Development of the Next-Generation, Low-Maintenance Concrete Surface

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ABSTRACT

In 2005, the Portland Cement Association, through the American Concrete Pavement Association, funded research to improve the noise performance of concrete pavements. The International Grooving and Grinding Association, through its affiliated contractors, supported the research effort through equipment development and test section construction.

The research was undertaken by Purdue University's Herrick Laboratories using their Tire Pavement Test Apparatus (TPTA). The TPTA is capable of testing any pavement texture that can be produced. This allows evaluation of texture designs that are not constrained by current construction capabilities or costs associated with construction and evaluation of field test sections. More importantly, the TPTA allows evaluation of textures without causing traffic control or safety issues.

Purdue's concrete pavement research was targeted on both new construction and pavement rehabilitation. Purdue's preliminary efforts focused on evaluation of the variables affecting tire–pavement noise generation characteristics of diamond-ground surfaces. This paper reports on the development and findings of that work.

The Purdue work evaluated the variables affecting construction of diamond-ground textures and the joint-slab effect associated with transverse joint noise generation. The findings of the Purdue work indicated that the geometric configuration of the blades and spacers used to construct diamond-ground textures was not the controlling factor in noise generation; rather the resulting fin profile was the most important factor. To produce a low-noise, diamond-ground surface required producing uniform and consistent fin profiles.

To verify this finding, a new surface was produced that consisted of a uniform fin profile design with essentially only negative texture. This surface texture produced the lowest tire–pavement noise levels in the research. The surface was then constructed in the field using actual diamond-grinding equipment to confirm the laboratory based study. A new surface, now called the Next Generation Concrete Surface (NGCS), was essentially implemented and is being constructed in test sections to evaluate its long-term performance.

NGCS is a term used to describe a category of textures that have evolved or will evolve through current research. The term may apply to several textures that evolve for both new construction and rehabilitation of existing surfaces. The desirable characteristics of such textures will be a very smooth profile coupled with good micro texture and excellent macro texture.

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To date, three field trials have been constructed and one competitively bid construction project. Friction testing and on-board sound intensity levels have been obtained at two of the sites and are reported herein.

INTRODUCTION

Recognizing the national interest in quiet pavements, in 2004 the Portland Cement Association (PCA) and the American Concrete Pavement Association (ACPA) developed a program to research the surface characteristics of concrete pavements. This program, funded by the PCA and administered by the ACPA, was designed as a 3-year program that began in 2005. The The International Grooving and Grinding Association (IGGA) and several of its members also provided financial and creative support for the program. The program had three main objectives: evaluation and development of a quieter diamond-ground surface, evaluation and development of new construction surfaces, and evaluation of the joint slap effect. Only the development of a quieter concrete diamond-ground surface is discussed in this paper.

PURDUE TIRE PAVEMENT TEST APPARATUS

Purdue University's Herrick Laboratory conducted the research using their Tire Pavement Test Apparatus (TPTA). The TPTA (shown in the right side of Figure 1) consists of a 38,000-lb (17,237 kg) drum, 12 ft (3.7 m) in diameter, that makes it possible to test numerous types of pavement textures and compositions in combination with various tire designs. Six curved test-pavement sections fit together to form a circle. Two tires, mounted on opposite ends of a beam, are then rolled over the test samples at varying speeds while microphones and other sensors record data. As indicated in Figure 1, two wheel tracks were constructed on each of the six curved test panels allowing 12 surface textures to be tested in one setup. Speeds of 0 to 30 mi/h (0 to 48 km/h) can be tested, and test temperatures ranging between 60 ^{o}F and 80 ^{o}F (15.5 ^{o}C and 26.7 ^{o}C) are possible.

TPTA Equipment

The left side of Figure 1 shows the diamond-grinding head that was constructed by Diamond Surfaces, Inc., of IGGA. This head was used to grind all the surfaces studied. It constructs a diamond-ground surface 8 in. (203 mm) wide. Typical diamond-grinding units grind paths 3 ft and 4 ft (0.9 and 1.2 m) wide and use 50–60 blades per ft (0.3 m). To fully "stack" a head can cost $50,000 and take 6 to 8 hours of stacking time. The use of a small head, 8 in. (203 mm) wide, tremendously reduces the blade cost and setup time. When comparing different grinding blade/spacer configurations, these savings are an important consideration. The grinding unit replaces one of the wheel setups, as indicated in Figure 1. Once the surfaces are diamond-ground, the unit is removed, the test wheel apparatus is re-installed, and testing is conducted.

The Purdue TPTA was the innovative workhorse for the PCA/ACPA/IGGA surface texture efforts. This device allows textures to be produced and tested that may not currently be possible to construct with present day equipment. Additionally, testing can be accomplished without requiring traffic control or endangering workers or travelers.

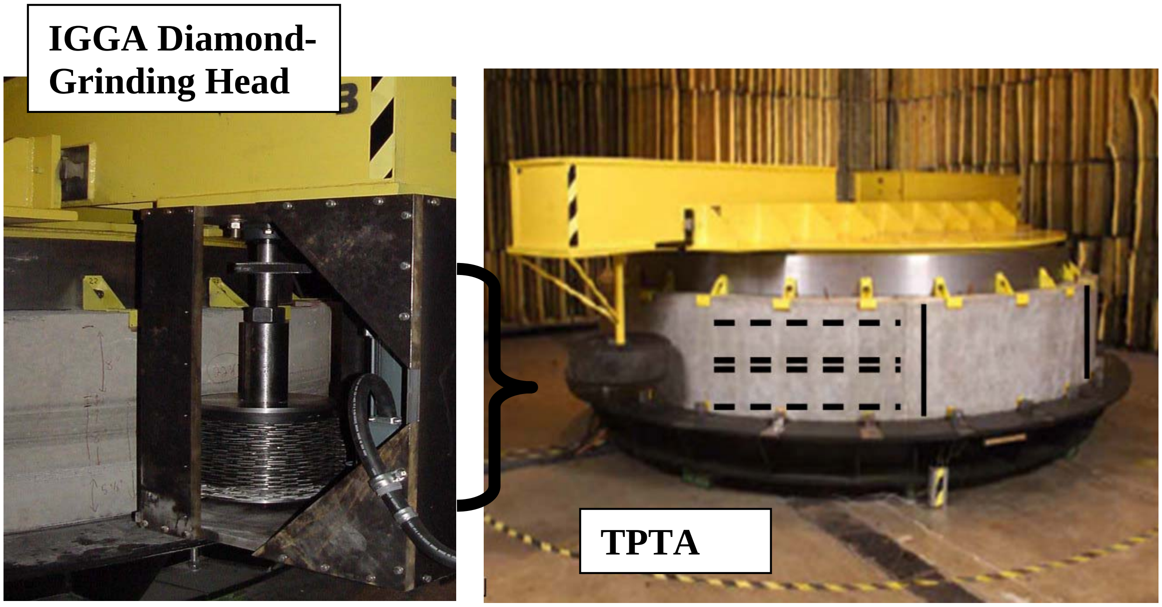

Figure 1. IGGA diamond-grinding head and Purdue Tire Pavement Test Apparatus (TPTA).

TPTA Measurement Systems

Figure 2 shows the OBSI equipment used to measure tire–pavement noise and the RoLine laser used to measure texture profiles. As indicated in the left side of Figure 2, the OBSI equipment was mounted to the test-tire support frame. Since two tires are used during testing, it was possible to test with two different tire types at the same time.

The right-hand side of Figure 2 indicates the texture measurement system. Texture measurement was accomplished by removing one of the tire support frames and installing an arm to support the RoLine sensor.

Figure 2. OBSI and RoLine test equipment mounted to TPTA.

Purdue Test Plan

The Purdue diamond grinding research was predicated upon varying the blade width and spacer width to develop the optimum grinding configuration. It was recognized that only one concrete mixture was to be used for all specimen preparation and that this would limit the optimization to the given mix and aggregate type. However, the belief was that any findings would be useful in understanding other mixes as well and that additional research could be pursued if necessary. Historically, the industry has constructed field test sections for research purposes, almost always varying the spacer and blade types. As such, the industry requested that Purdue approach their research by varying the blade and spacer widths and configurations.

After evaluating the range of blade and spacer widths requested by the industry, Purdue advised that no unique relationship could be found between spacer width, blade width, and spacer/blade configuration. Instead, it appeared that the controlling variable was the variability in the fin profile height resulting from the grinding process.

Figure 3 is a close-up photograph of the fin profile just after grinding and before any fins are knocked down due to traffic and winter maintenance operations. As evident in the photo, the harder aggregate stand "proud" in relationship to adjacent areas. Purdue indicated that it was probably this variability in fin profile that affected the tire–pavement noise generation. Textures with low variability were quieter than textures with high variability. In conventional diamond grinding, the resulting fin variability is affected by the blade/spacer configuration, the concrete mixture, aggregate type, pavement condition, equipment setup, and other influences, making it very difficult to control from an experimental standpoint.

To evaluate this hypothesis, it was decided to produce a texture with essentially no positive texture. That is, the surface would be diamond-ground smooth, and additional texture would then be imparted by grooving. In this way, the exact fin profile could be anticipated and controlled at the time of production, unlike conventional diamond-ground (CDG) surfaces, which are affected by many variables. Figure 4 shows one of these surfaces. It should be noted that the CDG surface shown in Figure 3 produces texture in the upward or positive direction, while the Purdue surface produces texture in the downward or negative direction. The Purdue texture, later called the Next Generation Concrete Surface (NGCS), was desirable from the standpoint that it was more of a "manufactured surface" and thus could be controlled as necessary from an experimental basis.

Figure 3. Variability of fin profile on conventional diamond-ground surface on MnROAD I-94.

When these new NGCS textures were tested on the TPTA, they produced the quietest of all surfaces tested to date. This was an epiphany in the research. It verified, for the first time, what the controlling factor was for tire–pavement noise generation of diamond-ground surfaces.

Figure 4. Photo of Purdue negative texture profile (NGCS) and land area.

TEST SECTION CONSTRUCTION

Proof-of-Concept Field Testing

The epiphany was soon confronted by reality. The Purdue grinding consisted of grinding a wheelpath 8 in. (203 mm) wide and 6 ft (1.8 m) long for each of the specimens. When grinding such small areas, the heat generated by the head is not excessive. However, when diamond grinding a pavement with a conventional machine, with a 3-ft or 4-ft (0.9 or 1.2 m) head, this is not the case. The typical 0.125-in. (3.2-mm) opening provided by a spacer between the grinding blades allows water to circulate between them, cooling them and removing grinding debris. This is an important consideration in production grinding. In addition, flush-grinding the surface prior to grooving requires approximately twice as many blades. For an 8-in. (203-mm) head such as Purdue's, this is not prohibitively expensive. To do it with a 3- or 4-ft (0.9-m or 1.2-m) grinding head could cost upwards of $60,000, a risky (or investment) for an unproven strategy. The Purdue research indicated that the flush-ground/grooved texture could produce a quieter texture, but it could not verify whether it could be constructed with conventional equipment in the field.

Prior to attempting field validation, two grinding/grooving configurations were developed and tested in the laboratory at Purdue. The first was a grinding configuration that used three smaller diameter blades stacked between two taller blades, and the pattern repeated across the grinding head. The taller blades were approximately 2 mm (0.079 in.) larger. This arrangement provided a single-pass operation that could grind the surface smooth and also groove it on approximate 0.5-in. (13-mm) centers in one pass of the machine. The smaller blades were used to flush-grind the roadway and provide micro texture, while the taller blades were used to create grooves. The Purdue work had also demonstrated the advantage of micro texture in reducing noise levels.

The second grinding configuration used the same smaller blades to "flush" grind the pavement in the first pass over the surface. A second pass was then made using the same taller blades with spacers between them to create on-center spacing of approximately 0.5 in. (13 mm). This second pass provided grooves similar to what was constructed with the single-pass configuration.

The purpose for the two different configurations, designed to achieve the same end result, was to allow consideration of either option by contractors. Some industry representatives did not consider the single-pass operation to be a viable option in a production environment due to excessive blade wear and the potential for ruining the head or blades. Many believed the two-stage process would be required. So both options were pursued. Both surfaces produced similar results on the TPTA, so field trials were pursued.

The opportunity to construct field test sections became a reality when the Minnesota Department of Transportation (MnDOT) allowed construction of the test sections shown in Figure 5 at the MnROADS Low Volume Road Test Cell Number 37. At approximately this same location, Diamond Surfaces, Inc., had equipment uniquely designed to construct the proposed sections. The equipment consisted of a diamond grinding unit with a 2-ft (0.6-m) head designed for curb cuts. This device not only allowed for fewer blades to be used but also was designed to allow quick blade changes. A head of blades could be changed in approximately 45–60 minutes versus 6–8 hrs.

The test strips indicated in Figure 5 represented a compromise between the ability to conduct OBSI testing at 60 mi/h (97 km/h) and requiring as few blades to construct a test strip. It was estimated that an 18 in. wheel track was the narrowest that that could be tested at 60 mi/h (97 km/h) and still ensure the test wheel was within the test strip.

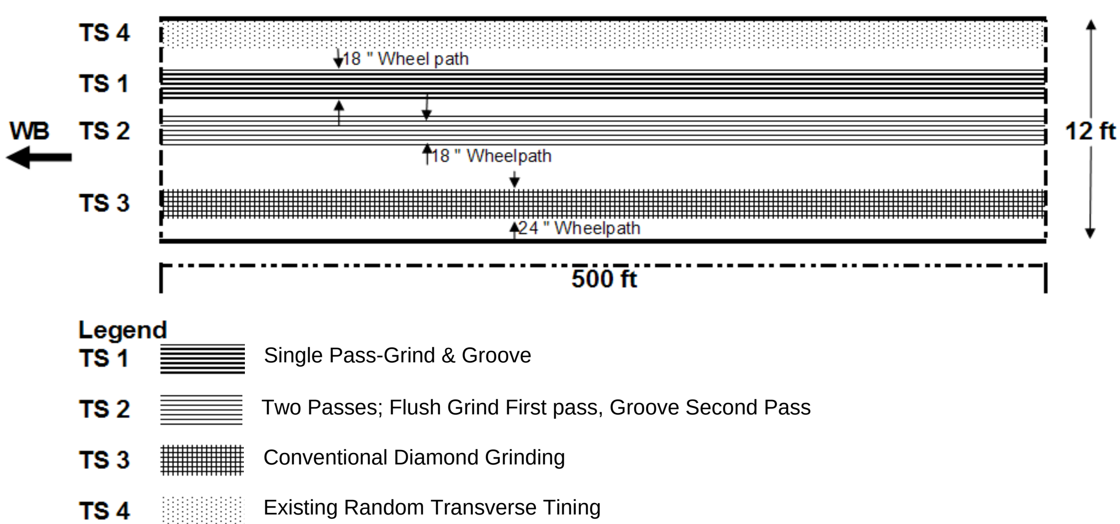

Figure 5. Proof of concept field test strips at MnROADs low-volume roads test area.

Additionally, the two Purdue surfaces were to be compared to a CDG surface to assist in determining the benefit achieved by controlling fin profile. This resulted in the need to construct three diamond-ground surfaces.

The purpose of the test section construction was twofold: first, to verify the hypothesis that controlling the texture (i.e., fin) profile in contact with the tire could result in lower noise surfaces; and secondly, to verify that the results obtained using the TPTA could be reproduced in the field on real pavements using actual construction procedures.

The standard diamond-grinding wheel track (TS3 in Figure 5) was constructed with the blades and spacers existing on the equipment to eliminate the need to restack the head one more time. This resulted in TS3 being constructed 24 in. (610 mm) wide while TS1 and TS2 were constructed 18 in. (457 mm) in width to reduce the number of blades. The test sections were constructed on a 14-year-old PCCP that had originally been textured with random transverse tinning.

Wheel tracks TS2 and TS1 were constructed with new “flush” grind blades, which had been dressed to ensure they were essentially the same diameter so that a flat surface with micro texture could be produced. Taller new blades were also used which were approximately 2 mm (0.08 in.) larger in radius than the “flush” grind blades. TS 2 was constructed in two operations and TS1 in a single operation. The diamond-grinding unit constructed each wheel track in approximately 40 to 50 minutes. Equipment travel speed was on the order of 10 to 12 ft (3.0 to 3.7 m) per minute. Both the single pass and double pass procedures were successfully constructed in June 2007.

The findings, as discussed later, validated both that the Purdue texture was quieter, at the time of construction, than the CDG texture and that the Purdue TPTA results could be reproduced in the field using conventional equipment. With the validation of the TPTA results, the next step was to construct a full-width test section using a conventional diamond-grinding machine. This would allow trafficking of the test section as well as additional insight into the production side of the Purdue NGCS texture.

Mainline Construction

The first opportunity to construct a full-lane-width test section occurred on the Chicago Tollway on I-355. At this site, both a CDG test section and a Purdue texture (NGCS) were successfully constructed in October 2007. The sections were 1,200 ft (366 m) long and one lane wide. This section of freeway was a newly constructed alignment that had not been open to traffic prior to constructing the test sections. The two-pass process was used to construct the Purdue texture.

The next opportunity to construct test sections occurred at MnROADs on the I-94 section. A section of Purdue NGCS two lanes wide by 500 ft (152 m) long was constructed in a single pass on a 14-year-old random transverse tined pavement in October 2007 on a new roadway. With the successful placement and performance of the two mainline sections, the ACPA officially named the Purdue textures the “Next Generation Concrete Surface” (NGCS). This naming occurred to describe a category of texture(s) that have or will evolve through current research. The term may apply to several textures that evolve for both new construction and rehabilitation of existing surfaces. The desirable characteristics of such textures will be a very flat profile coupled with good micro texture and excellent macro texture.

Two additional NGCS sections were constructed in fall 2008, one in Wisconsin and one in Kansas. The Kansas NGCS was constructed as part of the Kansas two-lift PCCP test project. Other Kansas textures evaluated consisted of drag textures, exposed aggregate, longitudinally tined, and a CDG section.

The Wisconsin project is unique in that it was the only project in which the NGCS section was bid as a normal construction project and not as a change order or section constructed by the industry. The Wisconsin section was constructed too late in the year to obtain meaningful test results. Additionally, the section was constructed through a town that had a posted speed limit of 25 mi/h (40 km/h) in the vicinity of the CDG section and 35 mi/h (56 km/h) in the vicinity of the NGCS section. OBSI testing is typically conducted at 60 mi/h (97 km/h).

All the NGCS sections were successfully constructed and were the quietest textures placed. The OBSI and friction characteristics are discussed in subsequent sections. The NGCS is still in the evaluation phase, and ways of making the surface more cost effective are being considered. Currently, this surface is considerably more expensive than CDG surfaces.

ON-BOARD SOUND INTENSITY MEASUREMENTS

The ACPA has conducted OBSI testing on the test sections to evaluate their long term performance. The testing is conducted at 60 mi/h (97 km/h) using a dual vertical-probe OBSI system mounted to a Chevy Malibu with an ASTM SRTT test tire. This testing is used to represent the tire–pavement noise generation of the respective surfaces.

Pre-Opening to Traffic

Pre-Traffic OBSI Conclusions

The pre-traffic OBSI results for the MnROADs and Illinois test sections are indicated in Figures 6 and 7. The proof-of-concept test section results conducted on the MnROADs low-volume road test sections are also presented. There are a number of things to note in these Figures: (1) the NGCS results were always lower than the CDG results; (2) the NGCS results are consistent while the CDG are variable; (3) the NGCS has a somewhat different spectral plot than the CDG, as indicated in Figure 7. Testing indicated that the NGCS surface is quieter below 1000 Hz and between 1000 Hz and 1600 Hz. Above 2000 Hz it is noisier. There is a significant drop in the spectrum at the 1600 Hz center band frequency for the NGCS surface.

It should be noted that no adjustments for the effect of temperature on OBSI levels have been made.

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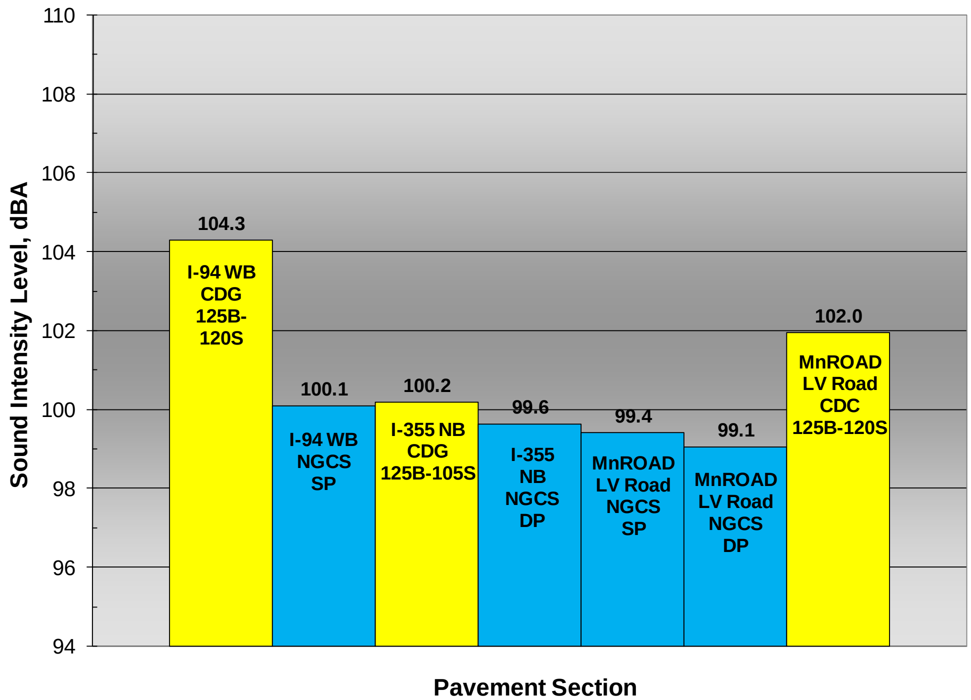

Figure 6. ACPA OBSI results for MN I-94 and IL I-355 sections.

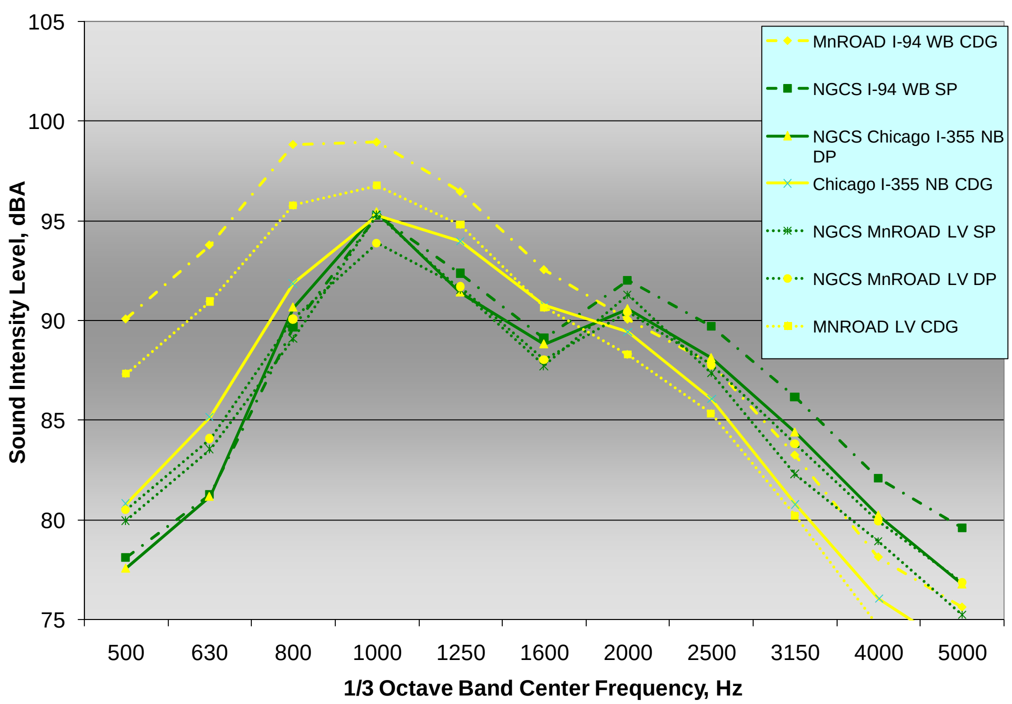

Figure 7. One-third octave spectral plots for MN I-94 and IL I-355 sections.

Comparison to Other Textures on I-355 on 11-4-07

OBSI testing of the diamond-ground surfaces was conducted on I-355 just prior to opening, and the results were compared to other textures on this same segment of roadway. The results are indicated in Figures 8 and 9. Figure 8 indicates the overall levels, while Figure 9 indicates the frequency spectrums. OBSI testing was conducted on all sections at the same time and temperature.

Figure 8 indicates that the NGCS surface was almost 5 dBA quieter than the random-transverse-tined surface. Figure 8 also indicates that the CDG and NGCS are similar in noise level. The longitudinal grooved drag texture was almost 2 dBA higher than the NGCS, suggesting that the grooves alone were not the solution.

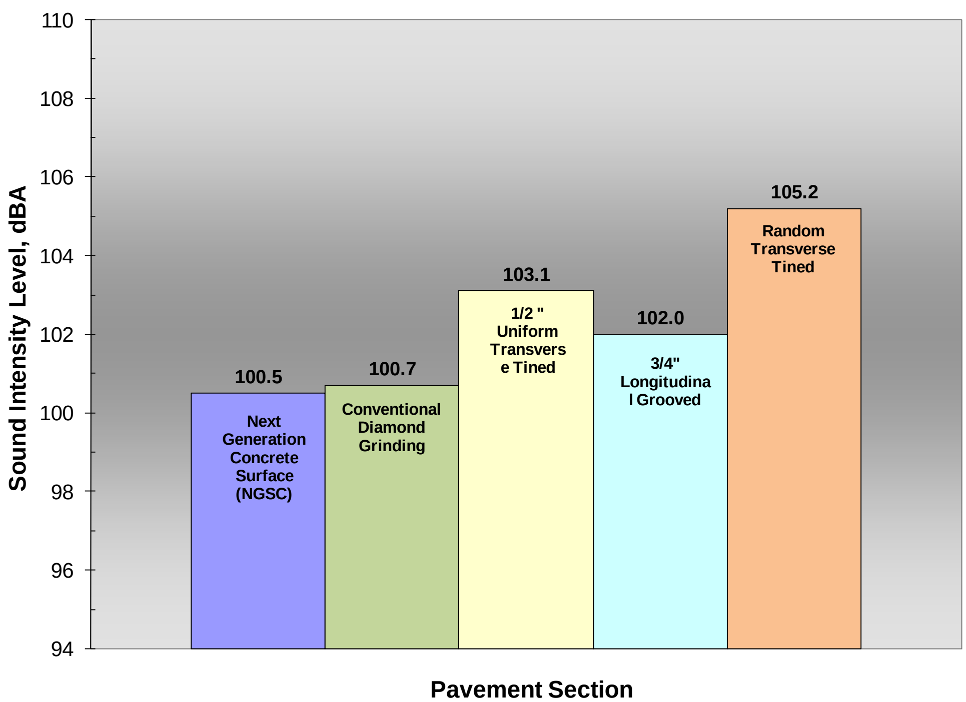

Figure 8. Chicago I-355 OBSI overall level results from 11-4-07.

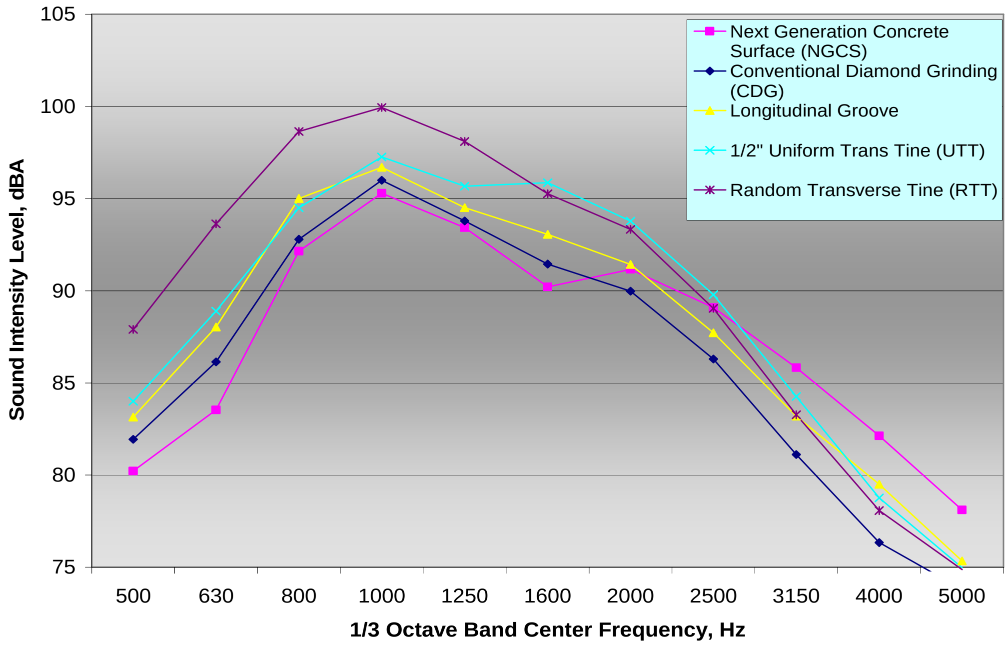

Figure 9. Chicago I-355 OBSI spectrum results of selected textures tested November 4, 2007.

Post Opening to Traffic Test Results

Both the I-94 and I-355 test sections are located in areas with harsh winters and experience snow plow operations. Test results reported in this section represent performance after one winter of snow and ice control and interstate-level traffic. I-94 in Minnesota has a high percentage of truck traffic, while I-355 has relatively low average daily traffic and truck traffic.

Figure 10 indicates the OBSI levels for each of the two field test locations that are under traffic conditions. Both sites had received approximately 5 months of traffic at the time of testing. For each location and surface type, the oldest test result is displayed to the left of the most current result. The I-94 sections are indicated in the left half of the figure and the I-355 sections in the right half. The results shown are the average of three tests for each surface type. Figure 11 displays the spectral results for both locations.

When reviewing Figures 10 and 11, there are a number of things to note: (1) As evident in Figure 11, the NGCS frequency pattern is slightly different than the CDG. The NGCS has a characteristic dip at 1600 Hz and is typically lower in level at all frequencies below this dip and higher in level at all frequencies above the dip. This is consistent with the pre-traffic results. The NGCS produces a more broadband noise and may be less objectionable. (2) The overall level of the CDG and NGCS are more similar in the trafficked condition than in the as-constructed condition. This is a result of the wearing down of the CDG fins (see Figure 12, and contrast this with Figure 3). (3) The NGCS has produced more consistent results. That is, the textures are essentially at their final noise level at the time of construction and do not have to wear away to a "finished level."

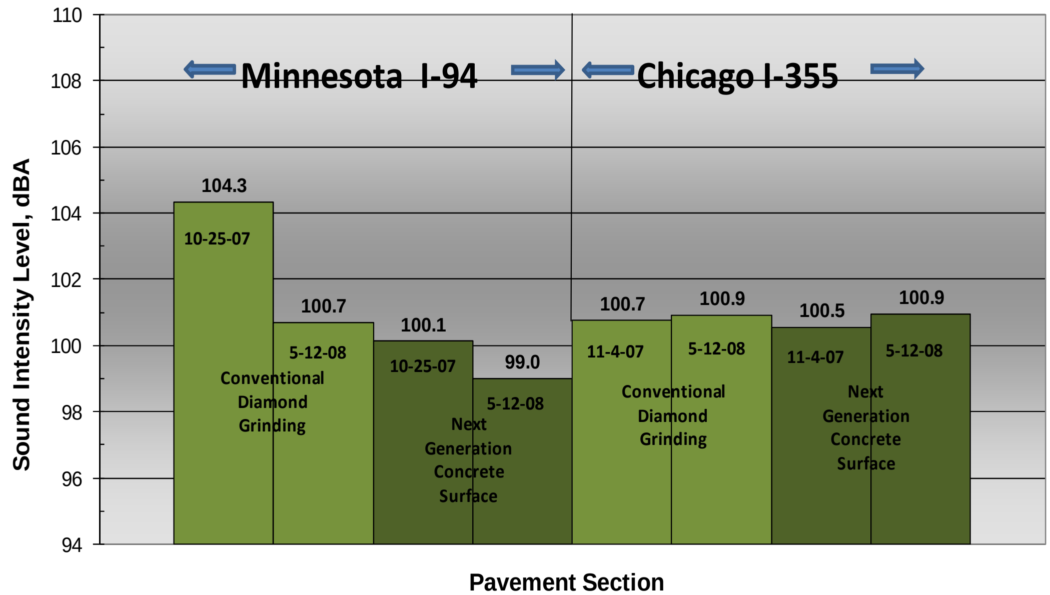

Figure 10. Comparison of CDG to NGCS OBSI levels through May 15, 2008.

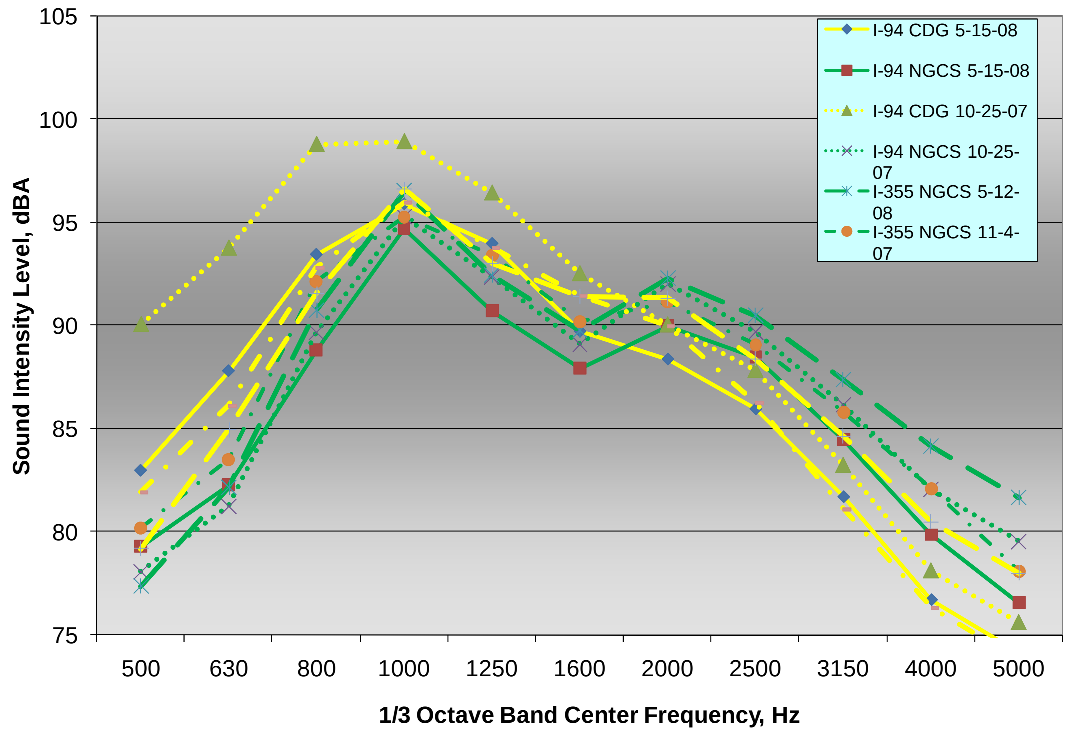

Figure 11. 1/3-octave spectra plots for I-94 and I-355 CDG and NGCS test sections.

As indicated in Figure 10, the CDG and NGCS sections were only 0.2 dBA different in level at the November 2007 testing, with the NGCS being quieter. During the May 2008 testing both surfaces produced similar results. The NGCS tested approximately 0.4 dBA louder in May than the November measurements, while the CDG tested 0.2 dBA louder. These differences are probably within the test repeatability of the OBSI equipment. In addition, this site location exhibits a slight joint slap. To date, the impact of the joint slap or diurnal change on test readings is undetermined.

It should be noted that the I-355 sections used 0.75-in. (19-mm) center-to-center groove spacing instead of the 0.5-in. (13-mm) center-to-center spacing developed at Purdue. This was to accommodate the use of the same grooving equipment that was used to construct the longitudinally grooved turf drag.

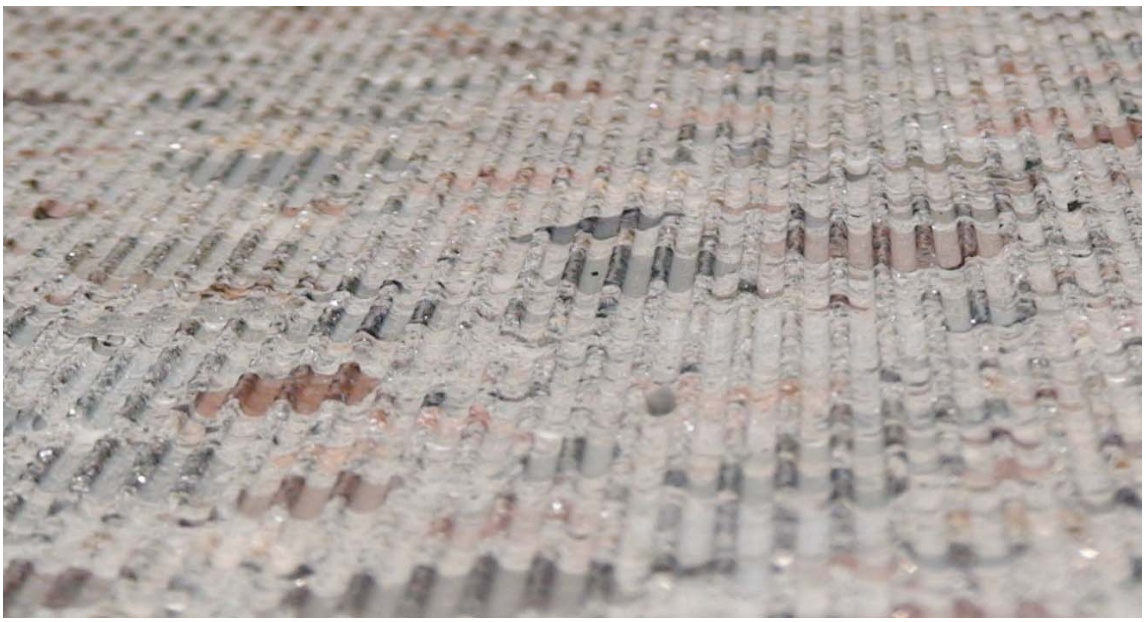

Figure 12. MnROAD I-94 conventional diamond-ground texture after 5 months of traffic.

FRICTION PERFORMANCE TESTING

The friction performance of the MnROADs I-94 test section has been monitored by MnROADs since the construction of the test sections. Figure 13 indicates the time series behavior of the sections for both the ASTM ribbed (E501) and smooth (E524) tires. It should be noted that I-94 was closed to traffic on April 2, 2008, to allow construction of new test sections on the facility. So there is approximately 5 months of interstate traffic on the test sections. The “traffic” occurring after the measurements obtained on May 28, 2008, would have been construction traffic and winter maintenance operations. Therefore the October 31, 2008, test results should represent changes to the surface subsequent to the May 23, 2008, testing as a result of recent construction-related or winter operations.

The October 23, 2007, measurements reflect the friction of the surfaces just after original diamond grinding and just prior to opening to traffic. The random-transverse-tined section is adjacent to the test diamond-ground sections and is a 14-year-old surface.

One of the more remarkable aspects of data presented in Figure 13 is that the smooth tire results are higher than the ribbed tire results for the diamond-ground surfaces. This is not the case for the random-transverse tining, which exhibits the difference found on most typical surfaces. At this time this finding is not well understood by the author. However, for the NGCS section, the data are essentially identical between the May 28 and October 23, 2008, testing, as would be expected. This would suggest that the repeatability of the MnDOT testing is very good. Since the NGCS has large lands (see Figure 4), it would not be expected to change much due to construction traffic or winter maintenance operations.

The NGCS smooth tire results are essentially the same after 5 months of traffic as at construction. This would seem appropriate as the surface is essentially a "manufactured" surface at the beginning, and little change is expected.

The NGCS LITE is a recently developed surface to provide an economical renewable surface for the NGCS. This surface is intended to develop more micro-texture on the land area. It is a further development of the NGCS concept. The texture produced by the NGCS LITE can be produced in the original NGCS construction or it could be used to "touch up" the texture on the land if it ever became necessary. The touch-up process could be accomplished cost-effectively, since little material is being removed. It is intended to re-establish or improve micro-texture.

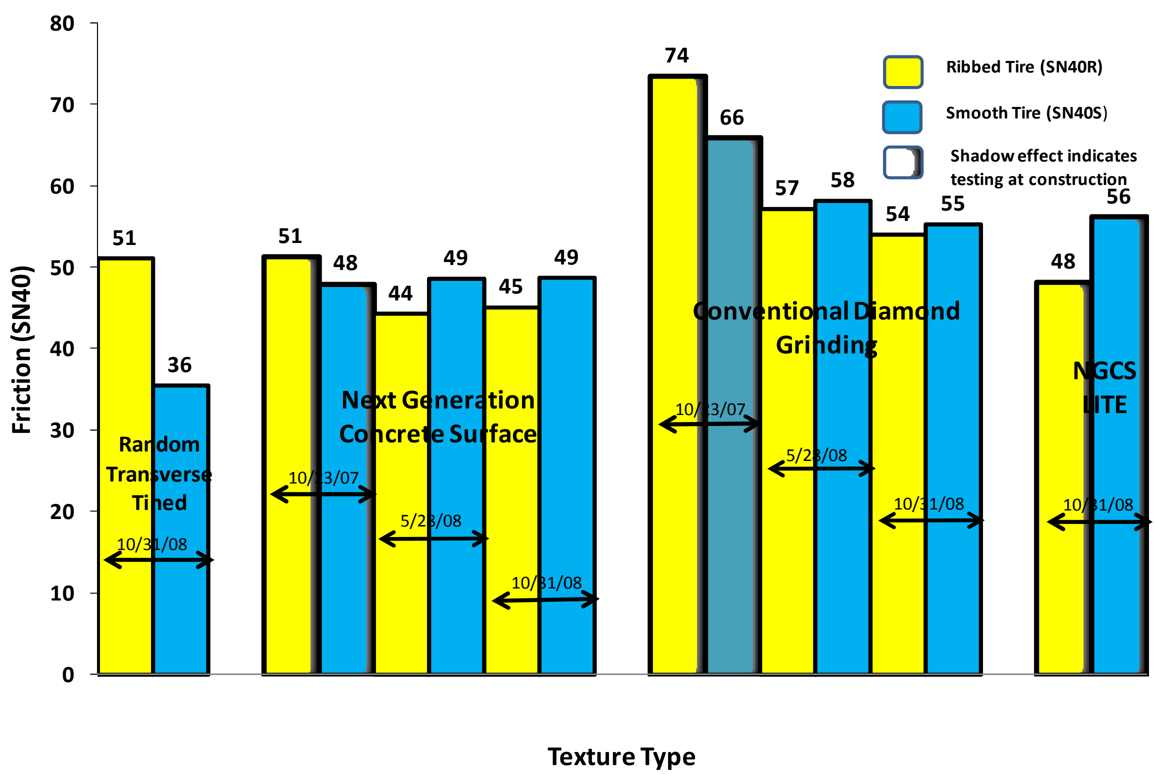

Figure 13. Friction (SN40) as a function of surface texture and time.

LESSONS LEARNED

Acoustic Longevity of Diamond-ground Surfaces

One of the questions that arose during evaluation of the NGCS was the expected acoustic longevity. Since it has been less than a year in implementation, the question could not be directly answered. Instead as an alternative, it became of interest to benchmark the existing CDG acoustic longevity. Although this maintenance strategy has been around since the 1960s, acoustic longevity curves were not readily available, so ACPA attempted to establish some findings

With the advent of noise measurement technologies such as OBSI, introduced by Caltrans into the highway industry in 2002, it became possible to develop acoustic longevity curves for selected pavements fairly efficiently. The first ACPA attempt at this occurred during summer 2008 on pavements in Kansas. The Kansas Department of Transportation provided a list of projects and a suggested testing scheme to the ACPA for OBSI testing. The selected pavements were intended to represent pavements of similar type, joint design, environment, and traffic, but of various ages. Pavement ages up to approximately 10 years were evaluated. Limestone is the predominate aggregate type found in Kansas and was used on these pavement sections. The top size aggregate is 0.75 in. (19 mm) to reduce D-cracking potential.

Seventeen pavements were tested. The results indicated in Figure 14. As indicated, there is a poor R^2 with the regression equation, suggesting that the data are randomly associated and no trend exists. This indicates that the acoustic performance of CDG remains almost constant throughout its early life. As noted, the data only include pavements up to 10 years old. The pavements selected and tested were all doweled pavements with little or no faulting, of uniform joint design, and had compression-sealed joints.

The acoustic durability of the NGCS surfaces placed to date has provided experience similar to the CDG surfaces.

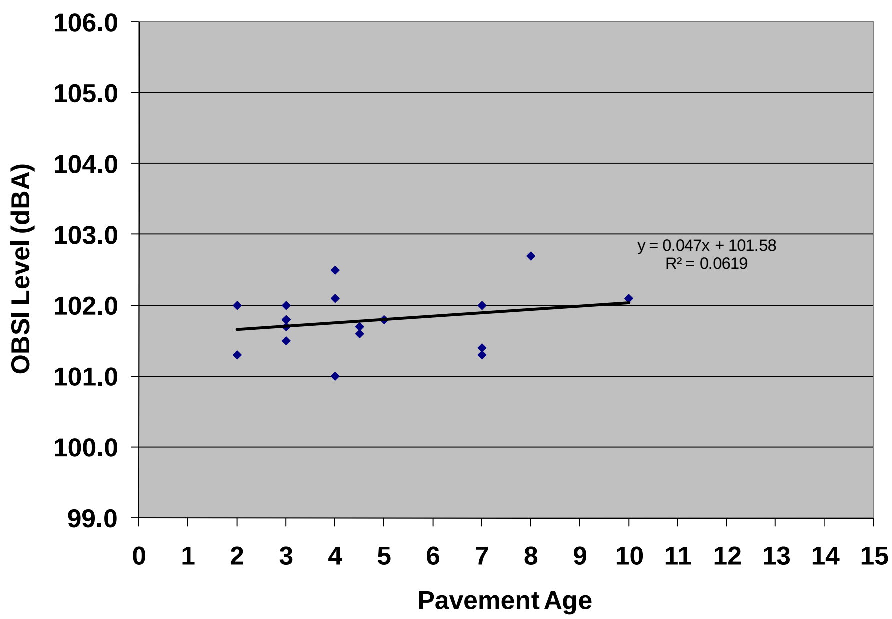

Figure 14. Acoustic durability of conventional diamond-ground projects in Kansas.

Anisotropic Friction Behavior

The NGCS texture consists of a flush ground surface that has grooves on 0.5-in. (13-mm) centers. Although currently the grooves do not provide a significant benefit from a noise perspective, there is a belief that they would provide additional benefit in regards to wet weather accidents.

Historically, studies have indicated that grooved pavements have demonstrated reductions in wet-weather accidents, often times with little or no change in ribbed tire friction values. The conundrum of the increased safety with little or no additional apparent improvement in friction value has always been difficult to explain.

To investigate this further, the IGGA contracted with MACTEC, Inc., to conduct friction testing using the California Test Method 342. This rather unique device, illustrated in Figure 15, allows friction to be measured at various angles to the centerline direction over a reasonable area. With this approach it is possible to gain insight into the anisotropic friction behavior of selected textures.

One end of the device is attached to the hitch of a pickup truck with a hitch that allows the device to pivot from directly behind the vehicle (e.g., in the direction of traffic) to 90 degrees to the centerline. Testing is conducted by lifting the wheel to 6 mm (0.24 in.) above the pavement, attaining a speed of 50 mi/h (80 km/h), dropping the wheel to the pavement, and measuring the distance the wheel travels along the pavement.

Once the wheel is dropped, there is no additional energy supplied to the wheel, so the kinetic energy of the wheel is transformed into potential energy of the springs that attempt to restrain the wheel. The distance traveled is a function of the friction level and kinetic energy of the wheel. Since the kinetic energy of the wheel is always known and constant, the distance relates directly to the friction level of the surface under investigation.

Testing was conducted at five angles (0, 15, 30, 45, and 90 degrees) at each test location. Three test locations were obtained for each surface type. For each test location, except the Astro-turf, the 0-degree test was repeated upon completion of the 90-degree test to evaluate repeatability of the equipment. During the evaluation, 117 friction tests were conducted.

A shortcoming in the data collection effort was that the test procedure requires testing to be conducted at temperatures above 40 ^{o}F (4.4 ^{o}C). Because of the time of year in which testing was conducted, this was not possible; testing temperatures were in the range of 33–35 ^{o}F (0.5 to 1.6 ^{o}C) on pavements of variable wetness.

To minimize the viscosity problem associated with the lower temperatures, friction was expressed in terms of a friction index as indicated in Figure 16. The friction index is derived by dividing the friction value obtained at the specified angle by the friction value obtained at 0 degrees (i.e., the direction of travel). Friction indexes greater than 1 indicate an increase in friction compared to the direction of travel, and lower indices, less friction.

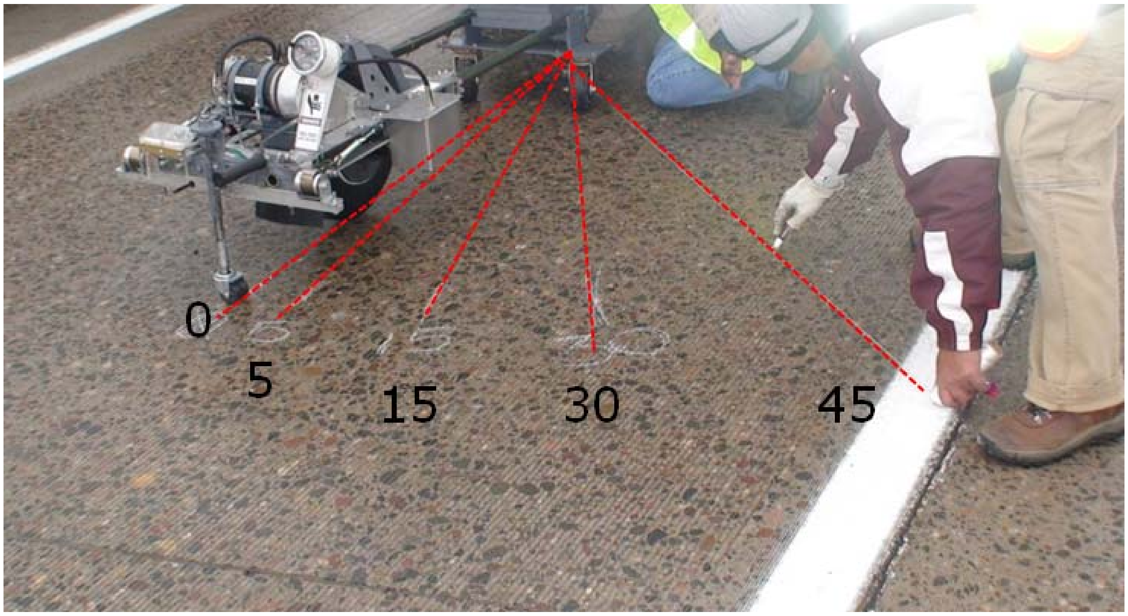

Figure 15. Photo of California CT-342 test device and selected angles of testing.

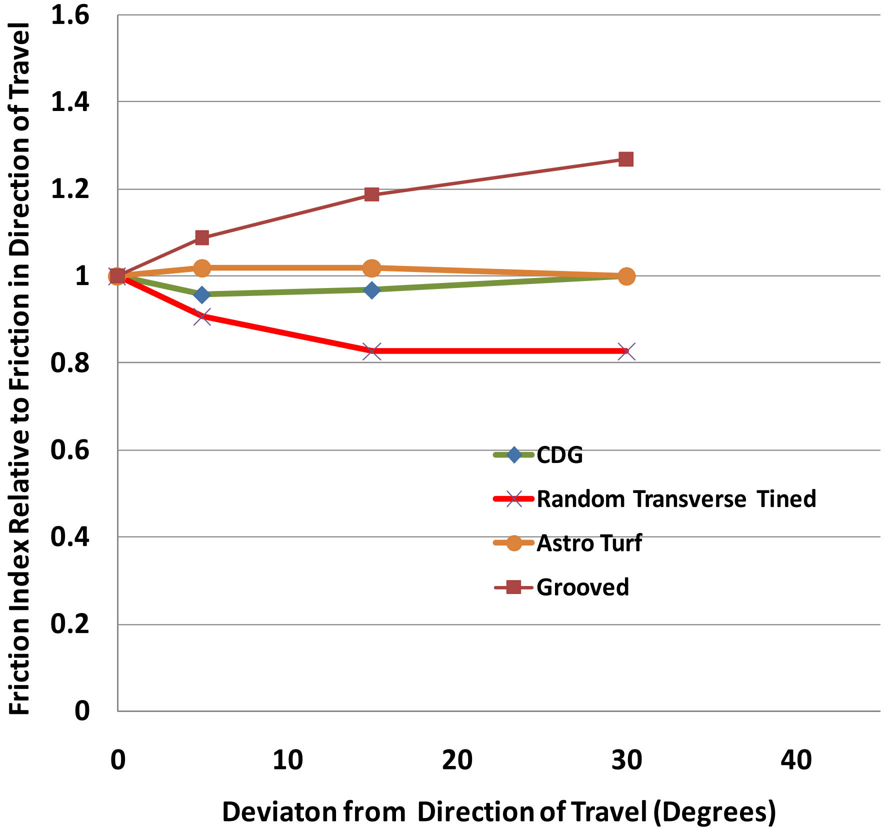

Figure 16. Friction index as a function of deviation from the direction of travel (uncorrected for cross slope).

The grooved textures exhibited an increase in friction as the device was oriented at an angle to the direction of travel (i.e., anisotropic behavior). This would suggest that the grooves are providing additional benefit for vehicles attempting to lose control since the friction increases. The Astro-turf and CDG, on the other hand, appeared to behave more like isotropic surfaces in regards to friction and indicated no apparent difference in direction. The random-transverse-tined pavement decreased in friction in regards to increasing deviation, which is consistent with what would be expected as the tines are already at right angles to the direction of traffic.

At this time these results should be considered preliminary until the experiment can be repeated under more favorable environmental conditions that allow complete adherence to the test procedure and employ replication of the results. It should also be noted that the CT-342 test method uses glycerin on the surface in the test method.

NGCS Lite—The Renewable Surface

As previously mentioned, the NGCS LITE surface was developed to provide additional microtexture on existing NGCS surfaces should it become necessary to do so. With the large land size of the NGCS surface, the texture wear has been assumed to be less than occurs on CDG surfaces. As such it should have extended life in comparison to CDG. The NGCS LITE surface provides an easily renewable surface that can be "touched up" in less time and costs than a CDG surface. Very little material is removed to create this surface, providing a significantly faster operation. It is intended as a perpetual surface strategy.

The first test section of the NGCS LITE surface was constructed in October 2008, and it became too cold to use proper OBSI equipment. Noise results will be available in spring 2009.

SUMMARY AND CONCLUSIONS

The NGCS diamond-ground surface, although only 1 year in implementation, has successfully demonstrated that it is a low-noise concrete surface. The NGCS, resembling a "manufactured surface," provides its low-noise benefits when initially constructed and does not require a wear-in period to break the fins down. In the test sections constructed to date, the NGCS begins approximately 1 to 4 dBA quieter than a CDG surface and is approximately 0 to1 dBA quieter after the 1st year. More time is necessary to establish the acoustic performance of the NGCS pavement, but as with CDG surfaces, the acoustic performance is not expected to change within the first 10 years of its construction when implemented on well-designed concrete pavements.

The early friction results of CDG surfaces have been superior to the NGCS surface. The NGCS surface smooth-tire results have not changed since construction, while the CDG, which started out much higher, is decreasing. At 1 year, the CDG still provides excellent friction results, as does the NGCS.

The potential benefit of anisotropic friction behavior of the NGCS (longitudinally grooved) surface needs to be further evaluated and verified as this may provide additional safety to the traveling public.

The ability to improve and maintain the NGCS surface over time is an important advantage, as it provides a renewable maintenance strategy that can be economically constructed. The efficacy of the perpetual surface strategy will require continued evaluation during 2009.