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16. Abstract

The effects of traffic noise are a serious concern in the United States and the rest of the world. One significant component of traffic noise is tire/pavement interaction. Protecting individual receivers by reducing pavement noise at the source rather than by using traffic noise barriers may result in substantial cost reductions and improved community acceptance of highway projects. This research consisted of field-testing 200 different pavements of several different types found in Texas using a trailer test vehicle developed to conform to ISO Standard 11819 "Method for Measuring the Influence of Road Surfaces of Traffic Noise – Part 2: The Close Proximity Method." The test results indicated a range of tire pavement noise measured approximately 7 dB with a jointed concrete pavement as the highest and a thin flexible seal coat as the quietest. A weak correlation was found between the age or serviceability rating of dense asphaltic concrete pavements and the measured noise levels that tend to weakly support the hypothesis of increasing noise over time. Testing indicated that the outer microphone location of 400 mm was influenced by tow vehicle and testing at the inner microphone location was independent of tow vehicle for the Texas test trailer constructed.

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FEASIBILITY OF USING QUIET PAVEMENT TECHNOLOGY TO ATTENUATE TRAFFIC NOISE IN TEXAS

by

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Woon Ho Yeo

Research Report Number 7-2957-3

Research Project 7-2957

Use of Pavement Surfaces to Attenuate Traffic Noise

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

July 2001

IMPLEMENTATION STATEMENT

No implementation is imminent at this time. It is recommended that further field testing be conducted with the improved trailer on specially designed pavements to determine if the pavements can be constructed for significantly less tire/pavement noise and remain durable. There remains the possibility, which can be confirmed through further research, that quiet pavements can be effective in reducing tire/pavement noise.

DISCLAIMERS

Dr. Michael T. McNerney, P.E. (Texas No. C70176)
Research Supervisor

ACKNOWLEDGMENTS

The authors thank TxDOT Project Director Gary Graham (DES) for his direction and facilitation of the research. Also appreciated is the assistance provided by the other members of the project monitoring committee, which included C. Herrera (CST), M. Shearer (ENV), and P. Henry (HOU).

Research performed in cooperation with the Texas Department of Transportation.

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CHAPTER 1 INTRODUCTION

PROJECT BACKGROUND

Traffic noise is often perceived as the most important environmental concern in many urban communities throughout the world. The typical method of mitigating traffic road noise is to erect physical barriers to block the direct path from the vehicles that generate the traffic road noise to the receivers living close to the roadway. The analysis of traffic noise is required in the design of roadways that use federal funds. If the projected roadside noise exceeds national noise abatement criteria, mitigation must be provided; assuming it can be provided in both a feasible and reasonable manner. In Texas, feasible and reasonable criteria equates to a barrier that can feasibly be erected that will provide a 5 dB noise reduction, and can reasonably be constructed for $25,000 per benefited receiver. Additional research on that subject is provided in Research Report 3565-1.

The STAMINA model is currently the analysis method required for federally funded projects, but it will soon be replaced with the traffic noise model (TNM). The Federal Highway Administration (FHWA) has developed the TNM with the ability to consider different pavement types in a noise analysis. In the TNM model and in the SoundPLAN model that was developed in Germany, a 5 dB noise reduction at the source results in a 5 dB noise reduction at the receiver.

However, tire/pavement noise is only one source of vehicle noise. Engine and exhaust noise, as well as aerodynamic noise, also contribute to the overall noise heard at roadside. Still, in automobiles moving at higher speeds, tire/pavement noise is the dominant noise source. Other researchers have identified several pavements that provided more than 5 dB reduction in noise. Therefore, it would seem feasible that using quiet pavements could reduce the traffic noise level at receiver locations near the roadside.

Currently, because of a lack of research, FHWA guidance does not permit the use of quiet pavement surfaces to mitigate required traffic noise abatement. However, in certain European countries, legislation has been developed that requires the use of quiet pavements in certain urban environments. The purpose of this research project was to understand the tire/pavement noise problem as it relates to traffic noise, measure tire/pavement noise in Texas and determine if it were feasible to develop specially designed pavement types that could be used effectively for noise abatement.

While conducting this research, several new developments occurred. First, after several years of delay, the TNM was released by the FHWA to the public for review and analysis, but the FHWA has delayed the date for which the TNM model is required for analysis. Second, the researchers were made aware of test standards that were being developed internationally for measuring tire/pavement noise using a trailer in the close proximity method. The researchers were encouraged by a committee of the Society of Automotive Engineers to study tire/pavement noise, to build a second-generation trailer that conforms to the International Organization for Standardization (ISO) standard, and if possible, to participate in a series of field tests. The second-generation trailer was built under this project. A series of field tests were conducted in Europe to measure tire/pavement noise on several test sections with test trailers from several other countries. However, owing to a bureaucratic delay in receiving outside funding, the researchers were not able to represent the U.S. with the second-generation trailer and participate in the European series of testing.

PREVIOUS RESEARCH

Research into the noise characteristics of different pavements has been conducted in many countries. Researchers in South Africa have developed an open-graded asphalt pavement called "Whisper Course" that has a noise reduction of 9 dB over a single-seal surface and a reduction as high as 11.7 dB over a grooved surface (1). Researchers in Belgium reported that on average, an open-graded asphalt pavement reduces noise by 4 dB compared to dense-graded asphalt surfacing and 7 dB compared to transversely grooved concrete pavements (2). Kenneth Polcak field tested open-graded asphalt pavements on the Baltimore Beltway and found a 2 to 4 dB reduction in overall L_{eq} (a time-weighted average), with a 6 to 7 dB reduction at the 2,000 to 4,000 Hz range when compared to concrete pavements (3). In Japan, Meiarashi et al. tested four different aggregate size mixes of open-graded asphalt road surfaces for noise characteristics. They found a 1 to 7 dB noise reduction for passenger cars on open-graded asphalt with a 10 to

13 mm aggregate size, and an additional 1 to 3 dB (4 to 9 dB total) noise reduction for a 5 to 10 mm aggregate size mix (4). In another test using a special porous elastic road surface, Meiarashi measured noise reductions of 13 and 6 dB for automobiles and trucks, respectively, over open-graded asphalt (5). Unfortunately, porous elastic road surfacing is expensive, flammable, and quick to deteriorate.

RESEARCH CONDUCTED

This research report is the third report in the series for this research project and describes research conducted in Phase 3 of the research project with the second-generation trailer. During the entire period of this research project, the researcher conducted a comprehensive literature review and met with fellow researchers and professionals in the traffic noise field. Most of the current research in this field is being conducted in Europe, South Africa, and Japan.

Phase 1 Initial Field Tests

In Phase 1 of this project, to measure tire/pavement noise, a test was developed and implemented using a trailer with closely spaced microphones to measure tire/pavement noise. As described in Research Report 2957-2, this first-generation trailer was developed with several changes based upon 1970s' research conducted by the University of Washington. The trailer, as shown in Figures 1-1 and Figure 1-2, had two closely spaced microphones at the 135- and 180-degree positions from the direction of travel of the tire. Both flexible (asphaltic concrete) and rigid (portland cement concrete) pavement surfaces were tested in various surface types. The roadside noise was also simultaneously recorded during multiple passes of the vehicle and trailer. The pavement types tested included grooved, jointed concrete, dense and open-graded asphalt, and various surface treatments such a chip seals and Novachip a proprietary product.

Figure 1-1: Original Trailer Design

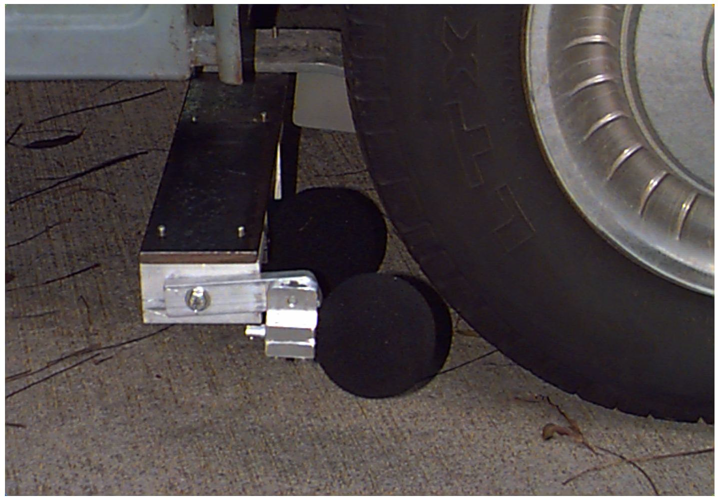


Figure 1-2: Microphone Locations on the Original Trailer

In the first series of trailer tests, fifteen pavement sections were tested. The results are shown in Table 1-1. The proprietary open-graded asphalt surfacing, Novachip, was the quietest of the 15 pavements tested, both as measured at the roadside location 7.5 meters offset from the travel lane and as measured at the 135-degree and 180-degree locations. The grooved asphalt and concrete pavements had the highest noise levels as measured on the roadside and nearly the highest as measured on the onboard microphone locations. For roadside noise, the quietest Texas pavement, which was designed to improve skid resistance and not for quietness, was approximately 6.5 dBA quieter than the grooved asphalt pavement and approximately 5 dBA quieter than the aged asphalt pavement. For onboard microphone readings, the difference between pavements ranged from 6.4 dBA for the 135-degree location between the aged Novachip and the aged asphalt on MoPac and 7.1 dBA for the 180-degree location between the aged Novachip and the grooved asphalt.

Table 1-1: Results from the First Series of Trailer Tests

Pavement	Roadside SPL (dBA)	Onboard SPL (dBA)	
	Average	135º Mic location	180º Mic location
Novachip (aged)	79.5	100.8	101.7
Microsurfacing (MoPac @ 45th)	80.1	102.3	104.0
Coarse Matrix High Binder	80.7	101.8	104.0
Asphalt (new)	81.5	102.9	105.0
Novachip (new)	81.6	104.4	106.6
JRCP (ungrooved)	81.9	101.2	104.2
CRCP (untined)	82.4	102.9	105.4
Microsurfacing (Corpus Christi)	82.5	105.0	107.6
Asphalt (aged, MoPac @ Duval)	83.1	107.2	109.7
CRCP (tined, aged)	83.8	104.9	107.8
CRCP (tined, new)	83.9	104.3	106.8
Chip Seal (Grade 4)	84.4	104.4	106.1
Asphalt (aged, Decker Lane)	84.4	104.5	107.2
JRCP (grooved)	84.8	104.7	106.3
Asphalt (grooved)	86.0	105.5	108.8

In addition to the pavement tested in Texas, a series of tests were conducted in South Africa, using the same tire and test procedure used by colleagues in Texas. The pavements tested included jointed concrete, open-and dense-graded asphalt, chip seals, and a special, open-graded asphalt nicknamed Whisper Course because of its low-noise qualities. The tests were conducted in the same manner as those conducted in Texas and the selection of the test tires was specifically made because they were commonly available in both locations.

The South African tests are reported in Table 1-2. The results show that the Whisper Course was the quietest pavement tested for both the roadside location and the onboard microphone locations. The Whisper Course was 12.2 dBA quieter than the 13 mm Seal Coat at the roadside location, but only 5.5 dBA quieter at the 135-degree location and 3.6 dBA quieter at the 180-degree location for the 13 mm Seal Coat. However, the 19 mm Seal Coat, was considerably noisier at the 180-degree location.

Table 1-2: Results from the South African Trailer Tests

Pavement	Roadside SPL (dBA)	**Onboard SPL (dBA)**	
	Average	135º Mic location	180º Mic location
Whisper Course	77.2	96.7	98
Open-Graded Asphalt	79.7	100	101
Dense-Graded Asphalt	79.8	97.7	104.1
Seal Coat (0.76 in. or 19 mm)	84.5	103.9	107.5
Jointed Concrete	89.0	102.3	104.6
Seal Coat (0.52 in. or 13 mm)	89.4	102.2	101.6

Phase 2 Laboratory Testing

In Phase 2 of this research project, laboratory tests and equipment were developed to test the variables in open-graded asphalt pavement, (aggregate type and size, thickness, and the amount percent voids in the pavement). As described in Research Report 2957-1, special equipment was developed to measure the normal incidence absorption of different mix designs of open-graded asphalt samples, both in the field and in the laboratory, using an impedance tube test. Additional tests were conducted using constructed slabs of pavement to measure coefficient of absorption using the reverberation chamber. However, the reverberation room tests were not conclusive, partly because of the difficulty in constructing the samples and limitations on the available facilities at the university. In this phase, the results of the laboratory test were used to develop some potentially quiet pavements designed to maximize absorption of tire/pavement noise at desired frequencies.

The laboratory tests using the impedance tube resulted in the most surprising findings. It was assumed from discussions and literature that aggregate size and percent voids would have the greatest potential for reducing tire/pavement noise. Tire/pavement noise has at least two main components, one being the generation component, which is related to the tread pattern of the tire and the aggregate surface of the pavement. The second component is the absorption of noise by the pavement. The findings of the absorption component were that it was not as sensitive to aggregate size as was expected. The percent of voids does affect the frequency that is absorbed the most.

However, the most surprising and unexpected finding was that the thickness of the open-graded aggregate overlay was the most important factor in defining the frequency and coefficient of absorption. As shown in Figure 1.4, if it is desired to maximize the coefficient of absorption in the 1,000 Hz frequency range, the best thickness of overlay is approximately 1.75 to 2 inches. The best reduction occurs with a double layer of 2 inches of open-graded asphalt over 3 inches of dense-graded asphalt. The high coefficient of absorption in the 0.90 to 1.0 range indicated that in those selected frequencies 90 to 100 percent of the noise in that frequency is absorbed. The recommended pavement was a open-graded asphalt mix design with a 1.75 to 2 inch overlay.

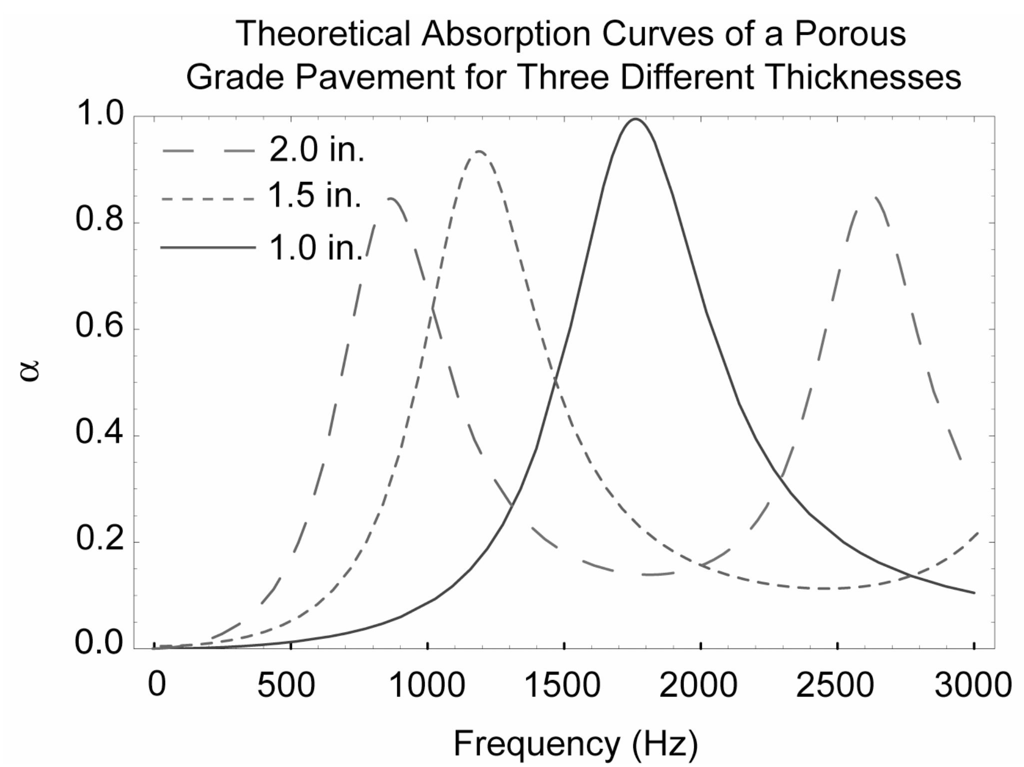


Figure 1.4. Graph showing theoretical prediction of the absorption curves of a typical porous grade pavement, for three different thicknesses.

Phase 3 Field Tests with Second-Generation Trailer

In Phase 3 of this project, a new second-generation tire/pavement test trailer was developed and constructed. This new test trailer was developed with advice from the Goodyear Tire and Rubber Company to meet the rigors of international scrutiny in a draft standard that was being developed for this testing method. After rigorous testing and fine-tuning, the test trailer provides accurate measurements of differences in tire/pavement noise and conforms to the ISO standard, except that the test tire is representative of tires used in Texas rather than one of the six test tires used in the draft standard. The test trailer as shown in Figure 1-4 has two microphones at the 45-degree and 135-degree close proximity positions. Over 200 pavement sections were tested on existing Texas highways. Test sections were all conducted with the same vehicle and microphones, and all results were corrected for speed variations to 100 kph.

Figure 1-3: Microphone Locations on Second-Generation Trailer

TEST OBJECTIVE

The purpose of this research project was to investigate techniques of using pavement surfaces to reduce tire/pavement noise from passenger vehicles. If sufficient noise reductions could be made at the source of traffic noise caused by tire/pavement interaction, then there would be a potential for mitigating noise impacts of traffic by means other than building traffic noise barriers at an approximate cost of $1 million per mile. Even if the noise reductions were not sufficient to qualify as full noise mitigation under FHWA guidelines, there would be a real possibility of making significant and noticeable noise reductions.

The actual scope and objectives of Phase 3 of this research were to:

- measure the variation in tire/pavement noise found in different types of Texas pavements,
- understand the tire/pavement interaction variables that contribute to noise,
- develop a field-test method in conformance with the ISO standard to measure tire/pavement noise of various pavements, and
- make recommendations for implementing actual quiet pavement technology.

CHAPTER 2 DEVELOPMENT OF THE SECOND-GENERATION TEXAS TEST TRAILER

The first-generation trailer used in the research project was a borrowed trailer that was modified to conduct the first series of pavement tests. Research Report 2957-2 gives a description of the trailer and the fifteen pavements that were tested. The second trailer was developed so that the Center for Transportation Research (CTR) would have a dedicated trailer built specifically to test tire/pavement noise and with encouragement from the Society of Automotive Engineers to be in conformance with an The International Organization for Standardization (ISO) standard that was under development at the time of the trailer design. With advice from the Goodyear Tire and Rubber Company, the second-generation trailer would correct deficiencies that existed in the first trailer and be capable of variable microphone locations.

ISO STANDARD

The ISO is a world organization that sets standards in many areas and functions internationally with the authority of setting standards that roughly are equivalent to ASTM standards or ANSI standards in the United States. There is an ASTM standard test tire used for braking measurements that CTR decided was not applicable to our tire/pavement noise testing. There are ANSI standards related to roadside noise measurements, but neither ASTM nor ANSI has any standard related to measuring tire/pavement noise.

ISO Technical Committee 43 has Working Group 33, which is the group of people who were drafting this standard as CTR was developing the trailer. Two of the U.S. representatives of this committee provided CTR with a copy of the 1997 draft standard to assist CTR in developing a trailer that would comply with this developing standard. It was hoped that the completed trailer would then be transported to Europe to participate in a series of different test sections with ISO standard tires in concert with other test trailers. The trailer was completed in time to participate but the funding did not arrive in time.

ISO/CD 11819-2 ACOUSTICS –Method for Measuring the Influence of Road Surfaces on Traffic Noise –Part 2: 'The Close Proximity Method"

The October 17, 1997, draft of the standard (the standard), gives guidance on test vehicles, measuring instruments, test sites, measuring procedures, meteorological conditions and normalization of data. It is a very comprehensive standard consisting of more than 50 pages and provides significant technical guidance.

The standard allows for a test vehicle that is either self-powered or a trailer vehicle. The standard also allows for enclosing the tire and microphone combination, but does not require an enclosure. The standard allows for testing up to four tires at once or testing a single tire. Although most of the other vehicles in the European tests were single-tire trailers with an enclosure, the researchers chose a two-tire vehicle without enclosure.

The advantage of an enclosed system is that background noise can be eliminated. In the nonenclosed vehicle, one must be careful to take measurements that are not affected by passing vehicles or opposing large-vehicle traffic. The technique of selective sampling to avoid other traffic noise was used in the Texas tests.

The Texas Department of Transportation (TxDOT) favors the two-tire vehicle because it has the advantage of testing in the pavement wheelpath rather than in the center of the traffic lane. The wheelpath testing was preferred because the effects of aged and vehicle-trafficked pavements can be measured.

The following are some important items of guidance in the standard for a test vehicle that were adhered to in the design of the Texas trailer.

1. Support tires should be at a distance of at least five times the measurement distance unless proper screening is provided.
2. The distance of the tow vehicle to the microphone must be ten times the distance from the microphone to the test tire.
3. Inside walls and screening material should be of absorptive material and extend down to within 50 mm of the pavement.
4. The microphone holder should be as slim as possible without providing vibration.
5. No support structures should be between the microphone and the test tire.

6. The camber angle of the test tire shall be no more than 1 degree and toe-in no more than 0.2 degrees.
7. The suspension of the trailer should be designed to have a spring rate and damping coefficient similar to the suspension of a car.

Standard Microphone Locations

As shown in Figure 2-1, there are two microphones placed at either the “inner” or “outer” distances on a line that is either 45 degrees (front) or 135 degrees (rear) to the direction of travel from the center of the tire. The inner location is at a distance d_1 of 200 mm from the plane of the undeflected sidewall of the tire and at a height h of 100 mm above the pavement surface. The outer location is at a distance d_1 of 400 mm from the plane of the undeflected sidewall of the tire and at a height h of 200 mm above the pavement surface.

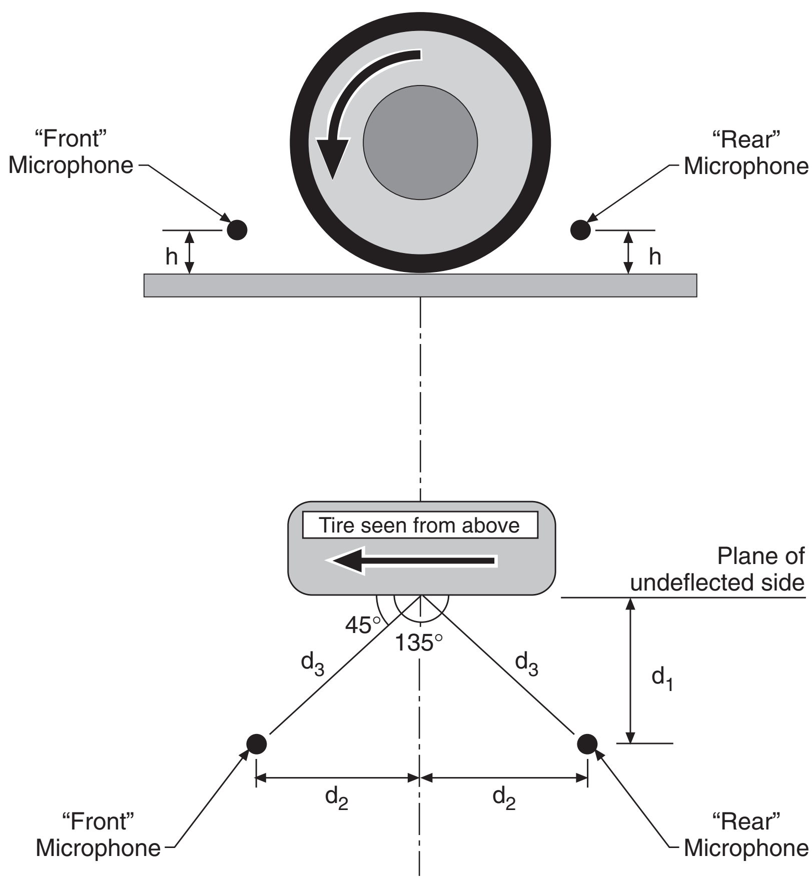


Figure 2-1: Microphone Locations in the ISO Standard

Table 2-1: Dimensions for ISO Standard Microphone Positions

Microphone position	h	d_1 and d_2	d_3
INNER	100 mm	200 mm	283 mm
OUTER	200 mm	400 mm	566 mm

"Annex E: Measurements on Absorptive Surfaces" of the standard recommends for porous pavement surfaces that the outer microphone positions be used. The reasoning is that the measurements are acoustically in the "near field" and therefore no benefits of the absorption of the pavement surface because of wave propagation can be measured. Therefore, the close proximity method in general can underestimate the benefits of absorptive surface pavements by as much as 3 dB. However, the standard states that based upon experience, the relative rankings of porous surfaces can be measured using the close proximity method.

The initial trailer design was based upon a hoop holder for microphones placed in any direction at the outer microphone distance. However, as will be described in the next chapter, after a series of reference testing it was decided that the Texas pavement tests would be conducted with the microphones positioned at the inner location to eliminate some influence upon the measurements by the tow vehicle.

CORRECTING DEFICIENCIES OF THE FIRST GENERATION TRAILER

There were several limitations of the first trailer constructed and used to test in Phase 1 of this research project. The most deficient item was that the microphone locations of the first trailer were fixed at a location that was closer than the ISO standard locations and it would have been very difficult to change.

The other deficiency in the first trailer was that there were some physical characteristics of the trailer, which was originally designed to carry a racecar, that could contribute to sources of noise at the new microphone locations. The first trailer used temporarily secured 55 gallon barrels filled with water for ballast to achieve the desired weight. Both of blunt ends of the barrel and the securing straps could have contributed background noise at the outer microphone locations. The first trailer had a metal grating as a floor to support whatever was hauled on the trailer and it was thought that the holes in the grating could also contribute background noise.

Because CTR was not the owner of the first trailer it was necessary to design and purchase a new trailer. The design principles of the new trailer were to make the trailer as aerodynamically simple as possible, support the new ISO standard microphone locations, and provide a greater distance between the trailer and tow vehicle by using a telescoping tongue on the trailer.

SECOND-GENERATION TRAILER DEVELOPMENT

Based upon advise from the Goodyear Tire and Rubber Company, which operates a tire noise trailer, CTR set out to design and construct a new second-generation trailer. The new trailer was custom made in Austin by Magnum Custom Trailers to CTR specifications. It was then modified by The University of Texas at Austin Mechanical Engineering Department machine shop to provide the microphone-mounting mechanism and the 16 steel plates that were added for ballast.

Trailer Description

As shown in Figure 2-2, the trailer resembles one designed to carry boats except that the frame is flat. No bed is mounted on the frame. The trailer has a regular leaf spring suspension and trailer lights. The only unusual item for the manufacturer was that a telescoping tongue was added to provide an additional 4 feet of distance between the tires of the trailer and tow vehicle when it is in the testing configuration. The total distance from the test tire to the trailer hitch is 12 feet.

Figure 2-2: Second-Generation Test Trailer

Sixteen steel plates (72 by 8 inches) were bolted to the trailer frame to provide sufficient ballast to achieve a static load of 720 lb on the test tire. A vertical screen was attached under the trailer frame with absorptive material to block noise from the left tire affecting noise measurements on the right tire. The wheel fenders are removable but they were kept in place for the testing program.

A support system was developed to serve as a platform to mount the microphone holders. A semicircular steel hoop is attached to the frame so that the hoop is adjustable in height. The steel hoop has a diameter of 58 inches that allows for adjustable positioning of microphones from 0 to 180 degrees from the direction of travel to the center of the tire. The microphones are then attached to the hoop using microphone holders designed and fabricated by the UT mechanical engineering department machine shop.

Figure 2-3: Outer Microphone Location of Second-Generation Test Trailer

Acoustical Testing System

The acoustical testing was accomplished using a system of components designed by Dr. B. J. Landsberger. The equipment purchased was all first-class scientific instruments. The equipment includes the following:

2 – Bruel & Kjaer 0.5-inch microphones, Type 4133

2 – Bruel & Kjaer 0.5-inch preamplifiers, Type 2669C with matching 50-foot cords

1 – Bruel & Kjaer 4-channel Nexus conditioning amplifier

1 – Sony DAT player model PC208Ax

1 – National Instruments CA-1000 converter

1 – DAQ 1200 card

1 - Apple G3 laptop

1- Omnistar L-3000R differential GPS receiver

Software Labview

Trailer noise was collected using two 0.5-inch Bruel & Kjaer microphones type 4133, located at the positions previously described. Prior to each test a calibration tone for each microphone was recorded on digital audiotape. The microphones had standard B & K windscreens that were held in place with a thin nylon mesh bag fastened to the microphone preamplifier. The B & K bullet-shaped nose cones for the microphones were used in the Phase 1 trailer tests, but were not used for this testing. A Sony digital audiotape (DAT) player model PC208Ax recorded the noise. While the noise was being recorded, an accompanying log that links the DAT identification numbers to the pavement test section was kept.

In addition to recording the road noise, the DAT player recorded the global positioning system (GPS) signal. The D-GPS information provided the location of the sample and vehicle speed for each second. With this information, it was possible to identify the type and age of pavement corresponding to the sample with the TxDOT Geographic Information System to match sections in the pavement management information system.

All data were analyzed using an Apple laptop computer. The system was designed to allow the researchers the option of analyzing data in the field with the Apple laptop while simultaneously recording to DAT.

A CA-1000 configurable signal enclosure with a CB – 50LP connector block was used to convert BNC cables to a 50-pin output. The 50-pin connection was then converted to a PCMCIA connection where it could enter the data acquisition (DAQ) card. From here the data could be sampled using Labview®. Data from the D-GPS were brought through the serial port of the computer, using an in-house created BNC to an 8-pin Macintosh cable converter. One D-GPS NEMA format data string was recorded per second.

LABVIEW Data Analysis

Labview® was used to produce the data necessary for evaluating the pavement noise. The overall sound pressure level for each microphone was determined using the standard integrating averaging techniques.

Sound pressure was then transformed from the time domain to the frequency domain using the fast fourier transformer. Sound pressure level versus frequency was then plotted in one-third octave bands. The position and speed of the vehicle was tabulated for each GPS sample. These data were written into a text file.

The information broken down in Labview® was then incorporated into a spreadsheet. The spreadsheet links the data of the pavement type with the field notes and overall sound pressure level of each microphone. The spreadsheet is located in Appendix B.

SELECTION OF THE TEST TIRE

The ISO standard 11819-2 entitled "Method for Measuring the Influence of Road Surface on Traffic Noise – Part 2: "'The Close Proximity method'" was still under review during the time of tire selection. Mr. Ulf Sandberg of the Swedish Road Research Institute informed the researchers of the decision point that the proposed test tires were the following:

Tire A: Vredestein Protrac. Dimension: 185/65R15

Tire B: Avon CR 322. Dimension: 185/65R15

Tire C: Avon CR 65. Dimension: 185/65R15

Tire D: Dunlop SP Arctic. Dimension: 185R14

He also suggested that Tire A be replaced by the Avon ZV1 and that one or more tires be omitted altogether from the standard. Test Tire A is a "summer" tread that represents a typical highway tread. Tires B and C represent more all-purpose/all weather-treads, and Tire D is a snow tread. Figure 2-4 is a photograph of the four proposed tires and their treads.

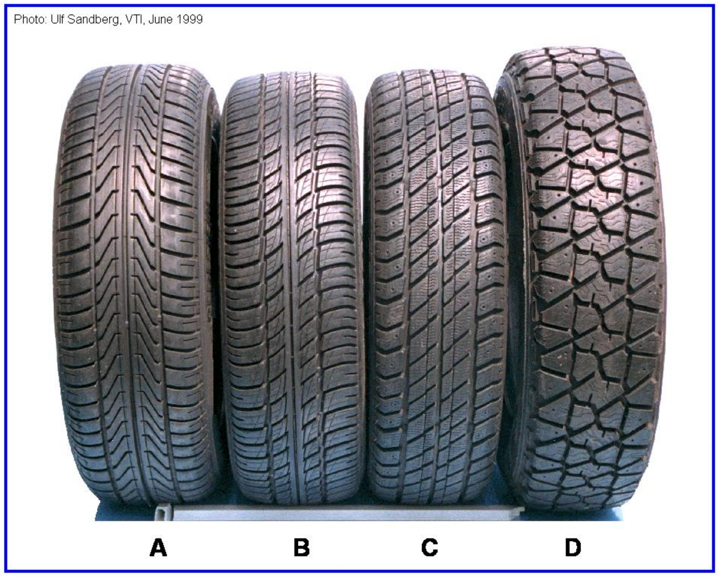


Figure 2-4: Photograph of Four Proposed ISO 11819-2 Test Tires.

Based upon the information available and consultation with the research project director, it was recommended that the second-generation trailer tests to be done under Project 2957 continue without using any of the proposed ISO test tires. The CTR trailer had been outfitted with Michelin LTX M+S P215/75R15 tires shown in Figure 2-5. The product data sheet is also included in Appendix A. This matches the same tire configuration used in the first round of tests performed under Project 2957.

Figure 2-5: Photograph of Michelin LTX M/S P215/75R15 Tire.

The decision to use the Michelin was based in part on remaining consistent with the previous tests. This does not preclude the use of the ISO test tire in the future and the CTR trailer could easily be equipped with the ISO tires if necessary.

The Michelin LTX matches most closely with Tire C from the standard; however, the tread and size are clearly different. Additional reasons to use a light truck tire are based on vehicle demographics and the continuing popularity trend of trucks and sport utility vehicles (SUVs) in Texas and throughout the United States. In the U.S., sales of trucks and SUVs have risen steadily through the 1990s. Since 1995 the top three model vehicles sold were pickup trucks or SUVs.

Another consideration is the manufacturing and shipping cost of the European test tire. Mr. Ulf Sandberg remarked that the test tires should cost only slightly more than normal production tires, however, shipping from overseas would be quite expensive.

CHAPTER 3 TRAILER REFERENCE TESTS

After the trailer was constructed there were several test runs to determine if the acoustical measurement system was working properly and if the data were as free from external noises as possible without providing a soundproof enclosure for the tires. The test site chosen was the same reference test site used in Phase 1 of the project. Thereby, data from the previous trailer tests with the Phase 1 trailer could be compared to the new trailer data if necessary.

The Decker Lane test site is located in Austin, Texas on Decker Lane just south of the southern entrance to the Travis County Heritage and Exposition Center. All tests were started from the driveway of the north entrance to the Travis County Heritage and Exposition Center. The vehicle was accelerated to constant test speed while traveling south on Decker Lane using the left travel lane. The data were collected on Decker Lane between the intersection of Loyola Lane and the intersection of Bagby Dr.

All reference tests were conducted using a differential global positioning system (GPS) to provide precise speed information that was monitored during testing and recorded on the digital tape recorder. The reference tests were used to determine the effects of speed, the effect of trailer weight, and the effect of the towing vehicle on sound pressure levels. There was a slight difference in frequency spectrum and sound pressure level at the outer microphone locations of 400 mm. Tests were conducted on the same day, at several speeds, and with two different tow vehicles, both with the engines running and coasting with engines turned off. The only method that was found to eliminate the difference of the two tow vehicles was to move the microphones from the outer position of 400 mm as specified in the International Organization for Standardization (ISO) standard to the inner position of 200 mm. As a result of the reference tests the conclusion was to conduct the Texas data collection at the inner location of 200 mm.

In all tests conducted, the microphone 1 location is the rear microphone (135-degree location) and the microphone 2 location is the front microphone location (45-degrees).

EFFECT OF SPEED ON SOUND PRESSURE LEVEL

Multiple trial runs were made using the Toyota 4-Runner tow vehicle at speeds of approximately 60, 70, 80, 90, and 100 kilometers per hour using the outer microphone locations. As shown in Figure 3-1, there is a highly significant effect of small variations in speed reference to sound pressure level of the microphones. Generally, as speed increases, the sound pressure level linearly increases at these close proximity locations.

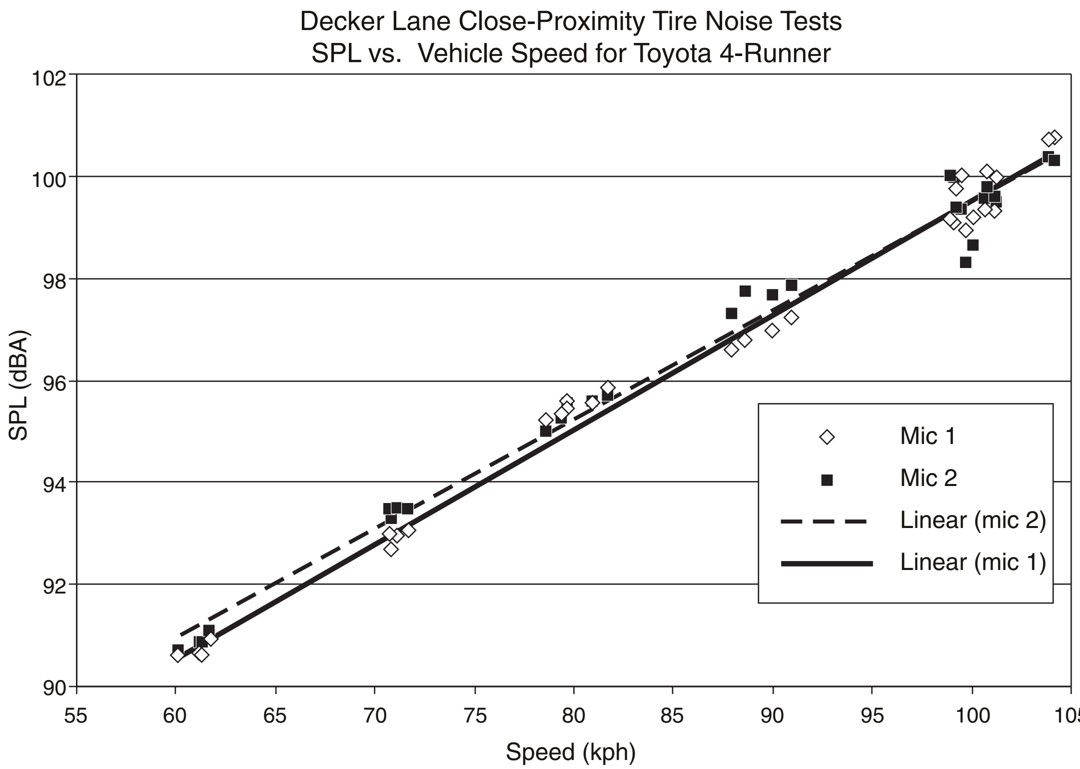


Figure 3-1: Decker Lane Close Proximity Tire Noise Tests

The same tread was found in both the back and front microphones (mic 1 and mic 2, respectively). The data suggests a linear relationship between the speed of the vehicle and the overall SPL. However, a more accurate comparison is realized by comparing the SPL to the 20*log (speed). This implies that the sound pressure is proportional to the speed of the vehicle because sound level is calculated by 20*log(pressure/pref.). This is shown below in Figure 3-2.

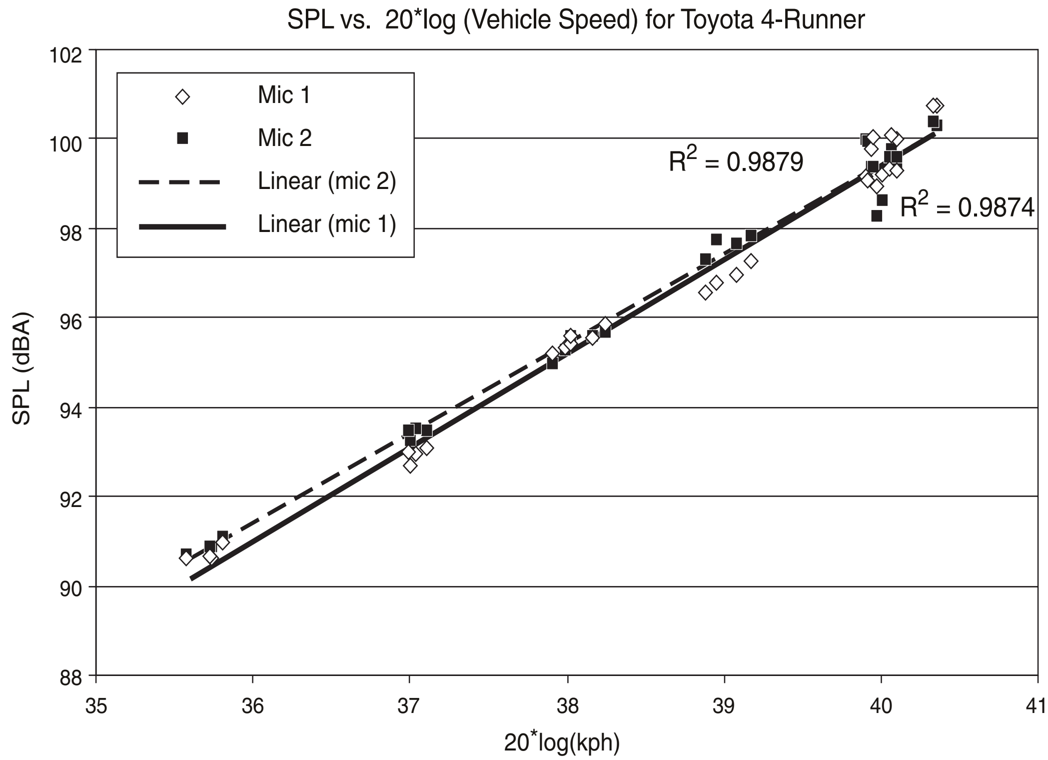


*Figure 3-2: SPL vs. 20*log (Vehicle Speed) for Toyota 4-Runner*

The speed data shown above can be used to normalize future trailer tests to a specific speed using the linear trend line. It was concluded that future tests will be normalized to 100 kph. This speed data also gives valuable insight into the importance of speed for measuring overall sound pressure level. Figure 3-3 compares the frequency data at three different speeds measured with the Toyota 4-Runner. As shown in Figure 3-3, the effect of speed on sound pressure level affects the entire one-third octave frequency band spectrum. Again as speed increases, there is a significant increase in sound pressure level at each one-third octave band frequency. The results indicate that there is little frequency dependence with varying speed. For the range of speeds for which testing is conducted, an accurate assumption will be to consider all frequencies as equally weighted when adjusting for speed. One exception is the 60 kph case, which is inconsistent in the lower and upper frequency bands. Fortunately, this is out of the primary frequency range of interest between 400 Hz and 2000 Hz.

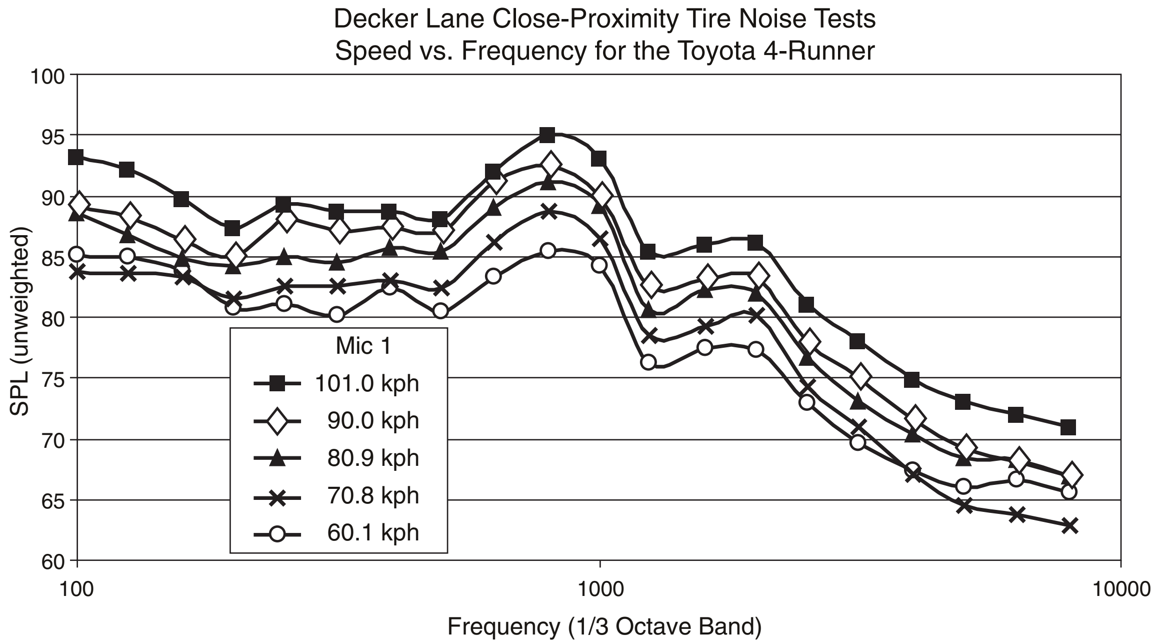


Figure 3-3: Decker Lane Close-Proximity Tire Noise Tests
Speed vs. Frequency for the Toyota 4-Runner

EFFECT OF TRAILER WEIGHT ON SPL

The ISO standard specifies that the static weight on the test tires is 720 lb (3,200 ± 200) N with a cold tire pressure of 23 psi (160 ± 10) Kpa. To achieve this static load additional steel plates weighing approximately 700 lb were added to the test trailer. A test was run using the van tow vehicle, both with and without this additional weight, to measure for reference the hour difference of the added weight affects the sound pressure levels.

Figures 3-4 and 3-5 show that there is a significant difference in the sound pressure levels so that with higher weight on the vehicle and, therefore, more tire contact area, less noise is produced. The level of significance of SPL (not corrected for A weighting) is more pronounced at lower frequencies and is not very significant at 800 and 1,000 Hz, which is an area of importance in tire/pavement noise.

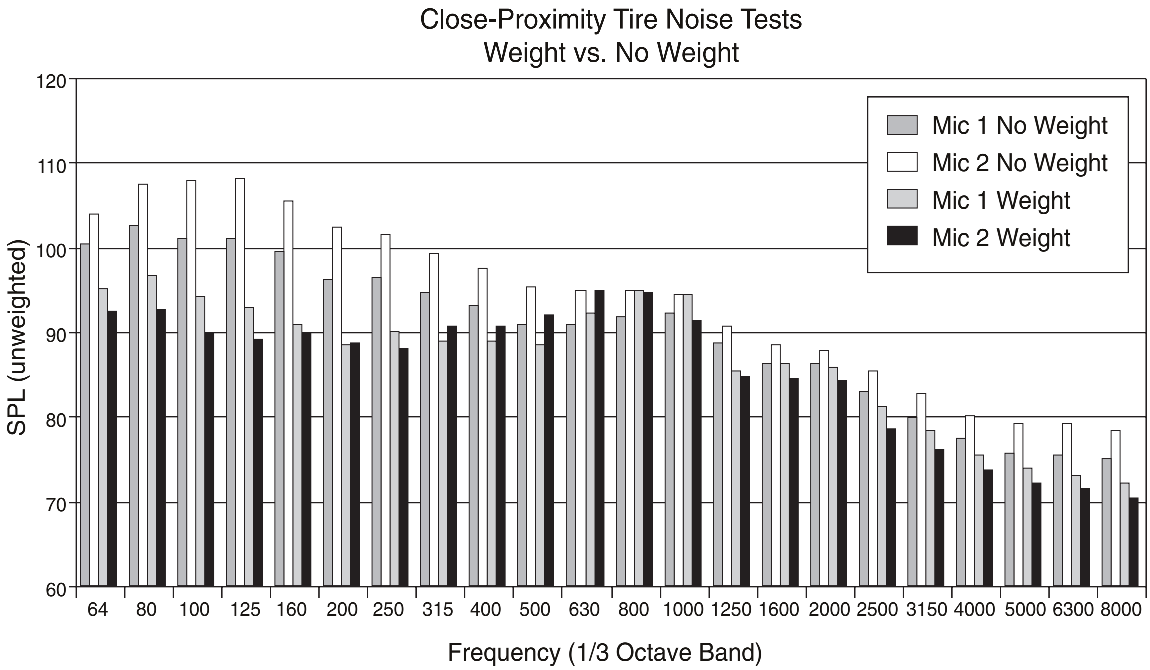


Figure 3-4: Close-Proximity Tire Noise Tests

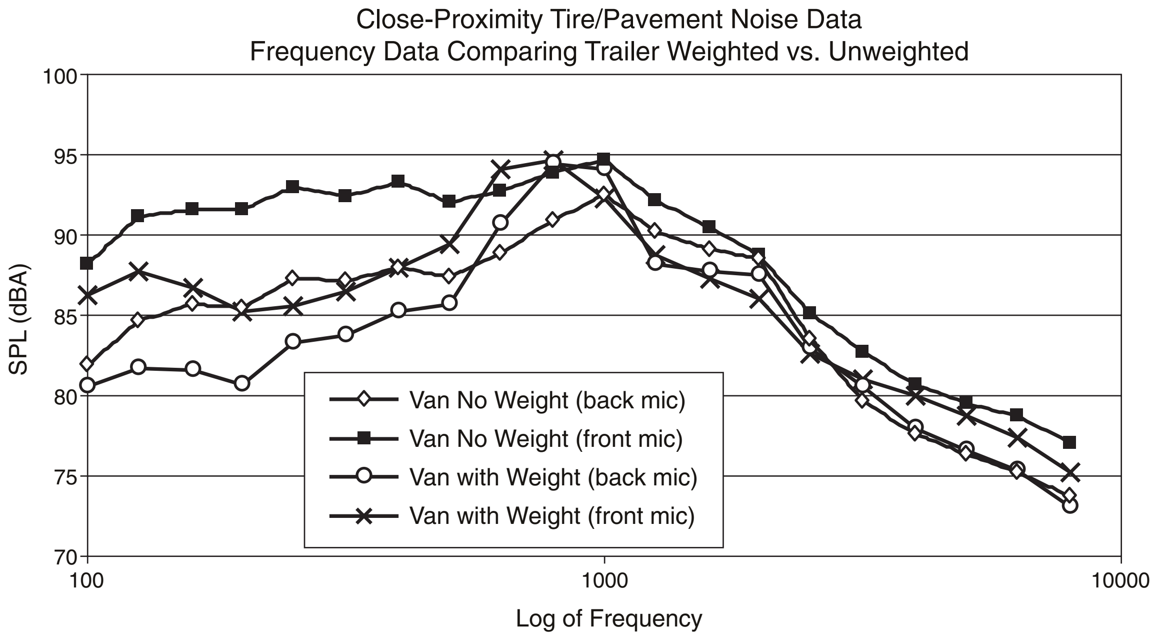


Figure 3-5: Close-Proximity Tire/Pavement Noise Data

EFFECT OF TOW VEHICLE ON SPL

In the construction of the test trailer, the test tire was placed 12 feet from the trailer hitch of the tow vehicle. It was assumed in the design phase that 12 feet would provide at least 20 dB difference from the influences of the test vehicle. The plan was to use the same test vehicle used in Phase 1, the GMC Safari Minivan shown in Figure 3-6, that had the same tires as the test trailer. This vehicle was used in Phase 1 for the roadside measurement as well as the onboard trailer noise measurement. However, there was concern about the age and reliability of the vehicle for use in a long testing cycle pulling the full weight of the test trailer. To address this concern, renting a test vehicle with towing capacity was considered. However, a suitable tow vehicle was not found for rental and the researcher's personal 1993 Toyota 4-Runner shown in Figure 3-6 was used.

Figure 3-6: Photographs of the CTR and 4-Runner Tow Vehicles with Trailer

The 4-Runner tow vehicle had tires that were also Michelin light-truck tires with a very similar tread pattern, but were one size smaller than the test tire and the van tow vehicle. It was assumed that the effects of the tow vehicle would be negligible on the recorded sound pressure levels because the distance from the tow vehicle to the test tires was greater than 12 feet. However, an initial test to verify that the effect of the tow vehicle would be negligible proved the assumption is false both in the frequency spectrum and in overall sound pressure levels. The van produced a higher sound pressure level than the 4-Runner as measured at the outer microphone location at 100 kph.

Tow Vehicle Comparison Tests

After determining from a single test that the initial assumption was false, a test was developed that tried to identify the source of the differences. A test was conducted on the same day, at the same site, and using both vehicles at multiple speeds to study the aerodynamic effects, both with the engines running and coasting with the engines turned off, to study possible engine noise effects. The Decker Lane location was used and trials were conducted at 60, 70, 80, 90, and 100 kph. The coasting tests were conducted near 100 kph. As shown in Figure 3-7, the van produced higher overall sound pressure levels at all speeds at both the front and rear microphone locations. The conclusion was reached that this was not an aerodynamic effect between the tow vehicle and the test trailer that might be corrected.

The tests were run both with and without the engines running by coasting through the test section. This proved to be a little difficult to achieve the correct speed through the test section, but after trial and error, comparative speeds were achieved near the 100 kph range. In Figure 3-8, the sound pressure level of the van and 4-Runner are compared in one-third octave bands for each one in normal engine operation and coasting operation. There is a significant difference at 1,600 Hz in which the van was higher than the 4-Runner for all runs both with and without the engine operating. The researchers did not determine the cause of the differences in spectrum at the 1,600-Hz frequency. From the tests, it appeared that it was insensitive to vehicle speed, which does not lead one to believe that tow vehicle aerodynamics were the cause. The test rigs were identical between tests to eliminate rigging of the microphones and cords as a difference. Engine noise was ruled out owing to the results in Figure 3-8 that showed no difference at 1,600 Hz whether the engine was operating or not.

The researchers concluded it was not necessary to identify the sources of the differences in sound pressure level and frequency spectrum if the differences could be eliminated. Therefore, a series of tests were conducted to determine if moving from the outer 400 mm location to the inner 200 mm location would eliminate the differences in tow vehicles.

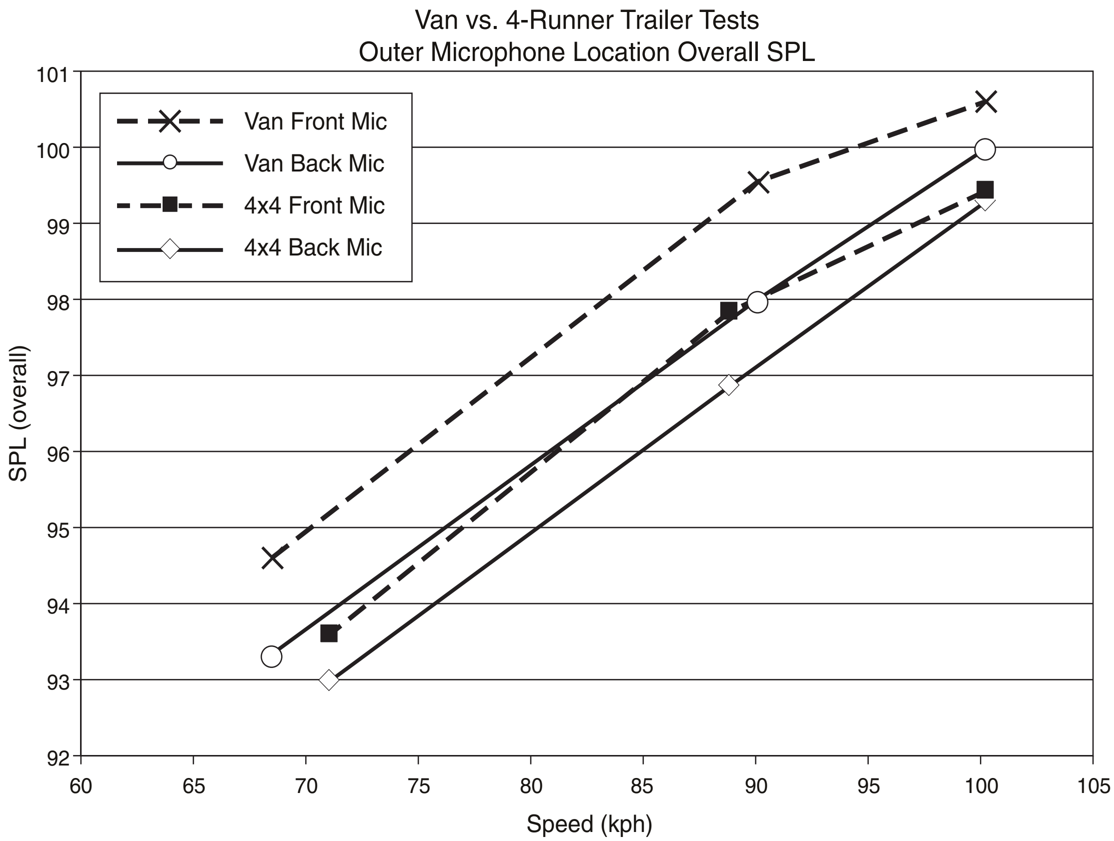


Figure 3-7: Van vs. 4-Runner Trailer Tests

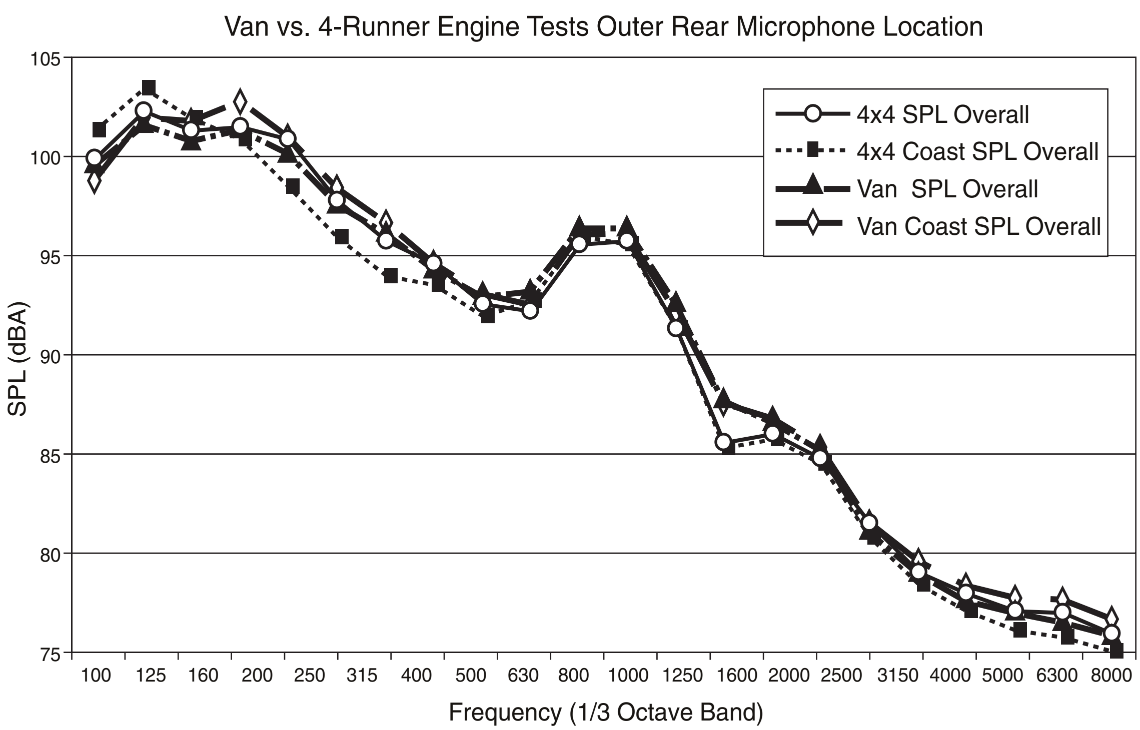


Figure 3-8: Van vs. 4-Runner Engine Tests Outer Rear Microphone Location

EFFECT OF MICROPHONE LOCATION ON SPL

A test was run again to determine if moving the microphones from the outer 400 mm location to the prescribed inner 200 mm location would eliminate the differences noted in the two tow vehicles. The change of microphone locations necessitated the fabrication of extensions to the microphone holders. Once this was completed, the tests were run on Decker Lane at 100 kph. As can be seen in Figure 3-9, there is virtually no difference in frequency spectrum or sound pressure level between the trials with the two tow vehicles.

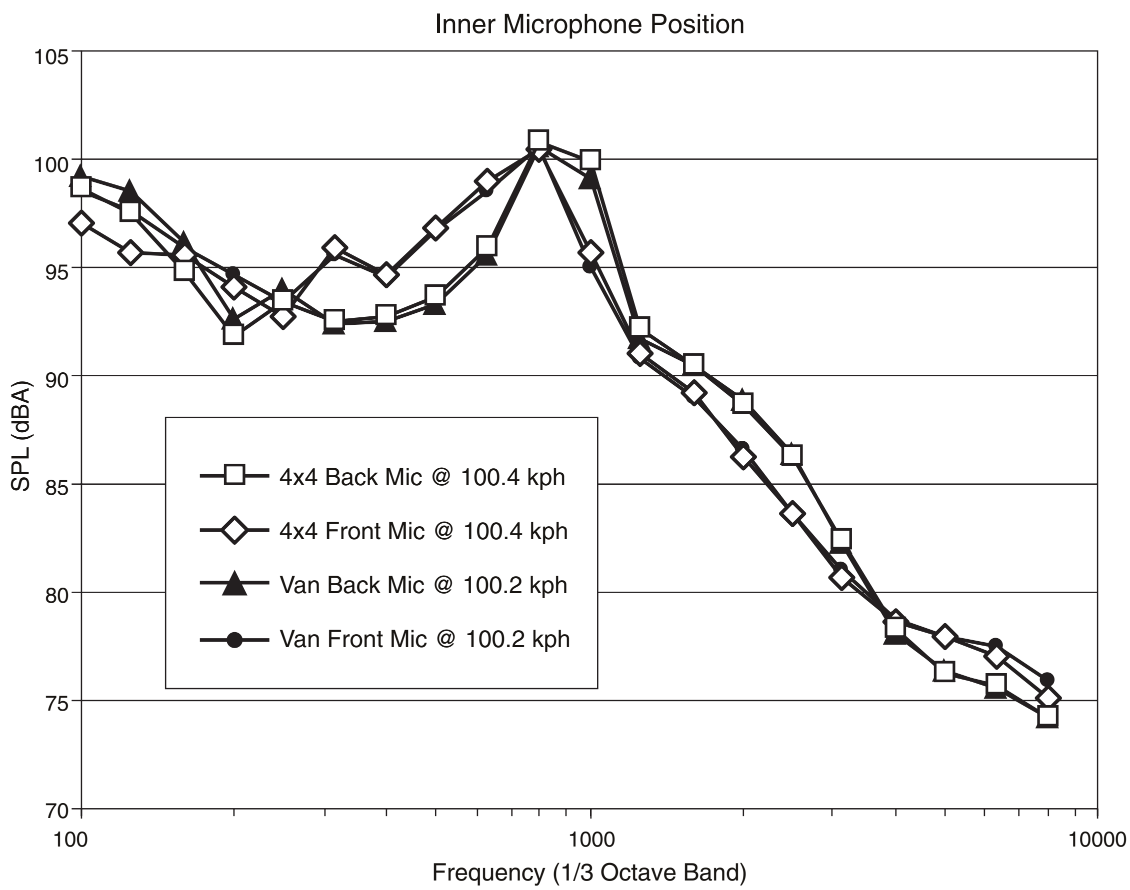


Figure 3-9: Inner Microphone Postition

It was concluded from the reference testing that the Texas test trailer was ready for deployment to test the tire/pavement noise characteristics of pavements in Texas using the inner microphone locations. The trailer was then deployed to test over 200 different pavements using the 4-Runner tow vehicle.

Comparing Figures 3-8 and 3-9, one can clearly see the effect that the microphone position has on the measurement. From the inner microphone, we see in Figure 3-9 that the van and the 4-Runner have almost identical spectra for the front and back microphones. In contrast, the outer microphone position as shown in Figure 3-8 is very different. The differences are apparent in the lower frequency region and around 1,600 Hz. It is concluded that using the inner microphone position is independent of vehicle type and is, therefore, recommended for future measurements. The outer position may be used, however, the vehicle type should be consistent from test to test.

CHAPTER 4 TEXAS TRAILER TESTS

After the reference testing was completed and the researchers were satisfied that the inner microphone location provided repeatable tire/pavement noise data independent of the tow vehicle, a series of pavement tests were conducted. In consultation with the project director, and after receiving input on potential pavements of concern from the Texas Department of Transportation (TxDOT) engineers, several testing days were selected.

TEXAS PAVEMENT TEST OBJECTIVES

The objective was to test as many different pavement types as possible and to test specific pavements that were selected for certain characteristics. The decision on which pavements to test was based upon the following considerations and limitations. Limitations of scheduling required that all tests had to be completed by the end of the fiscal year and the delays in the referenced testing left only a very short window of opportunity. Pavement sections that were tested in Phase 1 trailer testing were given consideration if they were open to road traffic. A separate research project was looking at the effects on pavement performance to see if transverse tining could be eliminated on continuously reinforced concrete pavements (CRCP). Therefore, a recently constructed section of CRCP pavement in Waco, Texas, that was constructed without tining was added to the schedule. Previously, it was suggested that crumb rubber modified asphalt pavements appeared quieter than non-modified asphalt pavements and several test sections near Odessa, Texas were added to the schedule. Engineers in Houston were concerned with the noise level of concrete pavements in their district and a trip was planned to test Houston-area concrete pavements.

CONDUCTING THE TESTING

The planning of the tests established four separate days of testing. The first day of testing would test some local test sections including several sections tested previously in Phase 1. The second day of testing was to start near Johnson City, Texas, to include some sections near San Antonio that had previously been tested in Phase 1. The researchers continued testing each different pavement type as it was encountered, ending the second day with the specified crumb rubber pavement sections in the Odessa District. This was a very long day of testing. One of the interesting pavement sections encountered was a fresh asphalt overlay near Junction, Texas, that was recently opened to traffic. It was so new that the paving machine was still operating in the other travel lane. The third day tested pavement from Austin, Texas to Waco, Texas on IH – 35, including the targeted CRCP sections without tining in Waco. The fourth day tested pavement from Austin, Texas to Houston, Texas on a route from State Highway 71 to Interstate Highway 10.

The objective was to collect and record tire/pavement noise data on all the different pavements available along these three routes. Generally, the testing method was to record three or more samples of 5 to 30 seconds for each change in pavement type that was noted by the driver. Each sample was timed to avoid passing vehicles as best as possible, with as flat a grade as possible, to avoid medians, jersey barriers, or rock-faced cut sections that could possibly affect the noise measurements. In some instances, the recorder was left to run for extended periods and notes were annotated on the log either when good sections that meet the selection criteria occurred or when events such as passing vehicles indicated that those times should not be used as a valid sample.

ANALYZING THE DATA

The actual data analysis used post-processing so that the researcher plays back the tape recorder into the Labview software choosing a 5-second time. Three or more 5-second intervals were chosen for each of the 107 pavement test sections. Using the Labview analysis software, the sound pressure levels were calculated and the global positioning system (GPS) position and speed recorded for each chosen 5-second duration. The three 5-second SPL averages for each microphone location were then plotted in a Microsoft Excel spreadsheet. Using the linear regression technique, an SPL was calculated for each microphone that was normalized to 100 kph.

FINDINGS

The complete reduced data are provided in Appendix B. The digital audiotape (DAT) tapes are available in their original form and could be further examined and analyzed in the future, if desired.

The data obtained from these field tests show that certain types of pavements already in use have the ability to reduce highway noise. For example, freshly constructed asphalt overlays were measured to be 6 dB quieter than jointed concrete. However, how long that freshly constructed asphalt pavement will retain that quiet characteristic is not known. Nor is it known whether the stiffness or modulus of elasticity of the pavements has any effect on the noise levels.

Table 4-1 shows the average sound pressure level for various specimens of pavement. The table not only includes common pavements, but also the results from the rubber-modified pavements in the Odessa District, which include coarse matrix high binder, plant mix seal, and hot rubber seal pavements.

Table 4-1: Ranking of Tire/Pavement Noise by Pavement Type

	Average SPL dBA		Number of Averages
	Rear	Front	
Thin Surfaced Flexible Base Pavement (Surface Treatment-Seal Coat Combination)	100.14	98.69	2
Coarse matrix high binder (CMHB-F)	100.99	98.77	2
Hot Rubber Seal (HRS)	102.10	101.28	1
Plant Mix Seal (PMS)	102.20	100.80	7
Intermediate Thickness Asphalt Concrete Pavement (2½" to 5½")	102.30	100.91	54
Thin Surfaced Flexible Base Pavement (less than 2½")	102.37	101.33	2
Overlaid and/or Widened Old Concrete Pavement	102.75	100.74	3
Continuously Reinforced Concrete Pavement	104.06	102.80	16
Jointed Reinforced Concrete	107.14	104.98	2

One of the original goals of the analysis was to investigate road noise with the age of pavement, but the information in the Texas PMIS database regarding the age of the pavement surface was not complete. As a substitute for graphing noise level versus age of pavement, noise level was graphed versus ride score, which is measured with the laser profilometer and computed as present serviceability index (PSI). It was possible to make this substitution because it is known that ride score or PSI decreases with age. A newly constructed pavement would have a ride score of at least 4.5, and a 5.0 would be a perfectly constructed section based on smoothness, which is not often achieved. Interstate highway sections with a ride score of 3.0 are considered at the end of pavement life and are scheduled for overlay as would state highways with ride scores of 2.5 or less.

Figures 4-1 and 4-2 are graphs of average sound pressure levels normalized to 100 kph versus ride score for asphalt and concrete pavement test sections, respectively. From these data it is possible to calculate a linear regression trend line for evaluating noise of pavements versus ride score, but the correlation between the data and the line is very low with an R^2 of around 0.1. Table 4-2 shows the coefficient of correlation for each trend line.

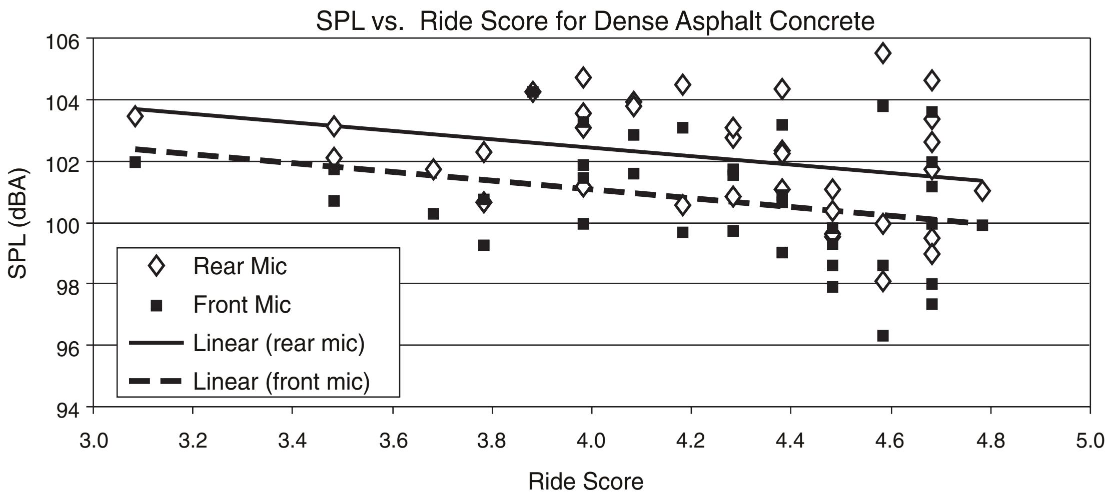


Figure 4.1: SPL vs. Ride Score for Dense Asphalt Concrete

Table 4-2: Coefficient of Determination of Linear Regression Trend Line

for Figures 4-1 and 4-2

	R^2	
Microphone Location	Asphalt (Figure 4-1)	Concrete (Figure 4-2)
Rear	.0915	.2247
Front	.0926	.1027

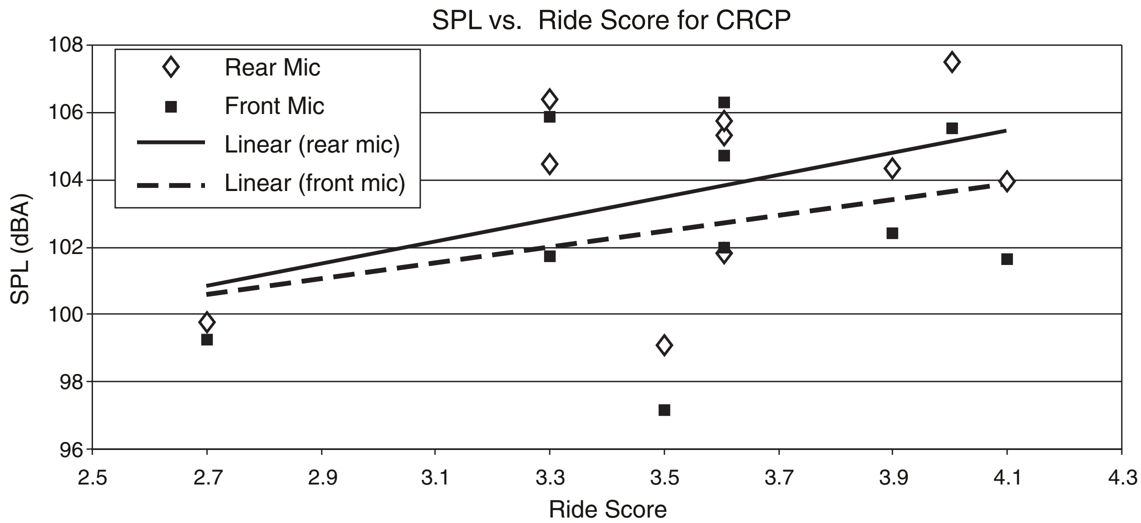


Figure 4.2: SPL vs. Ride Score for CRCP

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

It is a commonly accepted hypothesis that over time and wear from traffic asphalt pavement surfaces will become less quiet in relation to tire/pavement noise. Likewise, it is also commonly accepted that portland cement concrete pavements will become quieter over time as traffic begins to abrade the surface texture of the pavement. The data collected in this project only weakly support this hypothesis. Because of the spread of data shown in Figures 4-1 and 4-2 and the variations in sound pressure levels between the pavements that cause the poor R^2 value of the linear regression, the data of this project cannot statistically prove or disprove the hypothesis.

However, a conclusion can be reached that there are significant differences in existing Texas pavements with respect to tire/pavement noise. The differences are significant enough that testing and quantification are warranted and should be taken into account when analyzing situations where traffic noise barriers are being considered. The traffic noise model has the capability to differentiate between pavement types when making calculations.

None of the pavements tested was specially constructed as quiet pavement. However, based upon the results of the Phase 2 laboratory tests, the results of the field tests in Phase 3 with this test trailer, and the other scientific literature available, it is concluded that it would indeed be feasible to develop quiet pavements that would provide at least a 5 dB level of traffic noise reduction.

The test trailer constructed for this project provides an accurate measurement of tire pavement noise in accordance with ISO standards and should be used for further research into the development of safe, quiet, durable pavements.

RECOMMENDATIONS

In order to prove or disprove the hypothesis that tire/pavement noise changes over time, testing specific pavements over a period of time or traffic wear would be required. The only open-graded asphalt pavements in this project were the plant mix seal sections in Odessa, Texas and there were no pavements in this project that were specifically constructed to be quiet pavements.

The next step recommended in implementing this research is to build full-scale pavements designed and based upon the principles in the Phase 2 laboratory research, and test them with the test trailer close proximity method and the impedance tube normal incidence coefficient of absorption test. This research project recommends that research into quiet pavements should transition into an implementation project phase. Several test sections should be constructed with the desired goal of achieving a durable quiet pavement surface. The recommended test sections should include the following:

1. Open-graded plant mix asphalt with polymer binder with 20 percent or greater voids and a thickness of 1.5 to 2.0 inches (with and without crumb rubber added).
2. Novachip® open-graded asphalt overlay in one or two lifts to reach a thickness of 1.5 to 2.0 inches.
3. Econcrete® porous concrete overlay of CRCP concrete pavement.
4. Untined CRCP pavement.
5. SHRP Superpave or CMHB mix design with high voids.

APPENDIX A:
MICHELIN PRODUCT INFORMATION

product catalog

Light Truck

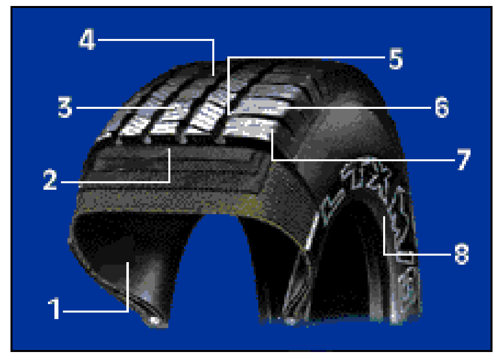
LTX® M/S

The premium, all-season light truck radial for pickups, full-size vans, and sport utility vehicles that delivers durability and traction in combination with exceptional mileage and the classic Michelin smooth, quiet ride.

1. State-of-the-art casing distributes stresses evenly for longer tread life.

2. Third steel belt in D & E load ranges provides greater puncture resistance for greater durability.

3. Unique tread block pattern minimizes noise for a quiet ride.



4. Large, stable contact patch maximizes the stability of the tread blocks for longer tire life.

5. Deep circumferential grooves channel water out from under the contact patch for exceptional wet traction.

6. Interlocking, full-depth sipes provide many biting edges for excellent snow traction while still maintaining tread block stability for enhanced cornering.

7. Special tread rubber compound helps the tire maintain excellent grip in all weather conditions.

8. Bold sidewall styling for an attractive, vehicle-enhancing look.

Tire Size	Load Index/ Speed Symbol	Tread Type/ Sidewall
LT195/75R14	93/90R LRC	ORWL/ORBL
LT215/75R15	LRC 100/97R	ORWL
LT215/75R15	LRD 106/103R	ORBL
LT235/75R15	LRC104/101R	ORWL
LT215/85R16	LRD 110/107R	ORBL
LT235/85R16	LRD114/111R	ORBL
LT235/85R16	LRE 120/116R	ORWL/ORBL
LT225/75R16	LRD 110/107R	ORWL/ORBL
LT225/75R16	LRE 115/112R	ORBL
LT245/75R16	LRE 120/116R	ORWL/ORBL
LT265/75R16	LRC 112/109R	ORWL
30X9.50R15LT	LRC 124R	ORWL
31X10.50R15LT	LRC 109R	ORWL
31X11.50R15LT	LRC 110R	ORWL
32X11.50R15LT	LRC 113R	ORWL

33X12.50R15LT	LRC 108R	ORWL
P195/75R14	92S	ORWL
P205/75R14	95S	ORWL
P205/75R15	97S	ORWL
P215/75R15	100S	ORWL
P225/75R15	102S	ORWL
P235/75R15	105S	ORWL
P235/75R15 XL	108S	ORWL
P225/70R15	100S	ORWL
245/75R16	107S	ORBL
P275/75R16	114H	ORBL
P215/70R16	99S	ORWL
P225/70R16	101S	ORWL
P235/70R16	104S	ORWL
P255/70R16	109S	ORWL
P265/70R16	111S	ORWL
P265/70R17	113S	ORWL
ORWL=Outlined Raised White Letters · ORBL=Outlined Raised Black Letters XL=Extra Load		

UTQG Rating: (P Metric sizes only)

Treadwear	Traction	Temperature
440	A Except P275/70R16 114H LTX M/S	B
440	A	A

Take care of your tires - Click here for important tire care tips

APPENDIX B:
FIELD DATA

Table 1: Field Data

			SPL	
Section	Field Notes	DAT Ids	Rear Mic (A)	Front Mic (B)
1.01		93,95,96	100.84	99.714
1.02		97,98,99	102.613	101.163
*1.03		101	103.9012	102.8225
1.04	No Surface Treatment	103,104,105	102.71	101.53
1.05	Novachip Southbound	106	100.64	99.22
1.06	Novachip Northbound	107,108	102.257	100.707
1.07	Novachip, eastbound, little pavement ware	110,111,112	103.686	103.584
1.08	Novachip, westbound	113,114,115	104.086	104.047
1.09	New Asphalt, surface treatment	116,118,120	103.064	103.076
1.10	Asphalt aged	123,125,127	104.24	104.24
1.11	1-2 years	129,130,132	101.691	99.916
1.12	Transverse groove rumble strips	132	105.47	103.76
1.13	2-4 years	132	101.872	100.238
1.14	2-4 years	132	102.32	100.849
1.15	Brand new overlay	132	98.417	97.148
1.16	1-2 years	134,135,136	100.878	99.393
1.17	1-2 years	138,139,141	99.443	97.957
1.18	Aged Overlay	142	101.021	99.864
1.19	Rock walls	143	99.944	98.598
1.20	Medium Aged	144	101.06	99.81
1.21	Recent Overlay	146,147	99.515	97.88
1.22	Pavement change	148,149	98.07	96.29
1.23	Pavement change	151,152,154	98.949	97.328
1.24	Pavement change	155	101.051	101.698
1.25		156,157,159	101.32	101.82
1.26	Recent Overlay	160	102.088	102.3
1.27		160	101.457	101.454
1.28	Aged, rough	161	101.956	102.03
2.01	Random patches	164	102.1	101.283
2.02		165	100.158	97.72
2.03	Rutted Asphalt Polished	165	102.832	100.704
2.04	Old with crack sealing	166	102.436	100.535
2.05	Very little cracking	166	102.05	99.74
2.06	Thin Overlay	167	102.37	100.541
2.07	Patching and Sealing	167	102.27	100.86
2.08	New Pavement	168,169	99.044	96.81
2.09	Old overlay with crack seal	169	102.53	100.265
2.10	Milled Asphalt with crack seal	170	103.255	101.53
2.11	Aged Asphalt	171	103.741	102.589
2.12		171	100.607	99.369

2.13		171	103.28	101.03
2.14	Old Asphalt	171	103.27	102.416
2.15	Rutted Asphalt Polished	172	102.473	100.8
2.16		173	100.867	99.76
2.17		173,174	103.672	102.309
2.18	Some crack filling	175	101.823	99.813
2.19	Overlay	177,178	102.99	101.74
2.20		179,180,181	101.49	100.03
2.21		183	102.908	100.982
2.22		183	101.47085	98.8747
3.01		5,7	100.346	99.294
3.02		8	101.145	99.934
3.03		12	99.61	98.57
3.04		13	100.527	99.649
3.05	New Overlay	13	103.11	101.72
3.06		13	104.592	103.57
3.07		13	102.075	100.664
3.08		13	103.343	101.931
3.09	Old Asphalt	13	104.686	103.255
3.10		13	103.061	101.696
3.11	Slightly Aged	13	102.213	100.614
3.12	Aged Asphalt	13	103.41	101.96
3.13		14	103.52	101.847
3.14		14	104.302	103.144
3.15	Slightly Aged	14	101.71	100.263
3.16	Quiet	14	No Data	
3.17		14	103.07	101.42
3.18	Slightly Aged	14	106.76	105.63
3.19		15	103.188	101.356
3.20		16	104.944	102.97
3.21	Concrete	16	106.595	103.503
3.22	Older Concrete	16	103.34	101.994
3.23	Patched Concrete	16	102.595	100.876
3.24	Old Asphalt	16	103.847	102.145
3.25	Asphalt with reflection cracking	16	103.565	101.845
3.26	Asphalt overlay with patched reflection cracking	16	101.017	99.851
3.27		16	104.4	102.96
3.28	Old Asphalt	17,18	102.442	101.006
3.29	Asphalt overlay with patch and crack seal	19	99.73	98.69
3.30	New Asphalt	20	100.6213	99.2868
*3.31	New Asphalt	21	101.851	100.633
3.32		224	105.64	103.73
4.01		225	104.457	103.06

4.02		226	104.27	101.671
4.03		227,230,231	104.16	102.36
4.04	Asphalt Overlay	236,237	103.53	103.619
4.05	Seal Coat	238,241	103.444	103.266
4.06		242,243	104.268	104.175
4.07		245,246,247	104.579	101.394
4.08		248,249,250	103.89	102.76
4.09	CRCP	251	99.58	99.2
4.10		252	104.04	101.52
4.11	Dense graded asphalt smooth	253	101.81955	100.10075
4.12	Six Expansion Joints	255,256,259	102.376	100.593
4.13	Dense Asphalt, slightly old	260	103.76	101.58
4.14	Dense Asphalt	260	106.22	105.81
4.15	Concrete	260	105.15	104.66
4.16		260	105.58	106.244
4.17		260	107.31	105.472
4.18		260	101.616	101.927
4.19		260	101.99	100.05
4.20	Asphalt	262	106.938	106.716
4.21	Concrete	262	101.06	99.01
4.22	Asphalt	262	109.457	106.687
4.23	Concrete, frontage			
4.24	Concrete, frontage			
4.25				
*Could not be normalized to 100 km/hr				

Table 2: Section location

Section	County #	County	Highway	Reference Marker
1.01	16	Blanco	US0281K	0486
1.02	16	Blanco	US0281K	0492
1.03	46	Comal	US0281K	0500
1.04	46	Comal	US0281R	0506
1.05	15	Bexar	US0281R	0516
1.06	15	Bexar	US0281R	0516
1.07	46	Comal	SH0046K	0504
1.08	46	Comal	SH0046K	0504
1.09	46	Comal	SH0046K	0498
1.10	131	Kendall	SH0046K	0486
1.11	131	Kendall	IH0010L	0532
1.12	133	Kerr	IH0010L	0510
1.13	133	Kerr	IH0010L	0504
1.14	133	Kerr	IH0010L	0486
1.15	134	Kimble	IH0010L	0467
1.16	134	Kimble	IH0010L	0450

1.17	218	Sutton	IH0010L	0432
1.18	218	Sutton	IH0010L	0418
1.19	218	Sutton	IH0010L	0415
1.20	218	Sutton	IH0010L	0398
1.21	53	Crockett	IH0010L	0379
1.22	53	Crockett	IH0010L	0357
1.23	53	Crockett	IH0010L	0341
1.24	186	Pecos	IH0010L	0327
1.25	186	Pecos	SH0349K	0422
1.26	53	Crockett	SH0349K	0402
1.27	231	Upton	SH0349K	0394
1.28	231	Upton	US0067K	0780
2.01	231	Upton	US0385K	0404
2.02	52	Crane	US0385L	0378
2.03	69	Edwards	US0385L	0368
2.04	165	Midland	IH0020R	0123
2.05	165	Midland	IH0020R	0127
2.06	165	Midland	IH0020R	0138
2.07	165	Midland	IH0020R	0139
2.08	165	Midland	IH0020R	0142
2.09	165	Midland	IH0020R	0145
2.10	165	Midland	IH0020R	0146
2.11	156	Martin	IH0020R	0151
2.12	156	Martin	IH0020R	0156
2.13	156	Martin	IH0020R	0161
2.14	115	Hudspeth	IH0020R	0163
2.15	156	Martin	IH0020L	0162
2.16	156	Martin	IH0020L	0157
2.17	165	Midland	IH0020L	0144
2.18	69	Edwards	IH0020L	0111
2.19	69	Edwards	IH0020L	0107
2.20	238	Ward	IH0020L	0078
2.21	238	Ward	IH0020L	0073
2.22	238	Ward	IH0020R	0084
3.01	227	Travis	SL0001R	0430
3.02	227	Travis	SL0001R	0430
3.03				
3.04	227	Travis	SL0001R	0434
3.05	227	Travis	IH0035R	0246
3.06	246	Williamson	IH0035R	0252
3.07	246	Williamson	IH0035R	0254
3.08	246	Williamson	IH0035R	0255
3.09	246	Williamson	IH0035R	0258
3.10	246	Williamson	IH0035R	0260
3.11	246	Williamson	IH0035R	0261
3.12	246	Williamson	IH0035R	0272
3.13	14	Bell	IH0035R	0284
3.14	14	Bell	IH0035R	0287
3.15	14	Bell	IH0035R	0295
3.16	14	Bell	IH0035R	0305
3.17				
3.18	14	Bell	IH0035R	0312
3.19	161	McLennan	IH0035R	0319

3.20	161	McLennan	IH0035R	0324
3.21	161	McLennan	IH0035R	0331
3.22	161	McLennan	IH0035R	0333
3.23	161	McLennan	IH0035R	0337
3.24	161	McLennan	IH0035R	0340
3.25	161	McLennan	IH0035R	0347
3.26	110	Hockley	IH0035R	0356
3.27	110	Hockley	IH0035R	0361
3.28	110	Hockley	IH0035R	0366
3.29	110	Hockley	IH0035ER	0371
3.30	110	Hockley	IH0035WR	0001
3.31	110	Hockley	IH0035WR	0002
3.32	110	Hockley	IH0035L	0369
4.01	227	Travis	US0290L	0576
4.02	227	Travis	IH0035L	0236
4.03	227	Travis	US0183L	0512
4.04	227	Travis	US0183L	0506
4.05	161	McLennan	#FM3051	0570
4.06	161	McLennan	#SL0340	0348
4.07	161	McLennan	#FM3051	0570
4.08	161	McLennan	#FM3051	0570
4.09	76	Fisher	SH0071R	0646
4.10	45	Colorado	SH0071R	0662
4.11	45	Colorado	IH0010R	0695
4.12	45	Colorado	IH0010R	0698
4.13	45	Colorado	IH0010R	0707
4.14	237	Waller	IH0010R	0729
4.15	237	Waller	IH0010R	0734
4.16	237	Waller	IH0010R	0736
4.17	237	Waller	IH0010R	0736
4.18	237	Waller	IH0010R	0737
4.19	80	Franklin	IH0010R	0739
4.20	102	Harrison	IH0010R	0742
4.21	80	Franklin	IH0010L	0741
4.22	237	Waller	IH0010L	0730
4.23	237	Waller	IH0010A	0729
4.24	237	Waller	IH0010A	0729
4.25	237	Waller	IH0010L	0729

Table 3: Section Type

	Pavement Type		
Section	**Broad_Code**	**DTL_RD_Life_Code**	**DTL_Visual_Code**
1.01	A	05	
1.02	A	05	
1.03	A	05	
1.04	A	05	10
1.05	A	05	
1.06	A	05	
1.07	A	06	
1.08	A	06	
1.09	A	06	10

1.10	A	05	
1.11	A	05	
1.12	A	05	
1.13	A	10	05
1.14	A	05	
1.15	A	10	
1.16	A	05	
1.17	A	05	
1.18	A	05	
1.19	A	05	
1.20	A	05	
1.21	A	05	
1.22	A	05	
1.23	A	05	
1.24	A	06	
1.25	A	06	
1.26	A	06	
1.27	A	06	
1.28	A	06	
2.01	A	06	
2.02	A	06	
2.03	A	06	
2.04	A	06	
2.05	A	06	
2.06	A	06	
2.07	A	06	
2.08	A	06	
2.09	A	06	
2.10	A	06	
2.11	A	06	
2.12	A	06	
2.13	A	06	
2.14	A	05	
2.15	A	06	
2.16	A	06	
2.17	A	06	
2.18	A	06	
2.19	A	06	
2.20	A	06	
2.21	A	06	
2.22	A	06	
3.01	A	05	
3.02	A	05	
3.03			
3.04	A	05	
3.05	A	05	
3.06	A	05	
3.07	A	05	
3.08	A	05	
3.09	A	05	
3.10	A	05	
3.11	A	05	
3.12	A	05	

3.13	A	05	
3.14	A	05	
3.15	A	05	
3.16	A	05	
3.17			
3.18	A	05	
3.19	A	05	
3.20	A	05	
3.21	A	05	01
3.22	C	01	
3.23	C	01	
3.24	A	05	
3.25	A	05	
3.26	A	05	
3.27	A	05	
3.28	A	05	
3.29	A	05	
3.30	A	05	
3.31	A	05	
3.32	A	05	
4.01	C	01	
4.02	A	05	
4.03	C	01	
4.04	C	01	
4.05	A	05	
4.06	A	05	
4.07	A	05	
4.08	A	05	
4.09	C	01	
4.10	C	01	
4.11	A	08	
4.12	A	08	
4.13	A	08	
4.14	A	05	
4.15	C	01	
4.16	C	01	
4.17	C	01	
4.18	C	01	
4.19	C	01	
4.20	C	01	
4.21	C	01	
4.22	A	05	
4.23	J	02	
4.24	J	02	
4.25	C	01	

Table 4:Section Description

Section	Pavement Description	Surface Type	Date Completed	Ride Score
1.01	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.3

1.02	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.7
1.03	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.1
1.04				4.3
1.05	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.8
1.06	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.8
1.07	Thin Surfaced Flexible Base Pavement (less than 2½")			3.9
1.08	Thin Surfaced Flexible Base Pavement (less than 2½")			3.9
1.09	Thin Surfaced Flexible Base Pavement (less than 2½")			3.5
1.10	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.6
1.11	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.7
1.12	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.6
1.13	Thin Surfaced Flexible Base Pavement (Surface Treatment-Seal Coat Combination)			4.4
1.14	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.4
1.15	Thin Surfaced Flexible Base Pavement (Surface Treatment-Seal Coat Combination)			4.7
1.16	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			
1.17	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.8
1.18	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			
1.19	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.6
1.20	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.5
1.21	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.5
1.22	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.6
1.23	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.7
1.24	Thin Surfaced Flexible Base Pavement (less than 2½")			0
1.25	Thin Surfaced Flexible Base Pavement (less than 2½")			0
1.26	Thin Surfaced Flexible Base Pavement (less than 2½")			0
1.27	Thin Surfaced Flexible Base Pavement (less than 2½")			0
1.28	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.01	Thin Surfaced Flexible Base Pavement (less than 2½")	HRS	09/04/96	0

2.02	Thin Surfaced Flexible Base Pavement (less than 2½")	CMHB-F	06/24/98	0
2.03	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.04	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.05	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.06	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.07	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.08	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.09	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.10	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.11	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.12	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	10/31/94	0
2.13	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	10/13/95	0
2.14	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")	PMS	10/13/95	0
2.15	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	10/13/95	0
2.16	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	10/31/94	0
2.17	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.18	Thin Surfaced Flexible Base Pavement (less than 2½")	CMHB-F	08/31/94	0
2.19	Thin Surfaced Flexible Base Pavement (less than 2½")			0
2.20	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	sub. Comp.	0
2.21	Thin Surfaced Flexible Base Pavement (less than 2½")	PMS	sub. Comp.	0
2.22	Thin Surfaced Flexible Base Pavement (less than 2½")			0
3.01	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.5
3.02	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4
3.03	No Data			
3.04	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.5
3.05	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.2
3.06	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.5
3.07	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.7

3.08	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.5
3.09	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.7
3.10	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4
3.11	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.3
3.12	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.4
3.13	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.1
3.14	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4
3.15	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.4
3.16	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			3.7
3.17	No Data			
3.18	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4
3.19	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.20	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.21	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.22	Continuously Reinforced Concrete Pavement			0
3.23	Continuously Reinforced Concrete Pavement			0
3.24	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.25	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.26	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.27	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.28	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.29	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.30	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.31	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
3.32	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
4.01	Continuously Reinforced Concrete Pavement			0
4.02	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.3
4.03	Continuously Reinforced Concrete Pavement			3.3
4.04	Continuously Reinforced Concrete Pavement			3.9
4.05	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0

4.06	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
4.07	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
4.08	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			0
4.09	Continuously Reinforced Concrete Pavement			0
4.10	Continuously Reinforced Concrete Pavement			2.7
4.11	Overlaid and/or Widened Old Concrete Pavement			0
4.12	Overlaid and/or Widened Old Concrete Pavement			0
4.13	Overlaid and/or Widened Old Concrete Pavement			0
4.14	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.1
4.15	Continuously Reinforced Concrete Pavement			3.3
4.16	Continuously Reinforced Concrete Pavement			3.6
4.17	Continuously Reinforced Concrete Pavement			3.6
4.18	Continuously Reinforced Concrete Pavement			4
4.19	Continuously Reinforced Concrete Pavement			3.6
4.20	Continuously Reinforced Concrete Pavement			0
4.21	Continuously Reinforced Concrete Pavement			0
4.22	Intermediate Thickness Asphaltic Concrete Pavement (2½" to 5½")			4.4
4.23	Jointed Reinforced Concrete			4
4.24	Jointed Reinforced Concrete			3.5
4.25	Continuously Reinforced Concrete Pavement			3.5

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