REPORT OF THE VIRGINIA
DEPARTMENT OF TRANSPORTATION

The Virginia Quiet Pavement Implementation Program Under Section 33.1-223.2:21 of the Code of Virginia - Interim Report

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

HOUSE DOCUMENT NO. 14

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RICHMOND
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COMMONWEALTH of VIRGINIA

DEPARTMENT OF TRANSPORTATION
1401 EAST BROAD STREET
RICHMOND, VIRGINIA 23219 2000

Gregory A. Whirley
Commissioner

June 30, 2012

The Honorable Robert F. McDonnell
Members of the General Assembly

Dear Ladies and Gentlemen:

Chapter 790 of the 2011 Acts of Assembly (codified as Va. Code §33.1-223.2:21) directs the Virginia Department of Transportation (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 mitigations is a consideration. The legislation requires VDOT to construct demonstration projects sufficient in number and scope to assess applicable technologies. The assessment shall include evaluation of functionality and public safety of these technologies in Virginia's climate and shall be evaluated over two full winters. VDOT is also directed to provide interim and final reports that include results of the demonstration projects, results of the use of quiet pavements 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.

This interim report describes VDOT's progress in assessing use of quiet pavement technology. It chronicles the selection of various quiet pavement technologies for study, the development and construction of demonstration projects, and the evaluation tools and analysis being used to compare performance of the alternative technologies. Three quiet asphalt and two quiet concrete technologies were installed in five demonstration projects in 2011 and this report provides interim results from testing and evaluations conducted on those demonstration projects. VDOT will continue its assessment of these demonstration projects throughout the next year and will provide a final report regarding use of and an implementation plan for quiet pavement technologies by June 30, 2013, in accord with Va. Code §33.1-223.2:21.

If you have any questions or need additional information, please contact me.

Sincerely,

Gregory A. Whirley

Gregory A. Whirley, Sr.

Attachment

cc: The Honorable Sean T. Connaughton

THE VIRGINIA QUIET PAVEMENT IMPLEMENTATION PROGRAM UNDER SECTION 33.1-223.2:21 OF THE *CODE OF VIRGINIA*

INTERIM REPORT

Virginia Center for Transportation Innovation and Research
June 2012

PREFACE

This study was conducted under the direction of the Virginia Department of Transportation (VDOT) Materials Division with guidance from the Quiet Pavement Task Force (QPTF). The QPTF includes representatives from VDOT's Materials Division, Maintenance Division, and Environmental Division; 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 includes the following individuals:

Mr. Charles A. Babish, P.E., State Materials Engineer, VDOT
Mr. Richard J. Schreck, Executive Vice President, VAA
Mr. Emmett R. Heltzel, P.E., Administrator, VDOT Maintenance Division
M. Trenton M. Clark, P.E., Director of Engineering, VAA
Mr. David T. Lee, P.E., Materials Engineer, VDOT Salem District, and Chair, VCTIR Asphalt Research Advisory Committee
Mr. Paul M. Kohler, Manager, VDOT Noise Abatement Section
Mr. Michael M. Sprinkel, P.E., Associate Director of Research, VCTIR
Mr. Kevin K. McGhee, P.E., Associate Principal Scientist, VCTIR
Mr. Edward C. Dalrymple, Jr., Vice President, Chemung Contracting Corporation
Mr. David M. Helmick, Vice President, Superior Paving Corp.
Mr. Robert R. Long, Executive Director, American Concrete Pavement Association
Del. James M. Lemunyon, Joint Commission on Transportation Accountability and Subcommittee on Quiet Pavements

This interim report was authored by Mr. Kevin K. McGhee, P.E., with contributions from Dr. Edgar de León Izeppi, Senior Research Associate, at the Virginia Tech Transportation Institute (VTTI) and Mr. Paul M. Kohler. 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 VTTI. Much of the data analysis was conducted by graduate researchers at Virginia Tech. Most field evaluation activities were carried out by Mr. Daniel Mogrovejo, Graduate Research Assistant, and Mr. William Hobbs, Engineering Technician, of VTTI, and Mr. Robert Honeywell, Engineering Technician, of VDOT. This report would not have been possible without the assistance and expertise of VCTIR staff member Linda D. Evans (Editor).

The report describes the selection of lower-noise pavement technologies (i.e., "quiet" 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 quiet 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, named the Next Generation Concrete Surface (NGCS), maintained an *obvious* (5 dB) noise advantage over the control concrete surface.

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EXECUTIVE SUMMARY

Introduction

Chapter 790 of the 2011 Virginia Acts of Assembly (*Code of Virginia* § 33.1-223.2:21; see Appendix A) provides, in part:

> The [Virginia Department of Transportation] shall expedite the development of quiet pavement technology such that applicable contract solicitations for paving shall include specifications for quiet pavement technology and other sound mitigation alternatives 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 assessment shall include evaluation of the functionality and public safety of these technologies in Virginia's climate and shall be evaluated over two full winters. The Department shall provide an interim report to the Governor and the General Assembly by June 30, 2012, and a final report by June 30, 2013. The report shall 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.

This interim report describes the selection of lower-noise pavement technologies (i.e., “quiet” 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. When comparing noise levels of QP strategies, it takes about 3 decibels (dB) of difference for the change to be “noticeable” while a 5 dB change is considered “obvious”. After one winter of service, the quiet asphalt technologies were *measurably* (2 dB or less) less noisy than the control surfaces on average and *noticeably* (≥ 3 dB) more quiet in several specific cases. The featured quiet concrete technology, named the Next Generation Concrete Surface (NGCS), maintained an *obvious* (5 dB) noise advantage over the control concrete surface. The late fall tire-pavement noise testing showed that none of the surfaces had become louder over the very mild winter.

Background

Traffic-generated noise comes from many sources. When travel speeds exceed 35 mph and the traffic stream is made up primarily of free-flowing passenger vehicles and light trucks, the predominant noise source is the tire-pavement interaction. The amount of noise generated at the tire-pavement interface is dependent on characteristics of the tire and the pavement surfaces. With regard to the traveled surface (i.e., pavement), the characteristics known to affect noise most include (in decreasing order of significance) texture, porosity, and stiffness. The contribution of each characteristic is complicated, but in most instances, a lower-noise (i.e., quiet) pavement will have a small, negative texture, a high porosity, and relatively low stiffness.

The category of materials known as open-graded or porous asphalt comes closest to having the optimum combination of properties that can deliver a quiet pavement. Use of these materials to reduce tire-pavement noise has been common in Europe since the early 1990s. Free-draining (i.e., porous) wearing surfaces offer other advantages as well, but early-generation open-graded mixes in Virginia were too often associated with premature and catastrophic material failures. Recent advancements have largely addressed the durability issues and enable designers to turn more specifically toward lower noise pavements.

The concrete pavement industry has also aggressively addressed the interaction of the tire and traditional concrete finishes. Recently developed diamond grinding and grooving techniques provide a highly uniform and lower-noise alternative for finishing existing concrete pavements.

Chapter 790 of the 2011 Virginia Acts of Assembly (*Code of Virginia* § 33.1-223.2:21; see Appendix A) directs VDOT to evaluate the installed QP technologies and provide an interim report in June 2012 and a final report in June 2013. The 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 interim report documents VDOT's progress in implementing a quiet 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. The report will be particularly focused on results from testing conducted on the 2011 series of quiet pavement demonstration projects.

Methods

Preliminary Work of Task Force

As the 2011 legislation began to take shape in the fall of 2010, VDOT and the Virginia paving industry formed the Quiet Pavement Task Force (QPTF) in an effort to address the legislation cooperatively as it became enacted into the *Code of Virginia*. As listed in the Preface, the task force includes representatives 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 worked with VCTIR to conduct a review of relevant literature (Appendix B). Further, the QPTF combined findings from the literature review with contemporary practical experience to develop a matrix of appropriate 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, the QPTF developed the material and construction specifications and helped assemble the contract documents that were used to advertise and award for construction.

Selection of Quiet Pavement Technologies

The QPTF selected three asphalt surface materials and two mechanically applied finishes to concrete pavement as candidate QP technologies for the 2011 demonstration projects. The three quiet *asphalt* materials included 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. The two lower-noise concrete technologies include conventional diamond grinding and the Next Generation Concrete Surface (NGCS), which is a diamond grind followed by a “flush-grind” operation and then a final longitudinal grooving step.

Selection of Demonstration Projects

VDOT used these five candidate QP technologies in five QP demonstration projects. 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 SR 7 Bypass in Leesburg, SR 199 west of Williamsburg, and SR 288 near Chester. The concrete sections are located on SR 76 in Richmond and I-64 near Virginia Beach. The asphalt demonstration projects each included four technologies: three experimental and one control. The concrete projects included the two QP technologies with the adjacent, existing (unground) concrete finish serving as the control.

Functional Evaluation

The noise production and mitigating character of a candidate QP material or treatment is 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 and durability. Moreover, it is important also to document when reduced noise is accompanied by improved function in other respects. For this reason, the assessment of QP technologies considered tire-pavement noise, community wayside noise, ride quality, texture, resistance to skidding, and 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. The local maintenance crews received guidance on what to expect and how to report any exceptions to winter maintenance practices for QP surfaces during Virginia’s winter weather.

Preliminary Findings and Discussion

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], distributed in 2007 by the FHWA, describes the fundamentals of noise and its measurement, and includes some helpful rules of thumb. 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 “obvious” to most people and a 10 decibel difference is equivalent to a doubling (or halving) of the sound level.

As mentioned previously, as of spring 2012, the quiet asphalt technologies were *measurably* less noisy than the control surfaces on average and *noticeably* quieter in several specific cases (i.e., rubberized porous friction course near Williamsburg, coarser porous friction course in Leesburg). The NGCS maintained an *obvious* noise advantage over the control concrete surface. The late fall tire-pavement noise testing showed that none of the surfaces had become louder over the very mild winter. On the contrary, the sound intensity levels appeared to have dropped by varying amounts. A comparatively larger sound level intensity drop for the control surfaces makes it more difficult for the human ear to discern a difference between the QP technologies and the control surface on the asphalt projects.

The QP technologies have a more distinct advantage over the control surfaces with regard to ride quality. The NGCS is smooth, and contractors earned smoothness incentives with the quiet asphalt materials, including the materials that were placed at thinner (1-inch) application rates. Although some wheel path consolidation was evident from the texture data for the asphalt technologies, all of the QP surfaces have excellent skid resistance and are receiving consistent recognition for wet-weather service.

Costs and Quantities

Table ES1 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. Reliable cost-comparison analyses will require additional examination of the life cycle costs associated with establishing and maintaining a lower surface noise level attributable to, and will require experience with full-production use of, these technologies. Even then the analysis will need to respond to project-specific characteristics.

Table ES1. Costs and Quantities: 2011 Quiet Pavement Technologies.

Pavement Description	**Average Cost**		**Total Quantities**	
	Per Ton ($)	**Square Yard ($)**	**Tons**	**Square Yards**
SMA 9.5 (Asphalt Control)	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

Next Steps

Among the plans for 2012 activities include two trial sections at the accelerated test track at the National Center for Asphalt Technology (NCAT). The raw materials from the most promising 2011 demonstration technologies will be sent to Auburn, blended with standard materials to produce “Virginia” QP technologies, and placed in the path of accelerated truck loads.

In addition to the NCAT sections, VDOT and the asphalt industry plan to install a 2-inch rubberized mix in the Northern Virginia District and a rubberized stone-matrix asphalt trial in the Culpeper and Northern Virginia districts.

The research team will continue to monitor the 2011 demonstration projects, as well as parallel activities around the United States and elsewhere in the world. The research teams will also examine the various factors impacting the costs associated with use of these technologies, factors such as life cycles, both as to durability as well as noise reduction, and replacement frequencies necessary to establish and maintain any lower surface noise levels attributable to these technologies. The quantifiable performance characteristics of the 2011 technologies will be incorporated into the Virginia selection and use policy that will come with the 2013 final report. As is nearly always the case, the local experience with the actual materials (quantifiable or not) will exert the most influence over the practical impact of the formal policy. It is important to not under-value the importance of the 2011 demonstration projects.

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 factors into the overall noise picture 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, openness or porosity, and stiffness. 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 openness or porosity, and relatively low stiffness.

The research program of the Virginia Department of Transportation (VDOT) has been exploring lower-noise pavements since 2004. This early work involved participation in a multi-state survey by the National Center for Asphalt Technology (NCAT) 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. By the early 2000s, smaller-stone open-graded and rubberized wearing course mixes were internationally recognized as lower-noise pavements.[3, 4] The absence of OGFC mixes in Virginia was not an oversight: they simply did not exist. The older-generation “popcorn” or OGFC mixes were prone to drain-down problems during transport and placement. Drain-down, the tendency for hot liquid asphalt to settle out of the body of the mix, 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 aggressively to explore finishing techniques for concrete pavements that would reduce tire-pavement noise production.[5] Conventional diamond ground concrete and longitudinal tining/grooving were recognized to be less noisy than the Virginia-typical transversely tined finish, although perhaps not as efficient at removing water from the pavement surface. Nonetheless, the industry was still working on a finishing technique that would consistently mute the tire-pavement interaction using more refined grinding and longitudinal texture.

A “New Generation” of Mixes and Finishes

Asphalt

By the late 1990s, other states and other countries that had not abandoned the use of OGFC mixes 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 even higher-porosity OGFC mixes are now often referred to as porous friction course (PFC) mixes.

In 2008, Virginia installed the first OGFC/PFC in at least two decades.[7] This trial installation was designed not only to gain experience with the new generation material but also to examine the considerable functional benefits that had been documented by so many (see Appendix B). After 31/2 years of service (and four winters), the trial material is performing well and continues to deliver excellent ride quality and skid resistance. Although by no means a “noisy” surface, April 2012 testing found it to be comparable to the neighboring dense-graded mix in terms of tire-pavement noise production (Kevin McGhee and Edgar de León Izeppi, unpublished data).

Concrete

Work in 2005 at Purdue University sought to determine how characteristics of concrete pavement finishes impacted tire-pavement noise.[8] Most of that research focused on diamond ground surfaces and determined that the predominant factor in noise generation was the resulting fin[1] profile, or more specifically, the variability in that profile. The lowest noise textures as determined through laboratory tests were constructed using actual diamond grinding equipment and follow-up testing confirmed them to be 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 “quiet” concrete pavement finish.

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[1] The thin ridge of concrete that remains following grinding with diamond-impregnated blades. The width of the ridge is controlled by spacers that are placed between the blades, which (stacked together) form the grinding “drum”.

A Quiet Pavement Initiative

The 2011 Session of the Virginia General Assembly brought a new focus to quiet pavement. In particular, Chapter 790 of the 2011 Virginia Acts of Assembly (*Code of Virginia* § 33.1-223.2:21; see Appendix A) 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 report documents VDOT's progress in implementing a quiet 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 interim report is particularly focused on results of testing conducted on the 2011 series of "quiet" pavement (QP) demonstration projects.

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 Quiet 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 worked with VCTIR to conduct a review of relevant literature (Appendix B). The QPTF combined findings from the literature review with contemporary practical experience to develop a matrix of appropriate 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 monitoring of one technology could be easily isolated from another.

Functional Evaluation

The noise production and mitigating 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 also to document when reduced noise is accompanied by improved function in other respects. For this reason, the assessment of QP technologies considered tire-pavement noise, community wayside 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.[9] The testing was conducted by the Virginia Tech Transportation Institute (VTTI) using equipment (Figure 2) fabricated by Acoustical and Vibrations Engineering Consultants (AVEC), Inc. in Blacksburg.[10] A detailed description of the equipment, software, and test procedures is provided in Appendix C.

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.

Figure 2. Virginia Tech Transportation Institute OBSI system.

Community Wayside Noise

To obtain an understanding of the effect QP may have on the adjacent communities; the evaluation of the demonstration technologies also included a modified wayside noise measurement program. This program included two sets of noise measurements: "before" measurements with the existing roadways surfaces and "after" measurements with new QP and "control" roadway surfaces. This approach allowed for direct comparisons of traffic noise levels between the new and original roadways as well as site-normalized relative comparisons between the quiet pavement and control roadway test section noise levels.

Wayside noise measurements were conducted in each roadway test section for a period of 30 minutes for the short-term monitoring and for a period of 24 hours during the long-term measurements. The short-term data collection procedure involved measurements of individual 1-minute equivalent sound levels (Leq), so that periods including events that were not representative of the ambient noise environment or not traffic-related could be logged, and then later separated out and excluded. Traffic classification counts, which included automobiles, medium trucks, and heavy trucks, were also conducted simultaneously with the short-term noise measurements.

In addition to the short-term measurements, one long-term noise measurement was made in each assessment area for a continuous 24-hour period. These measurements were made at or near the local roadway right-of-way line and adjacent to the closest and/or least-shielded residential neighborhood in each study area.

The noise monitoring equipment included Larson Davis Model 870 (ANSI Type I, "Precision") integrating sound level meters and accessories kits. Each kit includes a microphone, a pre-amplifier, a microphone stand, a windscreen and an acoustic calibrator, along with gel-cell batteries. All of the noise measurement instrumentation has current calibration traceable to the U.S. National Institute of Standards and Technology (NIST).

Ride Quality

Among the special provisions employed to construct the asphalt demonstration projects was *VDOT's Special Provision for Rideability*.[11] The special provision applies Virginia Test Method (VTM) 106 to measure wheel path elevation profiles from which a standard index of ride quality is produced. This standard index, the International Roughness Index (IRI), is generated using the American Society for Testing and Materials (ASTM) Standard Practice E 1926. Higher values of IRI suggest 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 for smoothness.

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 incorporated wheel path elevation profiles and summarized ride quality in terms of the IRI. However, the specification required 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.[12]

The special provision for smoothness (asphalt projects) and the specification used to construct the quiet concrete system require profile measurement of the newly constructed surface. At this point, ride quality assessments only reflect new-condition smoothness.

Texture and Resistance to Skidding

Texture and friction properties were measured with the Circular Track Meter (CTMeter) (ASTM E2157); the Dynamic Friction Tester (DFT) (ASTM E1911); the GripTester (GT) (ASTM E2340); and a lock-wheel tester (LWT) (ASTM E274). These devices are shown in Figure 2 and are described in the following sections. All friction and texture measurements were made in early spring 2012.

(a) Circular Track Meter (CTMeter) **(b) Dynamic Friction Tester (DFT)**

(c) GripTester (GT) **(d) Locked Wheel Tester (LWT)**

Figure 2. Devices for Collecting Texture and Friction Data: (a) CTMeter for measuring pavement macrotexture properties; (b) DFT for measuring microtexture; (c) GT for measuring Continuous Friction; (d) LWT for measuring General Resistance to Skidding.

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 in size. In addition to being the surface property that most profoundly affects tire-pavement noise, macrotexture influences surface drain-ability and is therefore important to 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.

For this study, 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. Since measurement requires at least temporary lane closure, only travel lanes were tested to minimize inconvenience to the traveling public.

Dynamic Friction Tester (ASTM E1911)

The DFT was designed to focus on microtexture. Microtexture, which is characterized by features less than 0.02-inches in length, is the most essential contributor to available skid resistance. The DFT measures friction by spinning a horizontal disk fitted with three spring-loaded rubber sliders that contact the wetted pavement surface. This causes the disk's rotational speed to decrease due to the friction generated between the sliders and the paved surface. A water supply unit delivers water to the surface being tested. The torque generated by the sliding is measured during the spin down and then used to calculate the friction as a function of speed. This device continuously measures the dynamic friction of the pavement, and the results are typically recorded at speeds of 12, 25, 37, and 50 mph.

The DFT is designed to measure the same circular track that is measured by the CTMeter. For the spring 2012 evaluation, a DFT test was conducted for every location at which a CTMeter test was conducted.

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 outside wheel path friction is recorded (see Figure 2c).

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.

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. For this reason, an emphasis area of the evaluation program was winter performance. 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 for Maintenance and Observation" (Appendix D). 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

Candidate Quiet 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), which is provided in Appendix E. The rubber-modified mix complied with the requirements of *VDOT's Special Provision for Asphalt Rubber Porous Friction Course* (AR-PFC), which is provided in Appendix F. 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. 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), which is a diamond grind followed by a "flush-grind" operation and then a final longitudinal grooving step. The conventional grind surface was achieved using *VDOT's Special Provision for Grinding Concrete Pavement* – Appendix G. The NGCS used the newly developed *Special Provision for Grinding Next Generation Concrete Pavement Surface* – Appendix H.

Demonstration Projects

VDOT used these five candidate QP technologies in five QP demonstration projects in 2011 (see Figure 3). 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 SR 76 in Richmond. Appendix I provides a more detailed location map for each project, as well as the limits of each QP technology within the demonstration projects.

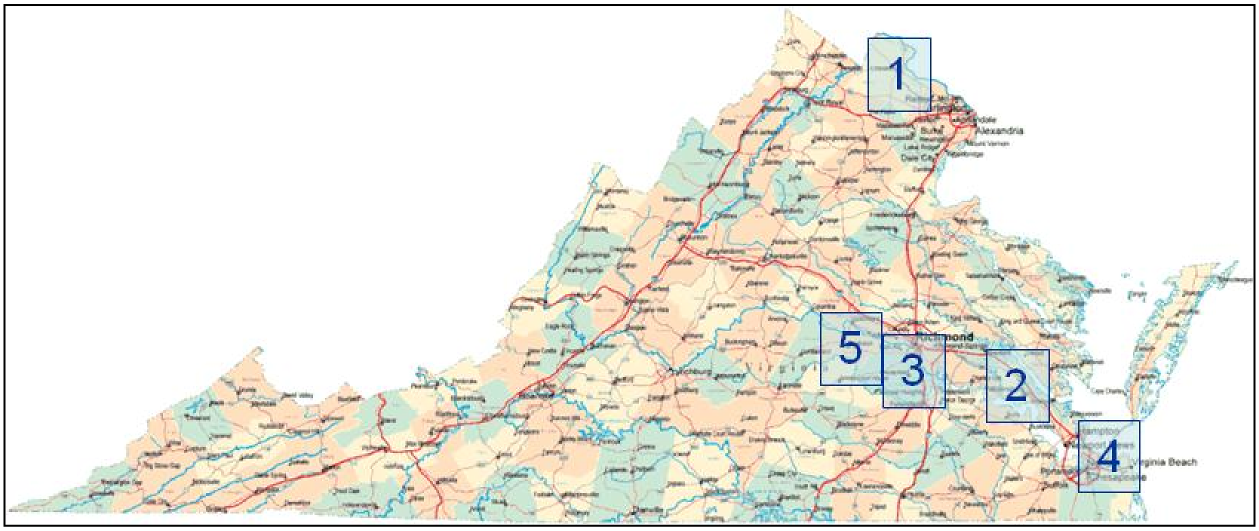

Figure 3. Locations for 2011 Quiet Pavement Demonstration Projects. 1 = State Route 7 Leesburg; 2 = State Route 199 Williamsburg; 3 = State Route 288 Chester; 4 = Interstate 64 Chesapeake; 5 = State Route 76 Richmond.

Asphalt

The asphalt demonstration projects each included four technologies: three experimental and one control. Figure 4 is a plan view of a typical quiet asphalt project. 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).

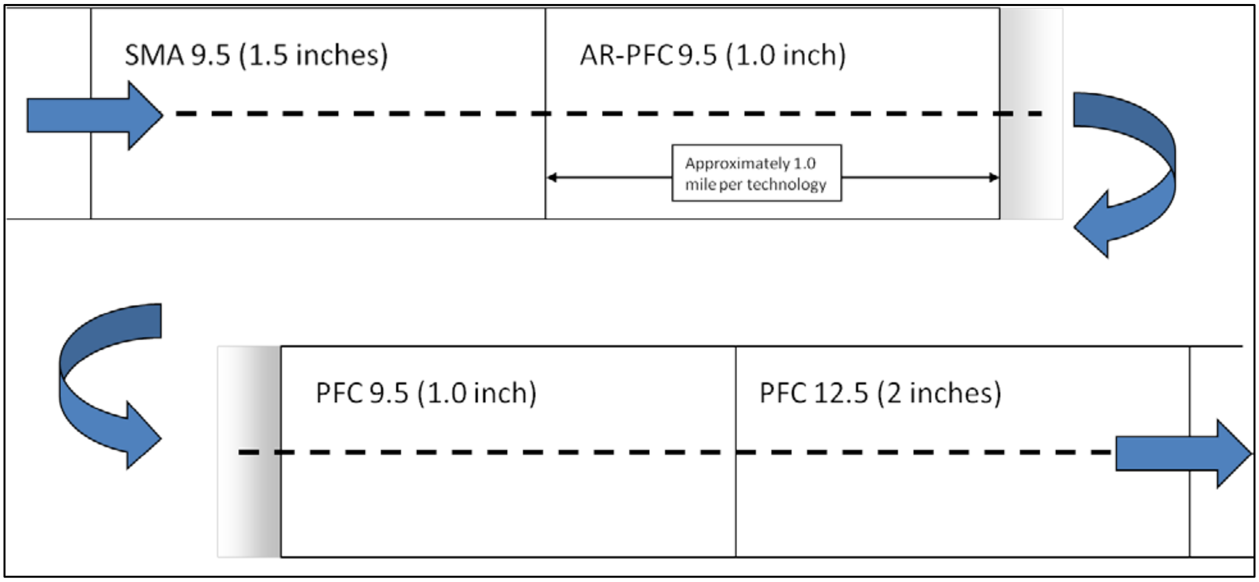

Figure 4. Plan View of Quiet Asphalt Demonstration Projects.

It was important to establish a sound and uniform construction platform upon which to place the four asphalt materials. The specific approach was dictated by existing conditions and therefore varied slightly at each of the three project sites. Figure 5 depicts the designed cross-section when the underlying material was an asphalt-based design. The top cross-section represents the approach taken when new asphalt layers were established as part of the project before the surface materials were placed. The lower cross-section represents the approach taken when the existing pavement was deemed to be sufficient to support the new wearing surface without structural improvement. When the original material was concrete, two additional layers of an intermediate asphalt mix (IM-19.0) were used to further isolate the eventual surface materials from the comparatively rigid concrete base. That cross-section is illustrated in Figure 6.

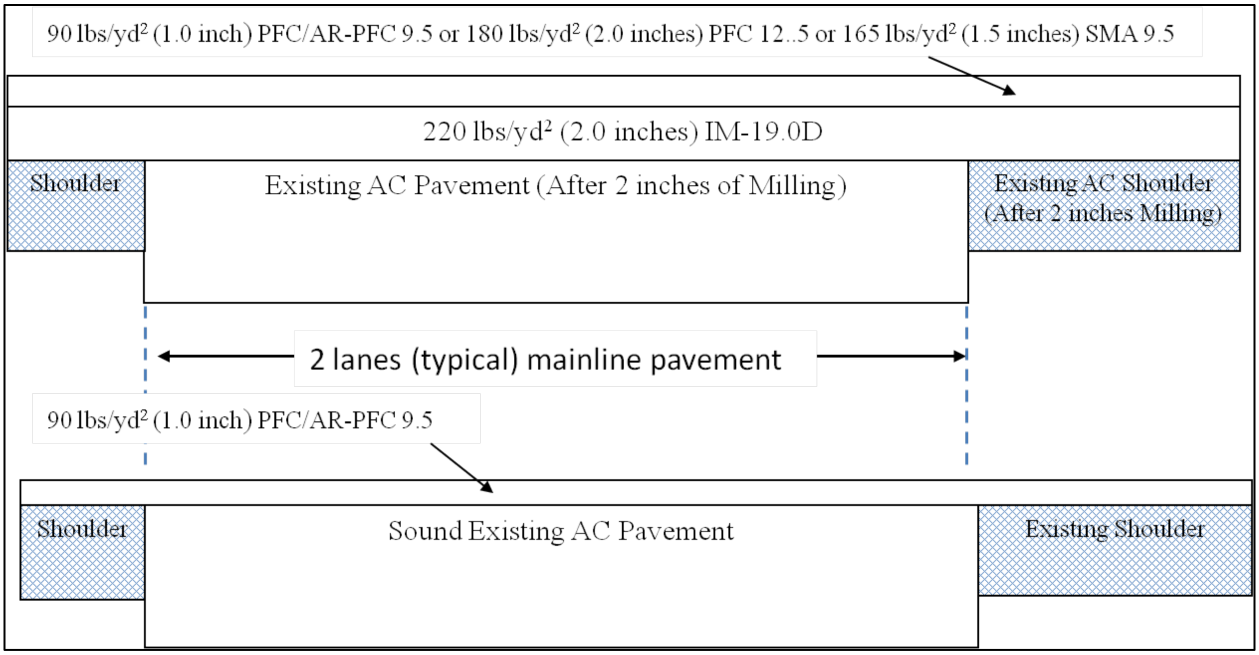

Figure 5. Typical Cross-sections of Pavement Structure with Asphalt Base: Top, QP Demonstration Projects 1 and 2; Bottom, QP Demonstration Project 1, only.

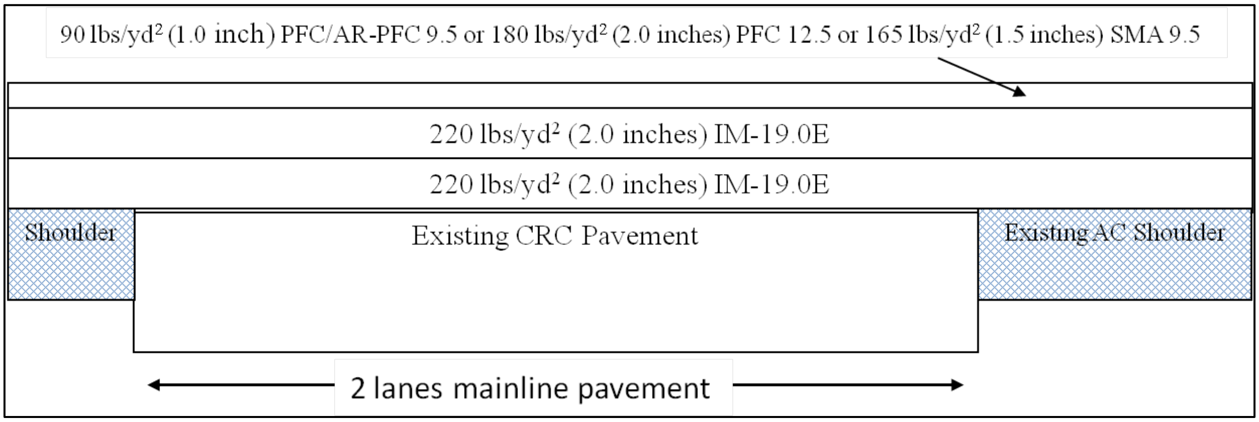

Figure 6. Cross-section of pavement structure with a Continuously Reinforced Concrete (CRC) Base: QP Demonstration Project 3.

Concrete

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. Figure 7 provides a plan view of a typical quiet concrete project. The control surface was the existing transversely tined texture as per VDOT's standard specifications.

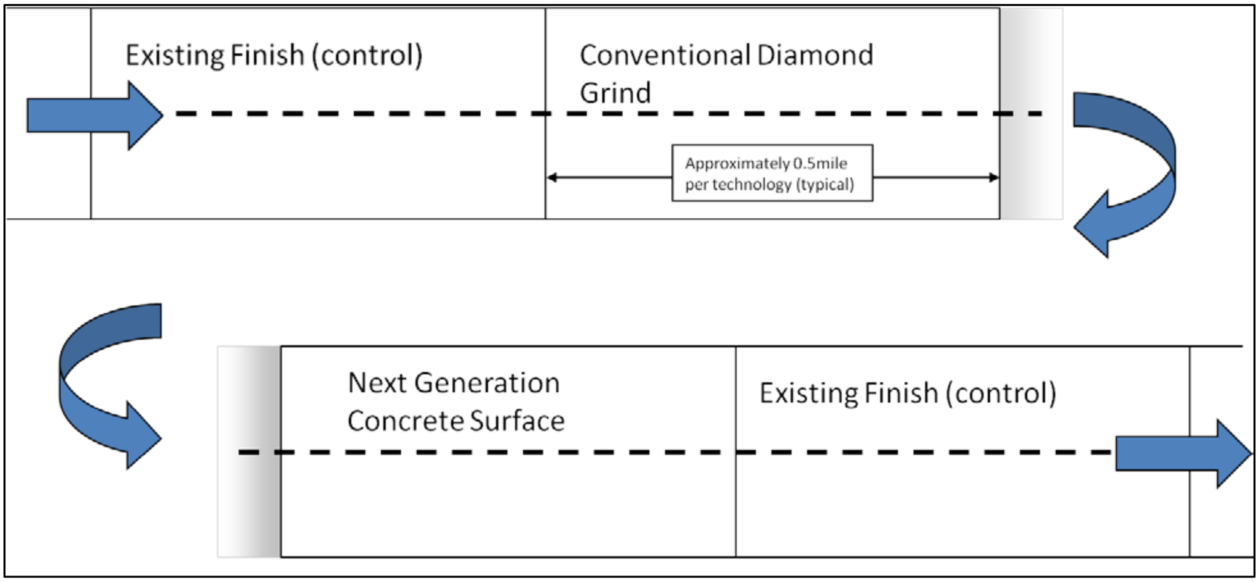

Figure 7. Plan View of Quiet Concrete Demonstration Project.

Functional Evaluation

Tire-Pavement Noise

As of May 2012, a tire-pavement noise survey has been conducted twice 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. 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 “obvious” to most people and a 10 decibel difference is equivalent to a doubling (or halving) of the sound level.

Table 1 summarizes the first series of measurements for the five demonstration projects. Figure 8 provides the average OBSI value and the minimum and maximum intensity levels for each technology. The PFC 12.5 had the lowest overall average intensity level at 99.3 dBA. However, the single most “quiet” new surface reading, 97.5 dBA, came from an AR-PFC 9.5 section in Williamsburg. The NGCS was notable for its consistency, as there was but 0.3 dBA difference between the highest and lowest measured intensity levels.

Table 3. Average Overall Intensity Level (dBA) for Late Fall 2011

SR 199

Section		East	West
1	SMA 9.5	101.5	102.7
2	AR-PFC 9.5	98.2	97.5
3	PFC 9.5	101.3	98.8
4	PFC 12.5	99.6	101.3
5	SMA 9.5	100.8	103.0

SR 288

Section		North	South
1	SMA 9.5	103.0	103.4
2	AR-PFC 9.5	98.8	99.3
3	PFC 9.5	99.8	100.9
4	PFC 12.5	99.7	98.4
5	SMA 9.5	103.1	102.1

I-64

Section		East	West
1	NGCS	100.6	100.5
2	CDG	104.4	102.8
3	Transversely Tined PCCP	105.0	106.5

SR 76

Section		East	West
1	NGCS	100.5	100.3
2	CDG	103.3	103.7
3	Transversely Tined PCCP	105.9	105.8

SR 7

Section		East	West
1	SMA 9.5	102.6	102.8
2	AR-PFC 9.5	102.8	102.1
3	PFC 9.5	101.6	102.8
4	PFC 12.5	99.1	97.7

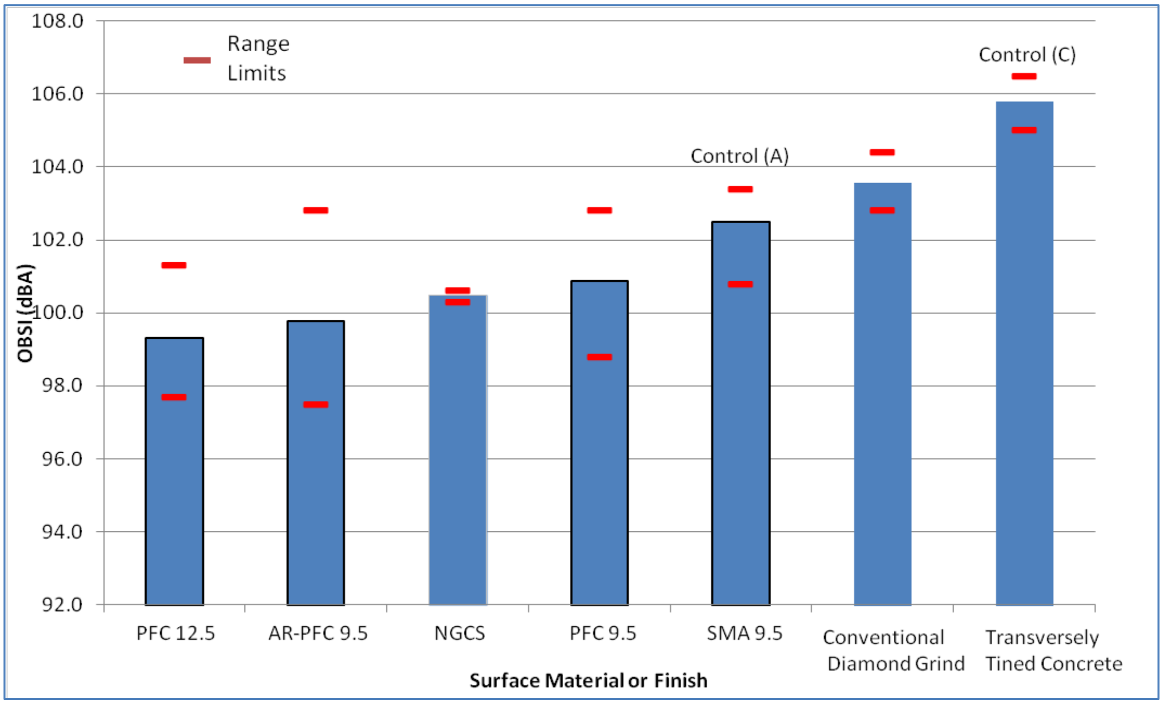

Figure 8. Average and Range of Variability for All On-Board Sound Intensity (OBSI) Measurements for Late Fall 2011.

Table 2 reports the noise measurements made in April 2012, and Figure 9 adds the spring results to the initial averages shown in Figure 8. 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, 0.5 dBA, while the SMA surfaces dropped almost 1.5 dBA. The comparative ranking 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[13, 14]).

Table 4. Average Overall Intensity Level (dBA) for Spring 2012

SR 199			
	Section	**East**	**West**
1	SMA 9.5	101.2	100.1
2	AR-PFC 9.5	97.5	96.6
3	PFC 9.5	101.6	97.9
4	PFC 12.5	98.6	100.5
5	SMA 9.5	99.1	101.3

SR 288			
	Section	**North**	**South**
1	SMA 9.5	102	102.2
2	AR-PFC 9.5	98	98.9
3	PFC 9.5	99.1	100
4	PFC 12.5	99.2	98.4
5	SMA 9.5	102.1	100.4

I 64			
	Section	**East**	**West**
1	NGCS	99.9	99.8
2	CDG	103.7	103
3	Transversely Tined PCCP	104.7	106

SR 76			
	Section	**East**	**West**
1	NGCS	99.6	99.3
2	CDG	102.1	102.2
3	Transversely Tined PCCP	104.9	104.7

SR 7			
	Section	**East**	**West**
1	SMA 9.5	101.5	101.4
2	AR-PFC 9.5	102.1	101.8
3	PFC 9.5	101	102.4
4	PFC 12.5	98.8	97.4

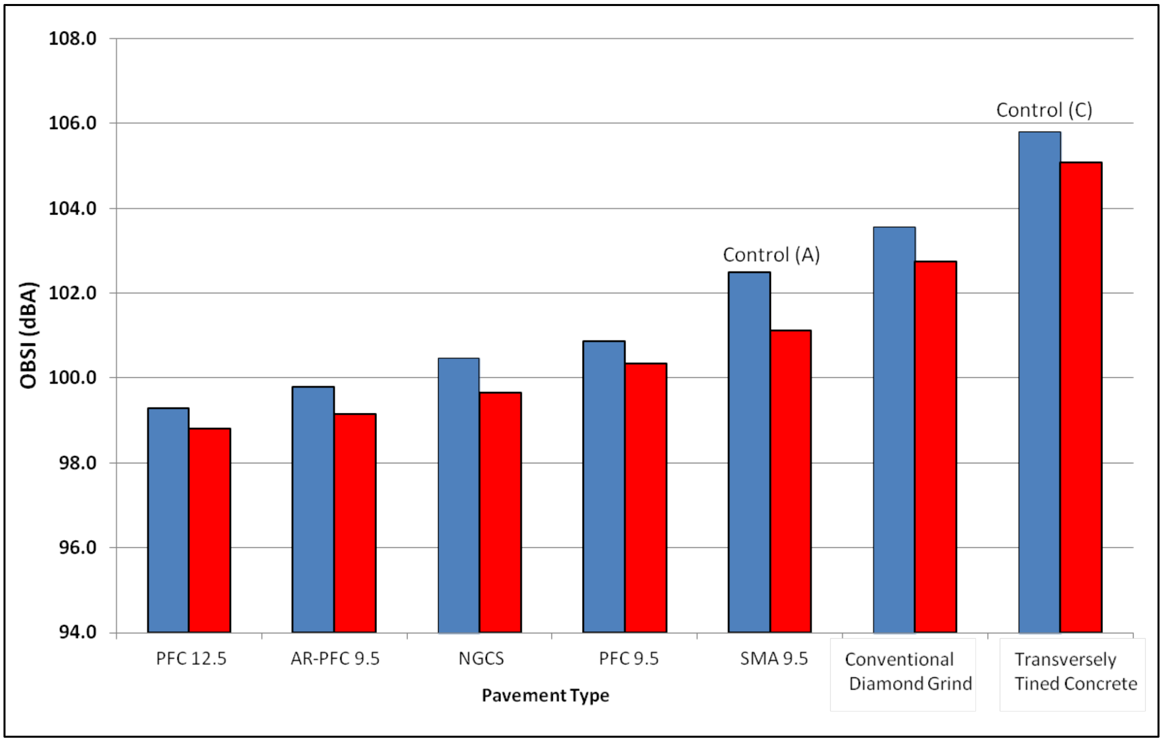

Figure 9. Average On-Board Sound Intensity(OBSI) Measurements: Comparison of Late Winter 2011 (left bar in bar pairs) and Spring 2012 (right bar in bar pairs).

Specific meteorological, pavement, and tire condition are provided in Appendix J. The appendix also includes the total distribution of OBSI values for the five candidate QP technologies and the respective control surfaces, as well as the detailed intensity level data that include one-third octave bands from 400 to 5,000 Hz.

Community Wayside Noise

The short-term wayside noise measurement locations, dates, time periods and results are presented in the Wayside Noise Study for VDOT/VCTIR Quieter Pavement Pilot Project technical memorandum,[15] which is available upon request from the authors. Unfortunately, construction activities precluded initial wayside testing on the Route 76 project and therefore eliminated it from the test matrix.

In order to compensate for the differences in the before and after traffic volumes, the traffic counted during the short-term noise measurements was used as a modeling input to the Federal Highway Administration (FHWA) Traffic Noise Model (TNM) to generate sound level normalization factors. A simplified, yet representative TNM of each roadway test section in each assessment area was created using appropriate roadway lengths, widths, lane separations, and elevations as well as the correct receiver setbacks and elevations. Intervening terrain in the roadway median was also included for Sections 3 and 4 in Richmond, and a median jersey barrier was included for Section 2 in Virginia Beach.

Each TNMwas run twice, once with the before traffic data input and then again with the after traffic data. The relative difference in the two computed sound levels was used to determine the appropriate normalization factor for each roadway test section. These values are shown in Table 3 and were used to improve the comparability of the before and after short-term wayside noise measurement results.

The application of QP technologies resulted in reduced traffic-normalized wayside noise levels of up to 11 decibels as compared with the original roadway surfaces. Comparisons of traffic-normalized noise levels in the QP and corresponding control roadway test sections indicate that the QP sections are generally 2 to 5 decibels quieter as outlined in Table 3.

Table 3. Normalized Short-Term Wayside Noise Measurements

VDOT District	Roadway	Pavement Description	Date	Time (24-Hour)	Measured Leq (dBA)	Traffic Normalization Factor (dBA)	Adjusted Leq (dBA)	After-Before Difference	Quiet Pavement Control Difference (dBA)
Northern Virginia	Route 7	SMA 9.5[1]	6/28/11 12/8/11	15:10 – 15:40 14:55 – 15:25	72.2 73.5	- - 0.3	71.2 73.8	2.6	- -
		AR-PFC 9.5[2]	6/28/11 12/8/11	13:25 – 13:55 13:30 – 14:00	73.9 73.1	- 0.7	73.9 73.8	-0.1	-2.7
		PFC 9.5[3]	6/28/11 12/8/11	12:10 – 12:40 11:55 – 12:25	72.4 70.9	- - 1.3	72.4 72.2	-0.2	-2.8
		PFC 12.5[4]	6/28/11 12/8/11	11:05 – 11:35 10:45 – 11:15	72.9 67.3	- - 0.7	72.9 68.0	-4.9	-7.5
Richmond	Route 288	AR-PFC 9.5[2]	7/6/11 12/2/11	13:57 – 14:25 14:05 – 14:35	79.2 69.9	- - -1.2	79.2 68.7	-10.5	-4.6
		PFC 9.5[3]	7/6/11 12/2/11	12:55 – 13:25 13:00 – 13:30	78.2 69.8	- - -0.1	78.2 69.7	-8.5	-2.6
		PFC 12.5[4]	7/6/11 12/2/11	11:45 – 12:15 11:50 – 12:20	77.3 67.8	- - -0.6	77.3 67.2	-10.1	-4.1
		SMA 9.5[1]	7/6/11 12/2/11	10:25 – 10:55 10:30 – 11:00	77.3 71.5	- - -0.2	77.3 71.3	-5.9	- -
Hampton Roads	Route 199	AR-PFC 9.5[2]	6/30/11 12/1/11	16:10 – 16:40 14:05 – 14:35	70.4 65.8	- - -0.1	70.4 65.7	-4.7	-3.2
		PFC 9.5[3]	6/30/11 12/1/11	14:56 – 15:26 13:00 – 13:30	72.1 66.3	- - 0.4	72.1 66.7	-5.4	-3.9
		PFC 12.5[4]	6/30/11 12/1/11	13:30 – 14:00 11:45 – 12:15	73.8 68.0	- - 0.1	73.8 68.1	-5.7	-4.2
		SMA 9.5[1]	6/30/11 12/1/11	12:05 – 12:35 10:30 – 11:00	73.5 71.9	- - 0.1	73.5 72.0	-1.5	- -
Hampton Roads	I-64	NGCS[5]	6/29/11 12/9/11	12:30 – 13:00 10:05 – 10:35	80.9 77.6	- - -0.6	80.9 77.0	-3.9	
		Diamond Grind[6]	6/29/11 12/9/11	11:10 – 11:40 11:20 – 11:50	81.2 78.8	- - 0.2	81.2 79.0	-2.2	

[1] Control.
[2] Quiet Pavement Technology 1.
[3] Quiet Pavement Technology 2.
[4] Quiet Pavement Technology 3.
[5] Quiet Pavement Technology 4.
[6] Quiet Pavement Technology 5.
Leq = equivalent (energy-average) sound level.

Ride Quality

Figure 10 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. 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.

As discussed earlier the asphalt projects were subject to *VDOT's Special Provision for Rideability*, which sets an IRI target (100 percent pay range) of between 65 and 80 inches/mile on non-interstate roadways. The results suggest acceptable to good overall smoothness. However, the VDOT provision is applied on a 0.01-mile (52.8-foot) basis 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 11 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 larger bonuses. It should be noted that SMA is subject to payment adjustments for insufficient compaction. Generally speaking, the short sections and frequent material changes present a considerable challenge to the best paving crews.

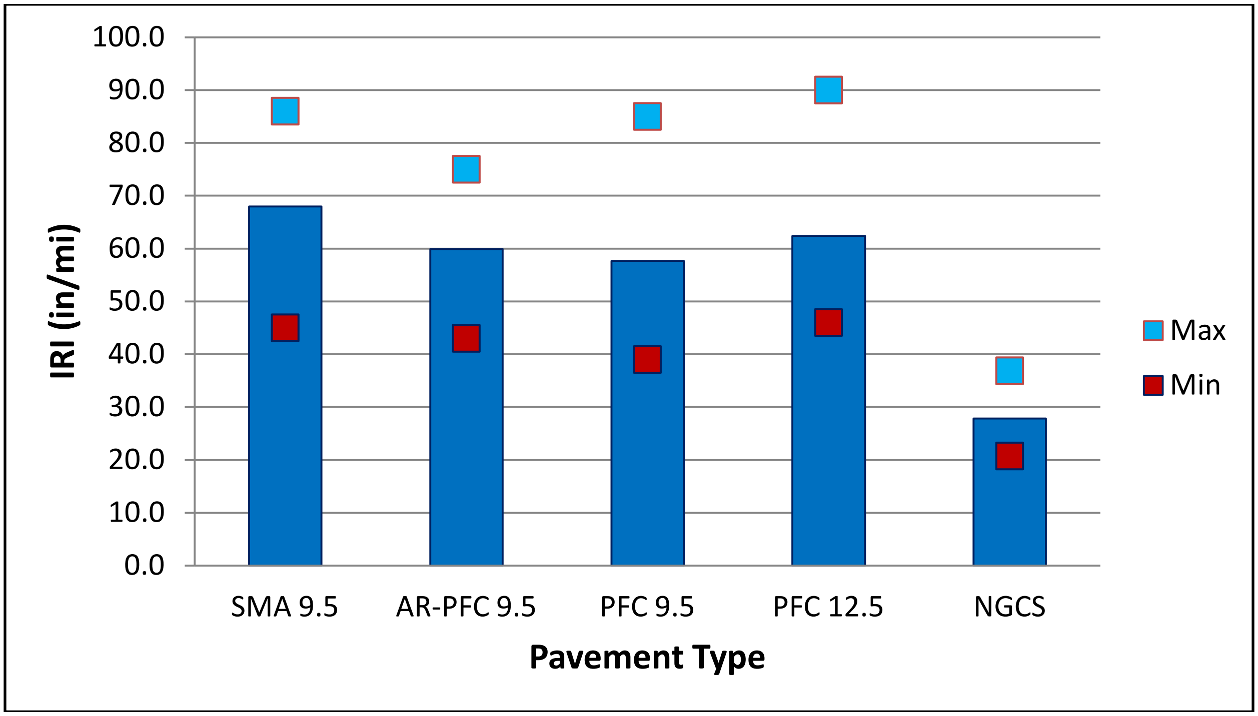

Figure 10. Summary of Ride Quality by Quiet Pavement Technology. IRI = International Roughness Index. Equipment for NGCS testing was a lightweight profiler with a wide-footprint height sensor as opposed to spot lasers for the other technologies.

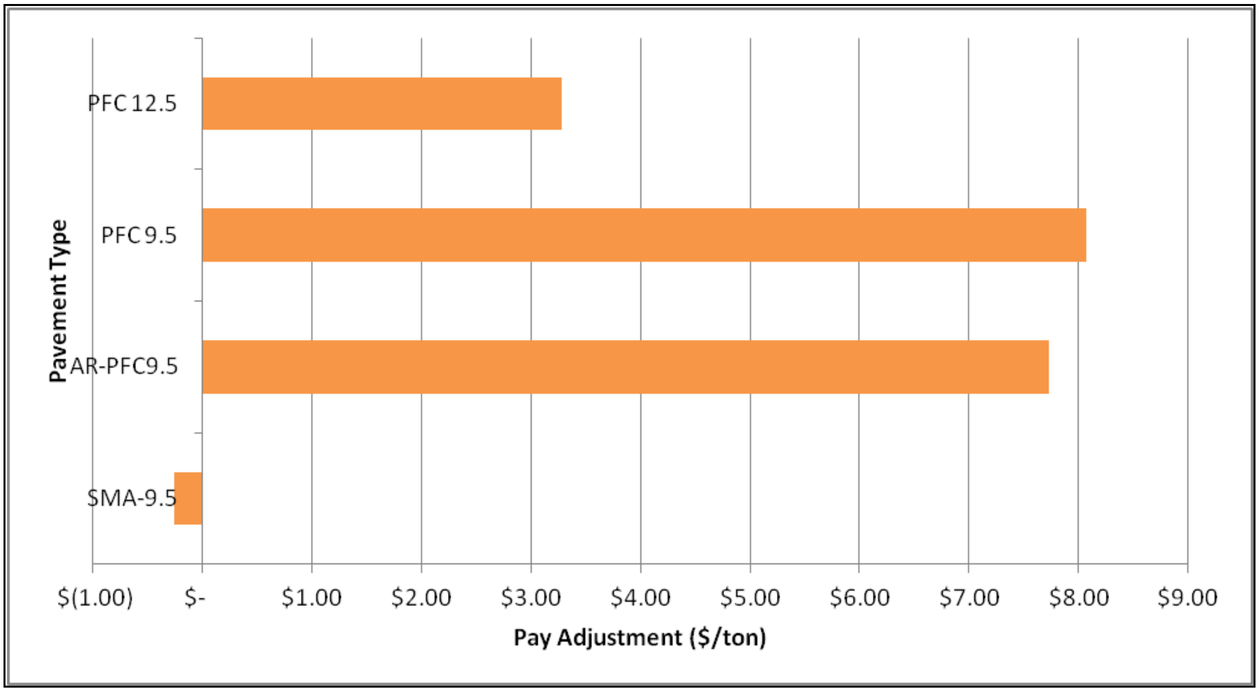

Figure 11. Average pay adjustments for smoothness.

Texture

Macrotexture

Figure 12 summarizes the macrotexture, measured in terms of mean profile depth (MPD), for each QP technology and the control surfaces. As part of a series of “static” measurements that require 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 12 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. This is at odds with the sound intensity changes that were noted earlier - a larger reduction in average tire-pavement noise occurred with the SMA surfaces so a larger loss of texture might have been expected.

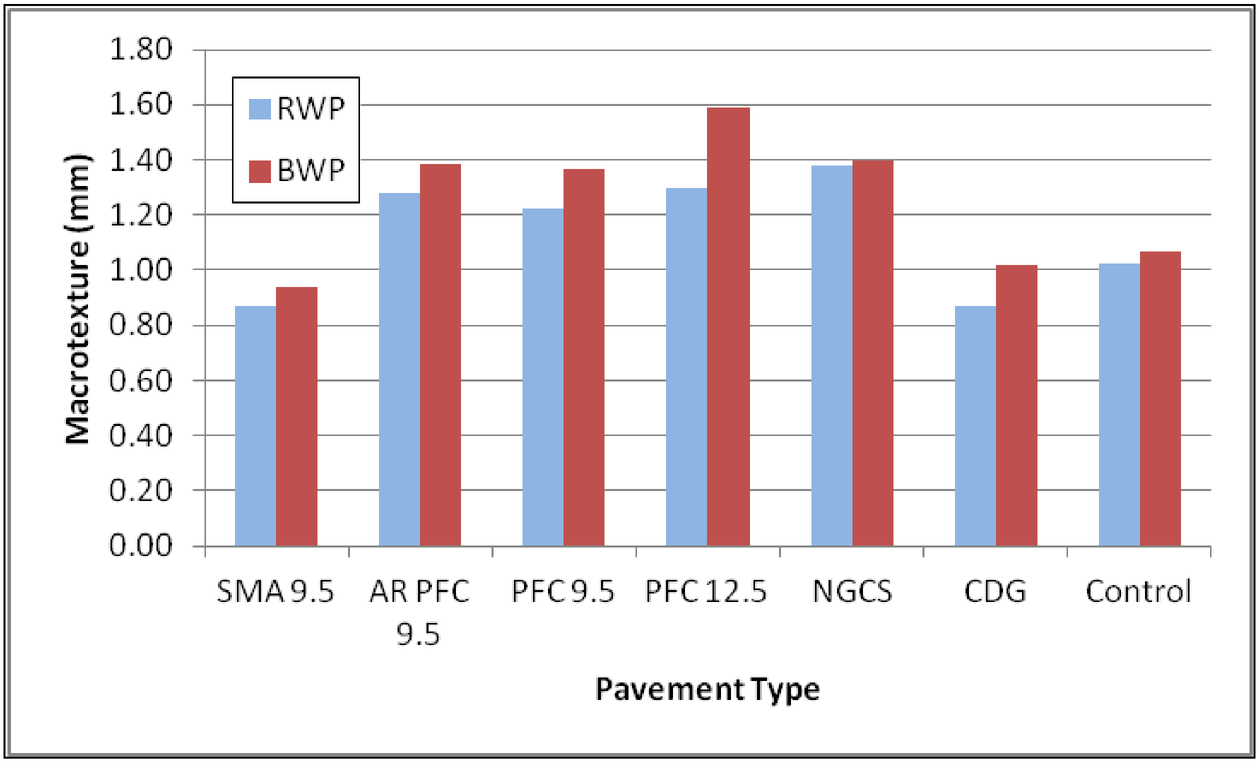

Figure 12. Macrotexture (MPD) measurements – spring 2012. RWP = Right Wheel-Path; BWP = Between Wheel-Path. Note: 1mm MPD = .04 inches.

Concrete surfaces were not expected to exhibit much change, especially within this limited period of time. The 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 (see CDG picture in Figure 7).

Microtexture

The DFT provides a surrogate for characterizing much smaller features in the surface; microtexture. In the short-term, a reduction of microtexture (lower DFT numbers) can result when aggregates are enveloped in liquid asphalt due to consolidation of asphalt under traffic. Under heavier traffic for a longer period of time, this loss is more typically attributed to aggregate polishing. Regardless of the mechanisms at work, the DFT results were slightly lower on average in the wheel paths than the lane center (see Figure 13). The asphalt surfaces were remarkably consistent across the entire spectrum of surfaces, especially in the wheel paths. Tests on the concrete surfaces revealed higher average numbers and not as much consistency – the NGCS exhibiting lower microtexture, especially in the wheel path.

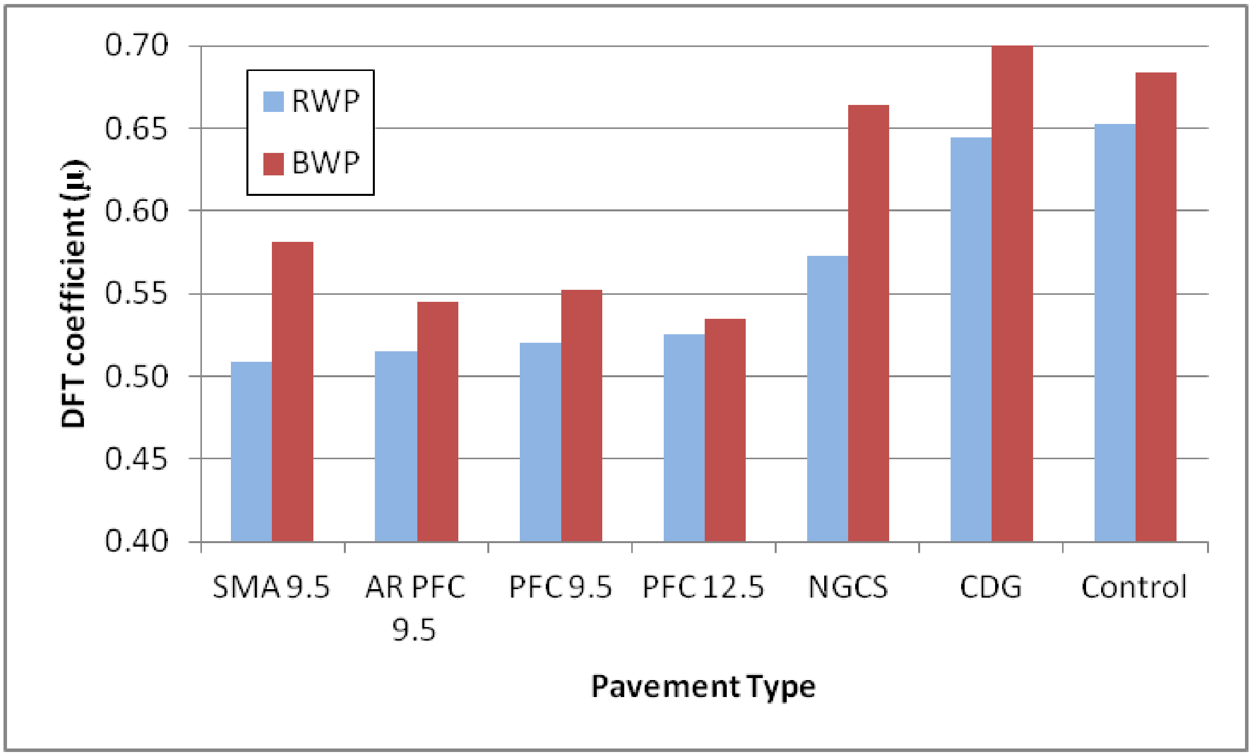

Figure 13. DFT friction results - spring 2012. RWP = Right Wheel-Path; BWP = Between Wheel-Path.

Resistance to Skidding

The GripTester and the Locked Wheel Tester provide a more general measurement of available tire-pavement friction. Figure 14 combines the results from both series of tests. The GT, a fixed-slip device, can be considered to provide conservative upper-bounds on available friction whereas the LWT can represent 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. At this point there appear to be no tire-pavement friction issues on any of the surfaces in the QP demonstration projects.

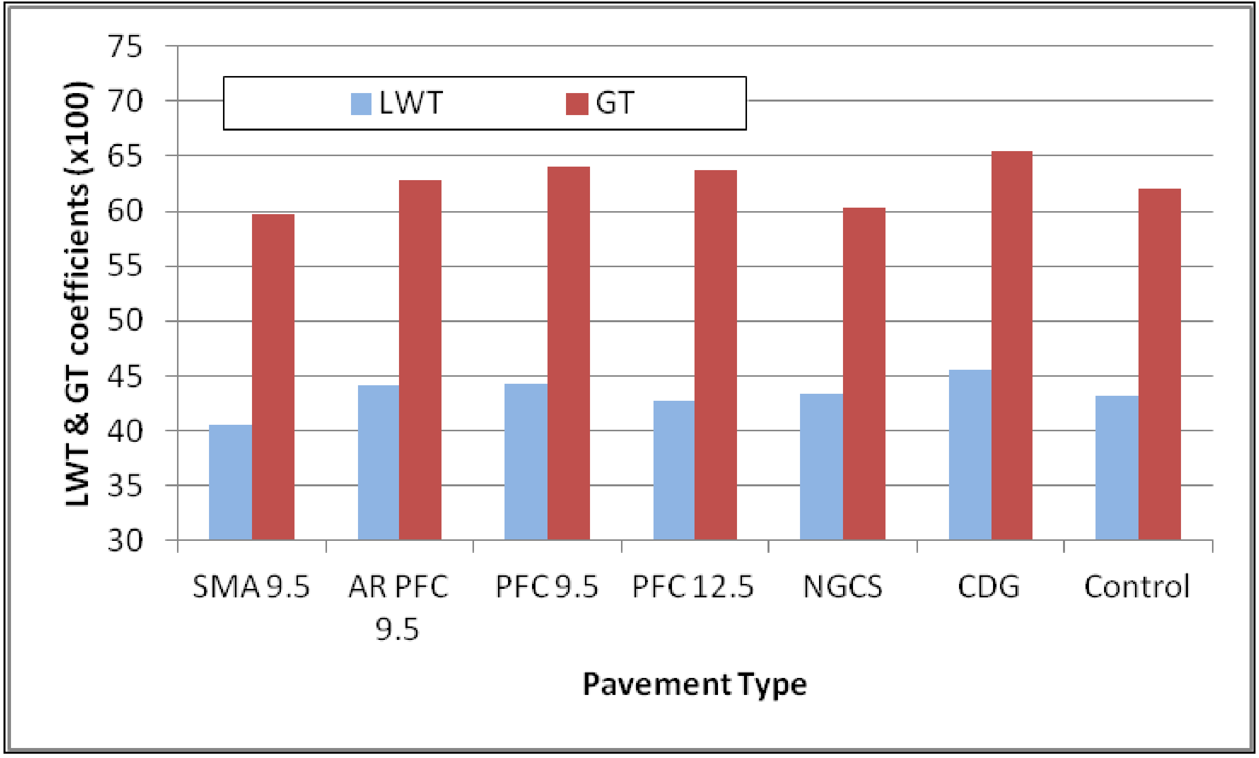

Figure 14. Locked Wheel Tester (LWT) and GripTester (GT) Results -spring 2012.

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[16], 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 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 potentially interrupting drainage from the porous materials.

Maintenance officials from Williamsburg provided "winter maintenance treatment" reports (see Appendix D) 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 quiet 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. 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.

The exceptional smoothness of the NGCS was not only quantifiable, but often noticed and reported by the traveling public (to include members of the research team). The "quietness" of the new surface was also readily noted and appreciated. Unfortunately, one of the quiet concrete demonstration projects already has structural failures in the pavement that neighbor some of the new patches (Figure 15).

Figure 15. New Material Failure on Quiet Concrete Demonstration Projects – SR 76, Richmond.

Costs and Quantities

Table 4 reports the average initial cost and total quantity for each QP technology.[2] 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

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[2] Initial cost includes only the cost of materials or treatment associated with a particular pavement or technology and does not take into consideration long term costs, such as those costs associated with maintaining any lower noise levels initially achieved by the technology.

process is experimental. Reliable cost-comparison analyses will require additional examination of the life cycle costs associated with establishing and maintaining a lower surface noise level attributable to, and will require experience with full-production use of, these technologies. Even then the analysis will need to respond to project-specific characteristics.

Table 4. Costs and Quantities: 2011 Quiet Pavement Technologies

Pavement Description	Average Cost		Total Quantities	
	Per Ton ($)	Square Yard ($)	Tons	Square Yards
SMA 9.5 (Asphalt Control)	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

SUMMARY AND NEXT STEPS

2011 Demonstration Projects

Three quiet asphalt and two quiet concrete technologies were installed in five demonstration projects in 2011. The quiet asphalt technologies were three porous friction course (PFC) mixes – two with semi-conventional asphalt binders and one with a rubber-modified asphalt binder. The quiet concrete technologies included a conventional diamond grind surface and the NGCS, a combination grind and groove process designed specifically to reduce noise on concrete pavements. 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 (i.e., AR-PFC 9.5 near Williamsburg; PFC 12.5 in Leesburg). The NGCS maintains an *obvious* (5 dBA) noise advantage over the control concrete surface. Comparison to the late fall tire-pavement noise testing shows that none of the surfaces has become louder over the very mild winter. On the contrary, the sound intensity levels appear to have dropped by varying amounts. A comparatively larger drop in sound intensity level for the SMA surfaces makes it more difficult to discern (with the human ear) a difference between the QP technologies and the asphalt control.

The QP technologies have a more distinct advantage over the control surfaces when it comes to achieved ride quality. The NGCS is smooth, and contractors earned smoothness incentives with the quiet asphalt materials, including 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 receiving consistent recognition for wet-weather service.

Future Activities

The plans for 2012 activities include two trial sections at the accelerated test track at NCAT. The raw materials from the most promising 2011 demonstration technologies will be sent to Auburn, AL, blended with standard materials to produce “Virginia” QP technologies, and place in the path of accelerated truck loads.

In addition to the NCAT sections, VDOT and the Asphalt industry plan to install a two-inch rubberized mix in the NOVA District, as well as a rubberized SMA trial in the Culpeper and NOVA Districts.

The research team will continue to closely monitor the 2011 demonstration projects, as well as parallel activities around the United States and elsewhere in the world. The research teams will also examine the various factors impacting the costs associated with use of these technologies, factors such as life cycles, both as to durabilitiy as well as noise reduction, and replacement frequencies necessary to establish and maintain any lower surface noise levels attributable to these technologies. The quantifiable performance characteristics of the 2011 technologies will be incorporated into the Virginia selection and use policy that will come with the 2013 final report. As is nearly always the case, the local experience with the actual materials (quantifiable or not) will exert the most influence over practical impact of the formal policy. It is important to not under-value the importance of the 2011 demonstration projects.

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APPENDIX A

CHAPTER 790

An Act to amend and reenact § 33.1-223.2:21 of the Code of Virginia, relating to highway noise abatement practices, technologies, and pavement standards.

[H 2001]

Approved April 6, 2011

Be it enacted by the General Assembly of Virginia:

1. That § 33.1-223.2:21 of the Code of Virginia is amended and reenacted as follows:

§ 33.1-223.2:21. Noise abatement practices and technologies.

A. Whenever the Commonwealth Transportation Board or the Department plan for or undertake any highway construction or improvement project and such project includes or may include the requirement for the mitigation of traffic noise impacts, consideration should be given to the use of noise reducing design and low noise pavement materials and techniques in lieu of construction of noise walls or sound barriers. Landscaping in such a design would be utilized to act as a visual screen if visual screening is required.

B. The Department shall 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 assessment shall include evaluation of the functionality and public safety of these technologies in Virginia's climate and shall be evaluated over two full winters. The Department shall provide an interim report to the Governor and the General Assembly by June 30, 2012, and a final report by June 30, 2013. The report shall 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.

APPENDIX B

BRIEF HISTORY AND RELATED RESEARCH

This appendix provides history of traffic noise and fundamentals of tire-pavement noise production and measurement. It also introduces lower noise pavement technologies and discusses relevant experience in the United States and other countries. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[7 pages]

APPENDIX C

TIRE-PAVEMENT NOISE MEASUREMENT SYSTEM

This appendix provides a detailed description of the equipment and test procedures used to measure tire-pavement noise for the Virginia Quiet Pavement Implementation Program. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[4 pages]

APPENDIX D

VIRGINIA WINTER AND QUIETER PAVEMENT SURFACES: A GUIDELINE FOR MAINTENANCE AND OBSERVATION

This appendix contains the guidance that was issued from the Quiet Pavement Task Force in advance of the winter of 2011/2012. The purpose of guidance was to prepare local maintenance crews for the unique responses that some quiet pavement strategies may require during winter weather and to solicit feedback on what strategies were actually deemed necessary. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[4 pages]

APPENDIX E

VIRGINIA DEPARTMENT OF TRANSPORTATION SPECIAL PROVISION FOR POROUS FRICTION COURSE

This appendix is a copy of the special provision that described two of the porous friction course materials (PFC 9.5 and PFC 12.5) that were included as quiet asphalt pavement technologies for the 2011 Quiet Pavement Demonstration Projects. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[8 pages]

APPENDIX F

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
ASPHALT RUBBER POROUS FRICTION COURSE

This appendix is a copy of the Special Provision that described the Asphalt Rubber Porous Friction Course material (AR-PFC 9.5) that was included as a quiet asphalt pavement technology for the 2011 Quiet Pavement Demonstration Projects. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[10 pages]

APPENDIX G

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
GRINDING CONCRETE PAVEMENT
—Quiet Pavement Project—

This appendix is a copy of the special provision that describes conventional diamond grinding (CDG) of concrete pavements. CDG is one of two surfaces to be included as a quiet concrete surface alternative in the 2011 Quiet Pavement Demonstration Projects. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[2 pages]

APPENDIX H

VIRGINIA DEPARTMENT OF TRANSPORTATION SPECIAL PROVISION FOR GRINDING NEXT GENERATION CONCRETE PAVEMENT SURFACE

This appendix is a copy of the special provision that describes the Next Generation Concrete Surface (NGCS). The NGCS is the second of two surfaces to be included as a quiet concrete surface alternative in the 2011 Quiet Pavement Demonstration Projects. The NGCS specification was developed by the International Grooving and Grinding Association and adopted as a VDOT special provision for this research. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[3 pages]

APPENDIX I

QUIET PAVEMENT DEMONSTRATION PROJECTS: DETAILED LOCATIONS AND TECHNOLOGY LIMITS

This appendix includes detailed maps for each of the five quiet pavement demonstration projects that were constructed in 2011. The maps further designate the limits of the various technologies that make up each demonstration project. The maps are essential to managing the extensive data collection program that will span the entire evaluation program. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

[4 pages]

APPENDIX J

TIRE-PAVEMENT NOISE: TEST CONDITIONS AND DETAILED RESULTS

This appendix includes specific meteorological, pavement, and tire condition data that were collected during the two series of tire-pavement noise measurements. This appendix also includes the total distribution of OBSI values for the five candidate quiet pavement technologies and the respective control surfaces, as well as the detailed intensity level data that include one-third octave bands from 400 to 5,000 Hz. The full text of this appendix is available from the primary author, Mr. Kevin K. McGhee, P.E., at the Virginia Center for Transportation Innovation and Research (Kevin.McGhee@VDOT.Virginia.gov).

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