Evaluation of Long-Term Pavement Performance and Noise Characteristics of the Next Generation Concrete Surface: Final Report

WA-RD 767.2

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WSDOT Research Report

Experimental Feature Report

Final Report: Experimental Feature WA 10-03

Evaluation of Long-Term Pavement Performance and Noise Characteristics of the Next Generation Concrete Surface: Final Report

Contract 7885
I-82
Granger to W. Grandview EB – Dowel Bar Retrofit and Concrete Rehab
MP 57.85 to MP 72.58

Washington State Department of Transportation

Engineering and Regional Operations
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15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report documents the performance of the first Next Generation Concrete Surface (NGCS) built by the Washington State Department of Transportation (WSDOT). A 1,500 foot test section was installed on the eastbound lanes of I-82 near Sunnyside, WA in October of 2010. On-board sound intensity (OBSI) measurements increased from initial levels of 100.6 dBA to 104.4 dBA in 30 months. The increase in noise level was attributed to the loss of aggregate and general roughening of the concrete surface by studded tires.

It was concluded that the NGCS is not a viable option as a noise mitigation strategy for Washington State.

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Introduction

This report documents the performance of a section of Next Generation Concrete Surface (NGCS) installed on I-82 near Sunnyside, Washington. NGCS is a new method of diamond grinding that has produced the quietest concrete pavement surfaces tested to date. This project was part of an effort by WSDOT to test new methods of decreasing noise generated from tires rolling over pavements. Noise can be reduced by changing the texture of new or existing concrete pavements or, in the case of asphalt pavements, by using special open graded asphalt mixes. Table 1 summarizes the quieter asphalt projects and the projects that have used different concrete finishing methods to combat noise.

Table 1. Projects with quieter asphalt or concrete pavement features.

Construction Year	Project	Feature Installed
2004-2005	I-90, Spokane, Argonne Rd to Sullivan Rd	Carpet drag texture
2005	I-5, Federal Way, Federal Way to S. 317th Street HOV Direct Access	Carpet drag texture
2006	I-5, Federal Way, Pierce County Line to Tukwila I/C – HOV – Stage 4	Carpet drag texture, longitudinal tining
2006	I-5, Lynnwood, 52nd Avenue West to SR 526 - Southbound	Open graded friction course mixes with recycled rubber and polymer additives
2007	SR 520, Medina, Eastside Quieter Pavement Evaluation Project	
2009	I-405, Bellevue, 112th Avenue SE to SE 8th Street	
2009	I-90, Lake Easton Vic to Bullfrog Rd I/C Vic WB – Replace PCCP	Longitudinal tining, conventional diamond grinding (CDG)
2010	I-405 Bellevue Design Build	Longitudinal tining
2010	US 395 North South Connection in Spokane	Longitudinal tining
2010	I-82 Sunnyside	NGCS and CDG

Background

The NGCS was developed through the combined efforts of the American Concrete Paving Association (ACPA), the Portland Cement Association (PCA), and the International Grooving and Grinding Association (IGGA). This effort was initiated in response to the efforts by the asphalt paving industry and various state DOTs to produce quieter asphalt pavements. The research effort was split into two phases, a laboratory phase that investigated the noise generated from different diamond grinding textures, and a field trial phase that saw the installations of the newly designed texture at various U.S. sites.

Laboratory Phase

The laboratory phase of the research was conducted at Purdue University's Herrick Laboratories beginning in 2005. The work investigated the variables that affected tire-pavement noise generation characteristics of diamond-ground surfaces (1). The Tire Pavement Test Apparatus (TPTA) was used to perform the laboratory testing. As seen in Figure 1, the TPTA consists of a revolving drum onto which slabs of concrete are attached. Tires run on the surface of the slabs as the drum rotates at speeds up to 30 mph. On-Board Sound Intensity (OBSI) measuring equipment is attached near the tire-pavement interface to measure the noise in the same manner as it is used to measure tire/pavement noise on highways. Twelve different surface textures can be tested at one time using the TPTA.

Figure 1. Tire Pavement Test Apparatus (TPTA) located at Purdue University's Herrick Laboratory. (Photo from Purdue University website)

Initial research efforts focused on measurement of the noise produced from slabs prepared using existing methods of diamond grinding. It was thought that different configurations of the blades and spacers were the key to producing a quieter surface. Findings, however, indicated that the configurations of the blades and spacers were not the controlling factor in the noise that was generated (1). The controlling factor was found to be the fin profile of the diamond-ground surface. A fin is a positive texture (sticks above the surface) as contrasted with a groove which is a negative texture. Uniform and consistent profiles with a minimum of positive texture were found to be the key to a low-noise generating surface. A new surface was then designed that consisted of a uniform profile with only negative texture. This produced the lowest laboratory noise test results. The new surface was named the Next Generation Concrete Surface. Figure 2 shows a positive fin texture and Figure 3 the NGCS texture with its uniform flat land surfaces and negative texture grooves.

Figure 2. Positive fin texture produced by conventional diamond grinding. (1)

Figure 3. NGCS on I-82 with flat land surfaces and negative texture grooves.

Field Trial Phase

The field trial phase was used to verify the laboratory findings through the construction of test installations of the NGCS. Two methods, single pass and two pass, were developed to produce the NGCS grinding pattern in the field. The single pass method uses a blade configuration that grinds the pavement smooth and cuts the grooves in one pass. The two pass method grinds the pavement smooth in one pass and then puts the grooves in on the second pass. The two methods were developed to ensure that contractors would have the option of using the two pass method that might be easier on equipment if the pavement is very hard, or the more aggressive single pass method if conditions are such that the pavement is easier to grind (1).

The first field trial of the NGCS was at one of the test cells on the MnROAD Low Volume Road located west of Minneapolis in October of 2007. A grinding machine with a special head was used to cut an 18-inch wide strip the length of the test cell. Three strips were ground, one with the NGCS cut in a single pass, one with the NGCS cut using the double pass method and one with conventional diamond grinding (CDG). One strip was left as a control section with its existing random transverse tining. The results of OBSI testing immediately after the grinding was completed are shown in Table 2 (1).

Table 2. OBSI results from initial NGCS field trial at MnROAD Low Volume Road cell 37. (1)

Texture Type	2007 (dBA)
NGCS Double Pass	99.1
NGCS Single Pass	99.4
CDG	102.0
Random Transverse Tining	103.0

The I-355 Veterans Memorial Tollway in Chicago was the site of the first full-lane-width installation of NGCS. In October of 2007 a section 1,200 feet in length was constructed using the two pass method along with a companion control section of CDG. The OBSI sound intensity data from post-construction through 2011 is shown in Table 3 (2, 7). Note the consistency of the sound measurements across the four year span of time.

Table 3. Historical OBSI sound intensity readings from I-355 Veterans Memorial Tollway. (2, 7)						
Texture	**Post Const. (dBA)**	**2007 (dBA)**	**2008 (dBA)**	**2009 (dBA)**	**2010 (dBA)**	**2011 (dBA)**
NGCS	**99.6**	**100.5**	**100.9**	**101.2**	**100.7**	**101.3**
CDG	**100.2**	**100.7**	**100.9**	**-**	**100.2**	**-**

The next full-lane-width NGCS was installed on MnROAD's mainline I-94 Cell 7 in October of 2007. A control section of CDG was installed on adjacent Cell 8. OBSI data for these cells, shown in Table 4, includes follow up testing through 2011 (3, 7). Note again the consistency of the measurements over time for the NGCS. The much higher reading for the CDG right after construction followed by lower readings over time may be due to the presence of positive texture fins that are worn away over time.

Table 4. Historical OBSI sound intensity readings for MnROAD's cell 7 and 8. (3, 7)						
Texture	**Cell**	**2007 (dBA)**	**2008 (dBA)**	**2009 (dBA)**	**2010 (dBA)**	**2011 (dBA)**
NGCS	**7**	**100.1**	**99.0**	**101.1**	**99.8**	**101.1**
CDG	**8**	**104.3**	**100.7**	**102.1**	**101.8**	**-**

The next two projects constructed were in Wisconsin and Kansas. The Wisconsin NGCS was the first trial that was bid as a normal construction item and not as a change order or trial section constructed by the industry. Unfortunately, the Wisconsin project is on a low speed roadway through a small town making it impossible to safely test at 60 mph. The Kansas section on I-70 was part of a project that used the two-lift European technique for the construction of the concrete pavements. The two-lift technique uses lower quality aggregate in a thicker lower layer with a high quality aggregate in the thinner upper wearing layer. Seven test sections were constructed using various textures including NGCS and CDS sections as shown in Table 5 (4, 7).

Table 5. Post-construction OBSI sound intensity readings on the Kansas two-lift concrete pavement. (4,7)				
Texture	2008 (dBA)	2009 (dBA)	2010 (dBA)	2011 (dBA)
NGCS	99.4	100.5	100.9	100.6
CDG	101.7	102.1	102.8	102.3
Longitudinal Grooved	101.2	101.8	101.9	101.4
Carpet Drag	101.3	-	102.6	102.1
Longitudinal Tined	-	102.9	103.1	102.7
Exposed Aggregate	103.2	104.5	104.5	104.3

Mn/DOT built the largest project to date with 104,000 square yards of NGCS installed on a section of I-35 through downtown Duluth, Minnesota in September of 2010. The existing surface was a 20-year old pavement on one end and a 45-year old pavement on the other end. The initial OBSI test results are summarized in Table 6 (5).

Table 6. OBSI results from I-35 in Duluth, MN. (5)		
Texture	Direction	2010 (dBA)
NGCS	NB	100.5
NGCS	SB	100.2
Existing Pavement (transverse tined)		107.2

Concrete Pavement Noise Level Discussion

The range of OBSI noise readings from the various finishing and diamond ground textures from the American Concrete Paving Association is shown in Figure 4 (6). The noisiest concrete pavement texture is transverse tining which was the texture required by FHWA until recently (interest in producing quieter pavements resulted in a lifting of the requirement). The noise generated by this surface is typically in the 103 to 110 decibel range. Longitudinal tining, which many states including Washington are instituting as a replacement for transverse tining, is the next quietest texture at 101 to 106 decibels. Conventional diamond grinding is next quietest at 100 to 104 decibels, followed by the quietest, the NGCS at 99 to 101 decibels.

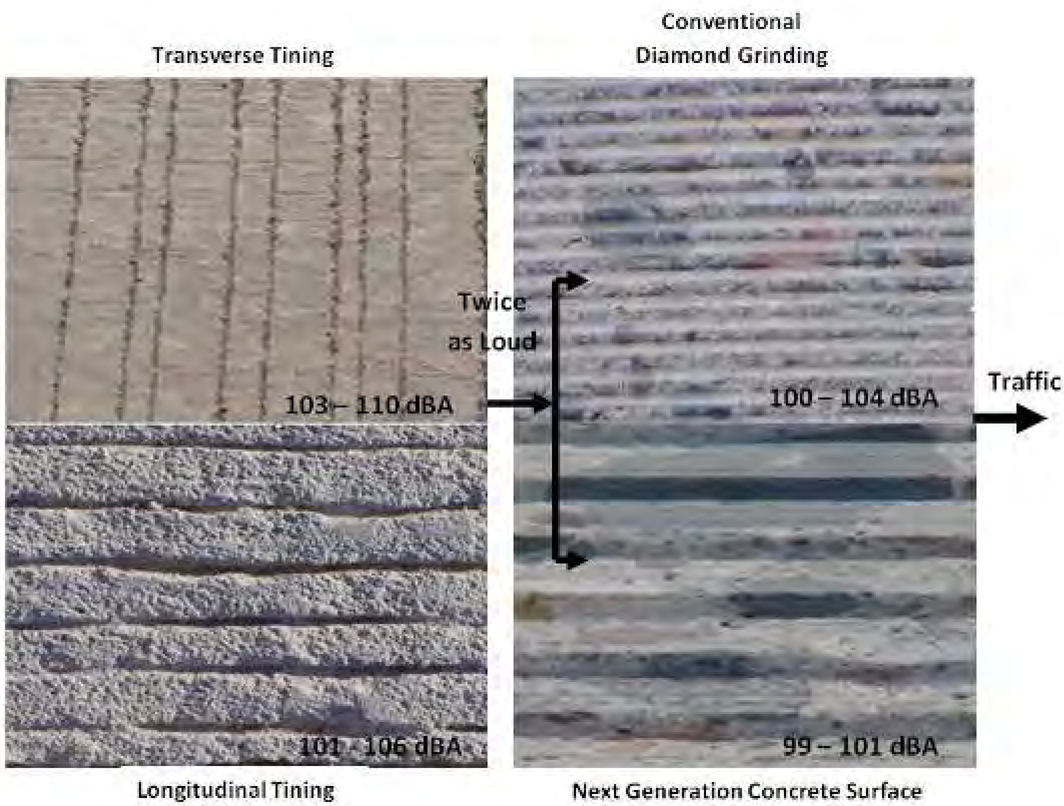

Figure 4. Two common concrete finishing textures, conventional diamond grinding and NGCS and their typical OBSI sound intensity readings. (6)

Table 7 shows sound level changes and how they affect loudness and acoustical energy. A three decibel difference is considered to be a perceptible change by most acoustical engineers; however, it is only changes greater than three decibels that are readily perceptible and a good target for any noise mitigation strategy. The NGCS at 99-101 decibels would be a big improvement over transverse tining at 103-110 decibels with a minimum difference of four decibels at the low end and nine at the high end of their relative noise ranges. The difference provided by the NGCS might not be as perceptible versus a longitudinal tined texture except at the high end of the longitudinal tining range. A perceptible hearing difference between a NGCS and a conventional diamond ground surface may be even less likely.

Table 7. Sound level change, loudness and acoustic energy loss. (6)		
Sound Level Change	**Relative Loudness**	**Acoustic Energy Loss**
0 dBA	Reference	0
-3 dBA	Barely Perceptible Change	50%
-5 dBA	Readily Perceptible Change	67%
-10 dBA	Half as Loud	90%
-20 dBA	1/4 as Loud	99%
-30 dBA	1/8 as Loud	99.9%

Project Location

Dowel bar retrofit and panel replacement was the primary focus of Contract 7885 under which the trial section of NGCS was installed. The project map and the location of the NGCS and CDG sections are shown in Figures 5 and 6.

Figure 5. Project map of Contract 7885, Granger to W. Grandview – Dowel Bar Retrofit and Concrete Rehab.

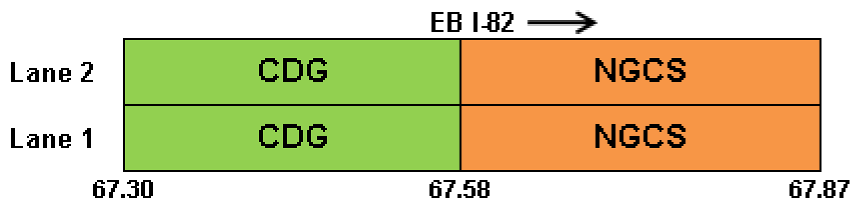

Figure 6. Plan map of the NGCS and CDG sections.

Construction

The dowel bar retrofit operations were conducted first followed by the diamond grinding to construct the NGCS. The contractor, Penhall Company, chose the two pass method due to the hardness of the aggregate in the pavement (see Appendix A). The first pass ground the pavement surface to a flush profile using a four foot grinding head stacked with 0.125 inch blades separated by 0.030 inch spacers (Figure 7). The second pass cut the longitudinal grooves using a grinding head with blades that were 0.125 inch wide and 0.125 inch to 0.375 inches deep. Spacers were used to separate the grooves 0.5 inches apart from center to center (Figure 8). The grooves were cut parallel to centerline. Observations and comments on the construction of the project as witnessed by Jim Weston, WSDOT Pavement Division, are documented in Appendix B.

Figure 7. Grinding head for the first pass flush grind operation.

Figure 8. Grinding head for cutting the grooves on the second pass.

Construction began on October 4, 2010 and was completed the following day. The entire roadway had been ground previously using conventional diamond grinding methods as part of the dowel bar retrofitting operation. This was done for two reasons, the first being to restore the surface of the pavement to remove faulting, and the second, to lessen the blade wear on the flush grinding head used for the first pass of the NGCS installation.

Figures 9 and 10 compare the pavement surfaces after conventional diamond grinding and the first pass of the NGCS with the fine grinding head.

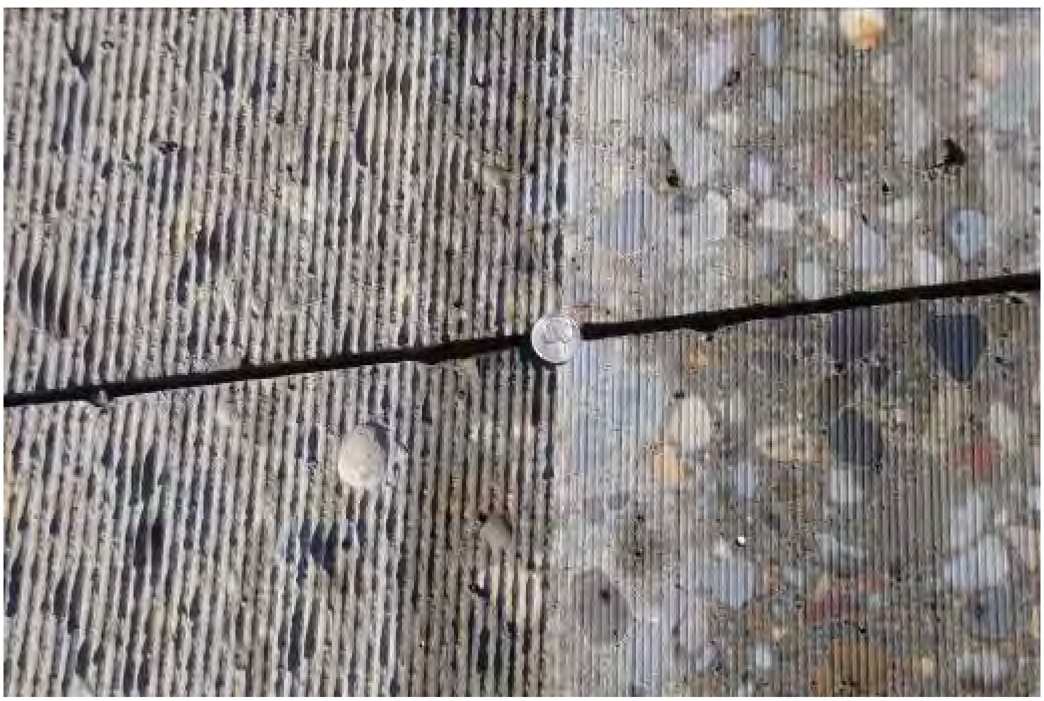

Figure 9. Conventional diamond ground surface on the left, fine flush grind surface of the NGCS first pass operation on the right.

Figure 10. Close-up of the CDG surface on the left and the, first pass of the NGCS on the right.

The final surface of the NGCS had flat, smooth land areas separated every 1/2 inch by grooves that were 1/8 to 3/8 inches deep as shown in Figures 11-13.

Figure 11. Conventional diamond ground surface on the left, first pass of NGCS in the middle and final pass of the NGCS on the right.

Figure 12. Finished surface of the NGCS with wide, flat land areas and deep grooves.

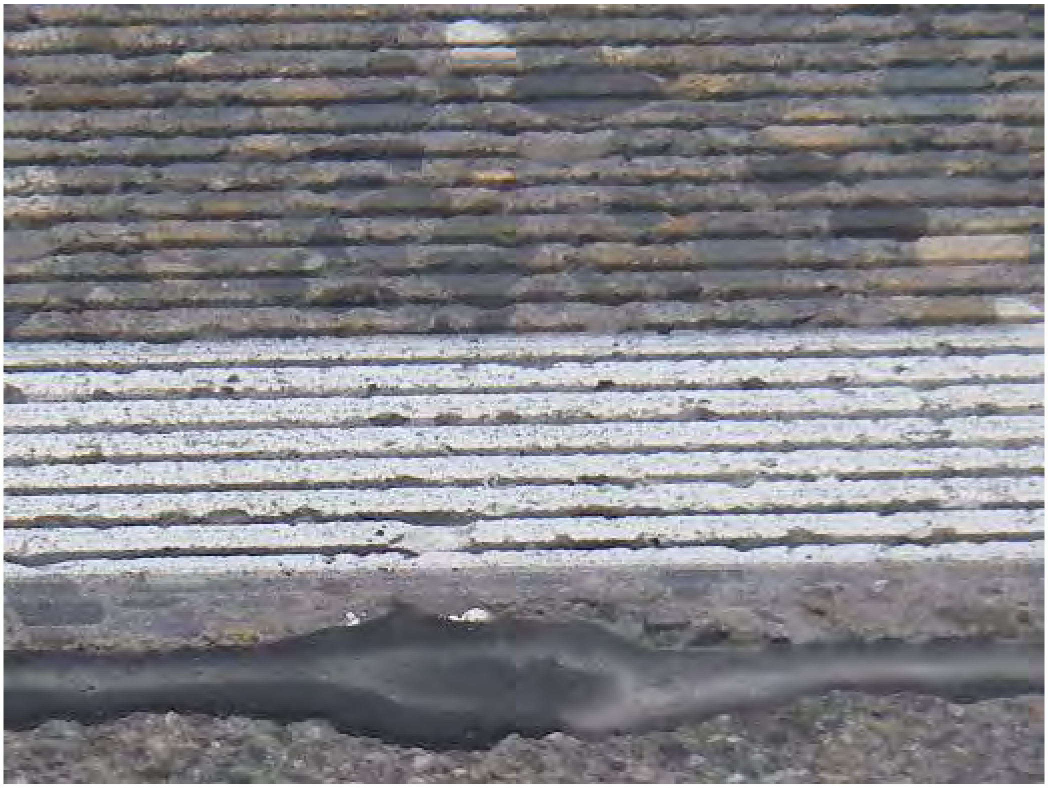

Figure 13. Close-up of NGCS with shoulder stripe in the foreground.

The contractor used three grinding machines on the project and reported no difficulties accomplishing the work of installing the NGCS. The project office indicated in January of 2011 that the State Patrol had received no complaints regarding the NGCS. Installation and operating characteristics of the NGCS seem to be in line with other such installations reported in the literature.

Construction Costs

Penhall Company, a member of the International Grinding and Grooving Association (IGGA) agreed to do the two lane wide 1,500 foot test section for $12.75 per square yard. The total price for the 4000 square yards on the project was $51,000. The average cost of conventional diamond grinding in various WSDOT Regions is captured in Table 8 to serve as a comparison of grinding costs incurred with the NGCS construction. The high cost of the NGCS at $12.75 per square yard was not unexpected given the small size of the project and the newness of the process.

Table 8. Conventional diamond grinding costs for dowel bar retrofit project in Washington from 2008 to 2010.	
Location	**Grinding Cost** (sq. yd.)
Northwest Region	**$11.55**
South Central Region	**$6.35**
Southwest Region	**$10.34**
Eastern Region	**$11.43**
Statewide Average	**$8.26**

Performance Testing

Acoustic performance was the primary focus of the testing with wear, ride, friction resistance and winter performance secondary issues of interest. Interpretation of the rutting and ride data on the NGCS is not attempted due to the complicating factor presented by the longitudinal grooves which affect the readings.

Noise

OBSI noise test results for the NGCS and CDG are listed in Table 9 and shown graphically in Figure 14.

Table 9. Noise data for the NGCS and CDG sections.

Section	Lane	November 2010 (dBA)	March 2011 (dBA)	June 2011 (dBA)	October 2011 (dBA)	April 2012 (dBA)	April 2013 (dBA)
NGCS	1	101.6	103.4	105.8	105.9	107.7	105.2
NGCS	2	99.6	102.9	101.8	102.4	104.1	103.6
CDG	1	104.4	105.0	104.6	106.3	105.2	105.4
CDG	2	103.0	103.6	103.3	104.0	104.0	103.6

Note: Lane 1 is the travel lane, lane 2 the passing lane. Colors for the lanes are the same in the bar charts that follow.

The initial measurements for the NGCS, November 2010, were 99.6 to 101.6 dBA for Lanes 1 and 2, respectively. These are within the range of 99-101 dBA reported by the ACPA (see Figure 4, page 14). The noise readings on the CDG were also within the 100-104 dBA range reported by ACPA with values of 103.0 dBA and 104.4 dBA for Lanes 1 and 2, respectively. Noise levels increased after the initial measurements for both types of grinding with travel lanes increasing more than passing lanes. The final measurements, April 2013, showed noise levels to be relatively the same on both types of grinding for the travel and passing lanes. Travel lane noise levels were 105.2 dBA and 105.4 dBA for the NGCS and CDG, respectively. Passing lane values were 103.6 dBA for both types of grinding. NGCS noise levels were not 3 dBA lower than the 106 dBA recorded for the pavement prior to grinding, therefore, at the end of the study there was no audible difference between the NGCS the CDG section or the pavement prior to grinding.

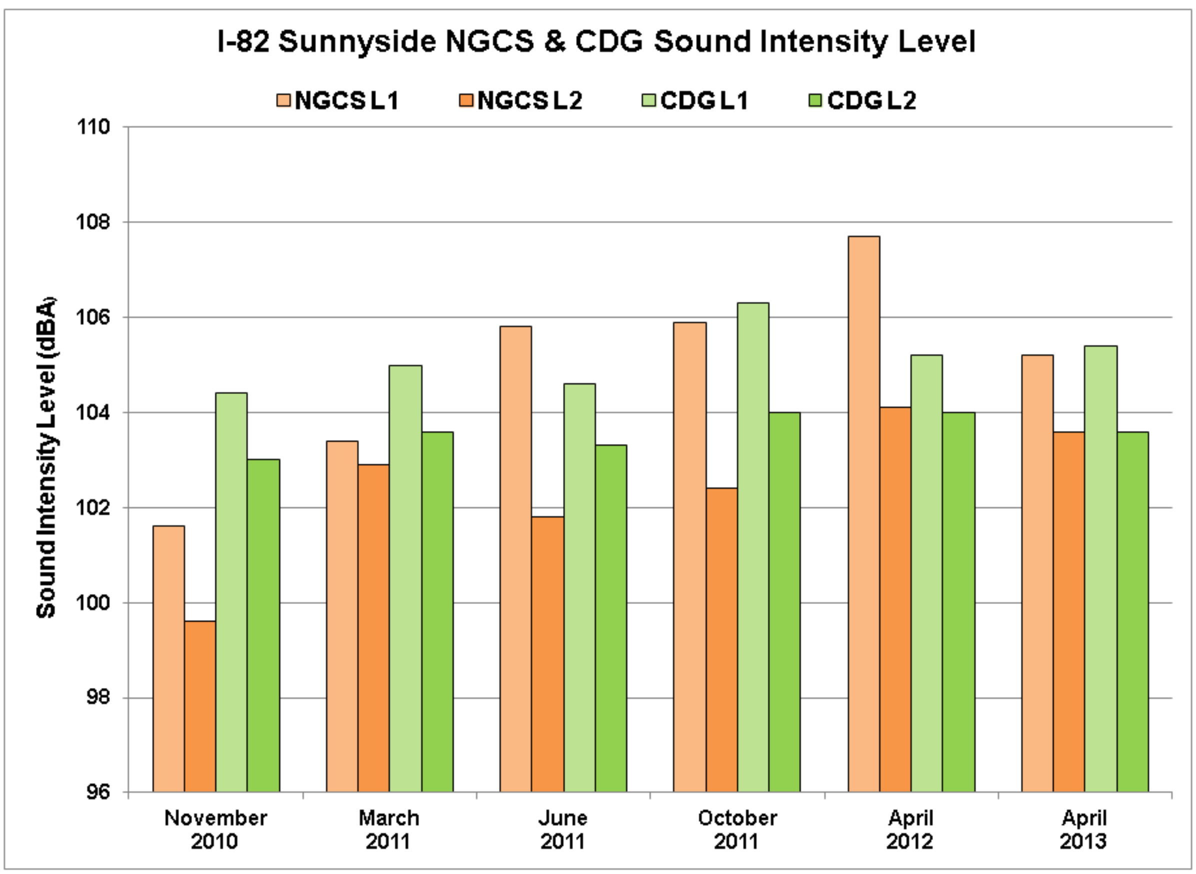

Figure 14. Noise measurements for the NGCS and CDG sections.

Figure 15 shows photos of the NGCS taken post-construction and one year after construction. Figures 16 and 17 were taken in October of 2013 and show the attrition on the surface of the NGCS. The wear from studded tires on the land areas of the NGCS is very evident. Field inspections also indicated that a large number of aggregate pieces are missing from the pavement surface. The added roughness of the pavement due to the studded tire wear is the probable cause of the noise increases on the NGCS. The conclusion is supported by the larger increases in noise levels for the travel lane with its higher traffic volumes as contrasted with the passing lane.

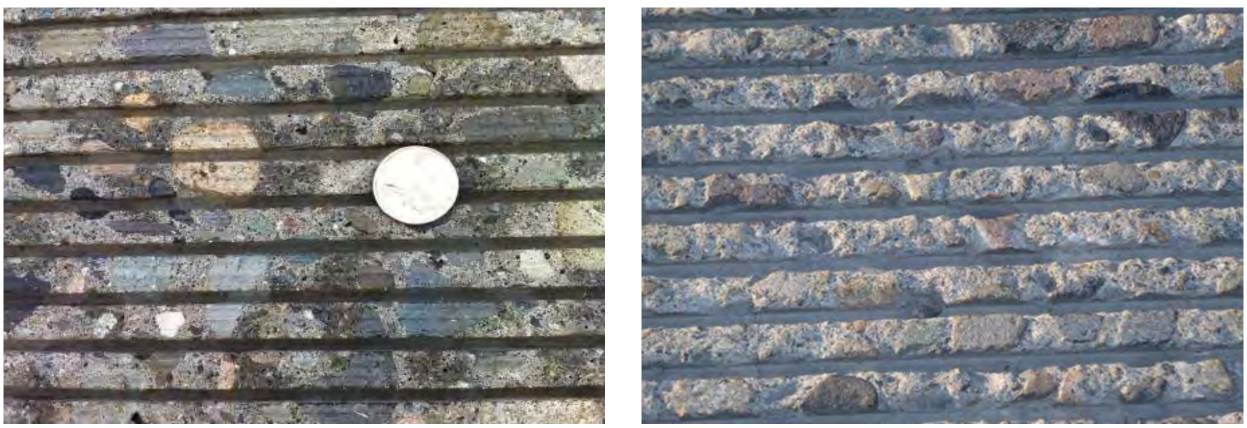

Figure 15. NGCS post-construction on the left, close-up from June 2011 on the right.

Figure 16. Attrition on the NGCS, October 2013.

Figure 17. Another view of the attrition on the NGCS, note missing aggregate, October 2013.

Friction

Friction measurements for the NGCS and CDG sections are summarized in Table 10 and shown graphically in Figure 18. The values are excellent with a range from 43.8 to 56.2. It is interesting to note that the values did not change a great deal for the NGCS; however those for the more heavily trafficked CDG in Lane 1 decreased with time. This would indicate that some of the positive fin roughness produced by the diamond grinding has been removed by traffic wear. The lack of change in friction number for the NGCS may be due to the presence of the deep grooves which would remove much of the water used to lubricate the surface of the pavement during testing. Less water also results in higher friction numbers because of the less lubrication between the tire and pavement. It should be noted that friction numbers in the 50's are at the higher range for concrete pavement.

Table 10. Friction data for NGCS and CDG sections.

Section	Lane	Fall 2010 (FN)	Spring 2011 (FN)	Spring 2012 (FN)	Fall 2012 (FN)	Summer 2013 (FN)
NGCS	1	47.1	46.6	50.7	47.0	50.8
NGCS	2	50.8	48.0	53.1	51.8	54.8
CDG	1	56.2	46.9	48.1	43.8	45.8
CDG	2	52.8	50.8	52.1	51.7	53.3

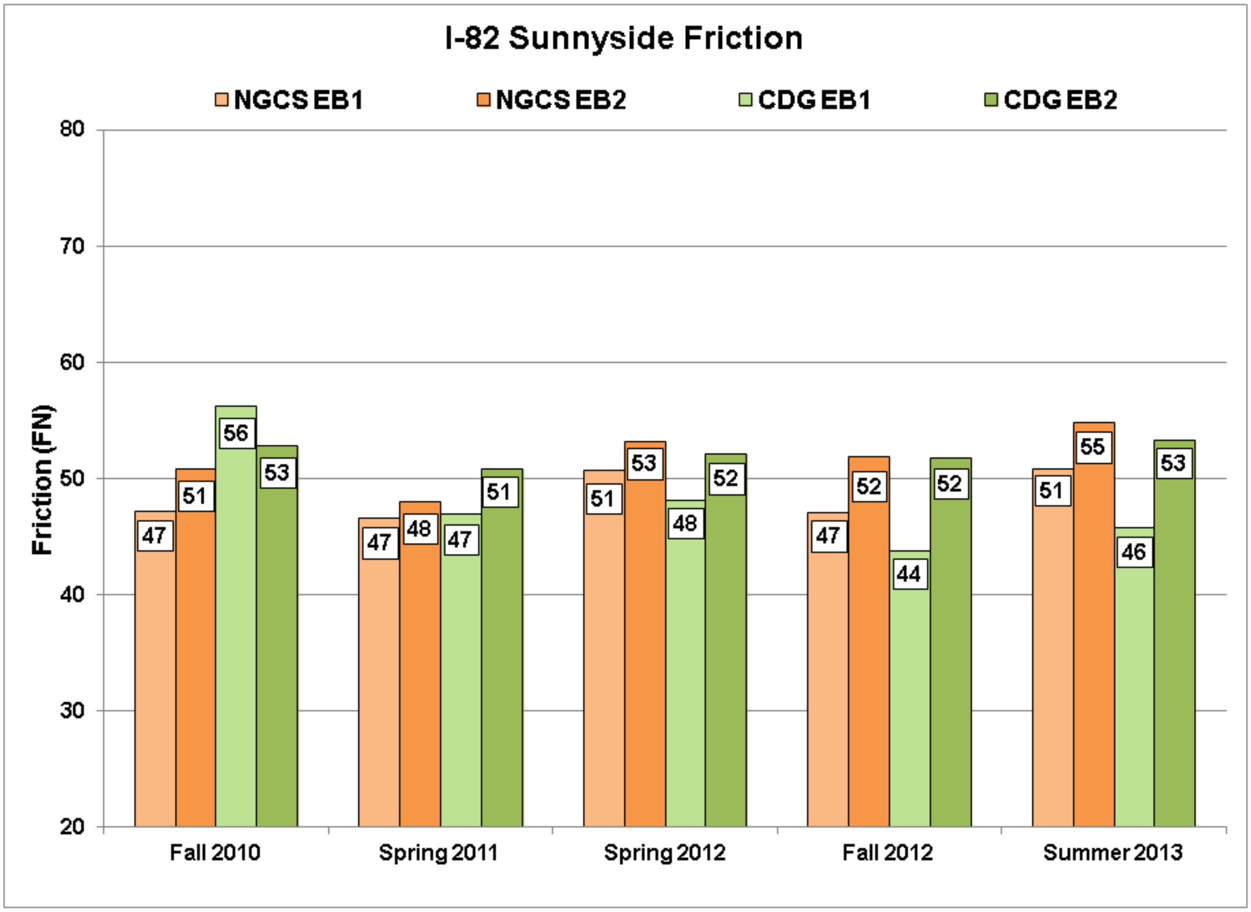

Figure 18. Friction measurements.

Wear

Wear measurements are listed in Table 11 and shown graphically in Figure 20. The wear on both the NGCS and CDG in the travel lanes (Lane 1) increased a small amount over the 2-1/2 years since the completion of the grinding. The grooves in the NGCS may be negatively influencing the depth of the rutting. Figure 19 is a diagram of how the rutting is measured using lasers mounted on a van. The lasers will average the depth of both the grooves and the flat areas between the grooves. The net result is that the actual rutting depths may not be accurate; however, the trends are probably representative of the overall wear that is occurring. The wear on the passing lanes did not change for either the NGCS or the CDG. The pattern of wear coincides with the higher traffic levels on the travel lanes.

Figure 19. Rut depth measurement using the Pathway Van.

Table 11. Wear measurements.						
Section	Lane	Fall 2010 (mm)	Spring 2011 (mm)	Spring 2012 (mm)	Fall 2012 (mm)	Spring 2013 (mm)
NGCS	1	3.2	3.7	4.9	3.9	4.5
NGCS	2	1.9	1.9	2.1	1.9	2.0
CDG	1	4.2	4.5	4.4	4.4	4.7
CDG	2	2.2	2.3	2.4	2.2	2.3

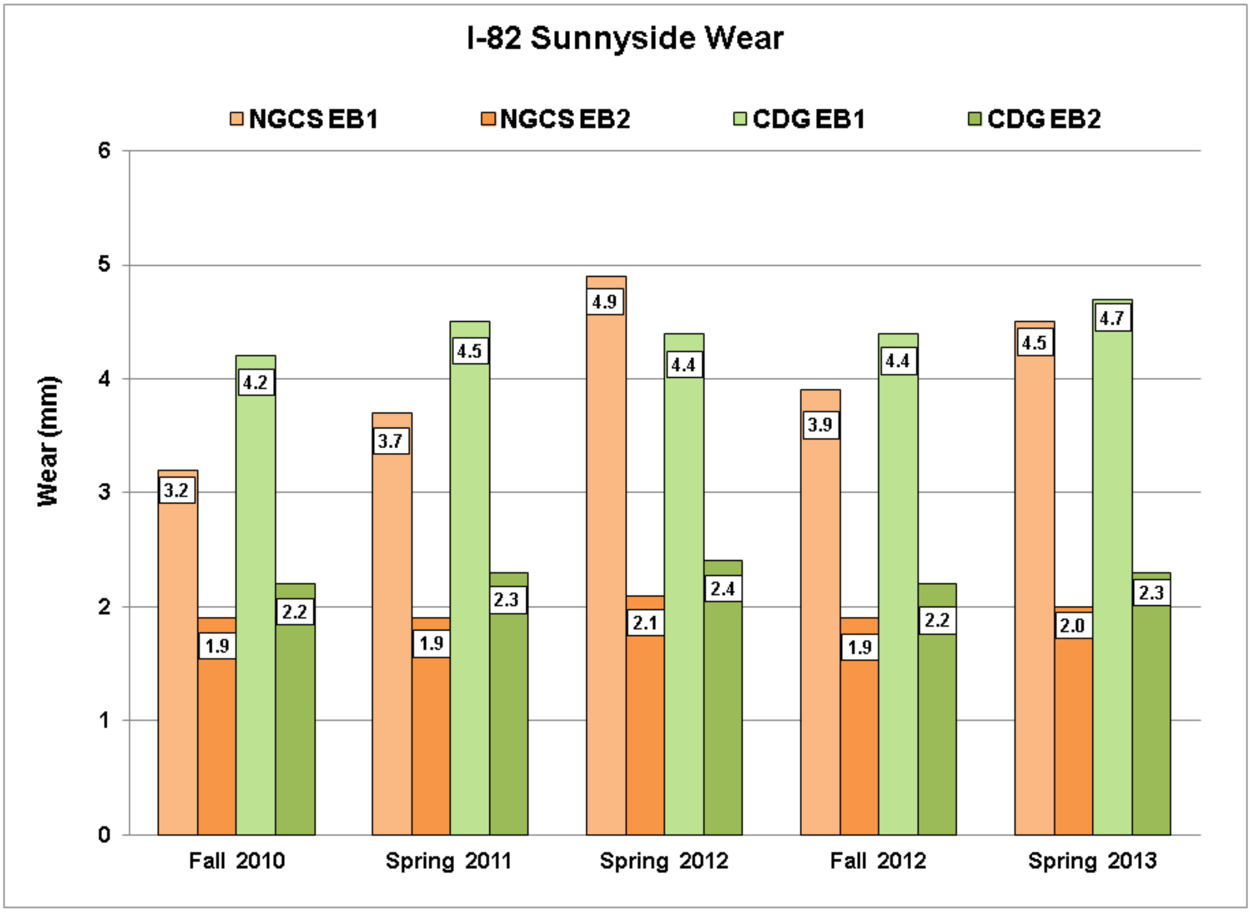

Figure 20. Wear measurements.

Ride

Ride measurements are listed in Table 12 and shown graphically in Figure 21. The ride measurement on the NGCS decreased on the travel lane and increased on the passing lane over the 2-1/2 year period. It appears that these measurements are being adversely influenced by the grooves in the NGCS section. Ride measurements for the CDG decreased for both lanes. It is concluded that traffic wear has removed the positive texture on the CDG by removing the fins that remain after the grinding, thus smoothing the pavement.

Table 12. Ride measurements.						
Section	**Lane**	**Fall 2010 (in./mi.)**	**Spring 2011 (in./mi.)**	**Spring 2012 (in./mi.)**	**Fall 2012 (in./mi.)**	**Spring 2013 (in./mi.)**
NGCS	**1**	**164**	**161**	**161**	**130**	**145**
NGCS	**2**	**110**	**112**	**121**	**116**	**129**
CDG	**1**	**97**	**71**	**66**	**67**	**72**
CDG	**2**	**76**	**53**	**51**	**52**	**49**

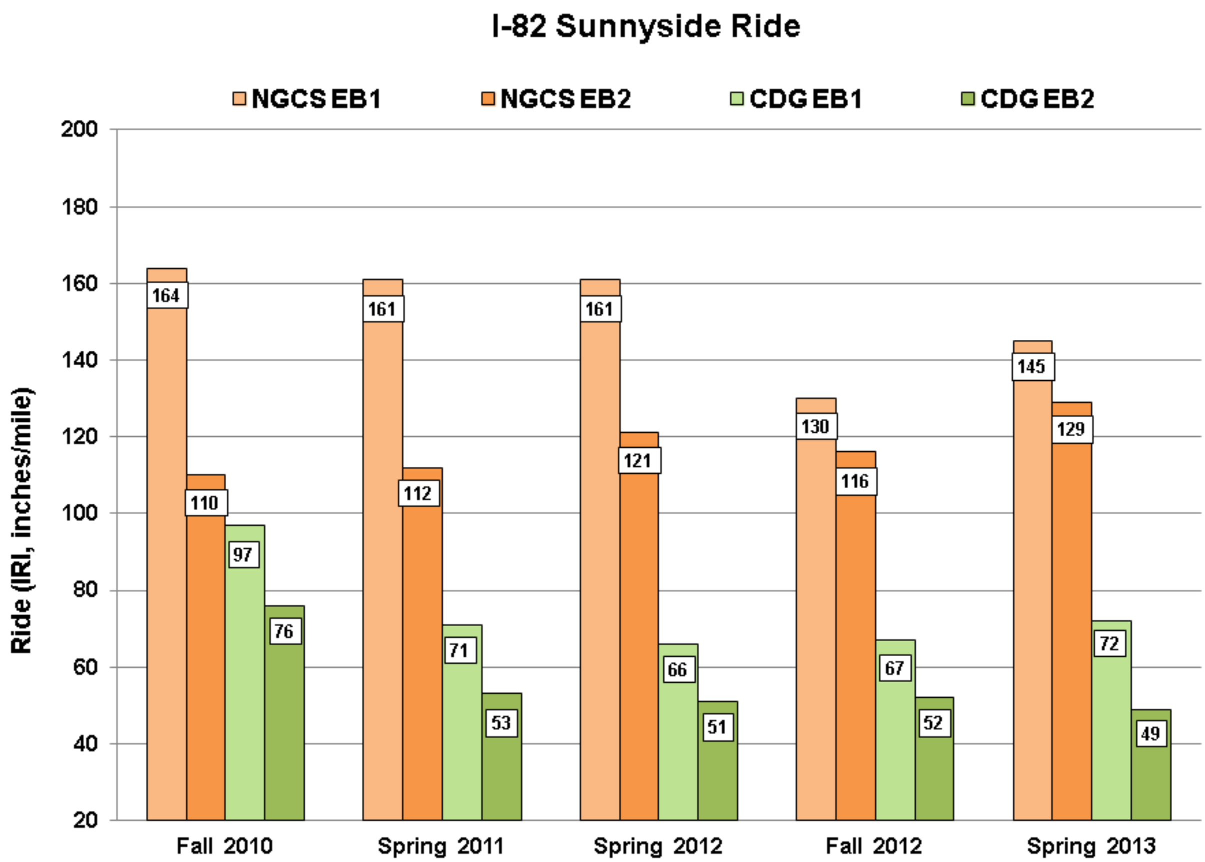

Figure 21. Ride measurements.

Winter Performance

Maintenance personnel were asked to comment on the performance of the NGCS as contrasted with the remainder of the project which received conventional diamond grinding. They indicated there were no problems associated with water collecting and freezing in the grooves or that the NGCS required greater amounts of anti-icing agents to keep them free of snow and ice. Maintenance also reported that they had not heard any comments from the public that the grooves in the NGCS decreased the lateral stability of motorcycles.

Discussion of Results

The noise reduction on the NGCS lasted only a brief period of time after construction. At the end of the 2-1/2 year study period the noise levels of the NGCS were equivalent to the levels of the CDG sections. The change in noise levels was attributed to wear from studded tires. Photos and field examination of the pavement support the conclusion that the attrition is due to studded tire wear.

Conclusion

NGCS is not a viable option for quieter concrete pavement for WSDOT.

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Appendix A

Contract Change Order

(Retyped from the original)

WASHINGTON STATE
DEPARTMENT OF TRANSPORTATION

DATE: 09/14/10

CHANGE ORDER

Page 1 of

CONTRACT NO: 007885 **FEDERAL AID NO:** ARRA-0822(132)
CONTRACT TITLE: I-82 GRANGER TO GRANVIEW CONCRETE REHAB
CHANGE ORDER NO: 7 CONSTRUCT NGCS TEXTURE SECTION

PRIME CONTRACTOR: 330349226 PENHALL COMPANY
14045 NORTHDALE BLVD

ROGERS MN 55375-9490

( ) Ordered by Engineer under the terms of Section 1-04.4 of the Standard Specifications

(X) Change proposed by Contractor

ENDORSED BY: **SURETY CONSENT:**

____________________ ____________________

CONTRACTOR Peter F. Lewis, Regional Manager
Penhall Company

ATTORNEY IN FACT

9-30-2010

________________ ________________

DATE **DATE**

ORITINAL CONTRACT AMOUNT:	4, 798, 496.52
CURRENT CONTRACT AMOUNT:	4, 800, 536.52
ESTIMATED NET CHANGE THIS ORDER	51, 000.00
ESTIMATED CONTRACT TOTAL AFTER CHANGE:	4, 851, 536.52

Approval Required: **( ) Region** **( ) Olympia Service Center** **( ) Local Agency**

( ) APPROVAL RECOMMENDED **(X) EXECUTED** **EXECUTED:**

____________________ ____________________

PROJECT ENGINEER **STATE CONSTRUCTION ENGINEER**

10/7/10

________________ ________________

DATE **DATE**

( ) APPROVAL RECOMMENDED **( ) EXECUTED** **OTHER APPROVAL WHEN REQUIRED**

REGIONAL ADMIN:

____________________ ____________________

BY **SIGNATURE** **DATE**

________________ ________________

DATE **REPRESENTING**

WASHINGTON STATE
DEPARTMENT OF TRANSPORTATION

DATE: 09/14/10

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All work, materials, and measurements to be in accordance with the provisions of the Standard Specifications and Special Provisions for the type of construction involved.

This contract is revised as follows:

Description
Section 5-01.1 is supplemented with the following:

(******)
This work shall consist of grinding concrete pavement to remove faulting, provide good riding characteristics and provide proper drainage.

Next Generation Concrete Surface Texture
This work also consists of constructing a test section of Next Generation Concrete Surface (NGCS) texture utilizing diamond grinding and grooving on an existing Portland cement concrete pavement.

Construction Requirements
Equipment
Section 5-01.3(1) B is supplemented as follows:
(******)
For the NGCS test section the Contractor shall use a diamond grinding machine with a 4 foot head.

Portland Cement Concrete Pavement Grinding
The first and second paragraphs of Section 5-01.3 (9) are revised to read as follows:

(******)
Once the grinding operation has started, it shall be continuous until completed. The pavement shall be ground in a longitudinal direction beginning and ending at lines normal to the pavement centerline. The maximum overlap between longitudinal passes shall be 1.50 inches. 95 percent of the surface area of the pavement is to be ground shall have a minimum of 1/8-inch removed by grinding.
Through roadway sections with a crown slope, the Contractor shall grind the lanes adjacent to the crown slope.
NGCS Texture
The construction of the NGCS test section can be accomplished as a single pass or two pass operation as determined by the Contractor. The existing pavement shall be pre-ground over the entire surface with a conventional diamond grinding process. The NGCS surface will be constructed after the pre-grinding has been completed.

The Contractor shall provide a single lane test grind of 500 feet in length to demonstrate that the equipment an procedures are capable of attaining the desired surface. The Contractor will not be allowed to proceed any further until the test grind has been approved in writing by the Engineer.
Single Pass Operation

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The construction operation will provide a flush ground surface that contains longitudinal grooves and shall be constructed in one single pass operation. The diamond blade stack shall consist of two types of diamond grinding blades arranged to provide a flush ground surface as well as those required to produce the longitudinal grooves. The diamond blade stack shall be mounted on a 4ft grinding head, stacked with 0.125 blades separated by spacers of 0.30 inches. The blades used to produce the flush grind surface should be flat across with other flush grind blades (excluding grooving blades) when mounted. The complete head when stacked with all blades shall be straight across its length without bowing when mounted on the diamond grinding machine. The flush grind blades shall be stacked in a manner that leaves no resulting fin between them. The grinding shall eliminate joint or crack faults and provide lateral drainage by maintaining a constant cross slope between grinding passes in each lane. The cross slope of the pavement shall match the existing and shall have no depressions or misalignment of slope greater than 0.125 inches in 10 feet when measured with a 10-foot straightedge placed perpendicular to the centerline. Areas of deviation shall be reground. Straightedge requirements will not apply across longitudinal joints or outside the ground area. Grinding shall begin and end at lines normal to the pavement centerline at the project limits. The blades used to create the longitudinal grooves shall be enough larger in diameter than the grinding blades used to create the flush ground surface so as to provide a groove depth of 0.125 to 0.375 inches. The longitudinal grooves shall be spaced among the flush grind blade stack approximately 0.5 inches center to center. The grooves shall be constructed parallel to the centerline. The Contractor shall us a guide to ensure proper alignment of the grooves to centerline.

Two Pass Operation
This construction method will allow for two separate operations to construct the NGCS section. The first operation will create the flush ground surface. The flush grind blades shall be mounted on a 4 foot grinding head, stacked with 0.125 blades separated by spacers of 0.030 inches. The flush grind head shall be flat across the blades when mounted on the diamond grinding machine with no bowing of the head. The flush grind blades shall be stacked in a manner that leaves no resulting fin between them. The grinding shall eliminate joint or crack faults and provide lateral drainage by maintaining a constant cross slope between grinding extremities in each lane. The cross slope of the pavement shall match the existing and shall have no depressions or misalignment of slope greater than 0.125 inches in 10 feet when measured with a 10-foot straightedge placed perpendicular to the centerline. Area of deviation shall be reground. Straightedge requirements will not apply across longitudinal joints or outside the ground area. Grinding shall begin and end at lines normal to the pavement centerline at the project limits. The second operation will provide the longitudinal grooves. The longitudinal grooves shall be 0.125 inches wide and will be 0.125 to 0.375 inches in depth.
The longitudinal grooves shall be spaced approximately 0.5 inches center to center. The grooves shall be constructed parallel to centerline. The Contractor shall use a guide to ensure proper alignment of the groves to centerline.

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Surface Finish
Section 5.01.3(9)A supplemented with the following:

(******)
NGCS Texture
The NGCS grinding process shall produce a pavement surface that is true to grade and uniform in appearance with a longitudinal grooved texture. The flush ground surface shall appear smooth and shall contain no ridges that exceed 0.03 inches. The longitudinal grooves shall be constructed parallel to centerline. At a minimum, 98% of the pavement surface shall be textured utilizing the NGCS. Depress pavement areas due to subsidence, edge slump or other localized causes will be excluded from this requirement when approved by the Engineer.
Measurement
Section 5-01.4 is supplemented with the following:

(******)
Next Generation Concrete Surface will be measured by the square yard final textured surface area regardless of the number of passes required to achieve acceptable results. Minor area of un-textured pavement within the designated areas to be textured will be included in the measurement.

Payment
The new bid item under Section 5-01.5 is revised to read as follows:

(******)
"Co #7 Construct NGCS Texture Section", per SQ YD
The unit Contract price per square yard shall be full compensation for all labor, equipment and material costs to complete the work as specified, including, removal and disposal of the residue from the grinding operations, and for all incidentals required.
The Contractor may disperse residue onto unpaved shoulders, adjacent roadside embankments, or median ditch areas of divided highways where the residue runoff can percolate into the soil, unless specified otherwise in the Contract.

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ITEM NO	GROUP NO	STD ITEM		UNIT MEASURE	UNIT PRICE	EST QTY CHANGE	EST AMT CHANGE
39	01		CONSTRUCT NGCS TEXTURE SECTION	S.Y.	12.75	4,000.00	51,000.00
							51,000.00

Appendix B

Construction Comments and Observations

Next Generation Concrete Surface (NGCS)

Construction Comments

Interstate 82

Contract 7885, Granger to Grandview EB Dowel Bar Retrofit and Concrete Rehab

Milepost 57.85 to Milepost 72.58

The content of this report reflect the views of the author, Jim Weston, who is responsible for the facts and the accuracy of the data presented herein. The content does not reflect necessarily the official views or policies of the Washington State Department of Transportation.

INTRODUCTION

Portland cement concrete pavements (PCCP) are damaged less than HMA by studded tires, but typically generate more tire pavement noise than HMA pavements. A new method of diamond grinding has been developed called the "next generation concrete surface" (NGCS) that promises a surface texture that is considerably quieter than conventionally diamond ground surfaces. This new method was placed so it could be evaluated for constructability, durability over time, performance when wet or ice covered, noise and cost.

The NGCS can be constructed using either a single pass or two pass method with a pavement grinder. The single pass method utilizes three smaller blades stacked between two taller blades. This pattern is repeated across the grinding head and is known as a single pass system. The second method utilizes two grinding machines. The first machine is equipped with the smaller blades across the entire grinding head and flush grinds the pavement in one pass. The second grinder is equipped with the taller blades and spacers across the grinding head and grinds the grooves into the surface in the second pass.

PLAN OF STUDY

The primary focus of the study is to measure the noise reduction characteristics of the NGCS as compared to pavement that has not been resurfaced and pavement resurfaced with conventional grinding methods. In addition, the diamond ground surface's resistance to studded tire wear, its durability, its friction resistance, and its splash/spray characteristics will also be evaluated as a part of the effort.

BACKGROUND

Panel replacement and dowel bar retrofitting was completed prior to the construction of the NGCS. The conventional diamond grinding of the PCCP surface required for dowel bar retrofitting had also been accomplished prior to the construction of the NGCS. The final step was the construction of the 1,500 foot test section of NGCS. This was done in both lanes beginning at MP 67.59 and progressing in the eastbound direction to MP 67.87.

TWO-PASS OPERATION

For this particular project, the two pass system was used. The two-pass operation has particular requirements for the grinding head and specifically the spacing of the blades. The following information is paraphrased from the Penhall Company's submittal for installation of the NGCS.

The construction method has two separate operations. The first operation creates the flush ground surface. The flush grind blades are mounted on a 4 ft. grinding head, stacked with 0.125 inch blades separated by 0.030 inch spacers. The flush grind head is flat across the blades when mounted on the diamond grinding machine with no bowing of the head allowed. The grinding eliminates the joint or crack faults and provides lateral drainage by maintaining a constant cross slope between grinding extremities in each lane. The cross slope of the pavement is to be constructed should not have depressions or misalignment of slope greater than 0.125 inch in 10 feet, when measured with a 10-foot straightedge placed perpendicular to the centerline. Any areas where deviations occur are to be reground. Straightedge requirements do not apply across the longitudinal joints or outside the area which is ground. Grinding is to begin and end at lines normal to the pavement centerline at the project limits. No un-ground surface area between passes is permitted.

The second operation provides the longitudinal grooves. The longitudinal grooves are to be 0.125 inches wide and 0.125 inches to 0.375 inches deep. The longitudinal grooves are spaced approximately 0.5 inches center to center. The grooves are constructed parallel to the centerline. The contractor will ensure proper alignment of the grooves to centerline by using a guide.

CONSTRUCTION

Construction of the NGCS began on October 4, 2010 and was completed the following day. Prior to placing the NGCS, the roadway surface was diamond ground using conventional surface grinding equipment. This was done for two reasons. The first reason is that the roadway surface needed to have the surface restored because faulting was present. The second reason is that the fine grinding head of the NGCS would encounter excessive blade wear if used to restore the pavement surface. This is also the reason for not utilizing the single pass NGCS system. Figure 22 shows the roadway surface after conventional grinding was completed.

Figure 22. Roadway surface after conventional grinding.

Once conventional grinding was complete the two pass NGCS began. The grinder outfitted with the fine grinding head was positioned in the outside portion of the outside lane (Lane 1) and progressed eastbound on I-82. When the fine grinding advanced down the roadway, the appearance of the surface was substantially smoother with grooves present. Figure 23 shows the fine grinding head and the configuration of the diamond blades and Figure 24 shows the pavement surface after fine grinding.

Figure 23. Configuration of fine grinding head and diamond blades.

Figure 24. Pavement surface after fine grinding.

When the fine grinding was complete, the grinder equipped with the taller blades commenced operation. The taller blade grind was also placed in the outside portion of the outside lane following the fine grinding machine. This is done to ensure that the taller blades achieve the required depth. Figure 25 shows the configuration of the taller diamond blades across the grinding head and Figure 26 shows the pavement surface after grinding with the taller blades.

Figure 25. Configuration of taller diamond blades.

Figure 26. Pavement surface after tall blade grinding.

The overall operation was no different than conventional grinding seen on dowel bar retrofit projects. The same equipment is used with the only variance being that different grinding heads were used to create a substantially diverse surface texture than typically seen. Figure 27 shows the conventional diamond grind texture next to the flush grind of the NGCS done prior to the cutting of the grooves. Figure 28 shows all three textures, the CDG, the flush grind, and the completed NGCS.

Figure 27. Conventional diamond grind on left with fine grind of NGCS on right before grooves were cut.

Figure 28. Conventional grind on left, fine grind in middle, and tall grind (complete NGCS) on right.

SUMMARY

- Conventional diamond grinding was complete prior to NGCS
- NGCS utilized the two pass grinding technique
  - Fine grinding followed the conventional grinding operation to smooth the land areas
  - Tall grinding followed the fine grinding operation to cut the grooves.
- The configuration of the blades and spacers on the grinding head were the only differences from conventional diamond grinding operations.

Appendix C

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

EVALUATION OF LONG-TERM PAVEMENT PERFORMANCE AND NOISE CHARACTERISTICS OF THE NEXT GENERATION CONCRETE SURFACE

I-82

Granger to W Grandview EB – Dowel Bar Retrofit and Concrete Rehab

MP 57.85 to MP 72.58

Mark A. Russell, PE
State Pavement Design Engineer
Washington State Department of Transportation

Introduction

Portland cement concrete pavements (PCCP) are damaged less than HMA by studded tires, but typically generate more tire pavement noise than HMA pavements. A new method of diamond grinding has been developed called the "next generation concrete surface" (NGCS) that promises a surface texture that is considerably quieter than conventionally diamond ground surfaces. This new method needs to be evaluated for constructability, durability over time, performance when wet or ice covered, noise and cost.

Plan of Study

The objective of this research study will be to determine the long-term pavement performance characteristics of the NGCS method of diamond grinding. It will focus primarily on the diamond ground surface's resistance to studded tire wear, its durability, its friction resistance, and its splash/spray characteristics. In addition, noise reduction characteristics will also be a part of the evaluation effort. WSDOT, at a minimum, will be evaluating noise levels using on-board sound intensity measurement equipment to capture tire/pavement noise.

Scope

This project will construct a 2,000 foot test section of NGCS in both eastbound lanes of I-82 located between mileposts 60 and 70.

Layout

The exact location of the test section will be layed out in the field prior to construction.

Staffing

This research project will be conducted through the combined efforts of the WSDOT Materials Laboratory and the WSDOT Acoustics Program Office. The South Central Region Project office will coordinate and manage all aspects of the construction. Representatives from the WSDOT Materials Laboratory (one – three persons) will also be involved in monitoring the construction activities.

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Testing

The following testing procedures will be conducted on the test sections and control section.

- Surface condition - both lanes (annually)
- Rutting/wear (biannually)
- Roughness (biannually)
- Friction (biannually)
- Sound intensity noise measurements (quarterly)

Reporting

An "End of Construction" report will be written following completion of the test sections. This report will include details of the construction of the test section and control section, construction test results, and initial sound, friction, roughness and rutting/wear results from all of the test sections. Annual summary reports will also be issued over the next five years that document any changes in the performance of the test sections. A final report will be written at the end of the five year evaluation period which summarizes performance characteristics and future recommendations for use of the next generation concrete surface grinding method.

Construction Costs

Construction costs are unknown at the time of the development of this work plan and no current cost data is available for the next generation concrete surface grinding method. Based on past cost data for grinding cement concrete pavement it is estimated the cost will be $21.00 per square yard. Based on an estimated quantity of 5,300 square yards the cost will be $111,300.

Testing Costs

Funds for all testing will come from the Quieter Pavements testing budget.

Report Writing Costs

Initial Report – 40 hours = $4,200
Annual Report – 10 hours (4 hours each) = $1,050
Final Report – 70 hours = $7,350

TOTAL EVALUATION COST = $12,600

Schedule

Estimated Construction – August/September 2010

Date	Pavement Condition Survey	Roughness Wear / Rutting	Friction	In-Vehicle Noise	Post Construction Report	Annual Report	Final Report
Summer 2010		X	X	X			
October 2010		X		X	X		
April 2011	X	X	X	X			
October 2011		X		X		X	
April 2012	X	X	X	X			
October 2012		X		X		X	
April 2013	X	X	X	X			
October 2013		X		X		X	
April 2014	X	X	X	X			
October 2014		X		X		X	
April 2015	X	X	X	X			
October 2015		X		X			
December 2015							X

Sound intensity will be tested quarterly.