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

by
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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

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES

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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 as chip seals and Novachip a proprietary product.

![Figure 1-1: Original Trailer Design](image-url)
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

<table>
<thead>
<tr>
<th>Pavement</th>
<th>Roadside SPL (dBA)</th>
<th>Onboard SPL (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>135° Mic location</td>
</tr>
<tr>
<td>Novachip (aged)</td>
<td>79.5</td>
<td>100.8</td>
</tr>
<tr>
<td>Microsurfacing (MoPac @ 45th)</td>
<td>80.1</td>
<td>102.3</td>
</tr>
<tr>
<td>Coarse Matrix High Binder</td>
<td>80.7</td>
<td>101.8</td>
</tr>
<tr>
<td>Asphalt (new)</td>
<td>81.5</td>
<td>102.9</td>
</tr>
<tr>
<td>Novachip (new)</td>
<td>81.6</td>
<td>104.4</td>
</tr>
<tr>
<td>JRCP (ungrooved)</td>
<td>81.9</td>
<td>101.2</td>
</tr>
<tr>
<td>CRCP (untined)</td>
<td>82.4</td>
<td>102.9</td>
</tr>
<tr>
<td>Microsurfacing (Corpus Christi)</td>
<td>82.5</td>
<td>105.0</td>
</tr>
<tr>
<td>Asphalt (aged, MoPac @ Duval)</td>
<td>83.1</td>
<td>107.2</td>
</tr>
<tr>
<td>CRCP (tined, aged)</td>
<td>83.8</td>
<td>104.9</td>
</tr>
<tr>
<td>CRCP (tined, new)</td>
<td>83.9</td>
<td>104.3</td>
</tr>
<tr>
<td>Chip Seal (Grade 4)</td>
<td>84.4</td>
<td>104.4</td>
</tr>
<tr>
<td>Asphalt (aged, Decker Lane)</td>
<td>84.4</td>
<td>104.5</td>
</tr>
<tr>
<td>JRCP (grooved)</td>
<td>84.8</td>
<td>104.7</td>
</tr>
<tr>
<td>Asphalt (grooved)</td>
<td>86.0</td>
<td>105.5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Pavement</th>
<th>Roadside SPL (dBA)</th>
<th>Onboard SPL (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>135° Mic location</td>
</tr>
<tr>
<td>Whisper Course</td>
<td>77.2</td>
<td>96.7</td>
</tr>
<tr>
<td>Open-Graded Asphalt</td>
<td>79.7</td>
<td>100</td>
</tr>
<tr>
<td>Dense-Graded Asphalt</td>
<td>79.8</td>
<td>97.7</td>
</tr>
<tr>
<td>Seal Coat (0.76 in. or 19 mm)</td>
<td>84.5</td>
<td>103.9</td>
</tr>
<tr>
<td>Jointed Concrete</td>
<td>89.0</td>
<td>102.3</td>
</tr>
<tr>
<td>Seal Coat (0.52 in. or 13 mm)</td>
<td>89.4</td>
<td>102.2</td>
</tr>
</tbody>
</table>

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.

![Theoretical Absorption Curves of a Porous Grade Pavement for Three Different Thicknesses](image)

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.

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

<table>
<thead>
<tr>
<th>Microphone position</th>
<th>h</th>
<th>d₁ and d₂</th>
<th>d₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>INNER</td>
<td>100 mm</td>
<td>200 mm</td>
<td>283 mm</td>
</tr>
<tr>
<td>OUTER</td>
<td>200 mm</td>
<td>400 mm</td>
<td>566 mm</td>
</tr>
</tbody>
</table>

“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.
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 – Brüel & Kjaer 0.5-inch microphones, Type 4133
2 – Brüel & Kjaer 0.5-inch preamplifiers, Type 2669C with matching 50-foot cords
1 – Brüel & 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.
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.
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](image)

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 $20\times\log$ (speed). This implies that the sound pressure is proportional to the speed of the vehicle because sound level is calculated by $20\times\log(\text{pressure/pref.})$. This is shown below in Figure 3-2.
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.
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
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.
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.
Van vs. 4-Runner Trailer Tests
Outer Microphone Location Overall SPL

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

Van vs. 4-Runner Engine Tests Outer Rear Microphone Location

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 Position](image)

**Figure 3-9: Inner Microphone Position**
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 timin 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>
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<tr>
<th>Table 4-1: Ranking of Tire/Pavement Noise by Pavement Type</th>
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<tbody>
<tr>
<td><strong>Average SPL dBA</strong></td>
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<tr>
<td><strong>Rear</strong></td>
</tr>
<tr>
<td>Thin Surfaced Flexible Base Pavement (Surface Treatment-Seal Coat Combination)</td>
</tr>
<tr>
<td>Coarse matrix high binder (CMHB-F)</td>
</tr>
<tr>
<td>Hot Rubber Seal (HRS)</td>
</tr>
<tr>
<td>Plant Mix Seal (PMS)</td>
</tr>
<tr>
<td>Intermediate Thickness Asphalt Concrete Pavement (2½&quot; to 5½&quot;)</td>
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<tr>
<td>Thin Surfaced Flexible Base Pavement (less than 2½&quot;)</td>
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<tr>
<td>Overlaid and/or Widened Old Concrete Pavement</td>
</tr>
<tr>
<td>Continuously Reinforced Concrete Pavement</td>
</tr>
<tr>
<td>Jointed Reinforced Concrete</td>
</tr>
</tbody>
</table>

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.

![SPL vs. Ride Score for Dense Asphalt Concrete](image)

**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

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<th>Microphone Location</th>
<th>Asphalt (Figure 4-1)</th>
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<tr>
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<tr>
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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.
4. Untined CRCP pavement.
5. SHRP Superpave or CMHB mix design with high voids.
APPENDIX A:
MICHELIN PRODUCT INFORMATION
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.

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ORWL=Outlined Raised White Letters · ORBL=Outlined Raised Black Letters
XL=Extra Load

**UTQG Rating: (P Metric sizes only)**

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**Take care of your tires - Click here for important tire care tips**
APPENDIX B: FIELD DATA
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