Arkansas Tire / Pavement Noise Study

APA ASPHALT PAVEMENT ALLIANCE

PAVEMENT/TIRE NOISE STUDY FOR THE ARKANSAS APA

By:

Douglas I. Hanson
Robert S. James
Brian Waller

January 2005

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By:

Douglas I. Hanson
Assistant Director
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

Robert S. James
Civil Engineer
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

Brian Waller
Mechanical Engineer
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

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INTRODUCTION

Background

Research in Europe and in the United States has indicated that it is possible to build pavement surfaces that will provide low noise roadways. The National Center for Asphalt Technology (NCAT) has initiated a study to develop a pavement selection guide or design manual for use by the DOTs and others to design low noise Hot Mix Asphalt (HMA) pavement wearing courses.

Throughout the world, sound caused by transportation systems is the number one noise complaint. Highway noise is one of the prime offenders. Engine (power train), exhaust, aerodynamic and pavement/tire noise all contribute to traffic noise.

In the United States, the Federal Highway Administration (FHWA) has published the noise standards for highway projects as 23CFR772(*1*). The FHWA Noise Abatement Criteria states that noise mitigation must be considered for residential areas when the A-weighted sound pressure levels approach or exceed 67 dB (A). To accomplish this, many areas in the United States are building large sound barrier walls at a cost of one to five million dollars per roadway mile. Noise barriers are the most common abatement strategy. The FHWA reports that the DOTs through 1998 have spent over 1.4 billion dollars on walls for noise control (*1*). At the time this report was written, these walls cost up to 5 million dollars per mile in California. Also, other strategies such as alterations of horizontal/vertical alignment, traffic controls, greenbelts and insulation of structures are used to reduce noise. Each of these noise reduction measures can add significant cost to a project. In addition, each is limited in the amount of noise reduction that is possible and in many cases cannot be used for practical reasons. For example, noise barriers cannot be used if driveways are present.

It has been shown that modification of pavement surface type and/or texture can result in significant tire/pavement noise reductions. European highway agencies have found that the proper selection of the pavement surface can be an appropriate noise abatement procedure. Specifically, they have identified that a low noise road surface can be built at the same time considering safety, durability and cost using one of the following approaches (*2*):

1. A surface with a smooth surface texture using small maximum size aggregate
2. A porous surface, such as an open graded friction course (OGFC) with a high air void content
3. A pavement-wearing surface with an inherent low stiffness at the tire/pavement interface

Purpose and Scope

The purpose of this paper is to present the results of noise testing accomplished by the National Center for Asphalt Technology using a close-proximity noise trailer. The paper discusses the nature of tire/pavement noise and the results of testing selected pavements in Arkansas.

NATURE OF NOISE

Noise is defined as "unwanted sound". Different people have different perceptions of what sound they like and what sound they don't like. The roar of the crowd at a baseball game or the laughter of children would commonly be considered pleasant sounds while the sound of a lawnmower or garbage truck would be considered noise or unwanted sound (*3*).

Noise like all other sounds is a form of acoustic energy. It differs from pleasant sounds only in the fact that it often disturbs us and has the characteristics of an uninvited guest. To understand noise or sound requires an understanding of the physics of sound and how humans respond to it.

Sound is acoustic energy or sound pressure that is measured in decibels. The decibel combines the magnitude of sound with how humans hear. Since human hearing covers such a large range of sounds, it does not lend itself to be measured with a linear scale. If a linear scale was used to measure all sounds that could be heard by the human ear, most sounds (assuming a linear scale of 0 to 1) occurring in daily life would be recorded between 0.0 and 0.01. Thus, it would be difficult to discriminate between sound levels in our daily lives on a linear scale.

Instead of a linear scale, a logarithmic scale is used to represent sound levels and the unit is called a decibel or dB. The A-scale is used to describe noise. The term dB(A) is used when referring to the A-scale. The curve that describes the A-scale roughly corresponds to the response of the human ear to sound. Studies have shown that when people make judgments about how noisy a source is that their judgments correspond quite well to the A-scale sound levels. It refers to the loudness that a human ear would perceive. It, in affect, is a dB corrected to account for human hearing. The ear has its own filtering mechanisms and the inclusion of the A after dB indicates that the scale has been adjusted or "fine tuned" to hear like a human. Thus, a noise level of 85 dB(A) from a noise source would be judged louder or more annoying than a noise level of 82 dB(A). The decibel scale ranges from 0 dB(A), the threshold of human hearing, to 140 dB(A) where serious hearing damage can occur. Table 1 (*3*) represents this scale and some of the levels associated with various daily activities.

Table 1 – Noise Levels Associated with Common Activities (*3*)

Activity	Noise Level (dB(A)
Lawnmower	95
Loud Shout	90
Motorcycle passing 50 feet away	85
Blender at 3 feet	85
Car traveling 60 mph passing 50 feet away	80
Normal conversation	60
Quiet Living room	40

A serene farm setting might have a decibel level of 30 dB(A) while a peaceful subdivision might be at 40 to 50 dB(A). Alongside a freeway the sound level (i.e. noise) might be in the range of 70 to 80 dB(A). The transition from a peaceful environment to a noisy environment is around 50 to 70 dB(A). Sustained exposure to noise levels in excess of 65 dB(A) can have negative health effects. As a general rule of thumb, one can only differentiate between two sound levels that are at least 3 dB(A) different in loudness.

In addition to sound level, people hear over a range of frequencies (and this is the reason for the A weighting described earlier). A person with good hearing can typically hear frequencies between 20 Hz and 20,000 Hz. An older person, however, may not be able to hear frequencies above 5,000 Hz. So this indicates, to some extent, some of the reasons why different people hear things somewhat differently.

Addition of Noise Levels

Noise levels are measured on a logarithmic scale. Therefore, when combining the effect of multiple sources this must be considered. The formula used to combine multiple sources of sound is (*3*):

$$dB(A)_t = 10 * \log [10^{\{dB(A)_1/10\}} + 10^{\{dB(A)_2/10\}} + \ldots. + 10^{\{dB(A)_n/10\}}]$$

Figure 1 illustrates the effects of adding two point source noise levels. If the sound level from one source of sound (a blender) measured at three feet from the blender is 85 dB(A) (from Table 1), then the sound level from two blenders would be 88 dB(A) and the sound level from three blenders would 89.8 dB(A). Therefore, doubling the sound emissions would result in a 3 dB(A) increase in noise levels. This can be determined for any number of sound sources by using the above equation. For roadway surfaces this means that if the number of vehicles in the traffic flow is doubled, the sound level will increase by 3 dB(A) (*3*).

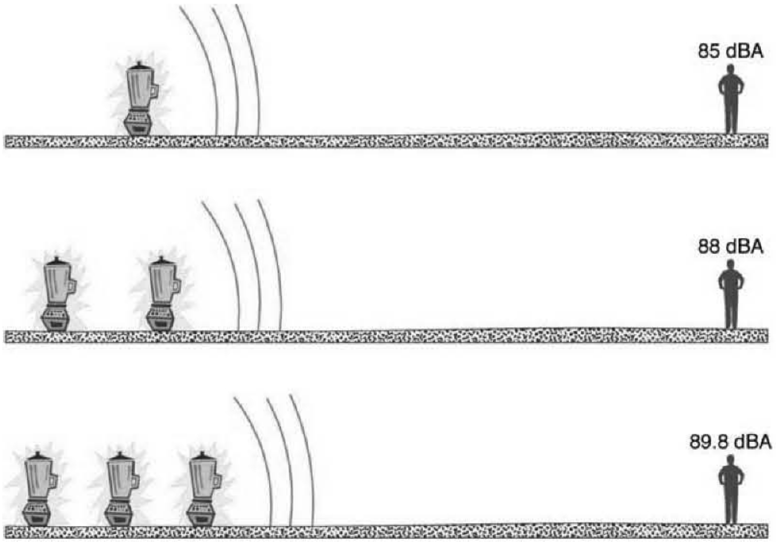


Figure 1 – Effect of Adding Noise Sources

Propagation of Noise from a Point Source

An important mitigating factor with regard to noise is the distance between the source and the receiver. Sound levels decrease in accordance to the inverse-square law. This law is a fundamental law of acoustics – it states that the sound varies inversely as the square of the distance. As the distance increases, the noise levels decrease. For a point source, such as a blender the attenuation factor is 6 dB (A) when the distance away from the source is doubled and is 9.5 dB (A) at three times the distance. Thus, again if you have a blender that has a sound level of 85 dB (A) at three feet then when you move six feet away from the blender the noise level would be 79 dB (A) and if you move three times the distance (9 feet) away from the blender the noise level would be 75.5 dB (A). This is illustrated in Figure 2.

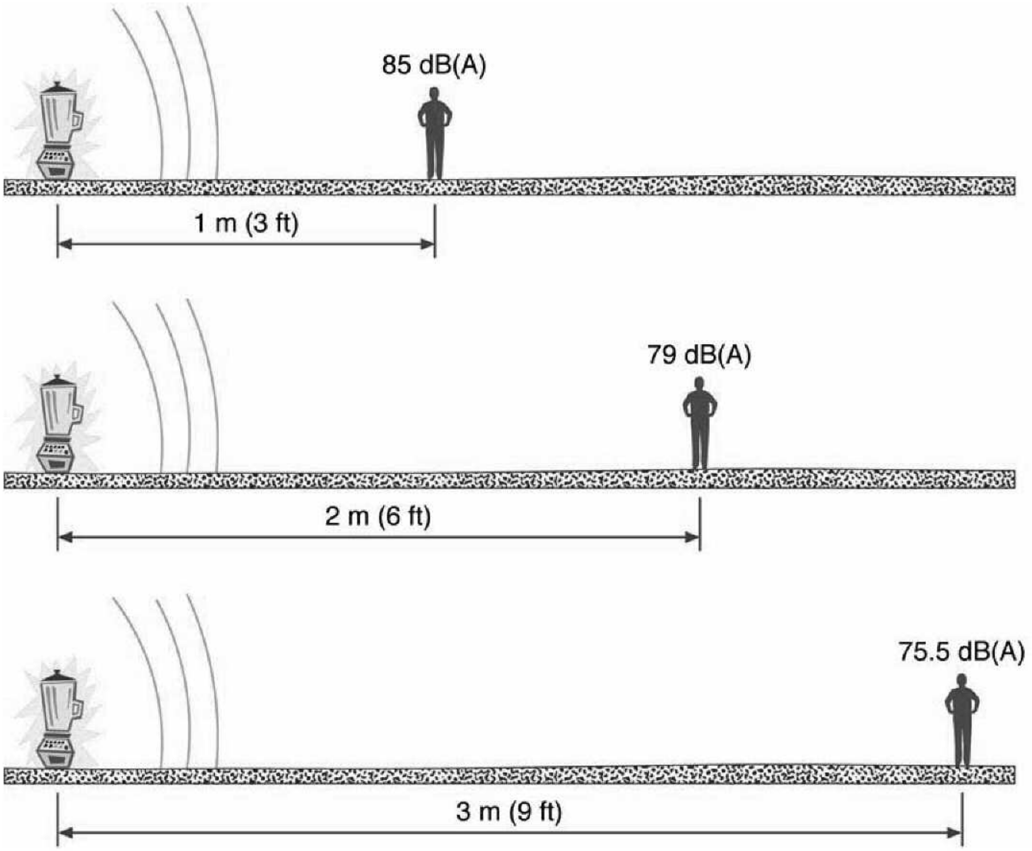


Figure 2 – Effect of Distance on a Point Noise Source

Propagation of Traffic Noise

Roadway noise acts in a different manner. Roadway noise is classified as a line source since noise is transmitted along the entire length of the roadway (*3*). As a vehicle passes by a point, the noise is reaching the point from all along the roadway, or from each point where the vehicle was. As the distance from the source increases, the noise level decreases at a lower rate than from a single point noise source. For paved surfaces, the doubling of the distance would result in a 3 dB (A) reduction in the noise level. Thus, if a point 16 feet from the center of the noise source (the center of the lane) of the roadway has a noise level of 85 dB (A), then a point 32 feet from the center of the noise source would have a noise level of 82 dB (A). This is illustrated in Figure 3.

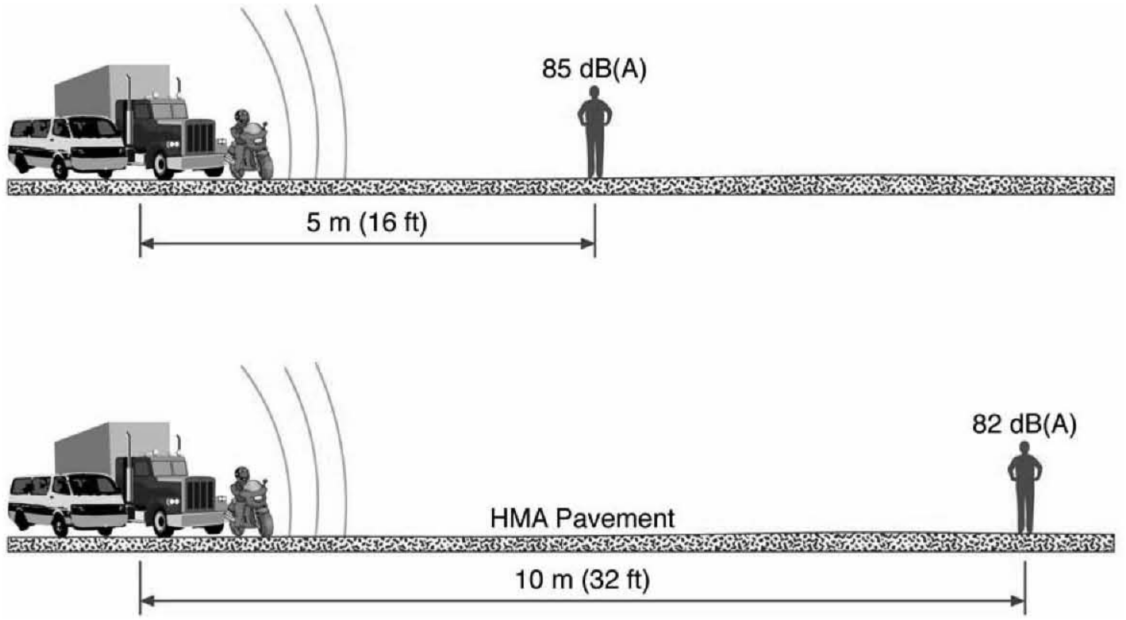


Figure 3 – Effect of Distance on a Line Noise Source Over a Paved Surface

The noise level near the road not only depends on the noise being generated by the traffic but, also the characteristics of the ground adjacent to the road. The Traffic Noise Model used by the Federal Highway Administration (*3*) to predict noise levels along side the roadway uses the following equation to approximate the drop off:

Distance Adjustments dB(A) = $10 * \log_{10}\{(d_2/d_1)^{1+\alpha}\}$

where: α = attenuation coefficient which is
0.0 for hard ground or pavement
0.5 for soft ground

d_1 , d_2 = distance from roadway centerline

Thus, if the noise level is 85 dB(A) at the edge of pavement which is at 16 feet (1/2 of a 12 foot lane plus a ten foot shoulder) from the center of the noise source and the man is 200 feet from the roadway edge with soft ground between the roadway edge and the man this equation would predict that the noise level would be 68.5 dB(A) at the man. This is illustrated in Figure 4. In a rural situation, where the ground between the roadway edge and the receiver is soft and covered with vegetation the noise level would be further reduced due to absorption of the sound into the ground.

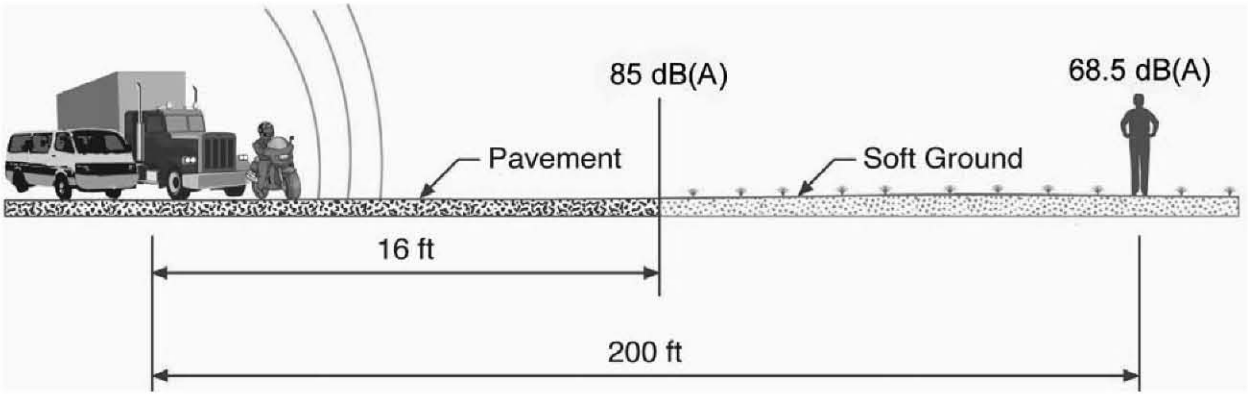


Figure 4 – Effect of Distance on a Line Noise Source Sound Traveling Over Soft Ground

FIELD MEASUREMENT OF ROAD NOISE

A standardized method for the measurement of noise is necessary to allow the pavement engineer to characterize the level of the noise from different pavement wearing courses. Considerable work has been done to develop such techniques. Three methods commonly used for measuring pavement noise levels in the field are:

1. The statistical pass-by procedures as defined by both International Standards Organization (ISO) Standard 11819-1 (*5*) and the FHWA manual Measurement of Highway-Related Noise (*6*)
2. The single vehicle pass-by method (*6*)\
3. The near-field techniques such as the close proximity method (CPX) that was developed in Europe and is defined by ISO Standard 11819-2. (*7*)

Statistical Pass-by Methods

The statistical pass-by method consists of placing microphones at a defined distance from the vehicle path at the side of the roadway. In Europe, the ISO Standard 11819-1 calls for placing microphones 25 feet from the center of the vehicle lane at a height of 4 feet above the pavement. It also requires that the noise characteristics and speed of 180 vehicles be obtained (100 automobiles and 80 dual-axle and multi-axle trucks). This data is then analyzed to determine the statistical pass-by index (SPBI) (6).

The FHWA procedure developed by the Volpe Transportation Systems Center (6) calls for the placement of a microphone or microphones 50 feet (instead of 25 feet) from the center of the travel lane. The ground surface within the measurement area must be representative of acoustically hard terrain, the site must be located away from known noise surfaces, and is to exhibit constant-speed roadway traffic operating under cruise conditions. The FHWA procedure does not specifically state the number of vehicles required for a valid sample. It states that the number of samples is somewhat arbitrary and is often a function of budgetary limitations. But, the procedure does provide some guidance. For example if the traffic speed is 51 to 60 mph the minimum number of samples recommended is 200.

Both of these pass-by methods are time consuming to conduct. The results vary based on the traffic mix (even if the vehicle types are the same the differences in tires can cause problems). The testing conditions that must be met to conduct these measurements are very restrictive. The roadway must be essentially straight and level, there is a limit on the background noise, no acoustically reflective surfaces can be within 30 feet of the microphone position, and the traffic must be moving at a relatively uniform speed. The result of these restrictions is that a limited number of pavement surfaces can be tested economically.

Single Vehicle Pass-by or Controlled Pass-by Method

In the single vehicle pass-by method, noise from cars and light trucks is typically measured at a specially designed test site. The vehicle approaches the site at a specified speed in a specified gear. There are no national standards for this type of testing. An example of this type of testing is a study conducted by Marquette University for the Wisconsin DOT (*8*). In this study, they used a 1996 Ford Taurus that was operated at 60, 65 and 70 mph in the right lane. They conducted their testing by placing two microphones five feet above the pavement and positioned at 25 feet from the center of the traffic lane. The microphones were placed two hundred feet apart. Three runs were made to collect enough data for each speed.

Close-Proximity Method (CPX) or Near-field Measurements

Near-field tire/pavement noise consists of measuring the sound levels at or near the tire/pavement interface. In the CPX method, sound pressure is measured using microphones located near the road surface.

The requirements for the CPX trailer are described in ISO Standard 11819-2 (*7*). This method consists of placing microphones near the tire/pavement interface to directly measure tire/pavement noise levels. In 2002, NCAT built two CPX trailers, one for the

Arizona Department of Transportation and one for use by NCAT. A picture of the NCAT trailer is shown in Figure 5.

Figure 5 – NCAT Close Proximity Trailer

The ISO Standard calls for the measurement of sound pressure and the microphones at eight inches from the center of the tire and four inches above the surface of the pavement. The microphones are mounted inside an acoustical chamber to isolate the sound from passing traffic. The acoustical chamber is required because sound pressure microphones will measure the sound from all directions and thus, there is a need to isolate the sound from other traffic and sound reflective surfaces. Figure 6 shows the mounting of the microphones and the acoustical chamber

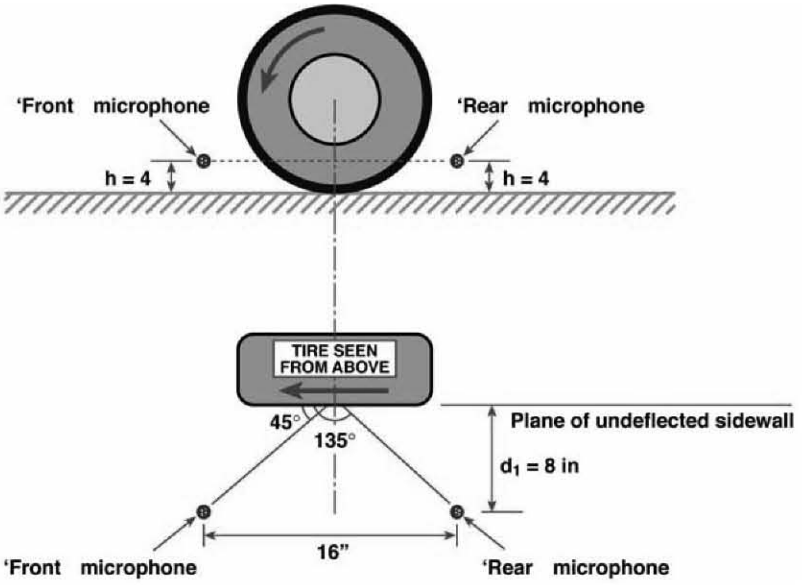


Figure 6 – Diagram Showing Microphone Locations in NCAT CPX Trailer

A concern with regard to the use of near-field measurements is that they measure only the tire/pavement noise component of traffic related noise (*2*). The standard method used by the FHWA's Volpe Laboratories for measuring traffic noise for use with the FHWA's traffic noise model is the statistical pass-by method. This method was selected because it includes both the power train and tire/pavement noise. Both the power train and tire/pavement noise are strongly related to vehicle speed. At low speeds power train noise dominates while at high speeds tire/pavement noise dominates. As was discussed earlier, work done in Europe has indicated that there is a crossover speed for constant-speed driving of about 25 to 30 mph for cars and about 35 to 45 mph for trucks (*2*). At speeds less than 25 to 30 mph for cars or 35 to 45 mph for trucks, the power train noise dominates; however, at higher speeds the tire/pavement noise is more prevalent. Therefore, it appears that the concept of measuring the noise level of roadways at the tire/pavement interface is valid for roadways having speed limits above 45 mph.

The near-field test procedures offer many advantages:

1. The ability to determine the noise characteristics of the road surface at almost any arbitrary site.
2. It could be used for checking compliance with a noise specification for a surface.
3. It could be used to check the state of maintenance, i.e. the wear or damage to the surface, as well as clogging and the effect of cleaning porous surfaces.
4. It is much more portable than the pass-by methods, requiring little setup prior to use.

SUMMARY OF RESULTS FROM OTHER NCAT NOISE TESTING

NCAT has now tested approximately 244 pavement surfaces in ten states. This includes 201 Hot Mix Asphalt (HMA) surfaces that includes different Superpave gradations, microsurfacing, NovaChip, Stone Matrix Asphalt (SMA) and Open Grade Friction Course (OGFC) surfaces. Forty-three Portland Cement Concrete Pavement (PCCP) surfaces have been tested. The following are average values from that testing (only test sections of at least one-mile in length are included in these averages):

1. HMA Pavements

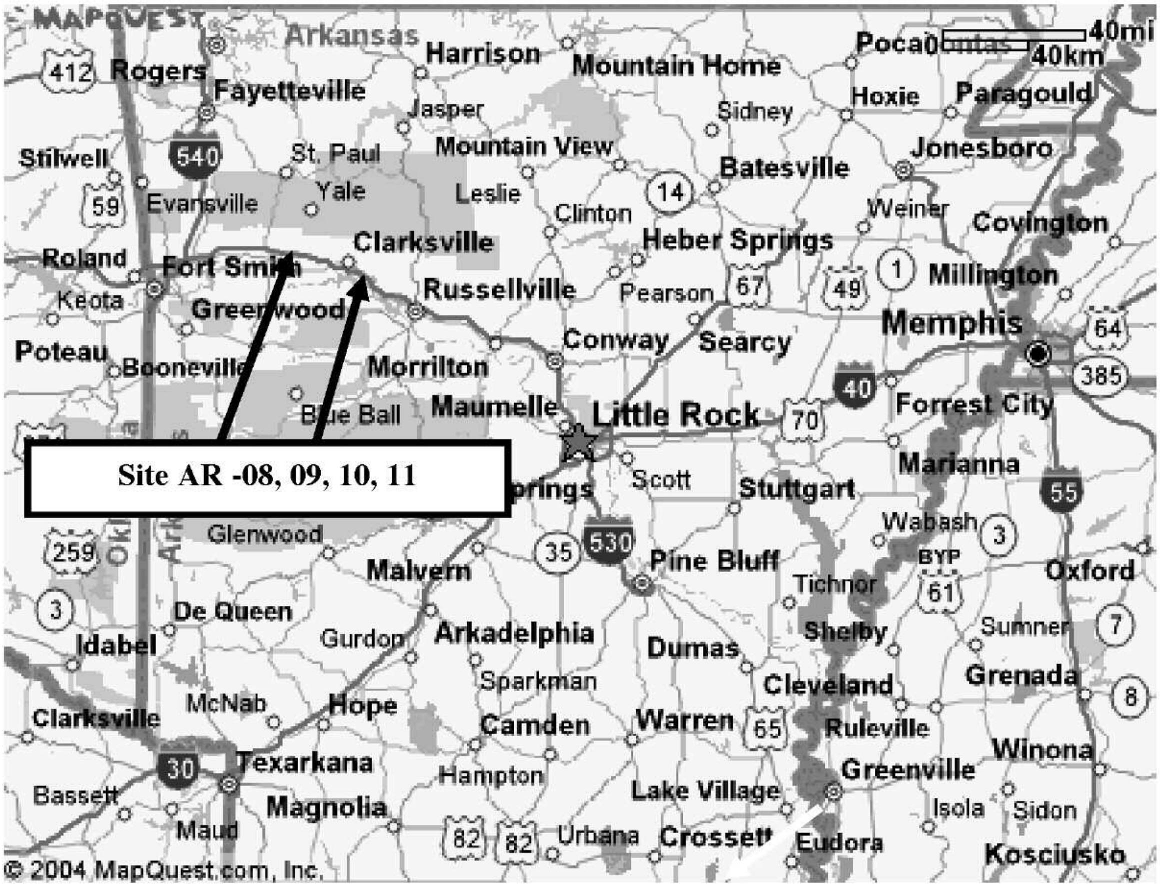
    a. Open-graded (fine gradation) mixes - 93 bB(A)
    b. Dense graded HMA - 97 dB(A).
    c. Stone Matrix Asphalt Mixes - 96 dB(A).
    d. Open-graded (coarse gradation) mixes - 97 dB(A).

2. PCCP pavements:

    a. Diamond Ground – 98.1 dB(A)
    b. Longitudinally tined – 98.8 dB(A)
    c. Longitudinally grooved – 101.6 dB(A)
    d. Transverse tined – 102.6 dB(A)

TEST RESULTS

In mid March 2004 the National Center for Asphalt Technology tested ten pavement surfaces in the Arkansas at the request of the Arkansas Asphalt Pavement Association. Appendix A shows pictures of the sections tested.



Site AR -08, 09, 10, 11

Figure 7 – Test Site Locations Outside of Little Rock

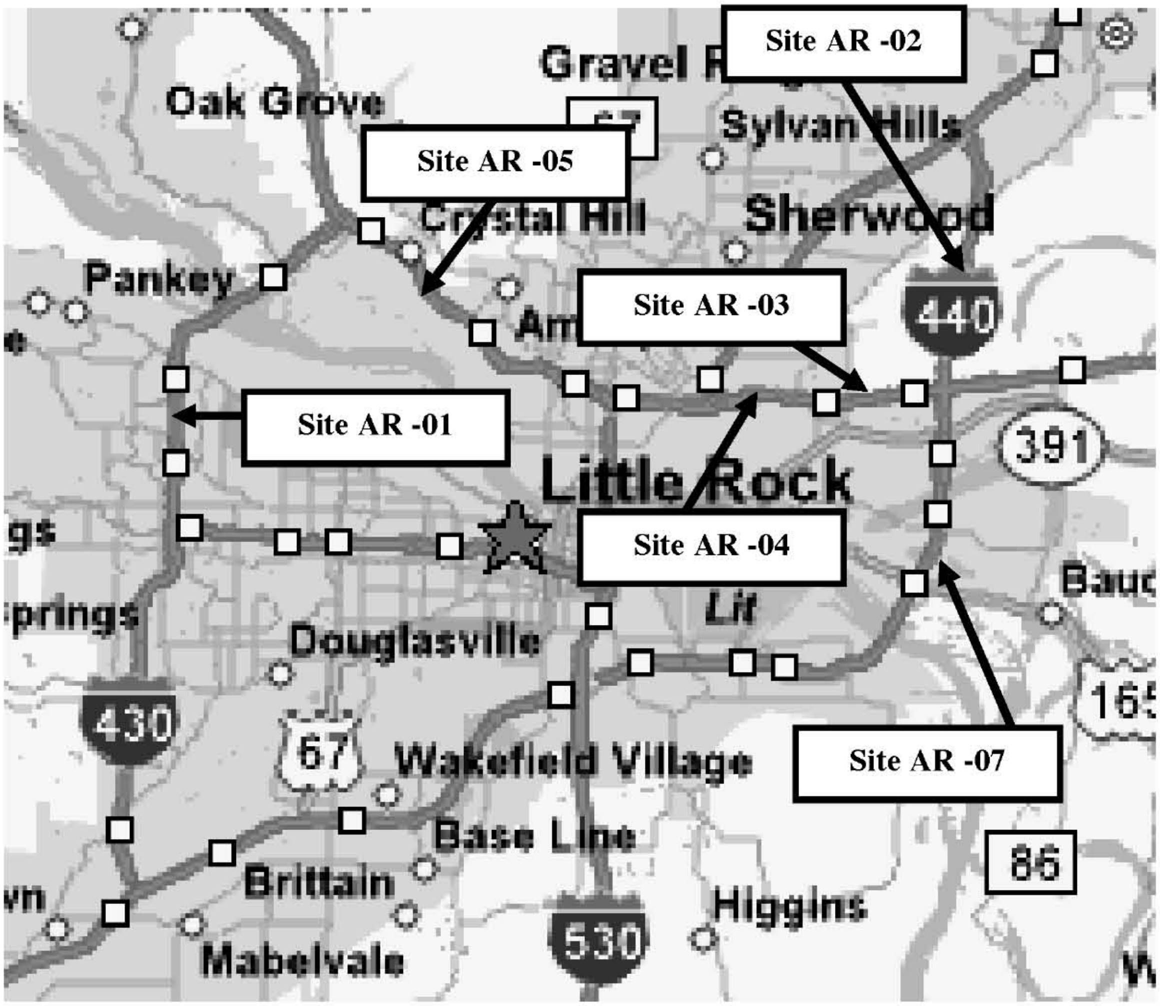


Figure 8 – Test Site Locations in Little Rock Area

Test Program and Results.

During November 2004 NCAT conducted testing to determine the noise characteristics of the pavement sections shown above. Each section was tested at 60 mph using two tire types. Three tests were conducted with each tire type on each pavement surface. The reason for conducting the tests with two different types of tire is to provide a better representation of the tire/pavement noise levels for each surface type. The two tires used were a Goodyear Aquatred and a Uniroyal Tiger Paw. Appendix B contains pictures of each tire type thus showing the tire tread pattern.

Table 2 shows a summary of the test results and figure 9 shows the test results graphically. The results shown are the average noise values for both tire types.

Table 2 – Summary of Test Data

Site No.	Highway	Direction	Mileposts		Surface Type	Average Noise Level (dB(A))
			Start	End		
AR -1	I – 430	N	7	8	PCCP	100.9
AR -2	SR - 440	W	Bridge	1 m W	PCCP	101.1
AR -3	I – 40	E	158	157	HMA	98.9
AR- 4	I – 40	W	156	155	PCCP	102.5
AR -5	I – 40	W	150	240	PCCP	100.9
AR -6	I – 30	W	Overpass		PCCP	101.6
AR -7	I – 440	E	7	8	PCCP	102.1
AR-8	I – 40	W	66	65	HMA	96.1
AR -9	I – 40	W	56	55	PCCP	101.4
AR-10	I – 40	E	49	50	HMA	97.0
AR -11	I – 40	W	46	45	HMA	96.9

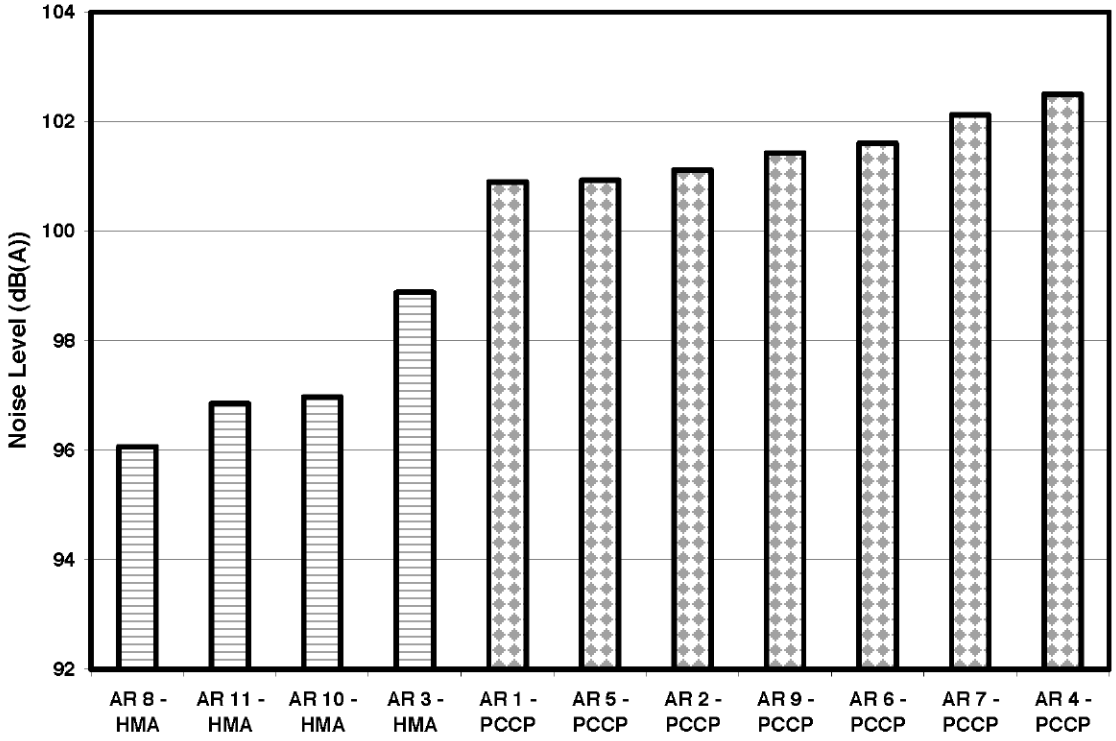


Figure 9 – Test Results Shown Graphically

FFT Analysis

For traffic noise, it is important to consider not only the magnitude of the noise but also the frequency of the noise. Sound at low frequencies is generally less attenuated by distance than sound at high frequencies and thus propagates further from the road. The sound wave files collected in this study were analyzed using a Fourier Transform technique to produce a frequency spectrum plot. Figure 10 presents the frequency spectrum (noise (dB) versus noise frequency) for the PCCP sections and Figure 11 presents the frequency spectrum for the HMA sections. The transverse tined PCCP surfaces (AR 2, AR 4 & AR 9) exhibit both a low frequency rumble (about 1000 Hz) and a high frequency whine at about (1400 hz). The other PCCP surfaces (AR 1, AR 3 & AR 7) do not have those characteristics. AR 1 appears to be burlap drag surface and the other two appeared to be ground PCCP. For the four HMA sections tested (AR 3, AR 8, AR 10, AR11) have a spectrum curve that is typical of a dense graded HMA pavement.

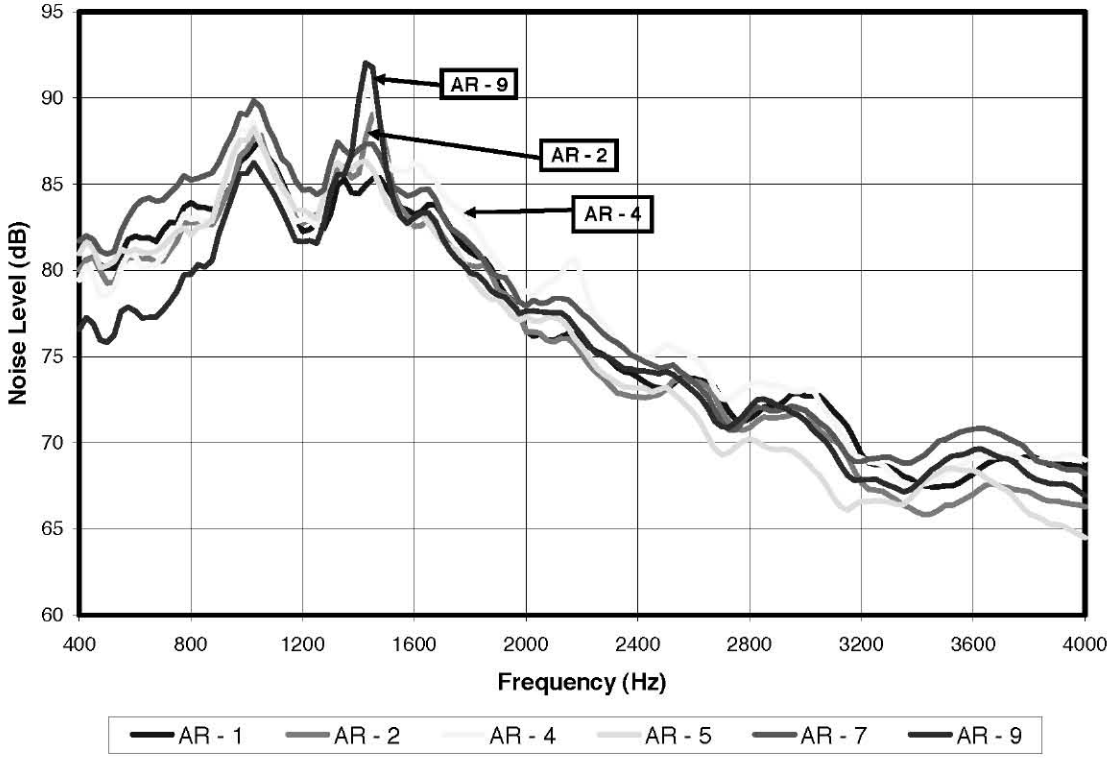


Figure 10 – Frequency Spectrum for Each of the PCCP Surfaces

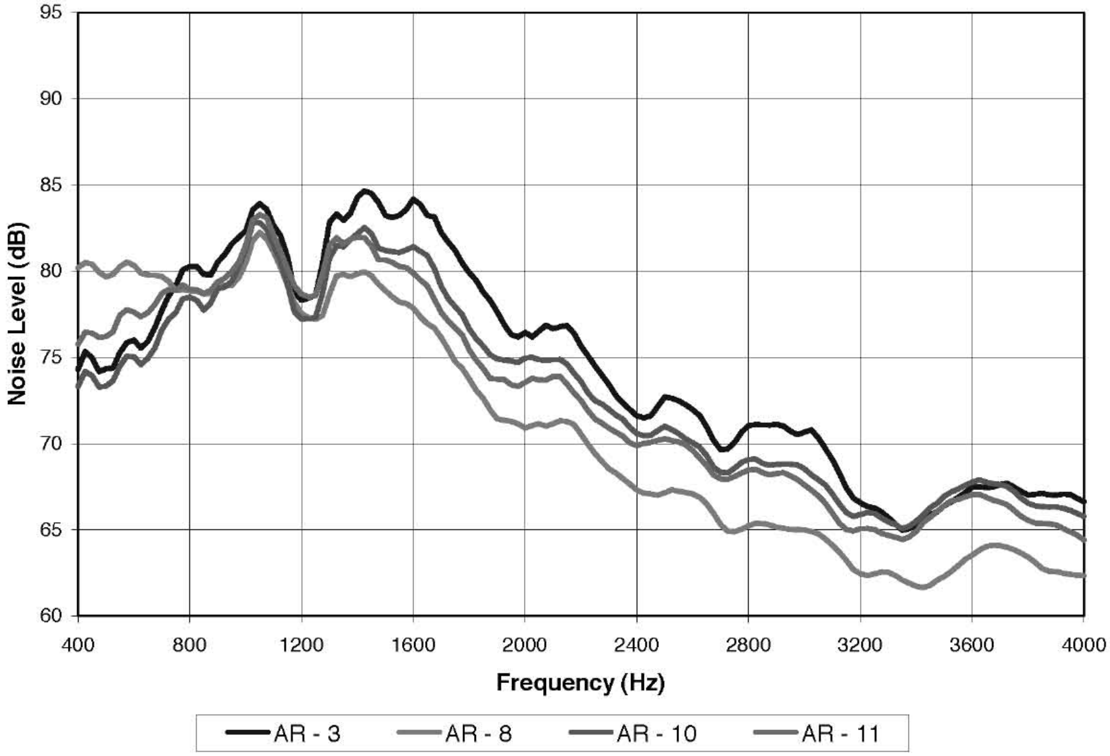


Figure 11 – Frequency Spectrum for Each of the HMA Surfaces

SUMMARY AND CONCLUSIONS

The National Center for Asphalt Technology conducted a noise survey of eleven sections of highway in Arkansas. The average tire/pavement noise for the HMA sections was 97.2 dB(A) and the average tire/pavement noise for the PCCP sections was 101.5 dB(A).

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(3) Highway Noise Fundamentals, Noise Fundamentals Training Document., Federal Highway Administration, US Department of Transportation, September 1980

(4) "Sound Barriers & Noise Control", Arizona Milepost, Vol. 3, No. 2, Spring 2002

(5) International Organization for Standardization, Measurement of the Influence of Road Surfaces on Traffic Noise- Part 1, Statistical Pass-by Method 11819-1., 1997

(6) Lee, Cynthia S.Y., and Gregg G. Fleming, Measurement of Highway-Related Noise, FHWA-PD-96-046, May 1996

(7) International Organization for Standardization, Measurement of the Influence of Road Surfaces on Traffic Noise- Part 2, Close-Proximity Method ISO Standard 11819-2., 1997

(8) Kuemmel, D. A., R. C. Sonntag, James Crovetti, Y. Becker, "Noise and Texture on PCC Pavements – Results of a Multi-state Study" Wisconsin Report SPR 08-99, June 2000

APPENDIX A

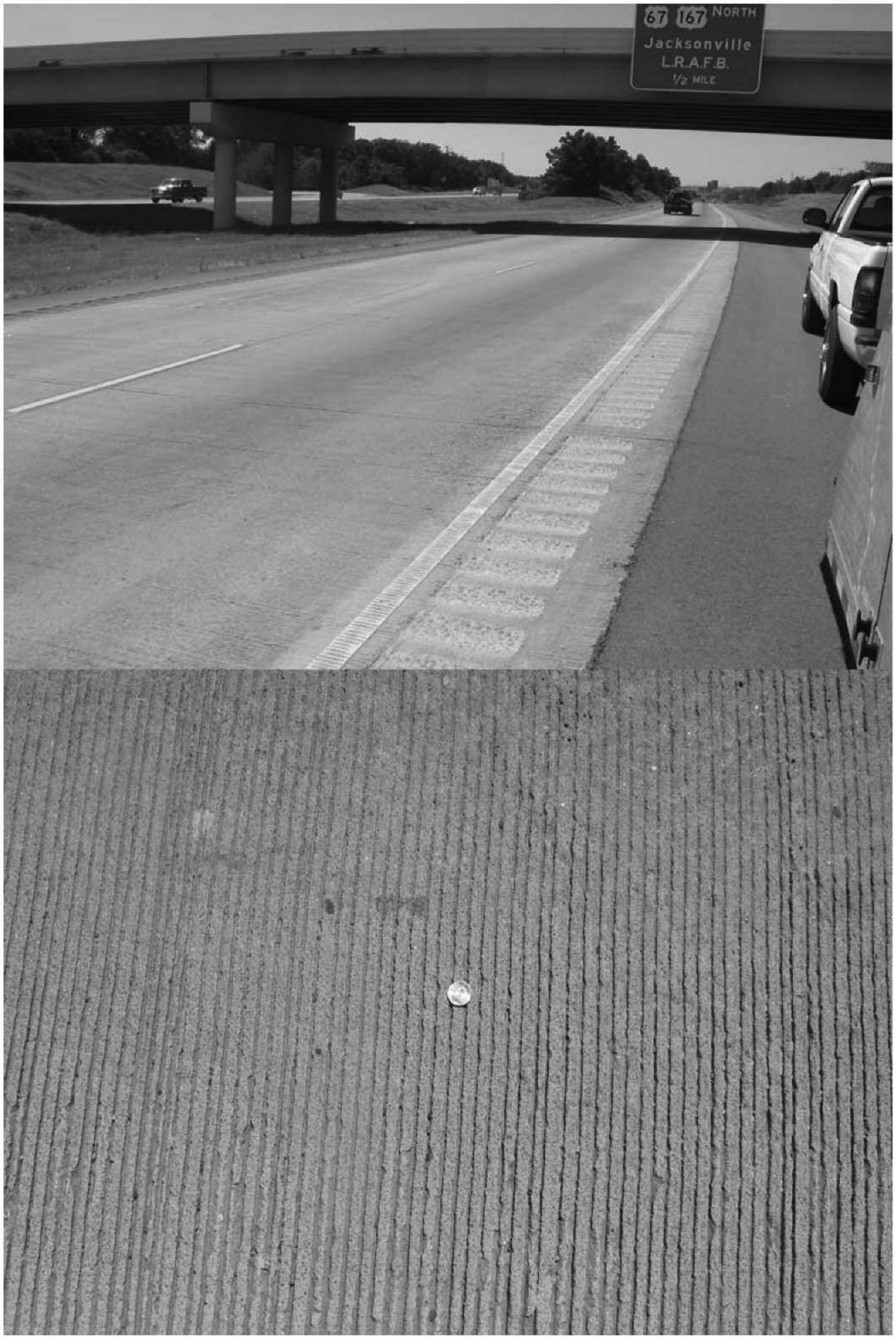
PHOTOS OF PAVEMENT SURFACES

Arkansas Site 1 (PCCP)
I -430 N Mile Marker 7 – 8 (100.9 dB(A))

Arkansas Site 2 (PCCP)
SR 440 W Bridge to 1 Mile W (101.1 dB(A))

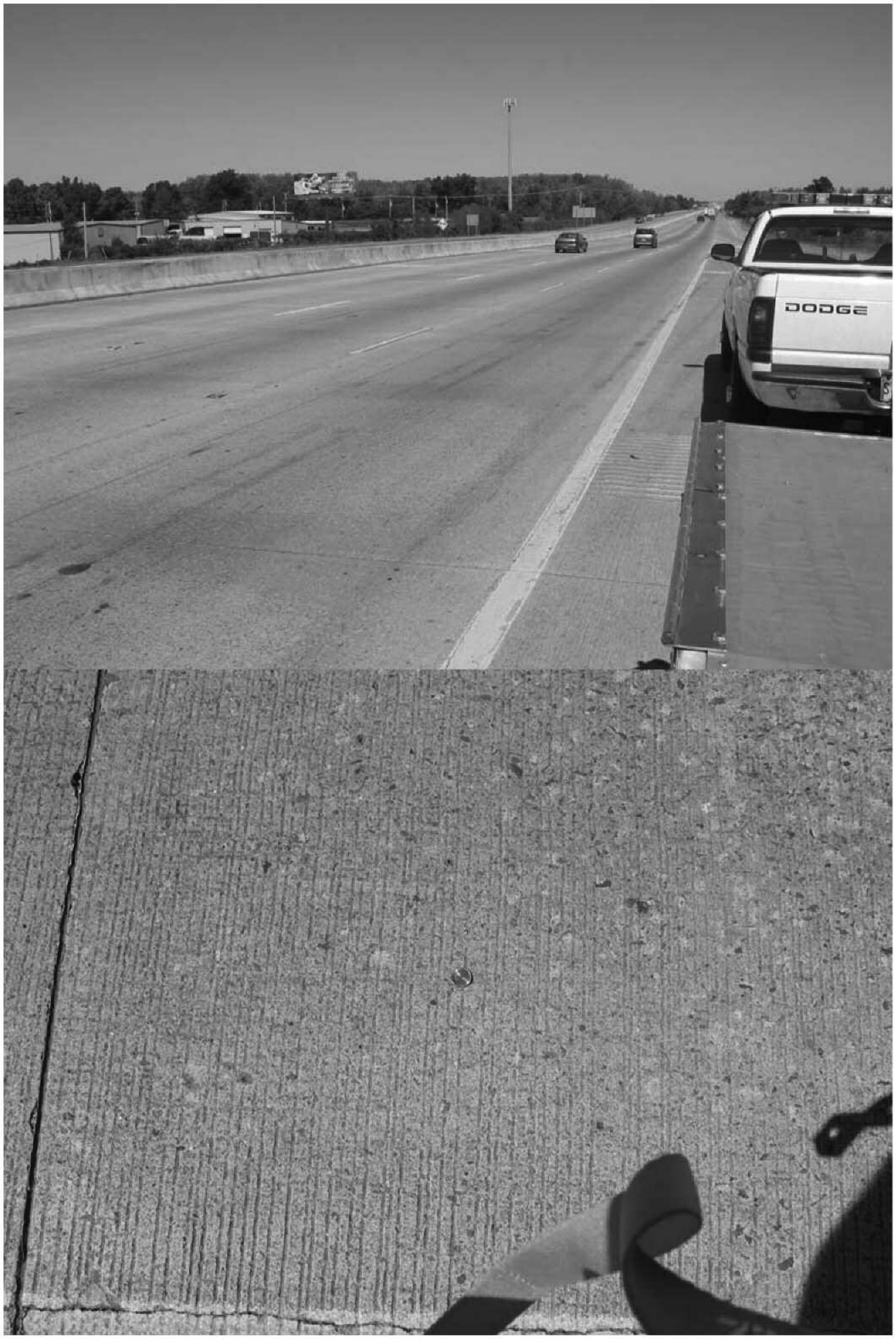
Arkansas Site 3 (HMA)
I -40 E Mile Marker 158 - 158 (98.9 dB(A))

Arkansas Site 4 (PCCP)
I -40 W Mile Marker 156 – 155 (102.5 dB(A))

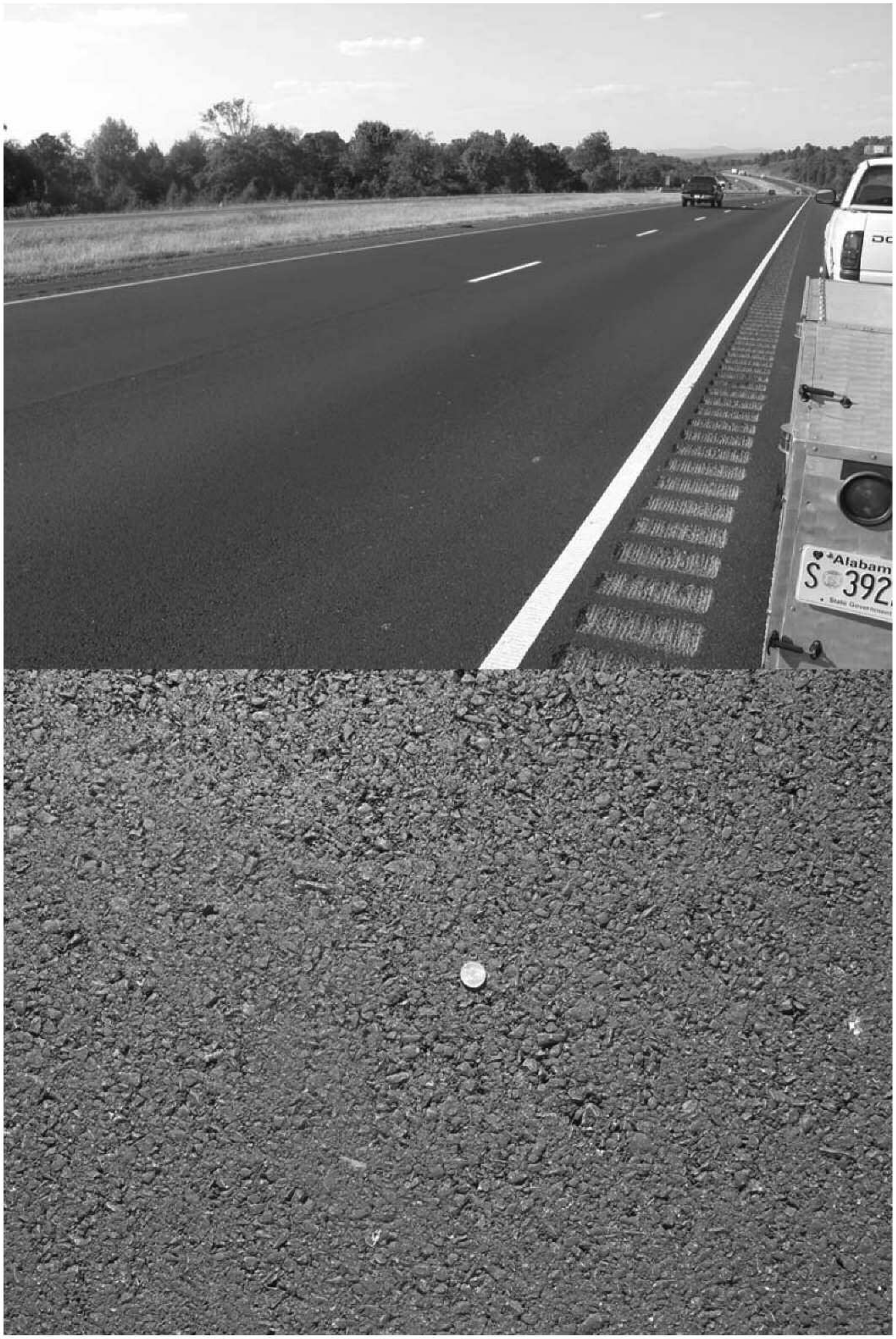


Arkansas Site 5 (PCCP)
I -40 W Mile Marker 150 – 149 (100.9 dB(A))

Arkansas Site 7 (PCCP)
I -440 E Mile Marker 7 – 8 (102.1 dB(A))



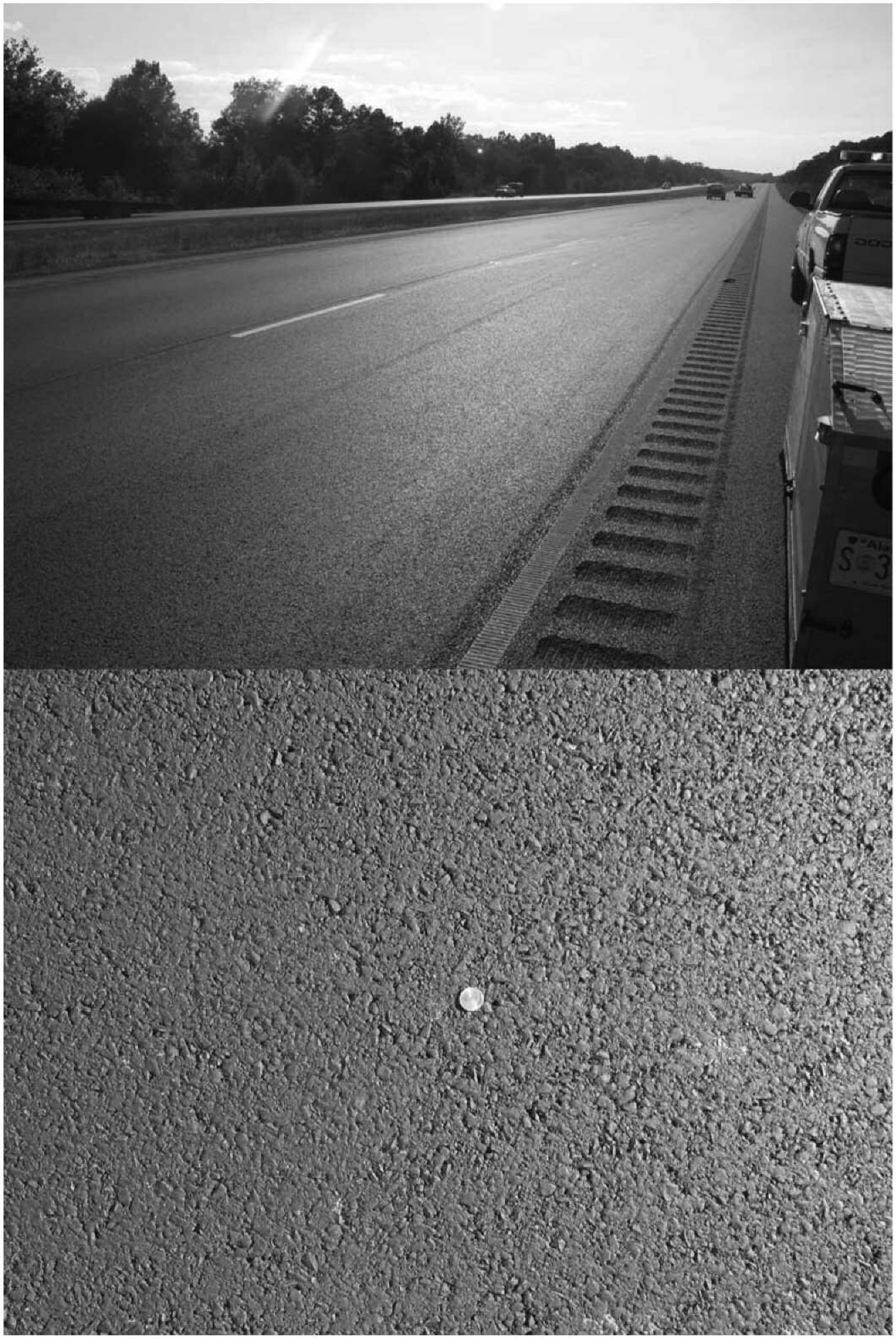
Arkansas Site 8 (HMA)
I -40 W Mile Marker 66 – 65 (96.1 dB(A))



Arkansas Site 9 (PCCP)
I -40 W Mile Marker 56 – 55 (101.4 dB(A))

Arkansas Site 10 (HMA)
I -40 E Mile Marker 49 - 50 (97.0 dB(A))

Arkansas Site 11 (HMA)
I -40 W Mile Marker 46 – 45 (96.9 dB(A))



APPENDIX C

Tires Used for Testing

TIRES USED FOR STUDY

Figure B – 1 Goodyear Aquatred

Figure B -2 Uniroyal TigerPaw

NOTES

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