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16. Abstract

The effects of traffic noise are a serious concern in the United States and in 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 in field-testing fifteen different pavement types found in Texas, in coordination with six pavement types in South Africa. A test procedure was developed using standard test microphones to simultaneously record noise levels at roadside and onboard the test vehicle within a few centimeters of the tire of a towed trailer. The data were analyzed to determine the tire/pavement interaction noise for the different pavements. The test procedure was designed to develop comparisons of pavements while keeping other variables constant. The results, measured on the standard A-weighted scale, indicated a range of 7 dB of roadside noise levels on the fifteen test pavements in Texas and a roadside noise level on one specially constructed pavement in South Africa to reduce noise that was measured as 3 dB quieter than that of any Texas pavement measured in the study.

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COMPARATIVE FIELD MEASUREMENTS OF TIRE/PAVEMENT NOISE OF SELECTED TEXAS PAVEMENTS

by

Michael T. McNerney, B. J. Landsberger, Tracy Turen, and Albert Pandelides

Research Report Number 7-2957-2

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

April 2000

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

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Research performed in cooperation with the Texas Department of Transportation.

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BACKGROUND

Traffic noise is of serious concern in many urban communities throughout the world. Researchers in many places have developed mitigation measures using traffic noise barriers. In addition, many have made measurements of the effects of pavement type on traffic noise. The Federal Highway Administration (FHWA) has developed a Traffic Noise Model (TNM) that has the ability to consider different pavement types in a noise analysis. In the model TNM and in the SoundPLAN model that was developed in Germany, a 3 dB reduction at the source results in a 3 dB reduction in noise 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. Therefore, through the use of quiet pavements, the traffic noise level at receiver locations near the roadside can be minimized. The purpose of this report is not to evaluate the potential for using quiet pavements for reducing traffic noise, but merely to present results of tests that could later be used in the study and development of quiet pavement technology.

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.

TEST OBJECTIVE

The objective of the test was to measure and analyze the sound spectra and sound levels of individual passes of a test vehicle on as many different pavement types in Texas as possible. It was reported that deeply tined Portland cement concrete pavements constructed in the Houston District produced a loud, annoying noise, greater than that predicted by STAMINA. It was also reported that specially constructed pavements in

South Africa were exceptionally quiet. Therefore, one goal of the testing was to develop a repeatable test method that could be used in South Africa, Europe, and the U.S. to compare Texas pavements to other pavements throughout the world. The prime objective of the test was to produce a high-quality historical data set that could be saved and used by other researchers interested in the effects of tire/pavement noise. To use as few variables as possible, the researchers developed the test plan with the following parameters:

- One speed, 100 ± 2 kph (62 ± 1.2 mph)
- One vehicle with single-axle trailer
- One tire type, Michelin LTX OWL P21575SR15
- Wind conditions less than 8 kph (5 mph)
- No significant grade
- Microphone height at roadside 1.5 m (4.8 ft)
- Microphone distance from roadside 7.5 m (24 ft)
- Dry pavement
- Tire pressure 221 kN/ms (32 psi)
- Weight on axle 7493 N (1,700 lb)
- No other vehicles within 60 m (200 ft) of test vehicle
- No traffic barriers or curbs present unless noted
- The terrain behind the microphone was relatively unobstructed and nonreflective

The layout of the roadside microphones as shown in Figure 1 was adopted from ISO standard 10844 for testing the noise emitted by vehicles. In their search for testing standards in the U.S. and abroad, the research staff determined that, at the time, no test standard existed for the onboard tire noise measurement test intended. Since then, a draft standard, ISO/CD 11819-2, "Method for measuring the influence of road surfaces on traffic noise–Part 2: The close-proximity method," has been distributed for review and comment. For the field tests performed, the microphone onboard the trailer at 135º is in a similar position but closer to the tire than the "inner rear" microphone location in the draft standard. Therefore, with some adjustment, it may be possible to compare these results with test results conducted using the ISO standard.

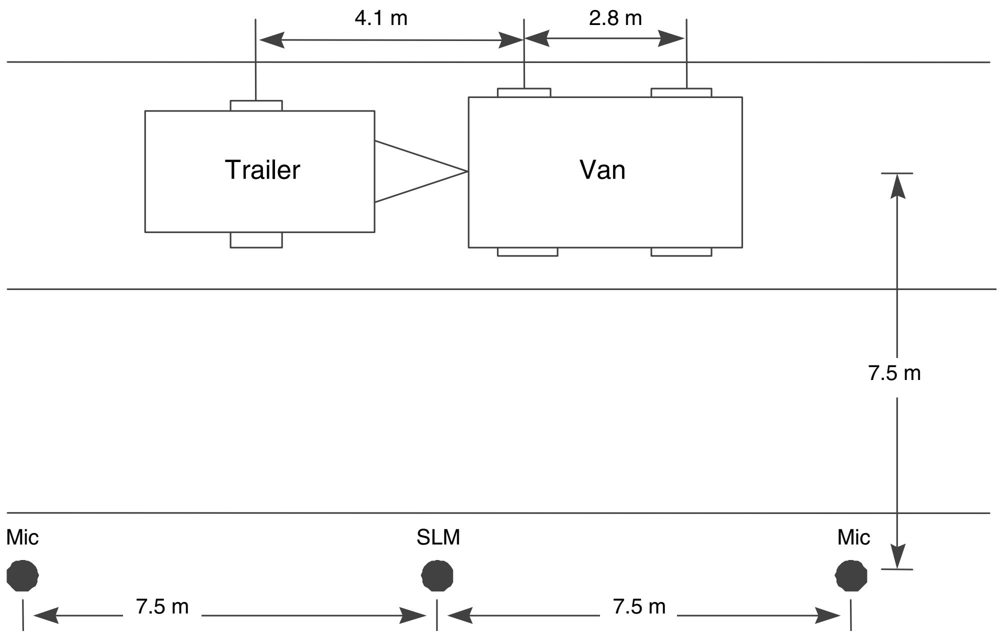

***FIGURE 1**. Schematic of the test vehicle with trailer and the roadside recording setup*

The location of the test microphones onboard the trailer was a modification of the tests conducted by Professor Chalupnik at Washington State University (6). Dr. Chalupnik, now retired, was consulted for his advice in the placement of the onboard microphones. As shown in Figure 2, the microphones were positioned at 135° and 180° from the vehicle's direction of travel, with respect to the trailer's right tire. In the Washington State University tests, the microphones were placed at 90° and 135°; however, the conclusion from these tests was that the results from the 90° location were no different than those from the 135° location.

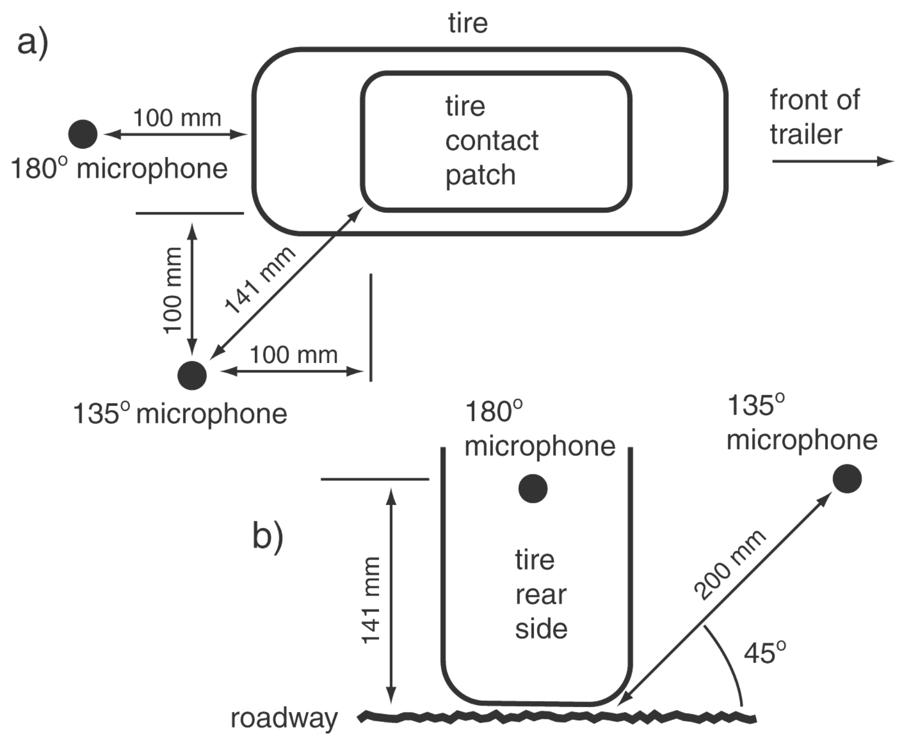

FIGURE 2. *Schematic of the onboard microphone setup in relation to the trailer tire, a) top view and b) rear view*

The test trailer was also developed by the Center for Transportation Research (CTR) on a limited budget. Originally, the trailer was locally constructed as a heavy-duty trailer designed to carry a racecar to the track. The trailer was loaned to CTR, and no modifications were made except for the specially constructed support arms designed to hold the B&K microphones in place and to secure 55-gallon barrels of water used as ballast to achieve the desired weight.

The trailer worked well for the tests, and the data collected were very good. However, in anticipation of participating in the European test trials of the draft ISO standard, CTR later constructed an all-new test trailer to minimize any design effects that could add additional wind noise to the tests. Some of the test pavements were later tested again with the new test trailer. A complete description of the new test trailer and its use is included in the third and final report of this project.

The test vehicle used for these tests was a 1989 GMC minivan with a vehicle empty weight of approximately 1,768 kg (3,897 lb). Both the test vehicle and the test trailer were outfitted with the test tires.

Test conditions required that the test vehicle and trailer travel in the passing lane of a four-lane highway to achieve the proper distance to the roadside microphones and sound-level meters. Only those test runs conducted when no other vehicles were within 198 ft (60 m) of the test vehicle and no other noise activities were present within 10 dB of the roadside site were considered to be satisfactory tests. Multiple passes were made with the test vehicle. For any pass in which another vehicle was within 198 ft (60 m); the engine noise was unusually loud; or another noise source such as a train or aircraft was present, the pass was repeated until at least two, but usually three, clean passes were obtained.

Tests were conducted at times when traffic was at a minimum; in some cases the tests were conducted at night, and in a few cases police assistance was required to create a large enough gap in the traffic. Tests were conducted only on days when dry pavement and wind conditions of less than 16.5 ft (5 m) per second were present. No obstructions, hillsides, walls, curbs, guard rails, barriers, or large reflective surfaces such as parked cars, buildings, or billboards were present in the test locations. All test locations were less than 2 percent grades on tangents. Many planned testing days were abandoned because of unsuitable weather conditions or unsuitable locations.

TEST PROCEDURE

The microphones were B&K ½ in. Type 4133, with matching B&K preamplifiers and cords. The microphones, preamplifiers, and cords were numbered and placed in the same location for each test. Prior to every test a calibration tone for each microphone was recorded on digital audio tape. The onboard microphones had bullet-shaped B&K nose cones to reduce the effects of wind noise. Standard B&K windscreens were also added to each microphone, as shown in Figure 3.

A calibrated type 2 sound-level meter was held between the roadside microphones to record L_{max} for each pass. For the handheld meter used, L_{max} is the highest $L_{pA\ (rms)}$ (root mean square A-weighted pressure level) for a 125 msec time interval during the vehicle pass.

FIGURE 3. *Photo of the onboard microphones with the windscreens in place*

TEST PAVEMENTS

All pavements considered for this project are listed in Table 1. The original test plan identified ten test pavements of both asphalt concrete and portland cement concrete (PCC) with varying age and surface conditions. As testing progressed, additional pavements were added, and pavements in which a suitable test site could not be found were dropped from the testing plan. Test pavements dropped included asphalt with longitudinal grooves, PCC with longitudinal and diagonal grooves, and a Texas open-graded asphalt overlay called "Plant Mix Seal."

The FHWA TNM groups pavements into three categories: PCC, dense-graded asphalt, and open-graded asphalt. The pavements tested in Texas and South Africa represent those three categories as well as some common surface treatments that are used as maintenance procedures on those asphalt pavements.

In Texas, nearly all PCC highway pavements are constructed without joints and have continuous steel reinforcement to provide controlled cracking approximately every 6.6 ft (2 m), with crack widths kept very narrow. This continuously reinforced concrete pavement (CRCP) was tested in new and aged conditions. In Texas, the transverse tining of the pavement is the choice of the contractor building the pavement because it provides excellent skid resistance. Although the specification of the tining is not a TxDOT standard, for new pavements it is generally a regularly spaced tining placed transversely with steel tines as part of the paving machines. One CRCP section without tining was found suitable for testing and was tested even though the pavement was more than 20 years old. In order to find a suitable jointed reinforced concrete pavement (JRCP) for testing, CTR conducted tests on Runway 17R/35L at Austin-Bergstrom International Airport after it had been grooved, but before it was placed back into service after more than 20 years of service as Bergstrom Air Force Base. The parallel taxiway at Bergstrom was tested as an equivalent JRCP without grooving.

TABLE 1. *TEXAS PAVEMENTS CONSIDERED FOR THIS PROJECT*

	PAVEMENT TYPE	PAVEMENT LOCATION	TEST DATE
1	Typical TxDOT Asphalt Pavement — New	Loop 1604 — San Antonio	1/22/97
2	Typical TxDOT Asphalt Pavement — Aged	MoPac @ Braker — Austin	1/26/97
3	TxDOT Asphalt Pavement with Microsurfacing	MoPac @ 45th — Austin	1/26/97
4	Grooved Asphalt Pavement	Robert Mueller Airport Runway 13R/31L	11/20/96
5	Chip Seal Pavement	SH 16 northwest of Helotes	1/22/96
6	TxDOT Coarse Matrix High Binder Asphalt Section	S. MoPac — 3 mile section south of Slaughter Lane — Austin	11/13/96
7	CRCP with Transverse Tining — New	Houston	2/17/97
8	CRCP with Transverse Tining — Aged	Houston	2/17/97
9	Novachip — New	So. Padre Island Dr. — Corpus Christi	3/2/97
10	Novachip — Aged	US 281 just south of SH 46 — San Antonio	1/10/97
11	Asphalt with Longitudinal Grooving	US 281 — San Antonio	Canceled
12	JRCP Ungrooved	Bergstrom AFB, Taxiway 17R	11/18/96
13	JRCP Grooved Transversely	Bergstrom AFB, Taxiway 17R	11/18/96
14	JRCP Grooved Diagonally	Bergstrom AFB, Taxiway 17R	Canceled
15	TxDOT Asphalt Pavement with Microsurfacing	So. Padre Island Dr. — Corpus Christi	3/2/97
16	Control Section — Decker Lane	Decker Lane — Austin	2/21/97
17	CRCP Untined	I-820 — Fort Worth	3/17/97
18	Plant Mix Seal Rubberized Open-Graded Asphalt	No sections available to test	Canceled

The asphalt pavements tested included a control section of aged dense-graded asphalt pavement tested at the beginning and at the end of the testing series; one aged dense-graded asphalt section in the Strategic Highway Research Program (SHRP LTTP section 480001); one new dense-graded asphalt section; and one new asphalt test section of an experimental mix called coarse matrix high binder (CMHB). The SHRP asphalt research program was a 5-year, $50 million program that has resulted in a change in the way asphalt mixes will be designed in the future. At the time of testing, no true SHRP level 2 mixes had been constructed in Texas, but several are currently under contract. The Texas CMHB mix is very similar in properties to the SHRP mix in that it has similar aggregate gradation, approximately 7 percent air voids, and a surface that is a little more open than traditional dense-graded mixes, but is not truly an open-graded asphalt mix.

An asphalt pavement was tested with transverse saw-cut grooving on Runway 13R/31L at Austin Robert Mueller Airport. A longitudinal highway-grooved pavement was included in the test program because of a citizen complaint, but the geometry of the roadway and locations of reflective barriers prevented testing of that section.

Also tested were several types of overlay used over asphalt pavements and common to TxDOT. Microsurfacing is a preventive maintenance surface treatment for asphalt pavements commonly used in Texas. Microsurfacing is a very thin overlay, which is sand asphalt, and polymer layer applied over cracked or slightly rutted asphalt pavements. In the Austin District, the procedure is to spray a thin seal coat on the surface and then immediately apply the microsurfacing over the seal coat with a paving machine. Microsurfacing is generally applied in coats only 0.08 in. (2 mm) in thickness if rutting is not present. Certain high-volume asphalt pavements in the Austin District receive microsurfacing as a preventive maintenance treatment every 2 or 3 years. One microsurfacing pavement was tested in Corpus Christi and one was tested in Austin.

A chip seal surface treatment was also tested. In Texas, a chip seal is constructed first by spraying on a thick seal coat; then grade 4 stones, approximately 0.32 to 0.40 in. (8 to 10 mm) in diameter, are placed and rolled into the seal coat. Excess stones are swept away, leaving a rough surface with high skid resistance.

Novachip is a proprietary product that is used in Texas on a limited basis to improve the skid resistance of pavements and provide a durable wearing surface. Novachip could be classified as an open-graded asphalt pavement; however, it is usually only applied as an overlay approximately 0.40 in. (10 mm) in thickness. It has the surface texture of an open-graded asphalt with approximately 10 to 15 percent air voids on the surface. The Novachip is a licensed product of a process patented in France that applies a water-based, polymer-modified asphalt emulsion just seconds before application of a hot-mixed asphalt with single-sized aggregate. The specially constructed paving machine applies the emulsion and asphalt mix in a single pass and screeds it level. The mix is rolled once with a very light steel-wheel roller to align the single-sized aggregate; the mix sets in only 5 minutes.

Two Novachip pavements were tested. One was a 4-year-old test pavement in San Antonio that was the subject of a research project that conducted 3 years of performance monitoring on the pavement (7). This pavement constructed with the French-made machine showed no signs of distress after the 3-year period. The second Novachip pavement tested was constructed with an American-made paving machine only months before testing. An open-grade asphalt overlay constructed as "Plant Mix Seal" in the Fort Worth District was suggested as a possible test pavement, but no suitable locations were found in time for it to be included in the test program.

Tests were also conducted for this project in South Africa under cooperative agreement with the University of Stellenbosch. The South African tests included the six following pavement types:

- "Whisper Course" asphalt,
- 0.52 in. (13 mm) seal coat,
- jointed concrete pavement,
- 0.76 in. (19 mm) Cape Seal,
- dense-graded asphalt, and
- open-graded asphalt.

The tests were conducted using a tire and methodology as similar as possible to the Texas tests. The complete test report is provided in Appendix B.

DATA ANALYSIS

The data from the field tests consisted of sound-level meter readings of L_{max}; digital audio tape recordings of the noise at the two roadside stations and at the two trailer onboard stations for each run on each test pavement; and field notes concerning test conditions. The L_{max} reading is the highest $L_{pA\ (rms)}$ (root mean square A-weighted pressure level) for a 125 msec time interval during the vehicle pass. The digital audio tape was recorded at a sample rate of 44,100 samples per second at 16-bit resolution. The digital audio tape data are used as the best measure of the noise level at the roadside site. The sound-level meter reading is used as a check of the sound level extracted from the digital audio tape.

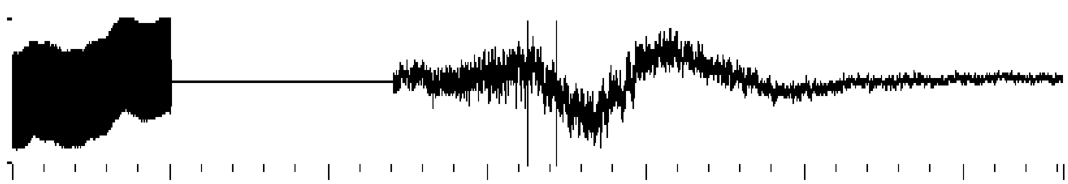

FIGURE 4*. Example noise signal recorded at roadside on digital audio tape and displayed on computer screen (display shows calibration tone and roadside noise from vehicle pass)*

The digital audio tape recording was read into a desktop computer, and the signal was displayed as recorded. Each recording contains a calibration tone for all the passes on a particular test pavement as shown in Figure 4. For the data analysis, the calibration tone and the usable vehicle pass runs, determined from the field notes and the observed waveform, were selected and saved in separate data files. These files were initially analyzed using JBL-Smaart software to compare them to the handheld meter readings (8).

For the detailed analysis, waveforms were Fourier transformed in overlapping groups of 4,096 data points (approximately 93 msec), and the amplitude was converted to decibel levels and displayed in 1/3 octave bands as shown in Figure 5. The calibration tone was known to be 94 dB at 1,000 Hz and thus provided the absolute scaling for the vehicle pass signal. For the drive-by tests, the portion (usually about ½ second) of the recorded signal corresponding to when the test vehicle was abeam the microphone was used to calculate L_{max}. L_{max} was calculated using Eq 1.

$$L_{max} = 10\log\sum_{i=1}^{n} 10^{L_{li}/10} \qquad (1)$$

where L_{li} is the sound intensity level and for practical purposes is equivalent to the sound pressure level. The sum is taken from all the A-weighted 1/3-octave band pressure levels.

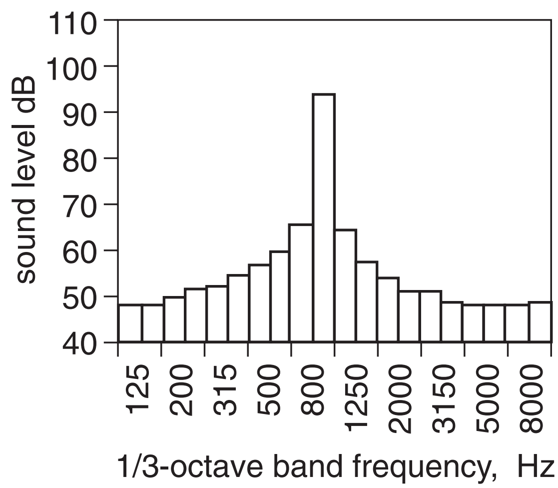

***FIGURE 5**. Example of 1/3-octave band data reduction (calibration tone is shown)*

Since 4,096 data points for the L_{max} calculation from the digital tape recording are roughly equal to 93 msec of signal, and the L_{max} from the handheld sound-level meter was over a 125 msec interval, the two readings are roughly comparable. The handheld meter readings were used as a check on the results of the analysis of the recorded noise.

***TABLE 2.** RECORDED NOISE LEVELS OF TEXAS PAVEMENTS*

Pavement	Roadside Data Rankings (dBA)			Onboard Data Rankings (dBA)	
	Average	Left Channel	Right Channel	135º location Mic	180º location Mic
Novachip (aged)	79.5	79.8	79.2	100.8	101.7
Microsurfacing (MoPac @ 45th)	80.1	79.9	80.3	102.3	104.0
Coarse Matrix High Binder	80.7	80.6	80.7	101.8	104.0
Asphalt (new)	81.5	81.6	81.4	102.9	105.0
Novachip (new)	81.6	82.0	81.2	104.4	106.6
JRCP (ungrooved)	81.9	81.8	82.0	101.2	104.2
CRCP (untined)	82.4	83.0	81.8	102.9	105.4
Microsurfacing (Corpus Christi)	82.5	82.6	82.3	105.0	107.6
Asphalt (aged, MoPac @ Duval)	83.1	82.9	83.3	107.2	109.7
CRCP (tined, aged)	83.8	84.0	83.5	104.9	107.8
CRCP (tined, new)	83.9	83.8	84.0	104.3	106.8
Chip Seal (Grade 4)	84.4	84.5	84.3	104.4	106.1
Asphalt (aged, Decker Lane)	84.4	84.1	84.7	104.5	107.2
JRCP (grooved)	84.8	85.1	84.5	104.7	106.3
Asphalt (grooved)	86.0	86.3	85.6	105.5	108.8

The results for the roadside and onboard test runs are shown in Table 2. Since the two roadside microphones should have recorded nearly identical waveforms, the calculated sound levels were averaged. The difference between the recordings from the two roadside microphones averaged approximately 0.5 dBA, with a standard deviation of 0.3 dBA, and was always less than 1.2 dBA. The L_{max} levels calculated from the roadside data were typically within 1 dBA of the handheld meter L_{max}. For test pavements where there were multiple good runs, the runs were analyzed to provide some idea of the repeatability of the test results. In those cases the results in Table 2 are averages. Different runs on the same pavements consistently had results that differed by less than 1 dBA, with a 0.7 dBA average and a 0.3 dBA standard deviation. These differences are likely due to small variations in test conditions, such as vehicle speed, extraneous noise, and pavement surface. Therefore, all data for the Texas pavement tests should be considered to have a ±1 dBA margin of error.

Using the recorded roadside data, Table 2 lists the pavements in order of increasing traffic noise. Note that some of the pavements are very close in noise level. For example, there are five pavements with noise levels between 81.5 and 82.5 dBA. Considering the previously mentioned margin of error, more extensive testing might change the relative order of some of the pavements. However, the researchers are confident that the general trend observed is accurate. From the quietest pavement (aged Novachip, a brand of open-graded asphalt) to the noisiest (grooved asphalt), there is a 6.5 dBA difference in noise level. Excluding the grooved pavements, there was a 4.9 dBA difference from the quietest to the next noisiest pavement (chip seal). CMHB pavement had comparatively low noise levels for the roadside and onboard recordings, placing second and third, respectively, among the fifteen pavements. In the roadside and 135º location onboard measurements, CMHB had a noise level just over 2 dB higher than the aged Novachip. This is significant since CMHB is similar to the SHRP recommended mix.

The 1/3-octave band levels for all fifteen pavements, listed in order of increasing traffic noise, are shown in Figure 6. Unlike those in Table 2, these levels have not been A-weighted, the standard adjustment for hearing sensitivity. The graphs show that tire/pavement interaction noise is generally wide band, with measurable frequency content from below 200 to over 3,000 Hz. They also show that the predominant content is below 2,000 Hz. When hearing sensitivity is considered, the frequency content below 500 Hz is not significant because the frequency content of tire/pavement interaction noise of concern is from 500 to 2,000 Hz. Differences in the frequency content of the roadside noise can best be illustrated by examining, in order of increasing volume, three pavements that span the noise characteristics of the group tested.

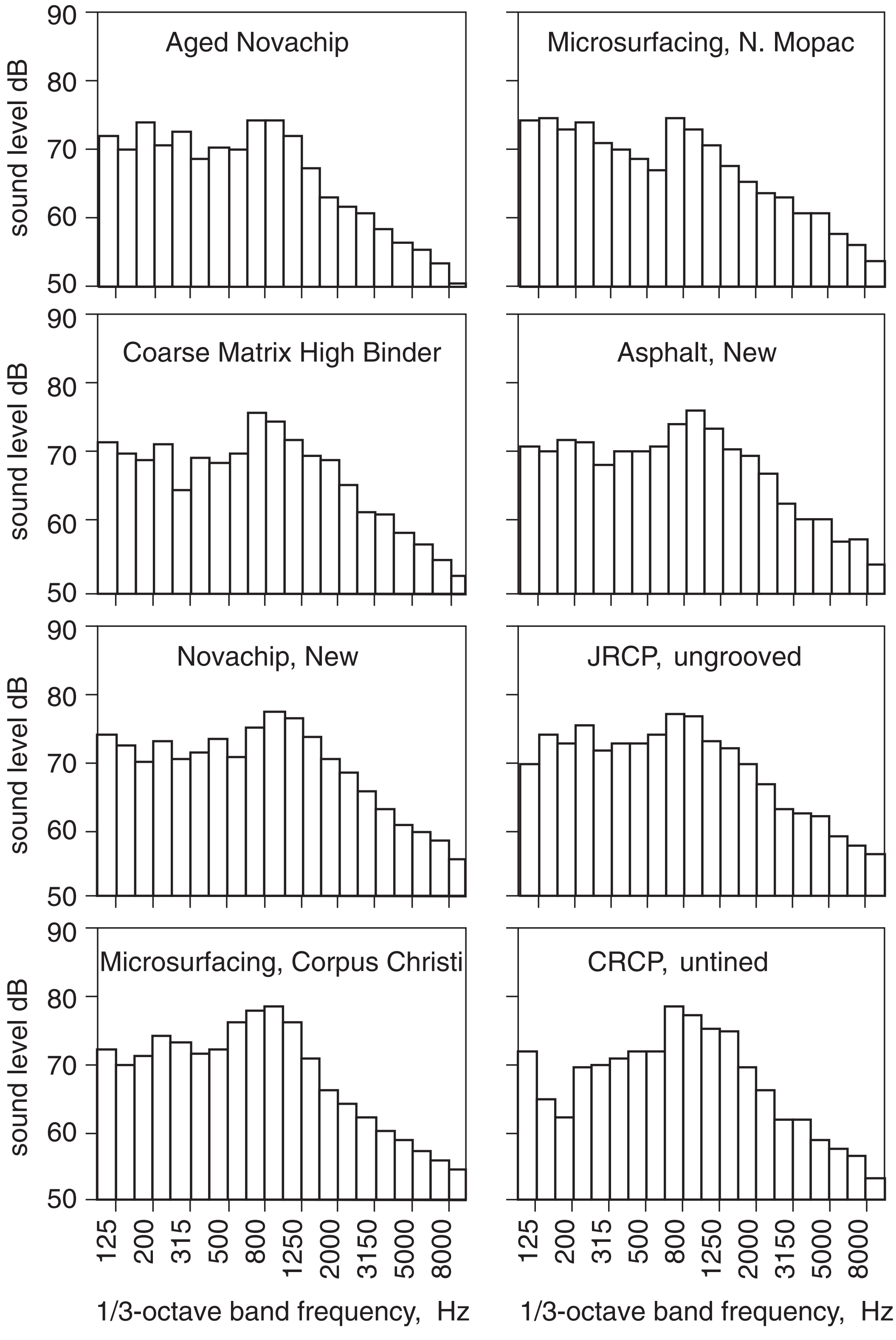

***FIGURE 6**. Spectral sound level of roadside noise of Texas pavements*

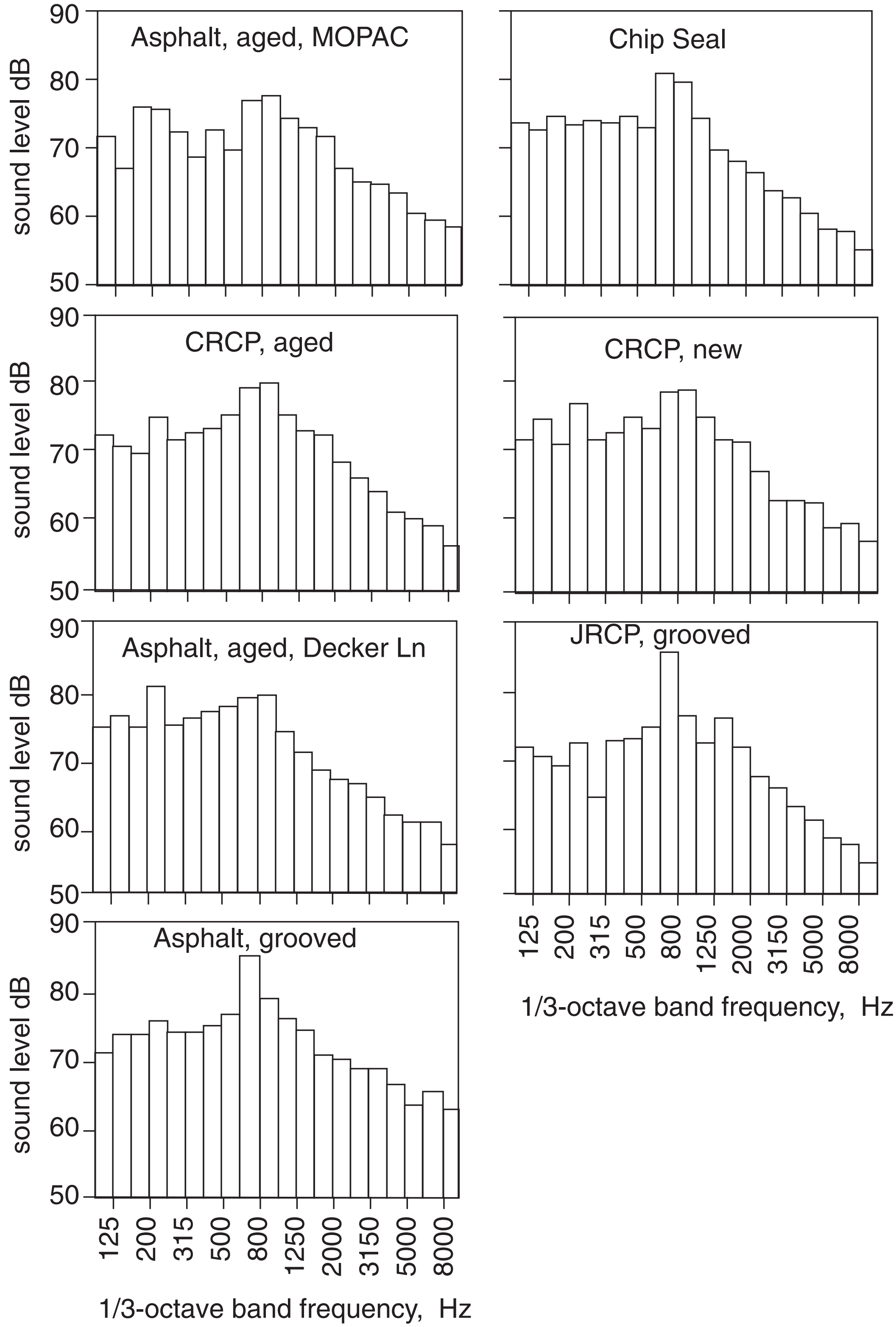

FIGURE 6 (continued). *Spectral sound level of roadside noise of Texas pavements*

The 1/3-octave band noise levels from one of the roadside microphones for aged Novachip, ungrooved JRCP, and grooved JRCP are shown in Figure 7. In a comparison of three spectra from top to bottom, there is an overall trend of increasing pressure levels in nearly every 1/3-octave band. Also notice that the grooved asphalt spectrum has a peak near 800 Hz, which corresponds to the frequency of the tires hitting the grooves. This octave band is at least 5 dB higher than the adjacent bands, which is considered as having a tone present near 800 Hz. This kind of tone is perceived as being more irritating to listeners than wide band noise at the same intensity level. The result is that the grooved JRCP is perceived as even more noisy than the recorded overall decibel level would indicate. This result is one indication of the importance of performing a spectrum analysis of the noise signal, since the tone information is absent in the overall decibel level but is obvious in the spectrum analysis. Novachip, the quietest pavement tested, had, by comparison, noticeably lower sound pressure levels at frequencies above 1,000 Hz.

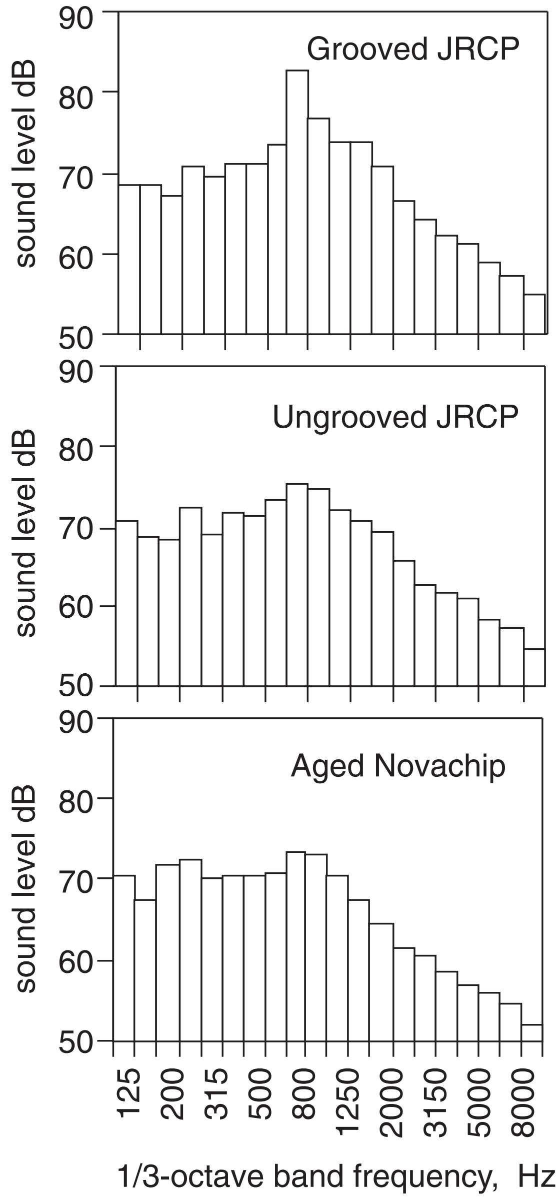

FIGURE 7*. Frequency spectrum of three different pavements for comparison*

The onboard data from the two microphones mounted on the trailer near one of the tires were recorded to capture a noise signal that was predominately tire/pavement interaction noise and less vehicle machine noise or aerodynamic noise (as compared to the roadside data). Also, since the largest single component of modern automobile noise is tire/pavement interaction noise — even at the roadside — by correlating the onboard data to the roadside data, it may be possible to estimate roadside noise levels from the onboard noise levels. The onboard noise levels recorded in these tests averaged 21 dBA higher than the roadside levels, with a standard deviation of 1.3 dBA. The sound levels at the 180º location, which is directly behind the tire, averaged 2.3 dBA higher than the sound levels from the microphone at the 135º location. Compared to the roadside measurements, the onboard noise levels for the different pavement tests show a similar span of dBA differences (~7 dBA), and the pavements are in about the same position when ranked by noise level. There are, however, a few exceptions. For example, aged asphalt (MoPac @ Duval) was the noisiest pavement on the onboard tests, but on the roadside tests its noise level was closer to the average for all the pavements. The reasons for the difference are unknown, but there are several possibilities. The difference could be due to the surface being rougher yet more absorptive. The roughness would generate high noise levels while the high absorption would cause higher attenuation as the sound propagates. Alternatively, some of the difference could simply be due to limitations in the accuracy of the measurements.

The 1/3-octave band levels from the 135º location and the 180º location onboard microphones for all fifteen pavements are shown in Figures 8 and 9, respectively, and are listed in the same order as they are in Table 2. These levels have not been A-weighted. The graphs show that tire/pavement interaction noise measured near the tire has a broadband signal with most content below 2,000 Hz. The onboard 135º location and roadside plots show a very consistent difference of approximately 21 dBA for the 1/3-octave bands in the interval of most concern for highway noise, 500 to 2,000 Hz. The much higher levels of noise for the onboard data in the very low frequency range, below 315 Hz, and for the high frequency range, above 4,000 Hz, are not significant since those frequencies contribute little to the A-weighted noise level. The onboard 180º location, 1/3-octave band data is very similar to the 135º location data with a 0 to 3 dBA increase in most 1/3-octave band pressure levels.

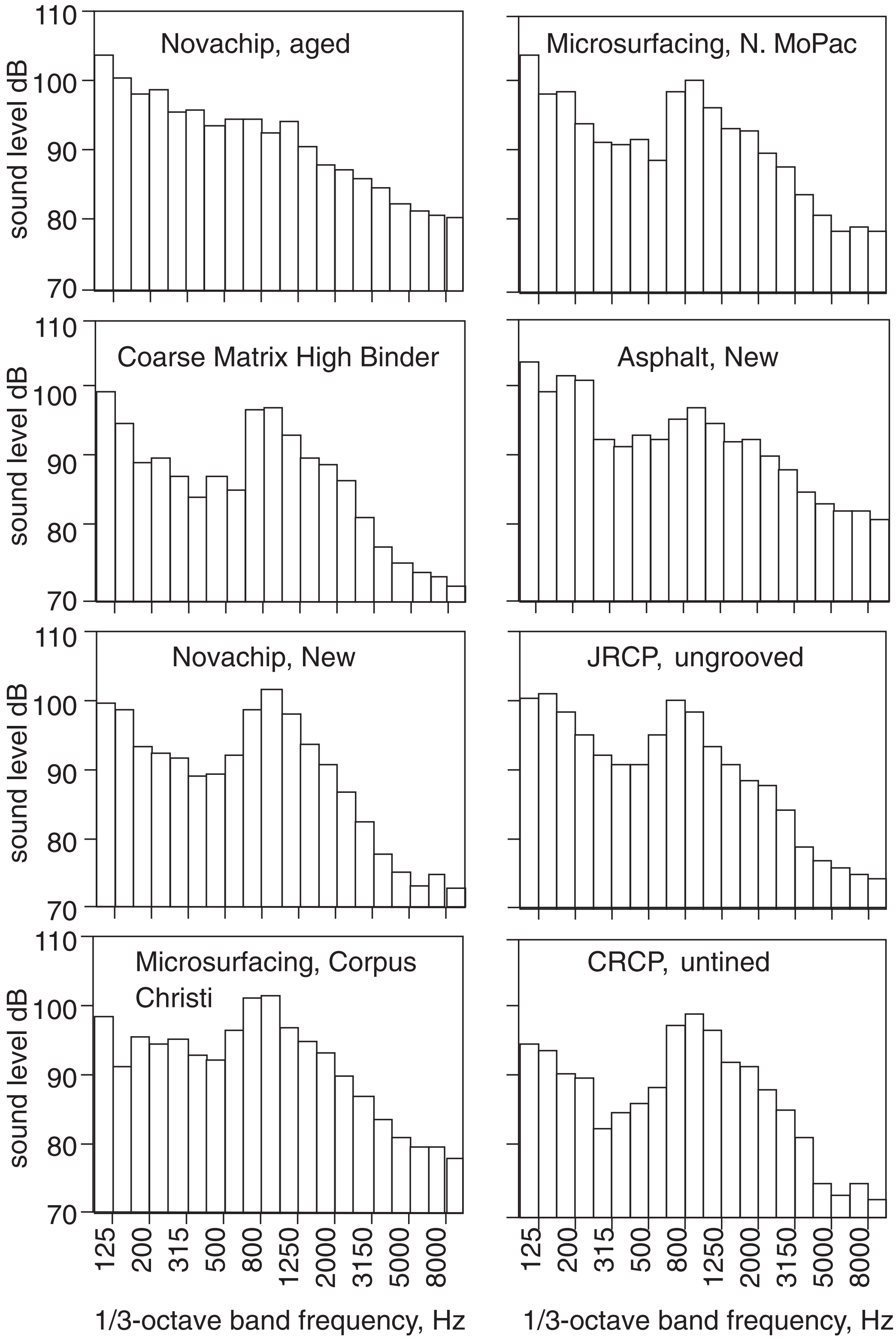

***FIGURE 8**. Spectral sound level of 135º location angle microphone, onboard noise of Texas pavements*

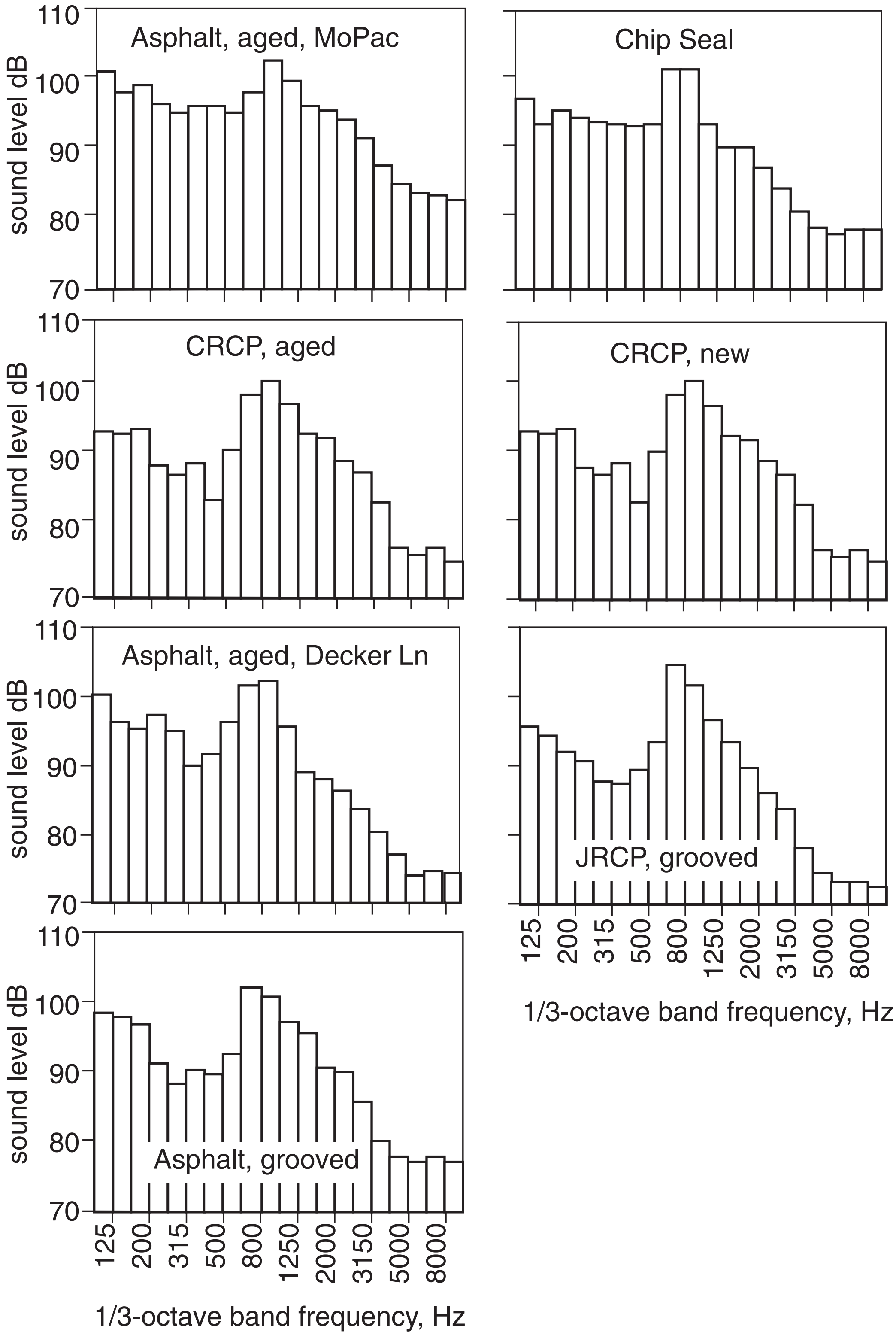

FIGURE 8 (continued). *Spectral sound level of 135º location angle microphone, onboard noise of Texas pavements*

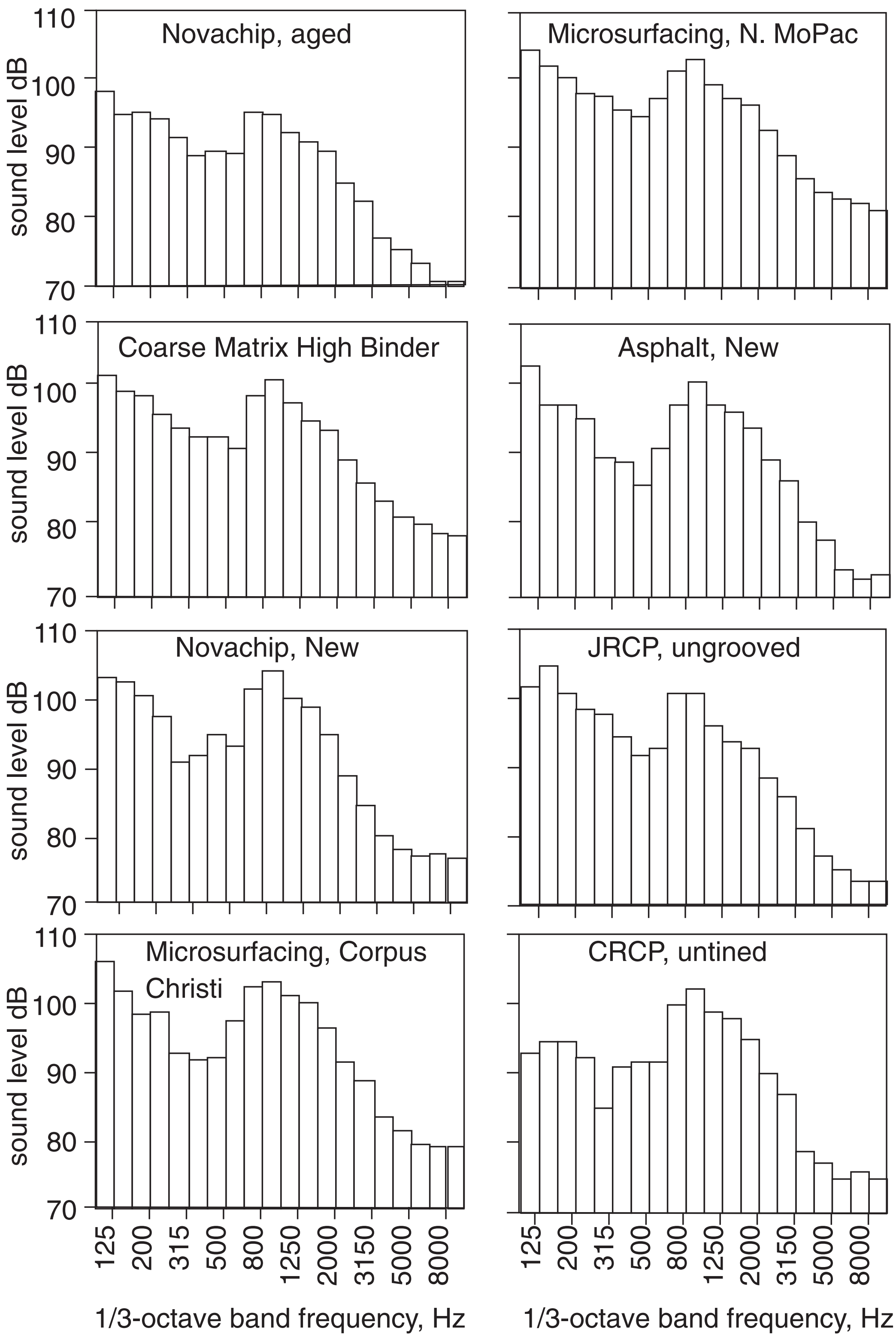

***FIGURE 9**. Spectral sound level of 180º location angle microphone, onboard noise of Texas pavements*

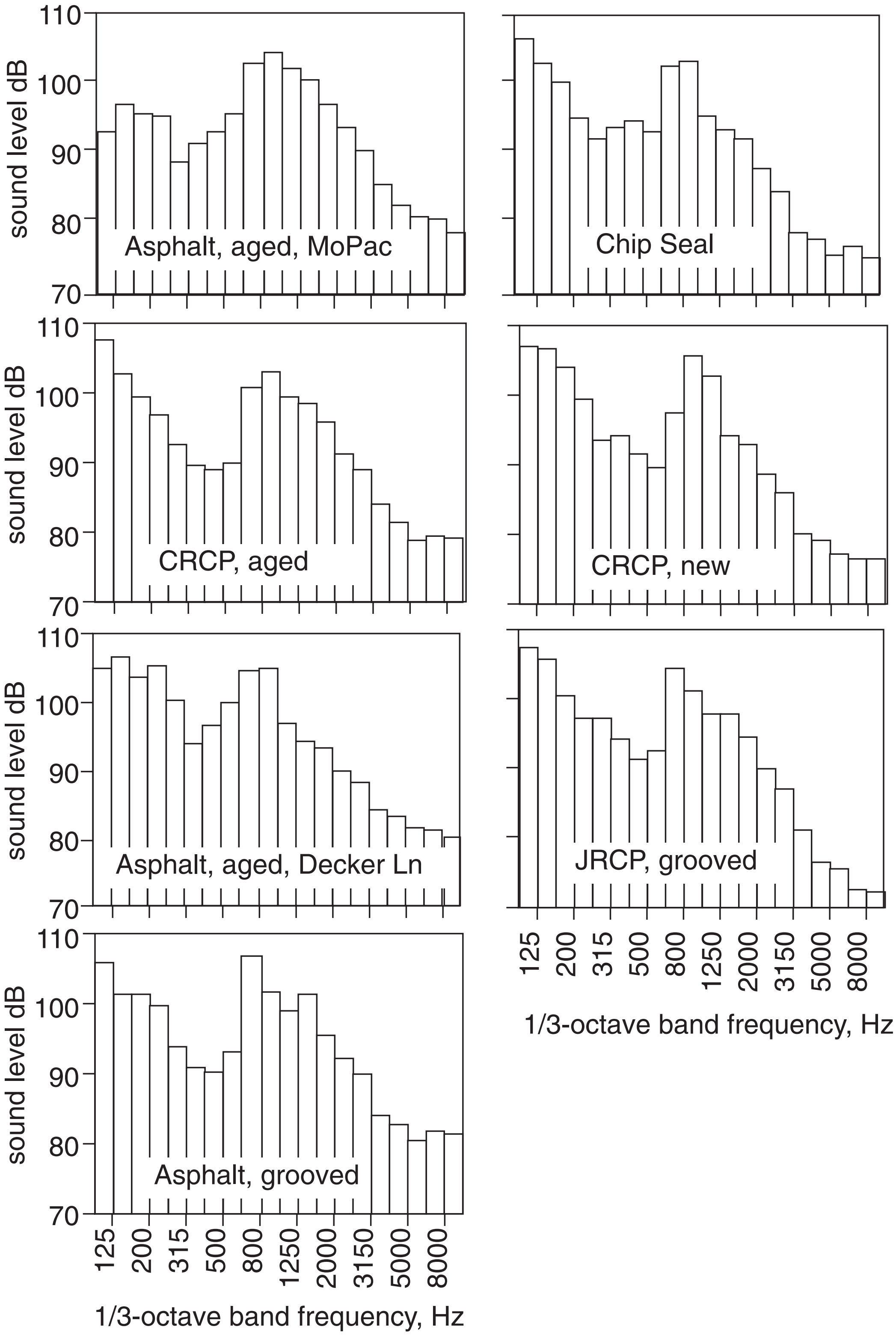

FIGURE 9 (continued). *Spectral sound level of 180º location angle microphone, onboard noise of Texas pavements*

The 1/3-octave band spectrums of the aged Novachip test from the roadside and the two onboard microphones are shown in Figure 10. The onboard 135º location and roadside plots show a very consistent difference of approximately 20 dB for the 1/3-octave bands in the interval of most concern for highway noise, 500 to 2,000 Hz. For this pavement, the correlation between onboard and roadside data is good. As noted earlier, we see higher levels of noise in the very low frequency range, below 125 Hz for the onboard data. The onboard 180° 1/3-octave band data is very similar to the 135º location data with a 0 to 3 dB increase in most pressure levels in the 500 to 2,000 Hz range. Again, at the octave bands below 125 Hz the noise levels are much higher than those at the roadside and even higher than those recorded at the 135º location position. The high frequency noise above 4,000 Hz is also noticeably higher, but these higher levels on the two frequency spectrum extremes do not affect the perceived noise levels.

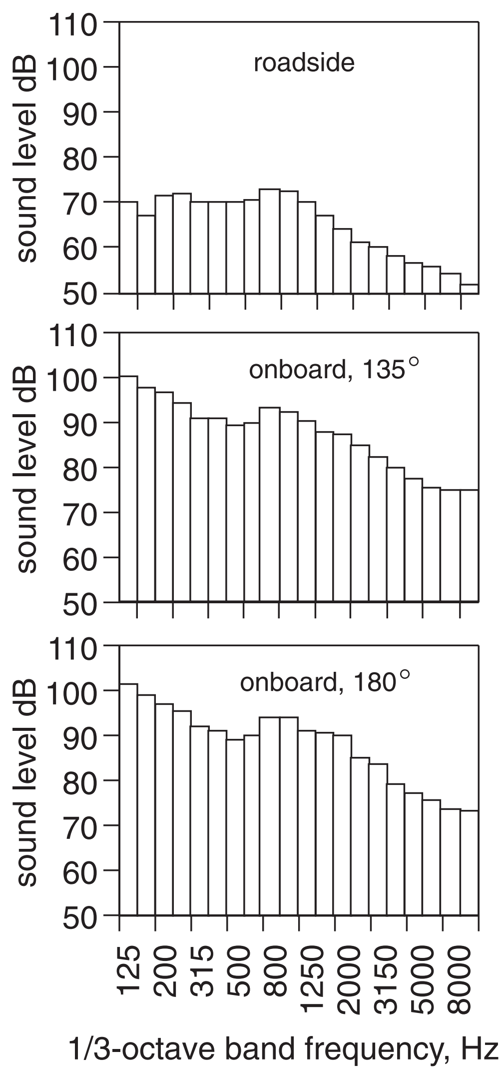

***FIGURE 10**. Frequency spectrum for aged Novachip recorded at roadside and two onboard, near-tire locations (angle measured from direction of travel)*

The onboard recording method can often be used in situations where the roadside method is impractical, but the noise levels of importance are not the onboard but the roadside levels. Therefore, a method to estimate roadside noise levels from onboard measurements would be very useful. A simple method of estimating the roadside noise level from the onboard level would be to assume sound level reduction owing to spherical spreading of the sound field from the source and excess attenuation owing to absorption during propagation. However, the noise measured onboard the trailer is primarily from one tire, while the noise measured on the roadside has contributions from all the tire/pavement interactions in addition to engine and aerodynamic noise. Also, the onboard microphones are well inside the near field of the source, and it is not clear how far they are from the effective source of the noise. Finally, the excess attenuation is usually unknown. However, based on the data obtained so far, the onboard data appear to be a reasonable tool for estimating relative noise levels between different types of pavements. Also, because the difference between roadside noise levels and onboard noise levels for the pavements in this study was fairly consistent, it may be used with onboard levels to estimate roadside noise levels caused by vehicles similar to the one used in these tests.

TABLE 3. *RECORDED NOISE LEVELS OF SOUTH AFRICAN PAVEMENTS*

Pavement	Roadside SPL dBA	Onboard Data Rankings (dBA)	
		135º location Mic	180º location Mic
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

The roadside noise measurement results from the testing in South Africa are shown in Table 3. Testing was done on six different pavements. While care was taken to conduct the tests the same way they were conducted in Texas, a different trailer and vehicle were used. Consequently, quantitative comparisons with the Texas data may not be very accurate. The large differences in noise levels among the South African pavement tests are noteworthy. For the roadside measurements, the difference from the noisiest to the quietest pavement was more than 12 dBA. In particular, the quietest pavement, called Whisper Course and designed to reduce traffic noise, was measured at 77.2 dBA at roadside; this made it the quietest pavement measured during this project. A comparison of the results of the onboard to the roadside measurements for the four quietest South African pavements is similar to that for the Texas pavements. The reason for the apparent low difference between the onboard and roadside measurements for the last two South African pavements is unknown.

CONCLUSIONS AND RECOMMENDATIONS

The pavements tested in Texas and South Africa showed significant differences in the level of noise generated during the test vehicle pass; noise level differences were 7 dBA in the Texas tests and 12 dBA in the South African tests. These results indicate that the noise characteristics of pavement surface types are significant and should be considered prior to a selection of highway surfacing.

For this purpose, the different types of highway pavements should be measured and classified according to their characteristics for noise level generation. Our test results are for a passenger automobile test vehicle. For a complete set of pavement characteristics for noise level generation, tests using trucks or truck tires should also be performed.

The frequency content of the different pavements' measured noise, both at the roadside and near the tire, shows significant differences in spectrum when noisy pavements are compared to quiet pavements. In particular, the quiet pavements have a significant drop in the frequency content at 1,600 Hz and above.

The noise levels measured onboard the test vehicles in the Texas tests show good correlations with the roadside results. The relative noise levels among the different pavements are reasonably consistent between the two methods. The fact that some pavements change positions between roadside and onboard measurements in the relative noise level rankings may indicate different levels of sound absorption by the pavement. It may be possible to estimate the roadside noise level caused by automobiles by taking onboard roadside measurements from a test vehicle like the one used in these tests and by adjusting the levels according to the differences between roadside and onboard noise levels measured in these tests.

Further testing of pavements for noise characteristics using both the roadside and onboard methods is recommended. Testing of sound absorption characteristics of different pavement surfaces should help to explain some of the differences in the noise levels measured on the pavements. Knowledge of absorption characteristics along with the noise level measurements should allow estimation of the noise generated at the tire/pavement interaction and thus indicate the effects of surface texture on noise production. Continuation of onboard testing will help to develop reliable ways to correlate onboard measurements with roadside noise levels.

A dedicated noise-measurement trailer should be built specifically for future noise tests. The new trailer should conform as closely as possible to the draft ISO/CD 11819-2 "Method for measuring the influence of road surfaces on traffic noise—Part 2: The close-proximity method." Recommended improvements for the new trailer would include the following:

- more stable microphone-holding mechanism,
- greater distance from the tow vehicle,
- minimum potential wind noise from trailer components, and
- shielding from the other trailer tire.

The data collection test equipment should be integrated with GPS to provide more precise speed measurement during testing. Very small differences in speed result in significant differences in noise levels.

Since this research was conducted, a new trailer has been procured and new tests have been conducted. Refinements in the testing techniques will be reported in the third and final report of this project but do not negate any of the findings in this report.

Both the data collected in this series of tests and those collected in the next series of trailer tests are archived and could be made available to accredited researchers in the field.

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APPENDIX A

Draft Summary Report

Road Noise Measurements in South Africa
by

Renaldo Lorio

Introduction

As part of Project 7-2957, "Use of Pavement Surfaces To Attenuate Traffic Noise," road noise measurements using the roadside as well as the trailer method of measurement were performed here in South Africa. This project started in July 1996 and was completed in early December 1996. The aim of the project was to conduct measurements on six different road surfaces and to determine their noise generation in the near field as well as in the far field in order to compare the results to the values measured by the research team at The University of Texas at Austin (UT) on selected Texas pavements.

Measurements

The Trailer Method

The trailer method was conducted according to the procedures provided by UT. In essence, this method consists in mounting a microphone at two prescribed positions behind the left tire of the trailer, traveling at a speed of 100 km/h over a selected road section, and measuring the sound intensity generated. Measurements were taken as the test vehicle assembly traversed the road section. From this data, mean and standard deviation (STD) as well as coefficient of variance (CV) values were computed. The results are shown in Table A1 (Summary of Information). The road section was traversed twice in order to obtain the data for each set.

The Roadside Measurements

Roadside measurements were performed according to the ISO 11819—Part 1 standard. The roadside measurement set up was passed three times by the test vehicle assembly in order to obtain the results for each data set.

Test Vehicle Assembly

The test vehicle for this study was a Toyota Hi-Lux 4x4 fitted with Michelin 215/75/14 LTX M/S tires. The trailer was a normal flatbed commercial trailer rented from a rental vendor and modified to accommodate tires identical to those mounted on the tow vehicle. The trailer was loaded with sandbags to an axle load of 4 kN. The tire pressure was 220 kPa — the tire pressure used commercially in South Africa.

Test Sections

Six road sections of different types were selected for this study, and a brief discussion on each will follow. The sections were selected according to the requirements stipulated in the report, "Description of Test Procedures and Equipment," by Tony Bivelacqua.

The tests were conducted in two locations in South Africa: Johannesburg in the Gauteng province and a location near Cape Town in the Western Cape province. The Western Cape province is situated in the southwestern tip of the continent. Gauteng is 1,500 km from the Western Cape in a northeasterly direction. The location at which the tests were conducted in the Western Cape is essentially at sea level (100 m above sea level), whereas Johannesburg is 1,600 m above sea level.

The Whisper Course (OGA) was available only in Johannesburg. The research team decided to conduct tests on two other road surfaces at the same altitude in order to establish a basis for comparison. The three sections in Gauteng were as follows.

1. Whisper Course Asphalt: The team selected the M2 West motorway in Johannesburg because this motorway had been paved with the new generation open-grade asphalt, also referred to as porous asphalt and nicknamed "Whisper Course." A high reduction in noise generation on the M2 West motorway has been reported by the Transitional Metropolitan Council of Greater Johannesburg after the construction of the Whisper Course. A value of 5.9 dBA has been reported. The Whisper Course layer on the M2 West was constructed in 1993. Thus, sufficient time has elapsed to provide insight into the effect of clogging of the voids in the mix.

2. 13 mm Seal: Surface seals on pavements are abundant in South Africa for economic reasons. Since these seals are used on major arterials in urban areas, the researchers decided to add it to the test matrix. The surface seal selected for this study was a 13 mm maximum chip size seal with bitumen rubber as binder. This section is located on the R24 motorway between Gillooly and the East Gate shopping center with residential and commercial areas adjacent to the roadside. The R24 motorway is the road connecting Johannesburg International Airport with Johannesburg CBD. It also links Johannesburg to the eastern metropolitan areas and therefore carries a high traffic volume.

3. Jointed Concrete Pavement (JCP): This pavement section is located on the northwestern section of the western bypass of Johannesburg on the N1. The N1 is a national route connecting the north and the south of the country. This road carries a high traffic load: 60,000 vehicles per day per direction, 10 percent of which includes heavy vehicles. The tined transverse grooves have an average depth of 3.4 mm. Complaints about the noisiness of this roadway that have been received in the past aided in the decision to add it to the test program.

The other three sections that have been tested are located in the Western Cape, northeast of Cape Town. They are all new pavement surfaces (constructed in 1996). The three sections are described below.

1. 19 mm Cape Seal: This section tested is on the MR00188 road, a rural road 60 km northeast of Cape Town.
2. Dense-graded asphalt: This section is also situated on the MR00188 and is adjacent to the 19 mm section tested.
3. Open-graded asphalt: This section is situated 100 km northeast of Cape Town near Malmesbury on the N7 (national route to Namibia), but it is designated as a provincial road (TR01101).

The tests were normally carried out between 10 a.m. and 3 p.m. in order to miss the peak-hour traffic. However, the tests carried out on the M2 motorway were at night since the traffic is much lighter then. Because of rainy weather occurring during the tests in the north, and owing to time constraints resulting from logistics problems, the test plan had to be altered so that the tests on the R24 and N1 were conducted during the day (the morning before the team had to return to the Western Cape). This posed some difficulty because the roadside measurements were taken amidst regular traffic and, thus, the noise of the test vehicle assembly could not be isolated from the surrounding noise generated by the other traffic.

Discussion of the Results

Table A1 shows that the Whisper Course OGA in Gauteng produced the lowest dBA values with the trailer method and the second-lowest values on the normal dB scale. The OGA on the N7 route (TR01101) produced the lowest values on the dB scale. It could be argued that there is more noise emitted with frequencies in the lower ranges on the M2 Whisper Course than on the OGA on the N7 section tested.

The roadside measurements of these two sections produced the lowest and second-lowest values, with the Whisper Course OGA producing the lowest (see Table A1).

It is not surprising that the 19 mm and 13 mm seals, with their coarse surface texture (average texture depth of 2.89 mm for the 13 mm seal and 2.32 mm for the 19 mm seal), produced a substantially louder noise of up to 5.8 dB and 4.9 dBA when measured with the trailer method. The roadside noise measurements measured alongside the 13 mm and 19 mm seals were, respectively, 7.8 dB and 8.6 dB louder than the OGA surfaces.

The measurements made with the trailer method on the JCP seem to indicate that the JCP is quieter than the roads with the seal surfaces. However, the roadside measurements indicate a different result. The roadside noise levels measured were in fact much the same. A plausible explanation for this phenomenon could be that the concrete surface does not absorb as much sound energy as do the asphalt surfaces.

In Table A1, the texture depth measured with the sand patch test for the JCP is reported as varying between 0.8 mm and 1.2 mm. It should be kept in mind that the average texture depth determined by this method will be due to the volume of glass beads that have been collected in the grooves and therefore may not mean much. This idea is supported by the fact that the groove depth measured with a laser-facilitated minitexture meter apparatus was found to be 3.4 mm.

It should be reiterated that the roadside measurement procedures on the N1 and the R24 had to be adapted because of the traffic intensity. It was not possible (owing to the high traffic volumes) to get the test vehicle alone on the test section and thus eliminate any contributory noise produced by other vehicles during roadside measurements. Consequently, to get an indication of what the roadside noise would be, researchers measured the noise level of vehicles corresponding with the test vehicle's size and shape in the normal traffic flow. The vehicles measured were limited to those in traffic traveling more or less at 100 km/h.

Closing Remarks

The research team concluded from the low CV values reported in Table A1 that there is merit in using the trailer method to measure the near field of the noise source (between the tire and the contact patch).

It is clear that the road surface plays an important role in the generation of noise. The primary factor appears to be the degree of smoothness relative to a flat plan of the road surface. The noise level is further reduced by an increase in the voids that enhance the sound-absorptive properties of the mix. This is in fact the basis of the Whisper Course asphalt.

The fact that the difference in dB and dBA values for both the trailer and the roadside measurements do not differ significantly from the OGA to the seals cannot be readily explained. One would intuitively expect the seals to produce lower dBA values owing to their having more activity in the lower frequency ranges.

It is apparent from the results obtained in this study that the new porous asphalt in the family of the OGAs has definite benefits. These benefits include the reduction of noise generated at the source as well as the material's ability to absorb sound energy. The latter reduces the propagation of noise to the surrounding environment.

Before Table A1 can be completed, the researchers must obtain further road information (as-built data) from the respective road authorities.

TABLE A1. *DRAFT SUMMARY OF INFORMATION*

Type of material	**OGA Whisper Course**	**13 mm seal**	**JCP**	**19 mm seal**	**DGA**	**OGA**
Road designation	M2 West	R24	N1	MR00188	MR00188	TR01101
City/Town	Johannesburg	Johannesburg	Johannesburg	Klipheuwel	Klipheuwel	Malmesbury
Province	Gauteng	Gauteng	Gauteng	Western Cape	Western Cape	Western Cape
Trailer Measurements						
Behind the wheel (dB)	**111**	**115**	**112.9**	**116.2**	**112.9**	**109.5**
STD	1.45	1.4	1.32	0.86	0.66	0.9
CV	1.30%	1.24%	1.17%	0.74%	0.66%	0.83%
Behind the wheel (dBA)	**98**	**101.6**	**104.6**	**107.5**	**104.1**	**101**
STD	1.27	0.84	0.84	0.89	0.72	1.13
CV	1.30%	0.83%	0.81%	0.83%	0.69%	1.12%
At the side of the wheel (dB)	**110.9**	**117.3**	**112.9**	**116.2**	**114**	**110.1**
STD	1.42	1.42	1.36	1.05	0.78	1.07
CV	1.28%	1.21%	1.21%	0.90%	0.69%	0.97%
At the side of the wheel (dBA)	**96.7**	**102.2**	**102.3**	**103.9**	**97.7**	**100**
STD	0.87	0.67	0.82	0.81	0.97	0.78
CV	0.90%	0.65%	0.80%	0.77%	1%	0.78%
Roadside measurements						
In dB	**80.2**	**90.3**	**91**	**87.5**	**82.1**	**82**
In dBA	**77.2**	**89.4**	**89**	**84.5**	**79.8**	**79.7**
Sand patch test (average texture depth in mm)	1.99	2.89	0.8–1.2	2.32	0.88	1.79
Pavement temperature (°C)	21	38	N/A	40	40	38
Air temperature (°C)	19	27	N/A	28	28	27
Construction date	1993	1996	1978	1996	1996	1996
Classification	New	New	Old	New	New	New
Voids		N/A	N/A	N/A		
Layer thickness (mm)	50	N/A	N/A	N/A	40	Unknown
Traffic volume (AADT)	50,000		60,000			
Percentage heavy vehicles	10%		10%			

APPENDIX B

SAND PATCH DATA

			Diameter			Mult. Test		Mult. Test
	M1 (cm)	M2 (cm)	M3 (cm)	M4 (cm)	Avg. (cm)	Avg. (cm)	Avg. Depth (cm)	Avg. Depth (cm)
Asphalt (new)								
Test #1	33.02	31.75	30.48	32.39	31.91	32.07	0.06	0.06
Test #2	31.75	32.70	32.70	31.75	32.23		0.06	
Bergstrom								
Test #1	34.50	35.00	32.00	35.00	34.13	32.81	0.05	0.06
Test #2	31.00	31.00	32.00	32.00	31.50		0.06	
Chip Seal								
Test #1	16.51	15.24	N/A	N/A	15.88	15.88	0.25	0.25
Test #2	16.51	15.24	N/A	N/A	15.88		0.25	
CRCP (aged)	34.93	33.66	36.83	35.56	35.24		0.05	
CRCP (new)	27.94	26.04	27.31	27.31	27.15		0.09	
Decker Lane	19.05	18.42	19.05	18.80	18.83		0.18	
Microsurfacing	24.45	26.04	27.31	27.94	26.43		0.09	
Novachip (old)								
Test #1	22.86	24.13	N/A	N/A	23.50		0.12	
Test #2	22.86	24.13	N/A	N/A	23.50		0.12	
Novachip (new)	20.96	22.54	21.59	20.96	21.51		0.14	
S. MoPac								
Test #1	23.70	23.00	24.00	22.70	23.35	23.72	0.12	
Test #2	23.10	22.80	24.00	24.50	23.60		0.11	0.11
Test #3	25.00	24.00	24.20	23.60	24.20		0.11	