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COLORADO DOT TIRE/PAVEMENT NOISE STUDY

Douglas I. Hanson
Robert S. James

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16. Abstract
In today's society, traffic noise is a serious problem. The term "noise" should not be confused with the term "sound." Noise is the generation of sounds that are unwanted. With respect to traffic, noise would be the generation of sounds that affect the quality of life for persons near roadways. Therefore, traffic noise can be considered an environmental pollution because it lowers the standard of living. Research in Europe and in the United States has indicated that it is possible to build pavement surfaces that will reduce the level of noise generated on roadways. This report provides the results of testing to define the noise levels of selected highway sections in Colorado. It documents pavement noise testing that was conducted on 18 concrete and asphalt projects throughout Colorado.

Conclusions:
-The quietest hot mix asphalt (HMA) pavement tested was an open-graded friction course (OGFC) surface.
-The age of the HMA can have a major effect on the noise level of the pavement.
-On the portland cement concrete (PCC) pavements that were between 2 and 3 years old, the type of texturing procedure did not seem to make a difference in the noise level measured.

Implementation:
It is recommended that the Colorado DOT consider the construction of a test section or sections that would evaluate the effect of thickness and gradation on the noise characteristics of an OGFC wearing course.

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Colorado DOT Tire/Pavement Noise Study

by

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

Robert S. James
Laboratory Engineering
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

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Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

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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 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 found that a low noise road surface can be built while 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 Colorado.

NATURE OF NOISE

Noise is defined as "unwanted sound." Different people have different perceptions of what sounds they like and what sounds 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 effect, 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 some of the reasons why different people hear things 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*).

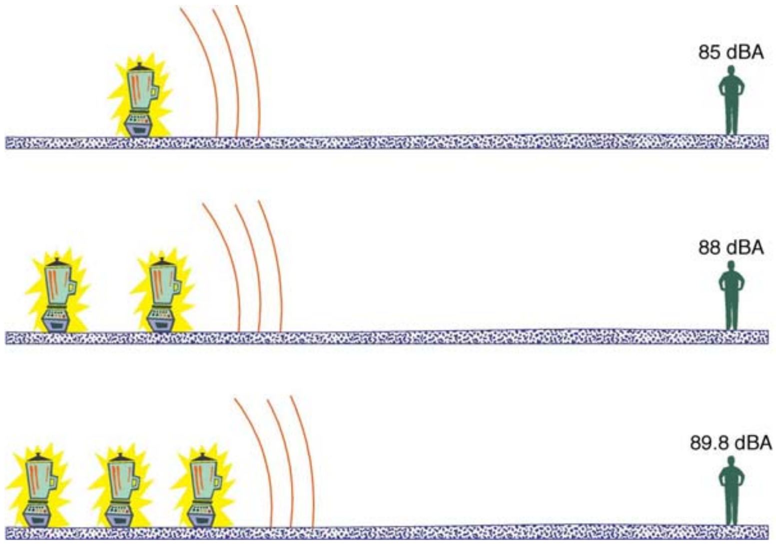

Figure 1 – Effect of Adding Noise Sources

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, 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.

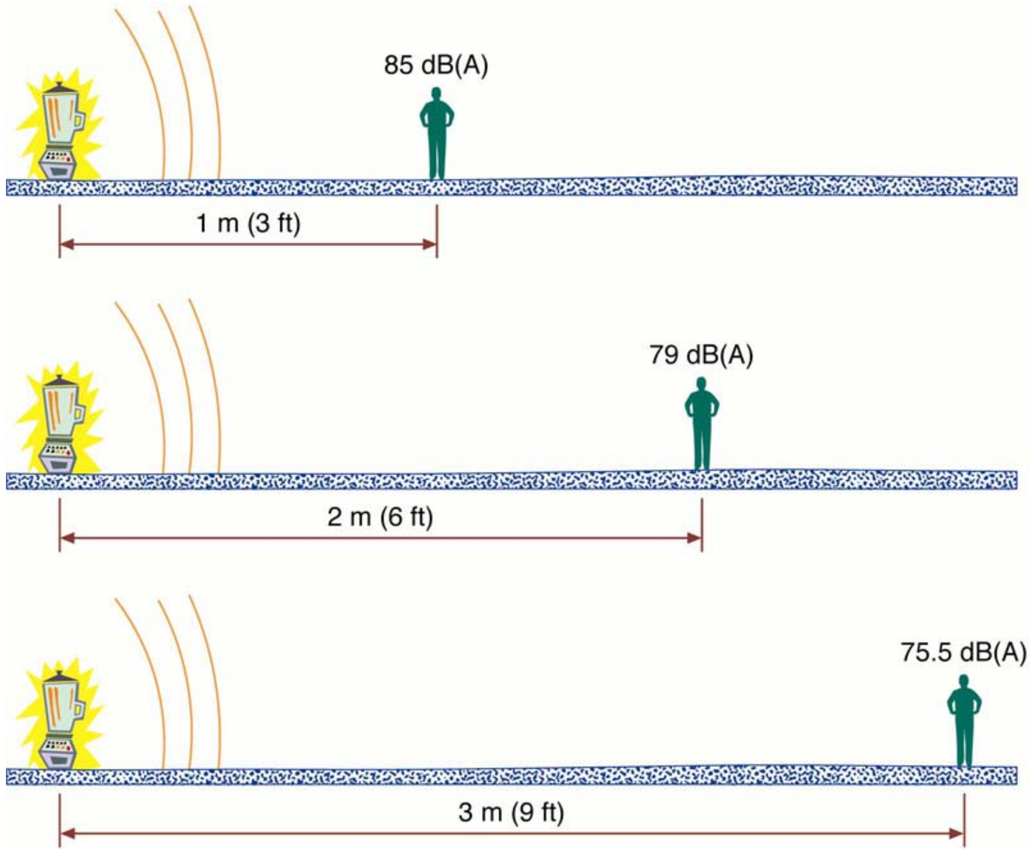

Figure 2 – Effect of Distance on a Point Noise Source

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 edge of the roadway would have a noise level of 82 dB (A). This is illustrated in Figure 3.

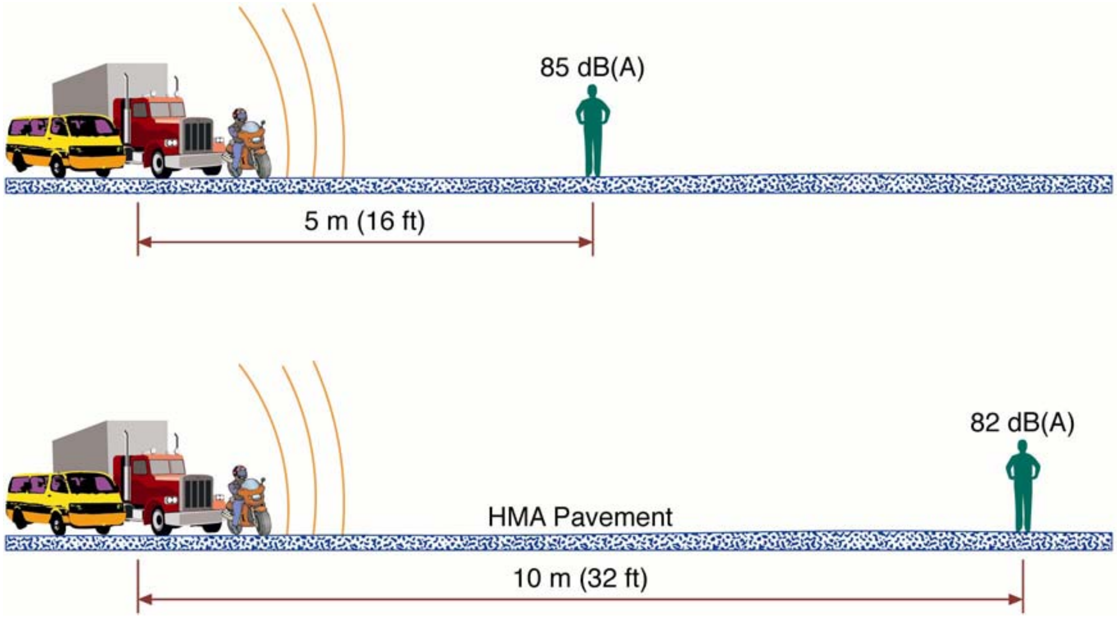

Figure 3 – Effect of Distance on a Line Noise Source Over a Paved Surface

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 alongside 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 = distance from the sound source to the first point of interest
d_2 = distance from the sound source to the second point of interest

Thus, if the noise level is 85 dB(A) at the edge of pavement which is at 16 feet (d_1) (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 (d_2) 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.

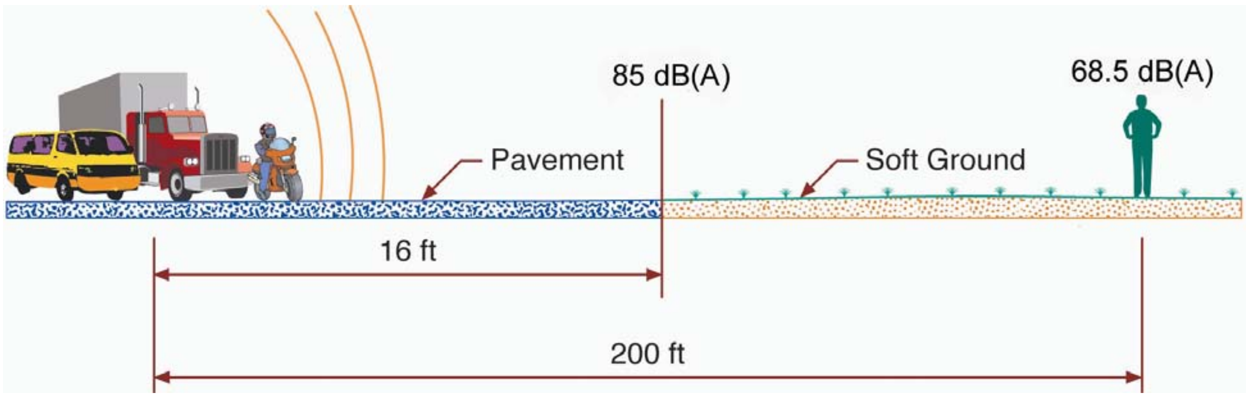

Figure 4 – Effect of Distance on a Line Noise Source
Sound Traveling Over Soft Ground

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 (SBP) procedures as defined by both International Standards Organization (ISO) Standard 11819-1 (*5*) and the FHWA manual <u>Measurement of Highway-Related Noise</u> (*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.

Another method (*8*) is to conduct the testing on an accelerating vehicle. In this procedure at the entrance to a "trap" section of the test site, the vehicle begins to accelerate at full throttle. A sound level meter is set at a specified distance from the center of the travel path of the vehicle and is used to capture the maximum sound level of the vehicle as it passes through the "trap." This procedure tends to emphasize power train noise since the vehicle is in full acceleration during the test.

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.

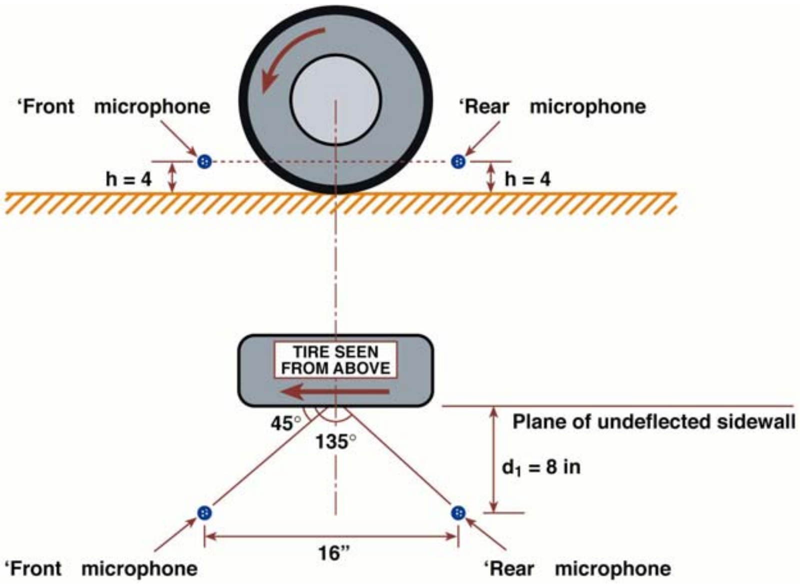

Figure 6 – Diagram Showing Microphone Locations in NCAT CPX Trailer

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 SPB method, requiring little setup prior to use.

TEST RESULTS

In October 2003 the National Center for Asphalt Technology tested eighteen pavement surfaces (12 HMA and 6 PCCP) located throughout Colorado at the request of the Colorado DOT. The Colorado DOT chose the pavements to be tested. All testing was done at 60 mph using two tires (except site 6 which was tested at 45 mph for safety reasons). Three tests were conducted with each tire on each pavement surface. The reason for conducting the tests with two tires was to provide a better representation of the tire/pavement noise levels for each surface type. The two tires used were a Goodyear Aquatread and a Uniroyal Tiger Paw. Appendix A contains pictures of the tire tread pattern. Table 2 contains a summary of the test results.

Table 2 – Summary of Colorado Test Data

Site No.	Route	Yr Const.	Mix Type of Surface	Milepost		Noise Level dB(A)		Average Both Tires
				From	To	Aquatread	Uniroyal	
1	SH 558	2003	Nova Chip	2	3	95.2	95.0	95.1
2	I-225 N Parker Road to Mississippi Rd.	2002	19 mm SMA	6	7	96.9	96.8	96.9
3	I-25, Northbound 120th Ave to SH 7	1997	Superpave (s)	226	227	100.8	100.1	100.6
4	US 285 S – Turkey Creek Canyon, west to Conifer	2001	Longitudinally Tined PCCP	242	243	98.8	98.5	98.6
5	US 285 S, Turkey Creek Canyon, west to Conifer	2002	Ground PCCP	244	245	98.3	97.6	98.0
6*	US 285 S, Turkey Creek Canyon, west to Conifer	1999	9.5 mm SMA	246.2	247.2	94.9*	95.2*	95.1*
7	I-25, North of SH 7 Southbound	2002	Longitudinally Tined PCCP	231	230	98.1	97.0	97.5
8	Hwy 85 Sedalia, South	2003	Superpave (sx)	189	188	96.0	95.5	95.6
9	I 225, I-25 to Parker Road Both Directions	1998	Superpave (s)	2	3	101.2	101.2	101.2
10	Parker Road, S/O Hilltop to Stroh Ranch Road (Southbound)	1992	Transverse Tined PCCP	59	58	103.0	102.2	102.6
11	Parker Road, Lincoln Ave. to S/O East Jamison Ave.	2003	Superpave (sx)	Did not test				
12	Parker Road, S/O Cottonwood to S/O East Jamison Ave. (Southbound)	2002	Minnesota Drag PCCP	64	63	98.6	97.9	97.9
13	Parker Road, S/O East Jamison S/O Arapahoe Road (Southbound)	1997	Carpet Drag PCCP	65	64	98.4	97.4	97.9
14	US 50 W Kannah Creek East	2002	12.5mm SMA	48	47	96.5	95.9	96.2
15	US 50 E Kannah Creek	2002	Superpave (sx)	47	48	96.4	95.9	96.1
16	Hwy 82, Aspen Villiage	2002	Nova Chip Type C	32	33	99.0	98.8	98.9
17	I-70W Morrison Road (SH 26) to W/O Genesse	1999	Superpave (s)	254.5	253.5	101.6	101.3	101.4
18	I-70 W Genesse to Chief Hosa Exit (WB Only)	2003	OGFC	Short section between 253 & 252		95.1	95.2	95.3
19	I-70 W Chief Hosa Exit to Floyd Hill Interchange	2003	19 mm SMA	252	251	96.5	96.0	96.3

Discussion of HMA Test Results

Table 3 presents the specification gradation requirements for each of the HMA surface types tested and Table 4 presents the results of the noise testing on the surfaces. There was little difference in overall A-weighted noise level measured by decibels (dB(A) between the OGFC, the SMA, and the Superpave Graded SX surfaces. They were also the newest surfaces. There was little difference in the age of these surfaces. However, there was a significant difference between these surfaces and the Superpave Grade S surface. This could be the result of either the gradation of the surface and/or it could be from the deterioration of the surface over time. Of the noise testing conducted by NCAT to date, coarser HMA mixtures have generally had higher noise levels.

Table 3 – Gradation Ranges for the HMA Types Tested in Colorado

Sieve Size	Percent Passing By Mass						
	Grading S	Grading SX	19 mm SMA	12.5 mm SMA	9.5 mm SMA	NovaChip Type C	OGFC[1]
25 mm (1 in)	100	-	-	-	-	-	-
19 mm (3/4 in)	90-100	100	100	-	-	100	100
12.5 mm (1/2 in)	-	90-100	85-95	100	100	85-100	98
9.5 mm (3/8 in)	-	-	55-75	85-95	90-100	60-80	64
4.75 mm (No. 4)	-	-	24-32	24-32	30-55	28-38	11
2 mm (No 8)	23-49	25-58	16-24	16-24	20-42	25-32	8
1.18 mm (No. 16)	-	-	-	-	-	15-23	6
0.600 mm (No. 30)	-	-	10-16	10-16	12-25	10-18	5
0.300 mm (No. 50)	-	-	-	-	-	8-13	4
0.150 mm (No 100)	-	-	-	-	-	6-10	3.5
0.75 mm (No. 200)	2-8	2-10	8-12	8-12	8-12	4-7	3.3

Note: The OGFC gradation is from the mix design for the project tested.

Table 4 - Summary of HMA Test Results with NCAT CPX Noise Trailer

Type Mix	Site	Type	Yr Const.	Noise Level dB(A)
SMA	2	19 mm	2002	96.9
	14	12.5 mm	2002	96.2
	19	19 mm	2003	96.3
	Average			96.5
Superpave Grading S	3	-	1997	100.6
	9	-	1998	101.2
	17	-	1999	101.4
	Average			101.0
Superpave Grading SX	8	-	2003	95.6
	15	-	2002	96.1
	Average			95.7
NovaChip	1	Type C	2003	95.1
	16		2002	98.9
	Average			97.0
OGFC	18	-	2003	95.3

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 away 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 7 presents the frequency spectrum (noise (dB) versus noise frequency) for the HMA surfaces tested. The OGFC surfaces show a low frequency noise (the peak is about 600 Hz) that rapidly drops off. This is typical of the OFGC surfaces that have been tested by NCAT. The frequency for the other four surfaces peaks at about 1000 Hz and then declines. The Superpave SX surface (the dense graded mix with the finest gradation) has the lowest low frequency noise level. The low frequency noise is thought to be the product of the gradation and is a subject of further investigation using test results from the NCAT test track.

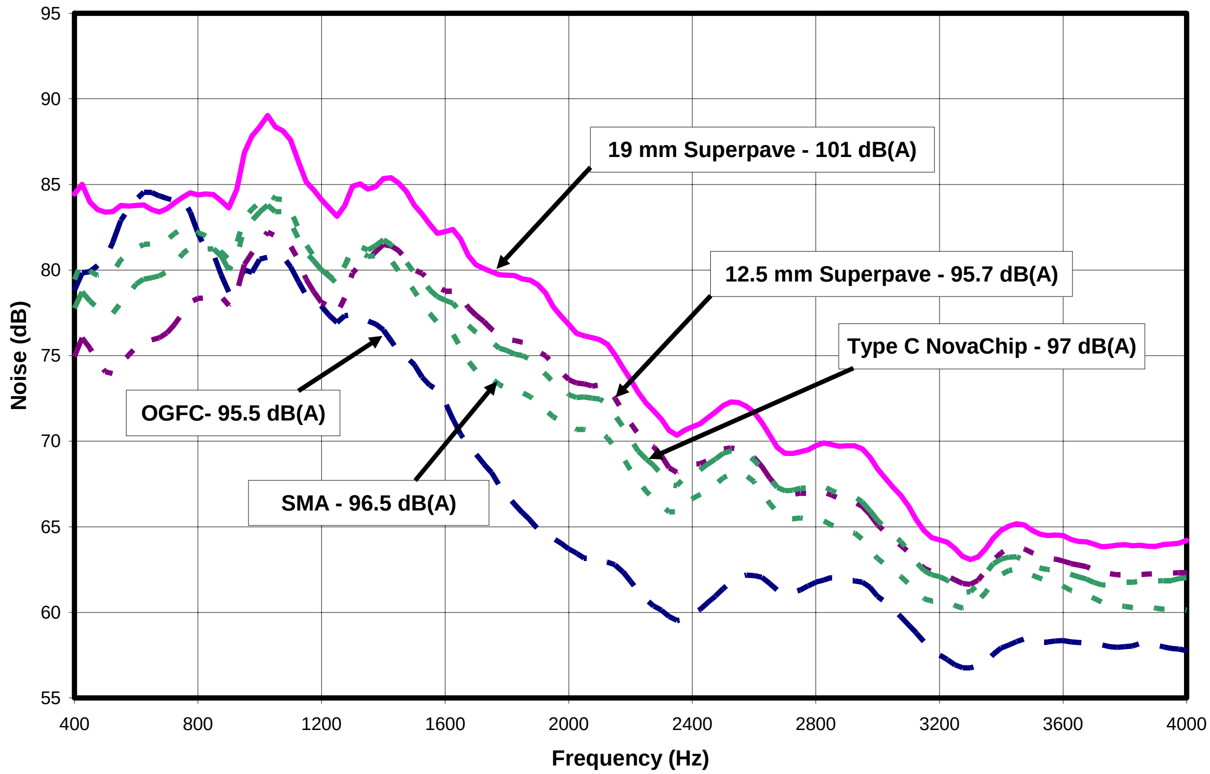

Figure 7 – Frequency Spectrum for HMA Pavements

A major concern in the potential use of pavement selection to address highway noise is the increase of noise level with age. A very limited evaluation of this problem was done using the test results obtained during this study. Figure 8 presents a graph of age versus pavement noise. As expected, there is a relationship between noise and age of pavement. There is large scatter in the data. Additional testing is needed to be able to better evaluate this relationship. This will be done by selecting a number of pavement sections representing different surface types and then testing them at specific time intervals.

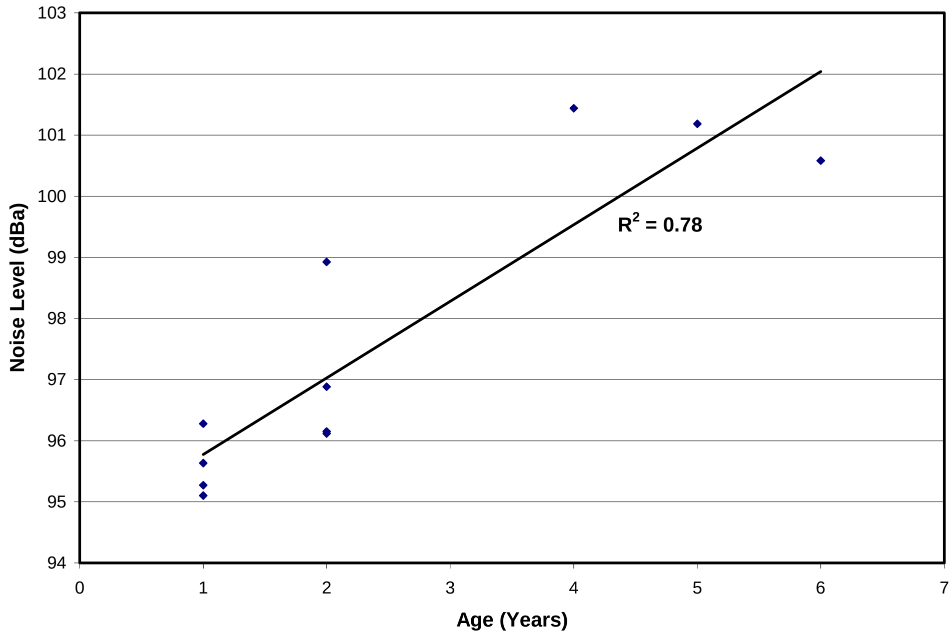

Figure 8 – Age versus Noise Level (dB(A)) for HMA Pavements Tested

Discussion of PCCP Test Results

Six different PCCP pavement sections were tested. They represented a variety of different PCCP texture types. As can be seen from Table 5 and from the frequency plot (Figure 9), there is little difference in the noise level for the newer PCCP pavements. The transverse tined PCCP is considerably noisier than all the other pavements tested. This could be due to the texturing procedure or due to the fact that the pavement was about eleven years old at the time of the testing.

Table 5 - Summary of PCCP Test Results

Surface Type	Site	Yr Const.	Noise Level
Longitudinally Tined	4	2001	98.6
	7	2002	97.5
Ground	5	2002	98.0
Minnesota Drag	12	2003	97.9
Carpet Drag	13	2003	97.9
Transverse Tined	10	1992	102.6

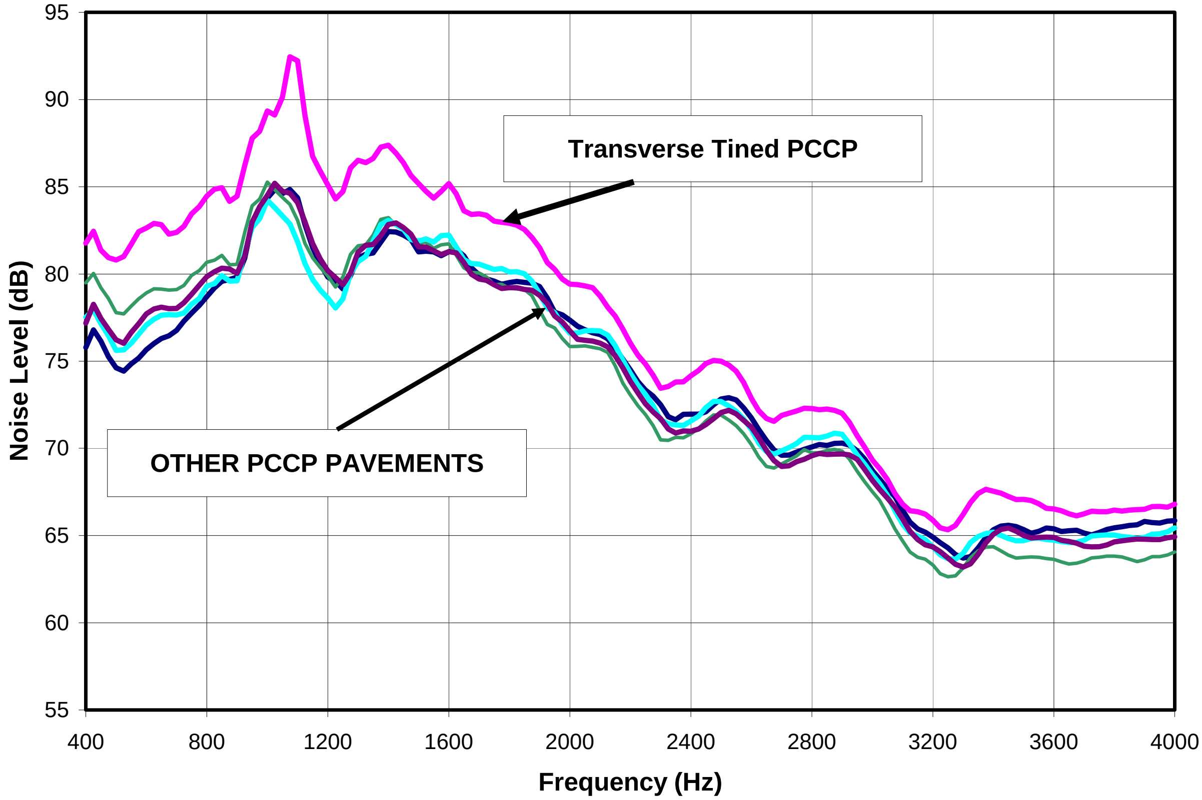

Figure 9 – Frequency Spectrum for PCCP Pavements

SUMMARY OF RESULTS FROM OTHER NCAT NOISE TESTING

Overall Summary

NCAT has now tested approximately 244 pavement surfaces in ten states. This includes 201 HMA surfaces with different Superpave gradations, microsurfacing, NovaChip, SMA and OGFC surfaces. Forty-three 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 - 95 dB(A).
    c. Stone Matrix Asphalt Mixes - 96 dB(A).
    d. Open-graded (coarse gradation) mixes 97 - dB(A).
    e. Average variability over a one-mile section - 3.8 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).
    e. Average variability over a one-mile pavement section – 4.4 dB(A).

The results presented above are representative of values reported with a CPX trailer in Europe. There is no official definition of what constitutes a quiet pavement. Dr Sandberg in his book *(2)* defines "A *low noise road surface* as a road surface which, when interacting with a rolling tyre, influences vehicle noise in such a way as to cause at least 3db(A) (half power) lower vehicle noise than that obtained on conventional and *most common* road surfaces." Thus, based on this statement and the information above that indicates that the "most common" road surface is a dense graded HMA, it would be logical to conclude that a "low noise road surface" would be a surface that has a noise level of about 92 dB(A) or less when measured with a CPX trailer.

Testing done on OGFC Pavements

Testing on OGFC mixtures has been done primarily in four states: Alabama, Nevada, Arizona, and Colorado. Table 6 shows the gradations for the mixtures used in each of these states and Figure 10 shows the frequency spectrum for these mixes.

Table 6 – Gradations of OGFC Surfaces Tested

Gradation	Arizona	Nevada	Colorado	Alabama
¾ inch	-	-	100	100
½ inch	-	100	98	89
3/8 inch	100	95	64	56
No. 4	38	45	11	14
No. 8	6	-	8	9
No. 16	-	11	6	-
No. 200	1.2	2	3.3	3.2
Average Noise Level dB(A)	91.5	93.8	95.1	98.6

It is thought that the noise characteristics of an open-graded friction course are dependent on three factors: the air voids of the mixture, the thickness of the layer, and the gradation of the mixture. It is thought that the air voids and thickness of the layer affect the high frequency component of the noise (greater than 1200 Hz.) and that the gradation affects the low frequency range (less than 800 Hz.)

An inspection of Figure 10 shows that all four mixes have the same general shape – high noise levels at about 600 Hz, a slight peak at about 1100 Hz and then dropping off rapidly. As the gradation of the mixture became finer (the percent retained on the 3/8 inch sieve was reduced) the noise level also decreased – primarily in the low frequency range.

No work has been done in the United States to evaluate the effect of thickness of an OGFC layer on tire/pavement noise. The difference between the Nevada and Arizona mixes is a different gradation and Arizona uses a thicker surface (Arizona's thickness is one inch and the thickness for the Nevada is ¾ inch). The gradation differences are small so the difference in noise level may be related to thickness.

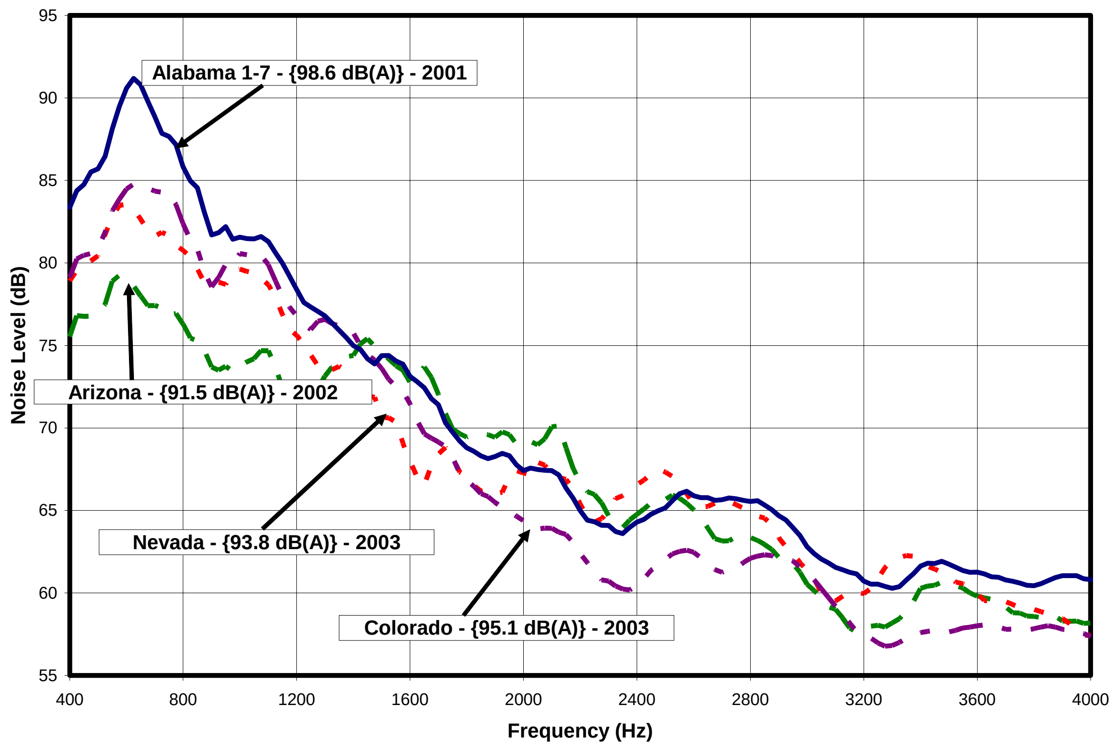

Figure 10 – Noise Spectrum for Different OGFC Mixes

The work in Europe indicates that as the air voids in an OGFC mix increase the noise level will decrease. Figure 11 presents some early work done by NCAT in four different states. As can be seen, as the air voids increase the noise level decreases.

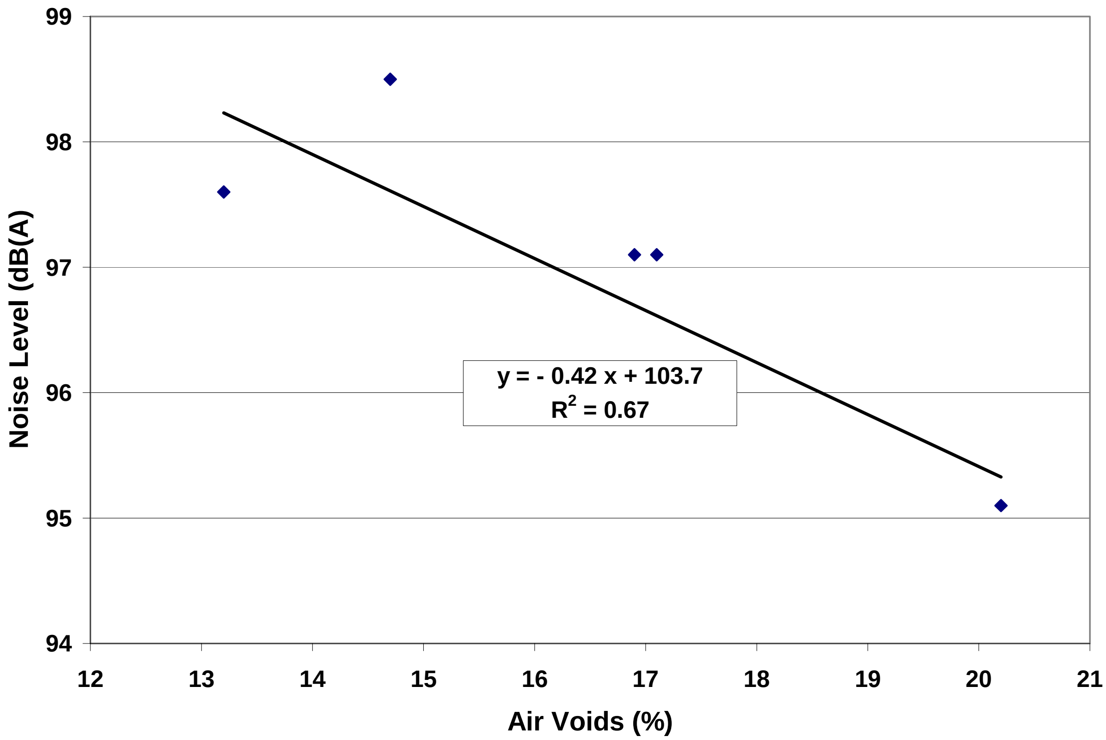

Figure 11 – Effect of Air Voids on Noise Level

The data presented above is preliminary in nature and needs further research. Controlled field experiments are needed in the United States to evaluate these concepts.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the testing that was accomplished that forms the basis for this report.

1. The quietest HMA pavement tested was the OGFC surface.
2. The age of an HMA pavement can have a major effect on the noise level of the pavement.
3. On the recently built PCCP pavements (2 to 3 years old) the type of texturing procedure used did not seem to make much difference in the noise level of the pavement.
4. The noisiest pavement tested in this study was an eleven year old transversely tined PCCP pavement.
5. It is recommended that the Colorado DOT consider the construction of a test section or sections that would evaluate the effect of thickness and gradation on the noise characteristics of an OGFC wearing course.

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APPENDIX A

Tires Used for Testing

TIRES USED FOR STUDY

Figure A:1 - Goodyear Aquatred

Figure A:2 - Uniroyal TigerPaw