# Virginia "Quieter" Pavement Demonstration Projects – Initial Functional Assessment

## TRB Paper # 13-3150

Kevin K. McGhee, PE
Associate Principal Scientist
Virginia Center for Transportation Innovation and Research
530 Edgemont Road
Charlottesville, VA 22903
Telephone: 434-293-1956
Fax: 434-293-1990
Kevin.McGhee@VDOT.Virginia.gov

**Edgar David de León Izeppi**
Senior Research Associate, Center for Sustainable Transportation Infrastructure
Virginia Tech Transportation Institute
3500 Transportation Research Plaza
Blacksburg, VA 24061
Phone: (540) 231-1504/ Fax: (540) 231-1555
Email: EdeLeonIzeppi@vtti.vt.edu

**Gerardo W. Flintsch**
Director, Center for Sustainable Transportation Infrastructure
Virginia Tech Transportation Institute
Professor, Charles Via, Jr. Department of Civil and Environmental Engineering
3500 Transportation Research Plaza
Blacksburg, VA 24061
Phone: (540) 231-9748/Fax: (540) 231-1555
Email: GFlintsch@vtti.vt.edu

**Daniel E. Mogrovejo**
Graduate Research Assistant
Virginia Tech Transportation Institute
Department of Civil and Environmental Engineering, Virginia Tech
3500 Transportation Research Plaza
Blacksburg, VA 24061
Phone: (540) 505-7288/Fax: (540) 231-1555
Email: danielmc@vt.edu

Corresponding author: **Kevin McGhee**

Word count: 5,386 + 1 table + 7 figures = 7,386

## ABSTRACT

This paper describes the first stages of the development of a formal "quieter" pavement use guideline for Virginia. It chronicles the selection of lower-noise pavement technologies (i.e., "quieter" pavement [QP]); the development and construction of the first season (2011) of QP demonstration projects; and the evaluation tools and analysis being used to compare the performance of the alternative strategies. After one winter of service, the lower-noise asphalt technologies were *measurably* (2 decibels or less) less noisy than the control surfaces on average and *noticeably* (≥ 3 dB) more quiet in several specific cases. The quiet concrete technology, the Next Generation Concrete Surface (NGCS), maintained an *readily noticeable* (5 dB) noise advantage over the control concrete surface.

Beyond tire-pavement noise, the QP technologies have a distinct advantage over the control surfaces when it comes to achieved ride quality. The NGCS is very smooth, and contractors earned incentives for ride quality with the quiet asphalt materials, including (and especially with) the materials that were placed at a 1-inch thickness. Although some wheel path consolidation was evident in the texture data for the asphalt technologies, all of the QP surfaces are exhibiting excellent skid resistance and are receiving consistent recognition for good wet-weather service.

# INTRODUCTION

## Background

Traffic-generated noise comes from many sources, including vehicle engines and drive-trains, exhaust, aerodynamics, and the interaction of the tire with the pavement. The degree to which each of these sources contribute to the overall sound levels depends on the kinds of vehicles in the traffic stream, the kinds of movement activities underway at a given location (e.g., acceleration, deceleration), and the average travel speeds. When these travel speeds exceed 35 mph and the traffic stream is made up primarily of free-flowing passenger vehicles and light trucks, the predominant source of noise is the tire-pavement interaction *(1).* The amount of noise generated at this interface is further dependent on characteristics of the tire and the pavement surface. With regard to the traveled surface (i.e., pavement), the characteristics known to affect noise the most include (in decreasing order of significance) the surface texture, porosity, and stiffness (much less significant). The contribution from each characteristic is complicated, but in most instances a lower-noise (i.e., “quiet”) pavement will have a small, negative texture (i.e., stone particles do not stick up from the surface), high porosity, and relatively low stiffness.

In 2004 the Virginia Department of Transportation (VDOT) participated in a multistate survey to compare common pavement surfaces in terms of relative tire-pavement noise production *(2)*. Among the surfaces represented in Virginia’s contribution to the survey were various dense-graded asphalt mixes, several stone-matrix asphalt (SMA) mixes, a thin hot-mix semi-proprietary asphalt overlay system (aka NovaChip®), and two conventional concrete pavement finishes. Absent from Virginia’s contribution to the multi-state matrix were open-graded friction course (OGFC) mixes, which consistently ranked well for noise performance in the larger study. The absence of these mixes in Virginia was not an oversight: they simply did not exist. Older-generation OGFC mixes were prone to drain-down, the tendency for hot liquid asphalt to settle out of the body of the mix, which led to “dry” in-place mixes that were, as a consequence, subject to premature and rapid failure. The mixes that did perform as anticipated under wet conditions also reportedly had “black icing” tendencies when *wet* approached *wet-freeze* conditions. Finally, the presence of an OGFC was widely reported to exacerbate the moisture-damage susceptibility of underlying dense-graded layers. The heavy interfacial membrane that was made even heavier by liquid drain-down trapped water in the lower layers and ultimately led to much deeper and substantial failures. For these reasons, the use of OGFC mixes was discontinued in Virginia in the late 1980s.

The early 2000s timeframe was also when the concrete pavement industry began to aggressively explore finishing techniques for concrete pavements that would reduce tire-pavement noise production *(3).* Conventional diamond ground (CDG) concrete and longitudinal tining and grooving were found in other studies (*20, 21*) to be less noisy than the Virginia-typical transversely tined finish. Nonetheless, the industry continued to pursue a finishing technique that would consistently mute the tire-pavement interaction.

## A "New Generation" of Mixes and Finishes

### *Asphalt*

Smaller-stone open-graded and rubberized wearing course mixes have been internationally recognized as lower-noise pavements for several decades *(4,5).* By the late 1990s, many US states and other countries were using a "new generation" OGFC mix *(6).* This new generation of mixes addressed the material performance and drain-down-related problems that were so problematic for Virginia in years past. Polymer modification of the binders was proving effective in battling oxidation and material stability, and the fibers helped suspend more liquid asphalt in the mix during production, haul, and placement. These improvements also permitted higher void levels, which are important for noise absorption. These higher-porosity OGFC mixes are now often referred to as porous friction course (PFC) mixes.

### *Concrete*

In 2005 researchers at Purdue University were making progress in understanding the characteristics of concrete pavement finishing that impacted tire-pavement noise *(7).* Their research found that the predominant factor in noise generation was the variability in the fin profile that remained after a surface was diamond ground. The lowest noise textures as determined through laboratory tests were constructed using a conventional diamond grind followed by a "flush-grind" operation and then a final longitudinal grooving step. Follow-up testing confirmed that this process produced the lowest noise texture to be produced in the research. That surface, now called the Next Generation Concrete Surface (NGCS), is promoted by the concrete paving and grooving and grinding industries as the "quieter" concrete pavement finish.

## A Lower-noise pavement Initiative

The 2011 Session of the Virginia General Assembly brought a new focus to "lower-noise pavement". In particular, Chapter 790 of the 2011 Virginia Acts of Assembly (*Code of Virginia* § 33.1-223.2:21) directs "the Department" (i.e., VDOT) to

> expedite the development of quiet pavement technology such that applicable contract solicitations for paving shall include specifications for quiet pavement in any case in which sound mitigation is a consideration. To that end, the Department shall construct demonstration projects sufficient in number and scope to assess applicable technologies.

The bill further directs VDOT to evaluate the installed technologies and provide an interim report in June 2012 and a final report in June 2013. This final report is to include

> results of demonstration projects in Virginia, results of the use of quiet pavement in other states, a plan for routine implementation of quiet pavement, and any safety, cost, or performance issues that have been identified by the demonstration projects.

## PURPOSE AND SCOPE

This paper documents VDOT's progress in implementing a lower-noise pavement use policy. It chronicles the selection of lower-noise pavement technologies, the development and construction of demonstration projects, and the evaluation tools and analysis being used to compare performance of the alternative strategies. This paper is particularly focused on results of testing conducted on the 2011 series of "quiet" pavement (QP) demonstration projects.

## MATERIALS AND METHODS

### Selection of Technologies and Demonstration Projects

As the 2011 legislation began to take shape in the fall of 2010, VDOT and the Virginia paving industry formed the Lower-noise pavement Task Force (QPTF) in an effort to address the legislation cooperatively. This task force includes representation from VDOT's Materials, Maintenance, and Environmental Divisions; the Virginia Center for Transportation Innovation and Research (VCTIR); the Virginia Asphalt Association (VAA); the American Concrete Paving Association (ACPA); the Virginia asphalt contracting industry; and the Virginia General Assembly.

The QPTF was responsible for a number of critical early-project activities and decisions. Members of the QPTF worked with VCTIR researchers to conduct a review of relevant literature. The QPTF combined findings from the literature review with contemporary practical experience  to develop candidate lower-noise materials and treatments. The QPTF established key requirements of the demonstration projects and engaged VDOT districts and contractors to identify suitable locations. Finally, members of the QPTF developed the material and construction specifications and helped assemble the contract documents that were used to advertise and award for construction.

The key elements of the criteria used to help identify appropriate demonstration projects were as follows:

- four-lane divided, high-speed (posted speed limit at least 55 mph) corridor
- good overall pavement structure and cross-section
- good overall corridor geometrics
- limited at-grade intersections
- 1-mile length for each asphalt technology/0.5-mile length for each concrete technology
- no curb and gutter and
- minimal existing sound mitigation measures.

The project selection criteria were designed to find projects that might be reasonable candidates for future noise mitigation measures. The higher posted speeds and limited at-grade intersections helped ensure that tire-pavement noise would be the significant source of overall traffic noise. Good pavement structure, cross-section, and geometrics were important to material performance and safety (i.e., good internal and surface drainage). The length requirements supported reasonable production and placement quantities and ensured that functional testing for one technology could be easily isolated from another.

## Functional Evaluation

The noise production and propagation character of a candidate QP material or treatment was of obvious primary significance to this research. However, it is important to make sure that good noise performance does not come at the expense of safety. Moreover, it is important to also document when reduced noise is accompanied by improved function in other respects. For this reason, the assessment of QP technologies considered tire-pavement noise, ride quality, texture, resistance to skidding, and winter performance.

### *Tire-Pavement Noise*

Tire-pavement noise was measured in accordance with AASHTO Standard TP 76-12: Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method *(8)*. The testing was conducted by the Virginia Tech Transportation Institute (VTTI) using equipment fabricated by Acoustical and Vibrations Engineering Consultants (AVEC), Inc. in Blacksburg *(9)*.

Each set of test runs were taken within a timeframe over which environmental conditions were considered to be the same or within the acceptable range of variability. The standard test speed is 60 mph, and the standard test length covers 5 seconds of travel (440 feet at 60 mph). The OBSI analysis and reporting system applies an A-weighted filtering scheme to  emphasize the frequencies to which humans are most sensitive. The sound levels are therefore reported in A-weighted decibels, or dB(A). A complete set of results includes an overall A-weighted sound intensity level and A-weighted one-third octave band levels.

### *Ride Quality*

Among the special provisions employed to construct the asphalt demonstration projects was *VDOT's Special Provision for Rideability (10)*. The special provision quantifies ride quality in terms of the International Roughness Index (IRI), a standard index generated using the American Society for Testing and Materials (ASTM) Standard Practice E 1926. Higher values of IRI represent rougher surfaces, and lower values indicate smoother pavements. VDOT's special provision defines target IRI ranges for full payment, as well as those quality ranges that will result in incentive or disincentive payments.

The ride quality requirement for the concrete projects was actually an integrated component of the specification that was assembled to construct the featured lower-noise technology. This requirement also summarized ride quality in terms of the IRI. However, the specification requires the profiling device to incorporate a special wider-footprint height-sensor, which is necessary when attempting to accurately measure profile along a surface texture with a strong longitudinal component *(11)*.

### *Texture and Resistance to Skidding*

Texture and friction properties were measured with the Circular Track Meter (CTMeter); the GripTester (GT); and a lock-wheel tester (LWT).

#### *Circular Track Meter (ASTM E2157)*

The CTMeter is a device designed to measure surface macrotexture, which consists of features in the traveled surface that are between .02 inches and 2 inches (0.5 to 50 mm) in size. In addition to being the surface property that most profoundly affects tire-pavement noise, macrotexture influences higher speed skid resistance, rolling resistance, splash/spray, and general wet-condition visibility. The CTMeter consists of a charge coupled device (CCD) laser-displacement sensor mounted on an arm that rotates such that the displacement sensor follows a circular track with a diameter of 11.2 inches. The device collects a high resolution profile of this track and reports a mean profile depth (MPD) and root mean square (RMS) value. MPD is defined in ASTM E1845 and the values stated in SI (metric) units are regarded as the standard.

The CTMeter measurements were taken on at least six different locations along each QP section, three each in the lane center and the right wheel path.

*GripTester (ASTM E2340)*
A Findlay Irvine GT was used to measure continuous skid resistance along the right wheel path of the travel lane of the test sections. The GT system is a fixed slip device in which the test tire is connected to the trailer wheel axle by a chain, allowing it to measure the rotational resistance of a constantly slipping smooth tire. The GT uses a constant slip ratio of 15.6 percent, which means that the test tire is rotating at a speed that is 15.6 percent slower than the other similarly sized tires on the trailer.

Measurements were taken at 40 mph using a constant water film thickness of 0.02 inch. Raw data for longitudinal friction forces and test wheel loads were (by default) recorded every 3 ft. Due to the location of the test wheel when the GT is attached to the vehicle, only the left (inside) wheel path friction is recorded.

*Locked Wheel Tester (ASTM E274)*
The LWT is the production-oriented friction measuring system used by most state agencies (including VDOT). It records the steady state friction force of a locked wheel on a wetted pavement surface as the wheel slides at constant speed. The LWT consists of a vehicle towing a trailer equipped with test wheels. During the test, when the vehicle reaches the desired speed, water is delivered ahead of the test tire and the braking system is activated, producing a 100 percent slip ratio. The wheel remains locked for approximately one second, and the data is measured and averaged. The skid resistance of the paved surface is reported as the skid number (SN), which is the force required to slide the locked test tire at the stated speed divided by the effective wheel load and multiplied by 100.

The LWT was used mid-construction on one of the featured quiet concrete surfaces, but was otherwise only used as part of the spring 2012 cycle of testing. The standard locked-wheel test in Virginia is conducted at 40 mph using a smooth tire (ASTM E524).

### *Winter Performance*

Porous wearing surfaces (i.e., the most common asphalt QP technologies) are widely known to respond differently than traditional materials to winter weather and winter maintenance tactics *(12)*. In an attempt to capture observations and responses that might be unique to QP surfaces in Virginia's climate(s), the QPTF developed and distributed a guideline document to field personnel that addressed maintenance and observation. This guideline was intended to both alert local maintenance crews to the kinds of phenomena that they might observe, as well as to seek feedback on any special treatments or application frequency changes that might be necessary for QP surfaces during Virginia's winter weather.

# FINDINGS AND DISCUSSION

## Lower-noise pavement Technologies

The QPTF selected three asphalt surface materials and two mechanically applied finishes to hydraulic cement concrete pavements as candidate QP technologies for the 2011 demonstration projects.

### *Asphalt*

The three quiet *asphalt* materials include two open-graded asphalt concrete mixes that use a polymer-modified binder. The third uses a similar aggregate gradation but with a rubber-modified binder. Each of these technologies has been used successfully in Virginia or elsewhere (e.g., Florida, California, and Europe). The polymer-modified mixes were designed in accordance with *VDOT's Special Provision for Porous Friction Course* (PFC) *(13)*. The rubber-modified mix complied with the requirements of *VDOT's Special Provision for Asphalt Rubber Porous Friction Course* (AR-PFC) *(14)*. The asphalt rubber mix (AR-PFC 9.5) and one of the polymer-modified mixes (PFC 9.5) was designed and produced using a 3/8-inch (9.5-mm) top-size stone. These two finer mixes were placed at approximately 1-inch thickness. The second polymer-modified mix (PFC 12.5) was designed with a ½-inch (12.5 mm) top-size stone and placed at 2 inches in thickness. The slightly coarser gradation was expected to generate slightly more noise initially, but the gradation and additional thickness were expected to retain the noise-reducing characteristics for a longer period.

### *Concrete*

The two lower-noise concrete technologies that have been considered include conventional diamond grinding and the Next Generation Concrete Surface (NGCS). The conventional grind surface was achieved using *VDOT's Special Provision for Grinding Concrete Pavement (15)*. The NGCS used the newly developed *Special Provision for Grinding Next Generation Concrete Pavement Surface (16)*.

## Demonstration Projects

VDOT used these five candidate QP technologies in five QP demonstration projects in 2011 (see Figure 1). These projects were made up of three new asphalt concrete projects and modifications to two existing concrete patching projects. The asphalt projects are located on the State Route 7 By-Pass in Leesburg, State Route 199 west of Williamsburg, and State Route 288 near Chester. The concrete sections are located on I-64 near Virginia Beach and State Route 76 in Richmond.

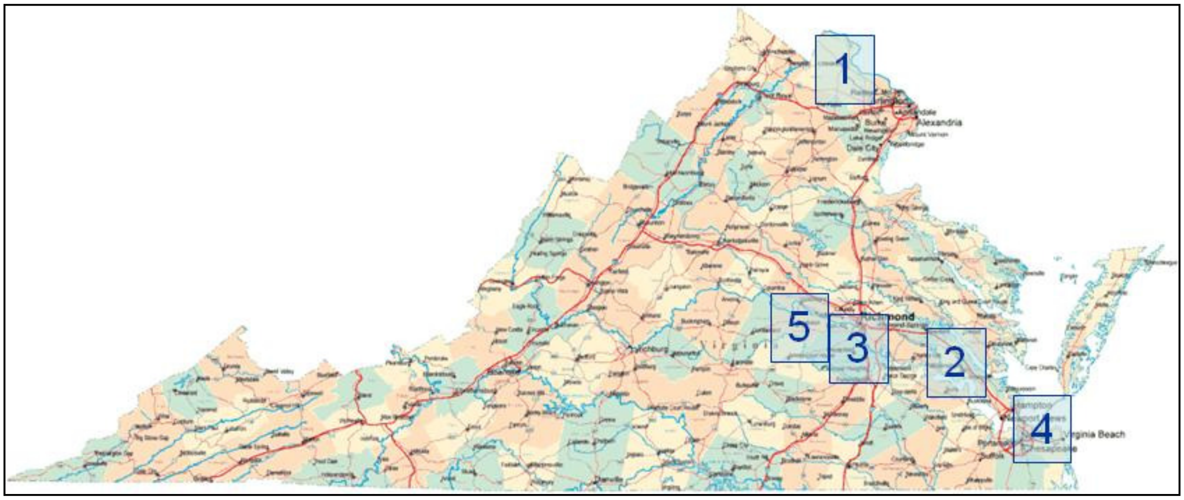

**FIGURE 1 Locations for 2011 Lower-noise pavement Demonstration Projects. 1 = State Route 7 Leesburg; 2 = State Route 199 Williamsburg; 3 = State Route 288 Chester; 4 = Interstate 64 Chesapeake; 5 = State Route 76 Richmond.**

### *Asphalt Projects*

The asphalt demonstration projects each included four technologies: three experimental and one control. The asphalt projects are constructed on four-lane divided facilities with approximately 1 mile of control material followed by 1 mile each of the 3 experimental materials. The control section is VDOT's finer-gradation Stone Matrix Asphalt (SMA 9.5), which is used on many high-speed, high-volume roadways. The SMA was placed at 1.5 inches in thickness (the typical application rate for this material).

It was important to establish a stable and uniform construction platform upon which to place the four asphalt surface materials. The specific approach was dictated by existing conditions and therefore varied slightly at each of the three project sites. In some cases it was possible to place the new surface materials directly on top of the existing pavement. In most cases, however, the existing surface material was milled and a two-inch intermediate layer placed as a foundation to the new surface layers. When the original material was concrete, two additional layers of an intermediate asphalt mix (IM-19.0) were used to isolate the eventual surface materials from the comparatively rigid concrete base. Note: for more detail on cross-section for asphalt projects, please refer to an interim report to the Virginia General Assembly, which can be found at http://www.virginiadot.org/VDOT/Projects/asset_upload_file884_5721.pdf.

### *Concrete Projects*

The existing facilities that were relevant to a "quiet" concrete project were far more limited, but the demonstration projects themselves were much easier to design, commission, and construct. One of the concrete projects was a four-lane divided facility and the other a six-lane divided (Interstate) facility. A quiet concrete demonstration project consisted of approximately 0.5-mile of existing transversely tined surface followed by a 0.5-mile of conventional diamond grind and then 0.5-mile of NGCS.

## Functional Evaluation

### *Tire-Pavement Noise*

As of May 2012, two series of tire-pavement noise measurements had been conducted for each section of every QP demonstration project. Since the final demonstration project was not complete until early December 2011, the first series of tests actually took place in late fall/early winter (December 2011). The second series of tests took place in early April 2012 and was intended to register any changes that might have resulted following a first winter of exposure.

When comparing noise levels of QP strategies, it is important to understand that decibels are logarithmic units and cannot be added by normal arithmetic means. The *Little Book of Quieter Pavements(1)* describes the fundamentals of noise and its measurement, and includes some helpful rules of thumb. For instance, while precision instruments can measure small changes in sound level, the human ear requires about 3 decibels (dB) of difference for the change to be "noticeable". A 5 dB change is considered "readily noticeable" to most people and a 10 decibel difference is equivalent to a doubling (or halving) of the sound level.

Figure 2 provides the average OBSI value, the first and third quartiles, and the minimum and maximum intensity levels for each pavement technology as measured in the fall of 2011. The PFC 12.5 had the lowest overall average intensity level at 99.1 dBA. However, the single most "quiet" new surface reading, 97.4 dBA, came from an AR-PFC 9.5 section in Williamsburg. The NGCS was notable for its consistency, as there was but 1.0 dBA difference between the highest and lowest measured intensity levels on any of the repeat runs.

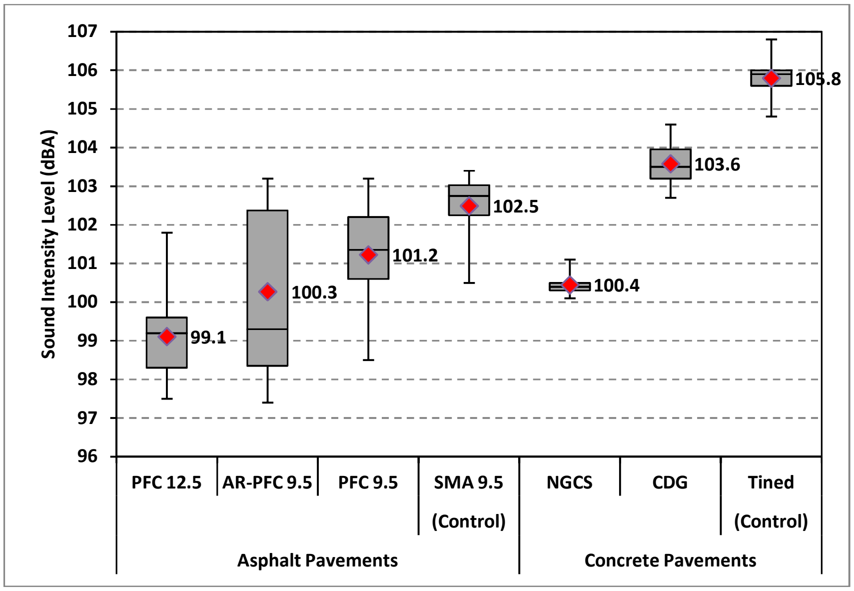

**FIGURE 2 Fall 2011 Tire-Pavement Noise Test Results. Note: 60 mph OBSI with Standard Radial Test Tire (SRTT – ASTM F2493). "Tined" refers to transversely tined concrete finish.**

Figure 3 summarizes an identical series of OBSI tests in April 2012. The overall intensity levels in the spring measurements have actually dropped just slightly from late fall. The two non-rubberized PFC mixes saw the smallest drop in overall intensity levels while the SMA and AR-PFC surfaces dropped by just over 1.0 dBA. The rank order remains unchanged and it is likely that much of the difference between the late winter and spring numbers can be attributed to differences in testing temperatures (colder temperatures resulting in higher intensity levels *(17, 18)*). The large variability in results for the AR-PFC 9.5 mixes is particularly perplexing. Most of it stems from the much higher noise levels that were measured on Site Number 1 in Northern Virginia. The specific gravities of the northern Virginia stone is much higher, which often affects designs. The mixes for the other two sites were also designed, produced and placed by the same the contractor.

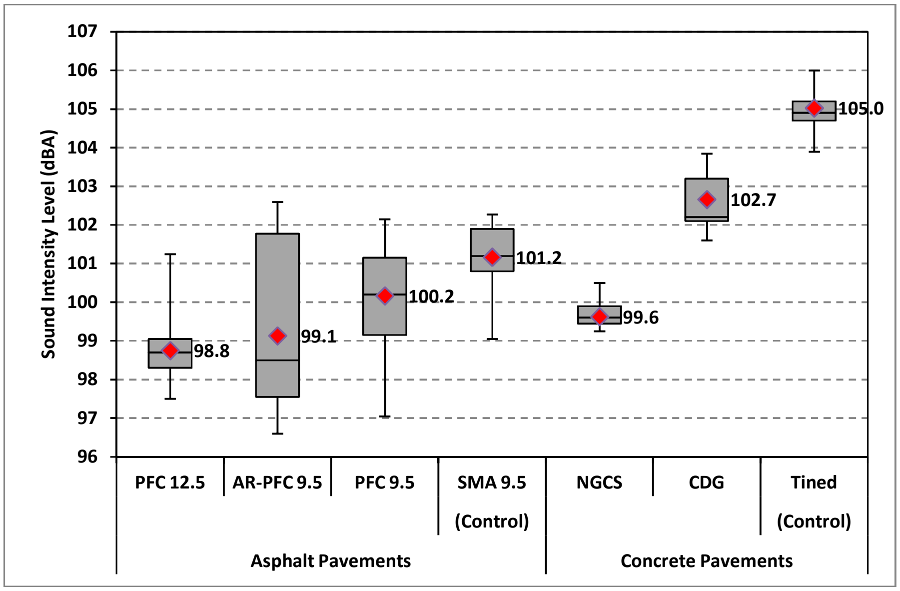

**FIGURE 3 Spring 2012 OBSI Test Results. Also see notes from Figure 2.**

***Ride Quality***

Figure 4 summarizes the overall average ride quality in terms of IRI for the asphalt materials and the NGCS. The asphalt sections averaged around 60 inches/mile of roughness with individual sections varying from as low as 40 to as high as 90 inches/mile. The highly machined NGCS technology supplied exceptionally smooth final surfaces, averaging below 30 inches/mile. However, it is important to remember that different equipment was used to conduct the testing on the concrete surfaces (a lightweight profiler with wide-footprint height sensors), so these results may not compare directly to those from the asphalt surfaces.

*VDOT's Special Provision for Rideability* sets an IRI target (100 percent pay range) of between 65 and 80 inches/mile on non-interstate roadways. These results therefore suggest acceptable to good overall smoothness. However, the pay-lots in VDOTs provision are fairly short (0.01-mile) and overall averages are not always indicative of expected pay adjustments. The demonstration projects included subsections with on-target smoothness, as well as incentive and disincentive quality work. Since the various technologies were placed at different application rates (i.e., thickness), Figure 5 normalizes the average "experience" for each material to an adjustment-per-ton basis. The control material, SMA 9.5, actually *cost* the contractor $0.26 per ton in disincentive whereas the thinner PFC mixtures resulted in significant incentive payment.

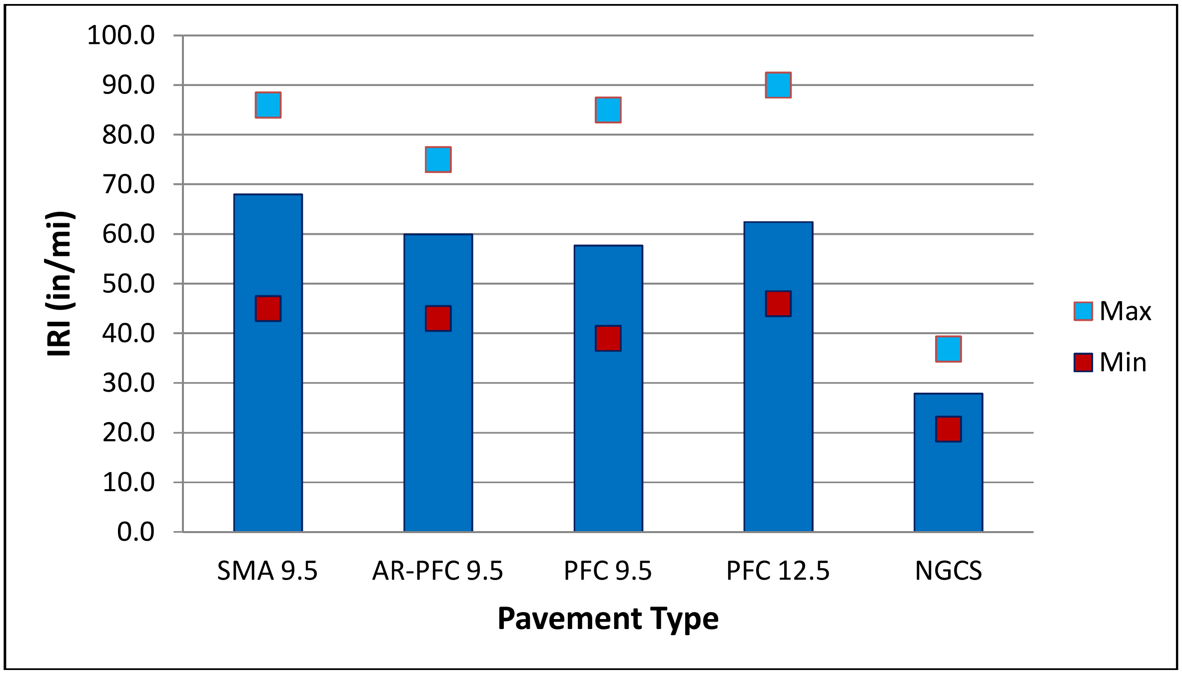

**FIGURE 4 Summary of Ride Quality by Lower-noise pavement Technology. IRI = International Roughness Index. Equipment for NGCS testing was a lightweight profiler with a wide-footprint height sensor as opposed to spot lasers for the other technologies. Profiles for CDG and Transverse Tined Concrete were not available.**

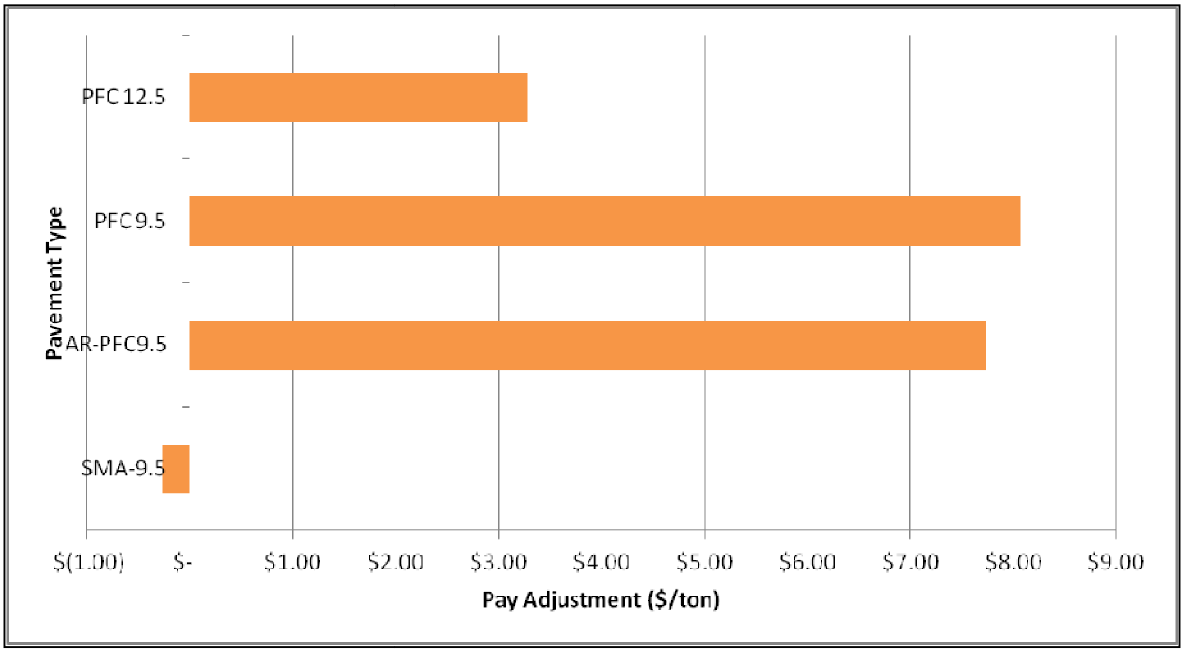

**FIGURE 5 Average pay adjustments for smoothness.**

### ***Texture***

Figure 6 summarizes the macrotexture, measured in terms of mean profile depth (MPD), for each QP technology and the control surfaces. As a “static” measurement that requires lane-closure, macrotexture tests were not conducted until spring 2012. Since traffic tends to consolidate asphalt surfaces, it is typical to see the texture decrease some in the wheel paths. A simple comparison between the lane center (Between Wheel paths [BWP]) and the right wheel paths (RWP) in Figure 6 suggests that to have been the case with the QP systems. The PFC materials had the highest loss of texture, whereas the SMA surfaces had the least. The larger comparative drop in sound intensity noted earlier for the SMA must therefore relate to something other than reduced texture.

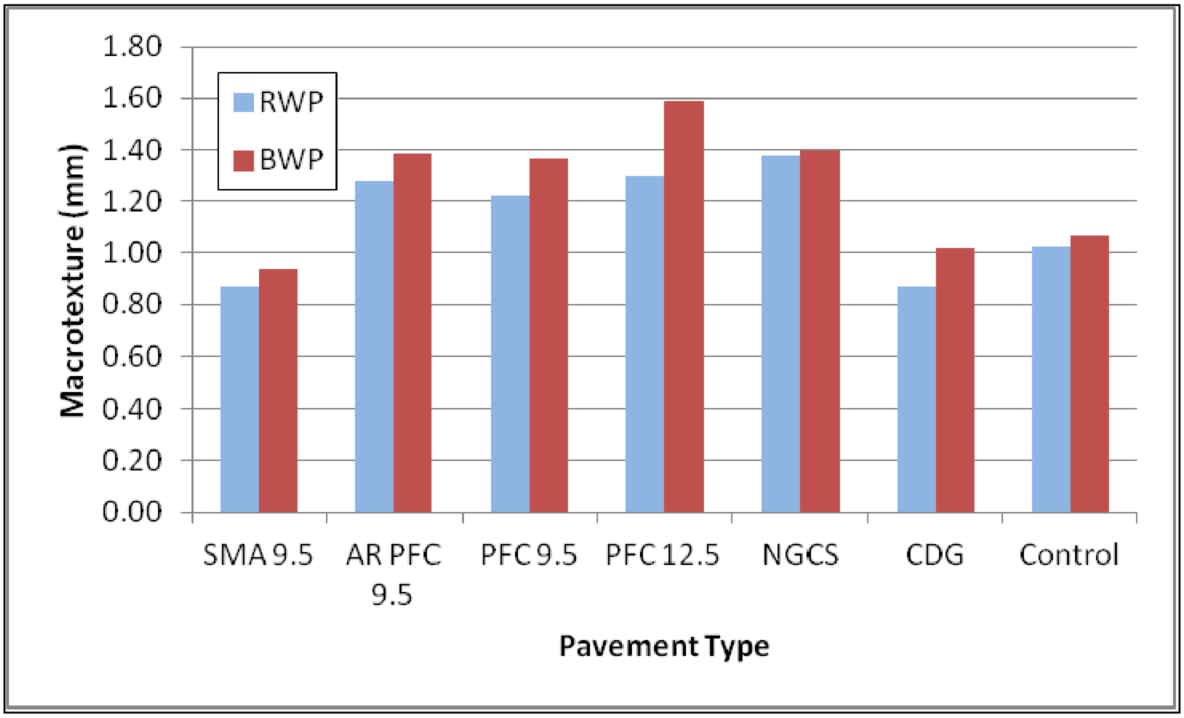

**FIGURE 6 Macrotexture (MPD) measurements – spring 2012. RWP = Right Wheel-Path; BWP = Between Wheel-Path. Note: 1mm MPD = .04 inches. CDG = conventional diamond grind, Control = mature transversely tined concrete.**

Concrete surfaces were not expected to exhibit much change, especially within this limited period of time. The conventional diamond ground (CDG) surface, the one concrete technology with a measureable average difference, is a surface that might experience some early-age texture loss as the residual grind “fins” break off under traffic.

### *Resistance to Skidding*

Figure 7 combines the results from both series of tire-pavement friction tests. The GripTester (GT) may be considered to provide a conservative upper-bounds on available friction whereas the lock-wheeled tester (LWT) represents the lower boundary. As a point of reference, VDOT has historically designated a LWT friction value of 25 to trigger an investigation into a possible tire-pavement friction problem. Virginia is also fortunate to have access to polish resistant aggregates and requires their use in surface mixes. At this point there appear to be no tire-pavement friction issues on any of the surfaces in the QP demonstration program.

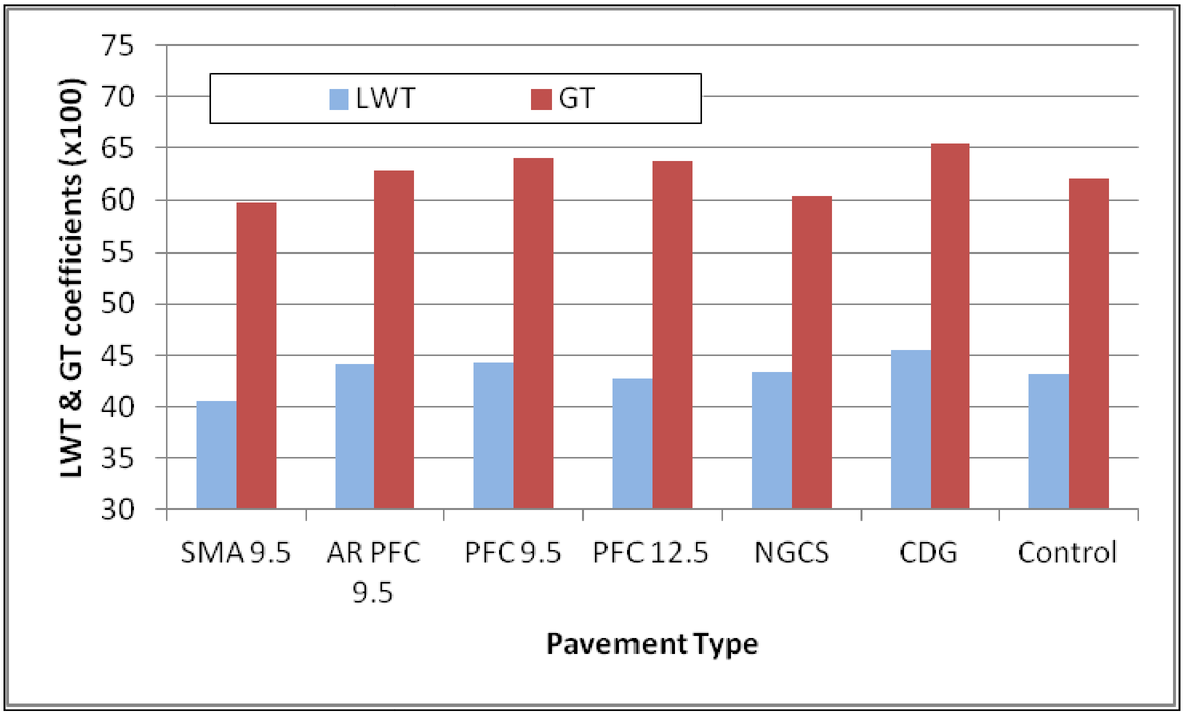

**FIGURE 7 Locked Wheel Tester (LWT) and GripTester (GT) Results -spring 2012. CDG = conventional diamond grind, Control = mature transversely tined concrete. Note: Locked wheel tests conducted at 40 mph with smooth tire – SN40S.**

***Winter Performance***

Winter 2011/2012 was intended to provide the first opportunity to gain widespread experience with the interaction of QP surfaces and Virginia's winter weather. Unfortunately, according to the National Oceanic and Atmospheric Administration *(19)*, the three month period starting December 2011 was the fourth warmest winter since records have been kept (starting in 1895). As a result, little in the way of frozen or freezing precipitation actually fell on the QP demonstration projects and there was correspondingly little feedback from the local crews with responsibility for winter maintenance.

Crews near Leesburg experienced one of the only significant snow events in late October 2011. In email correspondence from the nearby VDOT residency (Gaby Hakim, November 14, 2011), "more visible" freezing material was noted on the QP sections as distinguished from the typical pavement surfaces. The Leesburg office also noted a persistent dampness along the QP trials, but posited that some of it related to an adjacent turn lane that was not porous and therefore interrupting drainage from the porous materials.

Maintenance officials from Williamsburg provided "winter maintenance treatment" reports after two fairly minor events in mid February 2012. In neither case did crews report a difference in accumulated precipitation or necessary material or application rates with the QP versus conventional surfaces. Most importantly, as of late spring 2012 there have been no reports of an actual or perceived compromise of safety that can be attributed to the interaction of freezing weather and QP technologies.

### *Miscellaneous Observations*

Reduced splash and spray and improved wet-weather visibility was, overwhelmingly, the most commonly noted (and appreciated) property of the porous asphalt surfaces. Although the technology does not yet exist to quantify splash and spray characteristics of pavements, work at VTTI towards that objective is well underway (FHWA project DTFH61-08-R-0029). Once that capability exists it will still be very difficult to place a value on what is clearly a valued incidental property of the quiet asphalt surfaces.

## Costs and Quantities

Table 1 reports the average initial cost and total quantity for each QP technology. Since the asphalt technologies are placed at varying thicknesses and the concrete technologies simply "refinish" the existing surface, the cost figures are normalized to an average per-surface-area cost (i.e., per square yard). There are some important qualifications the reader should bear in mind when considering and comparing these costs. First, they apply to the surface material or finishing technique only. Any additional preparation (e.g., binder layers, patching, etc.) will add to this cost. Second, these projects are, by definition, demonstration projects and, therefore, not routine construction. Limited production of even conventional materials or processes will make it difficult to realize any economies of scale. That impact is exacerbated when the material or process is experimental.

**TABLE 1 Costs and Quantities: 2011 Lower-noise pavement Demonstration Technologies**

| Pavement Description | Average Cost | | Total Quantities | |
|---|---|---|---|---|
| | Per Ton ($) | Square Yard ($) | Tons | Square Yards |
| SMA 9.5 | 108.50 | 9.20 | 23,537 | 278,262 |
| AR-PFC 9.5 | 125.81 | 5.77 | 7,553 | 164,930 |
| PFC 9.5 | 116.00 | 5.32 | 10,394 | 228,020 |
| PFC 12.5 | 110.33 | 10.11 | 12,082 | 131,833 |
| Diamond Grind | N/A | 6.86 | N/A | 80,861 |
| NGCS | N/A | 10.84 | N/A | 42,434 |

While these demonstration projects use the PFC mixes as "equivalents" to the SMA, this is not a recommended operational practice. Unlike SMA, porous asphalt mixes are assumed to contribute no structural value. The designer will ultimately need to determine whether the additional function that may be provided by a PFC is worth the cost of an added layer. The effective life of this added function, something that may not be known for several years, is an important component of the whole life cost equation.

## SUMMARY

Three "quiet" asphalt and two "quiet" concrete technologies were installed in five demonstration projects in Virginia in 2011. The asphalt technologies were three porous friction course (PFC) mixes while the concrete technologies included a conventional diamond grind surface and the NGCS. As of spring 2012, the quiet asphalt technologies were *measurably* (2 dBA or less) less noisy than the control surfaces on average and *noticeably* (≥ 3 dBA) more quiet in several specific cases. The NGCS maintains a *readily noticeable* (5 dBA) noise advantage over the control concrete surfaces. Comparison to the late fall tire-pavement noise testing shows that none of the surfaces have become louder over the very mild winter.

The QP technologies exhibit a more distinct advantage over the control surfaces when it comes to achieved ride quality. The NGCS is smooth, and contractors earned incentives for ride quality with the quiet asphalt materials, especially with the materials that were placed at 1-inch thickness. Although some wheel path consolidation was evident in the texture data for the asphalt technologies, all of the QP surfaces are exhibiting excellent skid resistance and receiving consistent recognition for good wet-weather service.

## ACKNOWLEDGMENTS

This program of research is guided by the Virginia Lower-noise pavement Task Force. Ride quality and conventional friction testing was conducted by VDOT's Non-Destructive Testing Unit. Early noise testing and analysis was provided by consultants from Harris Miller Miller and Hanson, Inc. The later tire-pavement noise testing and some less conventional surface property testing (e.g., texture, continuous friction, etc.) were conducted by the Virginia Tech Transportation Institute (VTTI). Much of the data analysis was conducted by graduate researchers at Virginia Tech. Most field evaluation activities were led by Mr. Daniel Mogrovejo (Graduate Research Assistant) and Mr. William Hobbs (Engineering Technician) of VTTI, and Mr. Robert Honeywell (Engineering Technician) of VDOT.

## REFERENCES

1. Rasmussen, R.O., Bernhard, R.J., Sandberg, U., and Mun, E.P. *The Little Book of Quieter Pavements.* FHWA-IF-07. Federal Highway Administration, Washington, D.C., 2007.

2. Hanson, D., James, R., and NeSmith, C. *Tire/Pavement Noise Study*. NCAT Report 04-02. National Center for Asphalt Technology, Auburn, Ala., August 2004.

3. Cackler, E.T., Ferragut, T., and Harrington, D.S. *Evaluation of U.S. and European Concrete Pavement Noise Reduction Methods.* National Concrete Pavement Technology Center, Iowa State University, Ames, July 2006.

4. Gibbs, D., Iwasaki, R., Bernhard, R., Bledsoe, J., Carlson, D., Corbisier, C., Fults, K., Hearne, T., Jr., McMullen, K., Newcomb, D., Roberts, J., Rochat, J., Scofield, L., and Swanlund. M. *Lower-noise pavement Systems in Europe.* FHWA-PL-05-011. Federal Highway Administration, Washington, D.C., 2005. http://international.fhwa.dot.gov/quiet_pav/pl05011.pdf. Accessed February 8, 2011.

5. Arizona Department of Transportation. Welcome to ADOT'S Lower-noise pavement Pilot Program. http://www.azdot.gov/quietroads/. Accessed February 8, 2011.

6. Mallick, R. B., Kandhal, P.S., Cooley, L.A., Jr., and Watson, D.E. *Design, Construction, and Performance of New-Generation Open-Graded Friction Courses.* NCAT Report No. 2000-01. National Center for Asphalt Technology, Auburn, Ala.,2000.

7. Scofield, L. *Development of Next Generation Low Maintenance Concrete Surface.* Paper prepared for presentation at the National Conference on Preservation, Repair and Rehabilitation of Concrete Pavements, St. Louis, Missouri, April 2009.

8. AASHTO. Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method. AASHTO TP 76-12. Washington, D.C., 2011.

9. AVEC, Inc. Full OBSI System Model. Blacksburg, Va., 2012.

10. Virginia Department of Transportation. *Special Provision for Rideability*. Richmond, 2011.

11. Perera, R.W., and Kohn, S.D. *Issues in Pavement Smoothness: A Summary Report*. NCHRP Web Document 42 (Project 20-51[1]): Contractor's Final Report. March 2002. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_webdoc_42.pdf. Accessed May 1, 2012.

12. Cooley, L.A., Brumfield, J.W., Mallick, R.B., Mogawer, W.S., Partl, M., Poulikakos, L., and Hicks, G., *Construction and Maintenance Practices for Permeable Friction Courses*, NCHRP Report 640, Transportation Research Board, Washington DC, 2009.

13. Virginia Department of Transportation. *Special Provision for Porous Friction Course*. Richmond, 2011.

14. Virginia Department of Transportation. *Special Provision for Asphalt Rubber Porous Friction Course*. Richmond, 2011.

15. Virginia Department of Transportation. *Special Provision for Grinding Concrete Pavement*. Richmond, 2011.

16. Virginia Department of Transportation. *Special Provision for Grinding Next Generation Concrete Pavement Surface*. Richmond, 2011.

17. Donavan, P.R., and Lodico, D.M. *Measuring Tire-Pavement Noise at the Source.* NCHRP Report 630. Transportation Research Board of the National Academies, Washington D.C., 2009.

18. Donavan, P.R., and Lodico, D.M. *Measuring Tire-Pavement Noise at the Source: Precision and Bias Statement.* Transportation Research Board of The National Academies, 2011.

19. National Climate and Data Center. Temperature and Precipitation Rankings. http://www.ncdc.noaa.gov/temp-and-precip/ranks.php. Accessed May 3, 2012.

20. Rasmussen, R.O., Sohaney, R.C., Fick, G.J, and Cackler, E.T., *How to Design and Construct Quieter Concrete Pavements.* 10th International Conference on Concrete Pavements, Quebec City, Quebec, Canada, July 8 – 12, 2012.

21. Rasmussen, R.O., Garber, S.I., Fick, G.J, Ferragut, T.R., and Wiegand, P.D., *How to Reduce Tire-Pavement Noise: Interim Better Practices for Constructing and Texturing Concrete Pavement Surfaces*. Transportation Systems Preservation – Technical Services Program Library. http://www.tsp2.org/library-tsp2/uploads/491/cpscp-interim.pdf, Accessed November 6, 2012.