the decision to subdivide the data based on track location was the expectation that the individual sections would have consistent track properties and therefore result in normally distributed wheel loads. As shown in Figure 4.6, the amplitude distributions for the various sections were not normal in every case. The normality of the wheel load data can be seen to have visually increased for the individual sections when compared to the distribution for the complete loop. As will be shown in Chapter 5, the track geometry parameters had normal distributions when analyzed in individual sections. No other method for subdividing the data was found to yield more normally-distributed results. Consequently, the sectional analysis of the data was chosen for further evaluating the data.

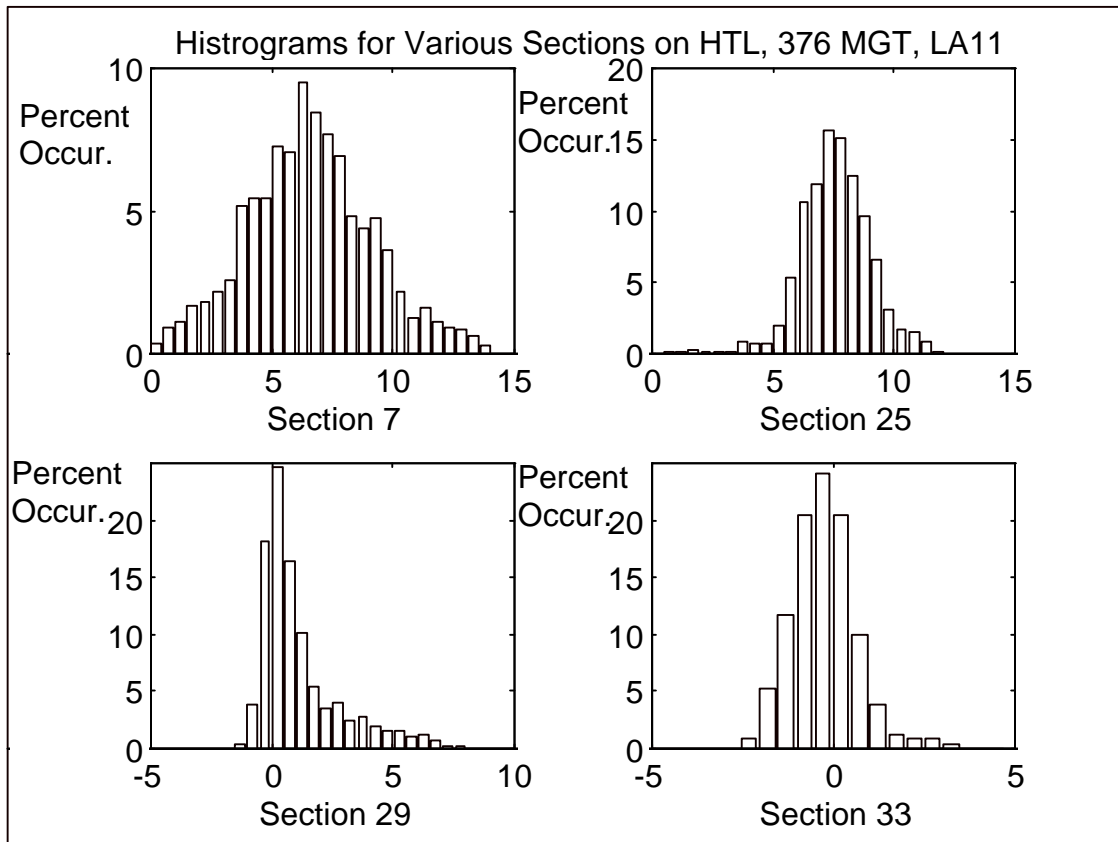


Figure 4.6. Histograms for Lateral Wheel Load LA11 for Curved (Sections 7 and 25) and Tangent (Sections 29 and 33) Track

Comparing the histograms for different sections, one can see that the mean, standard deviation, and shape of the amplitude distribution for each section are significantly different. Assuming that each histogram represents a sample of a greater population, one could conclude that each section comes from a different population and must therefore be analyzed individually. For these reasons, the data analysis was performed separately for each section for the remainder of this research.

4.7 Sectional Frequency Analysis

As discussed in previous sections, the track parameters are not consistent throughout the length of the HTL. Therefore, not surprisingly, the sectional

statistical analysis of the wheel loads revealed that the data for each section had its own amplitude characteristics. The next logical step was to determine how similar or different the frequency contents of the wheel loads were for each section. As shown in Figure 4.7, the lateral loads were for each section were similar in that the majority of the spectral energy occurred below 5 Hz, and several of the sections experienced two large peaks at approximately the same frequencies. Apart from these facts, the power spectrum densities (PSDs) were somewhat erratic from one data file to another.

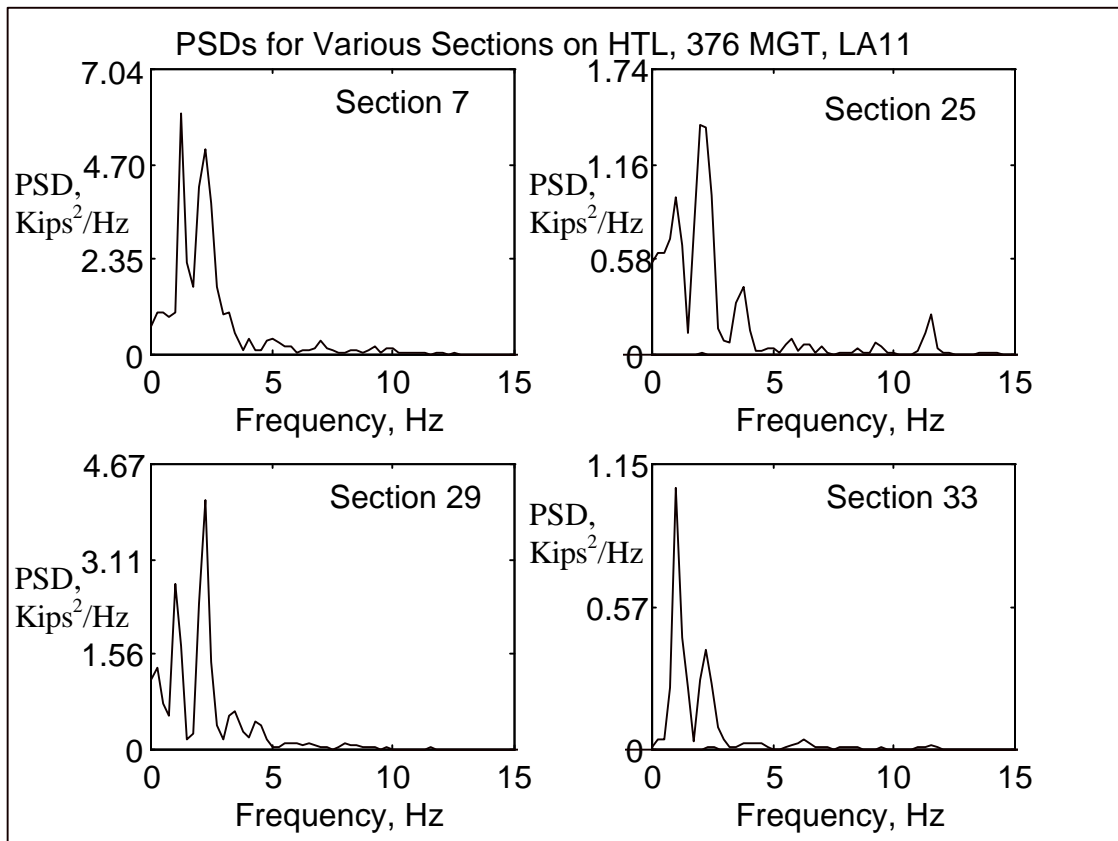


Figure 4.7. Power Spectrum Densities (PSD) for Various Curved and Tangent Track Sections

This behavior could be a direct result of conditions changing from one data file to another since the data was collected over a period of approximately ten years. The number of blocks available for averaging was

also reduced from the complete loop analysis, making the error present in each signal more noticeable. The increased non-deterministic content of the data, as well as the large volume of data, made it difficult for any conclusions to be drawn about the overall relationship of the individual sections. The sectional data would need to be evaluated in a logical manner that both reduced the error present in the data and allowed for relationships to be determined.

4.8 Sectional Data Reduction

Although all of the frequency and time domain analyses had been completed for each of the 14 data files, it was not yet possible to extract any of the information present in the data for several reasons. The subdivision of data into the five sections (3, 7, 25, 29 and 33) had reduced the number of data points and therefore the number of blocks available for averaging in the frequency domain analysis. Additionally, separating the data into sections had created five times the number of plots, making it more difficult to extract the information. Although the comparisons of the results from each file can provide useful information, one of the main objectives of this research was to determine the effects of various track parameters on the wheel loads.

If the data had consistently produced the exact same results for every data file, there would have been no need for further manipulation of the data. As mentioned earlier, the data were collected over a period of several years (approximately 10 years). During this time, much of the track and vehicle parameters changed due to use of the equipment, maintenance of the rail and vehicle, and simply the passage of time. Accordingly, the wheel loads were different in every file.

In order to evaluate the information in the data, an aggregate response was calculated. Since the frequency responses [i.e., the power

spectral densities (PSDs)] had been performed for exactly the same parameters, the aggregate frequency response could be determined simply by averaging the PSDs. This procedure would yield a significant increase in data and remove most of the non-deterministic responses present in the analysis conducted separately for the individual data files. Similarly, the time-domain aggregate was determined by averaging the data after the amplitude distributions had been calculated. Calculating the aggregate response before the amplitude distribution would have resulted in a more accurate estimation of the mean wheel loads, but would have been useless for determining the estimated standard deviation for a given load. Analyzing the data in this manner has several advantages: it highlights common trends that exist between the data files, it reduces the number of relationships that exist to a manageable number, and it minimizes the amount of non-deterministic data present in the frequency and time domain responses.

4.9 Aggregate Frequency Domain Analysis

The data was collected for a variety of parameters including the subgrade stiffness, degree of curvature, and two truck designs. Analyzing the aggregate data in the frequency domain shows the effect that each of these parameters has on the power spectrum density (PSD). Parameters not specifically designated should produce random variations in each data file and therefore have no net effect on the results after the averaging process has been completed.

The results of the analysis for the lateral and vertical loads with respect to the parameters will follow.

4.9.1 Lateral Wheel Loads

As shown in Figure 4.8, the aggregate power spectrum density (PSD) for the lateral load LA11 on the standard truck design shows that the majority of the content occurs below 5 Hz and that two peaks occur only on the inside wheel in the curves. Section 7 is a right-hand curve, and side A is the right side of the truck. Also during curving, the inside wheel has dynamic responses at higher frequencies as compared to the response of the same wheel on the tangent track or the outside wheel in a curve. Figure 4.8 shows the aggregate power spectrum density (PSD) bounded by the 95% confidence intervals for each frequency.

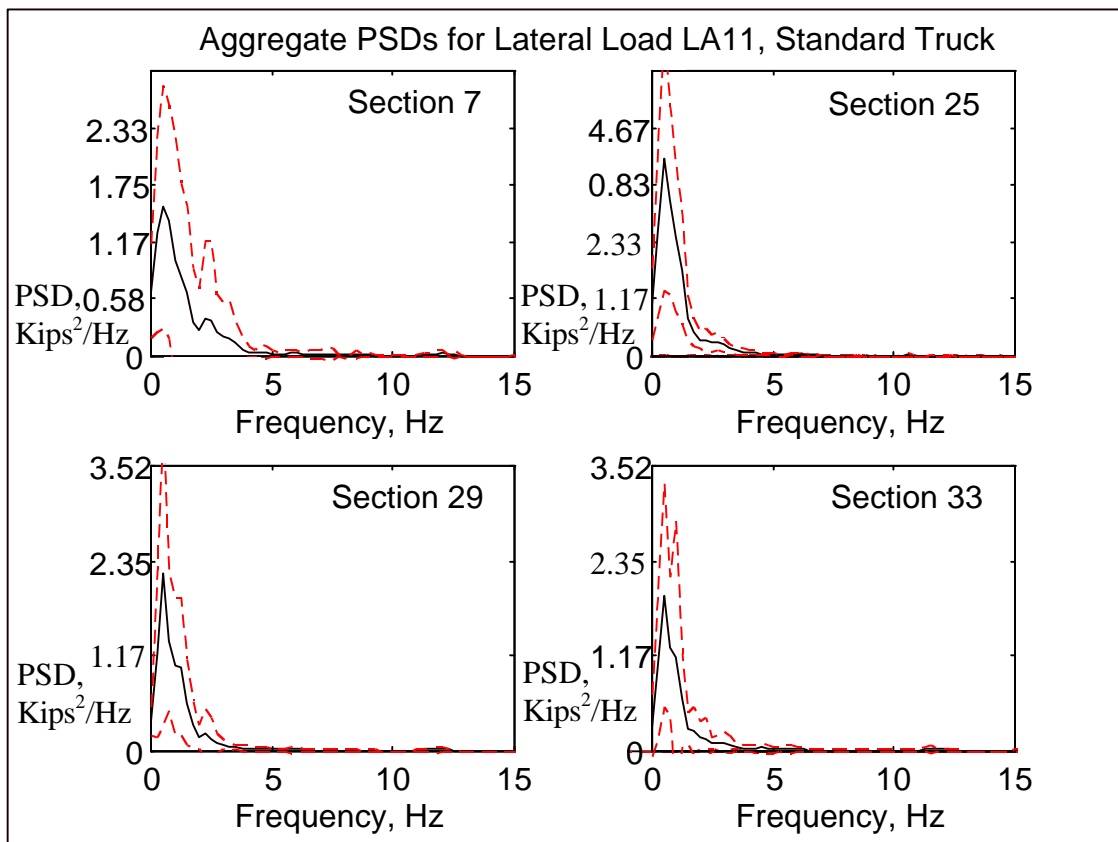


Figure 4.8. Power Spectrum Density (PSD) for Lateral Load LA11 on the NACO Wedgelock Truck

As shown in Figure 4.9, the trends observed for the lateral loads on the right front wheel are also prevalent for the left front wheel. The tangent and curved sections with the wheel on the outer rail experienced only one major peak at approximately 0.5 Hz. The lateral loads acting on the inner wheel exhibited a second peak at approximately 2.25 Hz. Without having analyzed the track geometry data, it would be impossible to draw any conclusions on the exact cause of these specific concentrations of dynamic energy.

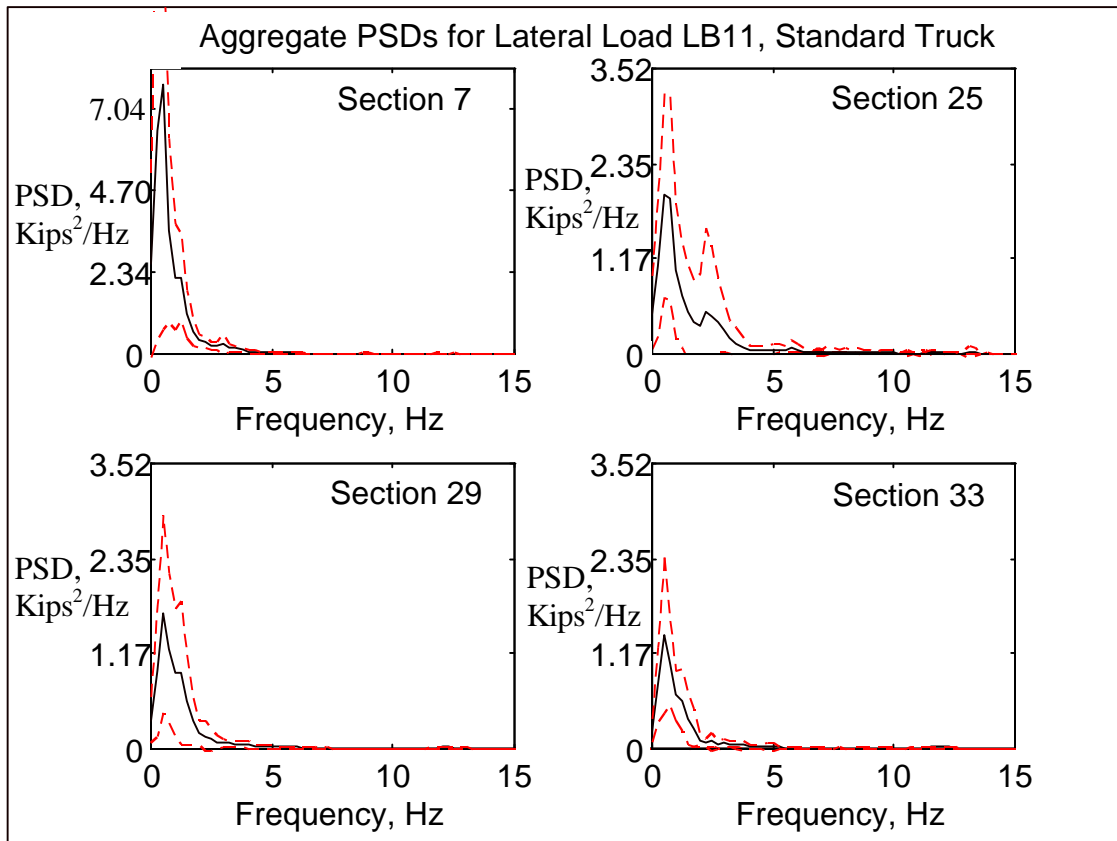


Figure 4.9. Power Spectrum Density (PSD) for Lateral Load LB11 on the NACO Wedgelock Truck

In comparison to the results found for the standard NACO Wedgelock truck in Figures 4.8 and 4.9, the improved Buckeye/Barber Truck designs had fewer, more concentrated peaks in the frequency domain. As shown in Figures 4.10 and 4.11, the new truck design resulted in only one frequency peak for the inner wheel, regardless of the truck side.

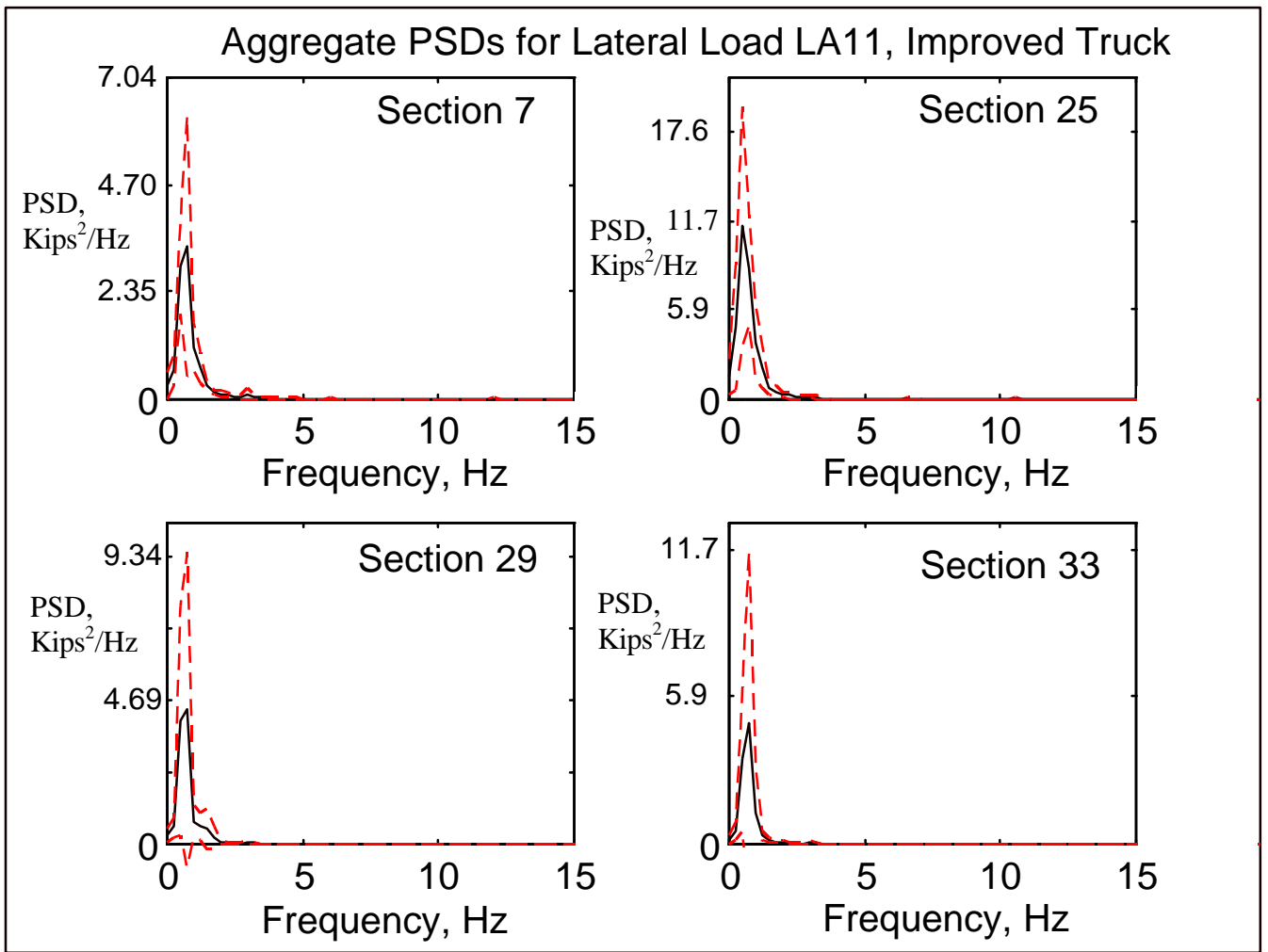


Figure 4.10. Power Spectrum Density (PSD) for Lateral Load LA11 on the Buckeye/Barber Truck

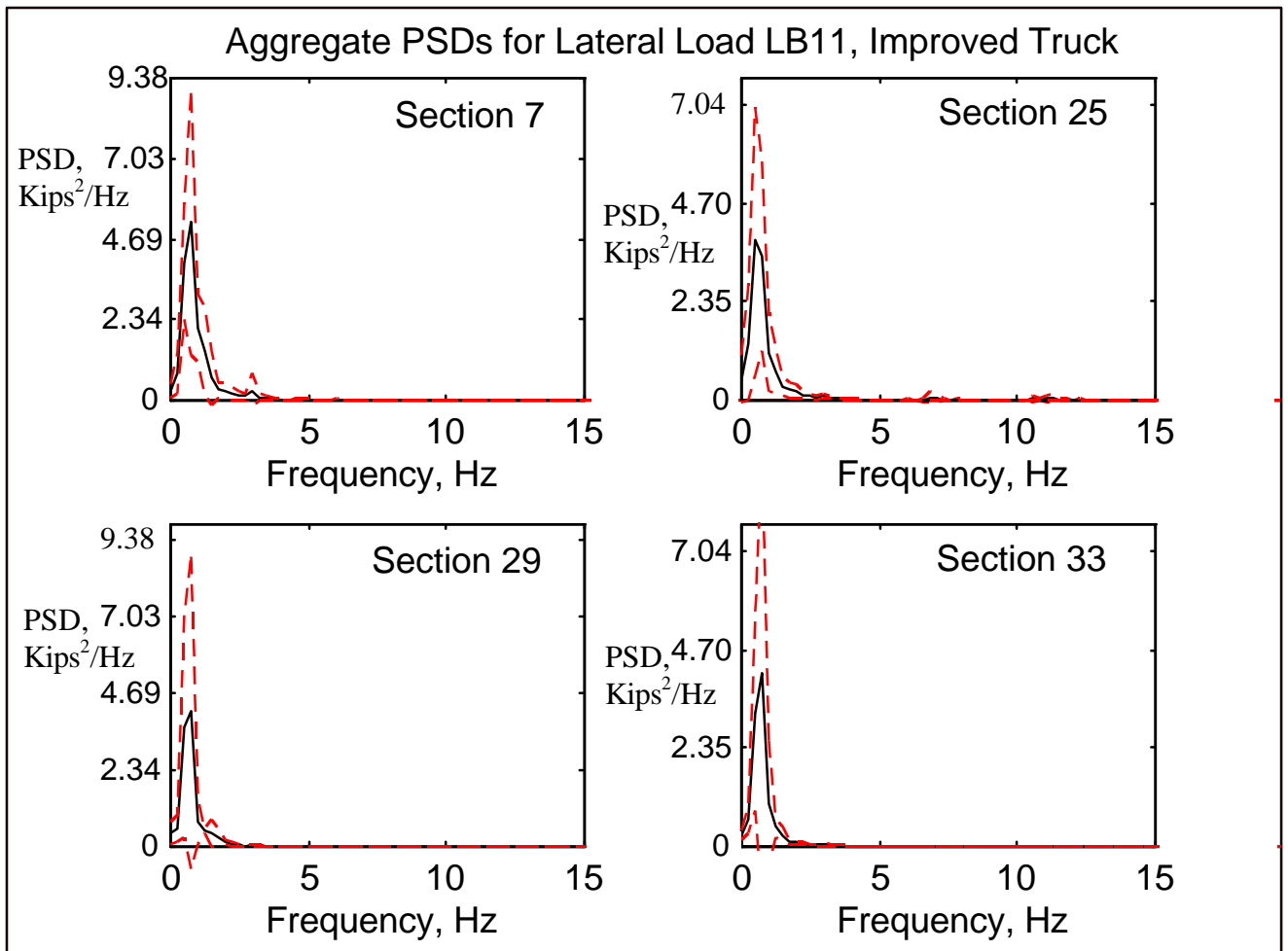


Figure 4.11. Power Spectrum Density (PSD) for Lateral Load LB11 on the Buckeye/Barber Truck

The power spectrum density (PSD) for the lateral loads contained several interesting findings. The subgrade stiffness had no noticeable effect. The tangent sections, 29 and 33, had a soft and standard subgrade, respectively. The PSDs for these sections were similar when analyzed for different truck designs and wheel positions. The inside wheel on the standard truck seemed to experience an extra 2.25 Hz excitation in a curve than on a tangent track. The PSDs for the new truck had a narrower bandwidth and did not experience a second excitation frequency when curving, as compared to the NACO Wedgelock truck.

4.9.2 Vertical Wheel Loads

As shown in Figure 4.12, the majority of the frequency contents for the vertical loads occur below 5 Hz. Much the same as the lateral loads, the vertical loads experience an excitation at 0.5 Hz. The vertical loads for the standard NACO truck, however, experience several peaks instead of only a couple. In particular, excitations can be observed at 1.25 Hz, 2.75 Hz, 5.9 Hz and 11.8 Hz. The 5.9 Hz and 11.8 Hz excitations may be related to the wheel speed. These relationships will be examined in more detail later.

No significant differences were observed between the various sections. In section 7, wheel A11 is on the inner rail, and in section 25 it is on the outer rail. Unlike the lateral load, the frequency contents for both of these sections are similar for the vertical load. In section 29, the vehicle travels on a tangent track with a soft subgrade, but generates a PSD as when the vehicle travels on a firm subgrade in section 33. Neither the degree of curvature nor the subgrade stiffness affects the excitation frequencies of the vertical loading on the standard NACO truck design.

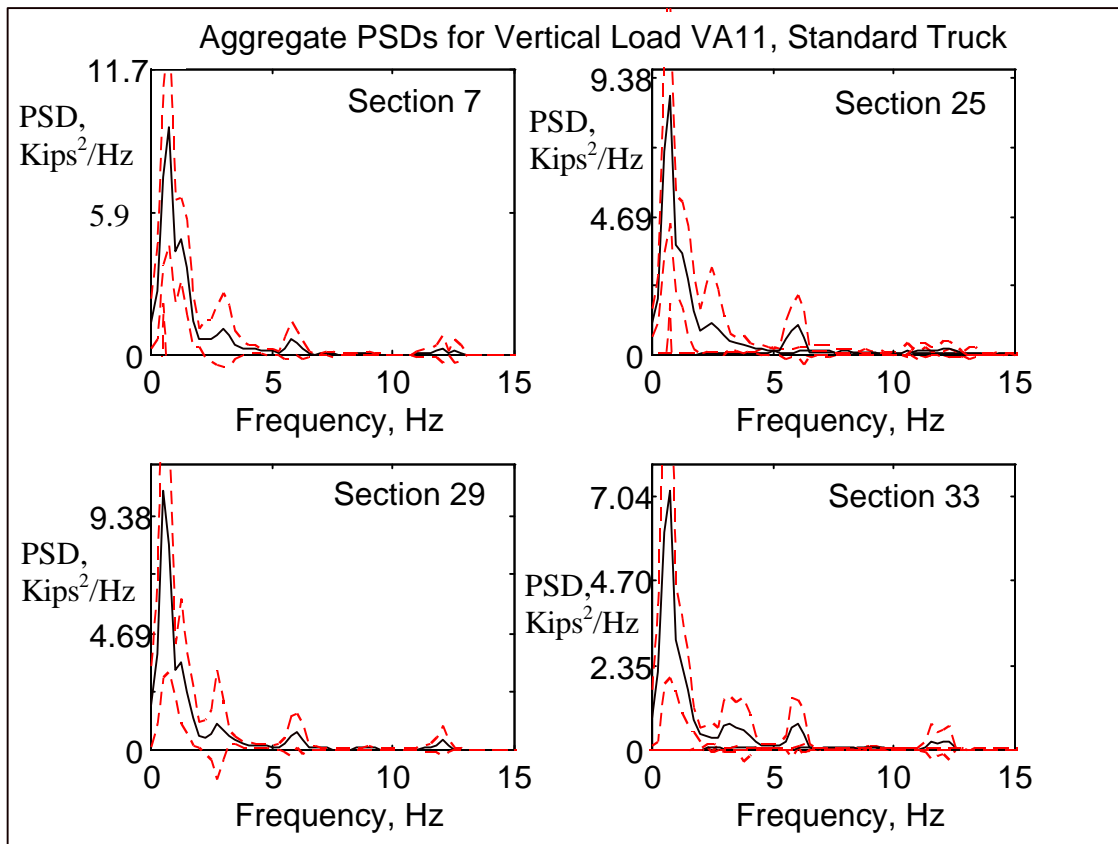


Figure 4.12. Power Spectrum Density (PSD) for Vertical Load VA11 on the NACO Wedgelock Truck

As shown in Figure 4.13, the power spectrum density (PSD) for the Buckeye/Barber truck design is quite different from that of the standard truck design. As was the case for the lateral loads, the vertical load PSDs for the newer design are more concentrated. The dominant 0.5 Hz frequency was still evident in all of the sections. The left-hand and right-hand curved sections produced similar results. The softer subgrade seemed to increase the vehicle's sensitivity to a 3.25 Hz excitation. The 5.9 Hz and 11.8 Hz peaks were not observed for the new truck. As mentioned in Chapter 3, the instrumented wheelsets can create a perceived excitation into the measurements because of the relative gain of the wheelsets at different positions, especially when the wheelsets are not calibrated properly. Therefore, it is with some reservation that the Barber truck design is

observed to not experience the 5.9 Hz and 11.8 Hz frequencies while the NACO design is observed to do so.

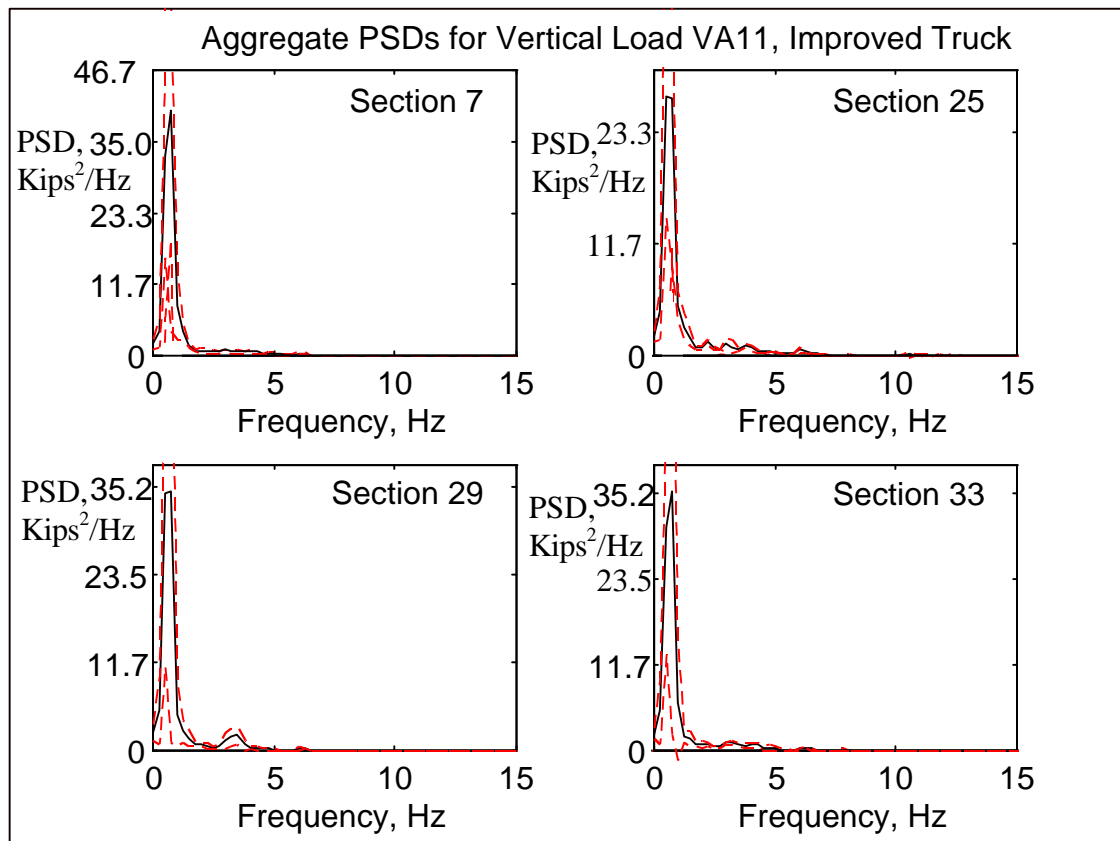


Figure 4.13. Power Spectrum Density (PSD) for Vertical Load VA11 on the Buckeye/Barber Truck

4.10 Known Frequency Excitations

A rail vehicle is subjected to specific excitation frequencies from the wheel/rail interaction, in addition to the natural frequencies of the vehicle. Some of these frequencies can be determined from the track and vehicle information. In particular, the hunting frequency, the track joint perturbation, and the periodic inputs relating to the wheel rotational speed are all frequencies that may be present in the data.

The wheel/rail interface is a nonlinear connection that induces a self-excited phenomenon known as hunting. The conical profile of the wheel results in different rolling radii depending on the lateral position of the axle. For an axle shift to the left, the rolling radius of the left wheel will increase, and the rolling radius of the right wheel will decrease. Since the wheels must have the same speed, the different rolling radii create a yaw moment about the axle. This same feature helps a rail vehicle negotiate a curved track. On tangent tracks, this relationship can result in a near sinusoidal oscillation of the axle back and forth across the track, with a frequency of [29]:

$$f_H = \frac{V}{2p} \sqrt{\frac{1}{aR}} \quad (4.1)$$

a: Half of tapping line width

λ : Wheel conicity

R: Rolling radius

V: Axle velocity

The information available allowed for the calculation of the hunting frequency with the following parameters:

a = 28 inches,

$\lambda = 0.05$,

R = 19 in

V = 40 mph = 704 in/sec

Using these parameters, the hunting frequency was approximated at 1.08 Hz.

Rails are traditionally fabricated in 39-foot sections. Joints at the ends of the rails are not as strong as other sections of the rail. This allows the track to eventually subside at 39-foot intervals, creating a perturbation in the form of a rectified sine wave as shown in Figure 4.14. The perturbation frequency is directly proportional to the speed of the vehicle. In this case, the vehicle speed is 58.667 ft/sec. At this speed, the 39-foot spatial interval relates to a time interval of 0.6647 sec. The frequency spectrum of a rectified sine wave having an interval of 0.6647 sec. has a dominant peak at 1.5 Hz. All of the joints on the HTL are not uniformly separated by 39 feet. However, this excitation frequency is still important to consider.

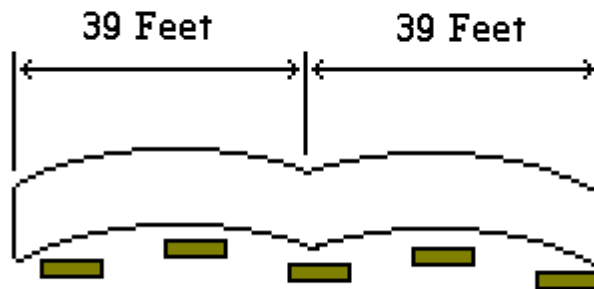


Figure 4.14. Rail Deformation at Track Joints

The wheel imbalance, wheel profile irregularity, inaccurately calibrated wheelsets, and several other track and vehicle irregularities can cause further excitations at the axle speed. In the tests conducted at TTCI, the rolling radius of the wheels was 19 inches. For a nominal velocity of 40 mph, the average wheel speed for this radius would be 5.9 Hz. Another excitation frequency that was observed in the frequency spectrum of the wheel load data was twice this speed, 11.8 Hz.

4.11 Aggregate Amplitude Analysis

Analysis of the data in the frequency domain yields only part of the information embedded in the data. In order to obtain the remainder of the information, the data must also be analyzed in the time domain. Subdividing the data based on the track location allows for the study of the effect of the degree of curvature and subgrade stiffness. The manner in which the data was collected allows for the study of the effect of the new truck design versus the standard truck design. The overall shape and distributions of the lateral and vertical wheel loads will be discussed next, with more specific findings.

4.11.1 Lateral Load

Figure 4.15 shows that the amplitude distributions for the NACO truck design are nearly normal, with the exception of the distributions for the outer wheel during a left-hand turn. Section 25 has a non-normal distribution with a large amount of variance and the highest mean of the four sections. The distributions for the tangent sections are skewed to the right. Although these observations are interesting, they need to be correlated against the loads on the left side of the vehicle in order to determine how different curved and tangent sections affect the inner and outer wheels.

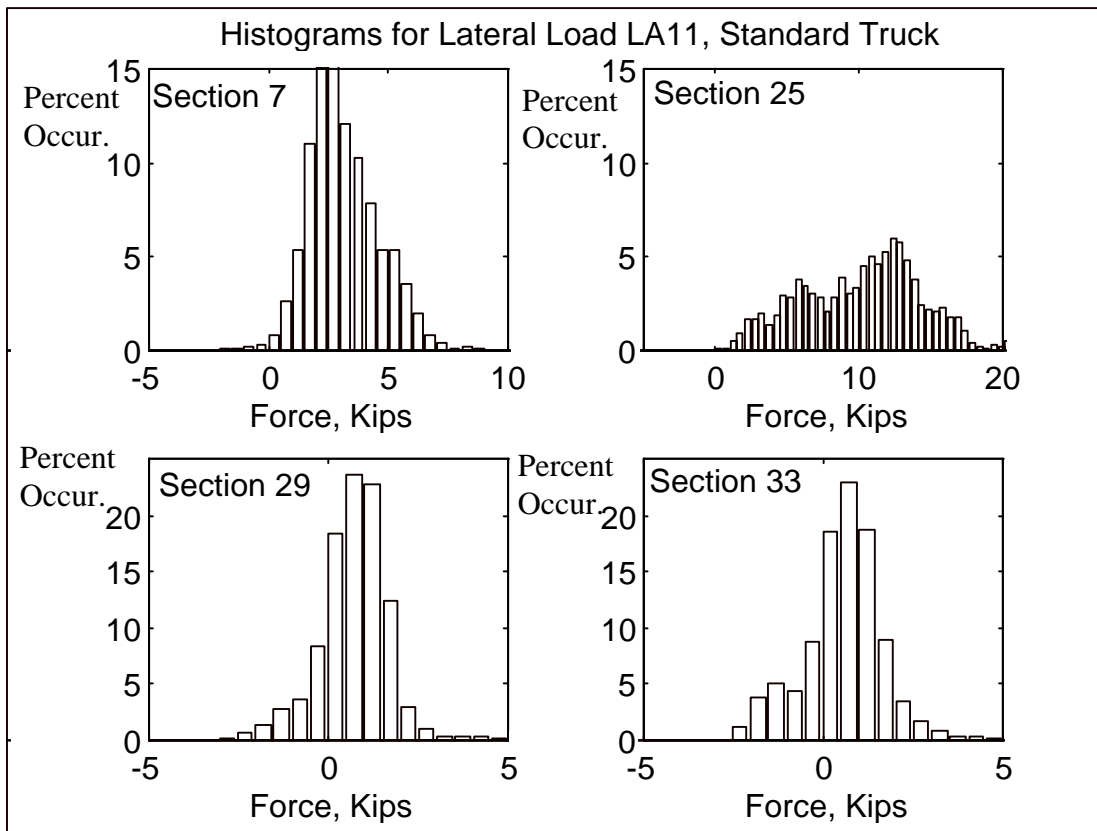


Figure 4.15. Amplitude Distributions for Lateral Load LA11 on NACO Wedgelock Truck

As shown in Figure 4.16, the distribution for the outside wheel in a right-hand turn also displays a non-normal distribution with a significant amount of variance. The distributions for the tangent sections (sections 29 and 33) show a skewness to the left. This is in direct contrast to the observations made for the skewness of the distributions for the right wheel. Arguably, the two wheels are coupled and by definition, a constant load on axle to the right would produce a positive reaction at the right wheel and a negative reaction on the left wheel. On a tangent track, however, the mean lateral load for both wheels would be expected to be zero. The non-zero mean could be related to some aspect of the track. Therefore, similar distributions can exist for both the standard NACO truck design and the improved Barber truck design.

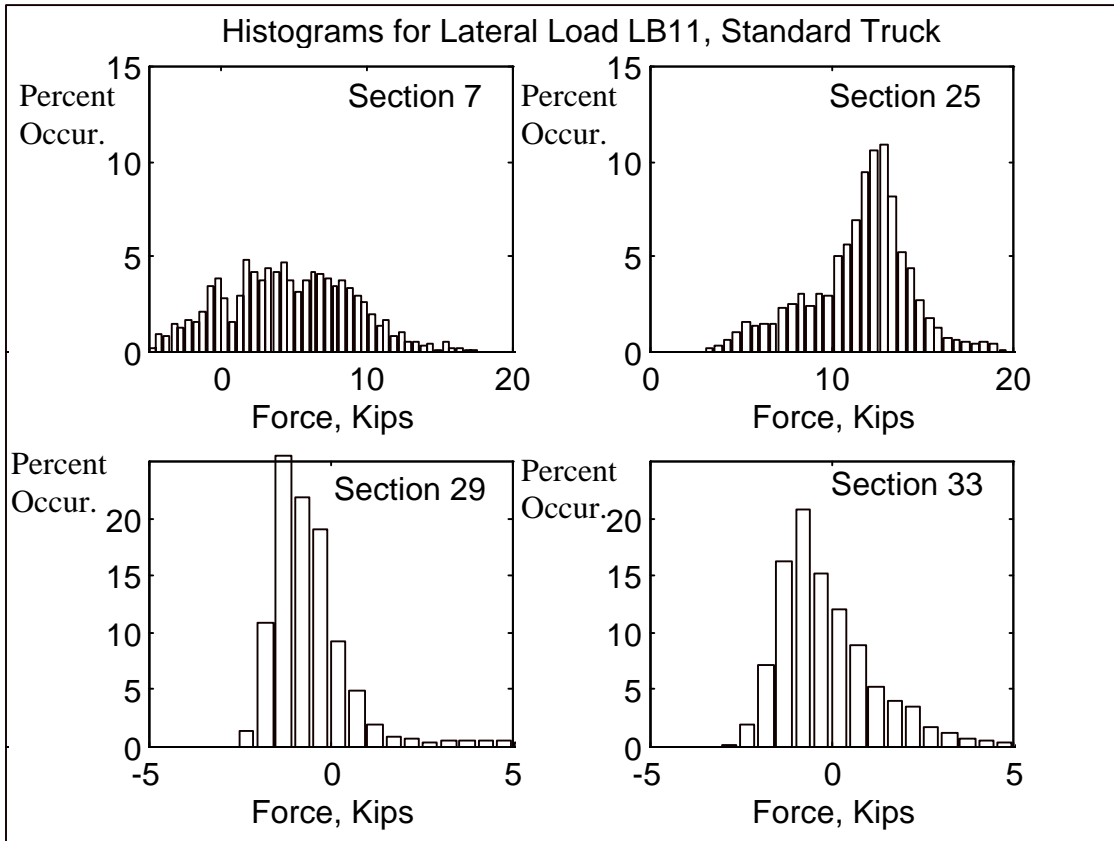


Figure 4.16. Amplitude Distributions for Lateral Load LB11 on the NACO Wedgelock Truck

As shown in Figure 4.17, the distributions for the lateral wheel loads for the Barber truck in the tangent sections do not agree with the distributions for the NACO truck. The tangent track loads under the improved truck have a mean of approximately zero and a larger variance than the loads under the standard truck. In the curved sections 7 and 25, the lateral loads are lower than the loads for the NACO truck. In general, the lateral loads are lower for the Barber truck.

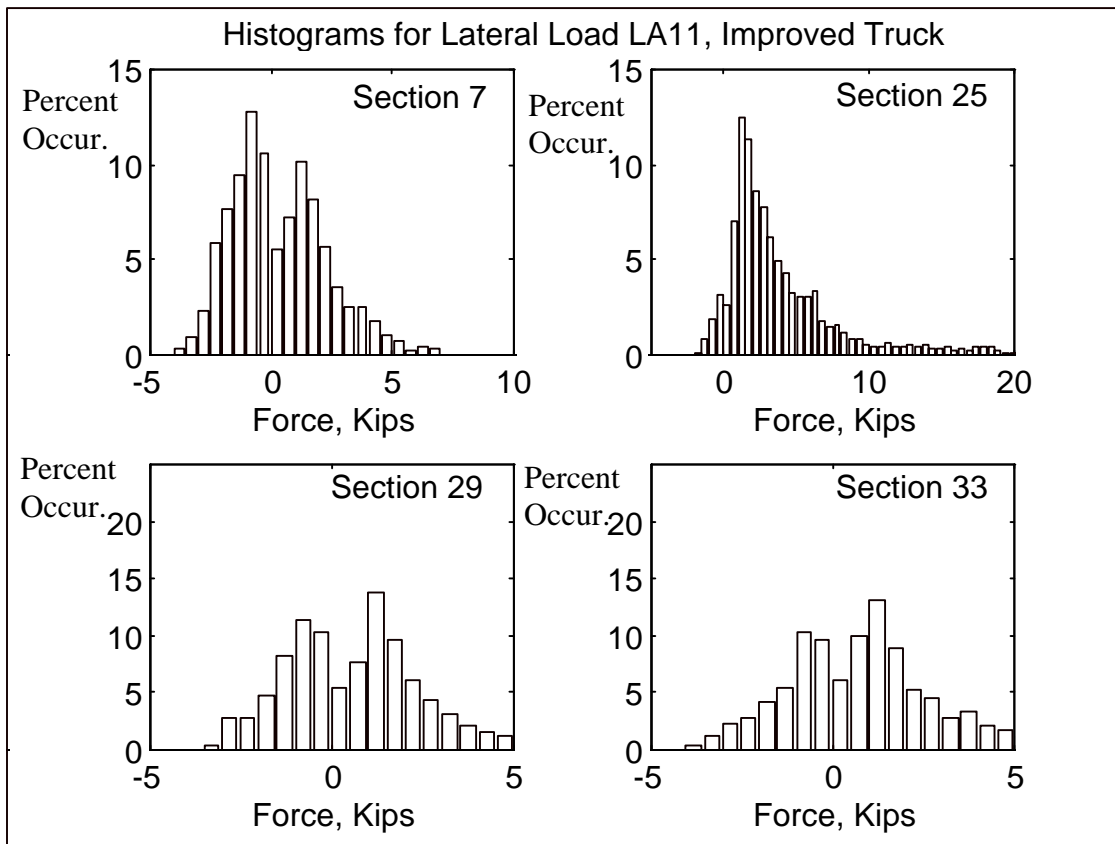


Figure 4.17. Amplitude Distributions by Section for Lateral Load LA11 on the Buckeye/Barber Truck

Figure 4.18 shows that the distributions for the left wheel agree with the distributions for the right wheel. The lateral loads for the Barber truck are generally lower than those observed for the standard truck design. In tangent sections, the loads for the improved truck have means of approximately zero, and a larger variance than the distributions observed for the standard truck. The subgrade stiffness did not have a noticeable effect on the lateral loads for either truck design. The distributions for section 29 with a soft subgrade were not significantly different from the distributions for section 33 with a firm subgrade.

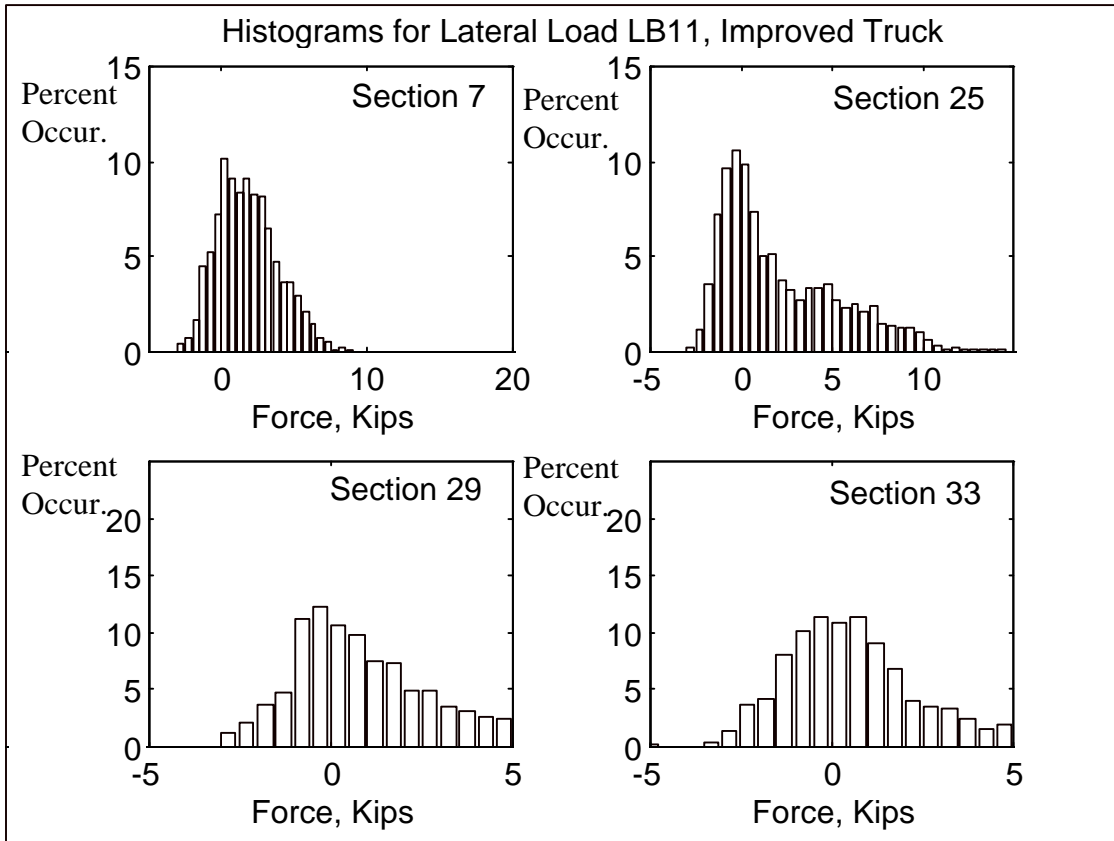


Figure 4.18. Amplitude Distributions by Section for Lateral Load LB11 on the Buckeye/Barber Truck

4.11.2 Vertical Loads

As Figure 4.19 shows, the vertical load VA11 on the standard truck has normal distributions in each of the sections studied. In the curves, the vertical load distribution between the right and left wheels of each axle depends on the speed of the vehicle relative to the balance speed for the curve [22]. Since the nominal 40 mph speed on the HTL is above the balance speed for both 5 and 6 degree curves, the vertical load can be seen to decrease on the inner rail (section 7) and increase on the outer rail (section 25). The average axle weight for the tests conducted on the HTL was 39 tons. This weight correlates well with the average vertical load observed on tangent sections.

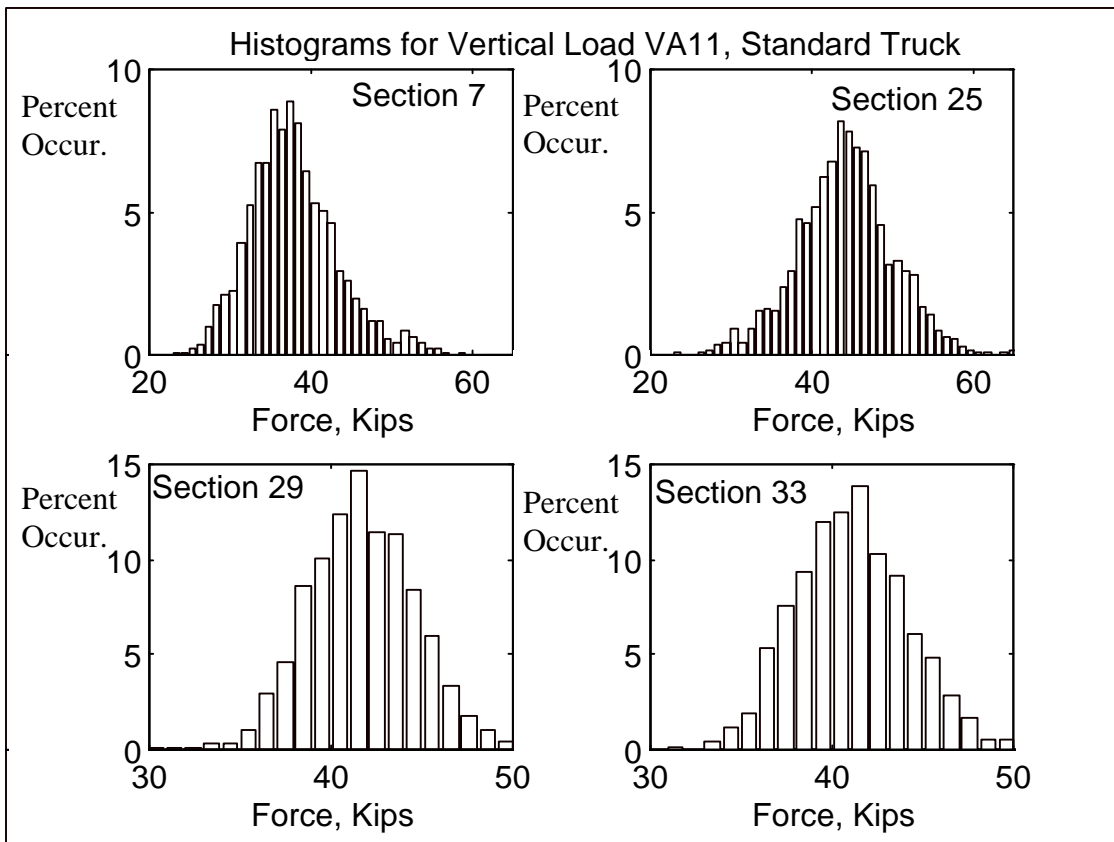


Figure 4.19. Amplitude Distributions for Vertical Load VA11 on the NACO Wedgelock Truck

As shown in Figure 4.20, the distributions for the vertical loads on the left wheel agree with the right wheel. The load increases when the wheel is on the outer rail during a curve, and decreases when the wheel is on the inner rail. Again, all of the distributions are normal with approximately the same variance as the right wheel distributions. It is difficult to determine the effect of subgrade here; this aspect will be addressed more closely later.

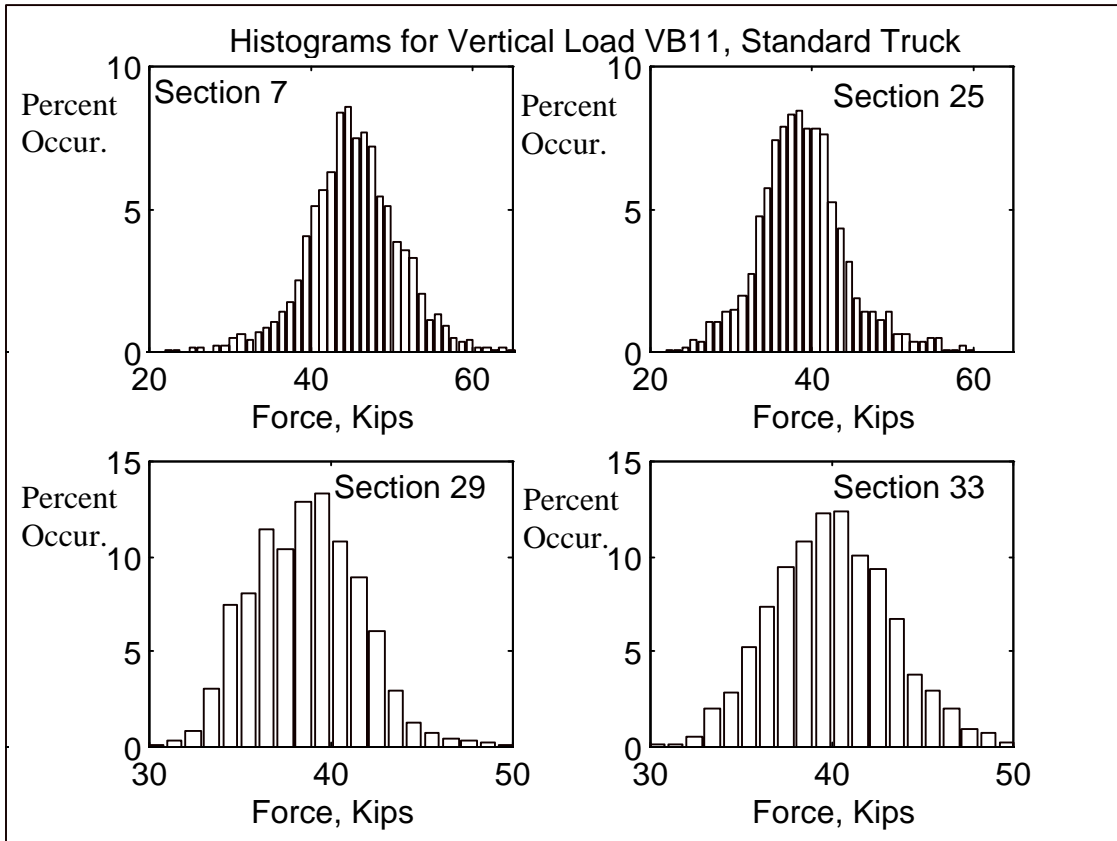


Figure 4.20. Amplitude Distributions for Vertical Load VB11 on the NACO Wedgelock Truck

As Figure 4.21 shows, the distributions for the Barber truck design are different than those for the NACO truck design. The variance of the vertical load in straight sections is more pronounced than with the standard truck. Some of the trends, however, remain the same, for instance during curving, the vertical load increases on the outer wheel and decreases on the inner wheel.

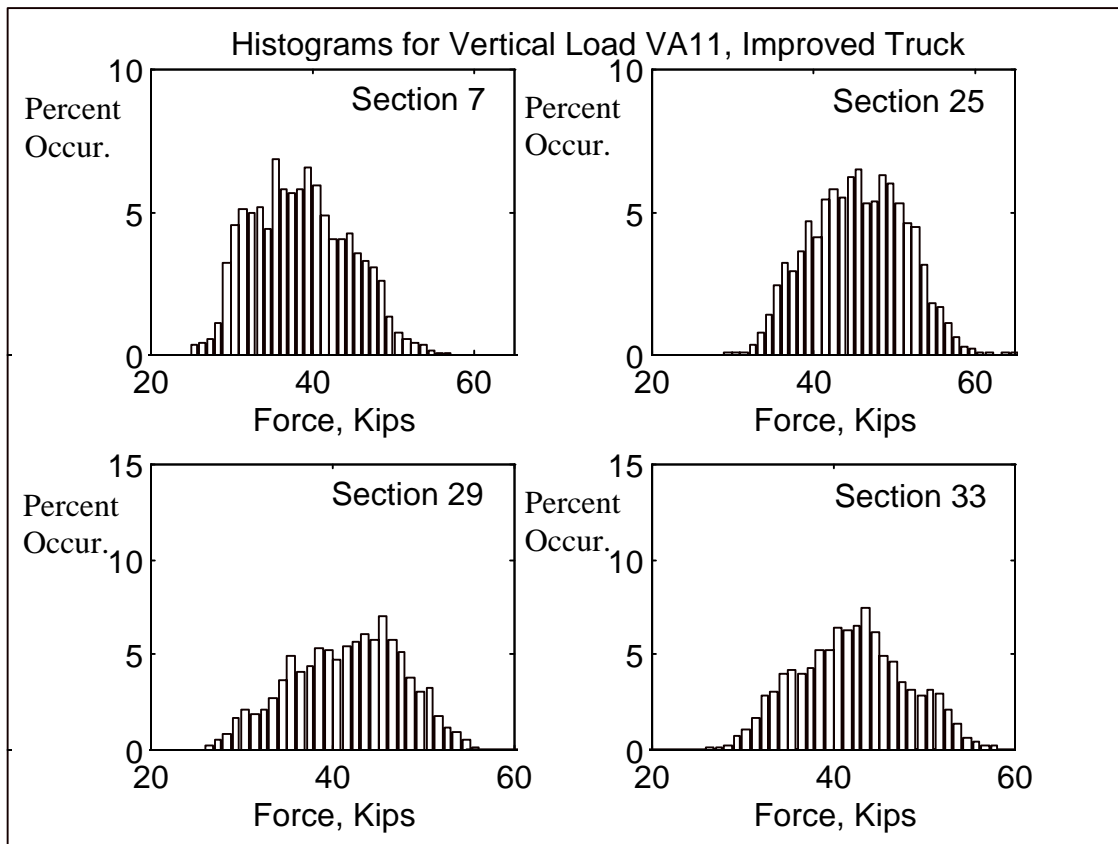


Figure 4.21. Amplitude Distributions for Vertical Load VA11 on the Buckeye/Barber Truck

As shown in Figure 4.22, many of the same features that are visible in the histograms for the right wheel are still prevalent for the distributions of the left wheel. In particular, the vertical load is affected by curvature in the same manner, and the distributions for the tangent sections have more variance than the same distributions for the standard truck.

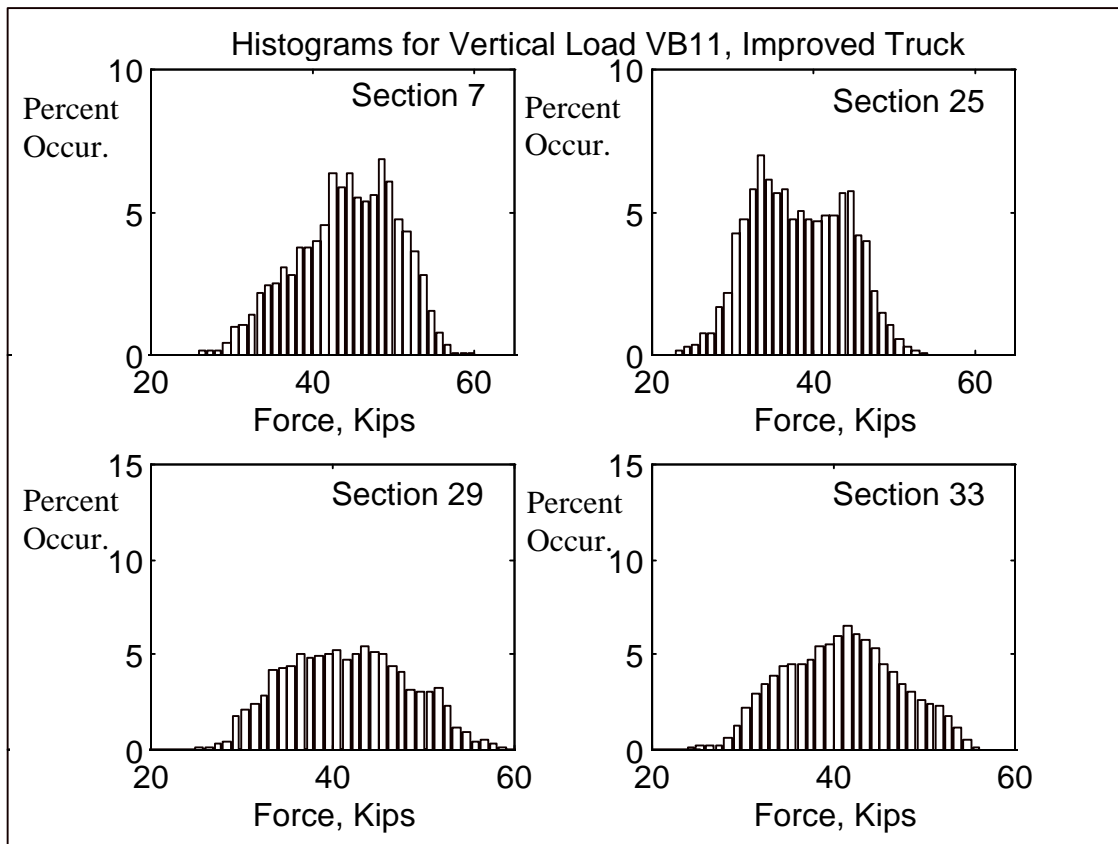


Figure 4.22. Amplitude Distributions for Vertical Load VB11 on the Buckeye/Barber Truck

The amplitude distributions are useful for determining the general shape and trends of the data. The normality and significant deviations can be seen and either corrected or acknowledged before an inaccurate conclusion is reached. In effect, the amplitude distributions are a qualitative measure of the data that needs to be analyzed. To determine the quantitative relationships that exist in the data, each section must be rigorously dissected and examined based on several statistical properties.

4.12 Statistical Analysis of Wheel Loads

The analysis of the amplitude distributions in the previous section was useful for determining that relationships needed to be further examined. Both the truck design and several track parameters seemed to significantly affect the loads observed at the wheels. In particular, the effect of the truck design on the lateral and vertical loads is of interest. The subgrade stiffness seemed to affect the variance of the vertical forces, and the degree of curvature made a significant change in the magnitude of wheel loads.

The truck design seemed to produce several changes in the wheel loads. As shown in Figure 4.23, the lateral wheel loads experienced during curves were significantly decreased using the newer truck design. The average lateral load on the leading outer wheel through the three curved sections (3, 7 and 25) was reduced from 7.8 kips with the NACO truck to 2.8 kips with the Barber truck. This is a reduction of approximately 65%. The lateral load is generally desired to be as low as possible. Several types of derailment can occur when the lateral loads are too large. As a result, any design that reduces the lateral load is typically considered an improvement. Infrequent high lateral loads, however, can also cause problems. Short duration, high lateral loads can cause damage to the track, such as panel shift, that degrades track quality and requires maintenance. The 10th percentile load is a good measure of this characteristic.

Lateral Wheel Loads for Section 25 (6 Degree Curve)

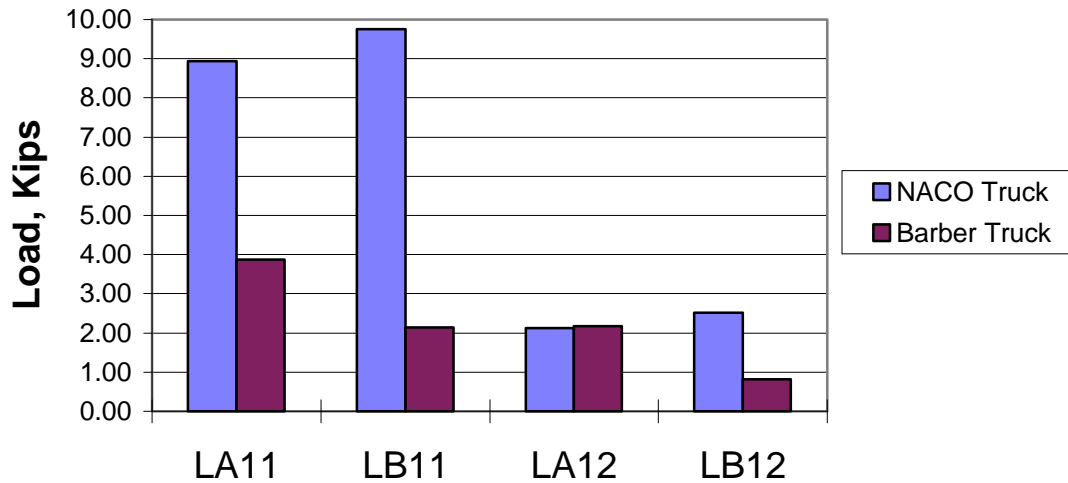


Figure 4.23. Lateral Wheel Loads Corresponding to the NACO Wedgelock and Buckeye/Barber Truck Designs

Figure 4.24 shows how the two truck designs affect the 10th percentile lateral load. The 10th percentile load is a statistically valid method to compare the upper range of loads experienced for one system with another. Essentially, this value is the force that the lateral wheel load is below 90 percent of the time. The newer truck design causes a lower 10th percentile loading during the curved sections than the standard truck design. Ninety percent of the lateral loads on the leading outside wheel on the odd truck occurred below 10.3 kips, whereas 90 percent of the lateral loads observed on the new truck occurred below 3.8 kips during the curved sections 3, 7 and 25. This is a reduction of approximately 65 percent. Simply considering the effect of the new truck design on the lateral loads while curving, one could conclude that this design was substantially better. During tangent sections, the newer design actually increased the lateral load by approximately 15 percent. Lateral loads are typically lower on tangent track than on curved

track, so this increase is less dramatic than the apparent reduction in loads during curves.

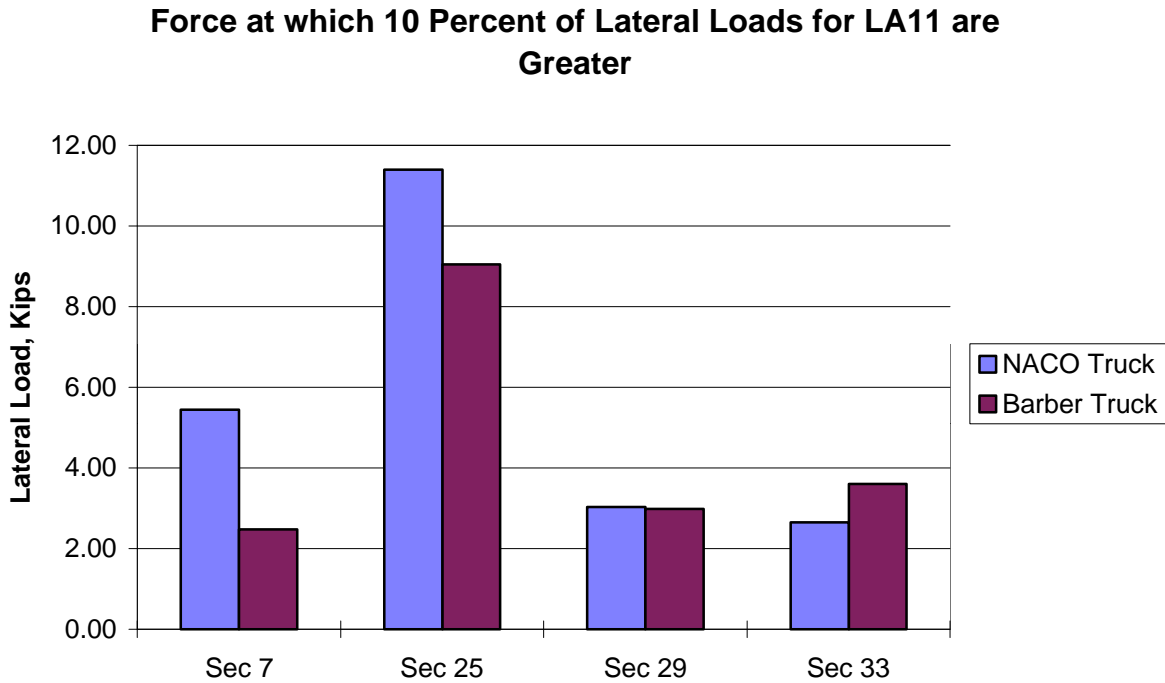


Figure 4.24. 10th Percentile Load LA11 for the NACO Wedgelock and Buckeye/Barber Trucks

The effect of the truck design on the vertical load is not of any particular interest in this study. The magnitude of the vertical load is principally determined by the weight of the vehicle. The effect of the truck on the variance of the vertical load is also of interest. Since this study involves the comparison of two systems, the 10th percentile load was used as the main measure. As illustrated in Figure 4.25, the Barber truck resulted in a higher 10th percentile load than the NACO truck. The new truck design had an average 10th percentile load of 48.9 kips on tangent track, whereas the standard truck had an average 10th percentile load of 47.8 kips. Most of this increase was related to the standard deviation of the vertical load that

increased by approximately 60 percent. The effect of the truck design on vertical loads during curved sections was also studied.

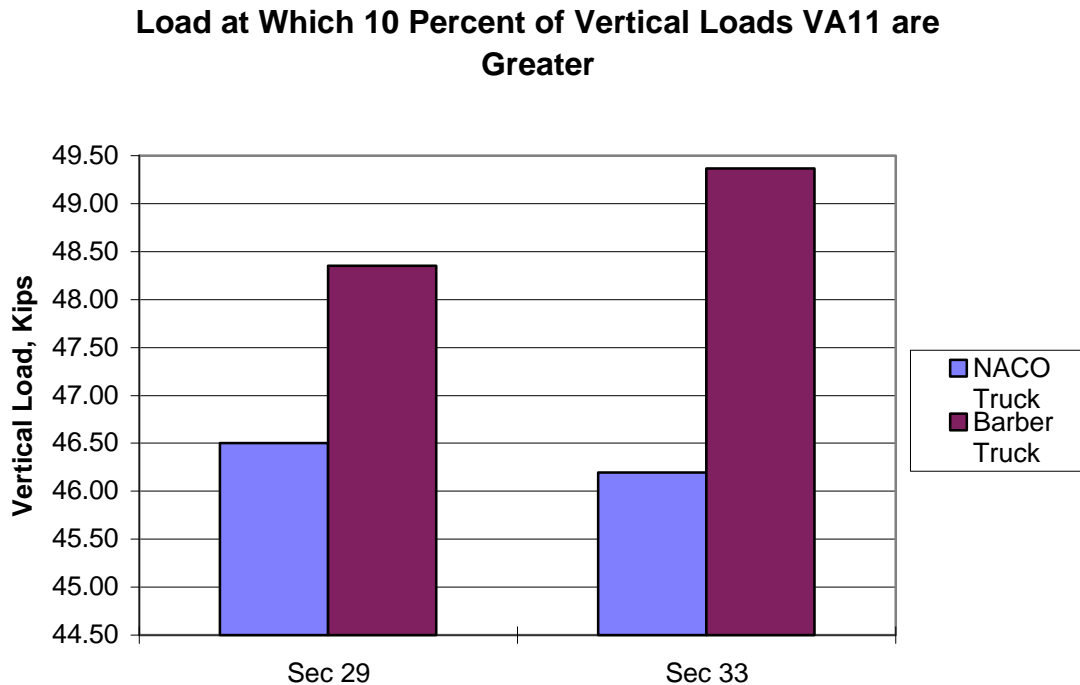


Figure 4.25. 10th Percentile Load for VA11 for the NACO Wedgelock and Buckeye/Barber Trucks

The degree of curvature has the largest effect on the leading outside wheel, both for vertical and lateral loads. Interestingly, the degree of curvature affects the two truck designs differently. As shown in Figure 4.26, the vertical load on the leading outside wheel increases proportionally to the degree of curvature. The Buckeye/Barber truck has slightly less of an increase per degree than the NACO truck.

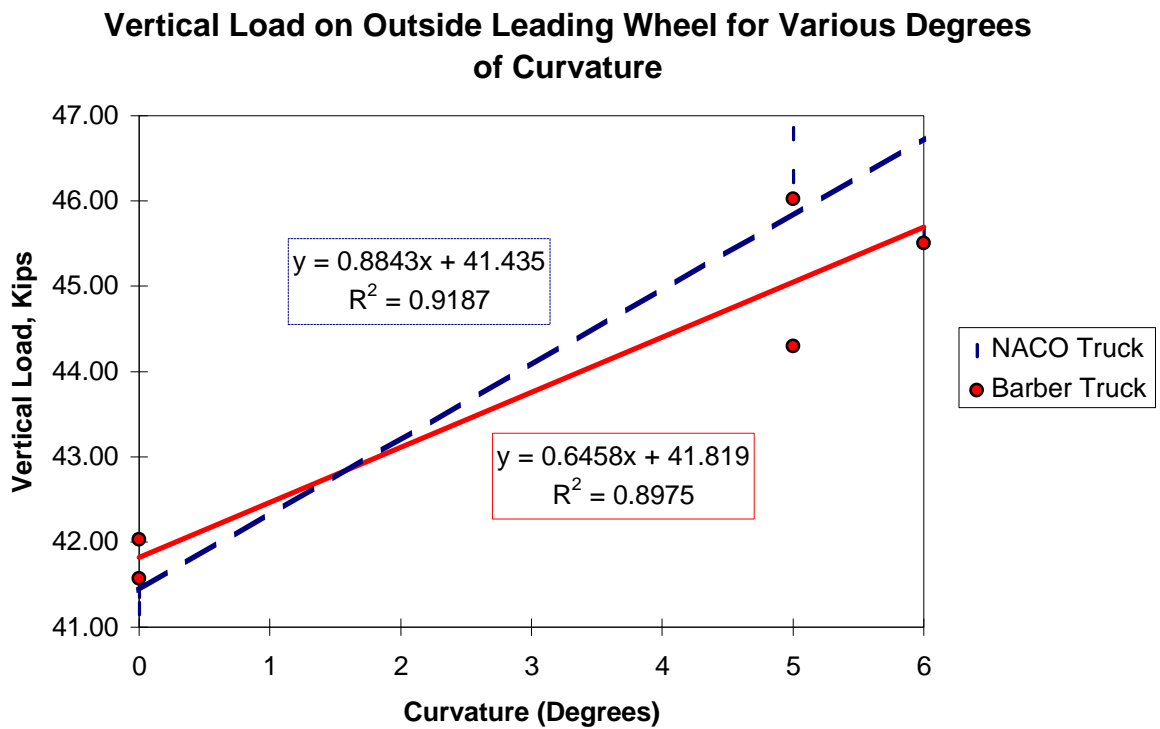


Figure 4.26. Effect of Curvature and Truck Design on Vertical Loads

As shown in Figure 4.27, the truck design has more of an impact on the lateral loads associated with negotiating a curve than the vertical loads. The improved truck has a much lower reaction to the degree of curvature than the standard truck. The standard truck, however, has a much more linear characteristic than the improved truck. A linear characteristic is important for situations where interpolation or extrapolation would be required as with relating these results to a track with curvatures, other than on the HTL. Unfortunately, the HTL only has tangent, 5 degree, and 6 degree curves available for study. Additional data from another track is needed to more accurately identify the characteristics for the curvature data.

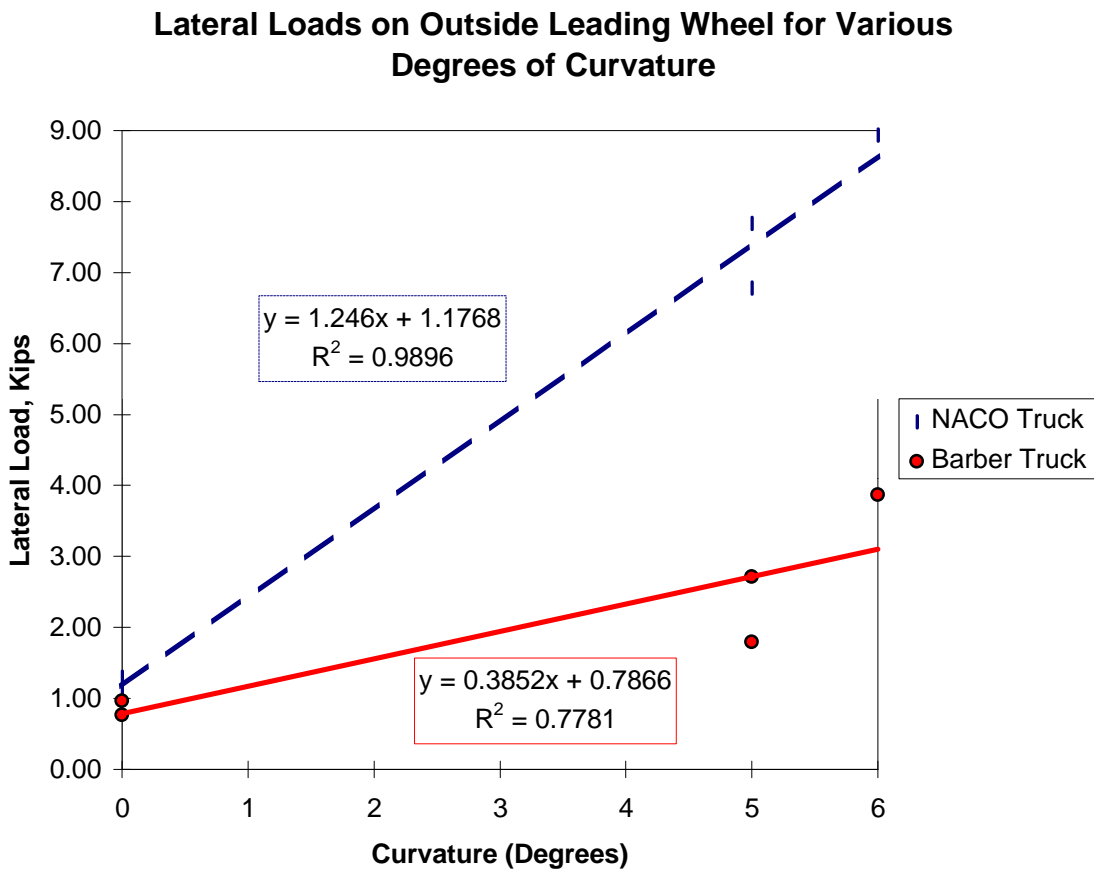


Figure 4.27. Effect of Curvature and Truck Design on Lateral Loads

The five sections of the HTL were selected to study the effect of certain parameters such as the degree of curvature (as discussed earlier) and subgrade stiffness. There is little reason to expect the lateral loads to be affected by the subgrade and as discussed before (in the section on the aggregate amplitude analysis), there were no noticeable effects. Arguably, the subgrade stiffness can increase the dynamic response of the track and produce a greater variation in the vertical loads. As shown in Figure 4.28, a softer subgrade does create a greater amount of variation in the vertical loads. On average, the softer subgrade increased the 10 percent exceedence force of the vertical loads from 45.6 kips to 46.1 kips. These loads corresponded to 4.6 kips and 5.1 kips more than the nominal load. This is

approximately a 10 percent increase in the variation above the nominal load as a result of the subgrade stiffness.

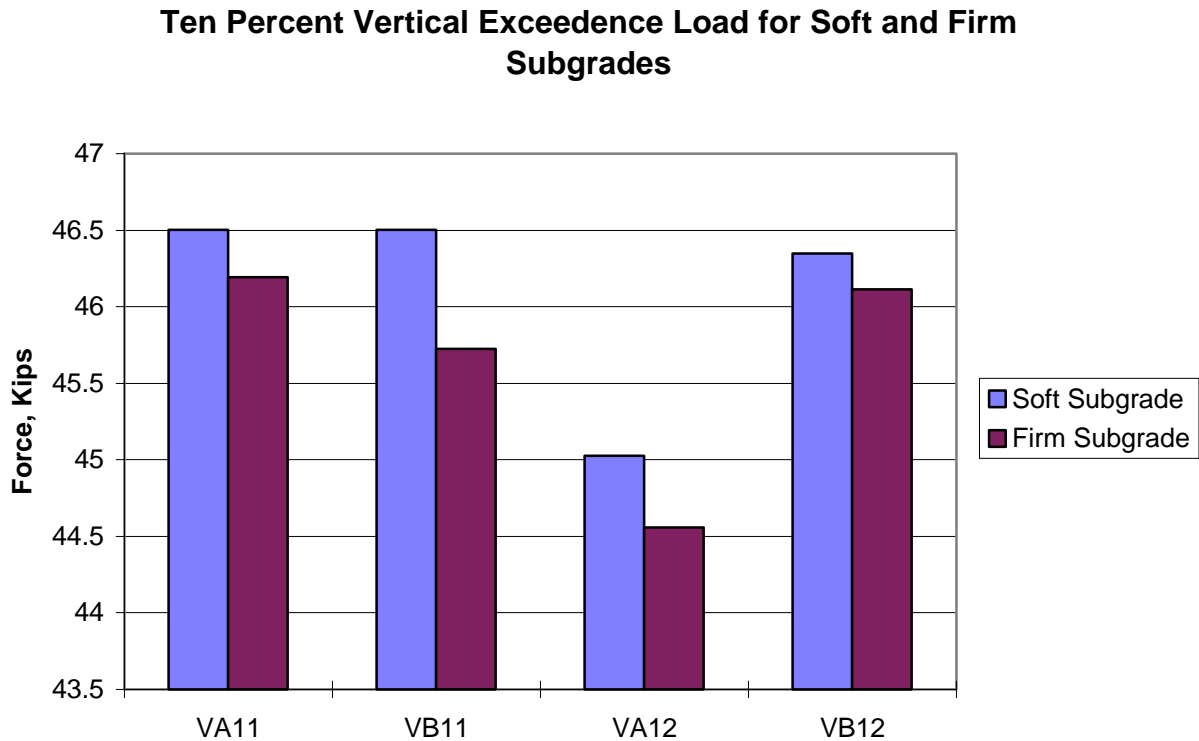


Figure 4.28. Standard Deviation of Vertical Wheel Loads Relating to Soft and Firm Subgrades

4.13 Conclusions for Wheel Load Data Reduction and Analysis

The wheel load data was successfully analyzed and yielded many significant findings. The wheel loads were scrutinized and manipulated until the analyses in the time and frequency domains were capable of producing accurate and meaningful results. The complete loop data was divided into five separate sections of track. Each of these sections made it possible for a

greater amount of information to be calculated for different aspects of the track and data. The influences of subgrade, truck design, and degree of curvature on the magnitude and frequency of the lateral and vertical wheel loads were determined. These effects were described, and all relevant sources of error or possible confusion were addressed.

Eventually, the wheel load data will be used for determining the relationships present between the track parameters and the vehicle response. Considering this, the load data has been inspected for defects that would lead to poor or misleading correlation of the relationships. None have been observed, and the wheel load data seems well suited for calculating the correlation between the track geometry and wheel loads, as will be discussed in Chapter 6.