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Rumble Strip Noise Evaluation

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Rumble Strip Noise Evaluation

Final Report

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EXECUTIVE SUMMARY

This *Rumble Strip Noise Evaluation* study presents results of sound level monitoring of three types of longitudinal rumble strips installed along the edge of two-lane rural roads in Polk County, Minnesota. The study is in response to objections raised by some landowners about the unwanted noise caused by vehicles traveling over rumble strips when they drift over the edge or centerline of the roadway. By changing and modifying the design, the ultimate goal is to provide the maximum safety by capturing the driver's attention through tactile and sound levels while minimizing the associated external noise generated by the rumble strips.

A limited number of references with substantial data on interior or exterior sound levels were identified for review. Most of the studies reviewed were based only on the overall A-weighted decibel (dBA) which in itself, is not sufficient to determine audibility or annoyance caused by rumble strip noise. Only two of the papers involved measurement of the spectral characteristics of rumble strips, using one-third octave band levels.

Testing was performed on three rumble strip designs – California (CA), Pennsylvania (PA), and Minnesota (MN) - which were installed on rural highways near Crookston, Minnesota. Tests were performed with three different vehicles – passenger car, pickup truck and a semi-trailer truck. Three speeds were used for each vehicle/rumble strip combination – 30 mph, 45 mph and 60 mph. One test with each vehicle was made on the normal roadway surface, but only at 45 mph due to time and personnel constraints. Typical pass-by levels without rumble strips were extracted from the FHWA Traffic Noise Model (TNM) data base, which compared favorably with the 45 mph test.

One-third octave band sound levels were taken 50 feet and 100 feet from the edge of roadway, as well as inside the vehicle adjacent to the driver. Video recordings were taken 50 feet from the edge of roadway. Digital audio recordings were captured for each of the sound level readings. The maximum observed pass-by level has been used in the comparative analysis.

Overall A-weighted (dBA) levels showed proportional increases with traffic speed and vehicle weight. Exterior sound levels with California and Minnesota designs were fairly similar, but levels increased more rapidly with speed with the Minnesota design, with a higher exterior sound level than the California design at 60 mph. Interior sound levels were similar for both the California and Minnesota designs for the passenger car and pickup. Interior levels in the tractor cab increased somewhat with speed but were difficult to isolate from normal road noise. In general, the Pennsylvania design had lower exterior and interior sound levels. When comparing sound level with and without a rumble strip, the same patterns described above were observed.

While comparisons of overall dBA levels between interior and exterior are somewhat complex, the data tend to show that the Minnesota levels are consistently greater than the California and Pennsylvania levels. While California and Minnesota levels are similar, the exterior California levels and frequency are generally lower than the Minnesota levels and frequency, suggesting an improved exterior-to-interior sound level ratio for the California design. The Pennsylvania design does not appear to show much change between interior and exterior levels, compared with the California and Minnesota designs.

Estimates of sound level with distance from the roadway were made using a typical outdoor sound propagation model, with one-third octave band source levels taken from the maximum pass-by levels at 50 ft. These were then compared with the background sound level spectrum that was measured during the California and Pennsylvania rumble strip tests. Using the concept of sound detectability developed originally for the Army Tank Automotive Command in the early 1970s, the detectability of the rumble strips was calculated. "Detectability" level is normally lower than "audibility" level since it is associated with actively listening for a sound compared with passively hearing a sound. For example, in a restaurant, one can hear people at the next table but not pay much attention to what is being said. This can be called "passive" hearing. On the other hand, when one tries to understand carefully what is being said at the next table, this can be called "active" listening.

In summary, it is the authors' opinion that the California strip provided adequate driver feedback while generating less exterior noise than the Minnesota strip. The Pennsylvania strip did not provide much driver feedback, although it did generate less exterior noise than either the California or Minnesota strips. Based on the study results, potential future studies could include wider strips to address the heavy commercial tire bridging that occurred with the 8-inch strips. Additional studies could also evaluate different width centerline strips and other vehicle types.

Chapter 1. Introduction

1.1. Introduction and Purpose of the Study

The reason this study was undertaken was due to lane departure crashes that resulted in fatalities or serious injuries. From 2009 to 2013, 3,781 out of 8,087 people involved in a lane departure crash suffered a fatality or serious injury. This *Rumble Strip Noise Evaluation Study* presents results of sound level monitoring of three types of longitudinal rumble strips installed along the edge of two-lane rural roads in Polk County, Minnesota. For more than 50 years, the Local Road Research Board (LRRB) has brought important developments to transportation engineers throughout Minnesota. Those developments range from new ways to determine pavement strength to innovative methods for engaging the public. The LRRB remains true to its important mission: supporting and sharing the latest transportation research applications with the state's city and county engineers.

The purpose of this study is to provide guidance to engineers in the selection and use of rumble strips that will generate the least external noise on adjacent land uses while maximizing the sound level at the driver. The study is in response to objections raised by some landowners about the unwanted noise caused by vehicles traveling over rumble strips when they drift over the edge or centerline of the roadway. By changing and modifying the design, the ultimate goal is to provide the maximum safety by capturing the driver's attention through tactile and sound levels while minimizing the associated external noise generated by the rumble strips.

1.2. Study Objectives

Collection of the most relevant data and information on external and internal noise generated by travel over rumble strips is the primary objective of the study. This includes collection of external sound level data as one-third octave bands that can be used to characterize the "quality" and perception of rumble strip noise. These data can then be used to predict how rumble strip sound decays with distance and ultimately how far from the roadway rumble strip sound can be audible, which is a major objective of this study because of the wide range of distances noted in the literature. This also includes collection of internal noise at the driver position to provide a basis for comparing relative differences between internal and external sound levels for different rumble strips, vehicles, and speeds.

Simultaneous collection of digital audio recordings with sound level data can provide the opportunity for persons other than the driver and the sound level monitoring technicians to experience these sound levels. While these cannot be included in this written report, a list of the available audio files is provided in **Appendix D** for those who would like to experience the results of these tests. Different vehicle types and speeds provide a range of data for evaluation. By choosing three different vehicle types (passenger car, pickup truck, and semi-trailer truck), the effectiveness of rumble strips was tested for both for the driver and the adjacent landowners. Three speeds were selected for the tests (30 mph, 45 mph, and 60 mph) although on rural highways, the 60 mph speed may be most critical.

Chapter 2. Literature Review

This chapter summarizes available and relevant literature on exterior noise from rumble strips and how it decays with distance. Detailed excerpts from these studies are included and discussed in **Appendix B**. Most of the studies reviewed are based only on the overall A-weighted decibel (dBA) which in itself, is not sufficient to determine audibility or annoyance caused by rumble strip noise. Only two of the papers involved measurement of the spectral characteristics of rumble strips, using one-third octave band levels.

Based upon the literature review, the proposed protocol will provide information not found in previous tests for determining the audibility or annoyance of rumble strip noise versus distance from the roadway. From the literature review, a wide range of distances from 60 to 500 meters have been mentioned for non-detectability of rumble strip noise, which doesn't provide any meaningful guidance. Use of the dBA alone cannot reliably identify level of audibility since a sound signal can still be audible even when the level is 15 dBA or more below the ambient dBA level. What determines audibility or detectability of a sound is the difference in frequency characteristics between the sounds. Normally, an intruding sound will be detectable if one of its one-third octave band levels meets or exceeds the ambient level at that frequency. This is the approach taken by the National Park Service in its extensive study of sounds in quiet areas. Therefore, the ambient frequency spectrum is a critical component for determining detectability, which the dBA cannot provide.

The approach proposed here is to measure the one-third octave band levels at 50 and 100 feet, to provide some guidance as to sound decay with distance from the roadway. It will also provide some information along the roadway up to 500 feet or more, depending upon where the vehicle can reach and maintain contact with the rumble strip. However, sound attenuation along the roadway will not be the same as attenuation perpendicular to the roadway, which can depend upon ground type and cover.

The Delaware study used less sophisticated sound level meters at distances up to 1000 feet but concluded with "typically" detectable distances of 275 to 350 ft. Since ambient levels and ground cover can vary (summer crops, fall and spring soil only, winter snow), detectability can also vary with distance. However, once the sound emission characteristics are available, it will be possible to reasonably model detectability under different ambient and ground cover conditions. For the test cases in Polk County, ambient measurements were taken and sound levels predicted versus distance from the roadway.

Chapter 3. Rumble Strip Designs

This chapter describes the three rumble strips designs that were tested in this study. Details of each rumble strip are described below.

3.1. California Design

Dimensions of the California rumble strip design tested here are listed below.

14" center to center
1/32" - 5/8" depth
8" rumble width

3.2. Pennsylvania Design

Dimensions of the Pennsylvania rumble strip design tested here are listed below.

24" (0.6 m) center to center
1/8" - 1/2" depth
8" rumble width

3.3. Minnesota Design

12" center to center
3/8" - 1/2" depth
16" rumble width

A comparison with superimposition the three cross-sections is presented in Figure 3.1.
A close-up photograph of the California strip and a road perspective are shown on Figure 3.2
A close-up photograph of the Pennsylvania strip and a road perspective are shown on Figure 3.3
A close-up photograph of the Minnesota strip and a road perspective are shown on Figure 3.4

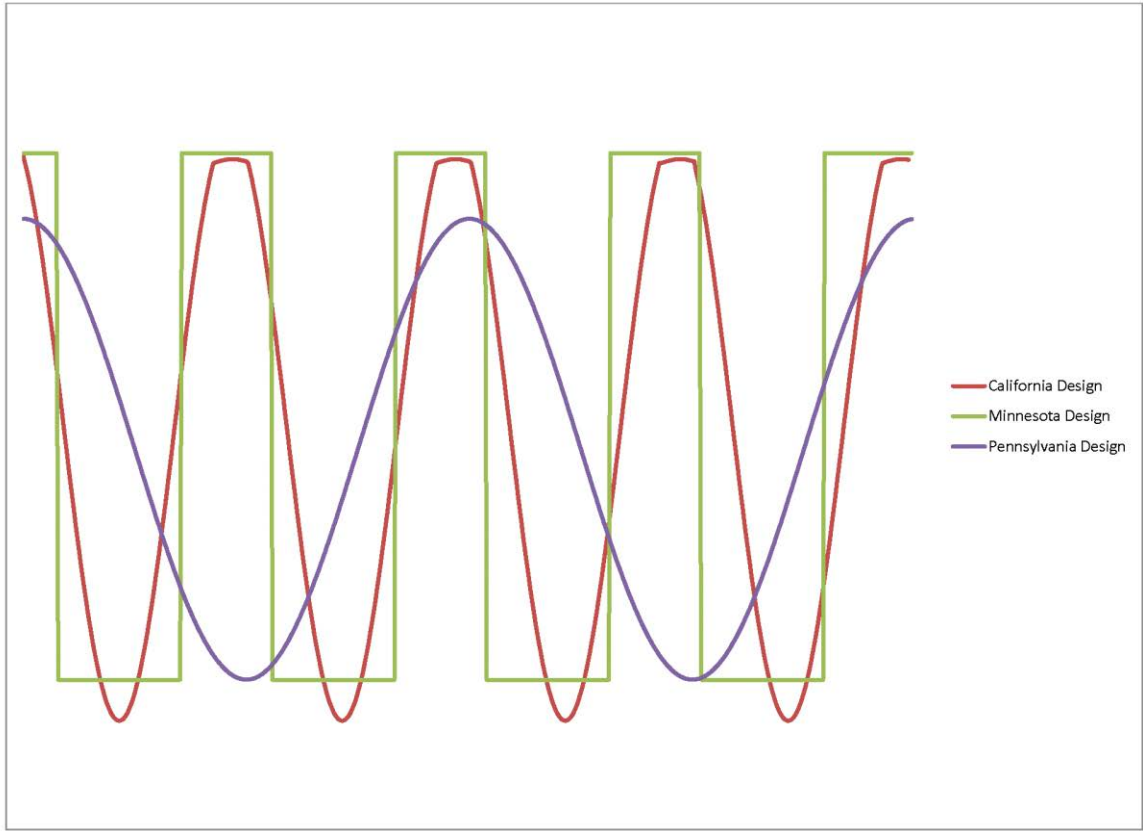


Figure 3.1 Comparison of Rumble Strip Cross Sections



Figure 3.2 California Design



Figure 3.3 Pennsylvania Design

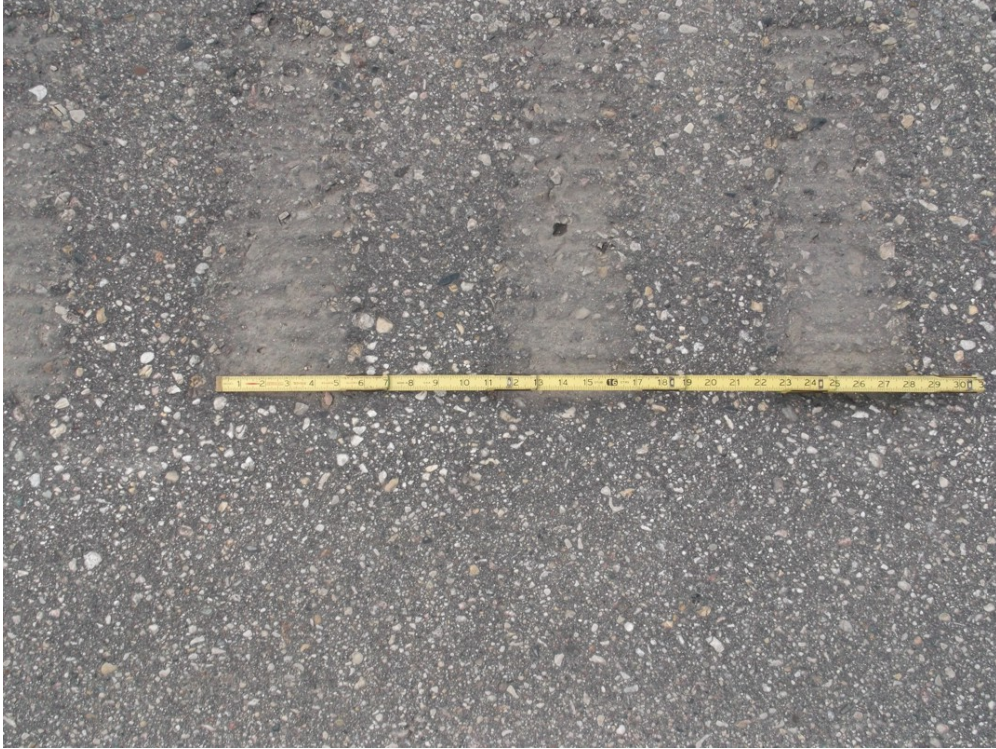


Figure 3.4 Minnesota Design

Chapter 4. Monitoring Program

4.1. Final Test Program for California and Pennsylvania Designs

Figure 4.1 shows locations for the westbound and eastbound tests. The monitoring locations are about midway between US 75 and US 2, providing ample distance for acceleration and deceleration. All data were collected on Thursday, June 5, 2014. Additional details of the testing protocol are included in **Appendix C**.

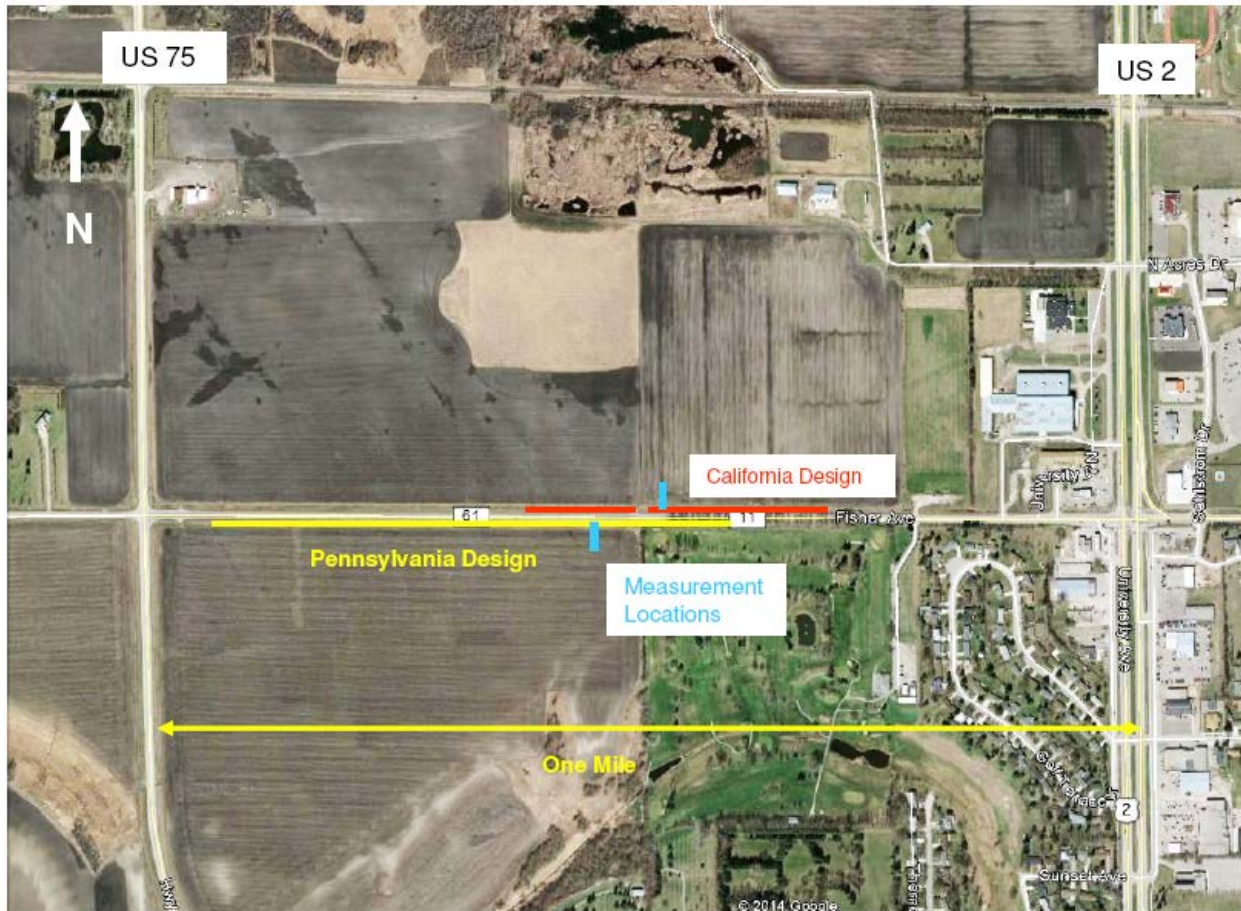


Figure 4.1 Test Area for California and Pennsylvania Rumble Strips

Testing was performed on the north for the California strip design and on the south for the Pennsylvania strip design. The 50 feet distance was from edge of pavement for each of the tests.

The proposed test setup was intended to provide adequate acceleration distance even for the semi-trailer truck 60 mph westbound test. However, this was ensured by closure of US2 for the 60 mph test to allow the truck extra distance for acceleration. There were no problems with the eastbound test. No effect by the limited tree cover was detected, especially for the maximum pass-by level perpendicular to the roadway.

The monitoring locations provided flat space for meter setup at 50 and 100 ft. The meter locations for the Pennsylvania tests are shown on Figure 4.2. The meter at 100 feet is closest to the camera. To the right of the 50 feet meter is a video camera used to capture all of the tests.



Figure 4.2 Location of Sound Level Meter for Pennsylvania Tests

Having any vehicles within 1000 to 1500 feet of the test might affect the readings however, so the roadway was closed to traffic during each of the tests. This provided gaps to allow traffic to pass through between tests.

4.2. Test Program for Minnesota Design

Detailed pre-planning was not included for the Minnesota test. However, tests were performed on County 11 east of Crookston as shown on Figure 4.3. The same vehicles (except the semi-trailer truck which was no longer available) were used for these tests, but only one pass-by was made at each speed to complete testing before rain began.

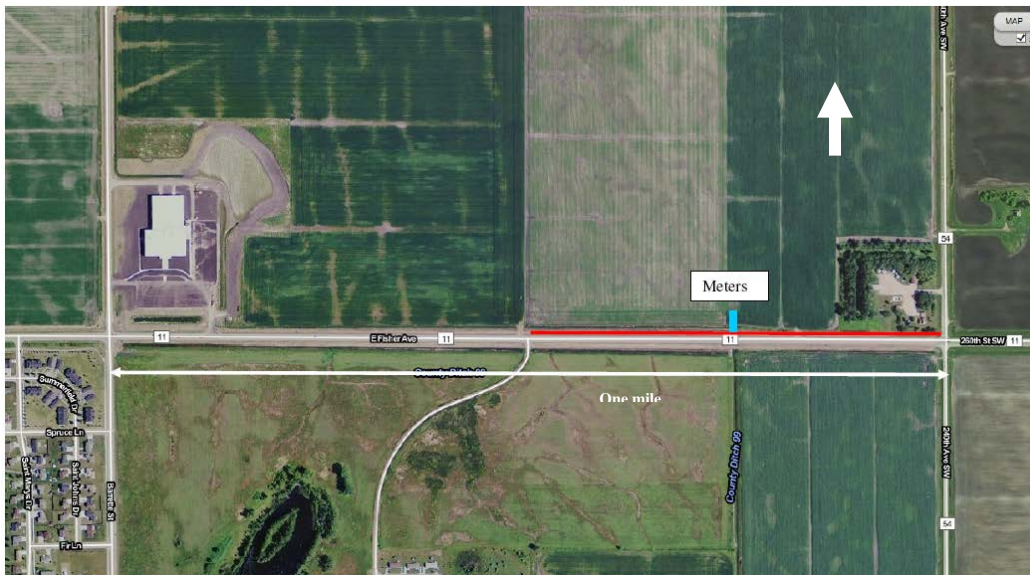


Figure 4.3 Test Area for Minnesota Rumble Strip Test

4.3. Vehicle Types and Interior Meter Location

The passenger car tested was a Chevrolet Malibu shown in Figure 4.4.



Figure 4.4 Passenger Car Used in Tests

Location of the sound level meter next to the driver position is shown in Figure 4.5.



Figure 4.5 Location of Sound Level Meter in the Passenger Car

The pickup tested was a Chevrolet Silverado shown in Figure 4.6.



Figure 4.6 Pickup Used in Tests

Location of the sound level meter next to the driver position is shown in Figure 4.7.



Figure 4.7 Location of Sound Level Meter in the Pickup

The semi-trailer truck combination, a Volvo tractor and trailer, is shown in Figure 4.8. For this test, the trailer was completely empty.



Figure 4.8 Semi-Trailer Truck Used in the Tests

Location of the sound level meter next to the driver position is shown in Figure 4.9.



Figure 4.9 Location of Sound Level Meter in the Truck Cab

Chapter 5. Test Results

Representative test results are presented and discussed in this chapter. Overall maximum dBA levels at 50 feet are presented and compared with readings at 100 ft. Overall levels within the vehicles are presented both in terms of dBA and C-weighted decibel (dBC) which can serve as a surrogate for vibration within the vehicle because of its low frequency content. Comparisons are also made between exterior and interior levels to show which strips signal the driver with the least amount of exterior noise. Following the overall sound level comparison, one-third octave band comparisons are made that show differences in sound level signatures with different rumble strips

5.1. Summary Charts –Overall Sound Level Results

Figure 5.1 compares all of the tests in the order in which they were made, with averages of three pass-bys for the California and Pennsylvania strips and one pass-by for the Minnesota strip.

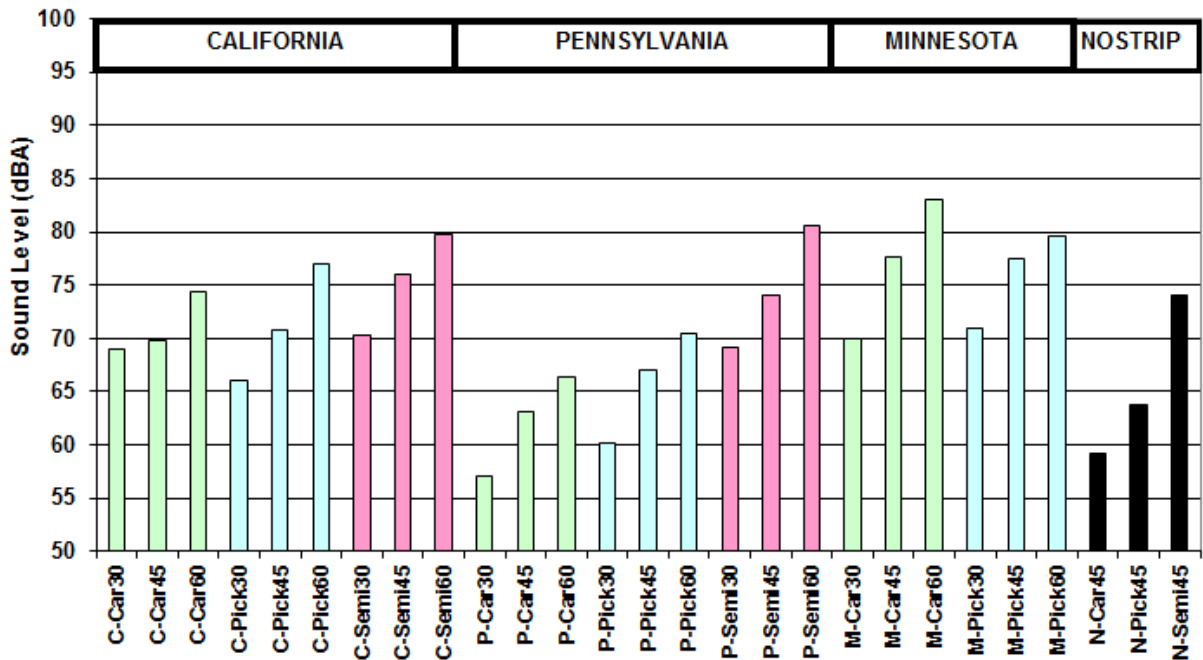


Figure 5.1 Exterior LAeq at 50 feet

The first three bars for California represent the passenger car, the next three the pickup truck, and the next three the semi-trailer truck. The black bars represent no rumble strip at 45 mph, first with the semi, second with the car, and third with the pickup. The semi-trailer results were first with the Pennsylvania to minimize use of the semi-trailer truck. The 60 mph test by the semi-trailer truck with the Pennsylvania design was performed before the 30 mph and 45 mph test, so as to limit time needed to block US 2 to provide adequate acceleration distance. Since the semi-trailer truck was only available for the California and Pennsylvania testing, the Minnesota tests did not include results for a semi-trailer truck.

Figure 5.2 presents differences in maximum pass-by levels between 50 and 100 ft. Since maximum levels were compared, which was essentially a point noise source, one would normally expect there to be a difference of 6 dBA between the 100 feet and 50 feet readings

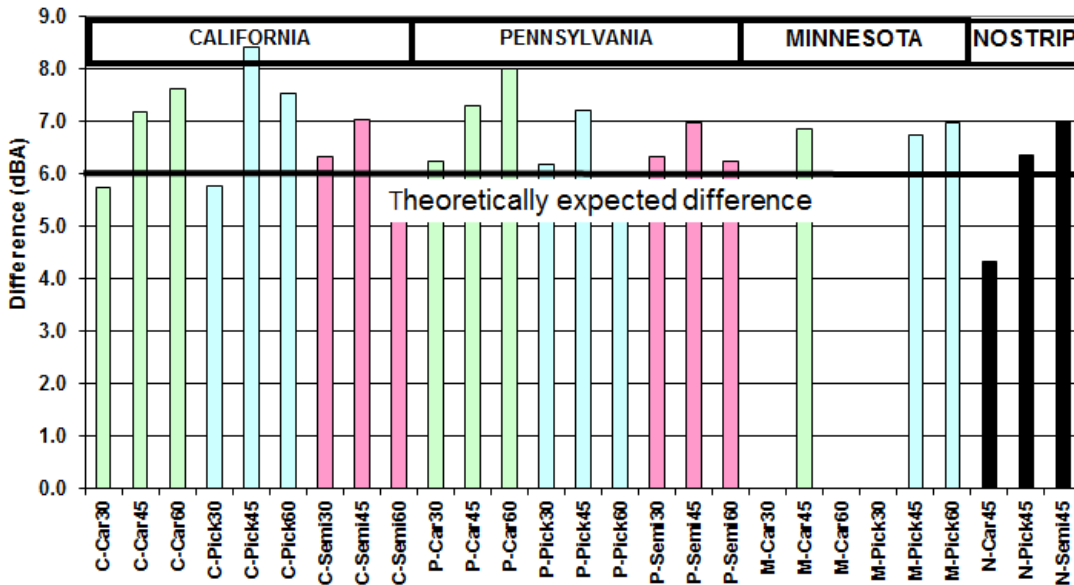


Figure 5.2 Exterior LAeq (50 feet) Minus Exterior LAeq (100 feet)

This figure shows a general tendency around the 6 dBA difference line, with differences generally less than 1 dBA. While no explanation for the differences was investigated, the 100 feet levels generally conform to the normal expected delay, and served as a backup if there were problems with the 50 feet meter.

Figure 5.3 compares the interior dBA averages for California and Pennsylvania and the dBA results for Minnesota. It can be seen that the interior level generally increases proportional to speed.

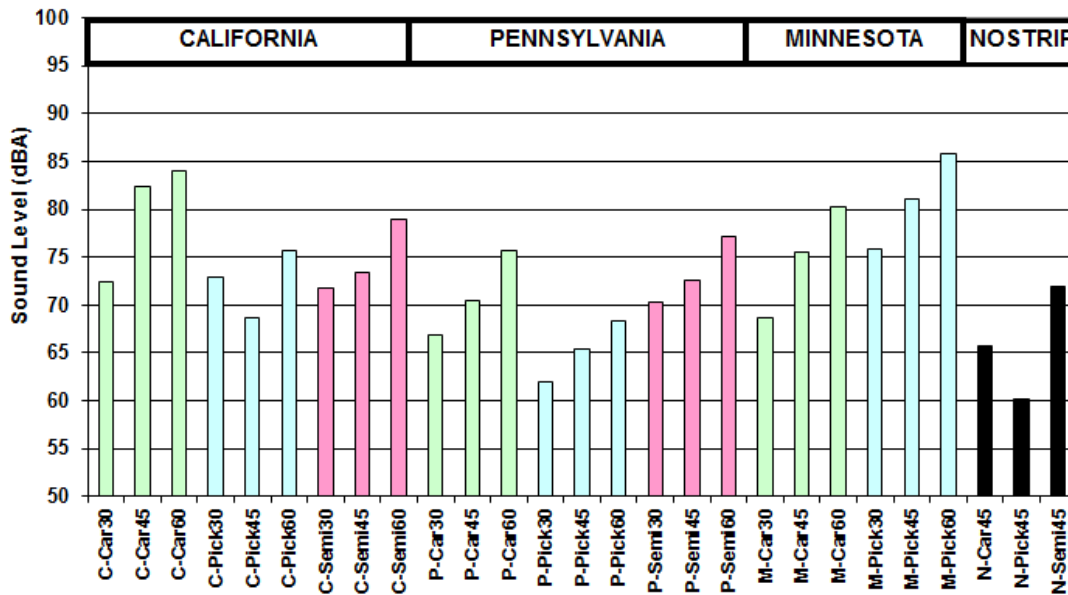


Figure 5.3 Interior dBA Levels

Figure 5.4 presents interior dBC levels, which might be considered a general surrogate for interior vehicle vibration.

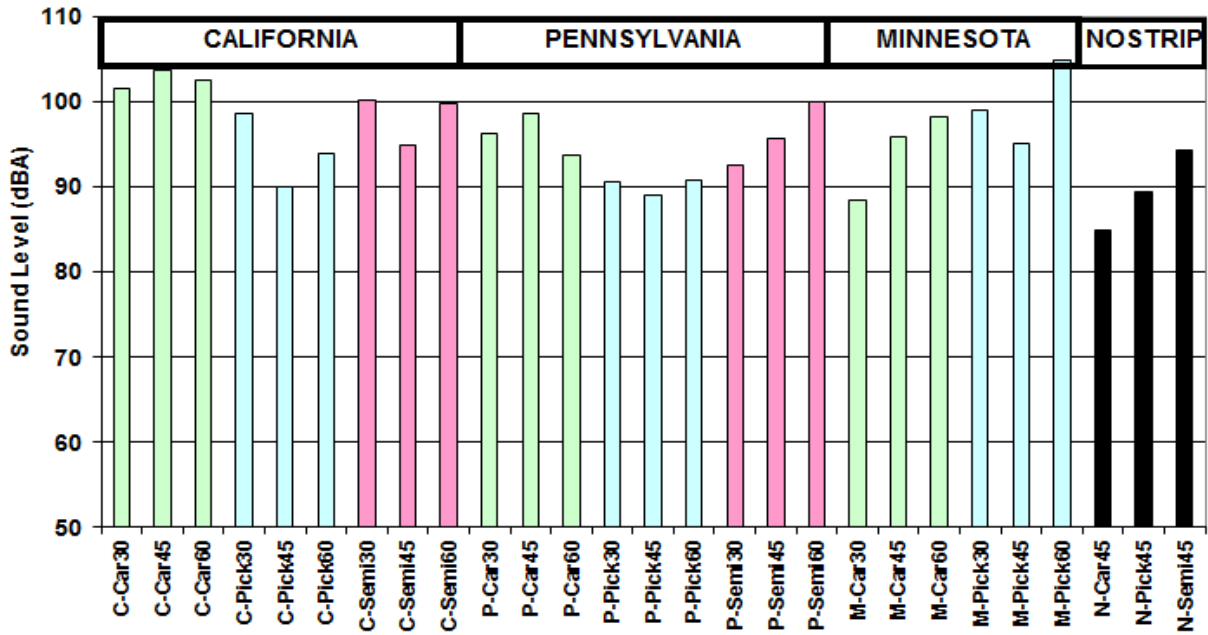


Figure 5.4 Interior dBC Levels

Figure 5.5 compares outside dBA levels with interior dBC levels.

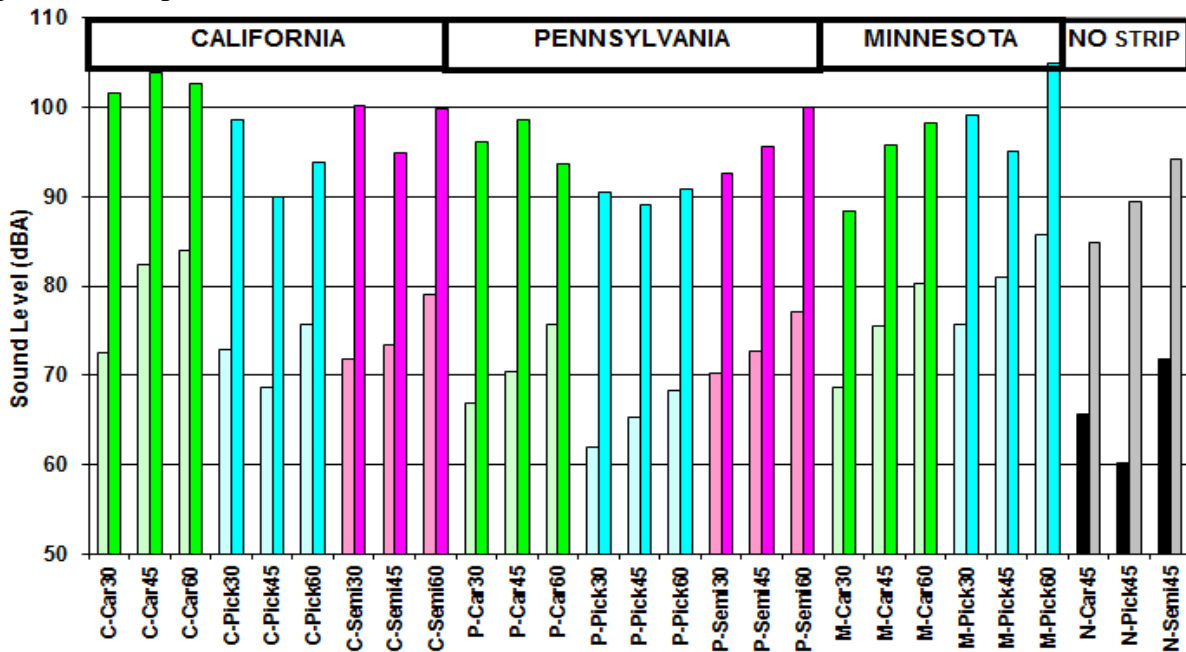


Figure 5.5 LAeq at 50 feet vs LCEq Inside

It can be seen from the figure that interior dBC levels generally do not correlate very well with exterior levels. This might suggest that interior vibration measurements may not relate well with exterior noise levels, so that the additional effort and expense for evaluating vibration may not be warranted.

5.2. Estimated No Rumble Strip Sound Levels

Figure 5.6 compares the monitored exterior level at 50 feet with standard curves for similar vehicles used in the FHWA Traffic Noise Model (TNM) (12).

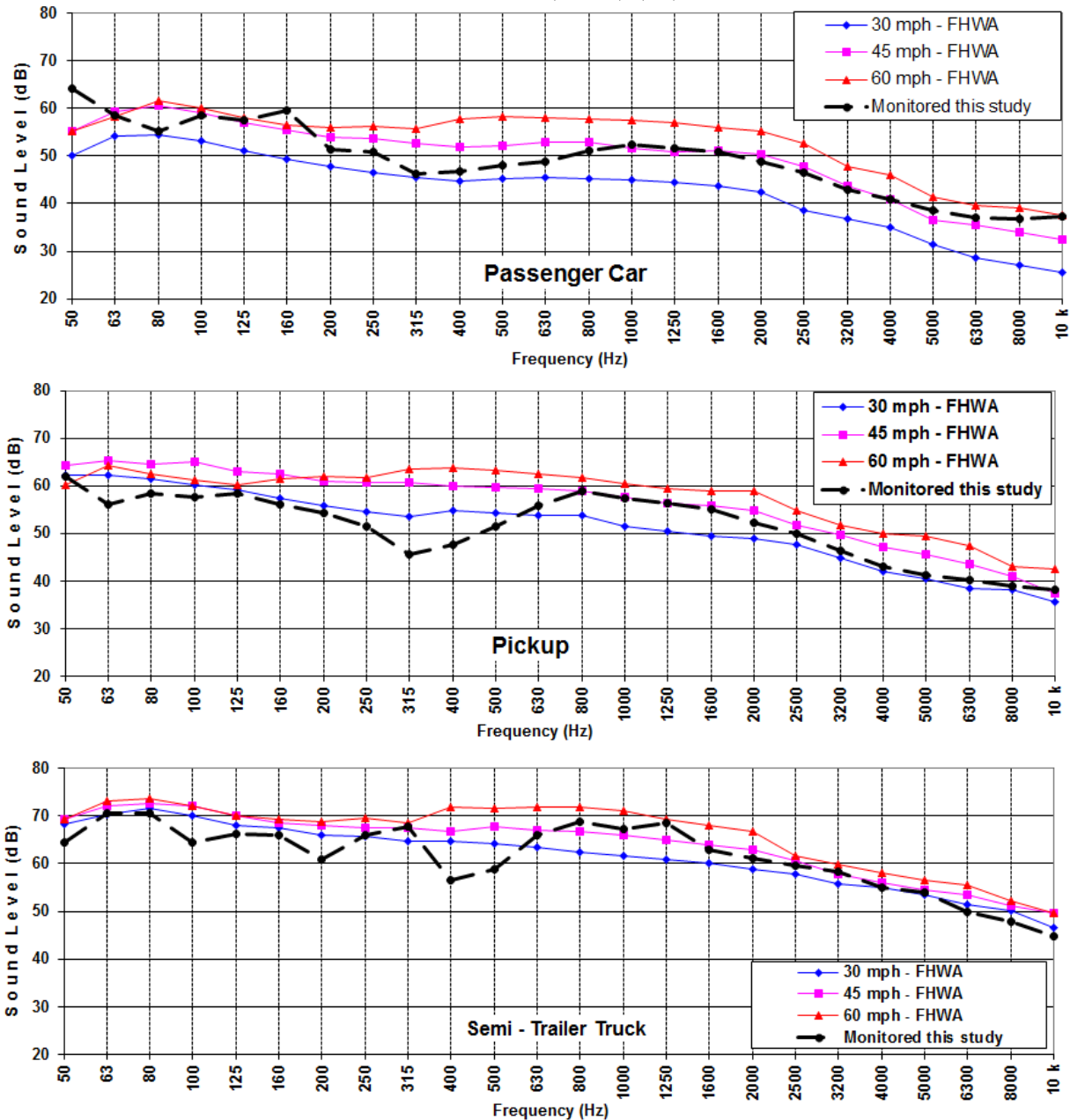


Figure 5.6 Comparison of Monitored Noise with No Strip at 45 mph

For each of the vehicles, it can be seen that the monitored spectrum at 45 mph closely matches the TNM 45 mph standard curve above 1000 Hz, and matches at some lower frequencies. Since the TNM curves were based upon extensive data, these standard spectra have been used here for comparison with the 30, 45, and 60 mph data measured with the three rumble strip designs.

5.3. Comparisons (dBA) Between Rumble Strips and No Rumble Strip

Figure 5.7 compares exterior sound levels at 50 feet for a passenger car traveling at 30 mph, 45 mph and 60 mph on three different rumble strip designs.

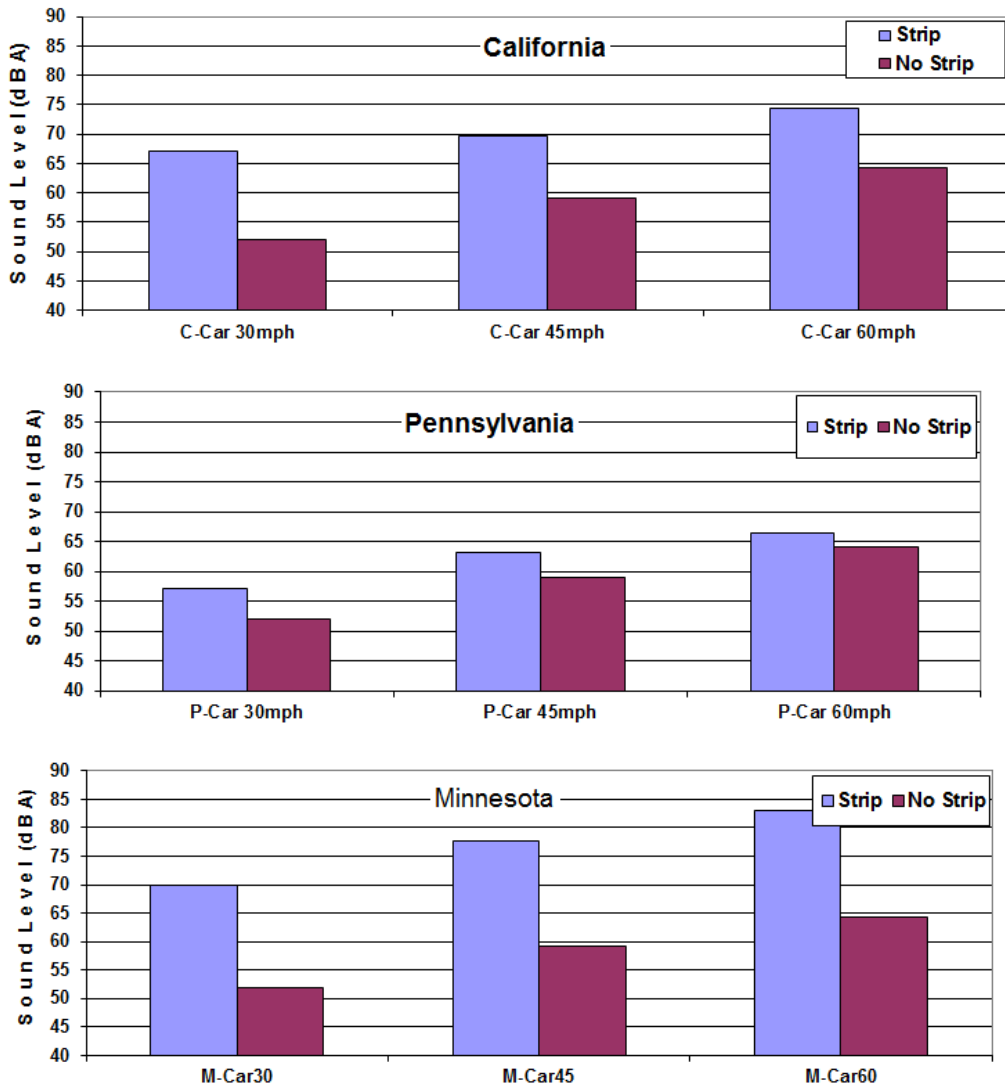


Figure 5.7 Comparison of Exterior Noise from a Car on Three Rumble Strips

The left bars represent the sound level with a rumble strip, while the right bars represent the sound level without a strip. The Minnesota strip exterior sound levels are consistently greater than the California and Pennsylvania strips with the lowest levels associated with the Pennsylvania strip. The Pennsylvania strip shows very little change in exterior noise with the rumble strip. Data will later show, however, that the interior level with the Pennsylvania strip is also quite low compared with the California and Minnesota strips.

Figure 5.8 compares exterior sound levels at 50 feet for a pickup truck traveling at 30 mph, 45 mph and 60 mph on three different rumble strip designs

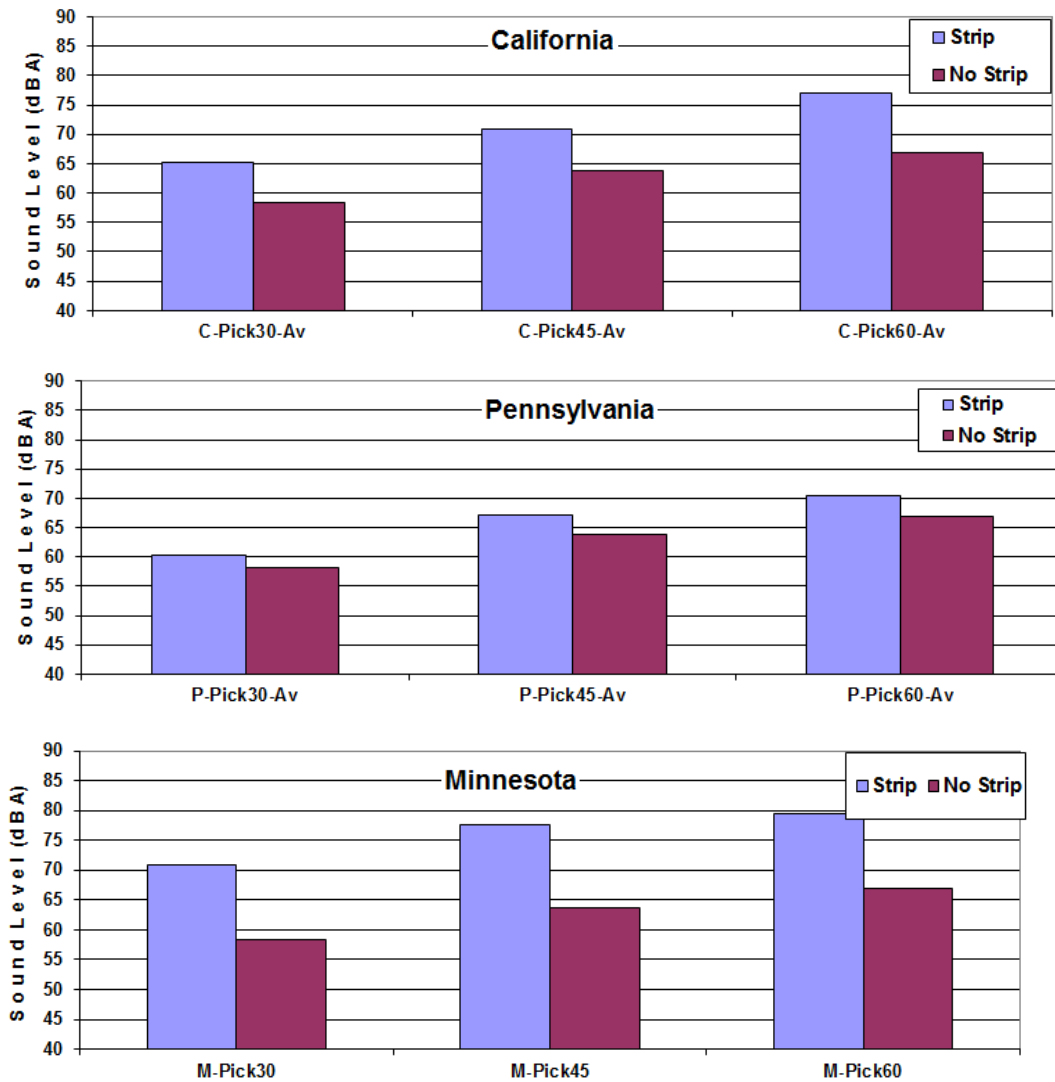


Figure 5.8 Comparison of Exterior Noise from a Pickup on Three Rumble Strips

The left bars represent the sound level with a rumble strip, while the right bars represent the sound level without a strip. As with the passenger car, the Minnesota strip consistently increases the sound level more than the California strip, while the Pennsylvania strip shows the small increases. The pickup on the Pennsylvania strip also shows slightly less increase in noise than with the car. As with the car, the interior level with the Pennsylvania strip is also quite low compared with the California and Minnesota strip.

Figure 5.9 compares exterior sound levels at 50 feet for a semi-trailer truck traveling at 30 mph, 45 mph and 60 mph on two different rumble strip designs. No tests were made with a semi-trailer truck and the Minnesota strip.

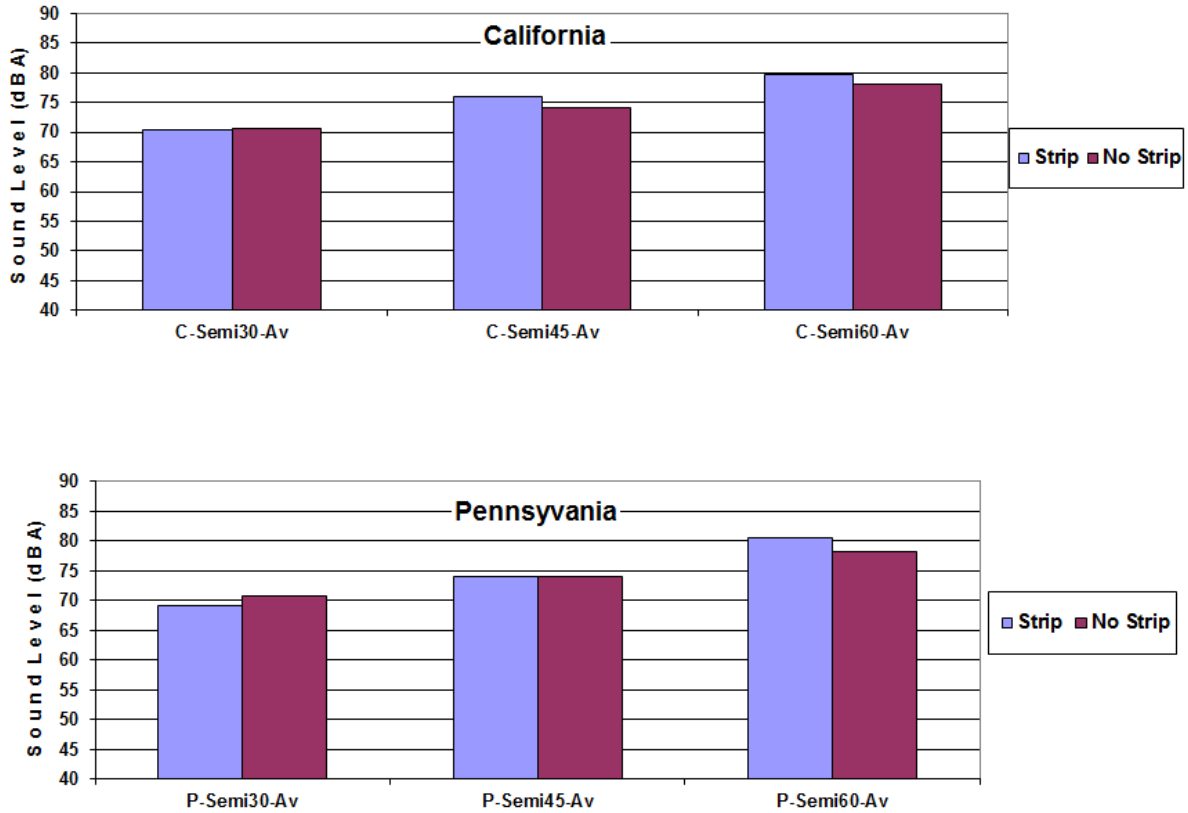


Figure 5.9 Comparison of Exterior Noise from a Semi-Trailer on Two Rumble Strips

The slight “decrease” in sound level with the rumble strip is due to the assumed no-strip noise level. At 45 mph, the California strip is slightly better, while the small increase at 60 mph is about the same.

5.4. Comparison of Sound Level Spectra

Sound level spectra can provide additional information on both exterior and interior sound levels. Figure 5.10 compares one-third octave band exterior sound level spectra for a passenger car with the California, Pennsylvania and Minnesota rumble strips and the standard spectrum for a car with rumble strip. As before, the no-rumble-strip spectrum was estimated from the TNM Traffic noise model so that there is some overlap in monitored rumble strip spectra.

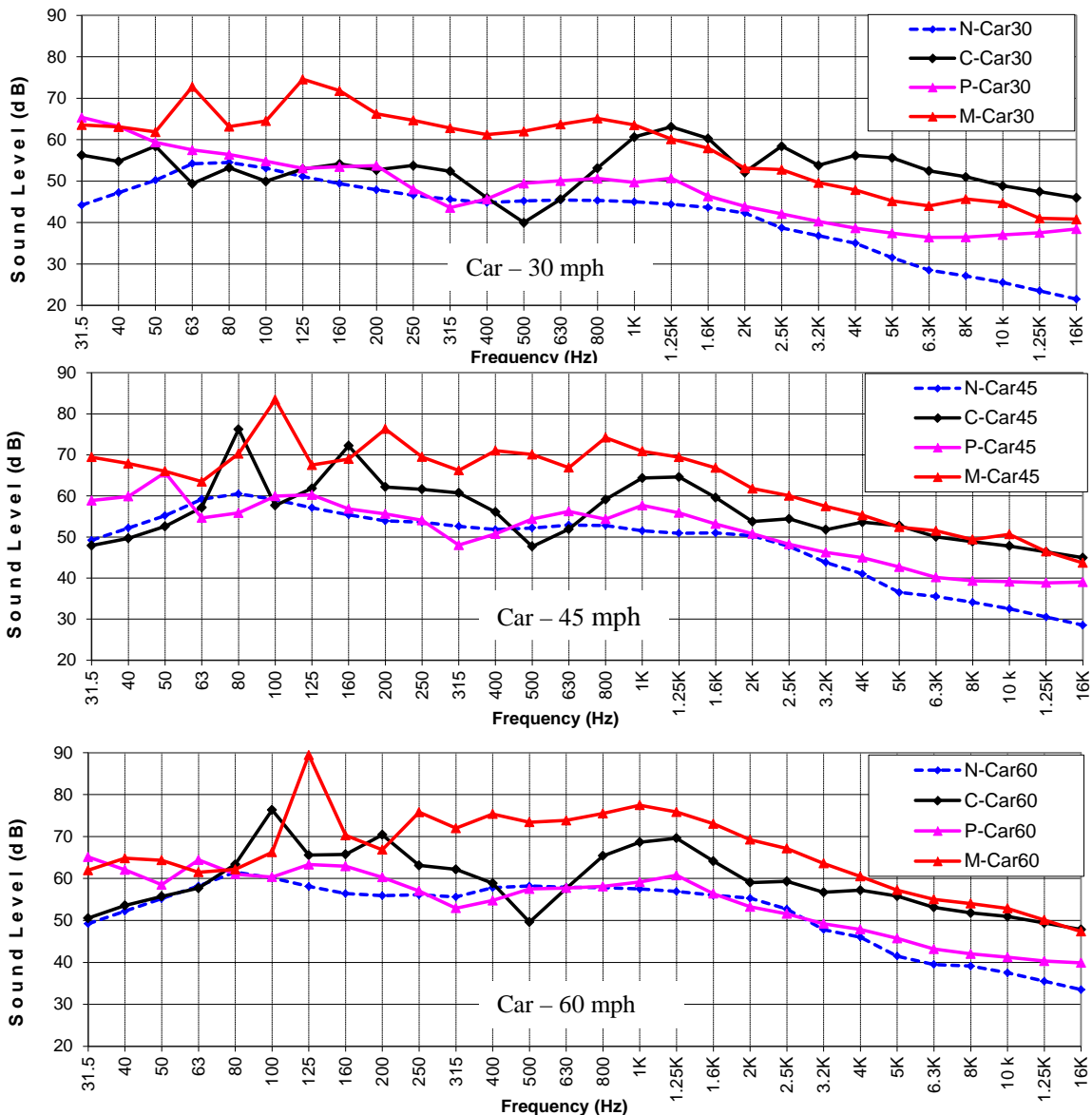


Figure 5.10 Exterior One-Third Octave Band Spectra for a Passenger Car

At 30 mph, only the Minnesota strip clearly shows tonal information with the high peaks at 63 and 125 Hz. At 45 mph, the Minnesota spectra move up to 100 and 200 Hz, while the California strip develops its classic two peak signature. At 60 mph the California two peak signature remains while Minnesota exhibits a very strong 125 Hz peak. The Pennsylvania spectra have no tonal information and do not change very much with speed.

Figure 5.11 compares sound level spectra for a pickup truck on different strip and different speed with the estimated standard no-rumble-strip spectra for a pickup truck.

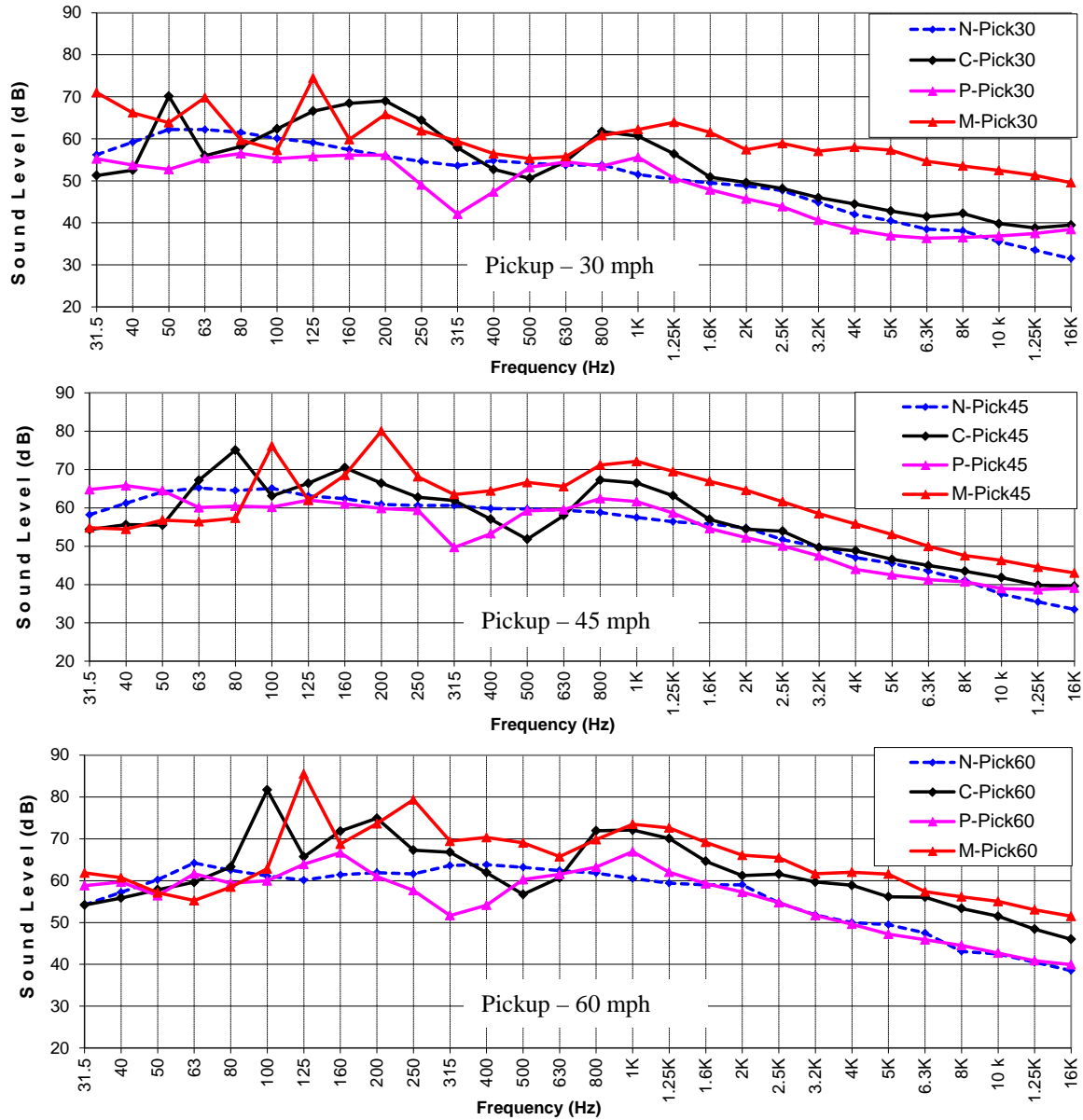


Figure 5.11 Exterior One-Third Octave Band Spectra for a Pickup Truck

The spectra for a pickup truck are generally similar to those for the passenger car except that the Minnesota strip maintains a double peak for all three speeds while the California strip has only one strong peak at 60 mph. The Pennsylvania strip exhibits more variation than with the passenger car with two widely spread peaks at 60 mph.

Figure 5.12 compares sound level spectra for the semi-trailer truck at three speeds for the California and Pennsylvania strips only.

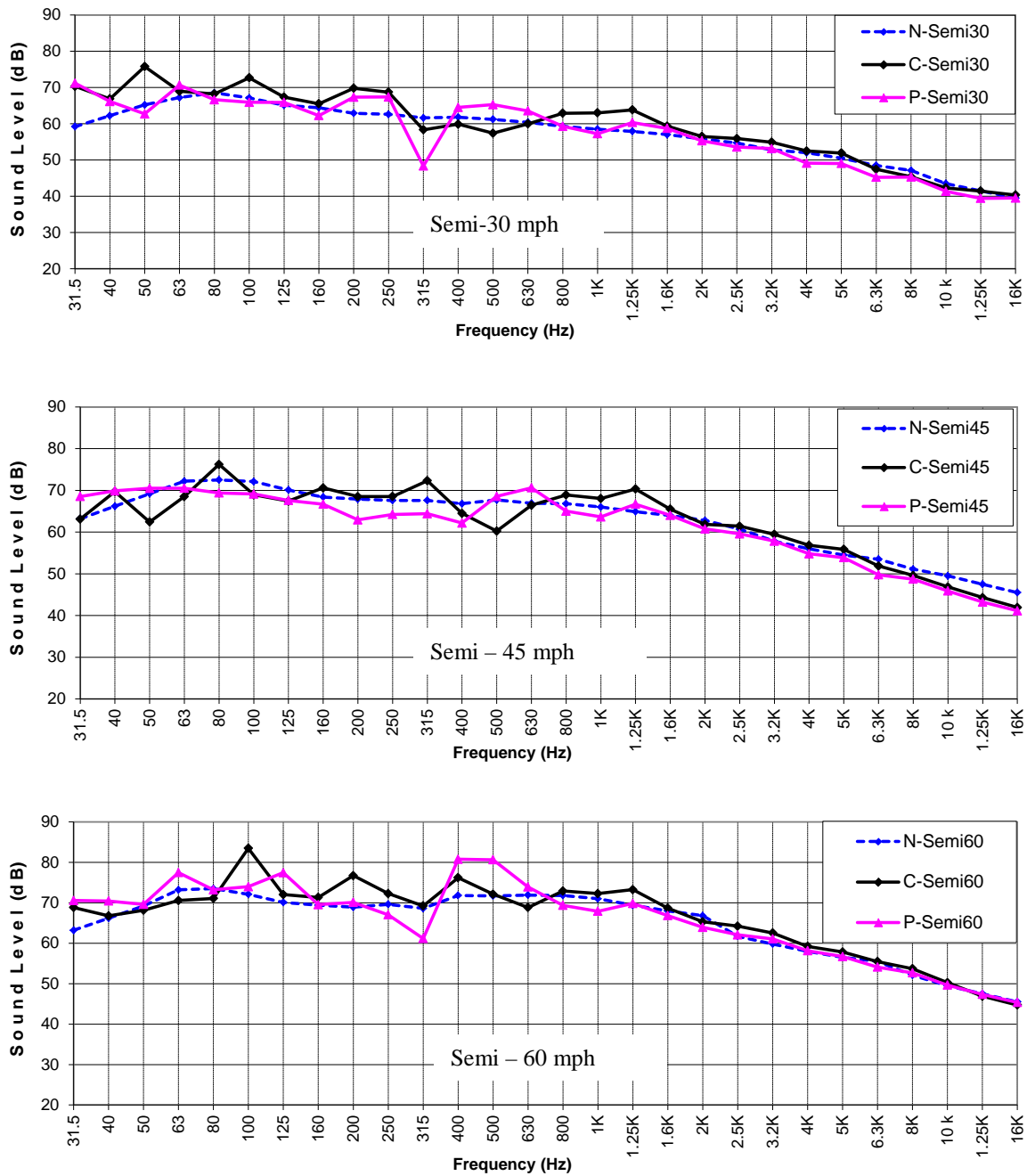


Figure 5.12 Exterior One-Third Octave Band Spectra for a Semi-Trailer Truck

The California strip maintains a very weak two-peak signature for all three speeds while the Pennsylvania strip exhibits some weak peaks at 60 mph.

Figure 5.13 compares spectra from the California and Minnesota strips by speed.

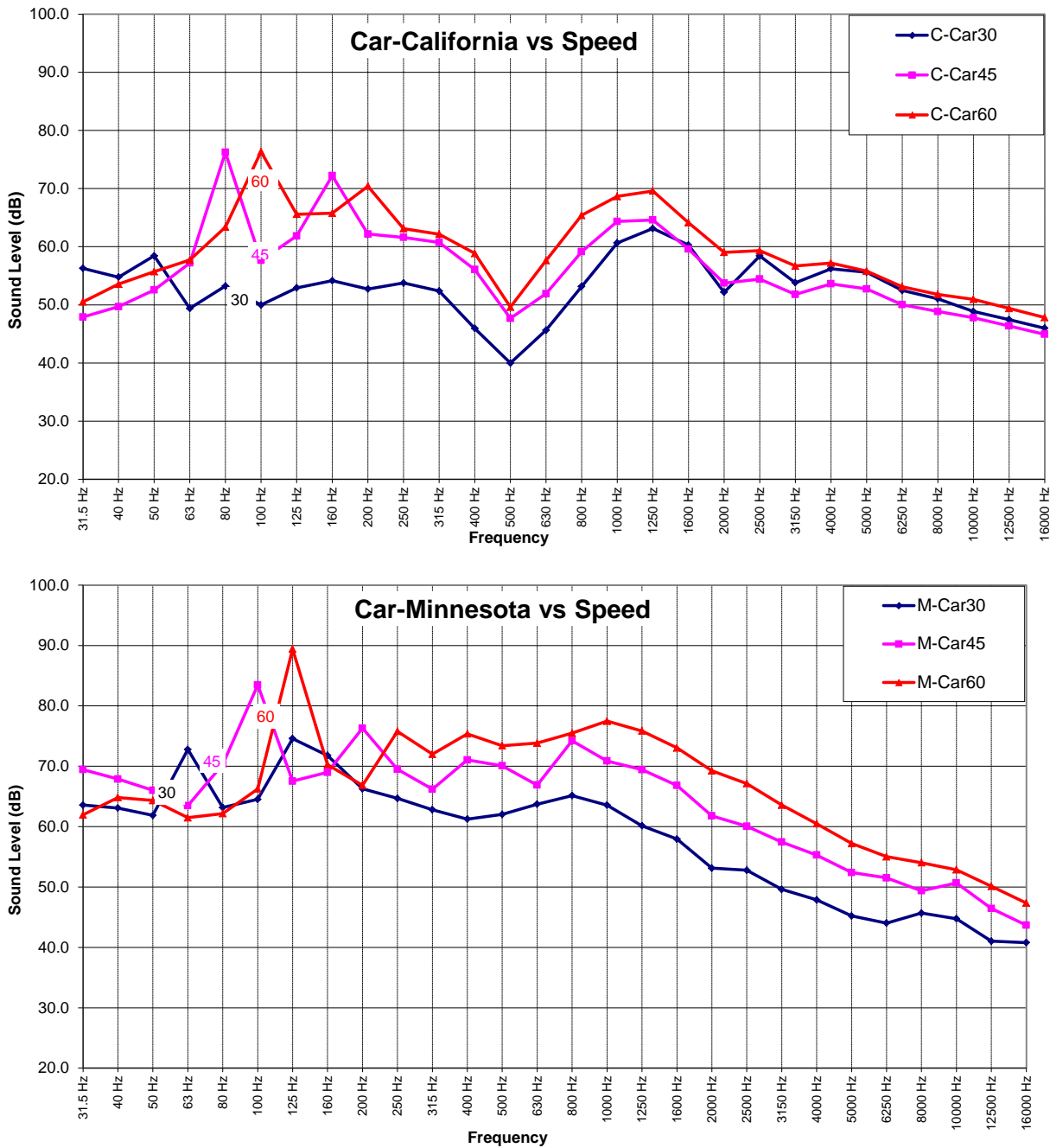


Figure 5.13 Sound Level Spectra by Speed for California and Minnesota Strips

For both strip designs, the tonal peaks clearly increase proportionally with speed. The strongest California peak has the same level for 45 and 60 mph, while the level of the Minnesota peak increases steadily to a very high peak (90 dB) at 60 mph, while the California peak remains at 75 dB. This explains why the Minnesota strip can be quite audible.

Figure 5.14 compares interior sound level spectra in the three vehicle types at 60 mph.

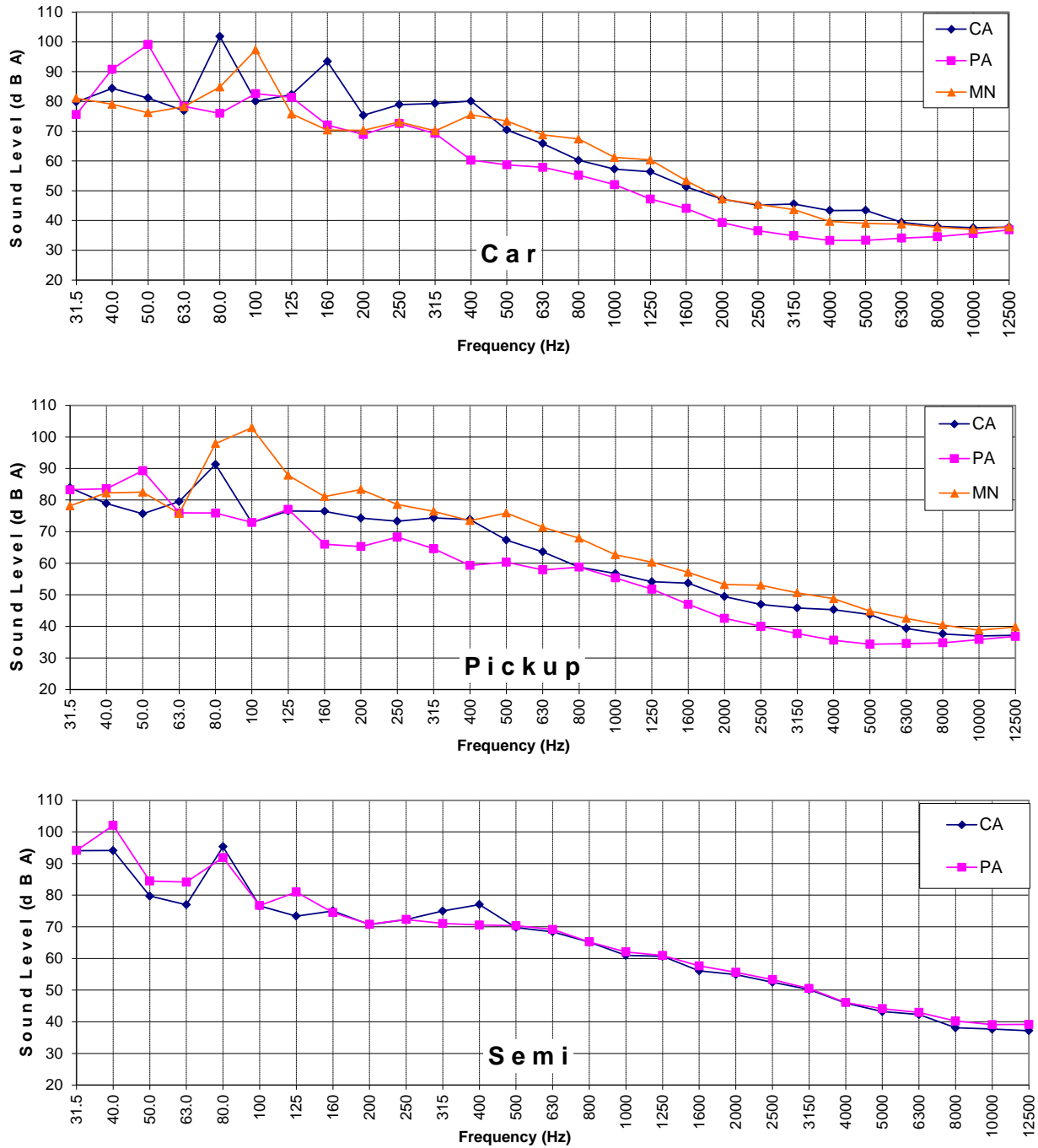


Figure 5.14 Interior Sound Level Spectra at 60 mph

At 30 mph the double peak in the car is likely to be more noticeable than the other two. The Minnesota strip clearly dominates in the Pickup, while only the 80 Hz peak may be noticeable in the semi.

5.5. Comparison between Interior and Exterior Levels

One objective of this study was to identify the rumble strip that generated a clear signal inside the vehicle while creating the least noise exterior to the vehicle. Therefore, comparisons are made here between exterior and interior noise for each of the vehicles by speed and type of rumble strip. Figure 5.15 compares exterior dBA at 50 feet with interior dBA levels.

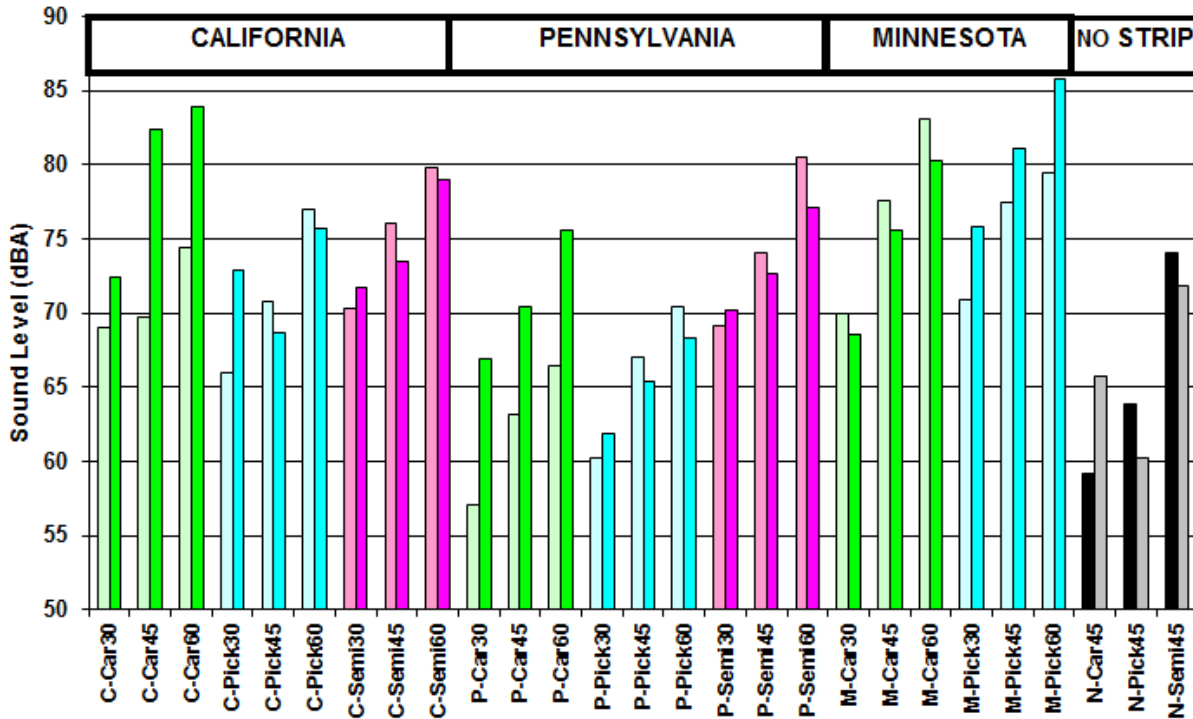


Figure 5.15 Comparison of Exterior dBA with Interior dBA Levels

The passenger car on the California strip (left three bars) shows significant interior sound levels relative to exterior levels. The relative shape of these bars is similar to the passenger car on the Pennsylvania strip, except that the interior levels are 5 to 10 dBA lower. However, the exterior levels are considerably lower. When compared with the passenger car on the Minnesota strip (next to last bar group), it can be seen that the interior levels are similar but the exterior levels are considerably higher with the Minnesota strip. These differences do not carry over to the pickup which shows lower exterior levels but much lower interior levels on the California strip, while much higher exterior and interior levels with the Minnesota strip. Both exterior and interior levels are lower on the Pennsylvania strip. Semi-trailer truck levels are relatively high outside and inside on the California strip and only slightly lower on the Pennsylvania strip, although in both cases, rumble strip noise was not very noticeable in the truck cab. No semi-trailer tests were performed on the Minnesota strip.

Figure 5.16 compares exterior dBA levels with interior dBC levels to see if lower frequency vibration generated sound might be a useful factor in comparing the effectiveness of rumble strips.

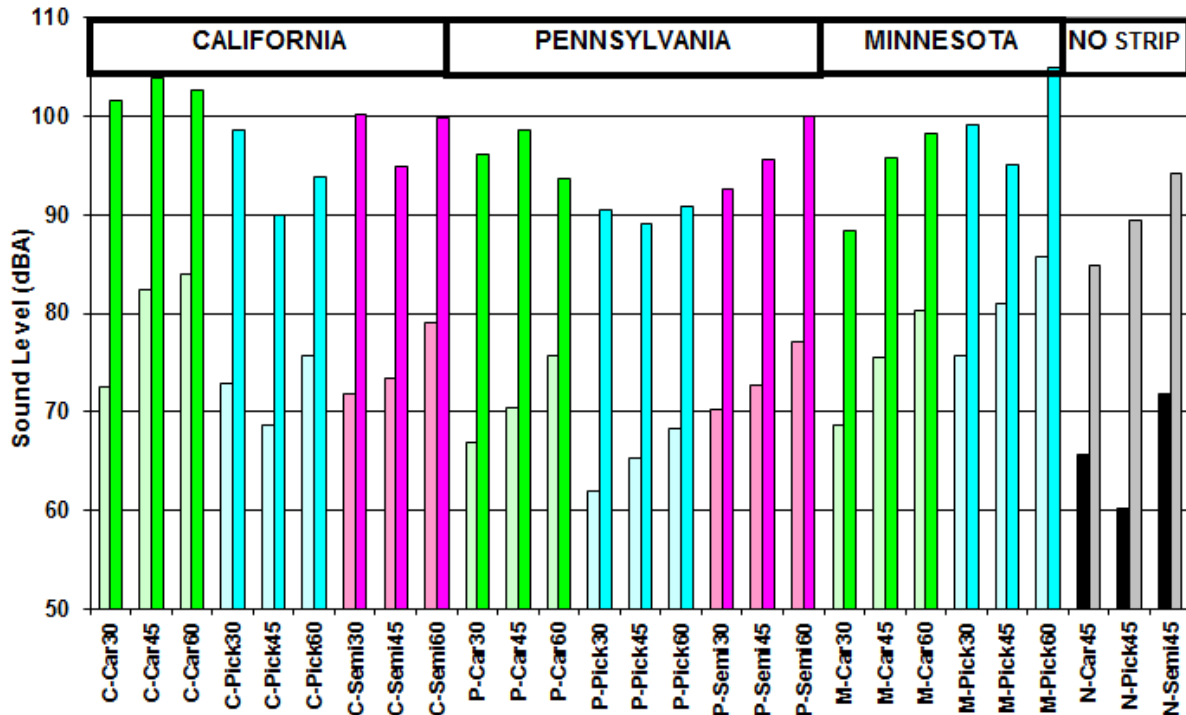


Figure 5.16 Comparison of Exterior dBA with Interior dBC Levels

In this figure the exterior levels are identical to those in Figure 5.15, while the dBC levels are considerably higher as expected. It can be seen, however, that the dBC data provide little correlation with the exterior sound levels, suggesting that vibration data may not be a useful variable in evaluating interior response and exterior sound level.

5.6. Exterior Sound Level Decay with Distance

As noted in the survey of literature, previous studies of rumble strip noise have attempted to determine the distance at which rumble strip noise could be heard by monitoring or observation. As noted in Chapter 2, this is not a very meaningful approach for determining the distance that rumble strips may be heard, since local conditions and especially the ambient sound level can have a major influence on audibility or detectability.

Before the detectability distances of rumble strip noise is addressed in Section 6.7, it is necessary to estimate the decay of rumble strip sound with distance from the roadway. For this, source levels for each vehicle type, speed, and rumble strip design were based upon the maximum measured pass-by levels at 50 ft. These sources were then used in an outdoor propagation model based in the international standard ISO 9613-1 and ISO 9613-2, which take into account distance and atmospheric absorption as well as less significant factors and shielding by barriers. For this analysis, no barrier or terrain shielding, no attenuation by trees or vegetation, or ground effect has been assumed.

Results of these model projections are presented in Figure 5.17 through Figure 5.20.

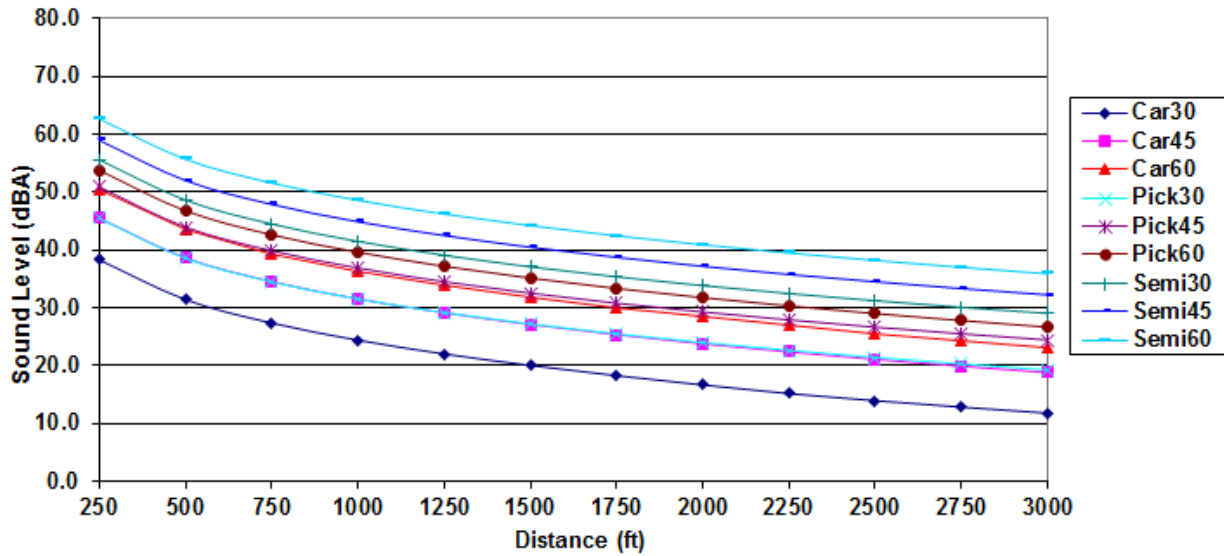


Figure 5.17 Decay of Sound with Distance – No Rumble Strip

These curves are based upon the standard TNM curves for vehicle pass-by noise. As can be seen, there is fairly wide spread between the curves.

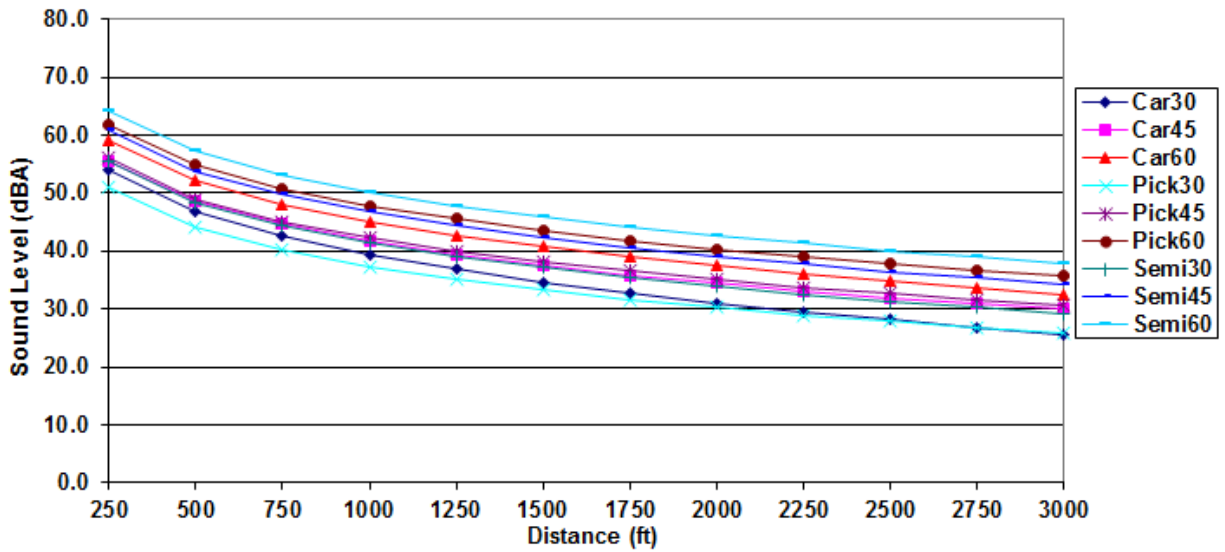


Figure 5.18 Decay of Sound with Distance – California Strip

Noise levels associated with the California strip do not vary greatly with speed and vehicle type which have a tighter group of decay curves.

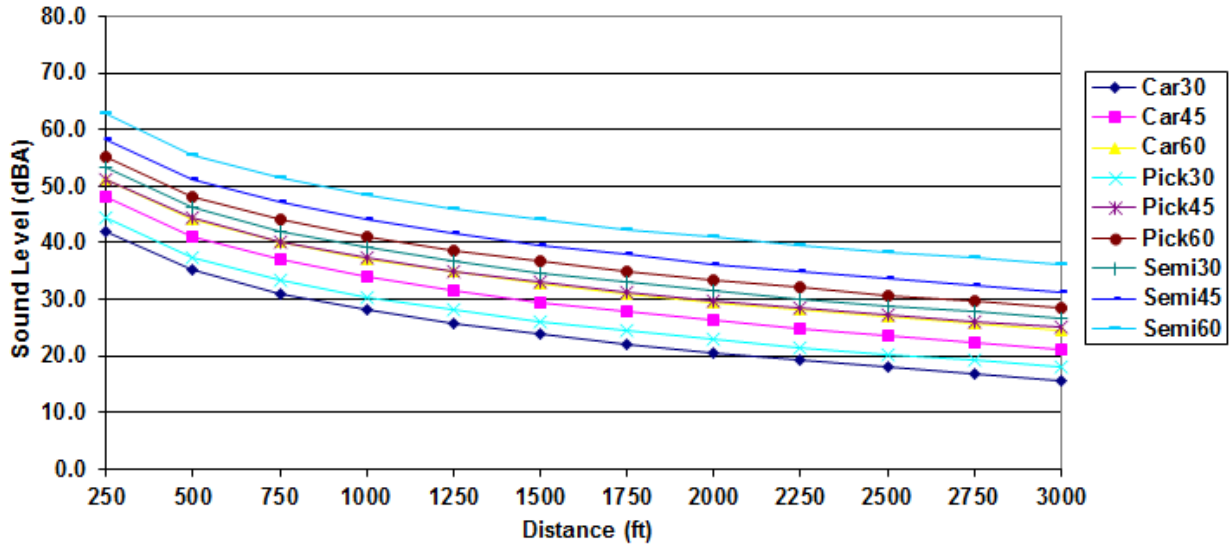


Figure 5.19 Decay of Sound with Distance – Pennsylvania Strip

Noise from the Pennsylvania strip decays generally at the same rate but is much lower than the California levels at a distance of 3000 ft.

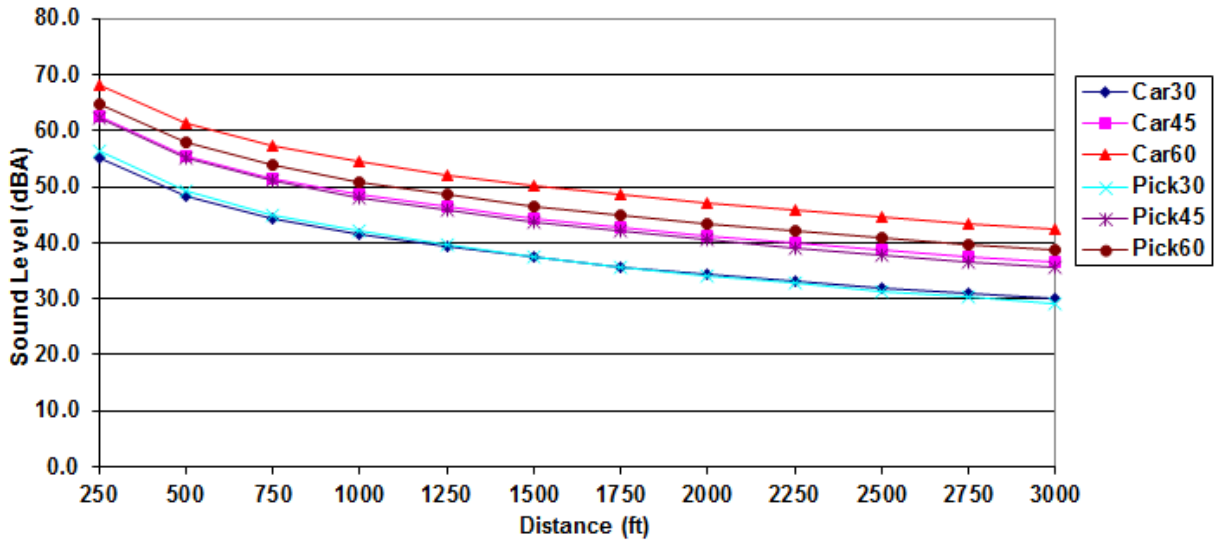


Figure 5.20 Decay of Sound with Distance – Minnesota Strip

Semi-trailer truck sound level decay is absent from the Minnesota curves, but these can be seen to be somewhat similar to curves with the California strip.

5.7. Detectability of Rumble Strip Noise

The approach used here to estimate the detectability of rumble strip sound is based upon a report for the US Army Tank Automotive Command prepared by Fidell and Bishop in 1974 (13). Detectability depends upon the difference between the ambient level spectrum and the noise or intruding spectrum. For very low noise levels, the threshold of hearing can also play a role. “Detectability” level is normally lower than “audibility” level since it is associated with actively listening for a sound compared with passively hearing a sound. For example, in a restaurant, one can hear people at the next table but not pay much attention to what is being said. This can be called “passive” hearing. On the other hand, when one tries to understand carefully what is being said at the next table, this can be called “active” listening.

5.7.1. Ambient of Background Level

In order to estimate detectability, a background or ambient level must be assumed. Figure 5.21 shows several monitored ambient levels from different regions.

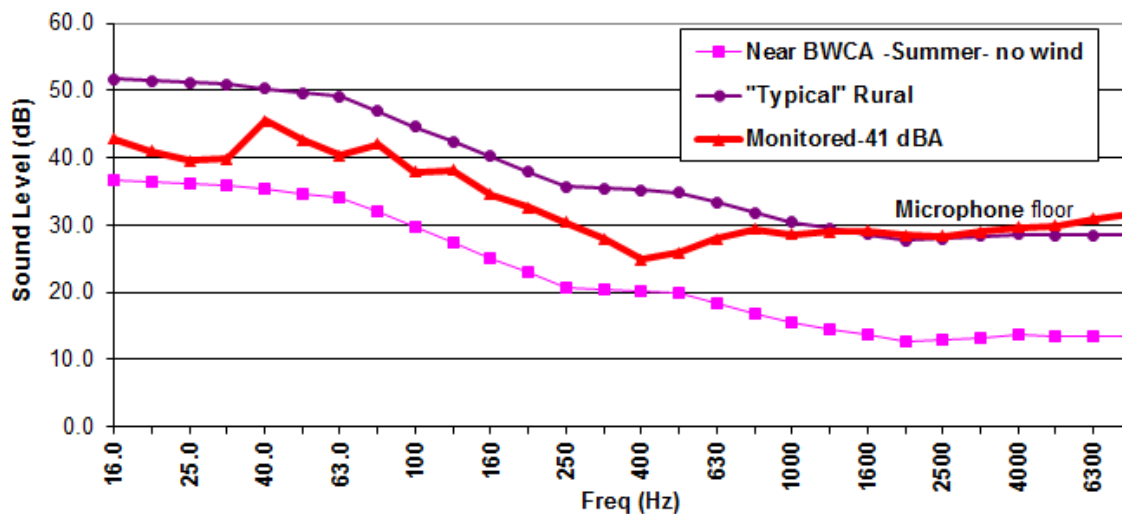


Figure 5.21 Some Typical Quiet Ambient Background Spectra

The top curve represents a typical rural area with a light housing and roadway density. The middle curve is an average of background levels measured during the rumble strip test period. The higher frequencies are primarily associated with vehicle traffic on US 75 which was about one-half mile away. The bottom curve was measured near the Boundary Area Canoe Area Wilderness in northern Minnesota, which has limited motorized traffic and aircraft over-flights. For the analysis here, the observed ambient during testing has been assumed.

5.7.2. Determining the Detectability of an “Intruding” Sound

The concept of determining detectability of an intruding noise is demonstrated in Figure 5.22. In this figure, a typical rural ambient level is shown (top curve) along with the predicted spectrum of a passenger car traveling at 60 mph on a Minnesota rumble strip. Also shown on the curve is the standard threshold of hearing curve, which in this case is well below ambient and plays no role.

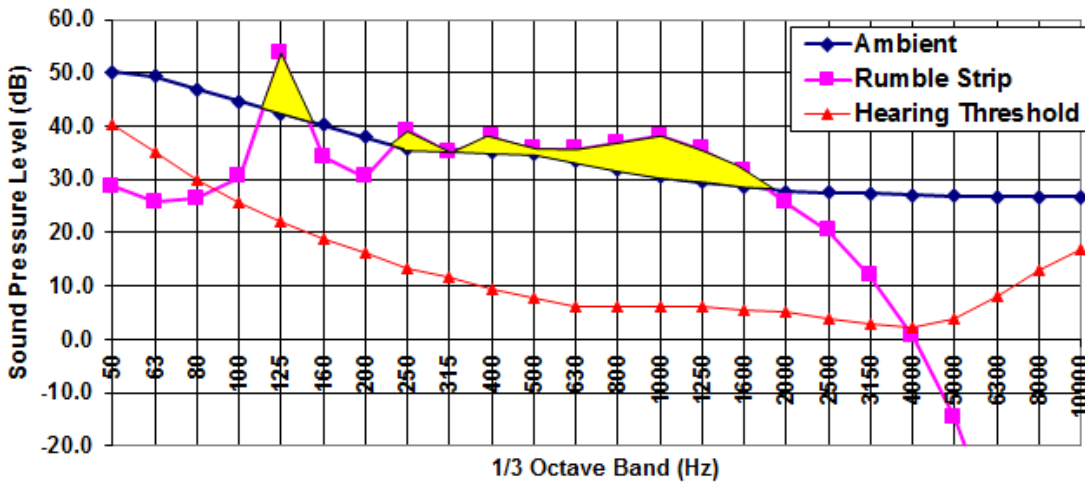


Figure 5.22 Example of Determining Detectability

This chart compares the spectrum from a car at 60 mph on a Minnesota strip at a distance of 3000 feet with the monitored ambient. The intruding sound is seen to exceed the ambient curve at a number of frequencies. A signal or intruding sound is deemed detectable when the signal exceeds the ambient level at any one frequency. Both ambient and intruding noise would have to be extremely low for the hearing threshold to play a role.

5.7.3. Rumble Strip Detectability-Theoretical

The detectability of sound from the California, Pennsylvania and Minnesota rumble strips is estimated here. In the calculation, a detectability factor of 7 dBA is considered just detectable. This is the baseline level shown in Figure 5.23 which shows the theoretical detectability of a passenger car. As can be seen in the figure, with a quiet ambient level, some strips can theoretically be detectable at distances greater than 3000 ft. Thus, values in the literature ranging from several hundred feet to 1500 feet may have been limited by higher ambient levels or other factors, or the rumble strips may have been quieter or have different frequency content that would more quickly decay atmospheric absorption. The 3000 foot distance for detectability is not unexpected, since tire noise from traffic on US 75 was detectable from at least one-half mile (or 2640 feet) away.

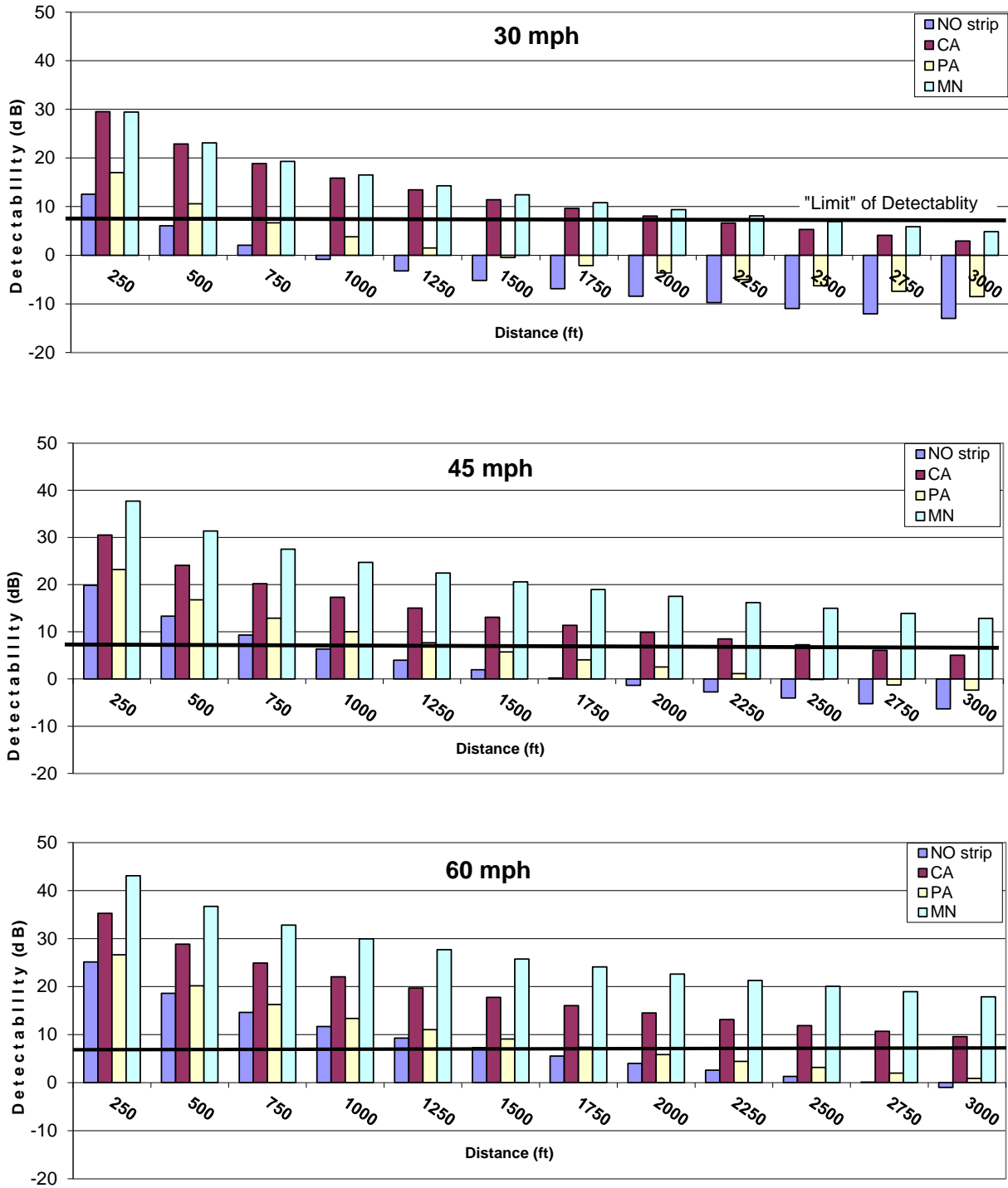


Figure 5.23 Theoretical Detectability of a Passenger Car

At 30 mph, the Pennsylvania strip is only detectable at 250 feet, while the California and Minnesota are detectable up to 2250 ft. At 45 mph, the Pennsylvania strip is detectable at 750 feet, the California strip at 2500 feet and the Minnesota strip greater than 3000 ft. At 60 mph, the Pennsylvania strip is detectable at 1000 feet, the California strip at 3000 feet, and the Minnesota strip well beyond 3000 ft.

Chapter 6. Study Conclusions

Overall A-weighted (dBA) levels showed proportional increases with traffic speed and also increased with vehicle weight. Exterior levels with the Pennsylvania design were below both the California and Minnesota designs. Exterior sound levels with the Minnesota design were consistently higher than the California design. Interior sound levels for the California design for the passenger car were higher than the Minnesota design. Interior levels in the tractor cab increased somewhat with speed but were difficult to isolate from levels with any rumble strip. In general, the Pennsylvania design had lower exterior and interior sound levels. When comparing sound level with and without a rumble strip, the same patterns described above were observed.

Spacing of peaks and valleys in the rumble strip design was clearly observable from strong tonal frequencies. For example, at 60 mph, the Minnesota design had a strong tonal peak at 125 Hz, while the California design had a strong peak at 100 Hz but also its double signature peak at 200 Hz. The tonal peaks increased in both frequency and level with speed increasing from 30 mph to 60 mph.

On the sinusoidal strips (California and Pennsylvania) the full impact was not realized until the tire was fully on the rumble strip. On the Minnesota strip feedback to the driver occurred immediately upon contact with the rumble strip.

While comparisons of overall dBA levels between interior and exterior are somewhat complex, the data tend to show that, while the interior California and Minnesota levels are similar, the exterior California levels are generally lower as was frequency compared with the Minnesota levels, suggesting an improved exterior-to-interior sound level ratio for the California design. The Pennsylvania design does not appear to show much change between interior and exterior levels, compared with the California and Minnesota designs.

Estimates of sound level with distance from the roadway were made using a typical outdoor sound propagation model. These were then compared with the background sound level spectrum that was measured during the California and Pennsylvania rumble strip tests. Using the concept of sound detectability developed originally for the Army Tank Automotive Command, the detectability of the rumble strips was calculated. “Detectability” level is normally lower than “audibility” level since it is associated with actively listening for a sound compared with passively hearing a sound. Results of this analysis showed that while detectability distance for the Pennsylvania design with a car traveling 60 mph was only 1000 feet, the detectability distance for the California design was 3000 feet and for the Minnesota design it was well over 3000 ft. These distances are well above those reviewed in the literature, but not unexpected, since typical traffic, primarily tire noise, was clearly audible at the California and Pennsylvania test sites from US 75, which was about one-half mile (or 2640 feet) from the test location. With a quieter nighttime ambient, the detectability distance would likely be farther.

In summary, it is the authors' opinion that the California strip provided adequate driver feedback while generating less exterior noise than the Minnesota strip. The Pennsylvania strip did not provide much driver feedback although it did generate less exterior noise than either the California or Minnesota strips. Based on the study results, potential future studies could include wider strips to address the heavy commercial tire bridging that occurred with the 8-inch strips. Additional studies could also evaluate different width centerline strips and other vehicle types.

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GLOSSARY

AMBIENT NOISE: The total of all noise in the environment, other than the noise from the source of interest. This term is used interchangeably with background noise.

dB: A unit of sound pressure level, abbreviated as dB. Decibel means 1/10 of Bel (named after Alexander Graham Bell). The decibel uses a logarithmic scale to cover the very large range of sound pressures that can be heard by the human ear. Under the decibel unit of measure, a 10 dB increase will be perceived by most people to be a doubling in loudness, i.e., 80 dB seems twice as loud as 70 dB

dBA: The A-weighted Decibel (dBA) is the most common unit used for measuring environmental sound levels. It adjusts, or weights, the frequency components of sound to conform to the normal response of the human ear at conversational levels. dBA is an international metric that is used for assessing environmental noise exposure of all noise sources.

dBc: The C-weighted Decibel (dBc) is the method of measuring sound which takes into account the low frequency components of noise sources, such as mechanical equipment, aircraft operations, and vibration and reflects their contribution to the environment.

FREQUENCY: The number of times per second that a sound or vibration repeats itself. This is now expressed in hertz (Hz) rather than in cycles per second (cps).

HERTZ (Hz): The Hertz is a unit of measurement of frequency which is numerically equal to cycles per second. High frequencies can be thought of as having a high pitch; like a whistle; low frequency sounds are more like a rumble of a truck or airplane.

Leq: The constant equivalent sound level that, in given time period (e.g. 1 second or 1 hour) represents the same sound energy of a variable sound in the same time period.

LAeq: The equivalent sound level with an A-weighting

LCeq: The equivalent sound level with an C-weighting

OCTAVE: The interval between two sounds having a frequency ratio of two. There are 8 octaves on the keyboard of a standard piano.

OCTAVE BAND: The segment or “band” of the frequency spectrum separated by an octave.

OCTAVE BAND LEVEL: The integrated sound pressure level of all frequencies within a specified octave band.

ONE THIRD OCTAVE BAND: The segment or “band” of the frequency spectrum separated by one-third of an octave for a more refined evaluation of sound level characteristics

Appendix A

Table of Comparative Sound Levels

APPENDIX A

TABLE OF COMPARATIVE SOUND LEVELS

Sound Source or Location	Level (dBA)
Rocket launching pad	180
Artillery at shooter ear	170
Rifle at shooter ear	160
Loud trumpet at 5 inches	150
Jet takeoff 200 ft	140
Jet aircraft workers on tarmac	130
20 ft from rock band speakers	120
Discoteque, diesel generator room	110
Subway, chain saw, stereo headphone	100
Noise appliances, lawn mower at user ear	90
Typical home stereo level, inside factory	80
Freeway at 200 ft	70
Speech at 3 ft, air conditioner at 20 ft	60
Typical urban ambient	50
Typical rural ambient (35-40), quiet office	40
Quiet rural ambient, quiet library, soft whisper	30
BWCA with no wind, concert hall	20
BWCA in winter	10
Threshold of hearing	0

Appendix B
Literature Excerpts and Comments

APPENDIX B

LITERATURE EXCERPTS AND COMMENTS

Measurements of non-freeway rumble strips in Michigan were presented in a study prepared by Wayne State University in 2012 (1). This study involved measurements using a Tenma Type 2 sound level meter with no spectral capability, taken 50 ft from the centerline for comparing different rumble strip designs and relating these to crash data. While estimates of sound level decay could be made using these measurements, predicted sound level decay and comparison with ambient sound level characteristics are best performed using spectral data with frequency information.

A detailed study prepared for CALTRANS by Illingworth & Rodkin in 2013 (2) described testing that was done to develop a strip design that would provide effective driver awareness. While extensive one-third octave band data were collected at 25 ft, the data were used exclusively to evaluate variations from different vehicles and explanations as to frequency changes due to vehicle size, panel types, etc. No discussion of exterior annoyance was included in this study.

A rumble strip perpendicular to traffic flow in New York state was studied in detail by Harris Miller Miller & Hanson Inc in 2002 (3). This study is the most detailed study that was found related to rumble strip noise and its abatement in a specific location. The rumble strips evaluated, however, were perpendicular to traffic flow, intended to slow down traffic approach. The objective of the study is described below:

“The New York State Department of Transportation (NYSDOT) installed rumble strips on the southbound side of I-87 in Guilderland, NY with the intention of reducing vehicular speeds in a heavy weave area, and thereby improving safety. Since 1994, the number of accidents along this stretch of highway has steadily increased primarily due to the formation of queues on an exit ramp that carries traffic from I-87 southbound to a local mall. The traffic queues form as a result of a traffic signal located at the end of the ramp within the mall’s parking lot – the severity of the queues is more pronounced during the holiday shopping season when traffic on the ramp backs up onto the southbound travel lanes. Six rumble strips – spaced 120 feet (37 meters) apart – were installed on the southbound side of I-87, from approximately 480 feet (146 meters) north of the Washington Avenue overpass to 120 feet (37 meters) south of the overpass.”

While one-third octave data were collected for vehicles passing the site, these were incorporated into the FHWA (TNM) to evaluate barrier effectiveness in terms of A-weighted decibels. This study did not involve any estimates of annoyance or distance from the roadway where the rumble strips could be heard.

A general study on best practices for the implementation of shoulder and centerline rumble strips was prepared by the Transport Association Of Canada in 2001 (4). A summary statement on potential impacts on adjacent areas states:

“Studies show that rumble strips terminated 200 m prior to residential or urban areas produce tolerable noise impacts on residences. At an offset of 500 m, the noise from rumble strips is negligible.”

These distances (converted to feet 666 ft and 1665 ft) were referenced in NCHRP 641 (5) However, after tracking down this paper from the Transportation Association of Canada (TAC),

these distances were not developed in this study but in a supplemental study requested by the TAC: “Report on Milled Rumble Strip Performance Testing”(6).

A Masters Thesis by Kohit Makarla at Kansas State University in 2009 (7) measured external noise produced by vehicles crossing over centerline rumble strips on undivided highways in Kansas. This Master’s Thesis predated the one described below and used the same type of sound level meter. Levels were measured at 50, 100 and 150 ft from the centerline and a regression equation developed up to this distance. Without spectral information, extrapolation to larger distances can be performed, but results are fairly general and can be related only generally to the audibility of sound.

A Doctor of Philosophy thesis by Daniel E. Karkle at Kansas State University in 2011 (8) studied the effects of centerline rumble strips on safety, exterior noise, and operational use of the travel lane. An associated published paper Centerline Rumble Strips: Study of External Noise concentrated on the external noise aspect of the rumble strip (9). Two references cited on page 64 of the thesis addressed noise level distance from the roadway:

Chen (1994) compared the exterior noise levels between a van driven over milled rumble strips to a truck driven over an asphalt surface without rumble strips, in Virginia. An important result found in this study was that at approximately **61 m** the effect of the rumble strips noise on surrounding environments can be ignored.

Sutton and Wray (1996) studied the increase of external noise associated with TRS in Texas. The results showed that at the edge of the pavement, the maximum difference in comparison to the base level noise was 12 dB. At 7.6 m and 15.2 m, the difference was 8 and 7dB, respectively. An important conclusion drawn from this study is that in order for the difference to be zero, the distance would be approximately **61m**.

As reported in the published paper (10), three Extech HD600 (Type 2) sound level meters were located at distances of 50, 100 and 150 ft from the centerline. The conclusion of the study was:

“Therefore, before installing CLRS, the distance from houses or businesses should be considered. A distance of **60 m** (200 ft) was recommended as the limit of the potential exterior noise problem area.”

External noise from milled centerline rumble strips was studied by the Swedish National Road and Transport Research Institute in 1995 (11). A summary of the study in English is presented below. Some text is in **bold type** for emphasis.

Milled centerline rumble strips are used as a safety measure by alerting the driver via sound and vibration inside the vehicle. **A secondary effect is that exterior noise is generated and that is a potential cause of annoyance and sleep disturbance for inhabitants living close to the road.** This report describes a series of measurements and calculations with the aim of determining how many rumble strip hits that can be expected and what sound levels can be generated.

The number of hits was determined using a total of ten days of measurements from four different locations and the results show that 0.2–1.0 per cent of all vehicle passages hit the rumble strip. The percentage of vehicles that hit the strip increases during night. The noise levels that are generated during a hit were determined by controlled pass-by measurements at different speeds with three different vehicles, a car with normal tires, a car with low profile tires and a truck (towing engine of semi-trailer). These measurements were then used to predict the outdoor and indoor noise levels. **The calculations show that the Swedish guideline values may be exceeded at short distances, but it may be questioned if the road traffic noise guidelines are valid for rumble strip hits, since the noise is both impulsive and tonal in character.**

This summary is included here since the last sentence raises an entirely different issue, that is, the impulsive character of the sound when vehicles encounter rumble strips. While our study plans to account for the tonal nature (using one-third octave band data) of the sound, the impulsive nature will not be a factor in our study since vehicles will be lined up on the rumble strip well before reaching the measurement location. However, this is another factor that could affect the detectability or annoyance from rumble strips in addition to a higher sound level with different tonal characteristics.

A recent study on longitudinal edge line rumble strip noise was prepared by the Delaware DOT by Whitman, Requart and Associates, LLP in 2012 (11) and is most relevant to the study described in this report. Therefore, some extensive excerpts are reproduced here for comparing the pros and cons of each approach. Some text is in **bold type** for emphasis.

In 2006, DelDOT performed a noise study to evaluate the noise impacts of edge line rumble strips along a rumble strip test area on I-495 at the 12th Street interchange. This location was selected because it was surrounded by industrial land uses, was easily accessible compared to other locations along I-495, and was not heavily wooded or wet. The results of the previous study indicate the following:

- Noise level increases at the test area due to a vehicle striking the rumble strips were clearly perceptible at 100 feet from the source, **barely perceptible at 250 feet** from the source, and **not readily perceptible at 400 feet** from the source. The study concluded that it was **not likely that the noise would be perceptible at a location 100 feet farther (i.e., 500 feet)** from the rumble strips.
- The study concluded that rumble strips **should not be considered along I-495 where residences are located within 500 feet of the proposed rumble strips**. For sections of I-495 with noise-sensitive adjacent land uses other than residences, proximity to rumble strips should be considered on a case by case basis.
- Highway traffic noise levels depend on several variables including traffic volumes, speeds, pavement type, percentage trucks, tires, horizontal and vertical roadway alignments, roadside terrain, vegetation, and other topography. **For these reasons and due to the small sample size, the results of this study should not be applied to other roadways of varying characteristics.**

Measurement Locations: Locations 1, 2, and 3 were selected for the noise study measurements and Location 4 was selected as an alternate location in the event that one of the other three locations were not available on the day of the study for any variety of reasons (e.g., **problems coordinating with the property owners to obtain permission to access their property, significant background noise present at the time of the study, etc.**). The parcel numbers and land owner information for each location was obtained from the Sussex County Online Mapping website, as shown below. **Prior to conducting the noise study measurements, DelDOT contacted the property owners to obtain permission to access their property and set up the noise meters.**

Noise Measurements: Noise measurements were conducted to quantify the noise generated by vehicles striking the edge line rumble strips at Locations 1, 2 and 3, as discussed above. Since residents are most aware of the noise produced by rumble strips during periods when background traffic noise levels are lowest, testing was performed during off-peak hours (i.e., between 9 AM and 3 PM). Noise measurements were conducted at Location 1 between 10:20 AM and 11:10 AM, Location 2 between 11:40 AM and 12:45 PM, and Location 3 between 1:15 PM and 2:15 PM. Two test vehicles were used for the noise measurements – a Honda Odyssey minivan and a large 3-axle DelDOT dump truck. Test vehicles were driven at the posted speed limit of 50 miles per hour. The study was conducted using ANSI S 1.4-1983 **Type II** noise level meters, which record noise levels in a variety of formats, including Leq dBA.

Sound levels: Based on the findings from the previous studies discussed above, **noise meters were positioned at 50 feet, 250 feet, 500 feet, and 1,000 feet distances from the outside of the rumble strips** at each of the

three study locations to assess the exterior noise impacts of the rumble strips on the surrounding areas. The positions of the four noise meters could have been relocated to different distances than those discussed above based on preliminary findings in the field. For example, if the noise meters were unable to detect rumble strip noise at distances of 1,000 feet, the farthest meter could have been moved to 750 feet, or if rumble strip noise is readily noticeable at 1,000 feet, the farthest meter could have been moved to 1,500 feet. However, relocating the noise meters was not necessary based on the preliminary findings while performing the study. **The noise measurements were conducted on a dry day with low winds and the sound meters were placed orthogonally from the edge line rumble strips.**

The noise [sound – sic] meters placed at the distances discussed above were used to record the exterior noise levels during at least **five base runs and five rumble strip runs** at each location. The base runs involved the test vehicles traveling over smooth asphalt pavement through approximately 400-foot segments along SR 24 at the locations discussed above. The rumble strip runs involved the test vehicles traveling over the edge line rumble strips through the 400-foot test segments along SR 24 at the same locations. The 400-foot test segments along SR 24 were marked with cones. Runs with increased background noise, such as when a tractor trailer was present within the marked test segments during the run, were discarded from the data set. **For future studies, a flagger or rolling road block could be used to eliminate any other vehicle from being present** within the marked test segments during each run to further isolate the noise generated by the rumble strip; however, based on the study findings, relatively consistent data was obtained; therefore, this was not necessary.

Study Results: Noise levels were measured in one second intervals at all three study locations. The five one-second intervals during the time the test vehicles were driven across the rumble strips were averaged for each rumble strip run. Similarly, the five one-second intervals were averaged for each base run as the test vehicle traveled through the marked test segments. Table 3 shows the average noise levels for the base runs and the rumble strip runs for each test vehicle and at **50, 250, and 500 feet from the outside of the rumble strip. The noise levels recorded by the meter located 1,000 feet from the outside of the rumble strip were indistinguishable between the background noise (the person monitoring this meter confirmed that rumble strip runs could not be audibly identified at this distance).** During the study, the noise meter located 500 feet from the outside of the rumble strip lost power at Locations 1 and 2; therefore, the number of runs used in the average noise measurement for this meter was significantly less than the other meters. However, the available data from this meter is consistent with the other readings. The average noise level during the rumble strip run was compared to the average noise level during the base run for each vehicle and the difference between these two measurements were used to determine whether the noise generated from the test vehicle striking the rumble strips was perceptible at various distances from the rumble strip under test conditions. Figures 3 and 4 are graphical representations of the average noise level increase during the rumble strip runs as compared to the base runs for each location and at each offset from the outside of the rumble strip for the minivan and dump truck, respectively.

Therefore, the noise generated by vehicles driving across rumble strips **will not typically be perceptible from distances 275 feet to 350 feet or greater from adjacent residences.** Noise impacts should be given special consideration when installing rumble strips adjacent to residences within these distances from the outside of the proposed rumble strip. Additionally, engineering judgment should be used when installing rumble strips in areas that differ from the conditions of this study.

Appendix C

Sound Measurement Test Protocol

APPENDIX C

SOUND MEASUREMENT TEST PROTOCOL

The final test protocol is outlined below.

Test locations

- Two low traffic roadways were used in the tests: County 61 West of Crookston, MN was used for the CA and PA tests; MN tests were performed on County 11 east of Crookston.
- Both roadways were asphalt paved.
- Both test areas were flat and surrounded by freshly planted farm fields.

Interior sound level meter

- The sound level meter mounted on a tripod propped against the back seat and next to the driver (see Figure 4.5, Figure 4.7 and Figure 4.9).
- This permitted the microphone to be in the same position for each test.

Exterior sound level meters

- One meter was placed 50 ft from the rumble strip or edge of pavement; a second meter was placed at 100 ft from the edge of pavement.
- Meters were mounted on tripods 5 ft above ground with wind screens.

Meteorology

- A handheld Kestrel wind meter was used to check wind speed; detailed hourly weather from Crookston Airport was obtained.
- Temperature, wind speed and direction, and relative humidity were compiled.
- Wind speeds were generally 6 to 8 mph. The pavement was dry, and precipitation began immediately after the MN tests which were limited to one pass-by for each speed.

Speed Measurement

- For the CA and PA tests, a portable digital speed reporting sign was provided by the County.
- For the MN tests, drivers had performed eighteen previous tests and were familiar with the speedometer settings.

Video

- A video camera was located adjacent to the 50 ft meter (see Figure 4.2)

Photos

- Photos of each vehicle exterior and interior were taken (Figure 4.3 through Figure 4.8)

Test Speeds and Number

- The following test speeds were used: 30 mph, 45 mph, and 60 mph
- For each speed, three tests were performed.

Sound level meters

- All meters were calibrated and synchronized
- Meters used were Larson-Davis Model 831 Type 1 logging sound level meters with audio recording capability

Exterior meter measurements

- Measurements were started approximately 5 to 7 seconds before pass-by and continued for approximately 5 seconds after the pass-by
- One-third octave band readings were taken with simultaneous digital audio recording
- 1-second readings were taken to permit evaluation of pass-by histories and establish the maximum pass-by level.
- Data were stored and documented after each test

Interior meter measurements

- Measurements began at the start of acceleration and continued for approximately 5 seconds after.
- One-third octave band readings were taken with simultaneous digital audio recording
- 1-second readings were taken to permit evaluation of time histories
- Readings were time-matched with exterior measurements to ensure synchronization of the exterior and interior tests.

Traffic control

- Each end of the roadway for the CA and PA tests were blocked to stop traffic during each set of tests by each vehicle.
- US 2 at the east end of this roadway was also blocked temporarily to provide ample acceleration distance for the semi-trailer truck

Appendix D
Audio Recordings
(Interior and Exterior at 50 FT)

APPENDIX D

AUDIO RECORDINGS (INTERIOR AND EXTERIOR AT 50 FT)

These represent the most representative of three recordings for the CA and PA tests. Only one recording is available from the Minnesota tests. C = CA, P = PA, M – MN.

	Meter 1 - Exterior 50 ft	Meter 3 - Interior
1	M1-C-C3-Car30.wav	M3-C-C2-Car30.wav
2	M1-C-C6-Car45.wav	M3-C-C5-Car45.wav
3	M1--C-C11-Car60.wav	M3-C-C10-Car60.wav
4	M1--P-C49-Car45-N.wav	M3-A-C48-Car45N.wav
5	M1--C-C14-Pick30.wav	M3-C-C13-Pick30.wav
6	M1--C-C15-Pick45.wav	M3-C-C15-Pick45.wav
7	M1--C-C18-Pick60.wav	M3-C-C17-Pick60.wav
8	M1--P-C59-Pick45-N.wav	M3-A-C58-Pick45N.wav
9	M1--C-C22-Semi30.wav	M3-C-C20-Semi30.wav
10	M1--C-C24-Semi45.wav	M3-C-C23-Semi45.wav
11	M1--C-C27-Semi60.wav	M3-C-C27-Semi60.wav
12	M1--C-C30-Semi45-N.wav	M3-A-C29-Semi45N.wav
13	M1--P-C41-Car30.wav	M3-P-C39-Car30.wav
14	M1--P-C44-Car45.wav	M3-P-C43-Car45.wav
15	M1--P-C47-Car60.wav	M3-P-C46-Car60.wav
16	M1--P-C50-Pick30.wav	M3-P-C50-Pick30.wav
17	M1--P-C53-Pick45.wav	M3-P-C52-Pick45.wav
18	M1--P-C56-Pick60.wav	M3-P-C55-Pick60.wav
19	M1--P-C32-Semi60.wav	M3-P-C33-Semi30.wav
20	M1--P-C34-Semi30.wav	M3-P-C38-Semi45.wav
21	M1--P-C39-Semi45.wav	M3-P-C31-Semi60.wav
22	M1--M-C60-Car30.wav	M3-M-C59-Car30.wav
23	M1--M-C61-Car45.wav	M3-M-C60-Car45.wav
24	M1--M-C62-Car60.wav	M3-M-C61-Car60.wav
25	M1--M-C63-Pick30.wav	M3-M-C62-Pick30.wav
26	M1--M-C64-Pick45.wav	M3-M-C63-Pick45.wav
27	M1--M-C65-Pick60.wav	M3-M-C64-Pick60.wav