

Demonstration Project – The Measurement of Pavement Noise on New Jersey Pavements Using the NCAT Noise Trailer

FINAL REPORT
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16. Abstract <p>A demonstration project was conducted for the New Jersey Department of Transportation (NJDOT) to evaluate the measurement of pavement/tire noise on New Jersey pavements. The pavement/tire noise is defined as the noise directly produced by the tire traveling over the pavement surface. It does not consider other traffic-related noise such as automobile/truck engines, braking, etc. This is important since the only factor the NJDOT can truly control to aid in the traffic noise reduction is the pavement surface.</p> <p>The demonstration project was developed to provide two key pieces of information: 1) An evaluation of the NCAT Noise Trailer as a means of measuring pavement/tire related noise, and 2) To develop an initial database of noise values for different pavement surfaces that are typically encountered on New Jersey highways.</p> <p>The NCAT (National Center for Asphalt Technology) Noise Trailer uses the Close-Proximity Method (CPX) to measure the pavement/tire noise. In this method, microphones are placed near the pavement/tire interface to directly measure the pavement/tire noise levels. The microphone set-up and tires are enclosed in a chamber that is insulated with noise absorbing insulation. This provides an enclosure that is only measuring the noise developed by the pavement/tire interface and not any external noise of the passing vehicles or environment. The NCAT Noise Trailer was evaluated for repeatability and also to evaluate the effect of traffic speed on the pavement/tire noise. Results of the testing showed the repeatability to be quite consistent, with the average standard deviation to be 0.15 decibels, as long as the test section is greater than 0.1 miles. The standard deviation proved to increase when the test section was less than 0.1 miles, such as for bridge decks. The effect of traffic speed was evaluated by testing the same pavement section at three different speeds; 55, 60, and 65 mph. The results indicated that the 55 mph speed produced the lowest pavement/tire noise and that it can be assumed that the noise increases linearly (at least within this range of traffic speed).</p> <p>The NCAT Noise Trailer was also used to develop an initial database of pavement/tire noise levels for different pavement surfaces tested. In general, the Portland Concrete (PCC) sections produced the loudest pavement surface while the Open-graded Friction Course (OGFC) produced the lowest pavement/tire noise.</p>					
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ABSTRACT

Traffic noise is a serious problem. Engine, exhaust, aerodynamic (power train) noise, and pavement/tire noise contribute to traffic noise. The FHWA Noise Abatement Criteria states that noise abatement must be considered for residential areas when the traffic noise 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. Research in Europe and the United States has indicated that it is possible to build pavement surfaces that will provide low noise roadways. In January of 2002 the National Center for Asphalt Technology (NCAT) initiated a research study with the objective to develop safe, quiet and durable asphalt pavement surfaces. The first step towards accomplishing this objective was to develop a fast and scientifically reliable method for measuring the acoustical characteristics of pavement surfaces. The next step is to conduct studies to evaluate the tire/pavement noise characteristics of various pavement surfaces and to evaluate what properties of those pavements will provide quiet pavement surfaces.

To measure the pavement noise related to only the tire and pavement surface, NCAT developed the NCAT Noise Trailer. The NCAT Noise Trailer uses the Close-Proximity Method (CPX) to measure the tire/pavement noise. In this method microphones are placed near the tire/pavement interface to directly measure the tire/pavement noise levels. The microphone set-up and tires are enclosed in a chamber that is insulated with noise absorbing insulation. This provides an enclosure that is only measuring the noise developed by the pavement/tire interface and not external noise of the passing vehicles or environment. It was developed in Europe and is defined by ISO Standard 11819-2.

The NCAT Noise Trailer was evaluated for repeatability and also to evaluate the effect of traffic speed on the pavement/tire noise. Results of the testing showed the repeatability to be quite good, with the average standard deviation to be 0.15 decibels, as long as the test section is greater than 0.1 miles. The standard deviation showed to increase when the test section was less than 0.1 miles, such as for the bridge decks and the SHRP test sections. The effect of traffic speed was evaluated by testing the same pavement section at three different speeds; 55, 60, and 65 mph. The results indicated that the 55 mph speed produced the lowest pavement/tire noise and that it can be assumed that the noise increases linearly (at least within this range of traffic speed). The increase rate of pavement/tire noise varied depending on the pavement surface type.

The NCAT Noise Trailer was also used to develop an initial database of pavement/tire noise levels for different pavement surfaces tested. In general, the Portland Concrete (PCC) sections produced the loudest pavement surface while the Open-graded Friction Course (OGFC) produced the lowest pavement/tire noise.

INTRODUCTION

Traffic noise is a serious problem. Engine, exhaust, and aerodynamic (power train) and pavement/tire noise contribute to traffic noise. The FHWA Noise Abatement Criteria states that noise abatement must be considered for residential areas when the traffic noise 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. Research in Europe and the United States has indicated that it is possible to build pavement surfaces that will provide low noise roadways. In January of 2002 the National Center for Asphalt Technology initiated a research study with the objective to develop safe, quiet and durable asphalt pavement surfaces. The first step towards accomplishing this objective was to develop a fast and scientifically reliable method for measuring the acoustical characteristics of pavement surfaces. The next step is to conduct studies to evaluate the tire/pavement noise characteristics of various pavement surfaces and to evaluate what properties of those pavements will provide quiet pavement surfaces.

Measurement of Pavement Noise

Two general methods have been developed for measuring pavement noise levels in the field - the statistical by-pass approach as defined by ISO Standard 11819-1, and the close proximity method (CPX) as defined by ISO Standard 11819-2.

Statistical By-Pass Method (SBP)

This method consists of placing microphones at a defined distance from the vehicle path at the side of the roadway (1). The statistical by-pass (SBP) is governed in the United States by procedures developed by The John A. Volpe National Transportation Systems Center. It calls for placing microphones 50 feet from the center of the vehicle lane and at a height of 5 feet above the pavement and requires that the noise characteristics and speed of a prescribed number of vehicles be evaluated. The statistical by-pass procedure is time consuming to conduct, the results can vary based on the traffic mix (even if the vehicle types are the same, the differences in tires can cause problems); and very specific acoustical conditions must be met to conduct these measurements (roadway that is essentially straight and level, limit on the background noise, no acoustical reflective surfaces within 30 feet of the microphone position, and a relatively uniform traffic speed). The result of these restrictions is that a limited number of pavement surfaces can be tested economically.

Close-Proximity Method (CPX)

In this method microphones are placed near the tire/pavement interface to directly measure the tire/pavement noise levels. It was developed in Europe and is defined by ISO Standard 11819-2 (3). In the CPX method sound pressure is measured.

In the close-proximity method the microphones are mounted as shown in Figure 1. They are mounted inside an acoustical chamber (each side of the chamber is covered with acoustical sound deadening material). The purpose of this is to eliminate the noise from traffic while testing.

The close proximity method offers a number of 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 of porous surfaces.
4. It is much more portable than the SPB method, requiring little setup prior to use.

The measurement of the tire/pavement noise at the interface is faster, more practical and more economical than the SPB method, but it is limited in that it is relevant only in cases where tire/road noise dominates and the power unit noise can be neglected.

The National Center for Asphalt Technology (NCAT) has designed and built two CPX trailers. The first one was delivered to the Arizona Department of Transportation (ADOT) in late January 2002 and is now being used by ADOT to evaluate the noise characteristics of pavement surfaces in Arizona. The second trailer (shown in Figure 2) was delivered to NCAT in October 2002. Both trailers meet the requirements of ISO Standard 11819-2 Measurement of the Influence of Road Surfaces on Traffic Noise – Part 2 The Close Proximity Method.

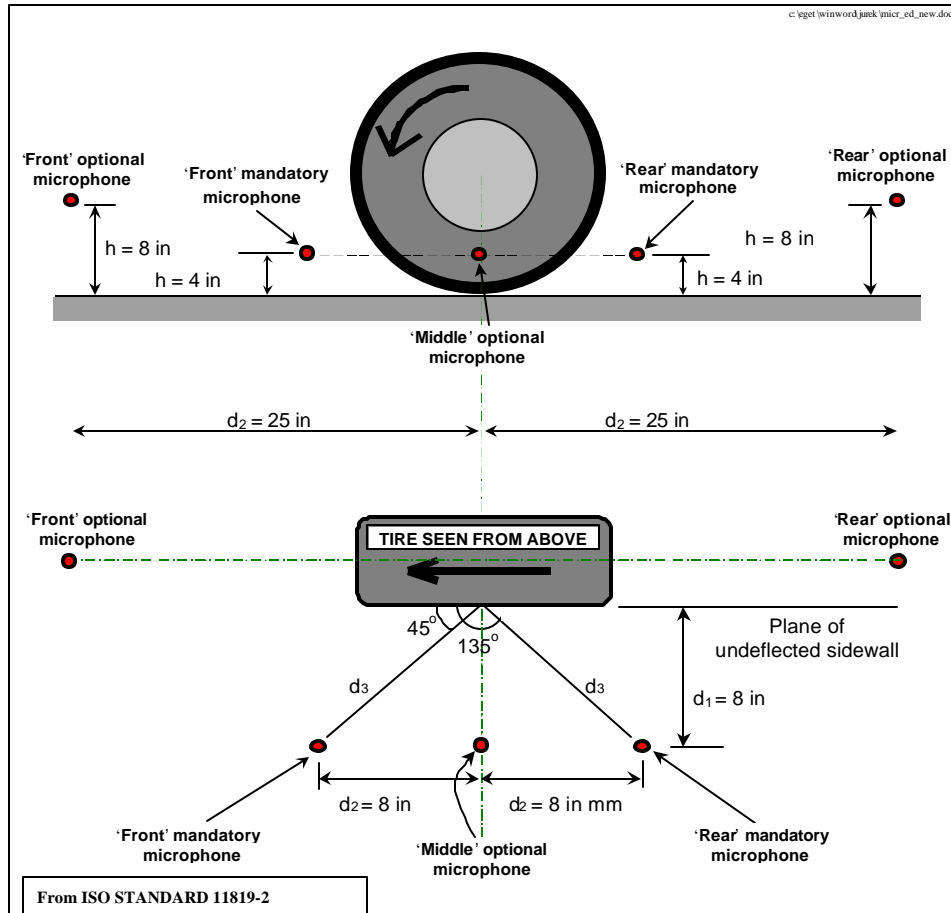


Figure 1 - Microphone Layout for Close-Proximity Trailer

Complimentary Testing - NCAT Test Program

NCAT is completing the testing of pavement surfaces at the NCAT test track. This information will provide a data base on the noise characteristics of forty-six different HMA pavement surface (primarily dense-graded Superpave) and an understanding of the tire/pavement noise characteristics of different tires (seven different tires are being used). A study was also recently completed in October 2002 for the Michigan DOT. This study evaluated 12 different pavement surfaces in Michigan (both HMA and PCC). NCAT is currently conducting a study for the Alabama DOT to evaluate the noise characteristics of pavements throughout Alabama.

Results of Michigan DOT Study

The Michigan DOT Study evaluated only twelve different pavement sections. The study used three different traffic speeds (45, 60, and 75 mph) and also two different types of tires (Mastercraft and UniRoyal). Research at NCAT has shown that the traffic speed



Figure 2 – NCAT CPX Trailer

has a direct impact on the pavement/tire noise. The general relationship is that as the traffic speed increases, the pavement/tire related noise increases. However, only a small amount of work has been conducted showing the effect of tire type on the pavement/tire related noise. Any work regarding tire type has shown that the more aggressive the tire tread pattern, the louder the pavement/tire related noise.

A summary of the general findings from the study are as follows:

1. The vehicle speed has a large influence on the pavement/tire related noise. In general, for every 1 mph increase in vehicle speed, a 0.2 decibel increase in the pavement/tire related noise can be expected.
2. For the test sections tested, the asphalt-related surfaces provided the lowest noise levels. Michigan DOT's SMA (Stone Matrix Asphalt) mix on I-96 showed the lowest pavement/tire related noise level with a value of 97.5 decibels. Surprisingly, the second lowest pavement/tire related noise level was found to be a PCC pavement surface treated by diamond grinding (I-275). This section had a noise level of 97.8 decibels. The loudest pavement section tested was a PCC surface treated with transverse tining (I-69). This section had a noise level of 100.6 decibels.

Unfortunately, a number of issues that are important to New Jersey pavements, as well as the test procedure, were not addressed.

1. The repeatability of the NCAT Noise Trailer. The general practices of the test are to run over the same test section three times and then average the noise values. However, do large variations affect the measurements? Also, to save time, can a test section be tested only once with the results being meaningful?
2. The effect of OGFC (Open-graded friction course) mixes on noise. It is generally accepted that the use of OGFC aids in the reduction of pavement/tire related noise. However, little OGFC sections have been tested using the NCAT Noise Trailer. This concern is of relevance for micro-surfacing techniques that the NJDOT use as well.
3. The effect of aging of the pavement surfaces on the pavement/tire related noise. Although to directly compare the true effect of aging, the pavement sections would need to be tested over time. However, a general conclusion can be drawn from the data as long as the pavement surfaces are of equal mix design type and of different age.

Pavement Sections Selected for Testing

Members of the New Jersey Department of Transportation (NJDOT) were asked by the Bureau of Research to provide recommendations as to areas of interest for the study. The members were predominantly from the Bureau of Materials, Pavement Technology Unit, Bureau of Pavement Management, Bureau of Research, as well as members from the Rutgers Asphalt/Pavement Laboratory (RAPL). Based on the discussions, the following test sections were selected for evaluation.

Hot Mix Asphalt

Open-Graded Friction Course (OGFC)

- Route 24 E. (MP 7.5 to 9.7) – Modified Open-Graded Friction Course (#1) (4 years old)
- Route 24 W. (MP 9.7 to 7.5) – Modified Open-Graded Friction Course (#1) (4 years old)
- Route 195 E. (MP 1 to 7) – Modified Open-Graded Friction Course (#2) (2 years old)
- Route 195 W. (MP 10) – Open Graded Friction Course with Crumb Rubber – SHRP site (10 years old)
- Route 78 W (MP 30: bridge deck) – Modified Open-Graded Friction Course (#1) (1 Year old)
- Route 9 N. – Open Graded Friction Course with Crumb Rubber (10 years old)

Novachip®

- Route 78 W. (MP 17 to 18) (8 years old)
- Route 195 W. (MP 1 to 5) (3 years old)

Dense Graded Asphalt

- Route 22 W. (MP 31.7 to 34.3) – 12.5mm Superpave mix (4 years old)
- Route 22 W. (MP 34.3) – 19mm Superpave mix (4 years old)

Route 78 W. (MP 31 to 42) – 12.5mm Superpave mix (4 years old)
Route 78 E. (MP 31 to 42) – 19mm Superpave mix (5 years old)
Route 78 E. and W. (MP 23.1 to 30.8) – 12.5mm Superpave mix (less than 1 year old)
Route 195 W. – SHRP Test Sections (mostly NJDOT I-4 and I-4 with RAP) (10 Years old)

Microsurfacing

Route 70 (3 years old)
Route 202 S. (MP 4.0 to 3.0)
Route 29 N. (MP 26 to 27)
Route 29 S. (MP 27 to 26)

SMA Pavements

Route 1 N. and S. (MP 11.3 to 11.8)
Route 78 E. and W. (roadway and bridge decks) (MP 23.1 to 30.8)

Portland Cement Concrete

Route 29 Tunnel (MP 0) (Diamond Grinding)
Route 29 (MP 4.5 to 6.5) (built in 1956 to 1957)
Route 280 (MP 5.8 to 13) (built in late 1960's to early 1970's)
Route 287 (MP 47.2 to 58.5) (Diamond Grinding)
Route 287 (MP 0 to 5.9) (built in early 1960's)
Route 195/Route 29 Junction - (Bridge over Watson's Creek) (Saw-cut Transverse Tining)
Route 78 (MP 0 to 4) (Transverse Tined after 14 years of service)

Overall, forty two pavement sections were selected for testing.

PRELIMINARY RESULTS OF EXPERIMENTAL PROGRAM – NOISE LEVELS

The preliminary results are shown as a single number with a unit in decibels (dB(A)). The decibel is a measurement of noise pressure that comprises of many different sound frequencies. However, the analysis used for determining the decibel level for a pavement section uses a weighted analysis procedure to give greater emphasis to the sound frequencies most commonly heard by the human ear. Normal conversation has a decibel level anywhere between 40 and 60 dB(A), with hearing discomfort usually occurring at a dB(A) level of 70 to 80 dB(A). When comparing the different dB(A) levels, the following can be used as a guide:

- A decrease of 1.0 dB(A) means a 12% decrease in the overall noise
- A decrease of 3.0 dB(A) means a 40% decrease in the overall noise
- A decrease of 6.0 dB(A) means a 200% decrease in the overall noise

Results of Testing of Hot Mix Asphalt (HMA) Materials

The HMA materials comprised of Open-Graded Friction Course, Novachip®, Micro-surfacing, Stone-Matrix Asphalt (SMA), and the dense graded asphalt (DGA) mixes. Each different material is compared individually based on similar HMA mixture type. A total of 30 different HMA test sections were recorded and analyzed.

Open-Graded Friction Course (OGFC)

A total of eight test sections of OGFC were evaluated. The results are illustrated in Figure 3. The lowest tire/pavement noise level was obtained by the OGFC that was modified with crumb rubber using the Rouse procedure. The Rouse procedure used a -80 mesh crumb rubber particle size, while the McDonald procedure used a -40 mesh crumb rubber particle size. The New Jersey Department of Transportation (NJDOT) MOGFC-1 and MOGFC-2 have different gradation specifications, with the MOGFC-1 coarser than the MOGFC-2 mix. The results from Figure 3 also show that there is some variability in the noise measurements within the same roadway, as indicated by the I-195 East section. The NJDOT MOGFC-2 was placed along a 5 mile section. The CPX test results indicated that depending on the exact location within this test section, the noise levels can vary by as much as 0.3 dB(A). The variability can also be seen from the Rt. 24 East and West test sections where the job mix formula and source material were used and placed at almost identical times, yet there is a 1.0 dB(A) difference in noise level. The difference may be attributed to in-place air voids or a change in the material's gradation. Further analysis on this section is being conducted.

The total range of noise levels between all OGFC sections tested was 2 dB(A). As shown in Figure 3, the asphalt rubber modified (AR-HMA) OGFC sections obtained the lowest noise levels. Recent work by the Arizona Department of Transportation (AZDOT) has indicated that the addition of crumb rubber to OGFC reduces noise more than OGFC without crumb rubber (Scofield, 2003). However, a further look into the gradation of the different OGFC mixes, illustrated in Figure 4, illustrates that the two AR-OGFC mixes also had the finest gradation.

Figure 4 indicates that the two AR-OGFC mixes were nearly identical in gradation, which may explain why the measured noise levels were almost identical; 96.6 and 96.8 dB(A) for the I-195 and Rt. 9, respectively. The NJDOT MOGFC-1 and MOGFC-2, which had louder noise levels than the AR-OGFC mixes, were coarser in gradation. Therefore, although the addition of crumb rubber may aid in reducing some of the tire/pavement generated noise, it may also be concluded that the finer gradation may also play a significant role. QA/QC data for the different OGFC mixes indicated that all of the in-place air voids were between 20 and 22%.

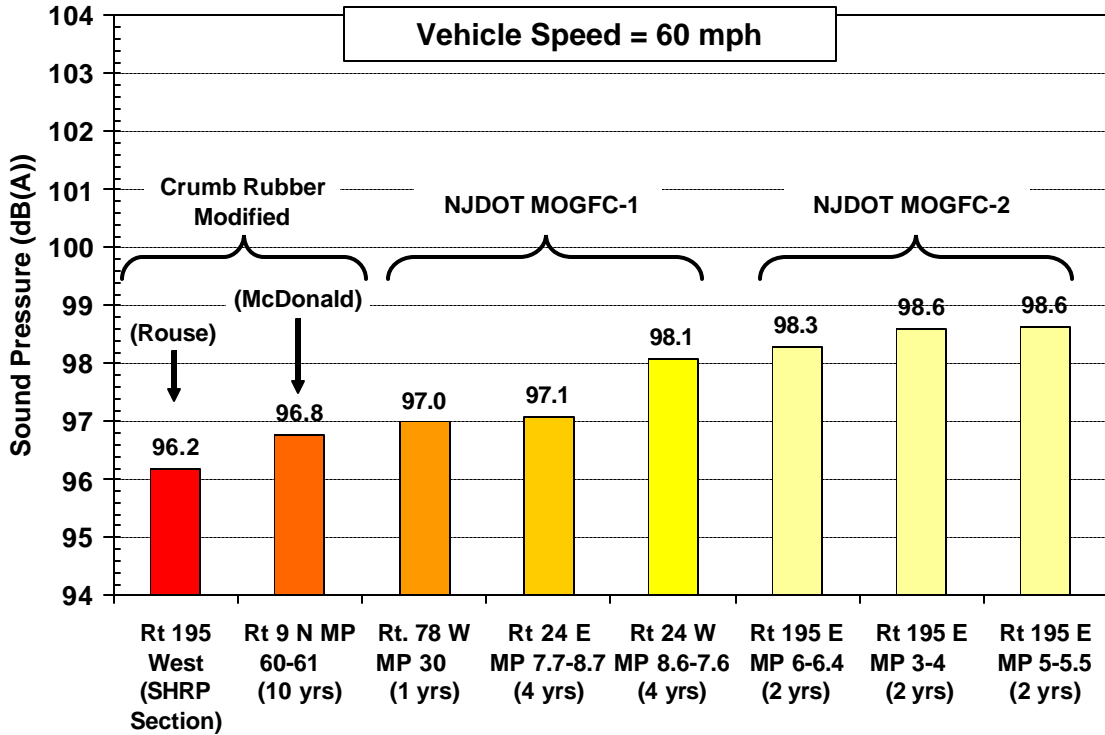


Figure 3 – Comparison of Tire/Pavement Related Noise for OGFC Mixes in New Jersey

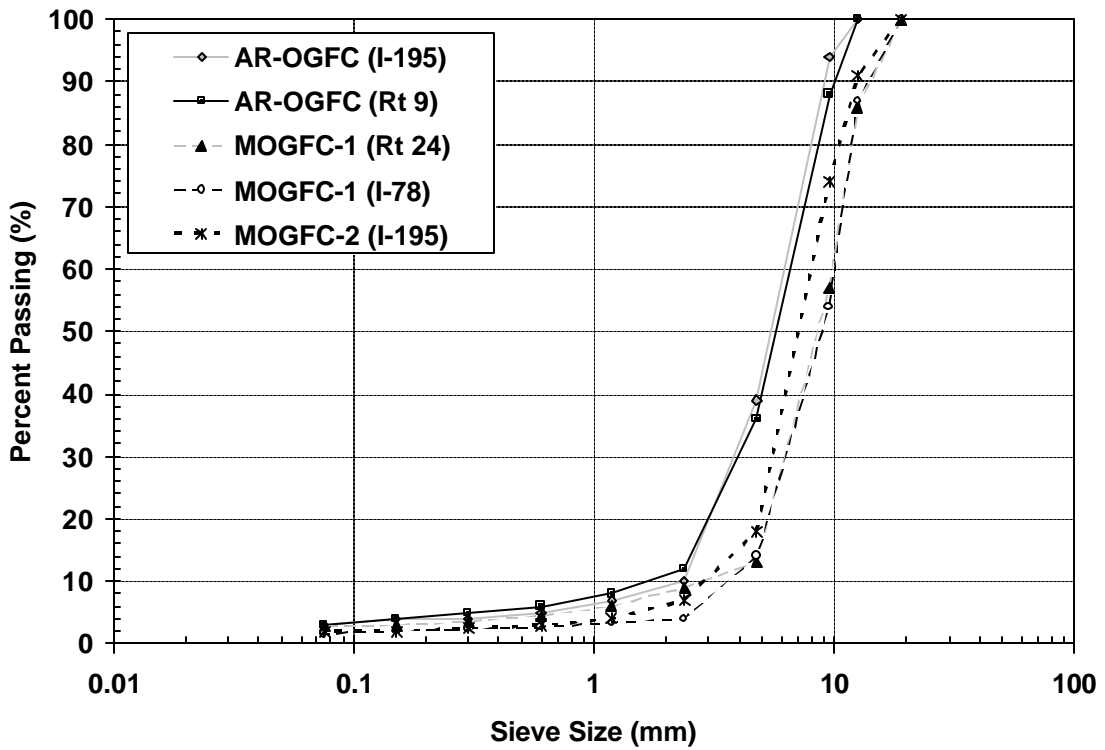


Figure 4 – Gradations of the OGFC Pavement Surfaces Tested by the Noise Trailer

One concern in the use of the OGFC is that the high porous nature of the mix tends to clog with time. By looking at the noise measurements of the NJDOT MOGFC-1 mixes, the Route 24 East section is four years old compared to the Route 78 West section which was only one year old. Both sections have comparable dB(A) values indicating that either clogging did not occur within the four year period or that the clogging of the OGFC pores has little effect on the tire/pavement related noise.

Novachip® and Micro-surfacing

Both the Novachip® and Micro-surfacing are surfacing and/or resurfacing techniques to provide a better ride quality on asphalt pavements. The Novachip® process places an ultra-thin, coarse aggregate with a polymer-modified asphalt binder over a special asphalt membrane. The coarse aggregate matrix helps to reduce splash and spray from traffic, sometimes even comparable to OGFC mixes. The Micro-surfacing is a mixture of quick setting polymer-modified asphalt binder, aggregate, water, and mineral filler. The materials are mixed into a slurry and placed onto existing pavements. There are generally 2 types of Micro-surface, Type 2 and Type 3. Type 3, which is generally used by the NJDOT, uses coarser aggregates than the Type 2 and is typically used in higher traffic volume areas. The results of comparing Novachip® and Micro-surfacing are shown in Figure 5.

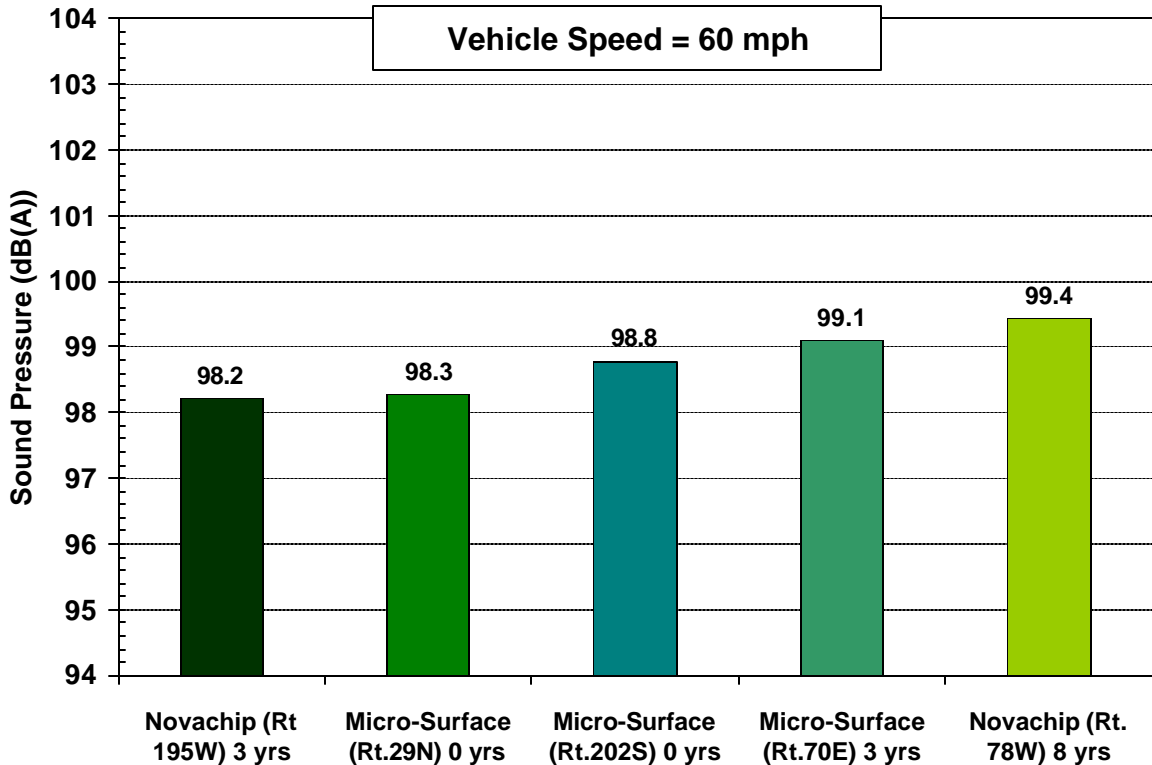


Figure 5 – Comparison of Tire/Pavement Related Noise for HMA Surfacing Techniques (Novachip® and Micro-surfacing)

The three sections of Micro-surfacing shown in Figure 5 are Type 3. In general, both techniques provide similar noise pressures. However, it is evident that during the service life of the pavement surfaces, the tire/pavement related noise increases. This is most likely due to both the natural aging of the material, as well as the impact of traffic loading on the pavement surface.

Stone-Matrix Asphalt (SMA)

Stone-Matrix Asphalt, also called Stone-Mastic Asphalt, is a gap-graded hot mix asphalt that was originally designed in Europe to maximize rutting resistance and durability. The goal is to create stone-on-stone contact within the mixture. Since the aggregates do not deform as much as the asphalt binder, the stone-on-stone contact provides a highly rut resistant mix. However, due the higher asphalt binder content and extremely coarse nature of the mix, some contractors may have difficulties in placing and compacting the mix.

The SMA evaluated in this study was located on Route 1 between mile posts 11.3 and 11.8, and the bridge decks of Route 78 East between mile posts 28 and 32. Figure 6 indicates the results of the testing.

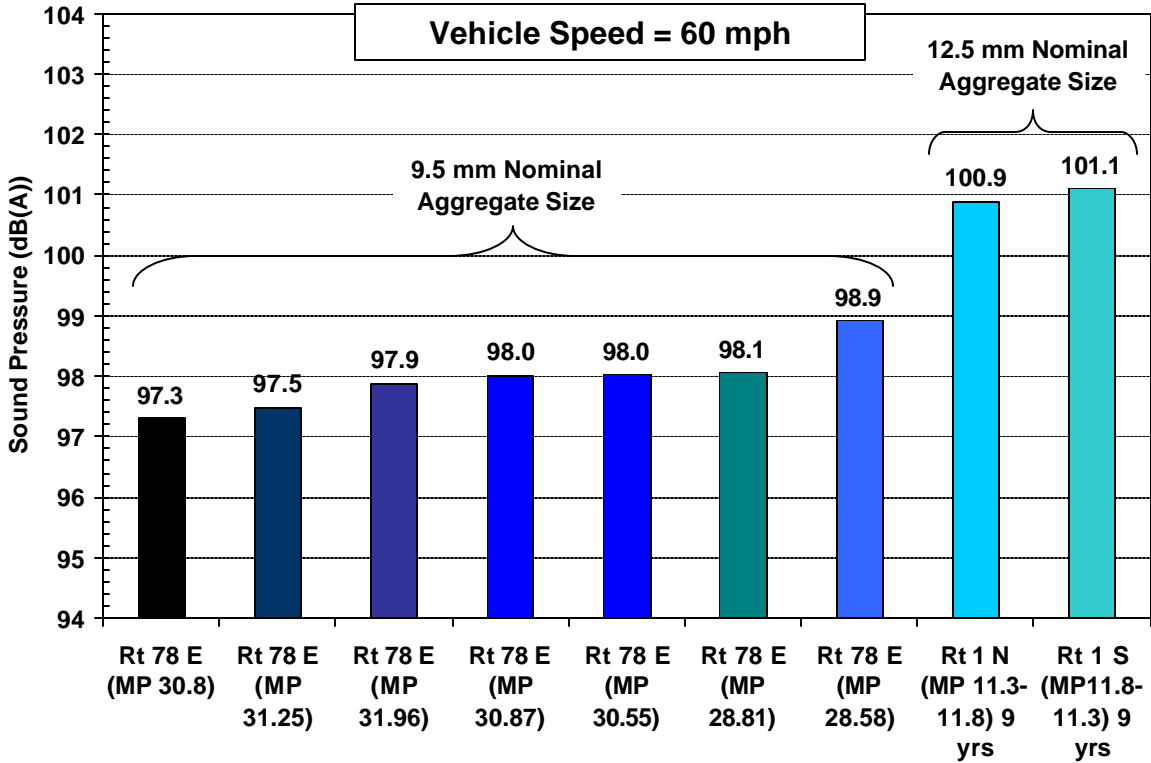


Figure 6 – Comparison of Tire/Pavement Related Noise for Stone-Matrix Asphalt (SMA)

Based on the figure, it is obvious that the nominal aggregate size of the SMA mix has a large impact on the tire/pavement noise. The 9.5 mm SMA mix had an average sound pressure value 98 dB(A), while the 12.5 mm SMA mix had an average sound pressure value of 100 dB(A). This increase on sound pressure corresponds to approximately 37% more noise.

Dense Graded Hot Mix Asphalt (DGA)

The dense graded hot mix asphalt contains well-graded aggregates intended for general use applications. This type of HMA is the most common type used by the NJDOT. The mixes evaluated in the study are from two different design methods, the Marshall design method and the Superpave design method. Similar to the other HMA mixes, the DGA can be designed to incorporate different aggregate sizes. Figure 7 shows the results of the testing conducted. It should be noted that unless specified in the figure, the test sections were located on Route 195 West as part of the Strategic Highway Research Program (SHRP) test site.

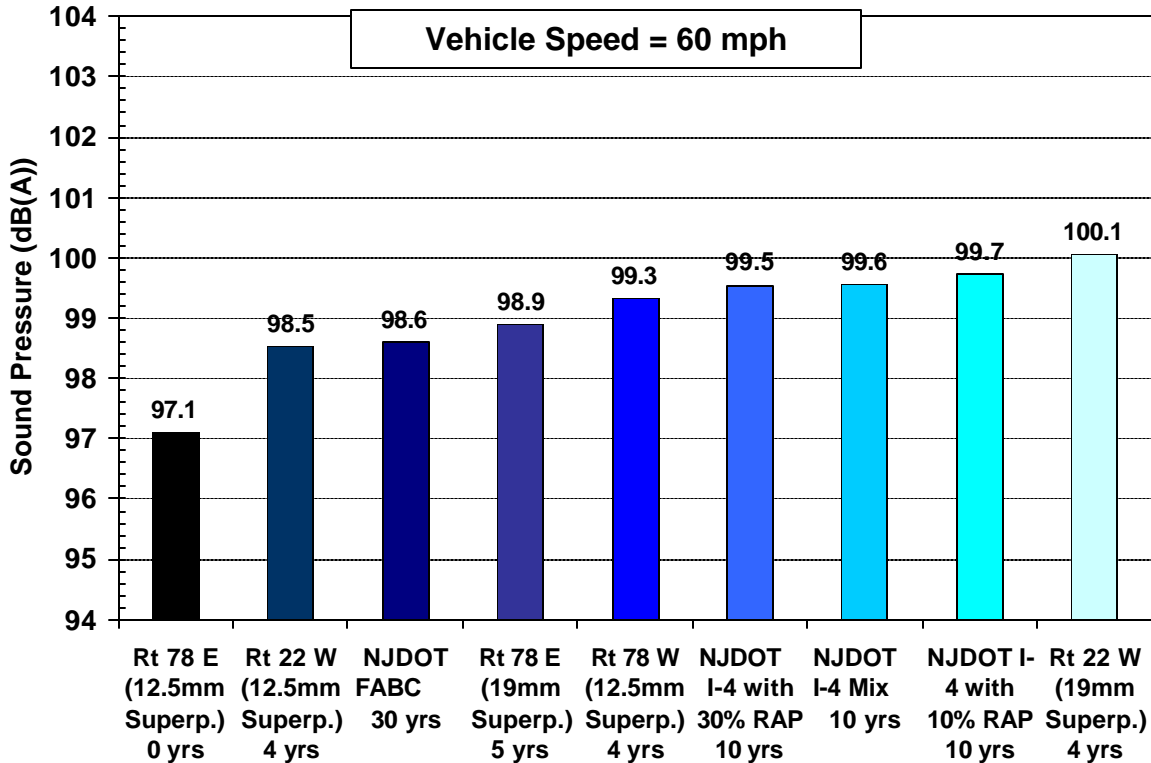


Figure 7 – Comparison of Tire/Pavement Related Noise for DGA HMA Mixes

All mixes that were designed using the Superpave method are indicated by “Superp.”, as well as its nominal maximum aggregate size. The mixes that were designed using the Marshall design are indicated as I-4 or FABC. The I-4 and FABC are pre-Superpave NJDOT designations for HMA mix designs.

The 12.5 mm Superpave mix located on Route 78 East had the lowest tire/pavement related noise level. It should be noted that this pavement section was essentially new (0 years) when it was tested. Another look at a 12.5 mm Superpave mix on Route 22 West had a value 1.4 dB(A) higher. This is almost an 18% increase in tire/pavement related noise. Meanwhile, another 12.5 mm Superpave mix located on Route 78 West was 2.2 dB(A) louder than the Route 78 East section. Both the Route 22 West and Route 78 West 12.5 mm Superpave sections were four years older than the Route 78 East section, again illustrating the effect of pavement aging on the tire/pavement generated noise.

The effect of age seemed to have varying results on the DGA mixes. The 12.5 mm Superpave mix showed an increase in noise levels. The 19 mm Superpave mixes (Route 78 East and Route 22 West) showed the opposite. Although the actual gradations of the mixes were not provided for this study, it appears that the overall gradation of the mix may have a greater impact on the measured noise levels than the age or simply the nominal aggregate size. The overall impact of traffic volume and vehicle type may also have an impact, but at the moment this can not be quantified. It should be noted that the FABC mix located on Route 195 West is almost 30 years old and still providing low tire/pavement noise levels (98.6 dB(A)). The NJDOT FABC would be comparable to a 9.5mm Superpave mix.

Results of Testing the Portland Cement Concrete (PCC) Paving Surfaces

A total of twelve test sections of PCC materials were evaluated using the CPX method. The PCC sections differed in the following surface treatments; diamond grinding, transverse tining, transverse tining via sawcutting, and broom finish (no treatment). The results of the tire/pavement noise testing are shown in Figure 8.

From Figure 8, it is evident that diamond grinding reduces the tire/pavement significantly. The average noise levels for the different PCC surface treatments are shown in Table 1. On average, diamond grinding reduces the tire/pavement noise by 5.1 dB(A) when comparing it to a PCC pavement with no surface treatment (Broom Finish). Similar findings on the diamond ground PCC surfaces were also found in Michigan (NCAT, 2003). On average, the transverse tining via sawcutting reduced the noise levels by 1.1 dB(A), while the traditional transverse tining increased the noise levels by 2.7 dB(A) when compared to the PCC surfaces with no surface treatment. The cost associated with diamond grinding the PCC pavement surface, as quoted to the NJDOT, is approximately \$6.00 per square yard.

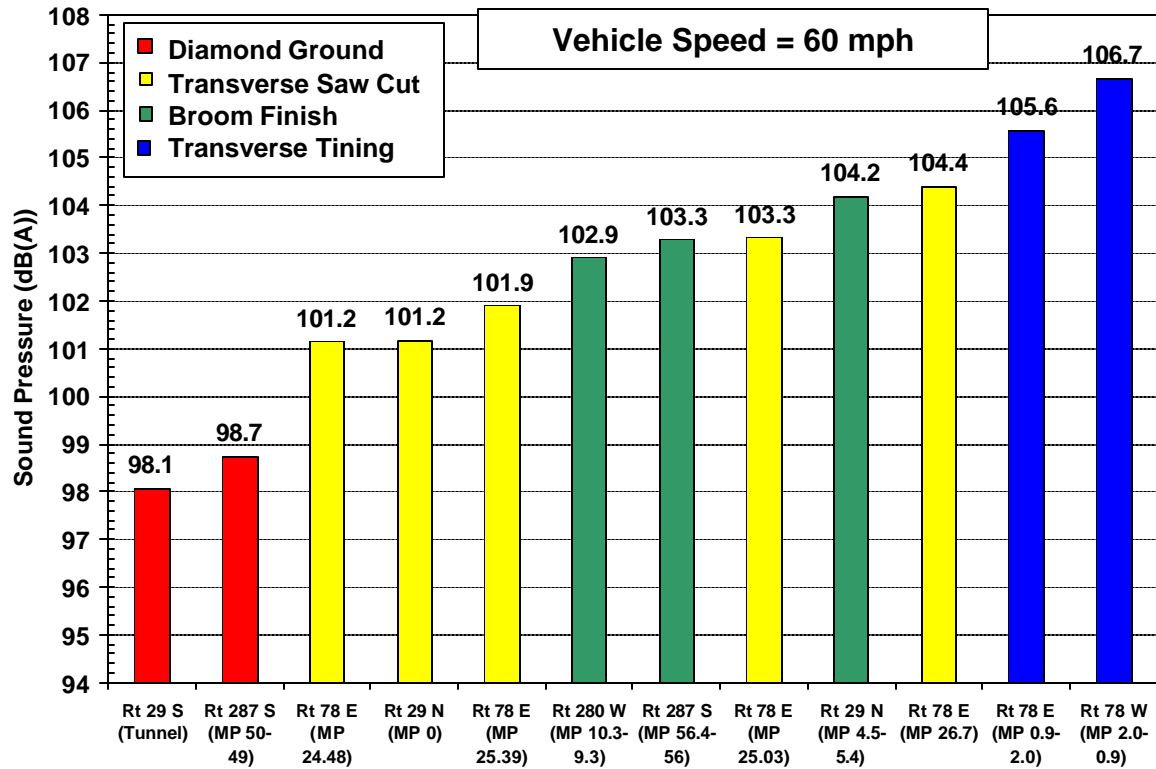


Figure 8 – Comparison of Tire/Pavement Related Noise for PCC Pavements

TABLE 1 – Average Noise Levels for PCC Surface Treatments

Surface Treatment Method	Number of Test Sections	Tire/Pavement Noise (dB(A))
Diamond Ground	2	98.4
Transverse Tined via Sawcut	5	102.4
Transverse Tined	2	106.2
Broom Finish (No Treatment)	3	103.5

Overall Comparison

In this study, 42 pavement sections were evaluated. These sections included both hot mix asphalt materials and Portland cement concrete. The pavement sections also included long highway stretches, as well as short bridge decks. All 42 sections were compared to produce the ten loudest and quietest pavements sections tested.

Figure 9 shows the 10 Quietest Pavement Surfaces tested in the study. The figure clearly shows that all, except one, of the pavement sections were hot mix asphalt materials, with four lowest being Open-Graded Friction Course mixes.

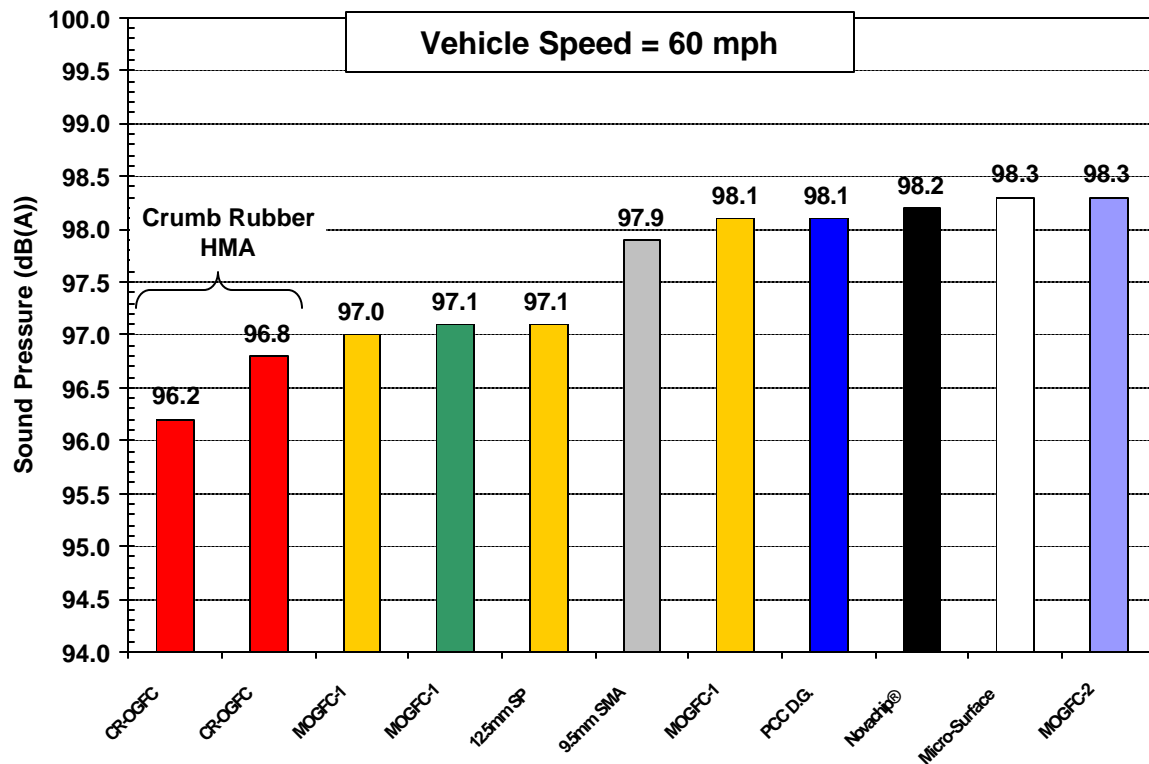


Figure 9 – The 10 (Out of 42) Quietest Pavement Surfaces Tested in New Jersey

The 10 Loudest Pavement Surfaces are simply the PCC test sections that were not diamond ground. All of these pavement surfaces had a dB(A) level greater than 101.2 dB(A). The only hot mix asphalt test section that obtained a close noise level was an SMA section located on the Route 1 South bridge deck (101.1 dB(A)).

PRELIMINARY RESULTS OF EXPERIMENTAL PROGRAM – EFFECT OF VEHICLE SPEED

Three different vehicle speeds were used to evaluate the influence of vehicle speed on tire/pavement generated noise. A total of 39 of the previous 42 pavement sections were tested at 55, 60, and 65 mph. Typical data from the vehicle speed analysis is shown as Figure 10. Figure 10, although not a comprehensive illustration of all sections tested, indicates that the PCC with diamond grinding surface treatment acts similar to most of the HMA test sections.

To provide a method for comparing the effect of traffic speed on the tire/pavement related noise, the noise gradient parameter was used. The noise gradient parameter in this study was defined as the change in noise versus the change in speed with units of dB(A) per mph. The noise gradient was calculated using the 65 and 55 mph noise level measurements, respectively. Pavement surfaces with lower noise gradients would be

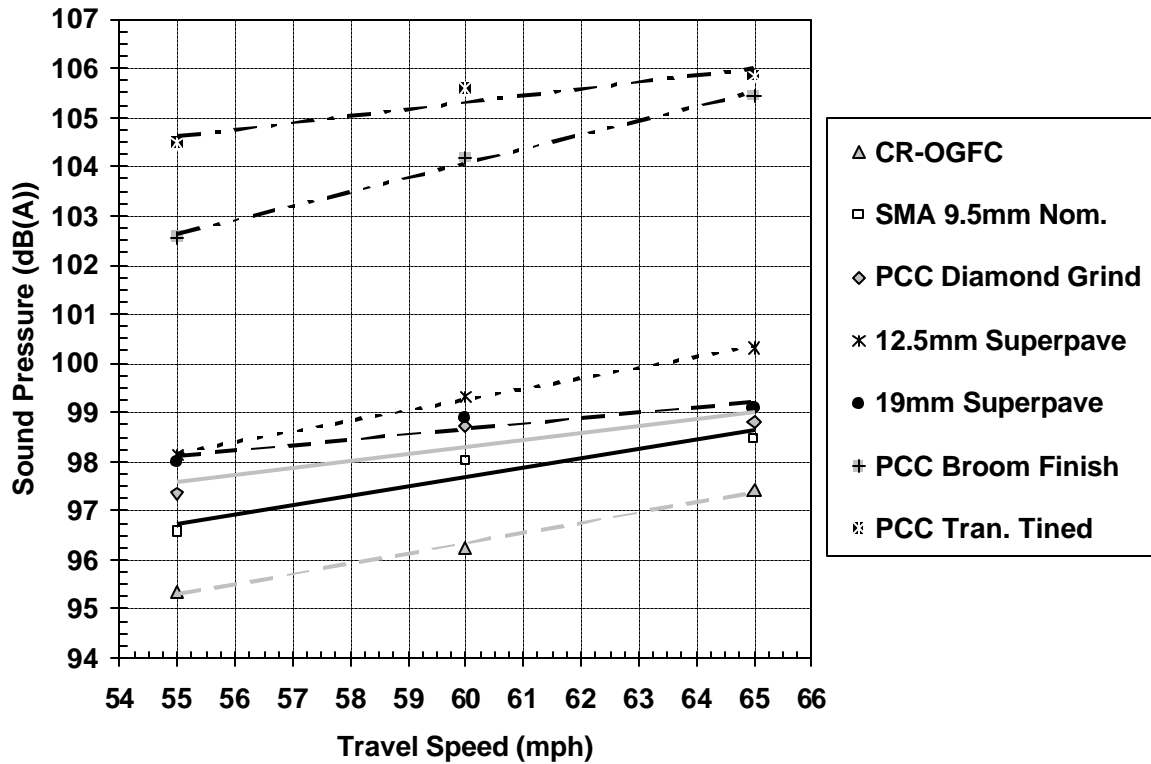


Figure 10 – Influence of Vehicle Speed on Tire/Pavement Generated Noise

less prone to have an increase in the tire/pavement related noise due to an increase in the traffic speed. This parameter may be important to state agencies who are deciding whether or not to raise traffic speed limits along residential areas.

The results for the calculated noise gradient are shown in Table 2. Table 2 indicates that the NovaChip® achieved the lowest noise gradient for the HMA based sections, while the transverse tined PCC surface treatment achieved the lowest noise gradient for the PCC based sections. However, it should be noted that both surface types had limited data (1 section for the NovaChip® and 2 sections for the transverse tined PCC).

Based on a weighted average for each test section surface type, the HMA materials had a noise gradient equal to 0.19 dB(A) per mph, while the PCC sections had a noise gradient of 0.17 dB(A) per mph. This is in good agreement with the previous testing conducted for the Michigan Department of Transportation where the average noise gradient found was 0.2 dB(A) for all materials (HMA and PCC). The vehicle speeds used in the Michigan DOT study were 45, 60, and 75 mph (NCAT, 2003). The noise gradient trendlines shown in Figure 9 indicate that the gradient may also be assumed to be linear. This was again in good agreement with the Michigan DOT study (NCAT, 2003).

TABLE 2 – Average Tire/Pavement Noise Gradients from Variable Vehicle Speed Testing

Pavement Surface Type	Number of Sections	Noise Gradient (dB(A) per mph)
OGFC	8	0.16
DGA	13	0.20
SMA	7	0.17
NovaChip®	1	0.15
Micro-Surfacing	2	0.28
.....		
PCC – Diamond Grind	1	0.15
PCC – Transverse Tining (Sawcut)	4	0.16
PCC – Transverse Tining	2	0.13
PCC – No Treatment	1	0.29

Summary of the Effect of Traffic Speed on the Tire/Pavement Related Noise

The results shown above were determined using only one type of tire and only one type of axle load. Although the results do compare favorably to the findings in the Michigan DOT report, the results may vary depending on the type on tire used, as well as if the axle loading changes (i.e. compact car vs large SUV).

Based on the results, one can basically expect a 0.2 dB(A) increase in tire/pavement related noise for every 1 mph increase in traffic speed. To put this in perspective, New Jersey had recently increased the speed limit on many of its high volume roadways to 65 mph from 55 mph, an increase of 10 mph. This increase in the legal speed limit potentially created a 2.0 dB(A) increase in tire/pavement related noise; basically a 37% increase in the traffic noise.

REPEATABILITY OF THE NCAT NOISE TRAILER FOR DETERMINING TIRE/PAVEMENT RELATED NOISE

When conducting the CPX measurements, the trailer needs to be driven over a particular test section at the given test speed. Normal procedures used by NCAT when conducting CPX testing suggest that each test section is tested three times to provide an average over that test length. However, this can be quite time consuming, especially if there are roadways that do not permit easy accessibility for the noise trailer exiting, turning around, and repositioning itself for another test run. An example of this in New Jersey is the New Jersey Turnpike, where the distance between some exits are 20 miles. Therefore, if the test section could be run only once with confidence, many more sections could be tested within a given time frame.

Another potential improvement to NCAT's current testing is the required test length. Typical test lengths that have been used for the CPX testing are approximately one mile. Unfortunately, the required one mile test length would not allow for testing on test sections like bridge decks or even the SHRP test sections in New Jersey. Therefore, the repeatability of the noise measurements with respect to the material type and section distance was important to evaluate.

A total of 33 test sections were used to evaluate the repeatability of the CPX method. Each surface type was represented with test section lengths ranging from 0.012 miles (64 ft) to 1.0 miles. The repeatability, as determined by the standard deviation, of the CPX test results is shown in Figure 11. The standard deviation of the CPX measurements is strongly correlated to the length of the test section. For the test sections that were less than 0.2 miles, which included all bridge decks in the study, the average standard deviation was 0.65 dB(A), while for the test sections greater than 0.2 miles, the average standard deviation was 0.13 dB(A).

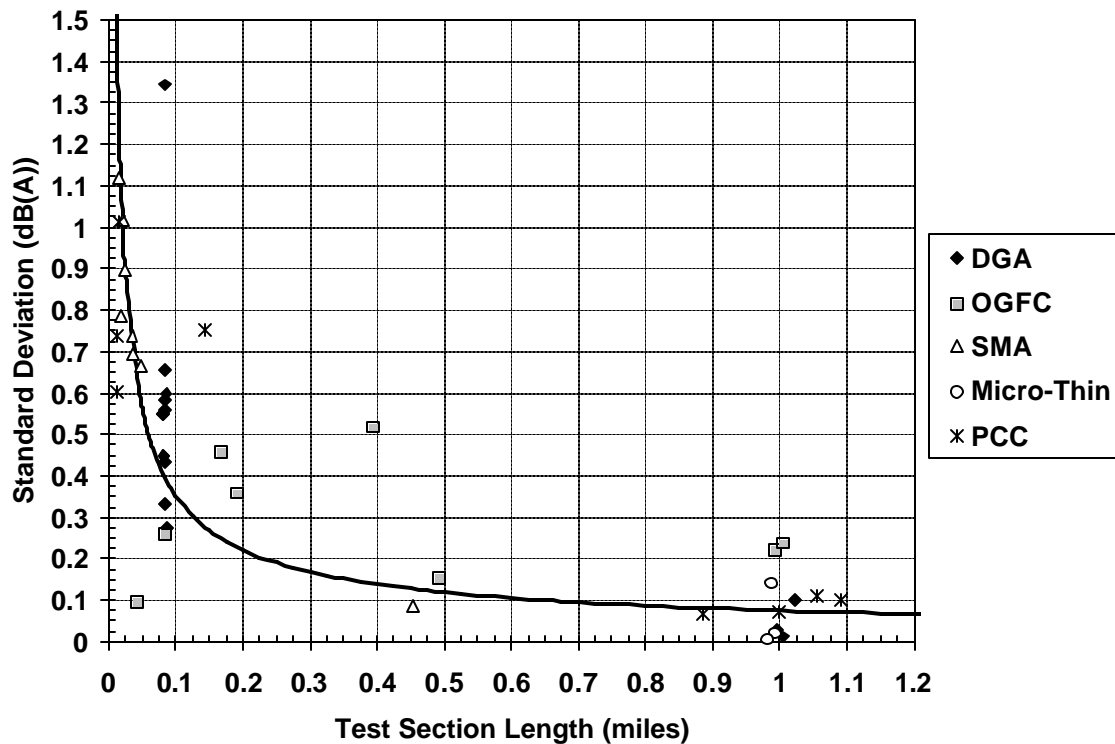


Figure 11 – Repeatability of Tire/Pavement Generated Noise from CPX Test Method

The level of repeatability may be attributed to the CPX test method's sensitivity. When the test section is of considerable length, the effect of not following the identical wheel-path from the previous test run may be nullified by the natural variation of the test section itself. Figure 11 shows the variability of the measured tire/pavement noise with distance for the 12.5mm Superpave HMA material on I-78. As can be seen from the figure, the range of tire/pavement generated noise is as high as 2.3 dB(A), with the

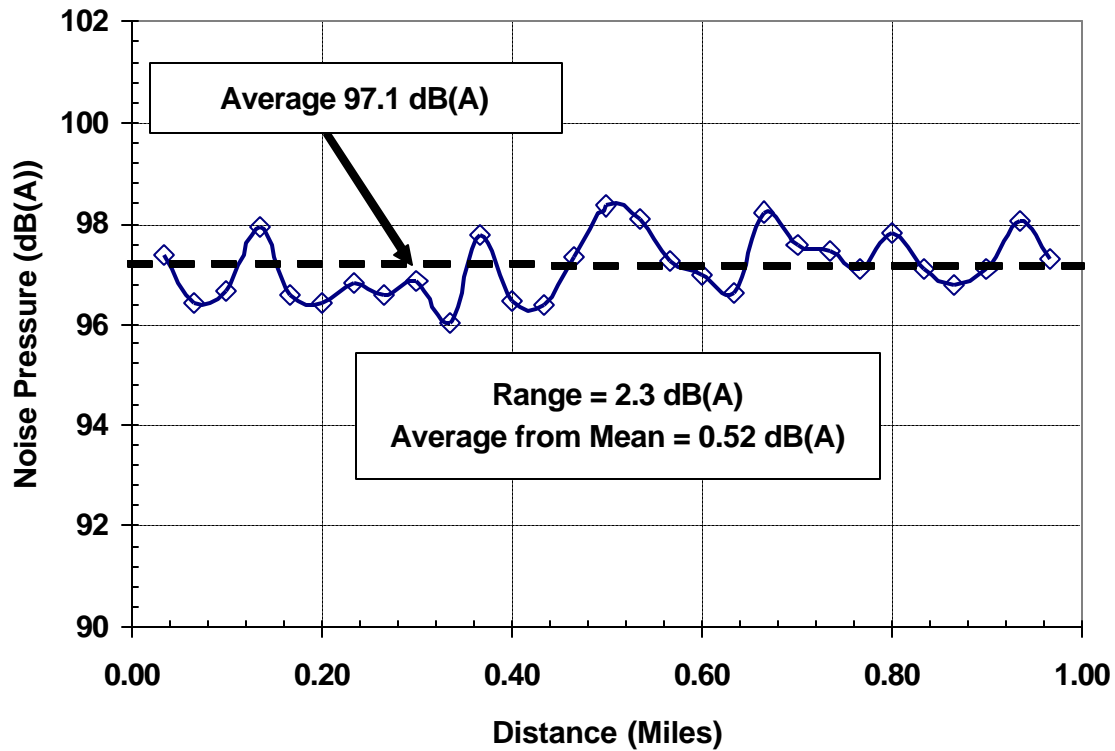


Figure 12 – Natural Variation in Noise Measurements versus Travel Distance

average from the mean equaling 0.52 dB(A). This is most likely due to macro-texture changes on the pavement surface. However, when the test section is considerably shorter, the sensitivity of the test method is more influenced by the noise trailer’s ability to track the identical wheel-path in successive test than macro-texture changes on the pavement surface.

CONCLUSIONS

A total of 42 pavement sections, varying from HMA to PCC, were tested using the Close Proximity Method (CPX) to evaluate the effect of pavement surface type on the tire/pavement generated noise. Comparisons for all of the pavement sections were conducted at 60 mph. Test was also conducted at 55 and 65 mph to evaluate the effect of vehicle speed on the generated noise. Multiple runs within the same test section were also conducted to provide evidence of the repeatability of the device. Based on this testing, the following conclusions can be drawn:

- On a whole, the HMA based surfaces generated lower noise levels than the PCC surfaces. However, if the PCC surface was diamond ground, noise levels of the PCC was comparable to the HMA materials. The average tire/pavement noise

level for the HMA materials was 98.5 dB(A) (n = 30). Meanwhile, the average tire/pavement noise level for the PCC materials was 102.6 dB(A) (n = 12).

- The nominal aggregate size of the HMA materials had an effect on the generated noise. Comparisons between the different dense-graded asphalt (DGA) mixes showed that the 12.5mm Superpave mixes produced less noise than the 19mm Superpave mixes. Meanwhile, the 9.5mm nominal aggregate size stone-mastic asphalt (SMA) mix had lower generated noise values than the 12.5mm nominal aggregate size SMA mix.
- A comparison of the open-graded friction course (OGFC) HMA surface courses, typically used to aid in reducing tire/pavement related noise, found that the OGFC mixes modified with crumb rubber attained the lowest noise levels. However, the crumb rubber modified OGFC mixes also had finer aggregate gradations than the traditionally used OGFC mixes in New Jersey.
- Measured noise levels at 55, 60, and 65 mph showed that, on average, the tire/pavement generated noise increases by 0.18 dB(A) for every one mph increase. These results compare well with a previous study conducted for the Michigan DOT where the average noise gradient was 0.2 dB(A) per mph. When broken down by surface material type, the HMA materials had a noise gradient of 0.19 dB(A) per mph, while the PCC surfaces had a noise gradient of 0.17 dB(A) per mph. Although based on a limited number of tests, the PCC with no surface treatment was affected the greatest by vehicle speed, with a resulting noise gradient of 0.29 dB(A) per mph. The pavement surface that was least affected by vehicle speed was the transverse tined PCC, with a noise gradient of 0.13 dB(A) per mph.
- The repeatability of the CPX method, as represented by the standard deviation of three consecutive test runs, was found to be dependent on the distance of the test run. If the test section was less than 0.2 miles, the average standard deviation was found to be 0.65 dB(A) (n = 19). However, when the test section was greater than 0.2 miles, the average standard deviation was 0.13 dB(A) (n = 14).

RECOMMENDATIONS

The following recommendations based on the work conducted in this research project are as follows:

1. To determine the effect of aging and/or traffic on the tire/pavement related tire noise. Since many of the pavement surfaces did not use the identical materials, it was difficult to come to any conclusion on the effect of age on the tire/pavement related noise. Therefore, it is recommended to try to evaluate the effect of aging and/or traffic on the tire/pavement related noise. This can be easily accomplished by repeating the study after a designated time period and estimating the traffic amount that the pavement section has seen since the last test period. By conducting this type of study, the NJDOT can consider the

viability of using a noise-type parameter in their current Pavement Management System.

2. Evaluate the relationship between pavement texture and tire/pavement related noise. Based on material type, hot mix asphalt materials and PCC, there exists a difference between the measured sound pressure. This is most likely due to each materials different pavement surface texture. By correlating the NCAT Noise Trailer with such devices as the ARAN's texture laser system, the NJDOT may be able to understand the relationship between surface texture and tire/pavement generated noise.

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