# Comparative Field Measurements of Tire Pavement Noise of Selected Texas Pavements

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ABSTRACT:
The effects of traffic noise are a serious concern in the United States and 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 conducted field testing on 15 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 was 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 of the 15 test pavements in Texas and a roadside noise level of one pavement in South Africa that was 3 dB quieter than any Texas pavement.

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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 by using of traffic noise barriers. In addition, many have made measurements of the effects of pavement type on traffic noise. The FHWA is developing a Traffic Noise Model (TNM) that will have the ability to consider different pavement types in a noise analysis. As in SoundPLAN, which was developed in Germany, a reduction at the source of 3 dB for a quieter pavement 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. However, in automobiles 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 paper 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 on going in many countries. Researchers in South Africa have developed an open-graded asphalt pavement called “Whisper Course” that had a noise reduction of 9 dB over a single seal surface and 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 5 to 10 mm aggregate size mix

(4). In another test using a special porous elastic road surface, Meiarashi measured a noise reduction of 13 and 6 dB for automobiles and trucks, respectively, over open-graded asphalt (5). Unfortunately, porous elastic road surfacing is expensive, flammable, and deteriorates quickly.

## 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 from as many different pavement types in Texas as possible. It was reported that heavily tined Portland cement concrete pavements constructed in the Houston District produced very loud annoying noise higher than predicted by STAMINA. It was also reported that specially constructed pavements in South Africa were exceptionally quiet. Therefore, one necessity of the testing was to develop a repeatable test method that could be used in South Africa, Europe and the US 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 minimize as many variables as possible, the test plan was developed 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 roadside, 1.5 m (4.8 ft)
- Microphone distance roadside, 7.5 m (24 ft)
- dry pavement
- Tire pressure, 221 kN/ms (32 psi)
- Weight on axle, 7493 N (1700 lb)
- No other vehicles within 60 m (200 ft) of test vehicle
- No traffic barriers or curbs were present unless noted
- The terrain behind the microphone was relatively unobstructed or non-reflective

The layout of the roadside microphones as shown on Figure 1 was adopted from ISO standard 10844 for testing the noise emitted by vehicles. In searching for testing standards in the US and abroad, it was determined that at that time no test standard existed for the onboard tire noise measurement test we intended to perform. 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. In the onboard method used, the microphone at 135º is in a similar but closer to the tire position compared to the "inner rear" microphone in the draft standard.

Therefore, with some adjustment, it may be possible to compare our results with results from tests run under the ISO standard.

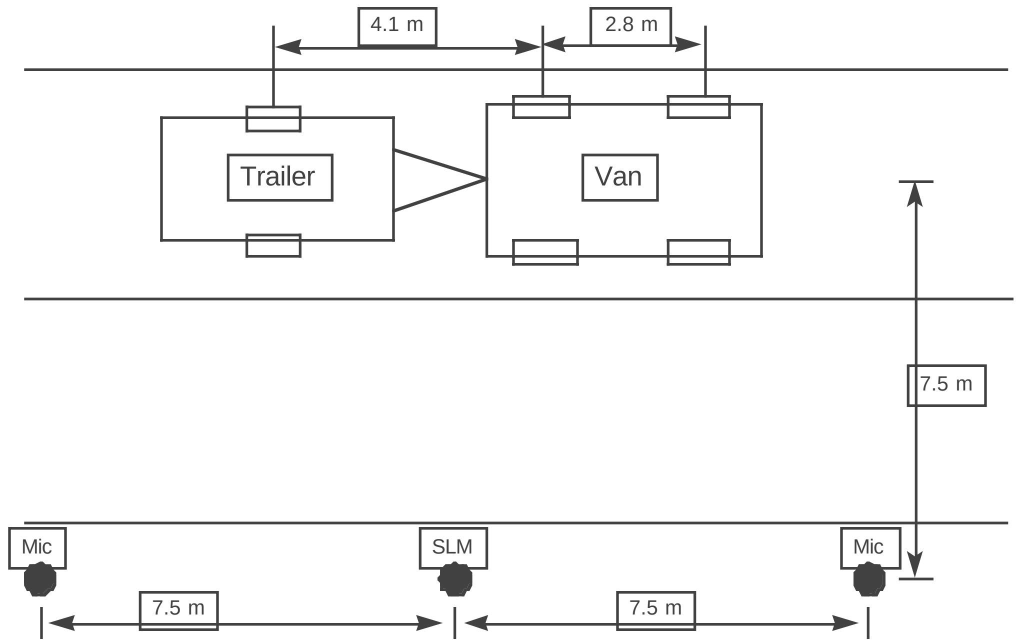


**FIGURE 1**. Schematic of the test vehicle with trailer and the roadside recording setup.

The location of the test microphones was a modification of the tests conducted by Professor Chalupnik at Washington State (6). Dr. Chalupnik, now retired, was consulted for his advice in the placement of the onboard microphones. The layout of the microphones as shown in Figure 2 were at 135° and 180° from the direction of travel with respect to the right tire on the trailer. In the Washington State University tests, the microphones were placed at 90°and 135° , however, the conclusion from those tests was that the 90° location provided no difference from the 135° location.

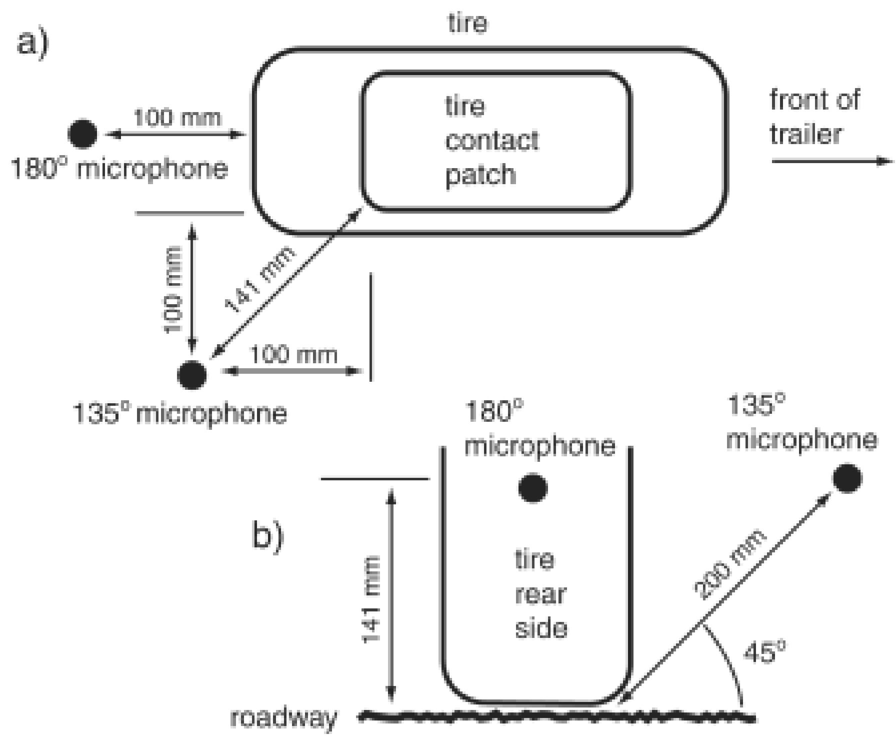


FIGURE 2**.** Schematic of the onboard microphone setup in relation to the trailer tire. a) top view and b) rear view.

**TEST PROCEDURE**

The microphones were B & K “1/2 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, for each microphone, a calibration tone was recorded on digital audio tape. The on board 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 hand held 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 drive by. Multiple passes were made with the test vehicle. For any pass in which another vehicle was within 60 meters, the engine noise was unusually loud, or another noise source was present such as a train or aircraft, 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. All tests were conducted on roadways with four or more lanes so that the test vehicle could use the second lane from the shoulder and the roadside microphones could be placed on the shoulder and have only test pavement in the field between the microphone and test vehicle. Many testing days were abandoned because of unsuitable weather conditions or unsuitable locations.

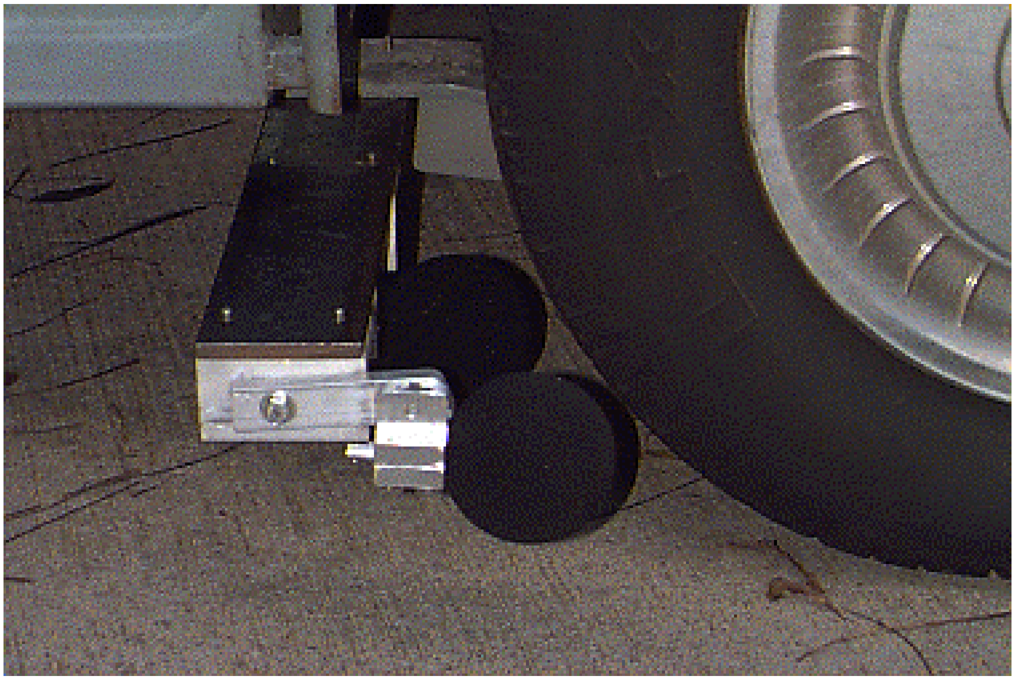

**FIGURE 3**. Photo of the onboard microphones with the wind screens in place.

## TEST PAVEMENTS

All pavements considered for this project are listed in Table 1. The original test plan identified 10 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 pavement 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 Traffic Noise Model 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 2 meters with crack widths kept very narrow. This continuously reinforced concrete pavement (CRCP) was tested in a new and aged condition. 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 pavement without tining was found suitable for testing and was tested even though the pavement was over twenty years old. In order to find a suitable jointed reinforced concrete pavement (JRCP) for testing, tests were conducted on Runway 17R/35L at Austin Bergstrom International Airport, after it had been grooved, but before it was placed back into service after over 20 years of service as Bergstrom Air Force Base. The parallel taxiway at Bergstrom was tested as an equivalent JRCP pavement but 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 | SH16 northwest of Helotes | 1/22/96 |
| 6 | TxDOT Course Matrix High Binder Asphalt Section | S. Mopac - 3 mile section south of Slaughter Lane | 11/13/96 |
| 7 | CRCP PCC with Transverse tining - New | Houston | 2/17/97 |
| 8 | CRCP PCC 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 SH46 - San Antonio | 1/10/97 |
| 11 | Asphalt with Longitudinal Grooving | US 281 - San Antonio | Cancelled |
| 12 | JRCP Ungrooved | Bergstrom AFB, Runway 17R | 11/18/96 |
| 13 | JRCP Grooved Transversely | Bergstrom AFB, Runway 17R | 11/18/96 |
| 14 | JRCP Grooved Diagonally | Bergstrom AFB , Runway 17R | Cancelled |
| 15 | TxDOT Asphalt Pavement with Microsurfacing | So. Padre Island Dr - Corpus Christi | 3/2/97 |
| 16 | Control Section - Decker Lane | Decker Lane | 2/21/97 |
| 17 | CRCP Untined | IH820 - Fort Worth | 3/17/97 |
| 18 | Rubberized open - graded asphalt | No sections available to test | Cancelled |

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 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 which 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 at this time. 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 the surface 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 type of overlay common to TxDOT over asphalt pavements. Microsurfacing, is a preventive maintenance surface treatment for asphalt pavements commonly used in Texas. Microsurfacing is a very thin overlay which is a 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, then immediately apply the microsurfacing over the seal coat by paving machine. Microsurfacing is generally applied only 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 in Austin.

A chip seal surface treatment was also tested. In Texas, a Chip Seal is constructed by spraying on a thick seal coat then grade 4 stones of approximately 8 - 10 mm in diameter (grade 4) 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 10 mm in thickness. It has the surface texture of an open-graded asphalt with approximately 10 - 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 one 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 up in only five minutes. Two Novachip pavements were tested. One was a four year old test pavement in San Antonio which was the subject of a research project that conducted three years of performance monitoring on the pavement (7). This pavement which was constructed with the French made machine showed no signs of distress after the three year period. The second Novachip pavement tested was constructed only months before testing with an American made paving machine. An open-grade asphalt overlay constructed as “Plant Mix Seal” in the Fort Worth District was suggested to be tested but no suitable locations were found.

## 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 on board 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 drive by. The digital audio tape was recorded at a sample rate of 44100 samples per second at 16 bit resolution. The digital audio tape data is 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.

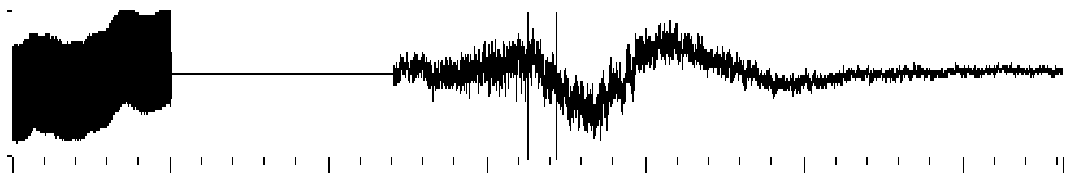

**FIGURE 4**. Example noise signal recorded at roadside on digital tape and displayed on computer screen. Display shows calibration tone and roadside noise from vehicle pass.

The digital audio tape recording was read into a desktop computer and the signal 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 drive by runs, determined from the field notes and the observed waveform, are selected and saved in separate data files. These files were initially analyzed using JBL-Smaart software for comparison to the hand held meter readings (8). For the detailed analysis, waveforms were Fourier transformed in overlapping groups of 4096 data points (approximately 93 msec), the amplitude converted to decibel levels and displayed in 1/3 octave bands as shown in Figure 5. The calibration tone was known to be at 94 dB at 1000 Hz, and thus provided the absolute scaling for the drive by signal. For the drive by tests, the portion (usually about 1/2 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)

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

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

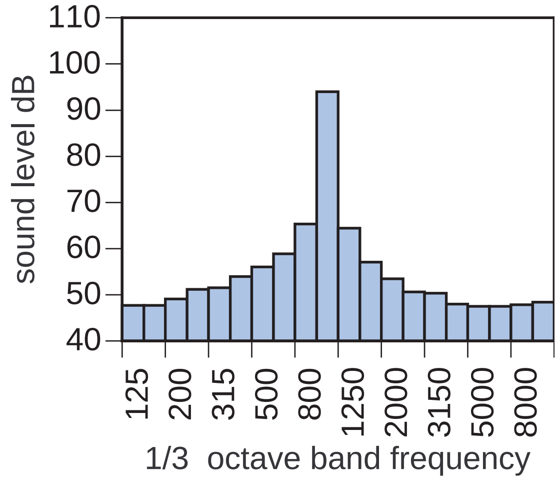


**FIGURE 5**. Example of 1/3 octave band data reduction. Calibration tone is shown.

Since 4096 data points for the $L_{max}$ calculation from the digital tape recording equates roughly to 93 msec of signal and the $L_{max}$ from the hand held sound level meter was over a 125 msec interval, the two readings are roughly comparable . The hand held 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 Mic | 180º 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 |
| Course 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 Ch.) | 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 on board 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 $L_{max}$ calculated from the roadside data were typically within 1 dBA of the hand held meter $L_{max}$. For test pavements where there were multiple good runs, the runs were analyzed to give some idea of the repeatability of the test results. In those cases the results in Table 2 are averages. The results between different runs on the same pavements consistently had differences 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, the pavements have been listed 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 we are confident the general trend observed is accurate. From the quietest (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). The coarse matrix high binder pavement had comparatively low noise levels for the roadside and on board recordings, placing second and third respectively, among the 15 pavements. In the roadside and 135º on board measurements, it was just over 2 dB higher than the aged Novachip. This is significant since coarse matrix high binder is similar to the SHRP recommended mix.

The 1/3 octave band levels for all 15 pavements, listed in order of increasing traffic noise, are shown in Figure 6. Unlike 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 3000 Hz. They also show that the predominant content is below 2000 Hz. When hearing sensitivity is considered, the frequency content below 500 Hz is not significant such that the frequency content of tire pavement interaction noise of concern is from 500 to 2000 Hz. Going from quiet to loud pavements, differences in the frequency content of the roadside noise can best be illustrated by examining three pavements that span the noise characteristics of the group tested.

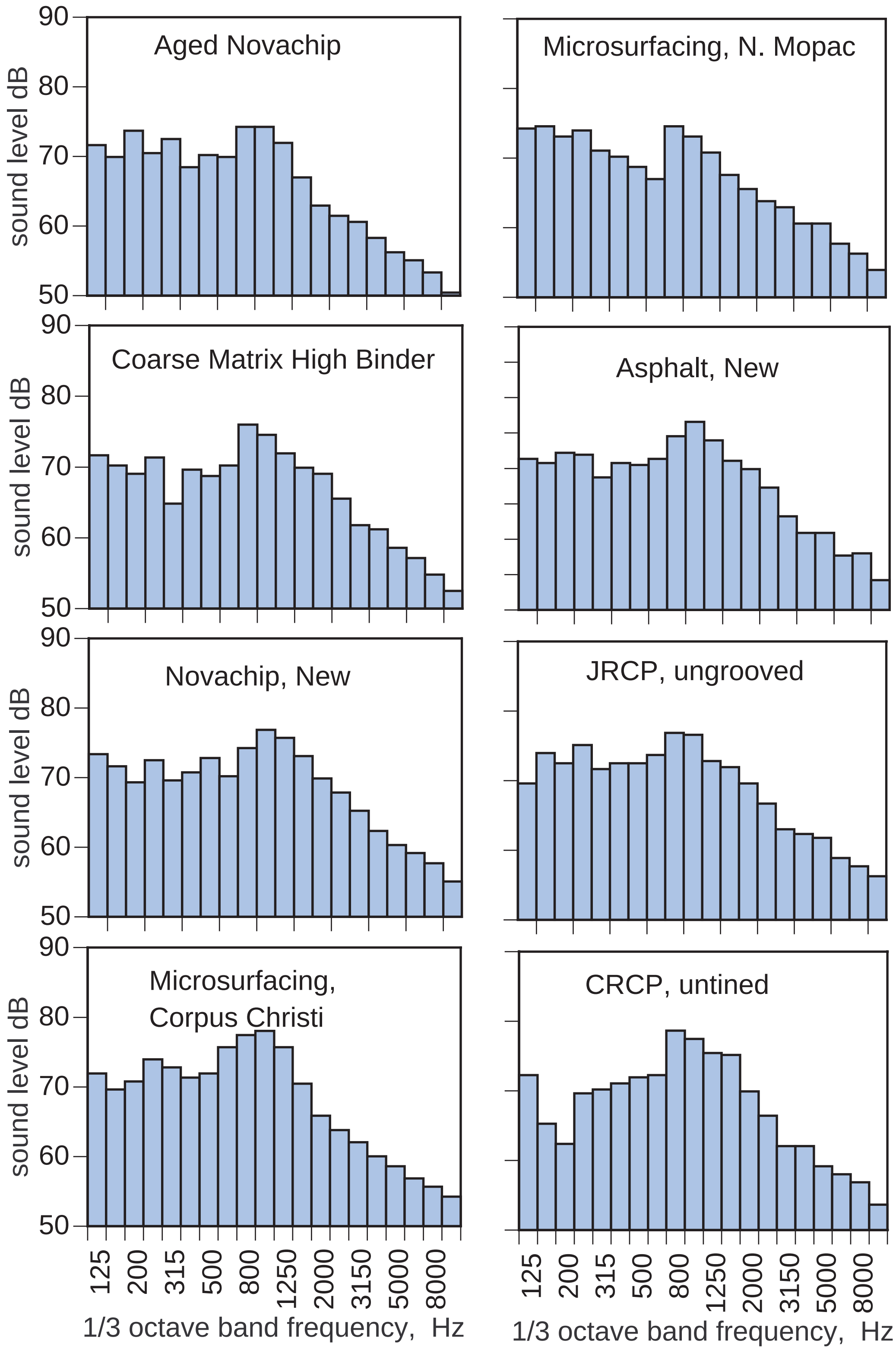


**FIGURE 6.** Spectral sound level of roadside noise of Texas pavements.

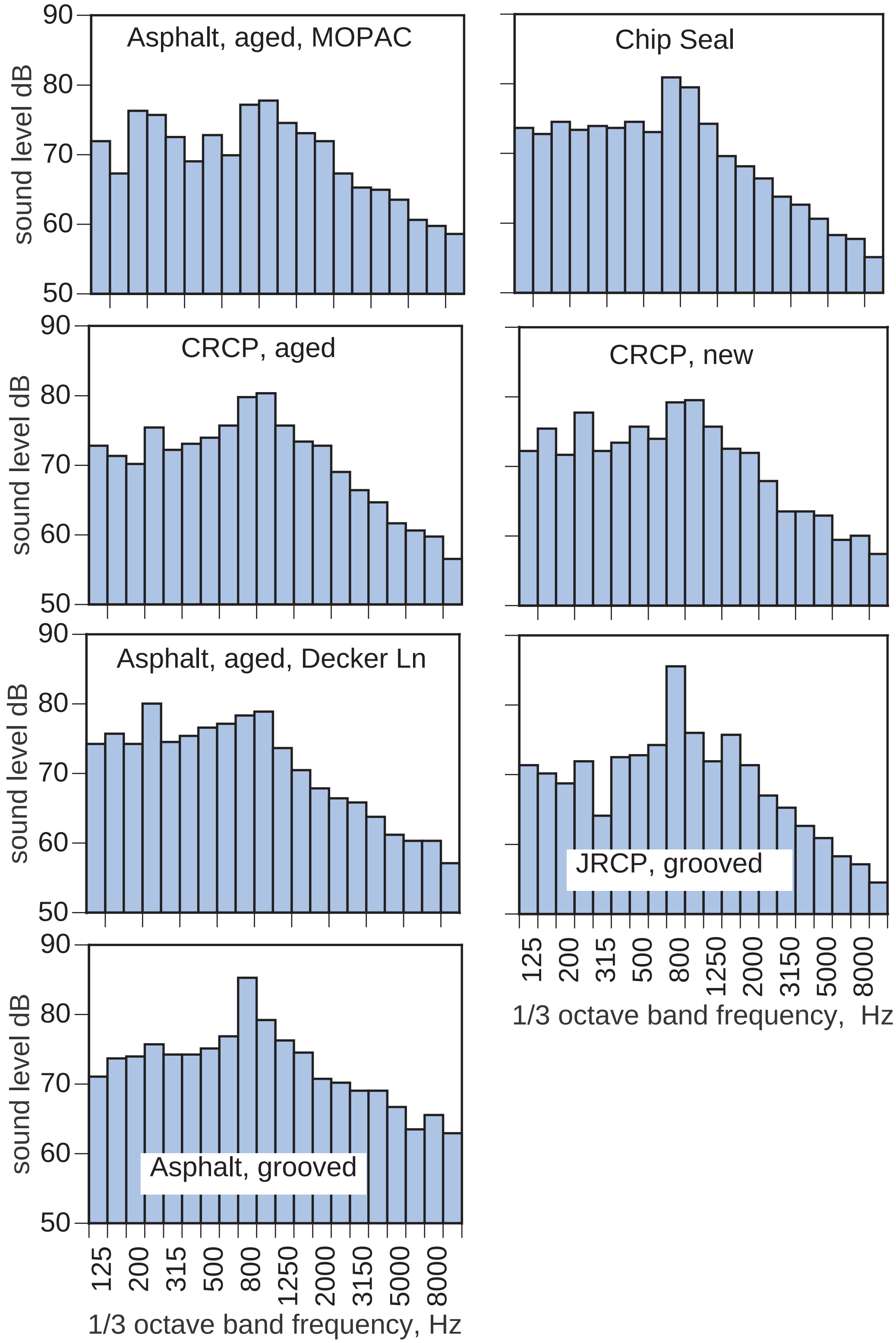


**FIGURE 6 (continued).** Spectral sound level of roadside noise of Texas pavements.

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. Comparing the three spectra from top to bottom, there is an overall trend of increasing pressure level 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 grooves hitting the tires. This octave band is at least 5 dB higher than the adjacent bands which is considered as having a tone present near 800 Hz. A tone such as this 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 1000 Hz.

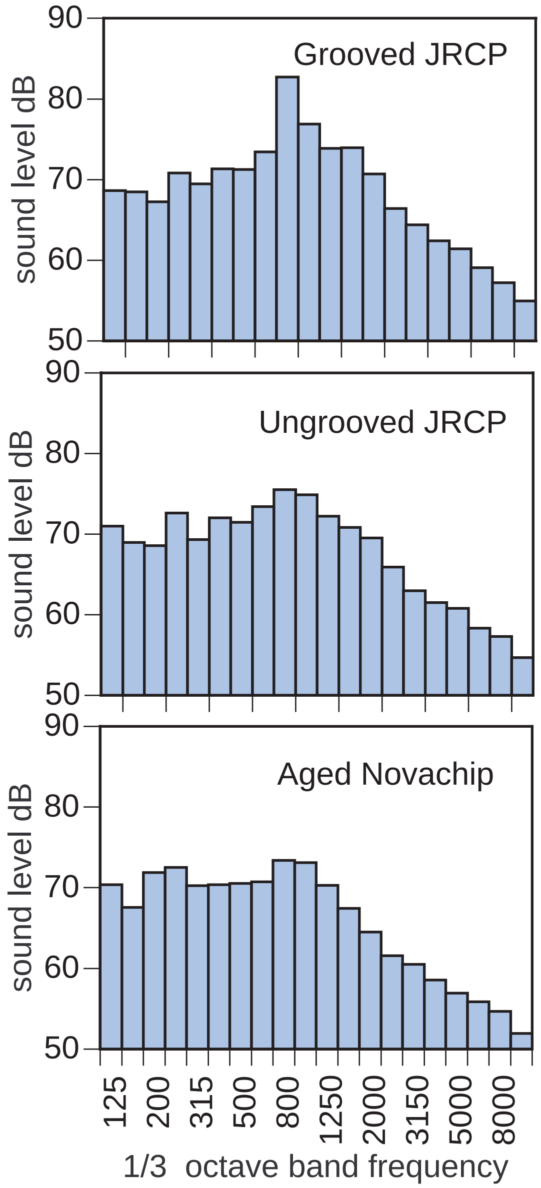


**FIGURE 7**. Frequency spectrum of three different pavements for comparison.

The on board data from the two microphones mounted on the trailer near one of the tires was 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 on board data to the roadside data, it may be possible to estimate roadside noise levels from the on board noise levels. The on board noise levels recorded on these tests averaged 21 dBA higher than the roadside levels, with a standard deviation of 1.3 dBA. The behind the wheel, 180º on board sound levels averaged 2.3 dBA higher than the levels from the microphone at a 135º. Compared to the roadside measurements, the on board noise levels for the different pavement tests show a similar span of dBA differences, (~7 dBA) and the pavements fall 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 pavements on the on board tests but on the roadside tests was closer to the average noise level 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 causing 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 135 degree and the 180 degree onboard microphones for all 15 pavements, listed in the same order as in Table 2, are shown in Figure 8 and 9 respectively. 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 2000 Hz. The on board 135º 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 2000 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 on board 180º 1/3 octave band data is very similar to the 135º data with a 0 to 3 dBA increase in most 1/3 octave band pressure levels.

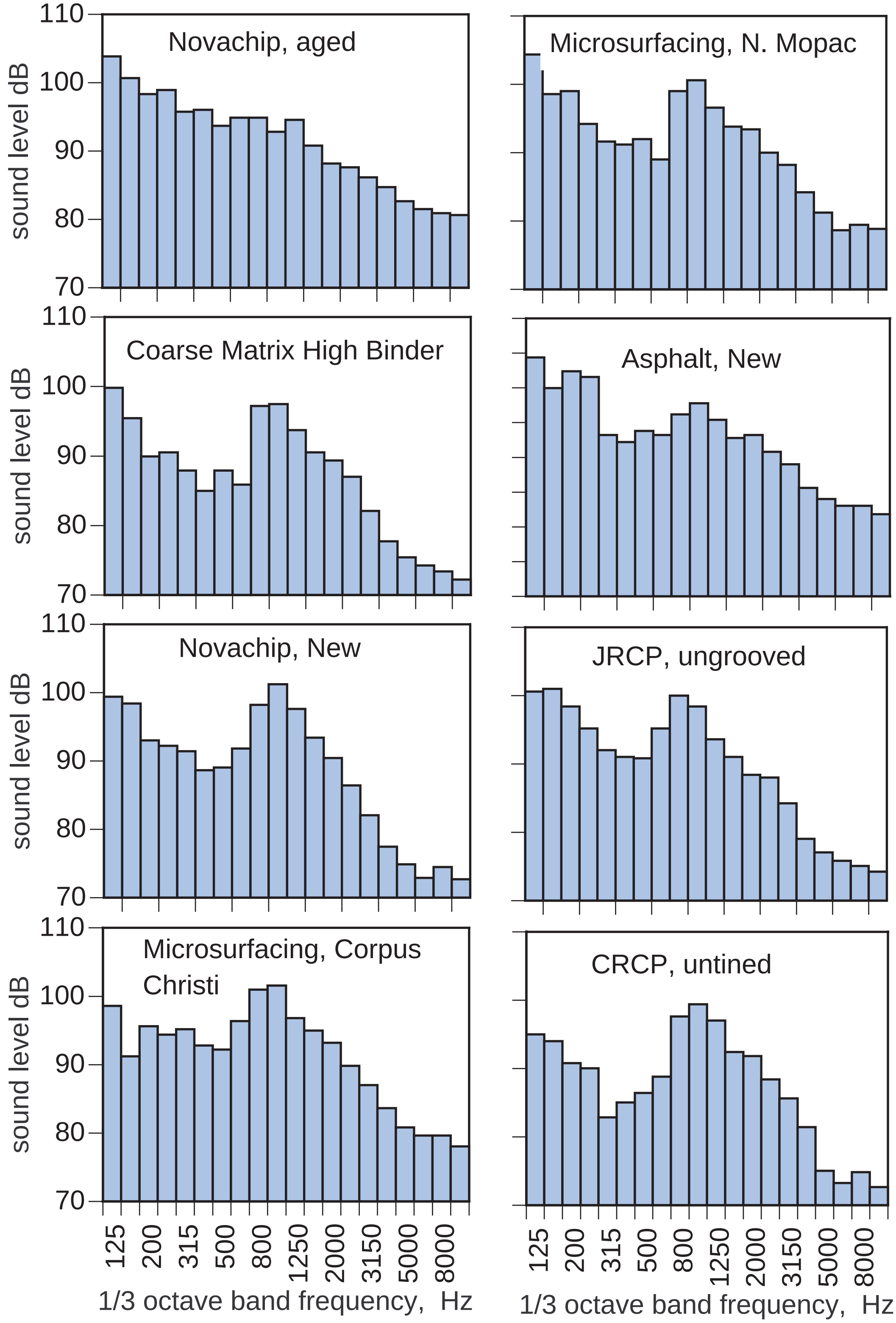


**FIGURE 8.** Spectral sound level of 135 degree angle microphone, on board noise of Texas pavements.

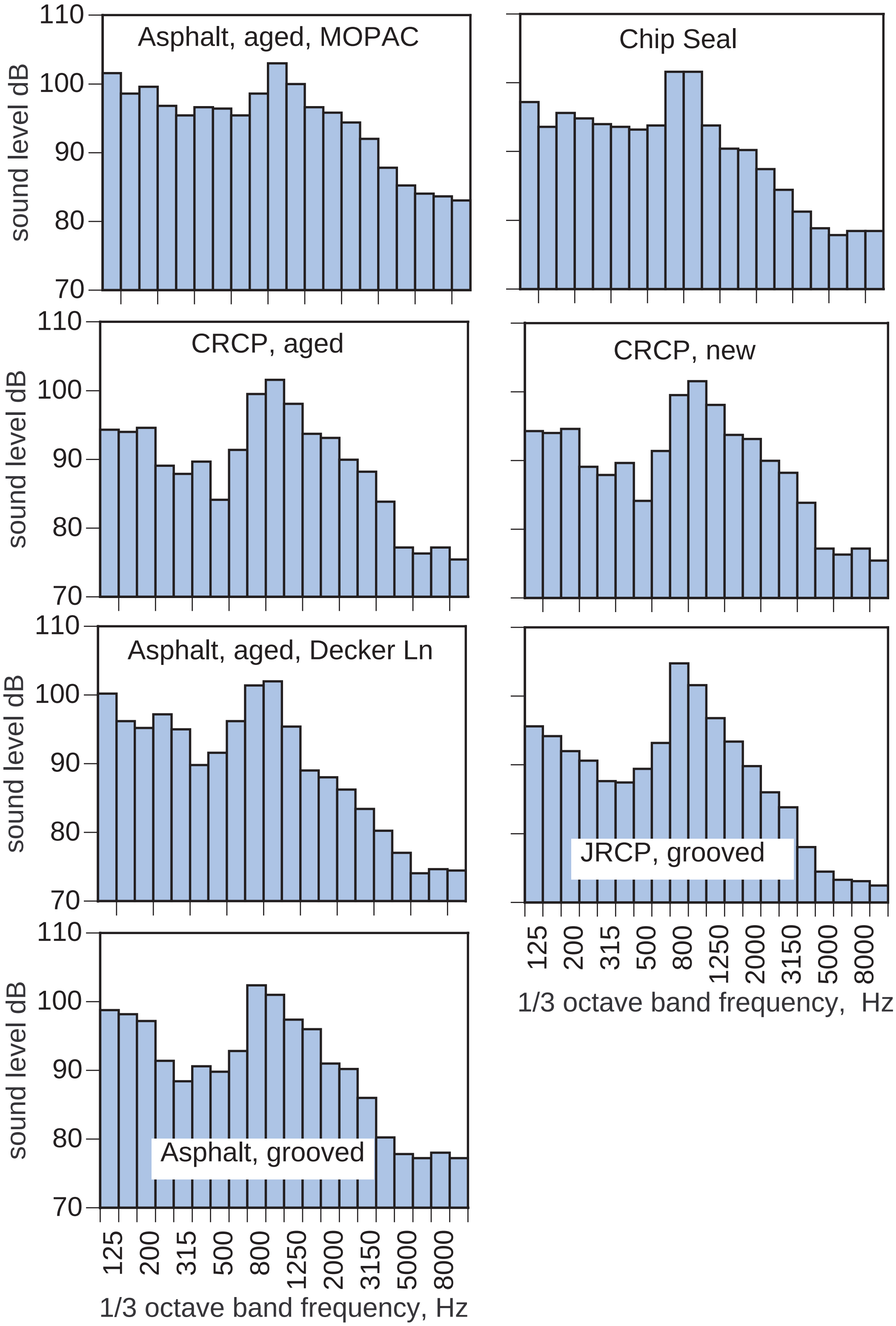


**FIGURE 8 (continued).** Spectral sound level of 135 degree angle microphone, on board noise of Texas pavements.

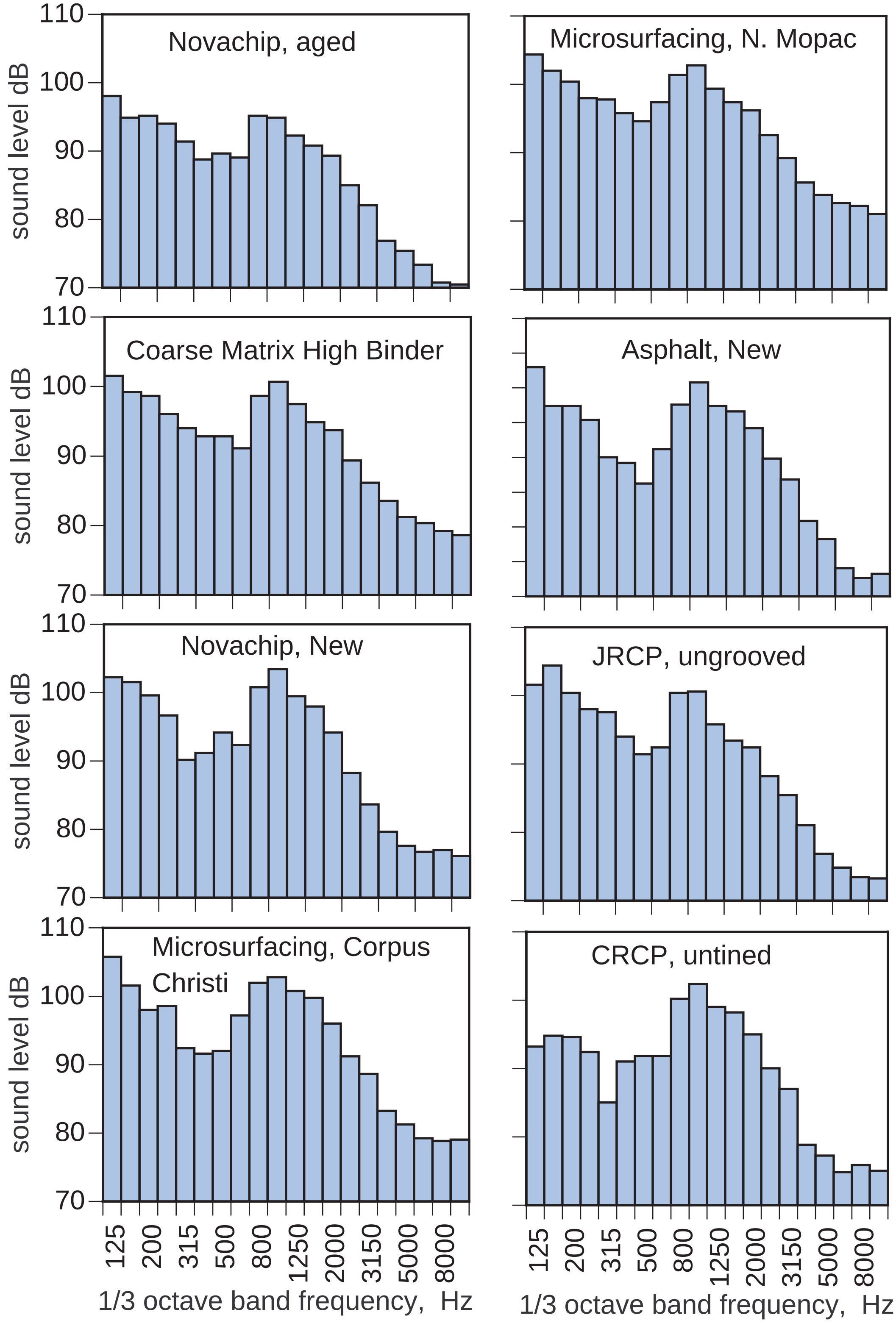


**FIGURE 9.** Spectral sound level of 180 degree angle microphone, on board noise of Texas pavements.

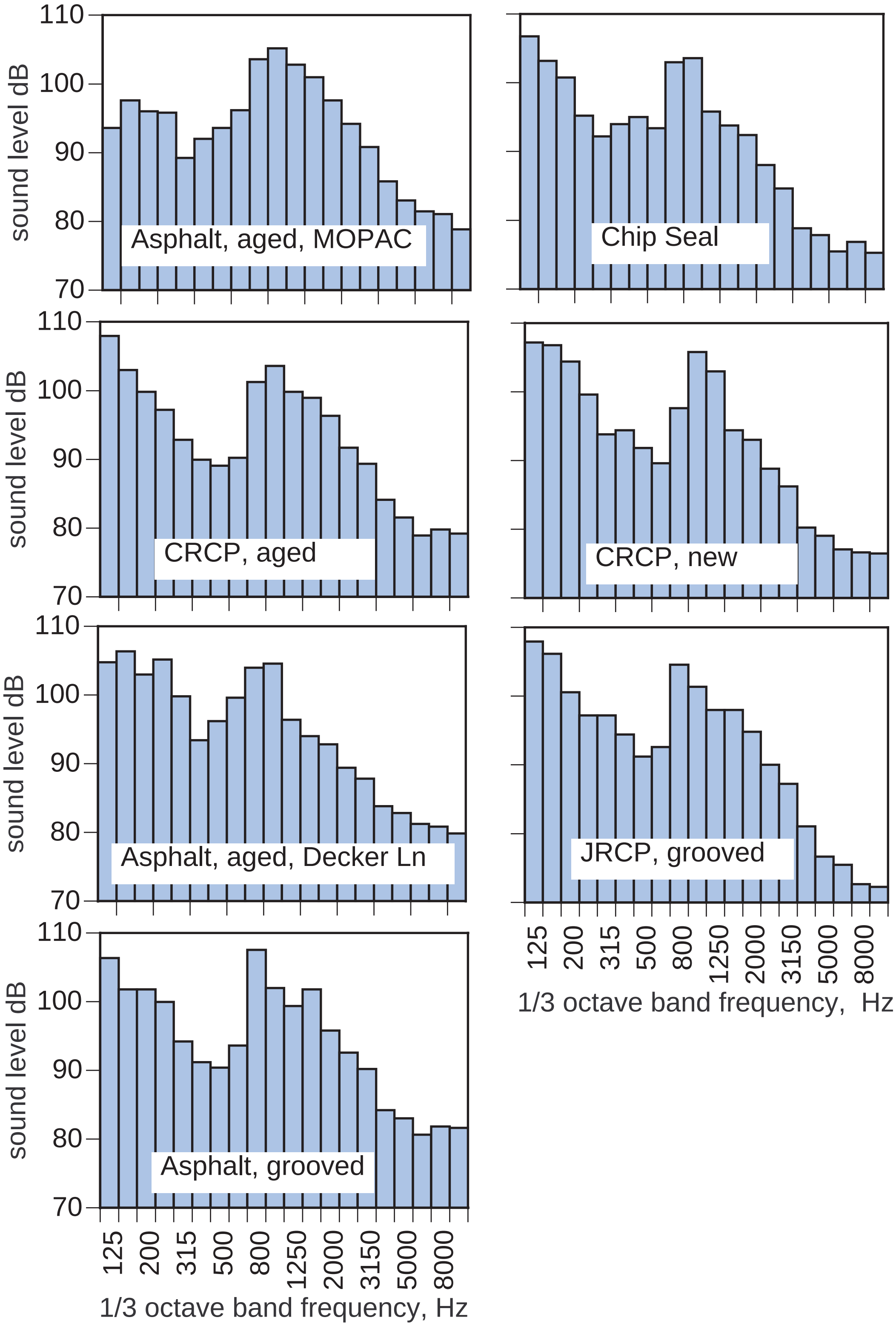


**FIGURE 9 (continued).** Spectral sound level of 180 degree angle microphone, on board noise of Texas pavements.

The 1/3 octave band spectrums of the Aged Novachip test from the roadside and the two on board microphones are shown in Fig 10. The on board 135 degree 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 2000 Hz. For this pavement, the correlation between on board 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 on board 180 degree 1/3 octave band data is very similar to the 135 degree 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 the roadside, and even higher than those recorded at the 135 degree position. The high frequency noise, above 4,000 Hz is noticeably higher also, but these higher levels on the two frequency spectrum extremes do not effect the perceived noise levels.

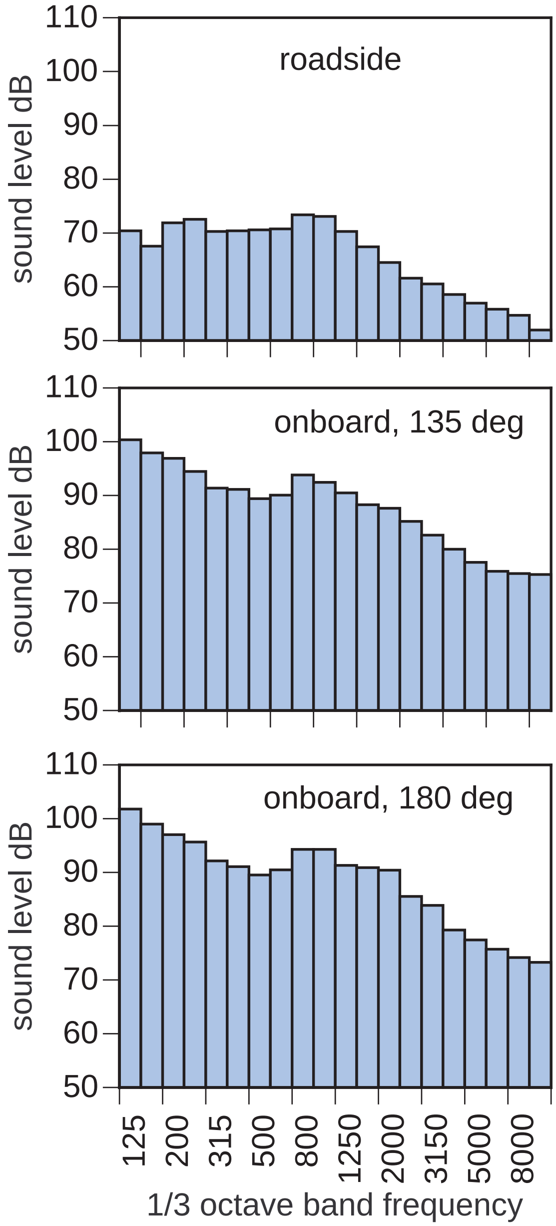


**FIGURE 10**. Frequency spectrum for aged Novachip recorded at roadside and two onboard, near tire locations. Angle measured from direction of travel.

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 to estimate the roadside noise level from the on board level would be to assume sound level reduction due to spherical spreading of the sound field from the source and excess attenuation due to absorption during propagation. However, the noise measured on board the trailer is primarily from one tire while the noise measured on the roadside has contributions from all the tire pavement interactions along with 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 appears to be a reasonable tool for estimating relative noise levels between different types of pavements. Also, because the difference between roadside noise levels and on board noise levels for the pavements in this study was fairly consistent, it may be used with on board 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 Mic | 180º 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 ( 19 mm ) | 84.5 | 103.9 | 107.5 |
| Jointed Concrete | 89.0 | 102.3 | 104.6 |
| Seal Coat (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 6 different pavements. Care was taken to run the tests the same as the tests in Texas, however a different trailer and vehicle were used. Therefore quantitative comparison with the Texas data may not be very accurate. The large difference in noise levels among the South African pavement tests is noteworthy. For the roadside measurements, the difference from the noisiest to the quietest pavement was over 12 dBA. In particular, the quietest pavement, called Whisper Course, designed to reduce traffic noise, was measured at 77.2 dBA at roadside, the quietest pavement measured during this project. Comparison of the results of the onboard to the roadside measurements for the four quietest South African pavements are 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 drive by where 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 is significant and should be a consideration before selection for highway surfacing. Toward this purpose, the different types of highway pavements should be measured and classified according to their characteristics for noise level generation. Our tests results are for a passenger automobile test vehicle. To compile 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 measured noise, both at the roadside and near the tire for the different pavements 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 1600 Hz and above.

The noise levels measured on board the test vehicles in the Texas tests show good correlation 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 in the relative noise level rankings between roadside and onboard measurements 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 on board roadside measurements from a test vehicle like the one used in these tests and adjusting the levels by the differences between roadside and on board noise levels measured in these tests.

Further testing of pavements for noise characteristics using both the roadside and on board method is recommended. Testing of sound absorption characteristics of different pavement surfaces should help to explain some of the reasons for 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 on board testing will help to develop reliable ways to correlate on board measurements with roadside noise levels.

## ACKNOWLEDGMENTS

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