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Development and Deployment of the Next Generation Concrete Surface

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"Moving Advancements into Practice"

MAP Brief January 2020

Best practices and promising technologies that can be used now to enhance concrete paving

Development and Deployment of the Next Generation Concrete Surface

Introduction

The Next Generation Concrete Surface (NGCS), introduced in 2007, is the latest innovation in concrete texture. It was conceived as a manufactured texture whose properties are consistent and predictable, and it represents the quietest non-porous concrete texture developed to date. At the time of construction, NGCS is typically 99 dBA in noise level and has a typical range up to 103 dBA over time. The NGCS has been in service for 12 years and has been constructed in 15 states and three countries. Over four million square yards have been constructed worldwide. Figure 1 illustrates the NGCS surface (left) and a conventional diamond-ground surface (right).

Background

It has often been said that necessity is the mother of invention, and this was also true for the development and deployment of NGCS. Historically, concrete pavements first utilized burlap drag textures, which served their purpose when traffic levels and speed were lower than they are today. These surfaces were quiet; however, with higher levels of traffic and increasing truck levels, friction began to surface as an issue. To address this, tining was used to increase the pavement's macro texture, subsequently improving friction.

By the 2000s, it became apparent that asphalt noise desirable textures were receiving greater attention as the quiet surfaces, and concrete pavements were associated with noisier pavements due to the tonal issues associated with transverse tining. When Arizona decided to cover up the freeway system of the fifth largest city in the U.S. (Phoenix) in 2003, the noise issue was elevated to a new level for the concrete industry.

There was also growing interest among the transportation industry in the use of quiet pavements as a substitute for more expensive noise walls. This presented a significant threat to the use of concrete pavements in major metropolitan areas where concrete was traditionally used. To address this growing threat, the Portland Cement Association (PCA) provided $2.1 million dollars to the American Concrete Pavement Association (ACPA) for the development of a solution to the noise issue. Several projects evolved from this funding, with research conducted by Purdue University between 2006 and 2009 as the flagship project (1).

PCA funded Research Program

Field Test Section Evaluation

At the time the research effort began, tire-pavement noise was measured by placing

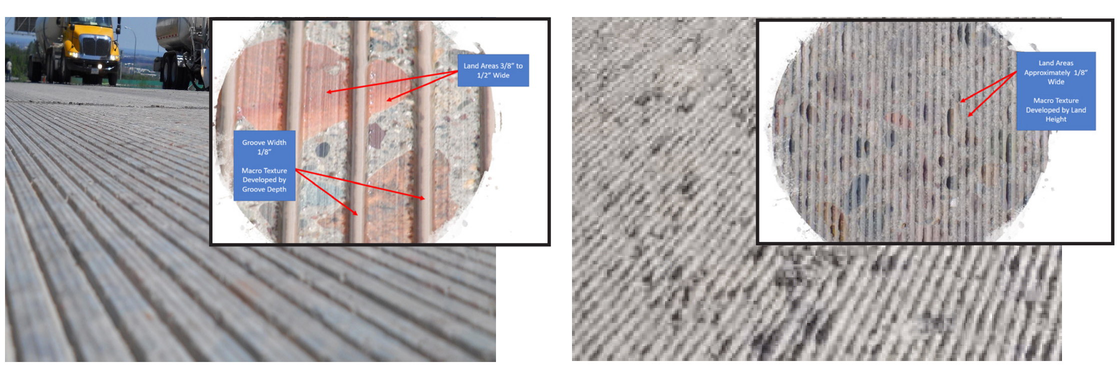


Figure 1. Photos of NGCS surface (left) and conventional diamond-ground surface (right)

microphones alongside a roadway in the right-of-way and measuring traffic noise as it passed by. However, this approach did not differentiate tire-pavement noise from other traffic noises such as exhaust, engine, etc. More importantly, this approach is very expensive and difficult to implement. As a result, the ACPA needed to acquire On-Board Sound Intensity (OBSI) testing capability to assess current and future pavement textures.

The GM OBSI equipment was a single-probe design and required two passes over a test location for a result. This was not efficient when attempting to do network-level testing. As a result, ACPA partnered with the Cement Association of Canada to fund the development of a vertical, dual-probe OBSI system (Figure 2). Once completed, ACPA worked with Caltrans and Dr. Paul Donavan to validate the efficacy of the dual-probe OBSI system. The system, developed by ACPA, proved successful and was the first use of an open-air dual-probe OBSI system. This device later became the AASHTO standard for tire-pavement noise measurement. ADOT had previously used a dual probe installation within an enclosure.

Figure 2. Comparison of GM (left photo) and ACPA (right photo) OBSI Equipment

Laboratory Testing

Existing Pavement Texture Evaluations

ACPA's major noise effort was a three-year contract (2006-2009) with Dr. Robert Bernhard of Purdue University to develop quiet pavement textures for both existing and new construction. Purdue University's Herrick Laboratory had a purpose-built Tire-Pavement Test Apparatus (TPTA) for this need. This device was unique in that it allowed testing of textures without the need to construct expensive test sections, provide traffic control, or incur the attendant safety issues with evaluating in-service pavements. It also allowed testing under controlled environmental conditions and better instrumentation capability.

The TPTA, shown in the right-hand side of Figure 3, consists of a 38,000-pound, 12-foot-diameter drum 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 test samples at varying speeds while OBSI microphones record data. As indicated in Figure 3, two-wheel tracks were constructed on each of the six curved test panels, allowing 12 surface textures to be tested in one setup. Testing was conducted at speeds ranging from 10 to 30 mph and temperatures ranging from 60° -80° F.

The left-hand side of Figure 3 indicates the diamond grinding head used for grinding. It produced an 8-inch-wide diamond ground surface. Typical diamond grinding units grind 3 ft and 4 ft wide and use 50-60 blades per foot. To fully "stack" a head, it can take 6-8 hrs. The use of a small, 8-inch-wide head tremendously reduced the blade cost and set-up time. When comparing different grinding blade/spacer configurations, this was a very important consideration. Note that testing with two different tire types at the same time was also possible.

Figure 3. Purdue TPTA and IGGA Grinding Head (1)

Figure 4 indicates the OBSI equipment used to measure tire-pavement noise and the RoLineTM laser used to measure texture profiles. The left-hand side of Figure 4 shows the OBSI equipment mounted to the test tire support frame and the right-hand side shows the texture measurement system.

It is important to note the Purdue testing was conducted at a maximum test speed of 30 mph which is only half the speed of OBSI testing conducted in the field (60 mph), so the results are lower than reported by field testing. This also created a risk regarding the predictive capability of the TPTA to represent in-service conditions. TPTA lab results could not be validated until test strips were constructed, at which time the results were validated.

Diamond Grinding Texture Evaluation and Research (1)

The first phase of the research consisted of identifying common blade and spacer widths used in the industry and testing various combinations to determine the effects of blade width, spacer width, and grinding depth on tire-pavement noise gen-

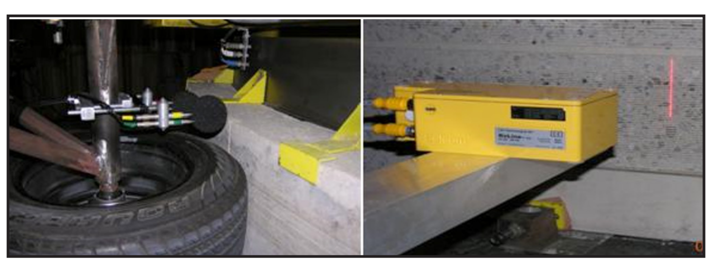


Figure 4. OBSI and Line Laser Texture Measurement on Purdue TPTA (1)

eration. To accomplish this, four blade widths, four spacer widths, and two grind depths were evaluated. To conduct OBSI testing, two tire types were used; an Aquatred 3 and a Uniroyal Tiger Paw. The Aquatred tire results were consistently 1.5 - 3 dBA higher than the Uniroyal Tiger Paw results indicating tires interact differently with different textures.

Effect of Grind Depth on OBSI Level (1)

The effect of two different grind depths, 1/8 in. and 3/16 in. were evaluated. On four of the six tests, the shallower grinding depths had lower OBSI levels. The shallower grinds are on average 0.5 dBA lower in level, but no firm conclusions could be drawn.

Effect of Blade Width on OBSI Level (1)

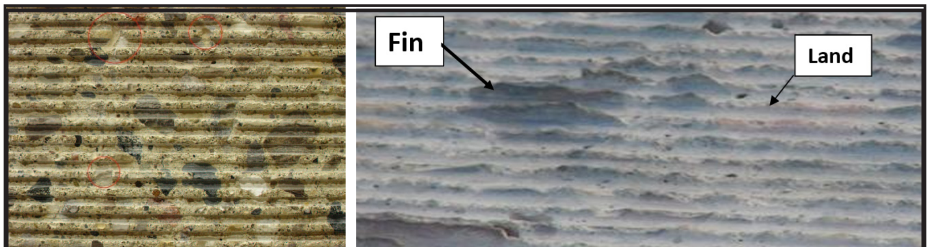
The effect of blade width was investigated by grinding samples with identical depths and spacer widths. The results indicated blade width affects overall level, but it is neither consistent nor predictable. Half of the time wider blades were quieter, and half the time narrower blades were quieter.

Effect of Spacer Width on OBSI Level (1)

The effect of spacer width on overall noise level was investigated by grinding samples using the same blade widths and grinding depths and varying the spacer widths. The results indicated the narrower spacer produced quieter results in 5 of the 6 cases with the difference being less than 1 dBA in most cases. However, it should be noted that only one concrete mixture was tested.

Initial Purdue Findings (1)

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 factor was the variability in the fin/land profile height resulting from the grinding process. This was the breakthrough. The left image of Figure 5 is a close-up photo of the fin/land profile of one of the Purdue grinds. The red circles indicate locations where the fin/land had broken off causing a variation in the profile. It was this observation that suggested to the researchers that this was causing increased noise levels.



Breakouts in CDG Fins/Lands during Purdue Testing | Variability of Fins/Lands on CDG Surface on MN-ROAD I-94 Surface

Figure 5. Variability in Fins/Lands/Breakouts in CDG Texture

The right side of Figure 5 indicates an actual diamond ground pavement just after grinding, and before any fins are broken 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 this fin profile variability that affected tire-pavement noise generation. Textures with low variability were quieter than textures with high variability. In conventional diamond grinding (CDG), the resulting fin variability is influenced by the blade/spacer configuration, the concrete mixture, aggregate type, pavement condition, equipment set up, operator skill, etc. This makes it very difficult to control from an experimental standpoint.

Development of A New Diamond Grinding Texture (NGCS)

To evaluate this hypothesis, a surface with essentially no positive (i.e. upward) texture was conceived. That is, the surface would be diamond ground smooth and then additional texture imparted by grooving. In this manner, the exact land profile could be controlled/anticipated at the time of production, unlike conventional diamond ground (CDG). A second phase of research was initiated to verify the new concept.

Fin/Land Wear Study (1)

Concurrent with initiating a second study to develop a new texture, a small fin wear study was initiated to evaluate the effects of micro texture and macro texture on the overall noise levels. The conclusions of this effort indicated that removing the micro texture by polishing the surface increased the overall noise level. Reducing the macro texture to promote a uniform fin profile reduced the overall level. This supported Purdue's hypothesis and attempted to explain the associated mechanisms.

Development of the NGCS Surface (1)

Purdue embarked on a second round of testing which had several objectives; the first was to evaluate additional conventional diamond ground textures. The Purdue hypothesis was not readily accepted by industry. The diamond grinding industry in 2002 and 2003 promoted a whisper grind technology developed in Belgium. This texture promoted the use of wider spacers and test sections were constructed in both Arizona and Kansas. This concept conflicted with the Purdue hypothesis, so additional conventional diamond grinding textures were evaluated.

A second goal was to investigate the effect of longitudinal grooving on OBSI level and to evaluate the noise generation characteristics of a blank specimen. A third goal consisted of evaluating different techniques by which a controlled profile could be constructed. The objective was to develop little to no macro texture but good micro texture. Grooves were included to produce negative (i.e. downward) macro texture.

Ten more samples were tested with various combinations to compare additional conventional grinding and various forms of what would become the NGCS surface. The results indicated the NGCS surfaces to be the quietest surfaces.

Two groove widths were evaluated, 1/8 in. and 1/4 in. wide. The results indicated wider grooves generate more noise, but they affected the two test tires differently. Since the two tire types responded quite differently to the grooving pattern, the effect of grooving may be insignificant from a noise perspective considering the multitude of tire types in the fleet.

Effect of Transverse Joint Opening Width (1)

One aspect of the Purdue research was to evaluate the impact of joint opening width and sealant recess on the resultant overall tire-pavement noise. The joint slap research indicated that the resulting transient joint slap effect increased with increasing joint opening width and sealant research, but the impact was also a function of the existing texture noise level.

Effect of Joint Faulting (1)

The Purdue work indicated that step-off faulting (e.g. the departure slab is lower than the approach slab) condition creates more joint slap than the step-up fault condition. This is unfortunate since the typical fault condition is the step-off condition. A ¼ inch fault level can add approximately nine dBA to a quiet pavement surface while only adding approximately two dBA to a very noisy surface.

Effect of Joint Sealing (1)

One of the effects discovered by Purdue was the pronounced influence that sealant recess or existence has on overall tire-pavement noise level. Both sealant recess depth and joint opening width contribute to joint slap, and its magnitude is based on the noise level of the existing textures.

Proof of Concept Field Testing

When the new texture (NGCS) was tested on the TPTA, it produced the quietest diamond ground surface evaluated. This was a breakthrough in the research as it verified, for the first time, what the controlling factor was for tire-pavement noise generation of diamond ground surfaces; namely the fin or land profile.

However, reality soon set in. The Purdue work consisted of grinding an 8-inch-wide wheel path for 6 ft with a water hose cooling the head for each of the specimens. When grinding such small areas, the heat generated by the blades/head is not excessive. However, when diamond grinding a pavement with a conventional machine, with a 3 ft or 4 ft wide head, this is not the case. The typical 1/8-in. opening provided by a spacer between the grinding blades allows water to circulate between the cutting blades, 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-inch-wide head such as Purdue's, this is not prohibitively expensive. To do it with a 3 or 4 ft wide grinding head would be expensive and a risky investment for an unproven strategy. The Purdue research indicated that the flush grind/grooved texture could produce a quieter texture, but it could not verify whether it could be constructed with conventional equipment in the field.

The Purdue testing was also limited to a maximum test speed of 30 mph. One concern that persisted was whether the TPTA results would be validated at higher test speeds such as 60 mph. So not only was constructability a question, but also the efficacy of the Purdue TPTA to predict in-service performance.

At the time, most of the grinding industry did not believe the Purdue texture (NGCS) could be constructed by conventional diamond grinding equipment. It wasn't until Diamond Surface, Inc. stated they would construct it, did implementation become a reality. The IGGA subsequently funded Diamond Surface to construct a test section.

Prior to attempting field validation, Purdue evaluated two grinding/grooving configurations to create the NGCS texture; a single pass and a double pass process. The purpose for the two different configurations, designed to achieve the same result, was to allow consideration of either option by contractors during field construction. Both surfaces produced similar results on the TPTA, so field trials were pursued for both options.

The opportunity to construct field test sections became a reality when the Minnesota DOT approved an ACPA proposal to construct a test strip at the MnROAD 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 head designed for curb cuts. This device not only allowed for fewer blades to be used, but it was designed to allow quick blade changes. Blades could be changed in approximately 45–60 minutes as opposed to 6 to 8 hours on conventional grinding equipment.

Three test strips were constructed on MnROAD cell 37 as a proof of concept test. Two NGCS surfaces and a conventional diamond grind surface were ground into the existing transverse tined pavement surface allowing comparison of four texture types. Although the TPTA work was conducted with 0.09-inch-thick blades, this was felt to be impractical for field work and instead, 1/8 inch blades used for the test strip construction.

The purpose of the test strip construction was threefold: First, to verify the hypothesis that controlling the texture (e.g. 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 third objective was to confirm the substitution of 1/8 inch blades provided similar or identical results.

The test strips validated both that the Purdue texture (NGCS) was 3 dBA quieter than conventional diamond grinding at the time of construction, and that the Purdue TPTA results could be reproduced in the field using conventional equipment (1). It also confirmed the substitution of the wider 1/8-inch blades was acceptable. The NGCS texture was 5 dBA quieter than the existing uniform transverse tining (1). MnROAD personnel conducted friction, texture, and profile testing on the test strips verifying the acceptability of the other surface characteristics properties.

Effect of Joint Sealing on Tire Pavement Noise (1)

Three attempts were made to validate the Purdue joint slap predictions in the field. The ACPA field testing at the MnROAD facility indicated that sealing of the transverse joints resulted in approximately a ½ to one dBA reduction in noise level for the approximately 0.4 inch wide joint. This improvement was seemingly independent of the surface texture noise and therefore did not confirm the Purdue work.

Chicago I-355 NGCS Construction

With the validation of the TPTA results, the next step was to construct roadway test sections using conventional diamond grinding equipment on in-service pavements and this was accomplished on I-355 in Chicago in October 2007. At that time, NCHRP 10-67 was constructing 12 concrete texture test sections on I-355 and a NGCS test section (i.e. 13) was constructed to tie into the NCHRP work. The NCHRP project included test sections for most current concrete textures in use at the time and this allowed a direct comparison of NGCS to these textures.

To evaluate the impact of the grooved NGCS surface on antilock braking (ABS), stopping distance testing was conducted by the University of Michigan Transportation Research Institute (UMTRI) in 2007. UMTRI conducted the testing with an instrumented SUV vehicle at the Chicago I-355 site while the roadway was closed during construction (Figure 6). Stopping distance testing was conducted to ensure there would not be any issues with deployment of this technology. ACPA also had E-274 locked wheel skid testing conducted

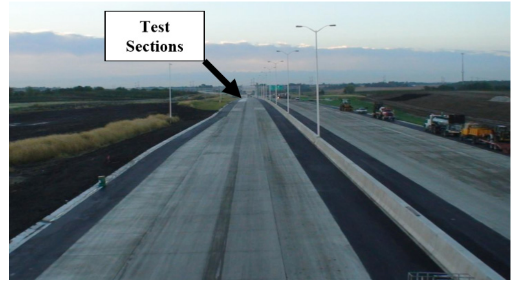
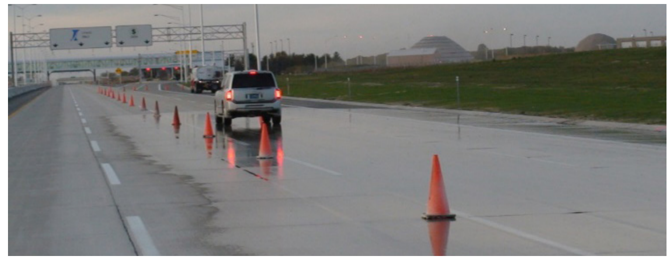


Photo of I-355 Test Section Location



Stopping Distance Testing with Instrumented Vehicle

Figure 6. Chicago I-355 NGCS and Other Test Sections (1)

on several of the surfaces for comparison. All results were satisfactory, and deployment continued.

MnROAD I-94 Test Sections

Soon after the I-355 test section construction, NGCS and CDG test sections were constructed on MnROAD I-94. The test sections were each two-lanes wide by 500 ft in length and constructed in a single pass operation on a 14 year old random transverse tined pavement in October 2007. ACPA and MnROAD subsequently conducted extensive evaluations of these and other grinding test sections.

NGCS Deployment (1)

The Minnesota DOT was the early implementer and biggest initial user of NGCS surfaces with MnROAD test section construction and several projects. They were also early researchers in evaluating NGCS performance. Other states quickly followed.

In 2008, NGCS test sections were constructed in Kansas and Wisconsin and in 2009 in Oklahoma and Minnesota. It appears that 2010 was an early tipping point for NGCS construction with four states (MN, AZ, WA, IA) constructing NGCS test sections. By 2012, Caltrans was the biggest user of NGCS surfaces at the time.

The first NGCS construction that was bid as a conventional project occurred in Wisconsin on SR21 near Omro in 2008. The first large construction project (104,000 sq yds) occurred in Duluth, Minnesota in the summer of 2010. In 2016, Texas became the world's leader in the use of NGCS surfaces with over three million square yards placed in Houston, Texas.

South Korea is a close second, with over one million square yards in use. South Korea's use is unique in that they install it in their highway tunnels. To date, NGCS has been placed in 15 U.S. states (see Figure 7) and three other countries including Australia and Canada. Four states have conducted research efforts studying NGCS performance: Minnesota, California, Virginia, and Texas.

Results of Recent Quiet Pavement Research Programs

Texas: Houston, Texas, the fourth largest city in the U.S., has very heavy urban traffic with major routes such as the 610, 290 and I-10 (Katy Freeway) extending through the urban area. The Katy Freeway (I-10), with the recent lane additions, is now the widest freeway in the world and is 16 lanes wide (including service roads) along a three-to-four mile stretch where it abuts several small villages.

When major improvements of these corridors began, noise was a significant concern for the communities. The existing roadway surfaces had been constructed with transverse tining which was creating excessive noise for abutting properties. Serious concern existed at the beginning of the corridor improvements regarding the impact of additional future capacity (traffic lanes). As such, TXDOT proposed to install NGCS to reduce tire-pavement noise generation and the communities supported this concept; the City of Houston and four affected villages along the corridor contributed funding in addition to the TXDOT funding.

When NGCS construction first began, TXDOT contracted with the University of Texas San Antonio to study the performance of NGCS, by comparing data collected before and after grinding on a test section located in Harris County, Houston, Texas. The study, which occurred between 2014 and 2016, evaluated the NGCS performance in terms of macrotexture, ride quality, skid resistance and tire-pavement noise. Unfortunately, due to construction scheduling, only pre NGCS measurements and 3- and 6-month post NGCS construction measurements were obtained on a ¾ mile segment of 610.

The study results, shown in Figure 8, indicated the average overall noise reduction from NGCS installation on the 610 was approximately 6 decibels which is equivalent to a 75% reduction in noise level (2). The ride quality (roadway smoothness) improved between 90 to 200 percent (2). The average overall improvement in friction was 35% (2). The macrotexture improved approximately 25% (2).

Virginia (3): Between 2011 and 2015 the Virginia DOT constructed pilot projects to evaluate both AC and Concrete Quieter Pavement Technologies as result of a legislative mandate. The mandate required VDOT to assess the quieter pavements' ability to reduce transportation noise and evaluate the functionality and public safety ramifications of these technologies in Virginia's climate.

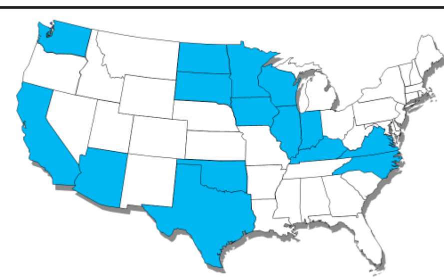
The AC quiet pavement applications, involved design, production, and placement of new materials. For the concrete quieter pavement sections, older existing roadways were used. This was unfortunate as one of the concrete projects began failing before the 3.5 to 4-year evaluation period ended. For all the pilot projects, ride, noise, and friction were evaluated.

As of June 2015, the NGCS concrete surface continued to have a noticeable (approximately 4 dB) advantage over the standard concrete finish (transverse tining) and a 1 dBA advantage over the CDG as shown in Figure 9. As indicated, the friction levels for all surfaces were satisfactory.

California (4): Between 2010 and 2013, Caltrans constructed seven NGCS pilot projects as part of their quieter pavement research program. One project was constructed in each of San Diego, San Joaquin, and Yolo Counties and four in Sacramento County.

To evaluate these projects, Caltrans contracted with UC Davis to perform the research. The evaluations were coordinated with the construction of each of the pilot sections so that a pre and post evaluation of the projects could be made. The pavement surface characteristics evaluated were tire-pavement noise, ride quality, friction, and drainability/macrotexture with the major emphasis on noise reduction and ride improvement.

NGCS Surface



States in Blue have Constructed NGCS Surfaces

Figure 7. Photo of NGCS Surface and Map of States Deploying It

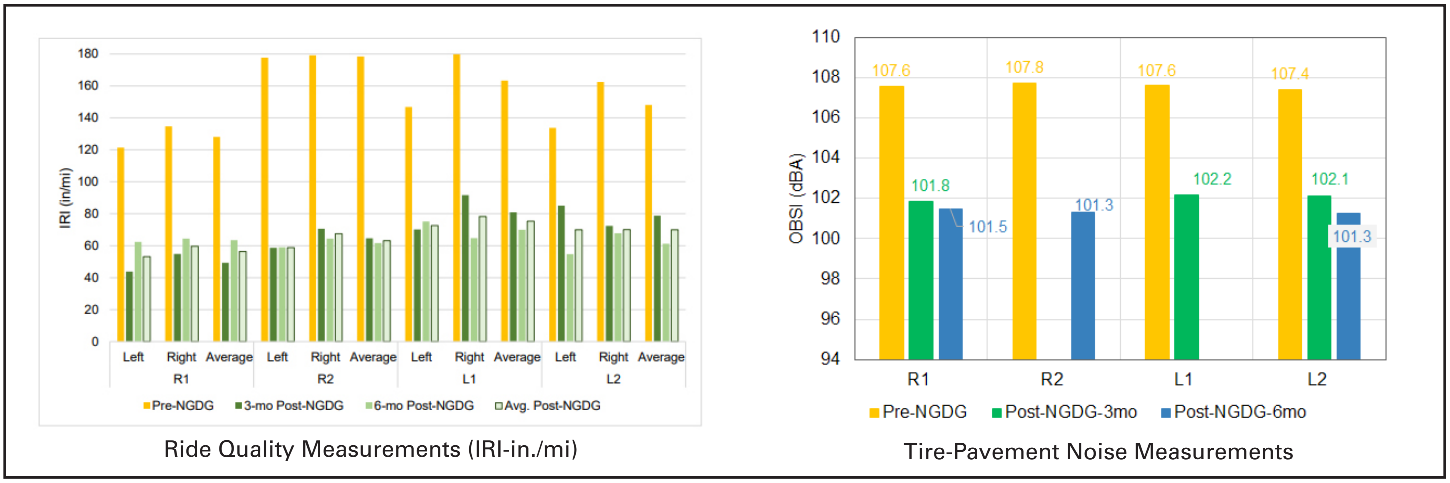


Figure 8. TXDOT 610 Before and After Ride Quality and Tire-Pavement Noise Measurements (2)

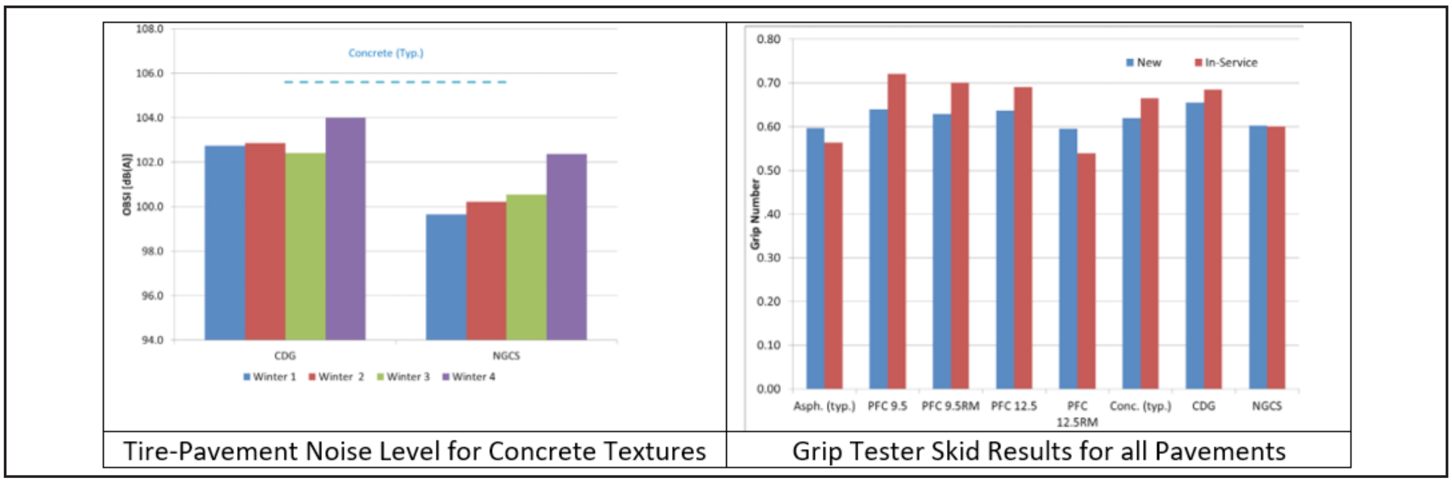


Figure 9. VADOT Tire-Pavement Noise and Friction Test Results

At five of the seven locations, both conventional diamond grinding (CDG) and NGCS surfaces were constructed enabling a comparison of both techniques to the existing pavement.

The results of the study indicated that the NGCS as-constructed tire-pavement noise level ranged from 99.5 to 101.7, with an overall average of 100.8 dBA. The CDG surface exhibited a range of 100.6 to 104.7 with an overall average noise level of 102.8. The NGCS surface exhibited a 2 dBA lower tire pavement noise than conventional diamond grinding. The NGCS exhibited almost a 4 dBA noise reduction over the existing surfaces. A 3 dBA change is usually required for a noticeable difference by human hearing.

The research also indicated that while the CDG texture shifted the noise (OBSI) frequency spectrum down across all frequencies, the NGCS texture tended to reduce noise more in the frequencies of 1,000 Hz and below. This shifted the peak noise to a higher frequency. As a result of these changes in the noise spectrum, the NGCS texture caused both a reduction in total noise and a change in the tonality of the noise to slightly higher pitches.

Summary

The Next Generation Concrete Surface has remained essentially the same since 2007 when Purdue created it, except for the substitution of wider grooving blades. NGCS improvements for future consideration include returning to narrower grooving blades which current technology has now made possible.

The first test section with the narrower blade technology recently occurred on a test section on SR101 in Phoenix, Arizona. Similarly, most NGCS construction is conducted with the two-pass operation and additional development should be focused on blade technology which would allow single pass construction and a more economical NGCS. Currently NGCS is significantly more expensive than conventional diamond grinding, particularly if a pre-grind is necessary. Costs are predicated on many things and estimates can be provided by available contractors with experience in the area.

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