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# Long Term Performance of a Porous Friction Course

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**JOINT TRANSPORTATION RESEARCH PROGRAM**

**FHWA/IN/JTRP-2009/22**

**Final Report**

**LONG-TERM PERFORMANCE OF A POROUS  
FRICTION COURSE**

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INDOT Research

# TECHNICAL *Summary*

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Final Report

## **Long-Term Performance of a Porous Friction Course**

### **Introduction**

In 2003, the Indiana Department of Transportation (INDOT) and the Federal Highway Administration allowed a test section of Porous Friction Course (PFC) to be placed on I74 east of Indianapolis. The design, construction and early performance of that surface were compared to an adjacent Stone Matrix Asphalt (SMA) surface and a conventional Superpave HMA surface in a report prepared for the Institute for Safe, Quiet and Durable Highways (I). The early performance indicated that the PFC offered several advantages over the SMA and the HMA surfaces, including reduced tire/pavement noise, high friction and surface texture, and reduced splash and spray. There was a concern, however, that porous surfaces can lose their porosity, and therefore their performance advantages, over time. Therefore, the project summarized in this report was planned to continue monitoring the performance of the PFC and

the comparison surfaces to investigate the durability of the experimental surface over a total of five years after construction.

This research project monitored the performance of an experimental porous friction course and compared that performance to an SMA and a conventional HMA surface over a four-year period (total of five years after construction) to determine:

- the tire-pavement noise generated by traffic on these three pavement surface types and changes in noise versus time,
- the changes in surface textures and frictional properties of these pavement surfaces over time, and
- the overall performance of these three surface types versus time.

### **Findings**

The results of this long term evaluation of a Porous Friction Course (PFC) showed that PFC surfaces could perform well under Indiana conditions. The PFC provided sound pressure levels that were significantly lower than those of comparable SMA and DGA surfaces for both heavy trucks and passenger cars. The PFC surface maintained its macrotexture, and the voids did not clog over the life of the study

under fast-moving interstate traffic. The PFC and SMA both provided similar, stable friction levels. There was a marked reduction in splash and spray from vehicles travelling over the PFC during a rain event as compared to the SMA. Visual inspections show that both the PFC and the SMA are performing well after five years under relatively heavy interstate traffic.

### **Implementation**

The primary focus of this study was on investigating the performance of PFCs under Indiana conditions. A follow up study comparing a longer section of PFC (10 miles or so) to an SMA on an interstate highway is recommended in order to more fully explore the impacts of the PFC on safety (accident rates,

visibility and friction) and cost (initial and maintenance).

Based on the good performance of the experimental PFC surface evaluated in this study, INDOT now has a new tool that can be used to provide high quality, high friction surfaces while also providing reduced tire/pavement noise and

reduced splash and spray. The use of this type of surface should be considered by the Office of Pavement Engineering and the Pavement Design Committee on a case by case basis for special locations as they determine the appropriate pavement design for a given project. If the results of the proposed follow-up study are favorable, use of PFCs could expand to more locations where the added cost is justified based on safety enhancements.

There are, however, some caveats that the implementers should consider. First, the performance of PFCs has not been verified under lower and slower traffic conditions, so they should only be specified for high speed roadways with moderate to high traffic volumes without additional evidence to support their use under other traffic conditions. Second, there may be an increase in winter maintenance costs associated

with the use of PFCs because of the observed need for more frequent applications of deicing chemicals. This increase is not expected to be significant unless the use of PFCs becomes common. Third, under current FHWA policy, the use of a quiet pavement surface does not reduce the need for noise mitigation (most commonly a noise barrier wall) on Federal-Aid projects, if abatement is required. Therefore, PFCs would most likely be used on non-Federal Aid projects where reduced noise, reduced splash and spray or high friction is desirable and where their use can obviate the need for a noise barrier wall. Eliminating or reducing the height of a barrier wall can offset the added material costs due to the PFC. Eventually FHWA policy may change in this regard, allowing pavement type to be considered for mitigation. If so, INDOT could make even greater use of this successful quiet pavement technology.

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<b>16. Abstract</b> In 2003, the Indiana Department of Transportation and the Federal Highway Administration allowed a test section of Porous Friction Course (PFC) to be placed on I74 east of Indianapolis. The design, construction and early performance of that surface were compared to an adjacent SMA surface and a conventional Superpave HMA surface in a report prepared for the Institute for Safe, Quiet and Durable Highways ( <i>I</i> ). The early performance indicated that the PFC offered several advantages over the SMA and the conventional surfaces, including reduced tire/pavement noise, high friction and surface texture, and reduced splash and spray. There was a concern, however, that porous surfaces can lose their porosity, and therefore their performance advantages, over time. Consequently, the project summarized in this report was planned to continue monitoring the performance of the PFC and the comparison surfaces in order to investigate the durability of the porous surface over a five-year period (after construction).  After five years under traffic, there have indeed been some changes in these properties. Most of the changes, however, took place quickly as the asphalt binder film coating the exposed aggregate particles was worn off by traffic. Since then, the changes have been relatively minor. The PFC section is still significantly quieter than the adjacent SMA section to which it has been compared. The PFC has retained most of its texture and is still providing good friction levels. Both the PFC and the SMA are still in very good condition with little distress and have higher friction levels than a section of dense graded asphalt constructed with similar materials that has also been evaluated for the duration of the study.			
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## **Abstract**

In 2003, the Indiana Department of Transportation and the Federal Highway Administration allowed a test section of Porous Friction Course (PFC) to be placed on I74 east of Indianapolis. The design, construction and early performance of that surface were compared to an adjacent SMA surface and a conventional Superpave HMA (DGA) surface in a report prepared for the Institute for Safe, Quiet and Durable Highways (*1*). The early performance indicated that the PFC offered several advantages over the SMA and the conventional surfaces, including reduced tire/pavement noise, high friction and surface texture, and reduced splash and spray. There was a concern, however, that porous surfaces can lose their porosity, and therefore their performance advantages, over time. Consequently, the project summarized in this report was planned to continue monitoring the performance of the PFC and the comparison surfaces in order to investigate the durability of the porous surface over a five-year period (after construction).

After five years under traffic, there have indeed been some changes in these properties. Most of the changes, however, took place quickly as the asphalt binder film coating the exposed aggregate particles was worn off by traffic. Since then, the changes have been relatively minor. The PFC section is still significantly quieter than the adjacent SMA section to which it has been compared. The PFC has retained most of its texture and is still providing good friction levels. Both the PFC and the SMA are still in very good condition with little distress and have higher friction levels than a section of dense graded asphalt constructed with similar materials that has also been evaluated for the duration of the study.

***Long Term Performance of a Porous Friction Course***

Final Report

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**Disclaimer**

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Indiana Department of Transportation or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

## **CHAPTER 1. INTRODUCTION**

In 2003, the Indiana Department of Transportation (INDOT) and the Federal Highway Administration allowed a test section of Porous Friction Course (PFC) to be placed on I74 east of Indianapolis. The design, construction and early performance of that surface were compared to an adjacent Stone Matrix Asphalt (SMA) surface and a conventional Superpave DGA surface in a report prepared for the Institute for Safe, Quiet and Durable Highways (1). The early performance indicated that the PFC offered several advantages over the SMA and the DGA surfaces, including reduced tire/pavement noise, high friction and surface texture, and reduced splash and spray. There was a concern, however, that porous surfaces can lose their porosity, and therefore their performance advantages, over time. Therefore, the project summarized in this report was planned to continue monitoring the performance of the PFC and the comparison surfaces to investigate the durability of the experimental surface over a total of five years after construction.

### **1.1 Background and Literature Review**

Traffic noise is an increasing problem for many transportation agencies as the public is becoming more aware of the issue and more demanding of solutions. Traffic noise comes from two major sources, the power train (engine, exhaust and cooling system) and the tires. (Although also present, aerodynamic noise is usually a lesser source (2).) Tire pavement noise has been shown to be a major contributor to the overall noise level (3). Noise generated by the tire/pavement interaction dominates over the noise produced by the power train at typical highway or interstate speeds. Tire/pavement noise-generating mechanisms include radial and tangential vibrations, air resonance and other mechanisms (2, 3). Modification of the tire/pavement interface can affect these mechanisms and reduce the noise generated.

Noise barrier walls can also be erected in an attempt to mitigate the noise, but experience and evidence is mounting to show that noise can be better and more economically controlled at the source by designing quieter pavement surfaces. Current FHWA policy and the Traffic Noise Model, however, do not recognize pavement type as a noise mitigation technique (4-6). If noise mitigation is required, erection of a noise barrier wall is generally the only practical option. In recent years, however, the FHWA has developed a Quiet Pavements Pilot Program in order to collect the data necessary to examine the effectiveness of pavement strategies for reducing noise and determine if a change in these policies is warranted (7). This program was initiated in response to the successful use of quiet pavements in Arizona and interest from other states.

The noise generated at the tire/pavement interface depends on environmental conditions, the speed of the vehicle, type of tire, type of pavement surface and the dynamics of the rolling process. Some European countries have successfully reduced tire/pavement noise on highways through the use of porous road surfaces (3, 8-11). Porous asphalt mixes made with hard aggregates, a modified asphalt binder and sometimes stabilizing fibers are widely used. The structure of a porous asphalt surface contains interconnected voids, which can drain away

rainwater during wet weather. The porous structure can also reduce tire/pavement noise by reducing some noise generation and propagation mechanisms. Porous pavements have also proven to be durable, to possess good surface friction and to decrease splash and spray during rain events (8). Similar porous surfaces used in the United States are alternatively called Permeable European Mixes (PEM) or Porous Friction Courses (PFCs). (In this report, the terms "porous surfaces," "porous asphalt" or "porous mixes" are sometimes used generically for these European-style noise reducing highway surfaces. It should be noted that these mixes are not necessarily the same as porous asphalt mixes used for drainage and groundwater recharge, which are more appropriate for parking lots and low speed roadways.)

Open graded friction courses (OGFCs) used in Indiana and other states in the past differ from current porous asphalt surfaces. In general, OGFCs have had lower void percentages (10-15%); usually used unmodified binders, at least in Indiana; and were less durable than porous asphalt mixes (9). Porous asphalt mixes, on the other hand, generally have strongly gap-graded aggregate gradations to yield higher air voids (18-22 percent) (9). High quality aggregates are needed to provide good aggregate interlock and long-lasting frictional properties in these mixes.

When INDOT used OGFC surfaces many years ago, they experienced problems with the surface voids clogging, especially when abrasives were used for snow and ice control. There is, therefore, a concern over how long the benefits of the PFC can be maintained. If the surface texture becomes clogged or decreases, will the PFC lose its frictional, noise control and splash and spray properties?

Today's PFC mixes are designed with higher air voids than the OGFCs on the theory that the suction effect of traffic will expel fine material from the pores, thus preventing this loss of texture. European experience suggests that this theory holds true for properly designed and constructed porous mixtures (14). The project reported on here was initiated to continue monitoring of the test sections for a period of five years after construction to determine if and when the PFC would begin to lose its surface texture and other properties.

In late 2009, the National Cooperative Highway Research Program (NCHRP) published NCHRP Report 640, *Construction and Maintenance Practices for Permeable Friction Courses* (15). This report includes the results of a survey of national and international agency specifications, practices and experiences with PFCs as well as a literature review. Based on this review of the literature and practices, three draft AASHTO standards related to PFCs were prepared; one dealing with Materials, Design and Construction of Permeable Friction Courses; one on the Standard Method of Test for Determining the Abrasion Loss of Permeable Friction courses Asphalt Specimens by the Cantrabro Procedure; and one Standard Practice for Maintenance and Rehabilitation of Permeable Friction Courses. Review, revision and balloting of these drafts is being initiated at AASHTO (16), so pending favorable outcomes of these efforts, national standards for PFCs should be available in the near future.

This project found that PFCs are increasingly popular in the US because of their safety and environmental benefits. Specific attributes cited include reduced hydroplaning, splash and

spray, glare and tire/pavement noise. The report also noted improvements in friction, visibility of pavement marking materials, and the water quality of runoff. (15)

PFC surfaces last between 8 and 12 years typically, according to the NCHRP report, and are resistant to permanent deformation. Research shows that the PFC helps to keep the underlying layers cooler, which increases their stiffness and resistance to rutting. (15)

Most agencies responding to the survey indicated that they do not assign a structural value to the PFC layer, but about one-quarter of them do. While little information was provided in the report on the typical pavement cross sections used, conversation with the primary author of the report, Dr. Allen Cooley, showed that while some states do use SMA under the PFC (Georgia and Alabama, for example), other states do not (such as New Jersey). (17) The performance of the pavements has been good with and without SMA. The use of premium aggregates in the underlying layer is not necessary as long as the mixture is rut resistant. This offers the possibility of offsetting the higher cost of the PFC by using less expensive materials underneath without sacrificing performance. Cooley did not recommend the use of sealants under the PFC as these have been shown to increase the chances of stripping in underlying layers.

## **1.2 Problem Statement**

In the initial study, the PFC section did exhibit lower noise levels, improved friction and reduced splash and spray compared to an SMA and a conventional HMA (Superpave Dense Graded Asphalt (DGA)) surface in the short term (1). This suggested that PFC may offer an effective and economical way to reduce noise while maintaining, or even improving, friction and visibility. The long term performance of PFC under Indiana conditions was unknown, however.

Based on the favorable early results, briefly summarized in Chapter 2, it was determined that research was needed to evaluate the longevity of Porous Friction Courses and their perceived benefits under typical Indiana climate, traffic and material conditions. The approach used in this extended evaluation is summarized in Chapter 3, and the results are presented and analyzed in Chapter 4. Conclusions and recommendations based on the results are then presented in Chapters 5 and 6.

## **1.3 Objectives**

This research project monitored the performance of an experimental porous friction course and compared that performance to an SMA and a conventional DGA surface over a four-year period (total of five years after construction) to determine:

- the tire-pavement noise generated by traffic on these three pavement surface types and changes in noise versus time,
- the changes in surface textures and frictional properties of these pavement surfaces over time, and

- the overall performance of these three surface types versus time.

## **CHAPTER 2. INITIAL FINDINGS AND RECOMMENDATIONS**

The initial field evaluation included three test sections. The porous friction course (PFC) and stone matrix asphalt (SMA) sections are located on Interstate Highway 74 east of Indianapolis. These adjacent sections were constructed by Milestone Contractors, LP, in August 2003. The third section consists of a conventional Superpave (DGA) section located on US52 in Lafayette that was paved in July 2003. This study continued the monitoring of the performance of these same three sections for four years, or a total of just over five years after construction. Additional details are available in the final report on the initial study (1).

### **2.1 Materials and Mixtures**

The PFC and SMA mixes were very similar in terms of the component materials used since both were placed on the same project and were designed to reduce the variables between them. The conventional mixture was not designed as part of this experiment, but was instead selected from recently constructed projects to represent typical INDOT mixes. A completed project on US52 near West Lafayette was used as the field test site for the conventional DGA noise testing. (Conventional mixtures in Indiana are dense graded asphalt mixes (DGA) designed according to Superpave specifications but are not placed on interstates.)

All of the mixtures evaluated used steel slag aggregate from the same source, though in different proportions and combined with various other aggregates and additives. (Details of the gradations and mix designs are provided in the next section.) The SMA and PFC mixes have the most in common, as noted above. The PFC was composed of 90% steel slag with 10% manufactured sand. The SMA consisted of 80% steel slag, 10% stone sand (from a different source than the PFC sand) and 10% mineral filler. The same binder, an SBS-modified PG76-22, was also used in these two mixes. The PFC included 0.3% cellulose fiber, and the SMA included 0.1% of the same fiber.

The conventional DGA consisted of steel slag coarse aggregate, from the same source as the PFC and SMA, blended 50-50 with dolomite. The mix also contained dolomitic manufactured sand. A PG76-22 binder was used, but it was from a different source than that used in the PFC and SMA.

### **2.2 Mix Designs**

The PFC was designed by Milestone with assistance from Heritage Research Group. Trial mixes were prepared and compacted to 20 gyrations in a Superpave Gyratory Compactor. The air void content was then measured. The target air void content was 18-22%. Table 2.1 shows the final mix design for the PFC in the second column. The gradations of all three mixes used in this research are shown graphically in Figure 2.1.

Table 2.1. Mix Design Parameters

Parameter	PFC	SMA	DGA
12.5mm	100	100	100
9.5mm	83.0	84.7	94.0
4.75mm	27.9	39.1	64.3
2.36mm	12.5	26.9	46.0
1.18mm	8.6	21.0	--
0.600mm	6.0	17.7	17.0
0.300mm	4.6	15.0	--
0.150mm	3.3	13.3	--
0.075mm	2.4	10.1	5.5
PG Grade	76-22	76-22	76-22
Pb, %	5.7	5.5	5.7
Air Voids, %	23.1	4.0	4.0
VMA, %	--	17.7	15.5
G <sub>sb</sub>	3.57	3.48	2.95
G <sub>mm</sub>	3.19	3.15	2.75
Fiber, %	0.3	0.1	--

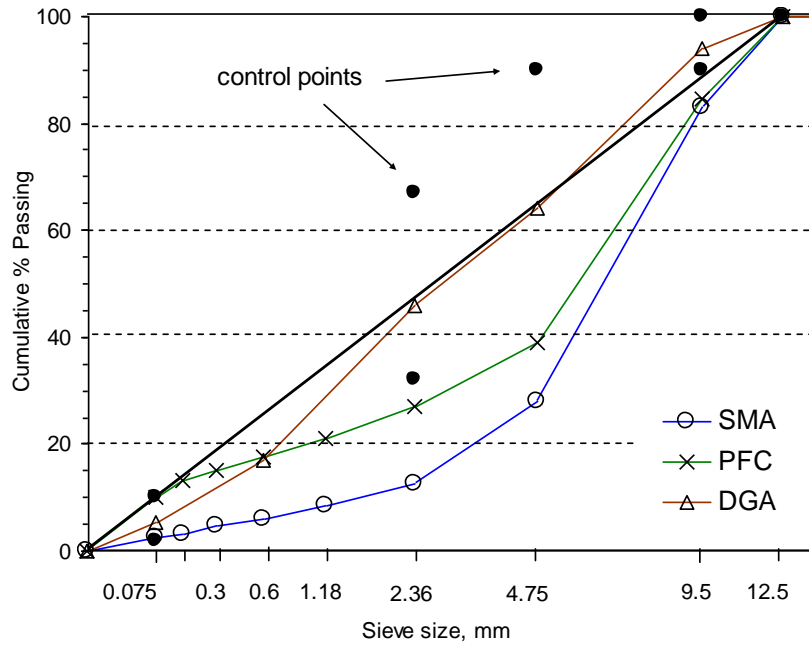


Figure 2.1. Gradations of the Experimental Mixtures



Following design of the PFC mixture, the Cantabro test was used to assess the durability of the mixture. This test consists of placing Marshall compacted specimens in an LA abrasion machine and revolving for 300 revolutions without the steel balls that are typically used in the LA abrasion test. The mass lost during this process, expressed as a percent of the original mass of the specimens, is the Cantabro mass loss. European specifications call for the mass loss to be less than 25% for unaged specimens and less than 30% for aged specimens. The maximum mass losses for specimens of this mix were 15.0% for the unaged specimens and 24.9% for the aged specimens.

The SMA was also designed by Milestone using the same steel slag, same fiber and same binder as used in the PFC. The details are shown in the third column of Table 2.1. This mix was designed at an  $N_{\text{design}}$  level of 100 gyrations for a traffic category of 10 to 30 million ESALs. The SMA gradation was similar to the PFC in the larger sizes, but had much higher amounts passing the smaller sieve sizes, as shown in Figure 2.1. This is typical since the SMA was designed for 4% air voids versus 18-22% for the PFC. SMAs generally consist of a somewhat gap-graded aggregate structure with a high voids in mineral aggregate (VMA) content to ensure good stone on stone contact. The space between the aggregate particles is then mostly filled with a mastic of binder (often polymer modified, as in this case), fibers (cellulose) and mineral filler.

The fibers in both the PFC and the SMA are added to keep the binder from flowing off the coarse aggregate particles, a phenomenon known as draindown. Fibers also reinforce the mixes somewhat, which may help control rutting and cracking in the future. Modified binders also help to reduce draindown by virtue of their typically higher viscosity.

The conventional mix was designed according to Superpave mix design procedures as outlined in AASHTO MP2, *Standard Specifications for Superpave Volumetric Mix Design*, and PP28, *Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA)*, for a design traffic level of 10 to 30 million ESALs. The  $N_{\text{design}}$  value was 100 gyrations, as for the SMA. The final mix design is shown in the last column of Table 2.1.

The binder contents by weight shown in Table 2.1 appear to be similar for all three mixtures. In terms of volume, however, the binder contents of the SMA and PFC mixes were higher than the DGA because the steel slag aggregate in the PFC and SMA has a higher specific gravity than the slag-dolomite blend of aggregate used in the DGA.

### **2.3 Construction of the Experimental Sections**

All three of the pavement sections were constructed in 2003 using typical construction equipment and operations. (For more detailed information, refer to the final report on Phase 1 (1).) The PFC and SMA mixes were placed using a material transfer device (MTD) to improve ride quality and control mix segregation. The MTD transferred mix from the haul trucks to the hopper of a conventional paver. Compaction was accomplished with two steel wheeled rollers. Only one pass with each roller was needed to seat the PFC and SMA, since relatively little compactive effort is needed to bring the coarse aggregates into contact and because over-rolling can lead to aggregate breakdown. Due to the gap-graded nature of those mixes, there is extensive stone-to-stone contact between the coarse aggregate particles with very little mastic or fine material to "cushion" the coarse aggregates; this is especially true for the PFC.

During construction of the PFC and SMA sections, mixture production proceeded smoothly. No significant mixture problems were observed, and no mixture quality penalties were assessed.

Samples of the PFC were collected by Heritage Research Group for shear testing for informational purposes. Six cores were taken from the road and tested for density. Air voids ranged from 22.0% to 24.9% with an average of 22.5%. Air voids were measured using ASTM D3203, *Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures*, which uses the dimensions of the specimen to calculate volume.

### **2.4 Initial Field Testing Methods**

In the initial short-term study, noise measurements were made on all three surfaces using both the pass-by and close-proximity methods. These methods are described in some detail in Chapter 3. For the initial study, the field testing of the PFC and SMA sections was conducted before the road was opened to traffic, which influenced both the test results and the methods which could be used to evaluate the performance, as will be explained later. The DGA section had been exposed to traffic prior to testing, but only for a short time (about two months) and at a lower traffic volume. Pavement surface characteristics are known to change under traffic. For example, traffic wears away the binder coating aggregates on the surface, which influences friction.

Tire-pavement noise measurements were conducted initially using two different methods. The controlled pass-by method was employed to measure the noise near the side of the road, while the close-proximity method was used to assess noise near the tire-pavement interface.

The three surfaces were also evaluated in the initial study with respect to their surface texture and friction by means of the Circular Texture Meter (CTM) and Dynamic Friction Tester (DFT), respectively. (These devices are both described in section 3.2 below.) Splash and spray were judged qualitatively.

The detailed results of all these tests are available in the final report (1).

## 2.5 Conclusions and Recommendations from the Short-Term Study

The previous short-term field evaluation led to the following conclusions (1):

- PFC mixtures can be designed to provide the desired air void content using Indiana materials. Mixture volumetric and Cantabro mass loss requirements were met using steel slag aggregate, polymer modified binder and cellulose fibers.
- The PFC had a more open gradation than the SMA. Both mixes were significantly more gap-graded than conventional Superpave DGA mixtures.
- The PFC did exhibit fairly low complex shear moduli when tested in the Frequency Sweep test in the Superpave Shear Tester at 40°C. Due to the reliance of this type of mixture on stone to stone contact, rather than a close packing of aggregates held together by a mastic of binder and fines, a high modulus would not be expected in an unconfined test. Without confining pressure, the stone to stone contact is not fully mobilized.
- Construction of the PFC and SMA mixtures proceeded smoothly with no major problems noted. Conventional equipment was used to produce, place and compact the mixes. Two steel wheeled rollers each applied one pass to seat the PFC; over-rolling should be avoided.
- The surface texture of the PFC is visually more open than that of the SMA. The DGA exhibited an even more uniform, dense surface by comparison.
- The noise, friction and surface texture measurements for the PFC and SMA mixes were made before the road was opened to traffic. Traffic action would be expected to wear away the binder film coating on the protruding aggregates, increasing the surface friction.
- Both close-proximity and pass-by noise testing showed that the PFC produced the lowest measured tire/pavement noise levels, the conventional DGA produced the next lowest noise levels and the SMA produced the highest noise levels.
- Close-proximity testing at two different speeds showed the DGA to produce noise levels that were 3.6 dB(A) higher than the PFC, and the SMA produced noise levels that were 4.8 dB(A) higher than the PFC.
- Pass-by noise measurements at 80 km/h (50 mph) showed that the DGA produced noise levels that were 4.2 dB(A) higher than the PFC, and the SMA produced noise levels that were 5.0 dB(A) higher than the PFC.
- Since the decibel scale is logarithmic, not linear, these differences in noise level are significant.
- Surface texture measurements using the Circular Texture Meter confirmed that the PFC had a much higher surface texture than the conventional DGA. The SMA also had a higher surface texture than the DGA, but not as high as the PFC.
- The PFC also provided higher friction than the DGA and SMA in terms of International Friction Index. The PFC and SMA friction values are expected to increase after traffic wears away the binder film coating.
- Visual observations of splash and spray showed that the PFC did significantly reduce the amount of water on the pavement surface, resulting in better visibility for drivers.
- Long term performance of the PFC section should be monitored to determine how long the improved performance will last.

## CHAPTER 3. CURRENT STUDY APPROACH

The tests used in the initial field evaluation were found to be appropriate for investigating the performance of and differences among the three pavement surfaces. Consequently, noise, friction and texture measurements were continued in this follow-up monitoring project. Additional tests or evaluations included visual inspections and towed friction trailer measurements.

### 3.1 Noise Testing Methods

To monitor the changes in noise generation with time and to investigate any seasonal variations, pass-by noise measurements were conducted periodically. There are currently two commonly used pass-by measurement techniques, the statistical pass-by and controlled pass-by methods. These pass-by or sideline methods involve placing microphones at prescribed distances from the side of the roadway and measuring the peak sound level as vehicles travel past the microphones, as shown in Figure 3.1. In the statistical pass-by (SPB) method, the noise from random vehicles in the existing traffic stream is measured. The vehicles must be acoustically isolated from the traffic stream, so that each can be measured independently. The International Standard (ISO 11819-1), which was used here, calls for placing microphones 7.5 m (25 ft) from the center of the vehicle lane at a height of 1.2 m (4 ft) above the pavement. The noise characteristics and speeds of 180 vehicles (100 automobiles and 80 dual-axle and multi-axle trucks) are measured and analyzed. From the data, a Statistical Pass-by Index (SBPI) can be developed for a particular pavement site. In the SPB method, the vehicle speeds are measured by radar gun to allow adjusting the data to account for variations in speed, as illustrated in Figure 3.2.

In the controlled pass-by method (CPB) specific vehicles are driven at known speeds past the same microphone array as used in the SPB method. There are advantages and disadvantages to each method (15). The deciding factor for the selection of the method to use in this study was the presence of traffic on I74; road closures on interstates near Indianapolis require specific justification and special approval.

Details and discussion about the results of controlled pass-by testing conducted while the road was still closed to traffic are available in both the final report on the short-term evaluation (1) and a TRB paper (22). Those results are shown in Chapter 4 for information, but it is important not to attempt to directly compare the results of testing using the two different methods.

It is also important to note that the standard decibel scale used for noise data, as presented in this report and elsewhere, is a logarithmic scale rather than a linear scale. This difference is particularly important when comparing relative levels. Doubling the sound energy (source strength) increases the sound pressure level (SPL) by 3 dB. (2) Also, sound is frequently reported in terms of A-weighted SPL; A-weighting reflects how the human ear responds to

sounds by giving more emphasis to the loudness of sounds at the frequencies to which we are most sensitive. SPLs to which the A-weighting scheme has been applied are designated dB(A).



Figure 3.1. Pass-By Measurement Site (I74) and Microphone Setup

In addition to the previously mentioned noise measurement methods, during the short-term study, the National Center for Asphalt Technology (NCAT) tested the three sections with a close-proximity trailer. This method consists of placing microphones near the tire/pavement interface to directly measure the tire/pavement noise levels. The microphones are arrayed near the tire on a trailer, as illustrated in Figure 3.3. A cover on the trailer is lined with acoustical foam to limit extraneous traffic noise. The measured noise levels are obviously higher than the sideline measurements because they are measured so close to the tire/pavement interface, thus allowing little opportunity for attenuation of the sound.



Figure 3.2. Measuring Vehicle Speed during SPB Measurement

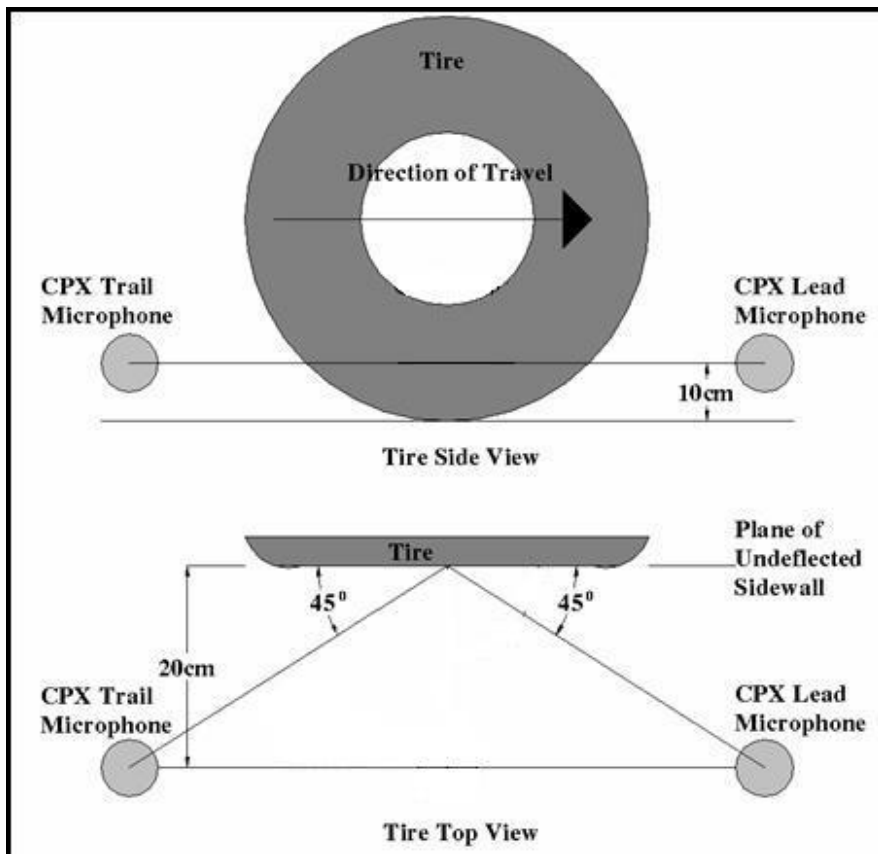


Figure 3.3. Schematic of Locations of CPX Microphones Relative to Tire/Pavement Interface

It was originally planned that the long-term follow-up study also include the use of the NCAT CPX trailer. Due to scheduling conflicts, however, this measurement could not be accomplished.

### **3.2 Friction and Texture Measurements**

It is well known that some of the noise generation mechanisms are strongly influenced by the surface texture of the pavement. (2) The friction level provided by the surface is also a function of the surface texture. Clogging of the voids in the porous surface, which could reduce the noise reduction characteristics of the pavement, could be measured by changes in the surface texture. Texture could also reveal loss of aggregate, or raveling of the surface, which could indicate a durability problem with the surface. Therefore, the measurement of texture and friction was continued throughout this evaluation. Attempts were made to conduct the friction and texture tests soon after the noise testing in order to measure the pavement characteristics in as similar a condition (combination of temperature, precipitation, traffic wear, etc.) as possible. Because the friction/texture testing required traffic control (whereas the noise testing did not), it was not always possible to coordinate these measurements to within a few days of each other.

The surface texture of the three pavements was measured using the Circular Track Meter (CTM) as described in ASTM E2157. The CTM uses a charge coupled device (CCD) laser displacement sensor to measure the surface profile. The laser sensor is mounted on an arm that rotates around a central point at a fixed distance above the pavement and measures the change in elevation of points on the surface. The laser spot size is  $70\ \mu\text{m}$  ( $2.76 \times 10^{-3}$  in) and the vertical resolution is  $3\ \mu\text{m}$  ( $0.12 \times 10^{-3}$  in). The CTM collects data around the circumference of a circle 284 mm (11.2 in) in diameter. The CTM allows determination of the mean profile depth (MPD) in mm.

The Dynamic Friction Tester (DFT) is a portable device that allows direct measurement of the friction of a variety of surfaces, including pavements. The testing and data analysis are standardized under ASTM E1911. The DFT consists of a horizontal spinning disk fitted with three spring-loaded rubber sliders that contact the surface. The standard sliders are made of the same type of rubber as is used in friction test tires (though other materials are available for other, non-highway applications). The disk rotates at tangential velocities up to 90 kph (55 mph). Water flows over the surface being tested, so wet friction is measured, as is done with the towed friction trailer. The rotating disk is then dropped onto the wet surface and the torque is continuously measured as the disk slows. Wet friction is then calculated from the measured torque. This continuous measurement allows determination of the speed dependency of the surface friction. The DFT is affected by both the microtexture and macrotexture of the surface. The unitless DFT number at a speed of 20 km/h ( $\text{DFT}_{20}$ ) is the main parameter of interest here as it is used in the calculations of friction index described below.

The CTM and DFT operate on the same footprint. Results from the two devices can be combined to yield the International Friction Index (IFI) according to ASTM E1960. The IFI was

developed in Europe to harmonize, or provide a means to compare, friction measurements from a wide variety of test methods (20). The IFI consists of two parameters, the calibrated friction at 60 km/h (F60) and the speed constant,  $S_p$ . The F60 value is of primary importance and is the one examined in detail in this report. More details on the CTM, DFT and IFI are available in Reference 21.

Lastly, friction was also measured annually (in the fall) by INDOT using the conventional ASTM E274 towed friction trailer shown in Figure 3.4. The towed friction trailer tests wet sliding friction by spraying water ahead of a test tire mounted on the trailer travelling at constant speed then locking the trailer brakes. The torque on the tire caused by friction with the surface is recorded and used to calculate the coefficient of wet sliding friction. The friction number (designated SN) reported is the coefficient of wet friction multiplied by 100.



Figure 3.4. Towed Friction Trailer

Different types of tires, ribbed and smooth, can be used on the trailer. The smooth, or bald, tire is generally considered to be sensitive to both micro and macrottexture, while the rib tire is more sensitive to microtexture. The ribs essentially provide the tire with its own macrottexture.

It was originally proposed to conduct permeability testing on these surfaces as well as the other tests described above. It was envisioned that this would help to evaluate changes in the air void content of the pavement without destructive coring. If clogging of the pores were to occur, the permeability of the pavement would likely decrease. Coring was also considered, as a last resort, to measure the air void content and/or determine the cause of loss of permeability (clogging or collapse of the PFC), but this was to be avoided, if possible, to prevent damaging the surface.



Permeability testing on the PFC was attempted, but the surface had so much texture that it was not possible to get reliable permeability measurements. The water would simply flow away too fast. Therefore, this testing was abandoned. The laser-based texture measurements are considered more reliable and more meaningful. (A substantial change in texture indicating a potential loss of permeability would have triggered a second attempt at permeability testing or coring for lab permeability testing, but this change was not observed.)

### 3.3 Traffic Levels and Field Testing Schedule

As already mentioned, the three pavements were constructed in 2003 and were tested for a period of five years (between April and the middle of October). An attempt was made to capture a wide range of the weather conditions and to conduct tests during different seasons. Pavements were tested at air temperatures between 5°C and 34°C (between 41°F and 93°F) and pavement surface temperatures between 5°C and 50°C (between 41°F and 122°F) on both cloudy and sunny days. The relative humidity during testing also varied from 40% up to 80%.

Information about the traffic on the three highway test sections monitored periodically over the last three years of the monitoring period is summarized in Table 3.1. Based on Average Annual Daily Traffic (AADT) information from INDOT, the number of vehicle axle passes (NVA) on each test section (per month) was calculated using several simplifications (22). It was assumed that an equal number of vehicles were driven in both directions (AADT was divided by two) and that 55% of the vehicles were using the driving lane on both I74 and US52, with the remaining 45% of vehicles using the passing lane. It was also assumed that the average truck has 4.5 axles and the average car has 2 axles. Results were multiplied by 30, which is the assumed number of days per month. No traffic growth adjustment factors were employed. This simplified equation for NVA has the following form:

$$NVA = (AADT) \cdot 0.5 \cdot 0.55 \cdot [\%Trucks \cdot 4.5 + (100\% - \%Trucks) \cdot 2] \cdot 30 \quad (1)$$

The number of vehicle axles was then used to express the cumulative traffic level. Cumulative traffic level was calculated based on the NVA passing through the test section multiplied by the period of time when the sections were exposed to traffic. Note that this is only an approximate calculation. However, for the purposes of this study, this should be precise enough.

The testing schedule for the DGA, SMA and PFC sections is shown in Table 3.1. Note that the CPX and CPB tests were conducted before opening the road to traffic while SPB tests were conducted periodically over the last four years of the study under traffic.

Table 3.1. Summary of Traffic Data, and Construction and Field Testing Dates

Section / Mixture	DGA	PFC SMA
Road Category <sup>a</sup>	US	I
Average Annual Daily Traffic, AADT (10 <sup>3</sup> )	31.5	37.3
% Trucks in AADT	5%	26%
Number of Vehicles Axle (NVA) /month (10 <sup>3</sup> )	451	980
Pavement Construction Date (Month, Year)	June 2003	July 2003
CPX Test, Date	9/3/2003	9/3/2003 <sup>b</sup>
CPB Test, Date	8/28/2003	8/28/2003 <sup>b</sup>
SPB Test, Date	6/20/2005	6/17/2005
	5/5/2006	4/27/2006
	10/10/2006	10/10/2006
	4/9/2007	4/20/2007
	7/9/2007	7/9/2007
	9/21/2007	9/18/2007
	8/19/2008	8/19/2008
Date of DFT/CTM Test	9/6/2003	9/10/2003 <sup>b</sup>
		8/1/2005
	5/5/2006	11/16/2005
	10/30/2006	10/3/2006
	4/10/2007	4/10/2007
	7/10/2007	7/25/2007
	9/25/2007	9/25/2007
10/30/2008	10/29/2008	
Date of Friction Trailer Test (Month, Year)		9/2004
	8/2004	9/2005
	9/2007	9/2006
		9/2007
		9/2008

<sup>a</sup> Road category: US – US highway, I – interstate highway.

<sup>b</sup> Before opening to traffic.

## **CHAPTER 4. DATA ANALYSIS**

This chapter summarizes the noise, friction and texture test data and the analysis of the results.

### **4.1 Noise Testing Results**

The analysis of the noise testing data focuses mainly on the SPB results because they were repeated at various points in time. The CPX method was only used for the initial tests; therefore those results will only be discussed briefly. The CPB results were also only collected initially. The measurement technique is very similar to SPB testing, however, so those results are discussed in somewhat more detail. In addition, because of the lower traffic level and lower speeds of vehicles on the DGA section, compared to the PFC and SMA sections, the DGA data is not as meaningful as it would be had that section been placed on I74 with the others. Therefore, this data will not be emphasized, though it will be discussed briefly.

For the SMA and PFC sections, two vehicle categories were investigated: category 1 (100 passenger cars) and category 2b (80 multi-axle heavy vehicles) as defined in ISO 11819-1. Due to the existing traffic conditions, only category 1 vehicles were investigated in the DGA section; there are so few heavy trucks on this roadway that the testing time would have been excessive.

For each section and for each vehicle category, a regression line of the maximum A-weighted SPL versus the logarithm of speed was calculated. The average SPL is determined at a reference speed from this regression, according to ISO 11819-1. The standard reference speeds considered depend on the vehicle and road category. Therefore, for the CPB tests conducted on the PFC and SMA sections, noise was determined for vehicles passing by at 110 km/h (68 mph) while for DGA section it was determined at a speed of 80 km/h (50 mph) due to the differences in road categories, i.e., interstate vs. US highways.

During the SPB testing, the vehicle speeds for cars in both the SMA and PFC sections were close to the appropriate reference speed, however, the speed of heavy vehicles was higher than the reference speed. For the DGA section, the actual average speed (92 km/h (57 mph)) was between two reference speeds of 80 km/h and 110 km/h (49 mph and 68 mph).

Due to the differences between the reference and existing speeds, the results of the CPB and the SPB tests cannot be directly compared. Moreover, due to the speed differences, the DGA section cannot be compared in a straightforward way to the PFC and SMA sections. Therefore, for analysis purposes, the sound levels at other speeds were compared. The tire/pavement noise of trucks driving at a speed of 100 km/h (62 mph) was calculated from the regression line. For the PFC and SMA sections, SPLs corresponding to car speeds of 110 km/h (68 mph) and 100 km/h (62 mph) were calculated, while for the DGA section SPLs corresponding to car speeds of 90 km/h (56 mph) and 100 km/h (62 mph) were determined. The speeds at which SPLs were calculated were within the allowable range, as per ISO 11819-1, where this range is

defined as “plus-or-minus one standard deviation from the actually measured average speed for heavy vehicles and plus-or-minus one-and-a-half standard deviations for cars.”

Changes in the tire/pavement noise with time and traffic volume are shown graphically in Figure 4.1 for passenger vehicles and in Figure 4.2 for heavy vehicles at 100 km/h (62 mph). (These results for the PFC and SMA are presented numerically in Table 4.1.) Sound levels produced by vehicles travelling at different speeds were normalized to 100 km/h (62 mph) to allow direct comparison between the sections and vehicle categories. Note that noise from the heavy vehicles driving on the DGA section was not determined because there were so few of them in the existing traffic stream.

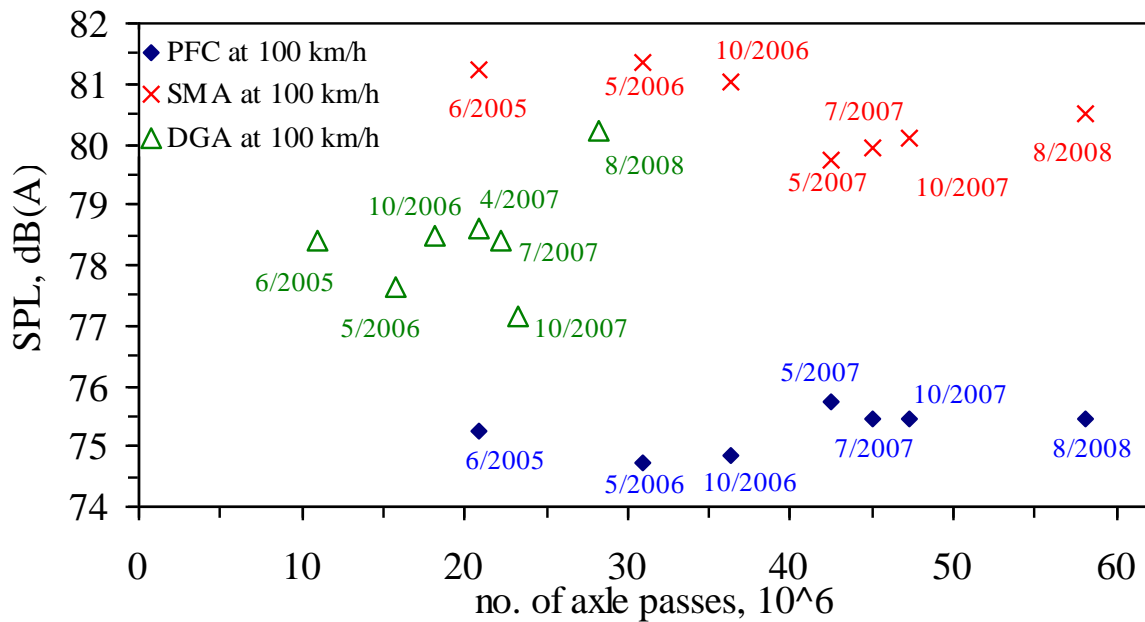


Figure 4.1. Changes in Noise Level (at 100 km/h) vs. Accumulated Traffic (Passenger Cars)

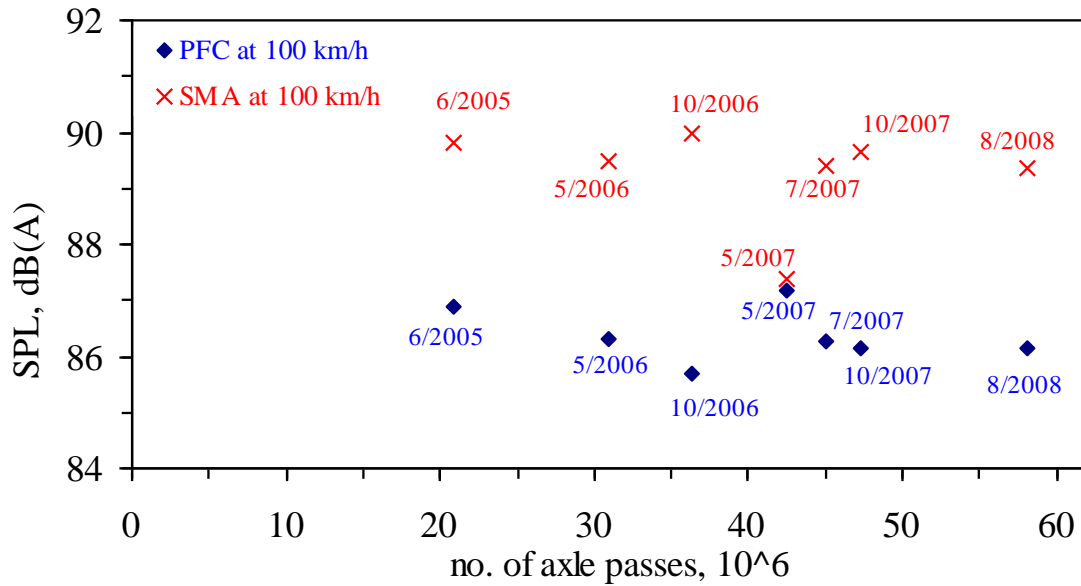


Figure 4.2. Changes in Noise Level (at 100 km/h) vs. Accumulated Traffic (Heavy Vehicles)

Note: noise from heavy vehicles was not measured on the DGA section.

Table 4.1. Comparison of SPB SPL on SMA and PFC for Vehicles at 100 km/h

Vehicles	Passenger			Heavy		
	SMA, dB(A)	PFC, dB(A)	Difference	SMA, dB(A)	PFC, dB(A)	Difference
6/2005	81.2	75.2	6.0	89.8	86.9	2.9
5/2006	81.4	74.7	6.7	89.5	86.3	3.2
10/2006	81.0	74.9	6.1	90.0	85.7	4.3
5/2007	79.8	75.7	4.1	87.4	87.2	0.2
7/2007	79.9	75.4	4.5	89.4	86.3	3.1
10/2007	80.1	75.4	4.7	89.7	86.1	3.6
8/2008	80.5	75.5	5.0	89.4	86.1	3.3

In general, it can be observed that the PFC section is the quietest, yielding a SPL of about 75 dB(A) for passenger vehicles and about 86 dB(A) for heavy vehicles at 100 km/h. The SMA section is the loudest, with a SPL about 80 dB(A) for passenger vehicles and about 90 dB(A) for heavy vehicles. The SPL in the DGA section is about 78 dB(A) for the passenger vehicles at 100 km/h, as shown in Figure 4.1.

Table 4.1 shows the numerical differences between the SPLs for the SMA and PFC for passenger cars and heavy vehicles at 100 km/h. Examination of this table reveals that the difference between the SMA and PFC was greater for passenger cars through 2006, then the difference decreased from around 6 to around 4 or 5 dB(A). (The SMA was louder in every

case.) Since 2007, the difference has increased from 4.1 to 5.2 dB(A), mainly because the SMA has gotten somewhat louder; the PFC SPLs have been quite consistent.

For heavy vehicles, the SPLs have been higher, as expected. The differences between the SMA and PFC have also been lower, averaging around 3 dB(A). There was one set of measurements (collected in May 2007) where the difference between the SMA and PFC was only 0.2 dB(A) at 100 km/h. This data appears anomalous since the passenger car data at the same time does not show this change and the measurements two months later are back in line with the other readings. Otherwise the readings in the two sections and the differences between them have been quite consistent.

Table 4.2. Comparison of SPL on SMA and PFC for Passenger Cars at 110 km/h

Date	SMA, dB(A)	PFC, dB(A)	Difference
8/2003*	79.6	73.2	6.4
6/2005	81.6	75.7	5.9
5/2006	82.0	75.2	6.8
10/2006	81.5	75.2	6.3
5/2007	80.1	76.6	3.5
7/2007	80.4	76.1	4.3
10/2007	80.6	76.1	4.5
8/2008	81.4	76.0	5.4

\*Measurements on 8/03 by CPB method, all others by SPB.

The results for passenger cars at 110 km/h, shown in Table 4.2, generally show slightly higher noise levels, as expected. This data also indicates a narrowing of the difference between the SMA and PFC after October 2006, followed by a slight increase in the difference. It is reasonable that the trends would be the same as at 100 km/h since the same data sets were used, but were merely analyzed at speeds that were only 10 km/h different. The analysis was done at 100 km/h, though, in an attempt to relate the CPB testing from 2003 to the SPB data collected later. The CPB testing was conducted with three vehicles at 100 km/h (1). Because of the differences in the traffic stream, the results are not strictly comparable. This analysis does show, however, that the relative difference between the SPLs on the SMA and PFC was comparable in 2003 to later years. The CPB-measured sound levels were lower on both pavement sections; it cannot be determined definitely if this is because of the different vehicles evaluated or differences in the pavements caused by traffic. Both factors probably played a role. It is reasonable to assume that the wearing away of the asphalt film coating the exposed aggregate particles on the surface of the pavement caused an increase in the noise level between the time of construction and the first SPB testing in 2005.

Close-proximity testing was conducted in early September 2003 by NCAT. The noise levels measured are shown in Table 4.3. These values are much higher than the sideline noise levels because the readings are taken near the tire/pavement interface. The difference in noise for

the SMA and PFC is around 5 dB(A), which is comparable to the CPB and SPB tests. So, despite differences in how the noise levels were measured, the PFC is consistently quieter than the SMA by about 5 to 6 dB(A), at least until 2006 when the difference decreases slightly to around 4 to 5 dB(A). Even the lower value represents a significant difference since an increase of 3 dB(A) is equivalent to doubling the sound energy.

Table 4.3. CPX Sound Pressure Levels (dB(A))

Speed	DGA	SMA*	PFC*
72 km/h	93.0	94.2	89.7
97 km/h	96.4	97.6	92.6

\*Tested before opening to traffic.

## 4.2 Texture and Friction Testing Results

The three sections were periodically tested for texture and friction as described in Chapter 3. Test data shown in this section were averaged for each specific section. The DFT/CTM data from both the left and right wheelpaths were combined; no appreciable differences were noted between the readings in different wheelpaths. Data from the friction trailer was collected in the left wheelpath only. The MPD,  $DF_{20}$  and IFI values are summarized in Table 4.4.

Changes in the macrotexture (expressed by MPD values) are shown in Figure 4.3 where dashed lines are used to mark the MPD range for each section. The MPD value for the PFC section was about 1.4 mm, for the SMA about 1.1 mm and for the DGA sections about 0.5 mm. For the SMA and PFC sections, the MPDs obtained from the pavements before they were opened to traffic were similar to those collected at later ages. However, for DGA the macrotexture increased after the initial tests (conducted soon after opening to traffic). There is not a significant change in texture corresponding to the change in noise levels that occurred between 2006 and 2007.

Table 4.4. Changes in MPD, DF20 and F60 over Time

Section	Date	MPD, mm	DF <sub>20</sub>	IFI (F60)
PFC	9/03	1.37	0.51	0.36
	8/05	1.52	0.65	0.45
	11/05	1.40	0.60	0.41
	10/06	1.37	0.52	0.37
	4/07	1.49	0.63	0.43
	7/07	1.44	0.61	0.42
	9/07	1.38	0.54	0.38
	10/08	1.48	0.60	0.42
SMA	9/03	1.17	0.37	0.27
	8/05	1.10	0.72	0.45
	11/05	1.10	0.72	0.45
	10/06	1.03	0.61	0.39
	4/07	1.08	0.77	0.47
	7/07	0.98	0.70	0.43
	9/07	1.08	0.66	0.42
	10/08	0.93	0.69	0.42
DGA	9/03	0.30	0.52	0.22
	5/06	0.48	0.41	0.23
	10/06	0.55	0.39	0.23
	4/07	0.58	0.45	0.26
	7/07	0.54	0.47	0.26
	9/07	0.59	0.44	0.26
	10/08	0.63	0.41	0.25



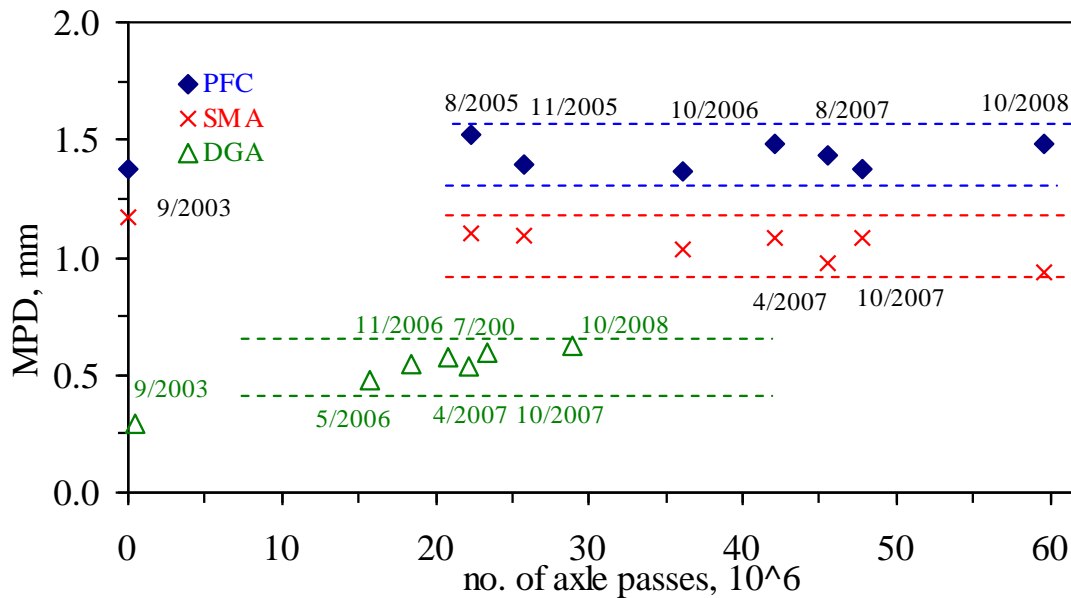


Figure 4.3. Changes in Macrotexture (MPD) over Time and Traffic for All Sections

Changes in the dynamic friction ( $DF_{20}$ ) values are shown in Figure 4.4. Again, dashed lines are used to mark the  $DF_{20}$  range for each section. The  $DF_{20}$  values for the PFC and SMA pavements before opening to traffic were lower than those measured at later ages. This finding is not a surprise, as new pavement typically has lower microtexture due to the binder coating the aggregate surface. This asphalt film is typically quickly removed by the polishing action of the tires, resulting in increased friction. Later, the  $DF_{20}$  values varied, but the changes were not significant and no consistent downward trend was observed.

For the analysis of the variations in  $DF_{20}$  values, the date when the tests were conducted should also be taken into account, because seasonal variations in friction are commonly observed. Indeed, the seasonal variations in friction reported in the literature (e.g., 23-25) could be observed here. For example, when comparing the test results obtained during different months of 2007, it can be observed that the  $DF_{20}$  values recorded in August were higher than those recorded in October. When the friction data of tests conducted during similar seasons (in October and November) of 2005-2008 were compared for the same section, average  $DF_{20}$  values were about 0.6 for PFC, 0.7 for SMA and 0.4 for DGA. It was noticed that the results of tests conducted in the fall of 2006 (for all three sections) were lower than the average values. This can be most likely explained either as a seasonal variation phenomenon or as a measurement error.

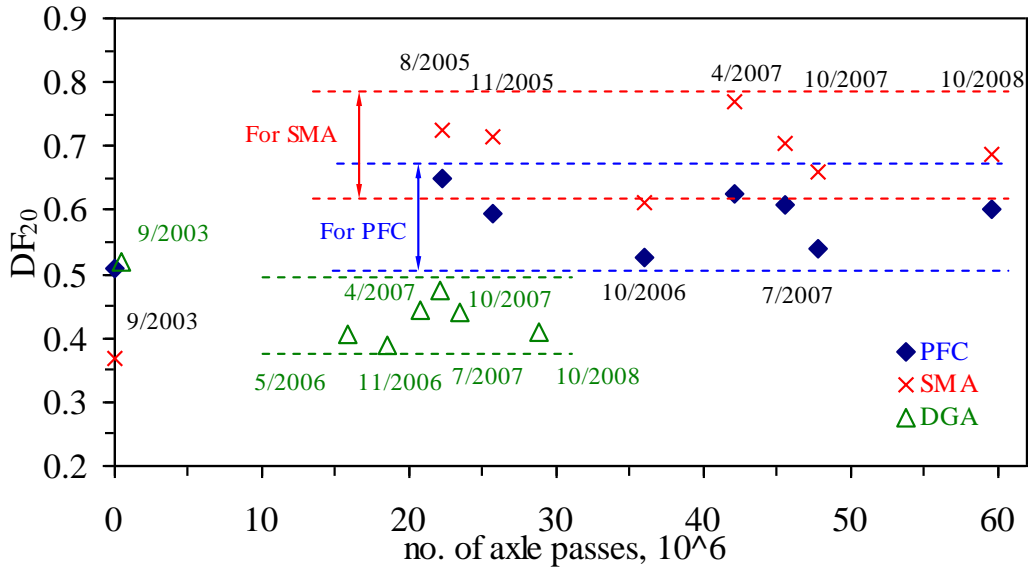


Figure 4.4. Changes in Dynamic Friction (DF<sub>20</sub>) over Time and Traffic for All Sections

Using the DF<sub>20</sub> and MPD data, International Friction Indices (IFIs) were calculated following ASTM E1960. Results of the calibrated wet friction F<sub>60</sub> (one of the IFI parameters) are shown in Figure 4.5 (dashed lines are used to mark the DF<sub>20</sub> range for each section) and in Table 4.4. This shows that the trend, in general, followed the previously mentioned results of tests with the DFT device. The average F<sub>60</sub> value is about 0.4 for the PFC and SMA and 0.2 for the DGA.

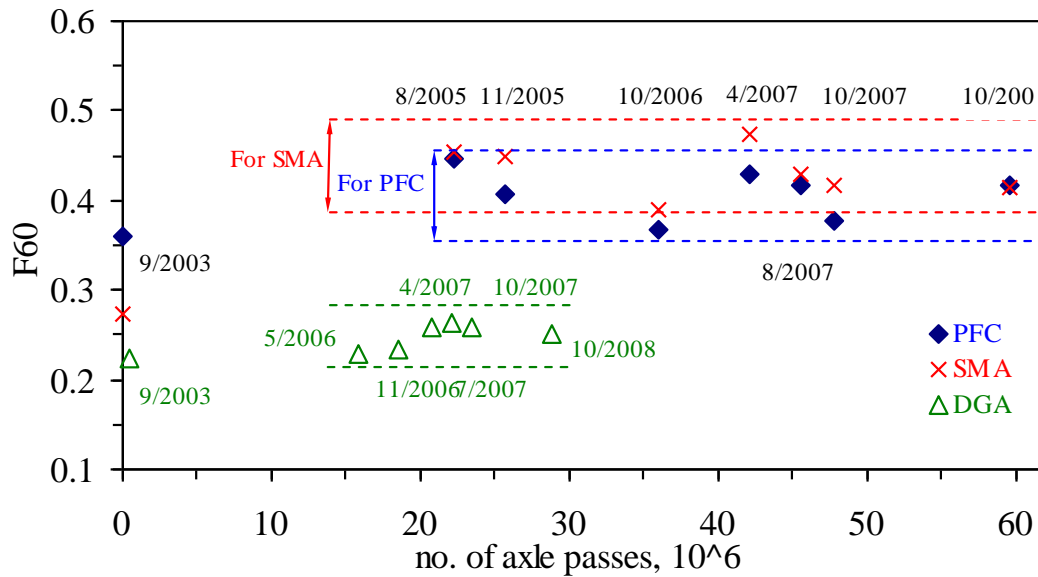


Figure 4.5. Changes in F60 over Time and Traffic for All Sections

In addition to the friction measurements conducted with the DFT device, changes in friction were also monitored using the ASTM E274 friction trailer at an adjusted speed of 64 km/h (40 mph) with a smooth tire (designated SN(64)S). The test results from the friction trailer, presented in Figure 4.6, seem to correspond well with those presented previously for the DFT device (see Figure 4.3). Note that for the PFC and SMA sections, the friction tests were conducted during the fall season only to avoid seasonal variations.

Figure 4.6 shows that the SMA and PFC surfaces provide similar friction levels and both provide significantly higher friction than the DGA section. (Note, however, that the DGA friction level is still acceptable.) The average friction level on the SMA was slightly above that of the PFC in 2007 and 2008, but this is not necessarily a statistically significant difference as it is within the typical variation in friction trailer testing on asphalt pavements with friction levels around 50 (26). The friction levels for both the PFC and the SMA appear to be fairly stable.

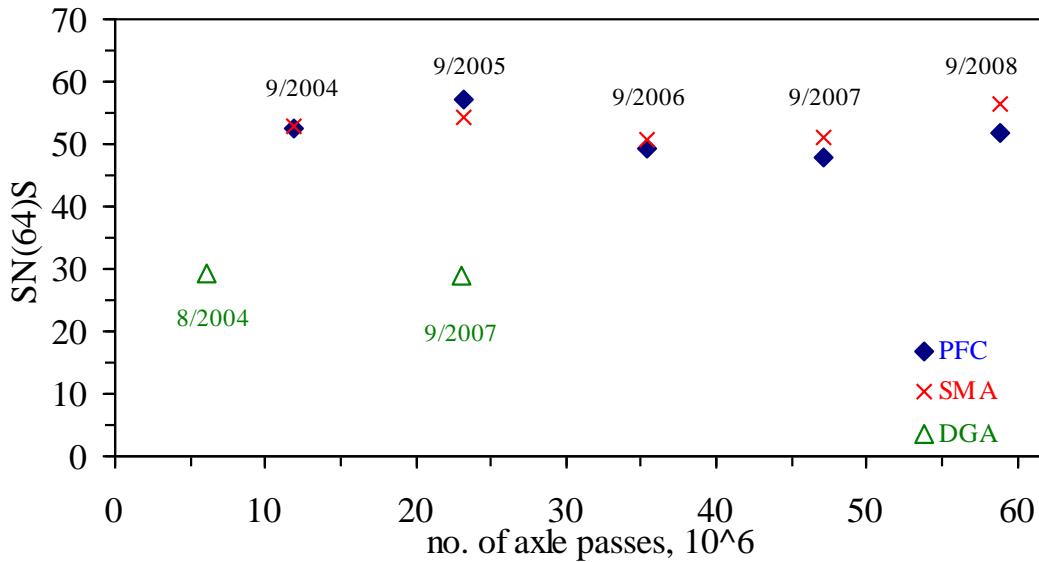


Figure 4.6. Changes in Friction Trailer Results (SN(64)S) over Time and Traffic

### 4.3 Other Considerations

Besides noise, texture and friction, there are a few other factors of concern regarding porous surfaces. One is their overall durability compared to more conventional surfaces; while some durability problems might affect the texture, others might not. Another concern is maintenance, especially in winter. There are some reports that porous friction courses can be cooler than other pavements, leading to earlier icing. Also, because of their void structure, additional quantities of salt might be needed for deicing. On the other hand, some salt can be "stored" in the pores after application helping to prevent icing at a later time. An advantage of porous surfaces is improved water drainage, which leads to reduced splash and spray, however, the longevity of that benefit is unknown.

#### Visual Inspection

Informal visual inspections were conducted each time the sites were visited. No significant distresses were observed during testing. As a close out activity, the I74 site was visited on March 3, 2009, for inspection and photographing (see Figures 4.7 through 4.11). Again, no particular distresses were noted in either the PFC section or the SMA. The SMA did appear to have some bleeding in the wheelpaths in some areas, but this phenomenon was spotty and not severe. Both the SMA and PFC appeared to be in very good condition and retained their deep black color.

Another observation made in March 2009 was that difference in the interior car noise was still discernable when passing from the SMA to the PFC. The interior noise immediately decreased, providing further confirmation that the PFC had retained its noise reduction properties.



Figure 4.7. Appearance of the PFC Surface after Five Years (3-3-09)



Figure 4.8. Close Up of the PFC Surface Texture (3-3-09)



Figure 4.9. Appearance of the SMA Surface after Five Years (3-3-09)



Figure 4.10. Close Up of the SMA Surface Texture (3-3-09)

## Maintenance

Maintenance was an area of performance that was evaluated somewhat subjectively. The responsible maintenance unit was contacted to provide feedback on any differences in the maintenance needs of the PFC section compared to the adjacent SMA sections.

One particular item of concern was the potential for icing of the PFC surface and the possible need for additional deicing chemical use during winter maintenance. Porous pavements may be colder than dense graded mixtures and may ice up faster. The maintenance unit supervisor noted that the test section tended to retain snow after the rest of the pavement was clear. It took one to two additional applications of salt to clear the PFC surface. Clearly this fact could have an impact on winter maintenance budgets if this type of surface were widely used.

The maintenance unit also noticed that although the PFC drains water into the surface during a rain event (reducing the splash and spray), the porous surface appeared to stay wet longer after the rain stopped than the SMA. This may be because water was held in the voids of the pavement instead of running off the surface or being dissipated through the splash and spray from tires. While it might seem that this could affect moisture damage of the pavement, it must be remembered that stripping also requires pressure from the tires to push water into the interface between the asphalt binder and the aggregate; the porous nature of the test surface may not allow that pressure to build up sufficiently. If the PFC is indeed holding water, that could also ultimately affect stripping of the underlying layer. This could become a problem if the PFC ever has an overlay placed on top of it, because water could certainly be trapped then. No indications of any stripping, either in the PFC or below it, have appeared to date.

During the inspection in 2009, surface temperature measurements were taken in the PFC and SMA sections to see if there was a difference. The air temperature (from weather.com) was around 2°C (28°F) and the PFC surface temperature (measured with a non-contact thermometer) was approximately 9°C (49°F). The SMA was slightly cooler at 7°C (44°F).

To further investigate the potential variation in surface temperature between these sections, the raw towed friction trailer data files were examined. The trailer records the air and pavement temperatures (in °F) continuously during testing. This data showed comparable temperatures on both pavements during individual runs through the test sections. The pavement temperatures increased from about 30°C (86°F) on the first run to about 37°C (99°F) on the second trip through the site. During these runs, the air temperature increased from about 24 to 26°C (75 to 79°F) as the day progressed (over about one hour at mid-day).

## Splash and Spray

Although no quantified measurements of splash and spray were conducted, based on visual observation of the pavement performance during a rain event, the drainage benefits of the PFC pavements were recognized. During the rainstorm event, the observed splash and spray in the PFC section was considerably lower than that observed in the SMA and DGA sections. This improvement was noticed especially when passing heavy vehicles, which typically produce large

amounts of splash and spray. A video documenting this is available online at [https://engineering.purdue.edu/NCSC/video/I-74\\_OGFC.MPG/](https://engineering.purdue.edu/NCSC/video/I-74_OGFC.MPG/). Figure 4.11 also illustrates the difference in the drainage properties of the PFC and SMA during a light to moderate rain event.

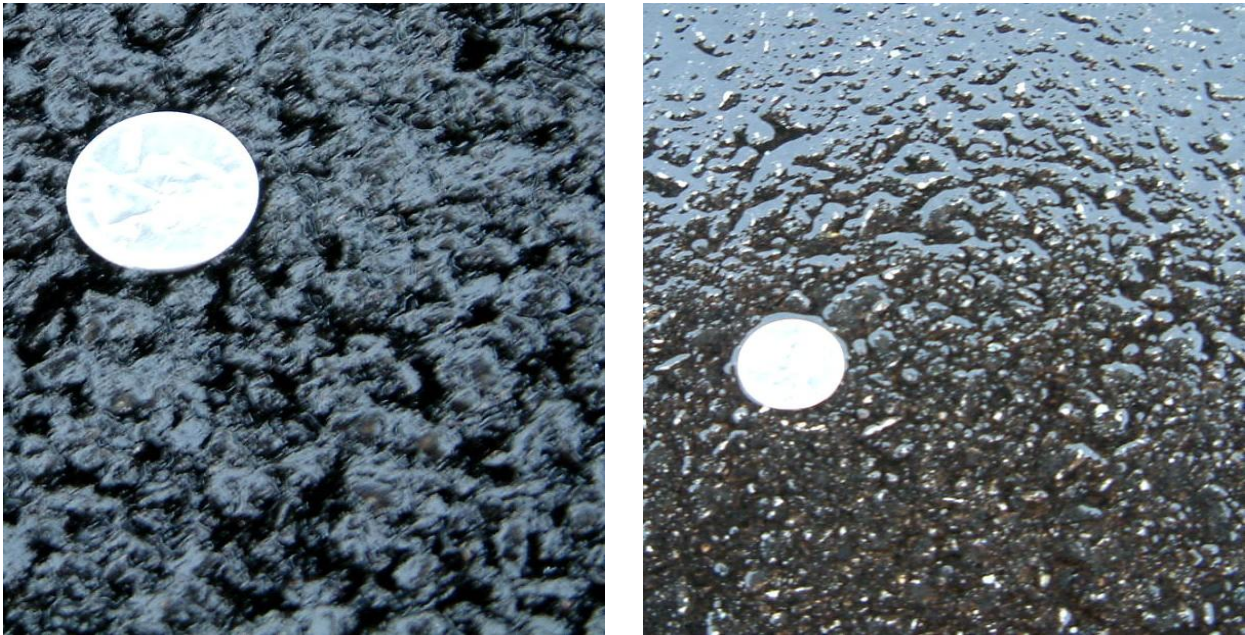


Figure 4.11. PFC Surface Draining Rainwater (left) vs. Standing Water on the SMA (right)



## CHAPTER 5. CONCLUSIONS

Based on the data presented here, the following conclusions can be drawn:

- The Porous Friction Course is still providing sound pressure levels that are significantly lower than those of the SMA or the DGA after five years under traffic in the Indiana climate.
- The SPL values for the PFC are about 5 dB(A) lower than the SPL values for the SMA for passenger cars and about 3 dB(A) lower for heavy trucks.
- Regardless of the measurement technique used (CPX, CPB or SPB), the relative differences between the SMA and PFC were similar.
- The PFC is still performing very well in terms of noise reduction after five years.
- The macrotexture of the SMA and PFC has remained quite consistent over time, but the macrotexture of the DGA increased after the initial test.
- There are no indications that the PFC voids have become clogged.
- The friction levels provided by the SMA and PFC increased after traffic abraded away the binder film coating the aggregates on the surface. This likely also happened with the DGA, but measurements were not made before this section was opened to traffic.
- After the binder film was worn away, the friction levels have been consistent, whether measured by DFT or towed friction trailer.
- The SMA and PFC provided similar friction levels, which were much higher than the DGA (though the DGA friction level was still acceptable).
- Visual inspections show that both the SMA and the PFC are performing well with little to no distress of any kind.
- The PFC reportedly requires one or two more salt applications than the SMA to remain ice-free in snowy conditions.
- Dramatically less splash and spray was produced by traffic on the PFC during a rain event than on the SMA.
- The PFC has not (yet) exhibited the deterioration of the noise, friction and texture properties that was thought to be probable under Indiana traffic and climate conditions.
- PFC surfaces appear to be viable tools for the design of low noise, high friction surfaces for Indiana roadways.

## CHAPTER 6. DISCUSSION AND RECOMMENDATIONS

Based on the successful performance of this test section of porous friction course, INDOT now has a new tool that can be used to provide a high quality, high friction surface while also reducing splash and spray and reducing tire/pavement noise. This surface type could be used on facilities where the high speed and volume of the traffic will help to keep the voids clear of dirt and debris. The use of this type of surface has not been proven for lower speed, lower traffic facilities, so it should not be used in those types of applications without further evaluation under those conditions.

INDOT's Traffic Noise Policy (27) describes how the State complies with the federal noise standards. The policy defines when abatement must be considered and what factors affect the need for abatement and type of abatement implemented. This policy is applicable to Type I projects, which include construction on a new location; significant changes in horizontal or vertical alignment; added travel, truck or high-occupancy vehicle lanes; or construction of new interchanges or ramps. Since current FHWA policy does not allow consideration of the pavement surface type as a mitigation factor, and since INDOT has limited ability to implement other measures such as traffic calming, changes in alignment, acquisition of buffering land or noise insulation of adjacent structures, the most common form of mitigation is the erection of a barrier wall. (The FHWA policy does not mean that a PFC cannot be used on Federal-Aid projects if it is selected for other reasons such as improved visibility or friction, but its use cannot be considered to obviate the need for noise abatement.)

This policy, however, only applies to federal-aid projects. It does not apply to state or locally funded projects. One of the requirements of the policy is for INDOT to share traffic noise information with local agencies that have jurisdiction over adjacent land use. As local agencies and the general public become more aware of traffic noise and mitigation strategies, as they have in many other locales, the demand for noise mitigation may expand beyond federal-aid projects. In these cases, PFC surfaces may satisfy the public's demand for lower traffic noise. Use of a PFC will reduce the noise generated at the tire/pavement interface and will reduce noise for those nearby properties that do not benefit from a noise wall (e.g., those not in the acoustical shadow of the wall). In other words, there may be cases where noise mitigation is not required by the FHWA but it may be desirable for public relations or in sensitive areas that are not on the federal-aid system. Possible locations where this might be the case include locations near schools, hospitals or other sensitive structures; on roadways adjacent to parklands or scenic areas; or in locales where the public is active and demanding noise reductions.

The INDOT policy also defines "substantial noise reduction" as providing at least 7 dB(A) for the majority of the receivers. The PFC achieved a noise reduction of 5 to 6 dB(A) compared to the SMA, which is a significant decrease even though it does not meet INDOT's definition of "substantial." Under this definition, then, a PFC would not qualify as a substantial noise mitigation measure even if FHWA allowed its consideration. Nonetheless, for some locations

where noise reduction may be desirable even though not required, use of a PFC may be effective and feasible.

PFCs also provide drivers with a safe surface offering improved visibility in wet weather. There may be isolated locations where this type of safety improvement is advantageous. The study section evaluated here was too short to allow an investigation of the safety impacts of the PFC aside from quantifying the friction levels and observing reduced splash and spray. The potential improvement in safety should be further evaluated on a longer section.

Eventually, the FHWA position on noise mitigation techniques may change as additional research demonstrates the longevity of the noise benefits of various pavement surfaces, including porous friction courses. The current philosophy is that once a noise wall is erected, it is essentially permanent. If enough evidence shows that the noise benefits of PFC last as long as the pavement surface itself, then FHWA policy may change. (The results may be of interest to the FHWA as they consider their current noise policies.) This could result in huge cost savings through the elimination, or at least reduction, in noise walls. It is also possible that future research and experience may show that the use of quieter pavement surfaces may reduce the required wall height, which can have a great impact on cost.

This study focused on evaluating the performance of a PFC under Indiana conditions because of the concerns that the performance would be compromised by clogging of the voids. The study was not designed to specifically evaluate costs. Nonetheless, some discussion of costs is appropriate.

The Georgia DOT, which has led the US in implementation of porous asphalt technology for many years, routinely uses the underlying SMA to stop the downward movement of water into the pavement structure. Water entering the PFC travels across the surface of the SMA to the shoulder. The Georgia cross-section was the example followed in construction of this experimental section. INDOT did small a smaller nominal maximum aggregate size PFC (9.5mm vs. 12.5mm) in a thinner lift (30mm vs. 40mm) than is typically used in Georgia to reduce costs and reduce the drop-off at the edge of the lane.

Adding the PFC atop the SMA, which would normally be the surface course for interstates in Indiana, increases the cost of the pavement. Since the SMA would not be used as the surface, however, it should be possible to replace the commonly used steel slag aggregate with dolomite in the SMA. The surface friction would be provided by the PFC, which would be constructed with steep slag. Replacing the steel slag in the SMA would have a major impact on costs and would help to offset the added cost of the PFC.

If the use of a PFC can reduce or eliminate the need for a noise barrier wall (on non-federal aid projects or if FHWA policy changes), this would more than offset the added material costs by greatly reducing the overall project costs, as discussed in section 6.1. If a PFC were to be used with a barrier wall, the overall project costs would be higher, so would be hard to justify unless a marked improvement in safety could be proven.

Use of PFCs may also result in higher costs for winter maintenance because of the need for more salt applications. If used extensively, this increased cost could be significant, therefore sites where PFCs are to be used should be selected carefully.

## **6.1 Expected Benefits, Deliverables, Implementation and Cost Savings**

In summary, PFC surfaces could be attractive options for high speed roadways adjacent to locations where reduced tire/pavement noise is desired for aesthetic or environmental reasons (parklands, scenic routes, schools, residential areas, etc.), especially where federal-aid funds are not being used to finance the improvements. PFC surfaces may also provide benefits in areas where high friction is needed or splash and spray is a particular problem.

The Office of Pavement Engineering and the Pavement Design Committee should consider specifying a PFC surface in specific locations where its benefits would be advantageous, especially when Federal-aid funds are not involved. These locations should have high speed and relatively high volume traffic. A PFC may also be used on Federal-aid projects for reasons other than noise, if desired, but the costs will be higher. Such locations might include areas where drainage issues between the noise barrier walls might lead to water on the pavement resulting in increased splash and spray or where higher friction (reduced hydroplaning) is called for.

Use of PFCs is likely to be limited under current policies and based on the results of this study, which did not evaluate safety in detail. Construction of a longer section of PFC and comparison to a section of SMA surface is recommended to better evaluate the safety effects (accident rates, friction, visibility) of the PFC as well as actual construction and maintenance costs. (Noise could also be measured occasionally to confirm the findings of this project.) Selecting and interstate paving contract and placing PFC (placed atop a dolomite SMA) on one half of the project with a steel slag SMA on the other half would be a positive next step in the implementation of this technology.

Noise barrier walls typically cost in excess of \$1-2 million per mile. For example, a 2004 contract in the Fort Wayne district included 33,460 linear feet of wall at a total cost of \$8.1 million dollars, or a cost of \$1.28 million per mile of wall. The total cost of this project was \$80,000. Therefore, if just one mile of wall is not needed, the benefit:cost ratio for this study would be over \$1 million/\$80,000, or 12.5:1 even considering the added cost of the PFC. Even though winter maintenance costs could be somewhat higher for PFCs, the number of miles where these would be used is likely relatively small (under current policies) so the overall impact of these increased costs is not expected to be great.

The findings of this project may also be of interest to the Office of Environmental Services, Division of Production Management, which oversees the Traffic Noise Policy and its implementation during the National Environmental Policy Act (NEPA) evaluation.

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