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Innovative Diamond Grinding on MnROAD Cells 7, 8, 9, and 37

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Minnesota State University, Mankato

December 2010

Research Project
Final Report 2011-05

MnROAD Office of Materials

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16. Abstract (Limit: 250 words)

This report describes the innovative grinding conducted on cells 7, 8, 9, and 37 at the MnROAD research facility of the Minnesota Department of Transportation, and the initial measurement of surface characteristics. The three types of diamond grinding studied include a conventional method (1/8” x 1/8” x 0.120 groove kerf configuration), the “innovative grind” (flush grind and groove) and the “ultimate grind” (flush grind and groove, with wider spacing between grooves than the innovative grind). The report describes the construction efforts followed by the initial testing, and the plans for long-term observation, monitoring, and surface characteristics testing.

Surface characteristics (noise, friction, texture, and ride) were measured immediately prior to and after the grinding operation. As expected, each of the measures of surface characteristics was improved initially. Subsequent testing and monitoring will be conducted over the next five years to evaluate the long-term performance of the different grinding methods.

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Innovative Diamond Grinding on MnROAD Cells 7, 8, 9 and 37

Interim Report

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Bernard I Izevbekhai, P.E.
Lead State Technical Contact
November 2010

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EXECUTIVE SUMMARY

With increased understanding of surface characteristics it was expedient to re-examine how the diamond grinding process can be used to improve performance and to enhance quietness, safety and ride comfort. An attempt to define the scope without replicating previous research led to a collaboration of the Institute of Safe, Quiet and Durable Highways (SQDH), Purdue University, the Federal Highway Administration (FHWA), the American Concrete Paving Association (ACPA), and the International Grinding and Grooving Association (IGGA) towards a laboratory development of a quieter grinding configuration. It was determined at that point that studies conducted at the Minnesota Road Research facility (MnROAD) would provide an opportunity to validate the Purdue results. Some meetings were held with IGGA and the Concrete Paving Association of Minnesota (CPAM) towards this objective.

The study was posted as solicitation 1048 in the Transportation Pooled Fund (TPF) website and responses were obtained from Mn/DOT (Lead state), the Texas Department of Transportation and Mr. Mark Swanlund at the FHWA. It was subsequently cleared by FHWA and assigned pooled fund study number TPF 5-(134). However, to fulfill the required 20 percent match for the Federal participation, a non-Federal source for a minimum of $25,000 was required. ACPA and IGGA agreed to perform the diamond grinding as an in-kind match. Mn/DOT developed a partnership agreement with ACPA pursuant to the diamond grinding. Mn/DOT made two cells available on the MnROAD Mainline for this study. Subsequently ACPA requested to do a proof-of-concept study at the MnROAD Low Volume loop to increase the comfort level of performing the unconventional grind before proceeding to the mainline. Mn/DOT provided Cell 37 in the low volume loop for the proof-of-concept or initial validation test.

The proof-of-concept grinding was performed during the week of 18 June 2007. On-board sound intensity (OBSI) measurements of noise were performed by Larry Scofield of ACPA and the texture, ride, and friction measurements were performed by the Mn/DOT Concrete Research and MnROAD Operations units. In the pooled fund meeting held on the 18 July 2007, member states expressed the need to see the performance of the grinding configurations in full lane width, compared to the 2-foot test strips in the low volume road. The group agreed on the following points.

- The grinding of the mainline has to be done. Messrs. Bernard Izevbekhai and Ben Worel met with IGGA and fully explored the original option of industry grinding the mainline. Diamond Surface Incorporated (DSI) agreed to construct the cells at their expense. Mn/DOT elected to perform the monitoring of the ground pavement.
- The scope of work includes monitoring of friction, noise, texture and ride quality. Development of a protocol for splash and spray is not included in the scope of work. However, a consultant will be hired to provide an advisory role. The consultant will make recommendations for other research needs, perform statistical analysis on the data collected, and will make comparisons to data from other surface characteristics initiatives.
- In this role the consultant will participate in meetings and render construction and periodic reports. Such a consultant will be proficient in surface characteristics work and should be knowledgeable in the interpreting analyzing data on texture, noise, ride and friction. Durability and cost/benefit information will also be documented and reported.

The proof-of-concept grinding validated the feasibility of producing the innovative grind at a production level. Although it was not a full-width grinding exercise, four test strips were created. The test strips are named TS1 through TS 4, and have the following characteristics.

- TS1 – flush grind and groove in one pass
- TS2 – flush grind and groove in two passes

- TS3 – conventional grind of 1/8” x 1/8” x 0.120 groove kerf configuration.
- TS4 – original non-uniform transverse tine that was in the entire lane before grinding.

Test strips TS1 and TS2 represent the innovative configuration with the difference of the number of passes to achieve each configuration. ACPA measured on-board sound intensity on each strip and Mn/DOT measured ride quality, friction, and texture before and after grinding. The results showed a friction number distribution of ribbed tire friction for the innovative grind ranging from 48 to 54. The disparity between ribbed and smooth tire friction was less than 5 in the innovative configurations. This is a significant issue in the interpretation of non-correlative texture degradation and friction degradation observations, and lends credence to the hysteresis theory of tire-pavement suction enhanced by better contact

Ride quality measurements were difficult to establish within the strips as the profile measurements in the wheel path were not consistent. This is due to the single laser response jumping from groove to ridge and back, thus providing unreliable data. This resulted in higher ride quality measurements after grinding. Ride quality before grinding averaged about 64 in/mi but ride quality after grinding ranged from 89 in/mi in the right wheel path to 160 in/mi in the innovative grind. Profiles using a triple laser configuration were also measured.

Texture measurements indicated greatly improved texture depths with the conventional grind and improved texture depths in the innovative grind, after grinding. On-board sound intensity tests showed that the innovative grind achieved a high level of quietness surpassing that of previously-used grinding configurations. At 98.5 dBA, the innovative grind was much quieter than the conventional grind, at 102 dBA and the un-ground tine, at 104 dBA.

After the pre-grind measurements, grinding on the mainline Cells 7 and 8 was done by DSI between 18 and 20 October 2007. The testing for post-grind friction, texture, ride and noise followed shortly thereafter. The innovative grind was conducted on Cell 7, and Cell 8 was ground in the conventional manner. An additional strategy was devised, and was placed on the left shoulder of Cell 8. This separate sub cell is described in Chapter 4. In that area, partial tine removal was performed by DSI.

Results showed improved ride quality in the innovative and conventional grinding partly because DSI performed some corrective grinding in cases of extreme faulting. The innovative grinding resulted in decreases in IRI 128 in/mi before grinding to 72 in/mi after grinding, in the driving lane. The passing lane showed the same percentage improvement in IRI after grinding in each cell while the driving lane showed a different percentage improvement. Thus, each lane had the same percentage improvement regardless of the configuration.

Prior to grinding, texture measurements ranged from 0.3 mm to 0.5 mm. In Cell 8, the shoulder texture measurements indicated that the original textures of 0.8 mm had been maintained over time. This texture was partially removed by grinding but the macro- and micro-texture of the diamond grind resulted in improved texture to 1.0 mm or greater after partial tine removal. Texture improved in the conventional grind between 1.2 mm to 1.5 mm range. The innovative grind textures improved to a range of 0.9 mm to 1.1 mm. This improvement was more uniform and, unlike the conventional grind, the texture was durable and could not be easily damaged by oblique impacts. Friction measurements in the mainline were similar to results obtained in Cell 37. Once again, the difference between the smooth and ribbed tire friction was small. OBSI noise levels for the conventional grind were measured by Mn/DOT at 102 and 103 dBA and the innovative grind was 98.5 dBA.

A new, innovative style of concrete diamond grinding, called “Ultimate Diamond Grinding” was performed on Cell 9 at the MnROAD facility in October 2008. This grind was characterized by additional corrugations on the kerf of the 2007 innovative grind that was found to be very quiet in comparison to the conventional grinding. A summary of the construction and characteristics of this grind is also contained in this report.

These cells will be monitored for a minimum of five years to determine durability and time-related texture and friction decay of the innovative grinds and the noise trends over the study period.

Chapter 1 in this report deals with the activities preceding the grinding, and how we got here. Chapter 2 discusses the Cell 37 proof-of-concept grinding in detail. Chapter 3 discusses the results and testing of the configurations in Cell 37. Chapter 4 discusses the grinding activities for Cells 7, 8 and 9 in the MnROAD mainline. Chapter 5 discusses the results of the testing, and Chapter 6 concludes that the innovative and ultimate grinds are quiet pavement innovations that should be monitored for many years to observe performance with time.

CHAPTER 1. INTRODUCTION

1.1 Background of the MnROAD Facility

The Minnesota Department of Transportation (Mn/DOT) constructed the Minnesota Road Research Project (MnROAD) between 1990 and 1994. MnROAD is located along Interstate 94, 40 miles northwest of the Minneapolis and St. Paul metropolitan area, and is an extensive pavement research facility consisting of two separate roadway segments containing 51 distinct test cells. Each MnROAD test cell is approximately 500 feet long. Subgrade, aggregate base, and surface materials, as well as roadbed structure and drainage methods vary from cell to cell. All data presented in this report, as well as historical sampling, testing, and construction information, can be found in the MnROAD database and in various publications. Layout and designs used for the Mainline and Low Volume Road (LVR) are shown in Appendix E. Figure 1.1 indicates the approximate location of Cells 7, 8 and 9 on the Mainline with a red solid line. Additional information on MnROAD can be found by accessing the MnROAD web site at: http://mnroad.dot.state.mn.us/research/mnresearch.asp.

Figure 1.1. MnROAD mainline and low volume road indicating Cells 7, 8 and 9.

1.2 Low Volume Road

Parallel and adjacent to Interstate 94 and the Mainline is the Low Volume Road. The LVR is a 2-lane, 2½-mile closed loop that contains 20 test cells. Traffic on the LVR is restricted to a MnROAD-operated vehicle, which is an 18-wheel, 5-axle, tractor semi-trailer with two different loading configurations. The "heavy" load configuration results in a gross vehicle weight of 102 kips (the “102K configuration”). The “legal” load configuration has a gross vehicle weight of 80 kips (the “80K configuration”). On Wednesdays, the vehicle is operated in the 102K configuration and travels in the outside lane of the LVR loop. On all other weekdays, the vehicle travels on the inside lane of the LVR loop in the 80K configuration. It was hypothesized at the inception of MnROAD that the two load spectra would yield similar damage. Equivalent Single Axle Loads (ESALs) on the LVR are determined by the number of laps (80 per day on average) for each day and are entered into the MnROAD database.

1.3 MnROAD Mainline

The mainline consists of a 2-lane, 3½-mile interstate roadway carrying “live” traffic. Cell design/layout can be found in Appendix E. Pavements installed in the mainline consist of both 5-year and 10-year designs. The 5-year cells were completed in 1992 and the 10-year cells were completed in 1993. Originally, a total of 23 cells were constructed consisting of 14 hot-mix asphalt (HMA) cells and 9 portland cement concrete (PCC) cells.

Traffic on the mainline comes from the traveling public on westbound I-94. Typically the mainline traffic is switched to the old I-94 westbound lanes once a month for three days to allow MnROAD researchers to safely collect data. The mainline ESALs are determined from an IRD hydraulic load scale was installed in 1989 and a Kistler quartz sensor installed in 2000. Currently the mainline has received roughly 7 million flexible Equivalent Single Axle Loads (ESALS) and 10 million Rigid ESALS as of December 31, 2006.

1.4 MnROAD Instrumentation and Performance Database

Data collection at MnROAD is accomplished with a variety of methods to help describe the layers, the pavement response to loads and the environment, and actual pavement performance. Layer data is collected from a number of different types of sensors located throughout the pavement surface and sub-layers. At the initial construction, there were 4,572 electronic sensors placed at the MnROAD site. Since that time, researchers have added to this total with additional installations and sensors types. Data flow from these sensors to several roadside cabinets, which are connected by a fiber optic network that is fed into the MnROAD database for storage and analysis. Data can be requested from the MnROAD database for each sensor along with the performance data that is collected thought the year. This includes ride, distress, rutting, faulting, friction, forensic trenches, material laboratory testing and the sensors measure variables such as temperature, moisture, strain, deflection, frost depth in the pavement, and many others.

1.5 History of the Diamond Grinding Initiative

Diamond grinding is the process of correcting defective surface textures and poor ride quality. When some agencies use diamond grinding as the initial pavement surface texture, grinding is not only a rehabilitation tool. Over the years agencies and researchers saw an added quietness benefit to diamond grinding. These observations led to series of research that culminated in the joint efforts of the Center for Quiet Safe and Durable Highways (SQDH) at Purdue University, the Federal Highway Administration (FHWA), the American Concrete paving Association (ACPA), and the International Grinding and Grooving Association (IGGA) towards a laboratory development of a quieter grinding configuration. With increased understanding of surface characteristics it was expedient to re-examine how the diamond grinding process can be improved to improve performance, and to enhance quietness, safety and ride comfort. The collaboration determined that, after a successful laboratory development of a quiet configuration, MnROAD studies would create an opportunity to validate the results of previous studies at Purdue University.

The study was posted as solicitation 1048 in the Transportation Pooled Fund (TPF) web site and responses were obtained from Mn/DOT (acting as the lead state), the Texas Department of Transportation and FHWA. It was subsequently cleared by FHWA and assigned pooled-fund study number TPF #5(134). However, to fulfill the required 20% percent match for the Federal participation, some non-Federal source for a minimum of $25,000 was required. The ACPA and IGGA agreed to perform the diamond grinding as an in-kind match. Mn/DOT developed a partnership agreement with ACPA pursuant to the diamond grinding. Mn/DOT made two cells available in the MnROAD mainline for this study. Subsequently, ACPA requested to do a proof-of-concept at the MnROAD low volume road to increase the comfort level of performing the unconventional grind before proceeding to the mainline. Mn/DOT provided Cell 37 in the low volume loop for the proof of concept or initial validation test.

1.6 Proof-of-Concept on MnROAD Low Volume Road

The proof of concept grinding was performed during the week of 18 June 2007. On-board sound intensity noise measurements (OBSI) were performed by Mr. Larry Scofield of ACPA and the texture, ride, and friction measurements were performed by Mn/DOT's Concrete Research and MnROAD Operations units. Since October 2007, Mn/DOT has performed all seasonal monitoring tests including OBSI measurements. In the pooled fund meeting held on 18 July 2007, member states expressed the need to see the performance of the grinding configurations over the full lane width, rather than the 2-foot test strips in the low volume road. The group agreed on the following points:

- The grinding of the mainline has to be done. Messrs. Bernard Izevbekhai and Ben Worel met with IGGA and fully explored the original option of industry grinding the mainline. Diamond Surface Incorporated (DSI) agreed to construct the cells at their expense. M/DOT elected to perform the Monitoring of the ground pavement.

- The scope of work includes monitoring of friction, noise, texture and ride quality. Development of a protocol for splash and spray is not included in the scope of work. However, a consultant will be hired to provide an advisory role. The consultant will make recommendation for other research needs, perform statistical analysis on the data collected, and will make comparisons to data from other surface characteristics initiatives.
- In this role the consultant will participate in meetings and render construction and periodic reports. Such a consultant will be proficient in surface characteristics work and should be knowledgeable in the interpreting analyzing data on texture, noise, ride and friction. Durability and cost/benefit information will also be documented and reported.

The research team subsequently saw the need to improve on the frictional characteristics of the innovative grind by providing additional corrugations on the kerfs. This new configuration, referred to as the Ultimate Grind or the 2008 Initiative was ground in both lanes of Cell 9 of the MnROAD Mainline on 10 October 2008.

CHAPTER 2. GRINDING PROOF OF CONCEPT IN CELL 37

2.1 Background

The IGGA and ACPA have been working with Purdue University to develop a diamond grinding texture with improved noise characteristics. The research began by attempting to optimize blade width and spacer configurations. Traditionally, this had been thought to control the resulting noise characteristics. However, the Purdue work indicated that fin profile was the controlling variable and not the blade/spacer configuration. Work then began to produce fin profiles that were essentially uniform on top.

After experimentation, two different techniques appeared to work best. The first is the use of three chopper blades utilized as spacers placed between two 0.125-inch conventional diamond grinding blades, and the second is a “flush” grind with grooving. The flush grind was produced by using 0.090-inch width blades with 0.090-inch spacers to lightly grind the surface. The Purdue grinding head was then offset slightly to grind a second time to remove the fins. The flush ground texture was then grooved with 0.125-inch diamond grinding blades spaced on 0.50-inch centers. The grooves produced measured 0.012 inches deep. The blade configuration used chopper blades that were dressed to 0.08 inches shorter in radius than the 0.125-inch blades.

The Purdue research uses the Purdue Tire Pavement Test Apparatus (TPTA) to evaluate the various textures. This laboratory-based device, shown in Figure 2.1 and Figure 2.2, consists of a 12-foot diameter drum upon which six cast segments are placed around the circumference as shown. The IGGA-developed grinding head was used to grind the various textures and is shown in Figure 2.1.

Noise testing, using sound intensity (SI) techniques could only be conducted to 30 mph in the laboratory, although field evaluations are typically conducted at 60 mph. The diamond ground surface, although resembling actual field grinding had not been produced using actual diamond grinding equipment in practice. The flush grind surface was produced on the TPTA by offsetting the head and making a second pass such that the fins were ground off.

Field validation was conducted as a two-part process. First, the proof-of-concept was used, with the intent to prove or disprove that textures created and measured on the TPTA reflect diamond ground textures on the MnROAD Low Volume Road. The second stage was the actual full-width, production-based construction operation. These configurations were tested for noise, friction characteristics as well as ride quality and texture in each case.

Figure 2.1. Grinding head developed by IGGA.

Figure 2.2. Top Track Purdue laboratory testing wheel and diamond grinder.

On 24 May 2007, Cells 37, 38, and 39 of the MnROAD low volume concrete test sections were reviewed by Mr. Larry Scofield, of the ACPA. It was noted that Cell 38 had significant cracking and distress. Cells 37 and 39 both appeared in fair condition, but one large transverse crack existed in section 39. All the sections had surface textures in good condition with well-sealed joints. The existing texture was a random transverse tine pattern installed at right angles to the roadway direction. The transverse joints were skewed. The joints appeared to be approximately 3/8 to 1/2 inch in width with an approximate 3/16-

inch recess in the silicone sealant. In the eastbound direction, two-inch cores had been retrieved across two joint locations. This requires that the west bound directions be used for the testing to avoid these joints. The cells in the west bound direction, however, included instrumentation access covers in the wheel path locations.

2.2 Diamond Grinding Configurations on the Low Volume Road

The field validation experiment consisted of grinding two wheel tracks, each 18 inches wide by 500 ft long, and one wheel track 24 inches wide by 500 ft long. One wheel track was ground using 0.125-inch blades with 0.120-inch spacers. This was termed TS3 and is similar to a conventional grind. This wheel track was considered the control, and will be used throughout the project as a benchmark to evaluate the other two strips. The TS3 strip was ground 24 inches wide to eliminate the need to restack the equipment head, since its standard configuration is 24 inches in width. Examples of the grinding blades and spacers are shown in Figure 2.4. The grinding shaft, prior to blade and spacer placement, is shown in Figure 2.5.

In a second strip, the grinders used the triple chopper blades in combination with 0.125-inch conventional blades. This was termed TS1. A third track, TS2, used a technique to produce a flush grind condition similar to the Purdue work and then grooved it with 0.125-inch blades spaced on 0.50-inch centers. The Purdue work used 0.090-inch blades and spacers to produce this texture and then offset and reground to remove the fins. An alternative technique was required in the field sections to produce the flush grind condition. Anticipating that the existing random transverse tined texture may have impact on the OBSI levels, flush grinding was performed in part to eliminate the existing random tine texture. Uniformity of removal of the existing tine was an issue of concern. The three test sections, two of which were 18 inches wide and one of which was 24 inches wide, were constructed leaving a strip (TS4) of existing random transverse tine in the right wheel path.

In summary, the configurations described above resulted in the following three grinding characteristics, and one control section left unground:

- TS1 – flush grind and groove in one pass,
- TS2 – flush grind and groove in two passes,
- TS3 – conventional grind of 1/8” x 1/8” x 0.120 groove kerf configuration, and
- TS4 – original non-uniform transverse tine that was in the entire lane before grinding.

The diamond grinding configurations were arranged in Cell 37 as shown in the diagram in Figure 2.3, and the images in Figure 2.6 through Figure 2.8.

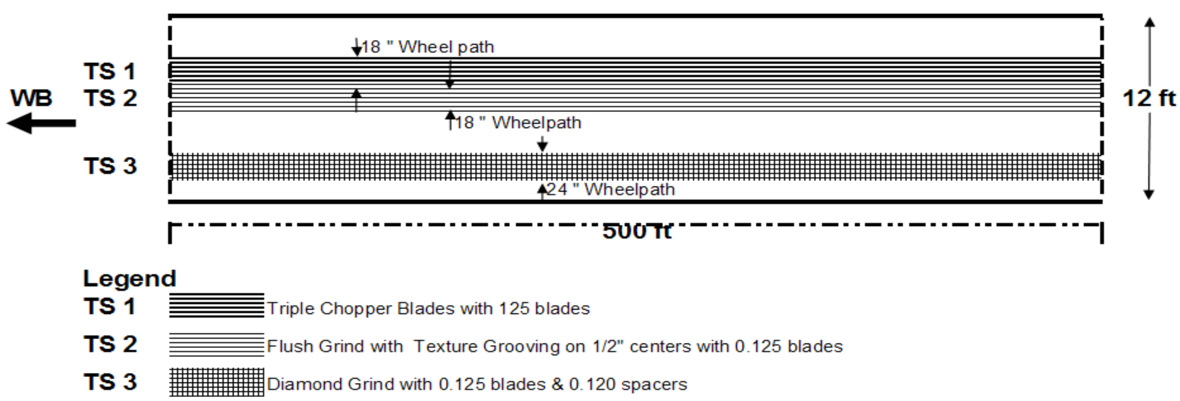

Figure 2.3. Diamond grinding test section layout on Cell 37.

Figure 2.4. Grinding head and spacers.

Figure 2.5. Grinding shaft before assemblage of cutters and spacers.

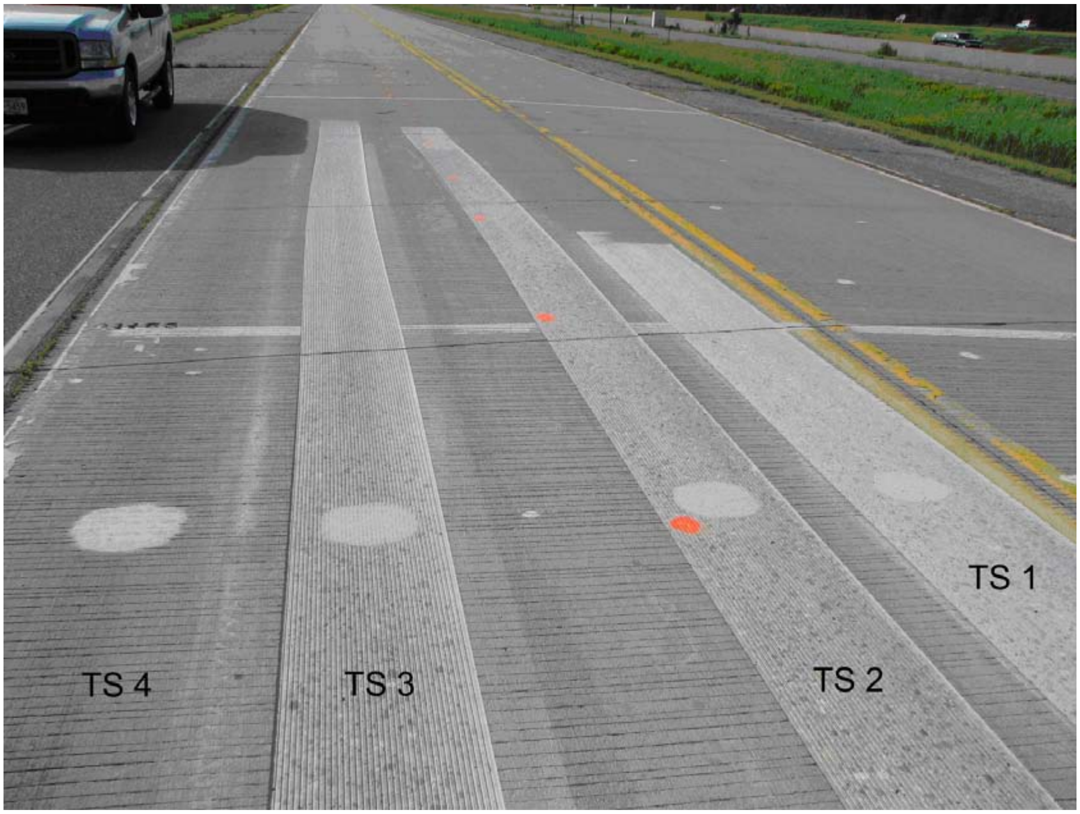

Figure 2.6. Grinding configurations in Cell 37, looking westbound.


Figure 2.7. Close-up view of quiet configurations TS1 and TS2.

Figure 2.8. A panoramic view of the texture strips looking west on Cell 37.

Figure 2.9. Close-up view of TS1, on Cell 37.

CHAPTER 3. POST GRIND TESTING IN THE LOW VOLUME ROAD

This chapter describes the testing that was conducted on the low-volume road cells after the proof-of-concept grinding had taken place. The testing conducted included on-board sound intensity, friction, texture and ride.

3.1 On-Board Sound Intensity Testing Sequence

Noise was measured by OBSI testing, which was conducted on the existing random transverse tining in each of the four strips prior to grinding. Upon completion of the diamond grinding, the surface of each of the three test grind wheel tracks were tested again. Subsequently, the joint sealant materials were removed using a joint plow or other suitable device. Upon completion of sealant removal, OBSI testing was conducted again on the four strips. The intent was to validate both the Purdue TPTA recommended surfaces and to validate the Purdue TPTA predicted joint effects for one joint width level.

For each test on each of the four strips, four replicate runs were conducted with the OBSI equipment provided by the ACPA. This resulted in 12 tests each for wheel tracks 1 through 3 and 8 tests for wheel track 4, for a total of 44 OBSI tests. Since the wheel track is only 18 inches wide, guidance and tracking of the test vehicle (e.g. Chevy Malibu) was carefully performed during OBSI testing. This was accomplished by painting dots on the PCC pavement surface to use for guidance. A separate set of dots was needed for each wheel track. The markings extended through the test areas and beyond to allow adequate alignment. The OBSI testing was conducted by the ACPA using the dual-probe configuration at 60 mph with the 16-inch ASTM Standard Reference Test Tire (SRTT).

Upon completion of the MnROAD testing, the ACPA OBSI test tire and wheel (e.g. ASTM SRTT tire mounted on Chevy Malibu Wheel) was dismounted from the vehicle, mounted on the Purdue TPTA and used to retest the original TPTA texture samples (e.g. triple chopper and flush grind). The recently calibrated ACPA Cal Tone was used to calibrate the Purdue equipment. This was done to remove as much tire bias and microphone calibration bias as possible between the field and laboratory comparisons.

Results of the proof-of-concept experiment in the low volume road are shown in Appendix F. All other testing – ride, friction, and texture – was conducted by Mn/DOT personnel, and is described in the subsequent sections of this chapter. Detailed test results and data obtained are provided in Appendix F.

3.2 Friction Testing

Throughout the remainder of the project, Mn/DOT will conduct ASTM E-274 – Locked-Wheel Skid testing with the ASTM smooth tire. Friction testing will be conducted twice during the experiment. The first was after completion of the initial OBSI testing (prior to grinding) on test sections TS1, TS2 and TS3. The second set of testing will be conducted on these same sections after the joint seal has been removed and the final OBSI test measurements obtained. This sequencing eliminates the possibility of contamination of the textures by the skid tester while still obtaining before and after measurements to evaluate changes in friction. If the first round of friction testing cannot be accomplished in advance of the grinding operation, similar nearby textures will be tested to provide a baseline friction level for the original texture.

3.3 Ride Testing

Ride measurements were accomplished with the AMES LISA Light weight profiler operated at 10 mph. To ensure measurements were within the cell auto start and stop commands were used.

CHAPTER 4. MAINLINE GRINDING ACTIVITIES

4.1 Mainline Grinding

Details of the construction activities for the three cells are shown in Figure 4.1. Surface grinding was preceded by an identification of the configurations to which the cells would be ground. The strategies chosen include the following.

- Conventional grinding on Cell 8
- Innovative grinding on Cell 7
- Partial grind on tied concrete shoulder of Cell 8
- Ultimate grind on Cell 9

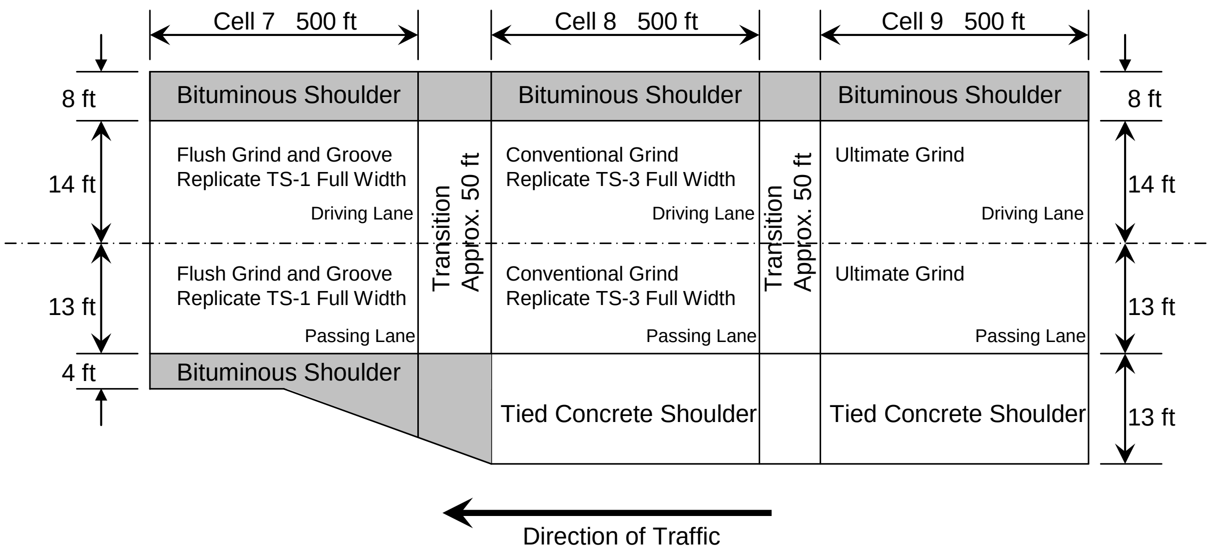

Figure 4.1. Layout of grinding activities – Cells 7, 8, and 9.

Diamond Services Incorporated (DSI) performed the grinding, and was assisted by Highway Services, Inc., for the grinding in Cell 9. Equipment on site included the diamond grinding equipment, consisting of the actual cutting equipment with an articulated water receptacle. DSI performed longitudinal grinding in minimally overlapping longitudinal strips. This resulted in 4 passes per 12-foot lane. Initially, all three cells were ground with the conventional grinding. That was the final grind for Cell 8 and the primary grind for Cells 7 and 9. The secondary grind for Cell 7 is the innovative diamond grinding configuration, and the secondary grind for Cell 9 is the ultimate grind.

4.2 Construction of Cells 7 and 8

DSI Performed the grinding in the sequence recorded below. Prior to the mainline closure that commenced on 15 October 2007, the Mn/DOT concrete research team had conducted pregrind OBSI and ride quality tests on Cells 7 and 8. The proceeding is a summary of the sequence of activities during the actual lane closure that spanned from 15 October 2007 to 23 October 2007.

15 October 2007

- 7:00 AM: MnROAD Operations closed the mainline to traffic to allow testing prior to the grinding.
- 10:00AM: Mn/DOT Concrete research marked the locations (BX-1 to BX-13, representing 52 locations) for pre- and post-grind texture measurements on the right shoulder on both cells so that the prescribed tests are located where lines drawn from the shoulder, parallel to the skew joints, intersect the wheel path. A series of locations labeled BX-14 to BX-21 representing 18 spots were also made on the shoulder of Cell 8.
- 12:00PM: Mn/DOT Concrete Research Operations conducted a visual survey and observed sensor caps predominantly in the Cell 7 wheel path and assess the extent to which that would affect statistical pass-by noise measurements.

16 October 2007

- The weather was overcast and characterized by intermittent drizzles. The Mn/DOT concrete research team conducted some texture testing using sand patch tests and circular track meter tests on some locations. The Concrete Research Operations team discussed possible removal of sensor shaft capping that was on the pavement surface predominantly on Cell 7 due to the anticipation that it may affect the noise testing measurements. These effects could be introduced as transient effects on the noise spectrum particularly in the statistical pass-by measurements. MnROAD Operations promised to work on the caps to minimize influence on grinding and accuracy of noise measurement.

Figure 4.2. DSI diamond grinding equipment.

17 October 2007

- Overcast, intermittent drizzles, with temperature of 55-60 °F.
- 7:30AM: MnROAD Operations secured water meter and hydrant in Otsego for the grinding.
- 12:00PM: Mn/DOT Concrete Research performed the final pregrind texture measurements to ASTM E-965 and ASTM E-2153 standards. DSI brought equipment to the site. Equipment included diamond grinder and water truck. The crew consisted of a supervisor, an operator, and the water truck driver. Mr. Terry Kraemer, of DSI, conferred with Mn/DOT Concrete Research Operations to confirm location and configuration of grinding. The grinding equipment is shown in Figure 4.2.

18 October 2007

- 6:30AM: DSI commenced grinding from the left edge of the driving lane and performed 4-foot wide conventional grinding strips nonstop from the east end of Cell 8 to the west end of Cell 7.
- 9:30AM: DSI performed corrective grinding to remove prominent bumps from Cell 8. The bumps were removed in six parallel runs though the 300-foot portion of the cell that was faulted and contained several bumps and dips. Original construction records indicated that this correction was suggested during the initial testing of the original pavement but that it was not done at that time.
- 12:00PM: DSI resumed conventional grinding in parallel strips from the east end of Cell 8 to the west end of Cell 7.
- 6:00PM: DSI Closed for the day after grinding the entire driving lane and half of the passing lane.
- The right side of Figure 4.3 shows a close-up image of the conventional grind.

19 October 2007

- Overcast, intermittently clear, temp 55-60 °F.
- 6:00AM: DSI commenced grinding of the remaining strip of the passing lane.
- 12:00PM: DSI completed conventional grinding of Cells 7 and 8 and partial texture removal grind of the shoulder on Cell 8. The Cell 8 shoulder was ground to a lesser groove depth than the conventional grind as requested by ACPA.
- 1:00PM: DSI disassembled the blades for the conventional grind and set up the blades for the single pass innovative grind.
- 4:00PM: DSI commenced the innovative grinding on Cell 7.
- 6:30PM: DSI completed the innovative grinding of the Cell 7 driving lane.
- Figure 4.4 shows the conventional grind (on the left) and the innovative grind (on the right). Figure 4.5 shows the conventional grind and the original transverse tining.

20 October 2007

- Clear, 55-60 °F.
- 6:00AM: DSI commenced innovative grinding of the passing lane on Cell 7.
- 12:00PM: DSI completed grinding of the passing lane, thus completing the entire grinding.
- Figure 4.6 and Figure 4.7 show the innovative grind after being tested for friction with the skid trailer.
- Figure 4.8 shows the statistical pass-by test setup with the microphone and portable weather station at Cell 8.

Figure 4.3. Conventional grind configuration (0.125X 0.125x.0.120).

Figure 4.4. Conventional and innovative grinds.

Figure 4.5. Conventional grind on Cell 8 and original transverse tining.

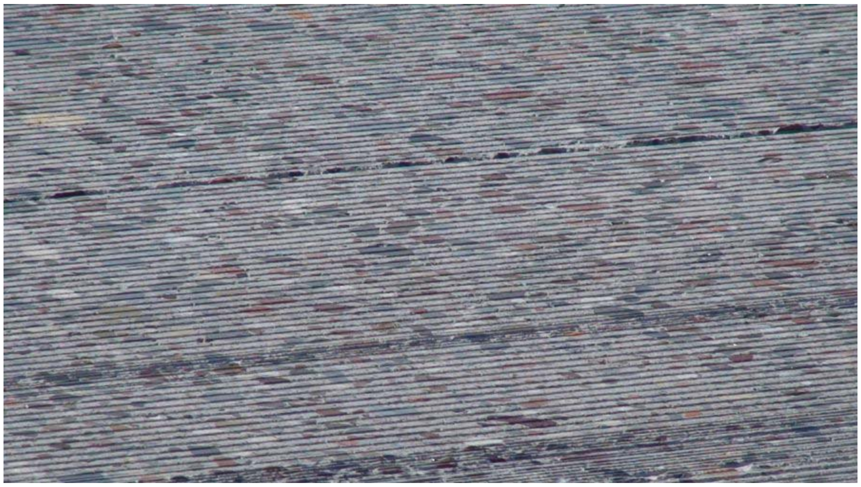

Figure 4.6. Innovative grind with skid marks after friction testing.

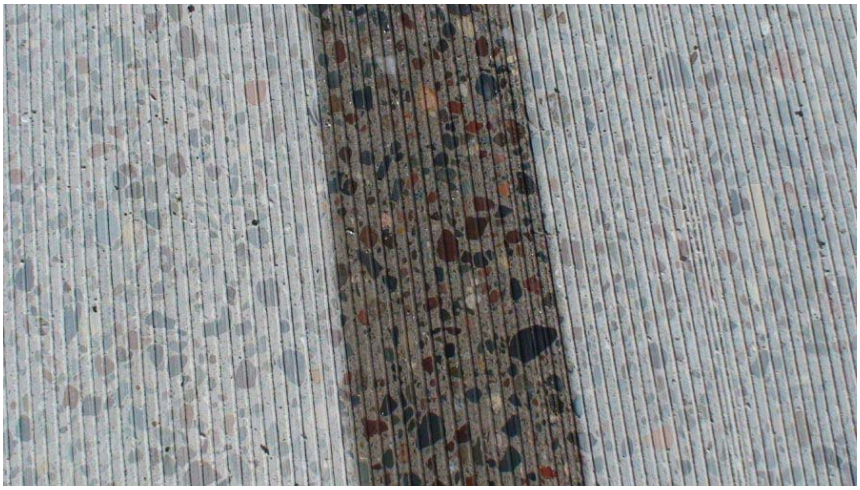

Figure 4.7. Wet tracks on innovative grind after friction testing.

Figure 4.8. Statistical pass-by showing microphone and weather station near Cell 8.

4.3 Construction of Cell 9

The contractor, Diamond Services Inc, teamed with Highway Services Inc, to grind the cell. The two grinding contractors jointly ground the cell in the following sequence.

- Mn/DOT removed the metal caps used for some sensors from the pavement surface. These steel plates are known to damage to the grinding blades
- The contractors stacked the blades for a combined flush grind and innovative grind.
- The contractors ground the cell in 4-foot strips
- The contractors restacked the blades for kerf corrugations of 1/16 of an inch by 1/8 of an inch longitudinal surface feature of kerf.
- The contractors ground the kerfs in 4-foot strips imparting the 1/8-inch width by 1/16-inch deep corrugation on the kerfs.

The grinding machine used for the ultimate grind process is shown in Figure 4.9.

Figure 4.9. The ultimate diamond grinding process.

Figure 4.10. Ultimate grind (Cell 9) immediately behind the grinding machine.

Figure 4.11. Ultimate grind groove width measurement.

4.4 Pre- and Post-Grind Testing Results

This section contains a summary of the data collected before and after the grinding had taken place on Cells 7 and 8 and later on Cell 9. These data include noise, ride quality, friction, and texture information.

Table 4.1 OBSI Summary, Pre-Grinding.

Cell	Lane	Average
7	Driving	101.9
	Passing	102.6
8	Driving	100.7
	Passing	101.5
9	Driving	103.0
	Passing	104.6

Table 4.2 OBSI Summary, Post-Grinding.

Cell	Lane	Leading Edge	Trailing Edge	Average
7	Driving	98.5	99.2	98.8
	Passing	98.4	99.3	98.8
8	Driving	103.8	102.8	103.3
	Passing	103.7	102.8	103.3
9	Driving	101.0	101.4	101.2
	Passing	101.4	101.9	101.7

Table 4.3 Pre-Grind vs. Post-Grind Mainline Ride Quality.

Cell	Lane	Wheel Path	Pre-Grind IRI, in/mi (9/8/07)	Post-Grind IRI, in/mi (10/22/07)
7	Driving	Left	88.3	46.4
		Right	68.0	50.5
	Passing	Left	72.8	50.4
		Right	78.5	46.3
8	Driving	Left	107.9	73.1
		Right	123.0	75.0
	Passing	Left	123.1	70.9
		Right	104.8	80.1
9	Driving	Left		50.1
		Right		45.5
	Passing	Left		
		Right		

Table 4.4 Historical Pre-Grind Friction Data.

Cell	Grind Type	Lane	Tire Type	Friction Number Recorded on Date											
				23 Jun 94	**20 Sep 94**	**4 May 95**	**20 Jun 95**	**29 Oct 97**	**14 Oct 98**	**20 Oct 98**	**31 Oct 01**	**3 Nov 04**	**24 May 05**	**19 Apr 06**	**24 Oct 06**
7	Innovative	Driving	Ribbed	60.0				55.1		47.4	38.1	57.7	53.3	55.7	59.5
			Smooth						31.0	36.2				26.2	35.9
		Passing	Ribbed	58.7	52.5	60.1	63.6	58.3	56.7	53.4	42.1	56.9	58.8	57.5	59.4
			Smooth						46.0	41.9		43.3		40.4	
8	Conventional	Driving	Ribbed	54.3	54.9	54.8	48.5	44.5	46.2	37.7	38.7	47.5	42.6	60.7	48.0
			Smooth						25.9	22.6				30.2	20.9
		Passing	Ribbed	56.4	47.0	57.7	55.4	52.8	54.4	39.9	41.2	50.4	46.8	52.6	47.0
			Smooth						41.3	24.3		29.7		28.0	
9	Ultimate	Driving	Ribbed	59.6	58.4	58.8	60.2		52.2	47.0	37.4	48.6	51.0	66.0	56.0
			Smooth						44.3	31.5				31.4	43.1
		Passing	Ribbed	60.3	54.5	62.6	64.2		57.6	50.2	41.4	57.2	54.2	54.2	54.0
			Smooth						57.2	40.3		49.6		44.5	

Table 4.5 Post-Grind Friction Measurement, Using Mn/DOT's Dynatest 1295 Friction Tester.

Cell	Grind Type	Lane	Tire Type	FN	Speed, mph	Air Temp, °F	Texture, ASTM E 274
7	Innovative	Driving	Ribbed	53.6	40.4	52	0.56
				54.7	40.3	52	0.53
			Smooth	51.2	42.1	52	0.53
				47.4	41.4	52	0.53
		Passing	Ribbed	47.4	42	52	0.64
				49.3	41.4	52	0.61
			Smooth	48.8	41.2	52	0.61
				44.6	40.8	52	0.64
8	Conventional	Driving	Ribbed	85.9	40.3	52	0.86
				80.2	41.3	52	0.81
			Smooth	63.5	41.4	52	0.81
				62.7	40.4	52	0.81
		Passing	Ribbed	62.6	40.4	52	1.24
				65.2	41.2	52	1.24
			Smooth	64.2	41	52	1.02
				73.1	40.2	52	0.89

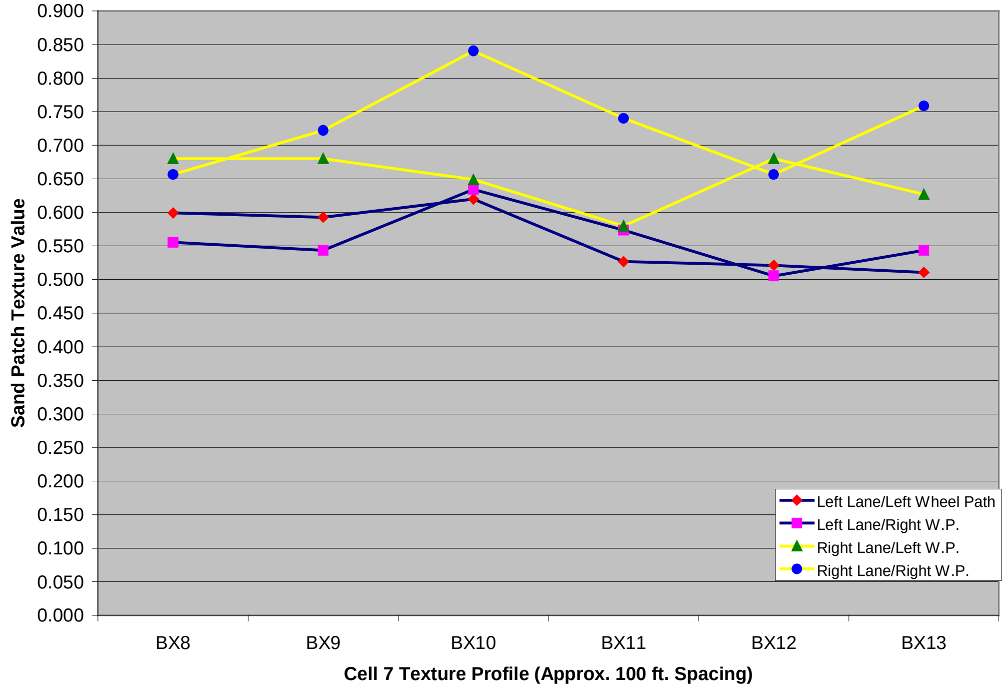

Figure 4.12. Sand volumetric technique ASTM E-965 test result on Cell 7.

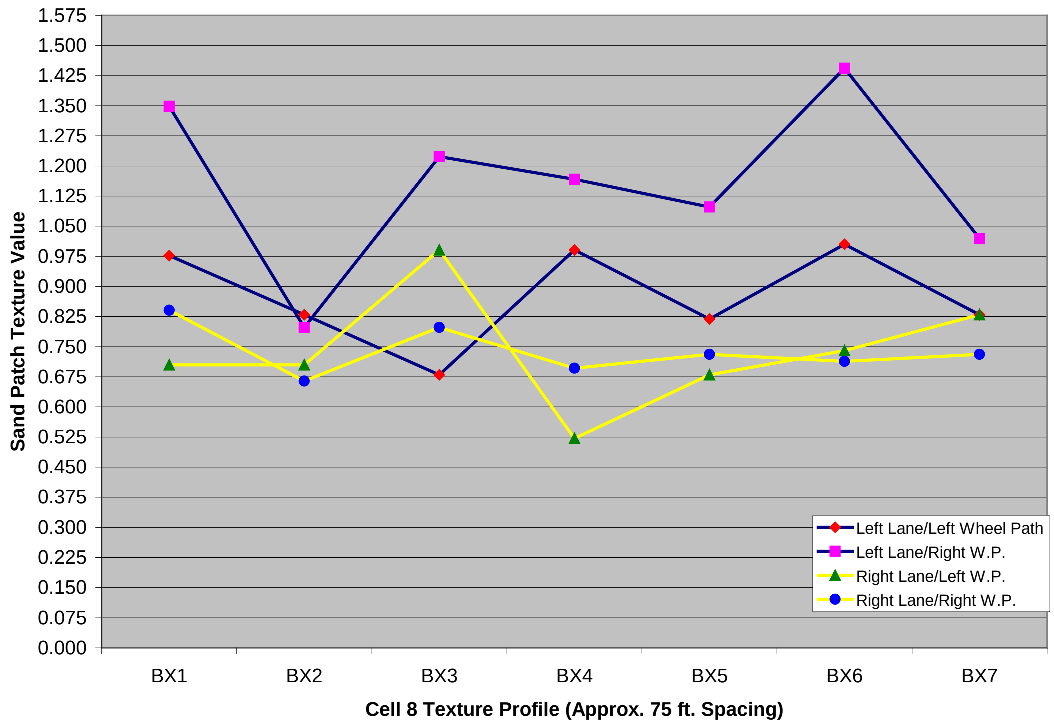

Figure 4.13. Sand volumetric technique ASTM E-965 test result on Cell 8.

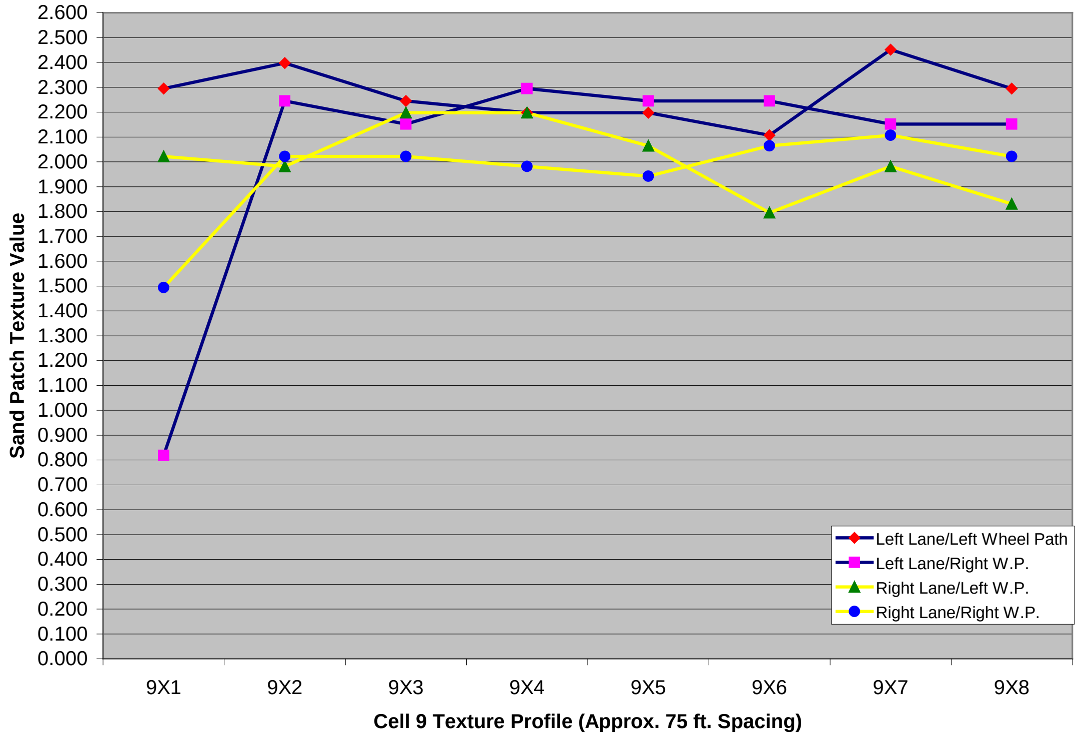

Figure 4.14. Sand volumetric technique ASTM E-965 test result on Cell 9.

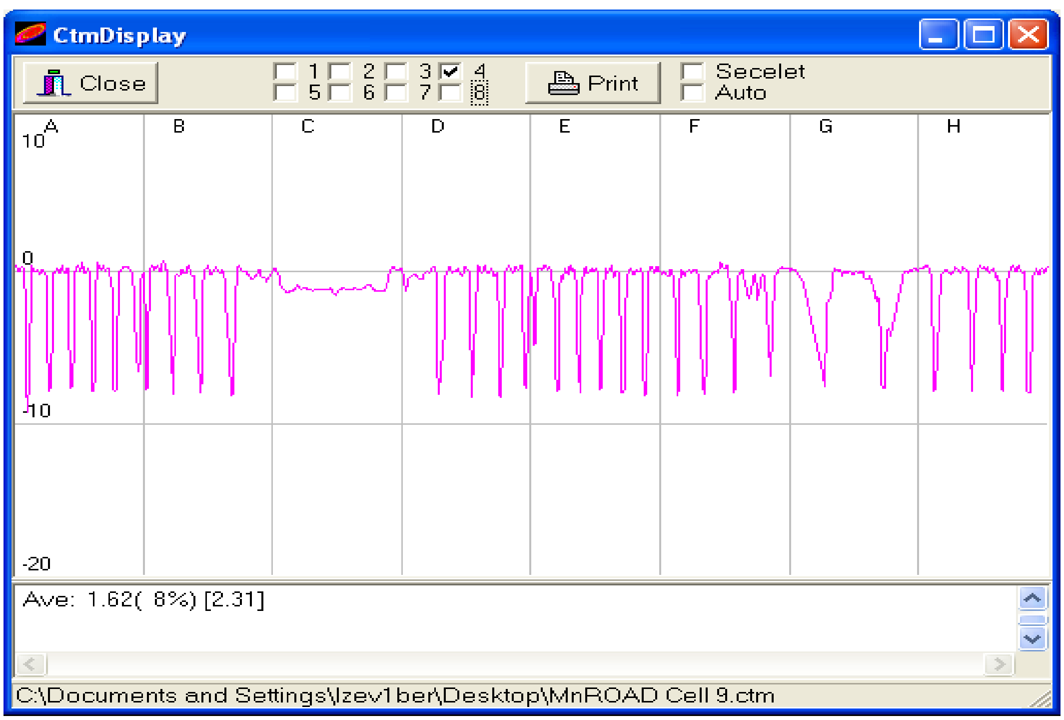

Figure 4.15. Screen capture of Ultimate Grind with CTM (ASTM E-2157).

CHAPTER 5. BRIEF DISCUSSION OF RESULTS

The proof-of-concept grinding validated the feasibility of producing the innovative grind at a production level. Although it was not a full-width grinding exercise, four test strips were created. Strip TS1 was a flush grind and groove in one pass, TS2 was the flush grind and groove in 2 passes, TS3 was the conventional grind of 0.125X 0.125 X0.120 groove kerf, depth. Configurations TS1 and TS2 represented the innovative grind with the difference of the number of passes to achieve each configuration. Configuration TS4 was the original, non-uniform transverse tine that was in the entire lane before grinding. The ACPA measured on-board sound intensity on each strip and Mn/DOT measured ride quality, friction, and texture before and after grinding. The results showed a friction number distribution of ribbed tire friction for the innovative grind ranging from the upper 40s to the middle 50s. The disparity in friction number between ribbed and smooth tires was less than 5 in the innovative configurations. This is a significant issue in the interpretation of non-correlative texture degradation and friction degradation observations, and lends credence to the hysteresis theory of tire-pavement suction enhanced by better contact.

After Mn/DOT had performed pre-grind measurements in the mainline Cells 7 and 8, grinding was completed by DSI forces between 18 and 20 October 2007, and the respective testing for post-grind friction, texture, ride, and noise followed shortly thereafter. Cell 7 had the innovative grind while Cell 8 had the conventional grind. By the strategy described in Chapter 4, a separate sub-cell was created in the left shoulder of Cell 8. In that portion, partial tine removal was performed by DSI. Table 4.3 through Table 4.5 show the pre- and post grind test results. More detailed results are shown in Appendices A through D. Cell 9 was ground using the "ultimate grind" configuration in October 2008. These cells will be monitored for a minimum of five years to determine durability and time-related texture and friction decay of the innovative grinds and the noise trends over the study period.

5.1 Ride Quality

Ride quality measurements were difficult to establish within the strips as the vertical acceleration of the wheel track was not representative of the single laser response that bounced from kerf to grove and vice versa. This may have contributed to higher ride quality measurements after grinding. Results showed improved ride quality in the innovative and conventional grinding partly because DSI performed some corrective grinding in portions of extreme faulting. The innovative grinding resulted in IRI improvement from 75 in/mi to 48 in/mi in the driving lane. The passing lane showed the same percentage improvement in IRI after grinding in each cell while the driving lane showed a different percentage improvement. Each lane, therefore, had the same percentage improvement in spite of the configuration.

5.2 Texture

Texture measurements indicated greatly improved texture depths with the conventional grind and improved texture depths in the innovative grind, after grinding. Texture measurements ranged from 0.3 mm to 0.5 mm prior to grinding. In the Cell 8 shoulder, texture measurements indicated that original textures of 0.8 mm had been maintained over time. This was partially removed by grinding, although the macro and microtexture of the diamond grind resulted in improved texture to 1.0 mm or greater after partial tine removal. Texture improved in the conventional grind to a range of 1.3 to 1.8 mm. The innovative grind textures improved to a range of 0.9 to 1.1 mm. This was more uniform, and, unlike the conventional grind, the texture was durable and could not be easily damaged by oblique impacts.

The ultimate grind provided more mean texture depth than the innovative grind and this difference is attributed to the additional corrugations on the kerf. It is evident that the ultimate grind (Cell 9) provides more mean texture depth than the innovative and conventional grinds. The average was found to be 2.1 mm

5.3 Noise

On-board sound intensity tests showed that the innovative grind achieved a high level of quietness surpassing previously known grinding configurations. At 98.5 dBA, the innovative grind was much quieter than the conventional grind, at 102 dBA and than the un-ground tine, at 104 dBA. OBSI noise levels for the conventional grind measured by Mn/DOT averaged about 103.3 dBA. The innovative grind was measured at an average of 98.8 dBA, while the ultimate grind had an initial OBSI level of about 101.4 dBA. It may be garnered from the grinding report of Cells 7 and 8 (*1*) that the innovative grind is quieter than the conventional grind by 3.5 dBA. The noise reduction benefit of the ultimate grind is expected at the minimum to be similar to that of the innovative grind.

5.4 Friction

Friction measurements in the mainline were similar to results obtained in Cell 37. Once again, the difference between the smooth and ribbed tire friction was small. In comparison to the innovative and conventional grinds (Cells 7 and 8, respectively), it is evident that the ultimate grind shows higher friction than the innovative grind but less than the conventional grind. It is also evident that the innovative and the ultimate grind have comparable smooth tire and ribbed tire friction numbers and in some cases, the smooth tire friction exceeds the ribbed tire friction. The innovative grind brings this advantage to the pavement surface. The same observation is made in the ultimate grind, although it showed slightly higher friction values than the innovative grind.

CHAPTER 6. CONCLUSIONS

The grinding configuration produced by the Purdue SQDH laboratory is an innovative and quiet pavement solution. At 98.5 dBA it represents the quietest diamond ground pavement in the United States. It provides lower ribbed tire friction than the conventional grind but higher smooth tire friction comparable to the ribbed tire friction numbers. This is an interesting phenomenon as it provides higher than expected friction numbers for worn tires.

Successful placement of the innovative configuration in the MnROAD mainline confirms the feasibility of performing the innovative grinding in a single pass.

Improved ride quality was not validated in the low volume road due to difficulty in measuring ride quality. In strips thinner than the light weight profiler, proper data collection could not be conducted. However both the conventional and innovative grind resulted in improved ride quality in the mainline where full width grinding was done.

The ultimate grind was developed primarily to improve the friction characteristics of the innovative grind. Results have demonstrated that this improvement has been achieved. This new configuration exhibits improved friction over the 2007 innovative grind and provides sufficient skid resistance, which meets and exceeds most institutional requirements. This configuration exhibits more mean texture depth and this indicates that the configuration will be durable. Degradation of kerfs is usually more pronounced in the conventional grind that is only 1/8 inch by 1/8 inch by 1/8 inch. The 1/8-inch by 1/4-inch by 1/4-inch configuration of the innovative grind assures durability of the kerfs and the 1/16-inch by 1/8-inch by 1/16-inch currugation which is the unique feature of the ultimate grind on the kerfs assures better friction than innovative grind.

APPENDIX A. OBSI TEST DETAILS

Table A.1. Cell 7 Passing Lane Run 1.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	74.6	10.3	0.5	83.6	3.6	0.5	81.1
315	no data	no data	0.6	85.5	1.2	0.6	no data
400	80.5	3.2	0.8	77.6	7.9	0.6	79.3
500	81.9	2.3	0.9	77.5	7.3	0.8	80.2
630	83.2	2.6	1.0	82.3	3.1	0.9	82.8
800	87.9	1.4	1.0	88.9	1.4	1.0	88.4
1000	94.3	0.6	1.0	94.8	0.9	1.0	94.6
1250	90.1	0.5	1.0	93.7	0.7	1.0	92.2
1600	88.6	1.1	1.0	88.8	1.1	1.0	88.7
2000	88.0	1.3	1.0	87.7	1.2	1.0	87.9
2500	85.4	1.1	1.0	86.4	0.9	1.0	85.9
3150	80.6	0.9	0.9	81.0	0.9	0.9	80.8
4000	76.5	1.7	0.8	77.4	1.6	0.8	77.0
5000	73.2	2.1	0.7	73.3	2.0	0.7	73.2
A-wtd	**98.2**			**99.2**			**98.7**

Table A.2. Cell 7 Passing Lane Run 2.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	83.6	0.6	0.4	84.9	0.5	0.5	84.3
315	82.8	0.2	0.6	83.1	1.9	0.6	82.9
400	81.6	2.0	0.8	80.9	3.1	0.7	81.3
500	81.7	2.0	0.9	79.8	4.3	0.8	80.8
630	82.6	2.6	1.0	81.2	3.4	0.9	82.0
800	88.1	1.4	1.0	89.1	1.3	1.0	88.6
1000	94.4	0.6	1.0	94.7	1.0	1.0	94.6
1250	89.9	0.7	1.0	93.5	0.7	1.0	92.1
1600	89.0	1.1	1.0	88.9	0.9	1.0	89.0
2000	87.8	1.2	1.0	87.8	1.1	1.0	87.8
2500	85.5	1.0	1.0	86.4	0.8	1.0	86.0
3150	80.3	0.8	0.9	81.1	0.6	0.9	80.7
4000	76.7	1.3	0.8	77.6	1.2	0.9	77.1
5000	73.5	1.7	0.8	73.2	1.5	0.7	73.4
A-wtd	**98.2**			**99.2**			**98.7**

Table A.3. Cell 7 Passing Lane Run 3.

Frequency	Leading Edge			Trailing Edge			AVG
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	81.3	4.8	0.5	85.8	2.3	0.4	84.1
315	no data	no data	0.6	84.5	3.4	0.6	no data
400	79.4	5.5	0.8	85.1	1.5	0.6	83.1
500	82.6	2.4	0.9	81.6	4.6	0.8	82.1
630	83.5	2.7	1.0	82.6	3.8	0.9	83.1
800	88.3	1.5	1.0	89.1	1.4	1.0	88.7
1000	95.1	0.7	1.0	95.5	1.0	1.0	95.3
1250	90.9	0.6	1.0	93.8	0.8	1.0	92.6
1600	89.0	1.1	1.0	89.0	1.1	1.0	89.0
2000	88.0	1.3	1.0	87.9	1.3	1.0	87.9
2500	85.5	1.2	1.0	86.5	0.9	1.0	86.0
3150	80.8	1.0	0.9	81.3	1.0	0.9	81.1
4000	76.9	1.7	0.8	78.0	1.5	0.8	77.5
5000	73.9	2.1	0.7	73.8	2.0	0.7	73.8
A-wtd	**98.7**			**99.6**			**99.2**

Table A.4. Cell 7 Mid-Lane Post-Grind Run 1.

Frequency	Leading Edge			Trailing Edge			AVG
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	84.9	0.7	0.4	87.6	-0.2	0.5	86.4
315	80.9	3.6	0.6	82.5	4.3	0.6	81.8
400	83.2	2.9	0.8	82.0	3.9	0.7	82.7
500	86.0	1.5	1.0	85.4	2.6	0.9	85.7
630	86.1	1.9	1.0	85.6	2.5	0.9	85.9
800	89.0	1.1	1.0	89.0	1.3	1.0	89.0
1000	94.0	0.8	1.0	93.8	0.9	1.0	93.9
1250	89.4	0.9	1.0	92.4	0.8	1.0	91.2
1600	89.8	1.1	1.0	88.9	1.1	1.0	89.4
2000	88.7	1.3	1.0	88.4	1.1	1.0	88.5
2500	86.0	1.1	1.0	87.5	0.8	1.0	86.8
3150	81.0	0.9	0.9	82.4	0.7	0.9	81.8
4000	77.3	1.6	0.8	78.6	1.4	0.8	78.0
5000	73.8	1.9	0.7	74.0	1.6	0.7	73.9
A-wtd	**98.6**			**99.0**			**98.8**

Table A.5. Cell 7 Mid-Lane Run 2.

Frequency	Leading Edge			Trailing Edge			AVG
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	83.4	1.7	0.5	82.0	4.1	0.5	82.8
315	81.1	2.6	0.6	70.8	14.3	0.6	78.5
400	82.2	2.1	0.8	81.4	3.3	0.7	81.8
500	82.3	2.4	0.9	81.6	3.4	0.9	81.9
630	84.5	1.9	1.0	83.4	2.7	0.9	84.0
800	88.7	1.0	1.0	88.9	1.1	1.0	88.8
1000	93.8	0.8	1.0	93.5	0.9	1.0	93.7
1250	90.2	0.8	1.0	93.2	0.7	1.0	92.0
1600	89.6	1.1	1.0	88.9	1.1	1.0	89.3
2000	88.6	1.2	1.0	88.9	1.0	1.0	88.8
2500	86.3	1.1	1.0	87.7	0.6	1.0	87.0
3150	80.9	0.8	1.0	82.8	0.4	1.0	82.0
4000	77.1	1.3	0.9	78.6	0.9	0.9	77.9
5000	73.7	1.6	0.8	73.8	1.2	0.8	73.8
A-wtd	**98.4**			**99.0**			**98.7**

Table A.6. Cell 7 Mid-Lane Run 3.

Frequency	Leading Edge			Trailing Edge			AVG
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	87.0	-0.9	0.4	77.9	9.1	0.5	84.5
315	81.0	3.6	0.5	85.1	1.1	0.6	83.5
400	83.2	1.4	0.7	82.3	2.5	0.7	82.7
500	82.3	1.9	0.9	79.5	4.8	0.8	81.1
630	83.1	2.2	1.0	81.1	4.0	0.9	82.3
800	88.1	1.2	1.0	88.4	1.4	1.0	88.3
1000	93.9	0.8	1.0	93.5	0.9	1.0	93.7
1250	89.8	0.7	1.0	92.9	0.7	1.0	91.6
1600	88.9	1.1	1.0	88.8	1.0	1.0	88.8
2000	88.6	1.2	1.0	88.9	1.0	1.0	88.7
2500	86.2	1.1	1.0	87.6	0.6	1.0	87.0
3150	80.9	0.8	1.0	82.1	0.6	0.9	81.5
4000	77.3	1.3	0.8	78.6	0.9	0.9	78.0
5000	74.1	1.6	0.7	74.1	1.2	0.8	74.1
A-wtd	**98.2**			**98.7**			**98.5**

Table A.7. Cell 8 Passing Lane Run 1.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	87.1	0.3	0.7	89.8	-1.5	0.6	88.6
315	83.4	3.9	0.8	86.1	2.3	0.7	85.0
400	88.6	1.3	0.9	86.5	1.7	0.8	87.7
500	90.9	1.2	1.0	89.0	2.0	0.9	90.0
630	95.2	1.3	1.0	92.7	1.7	1.0	94.2
800	99.6	0.5	1.0	97.1	0.8	1.0	98.6
1000	95.8	1.1	1.0	96.9	1.0	1.0	96.4
1250	93.1	0.6	1.0	95.0	0.8	1.0	94.1
1600	90.0	0.8	1.0	90.4	0.9	1.0	90.2
2000	87.8	1.2	1.0	87.4	1.2	1.0	87.6
2500	84.7	1.2	1.0	84.4	1.2	1.0	84.5
3150	80.2	1.0	0.9	79.8	1.3	0.9	80.0
4000	76.2	1.6	0.8	75.9	2.1	0.8	76.1
5000	73.7	1.8	0.7	72.8	2.2	0.7	73.3
A-wtd	**103.4**			**102.5**			**103.0**

Table A.8. Cell 8 Passing Lane Run 2.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	88.0	-0.3	0.7	88.8	0.4	0.7	88.4
315	83.5	4.2	0.8	87.8	2.7	0.8	86.1
400	89.6	1.2	1.0	89.4	2.4	0.9	89.5
500	91.4	1.4	1.0	90.7	1.7	1.0	91.1
630	95.5	1.3	1.0	92.9	1.6	1.0	94.4
800	99.7	0.6	1.0	97.1	0.8	1.0	98.6
1000	96.1	1.1	1.0	97.2	1.0	1.0	96.7
1250	93.1	0.6	1.0	94.8	0.8	1.0	94.0
1600	89.5	0.9	1.0	90.1	0.9	1.0	89.8
2000	87.7	1.2	1.0	87.2	1.2	1.0	87.4
2500	84.7	1.1	1.0	84.5	1.1	1.0	84.6
3150	80.2	0.8	0.9	79.7	1.1	0.9	79.9
4000	76.2	1.3	0.8	75.7	1.8	0.8	76.0
5000	73.5	1.6	0.7	72.5	1.9	0.7	73.0
A-wtd	**103.5**			**102.6**			**103.1**

Table A.9. Cell 8 Passing Lane Run 3.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	75.8	11.8	0.7	90.1	-1.9	0.6	87.2
315	85.6	2.0	0.8	82.3	6.3	0.7	84.3
400	89.1	1.4	1.0	86.5	2.1	0.8	88.0
500	91.7	1.3	1.0	89.8	1.9	1.0	90.8
630	96.3	1.2	1.0	93.5	1.4	1.0	95.1
800	100.4	0.5	1.0	97.9	0.8	1.0	99.3
1000	96.5	1.0	1.0	97.9	1.0	1.0	97.3
1250	93.5	0.6	1.0	95.6	0.8	1.0	94.7
1600	90.2	0.9	1.0	90.7	0.8	1.0	90.5
2000	88.1	1.1	1.0	87.5	1.2	1.0	87.8
2500	84.9	1.1	1.0	84.8	1.1	1.0	84.8
3150	79.9	1.0	0.9	79.7	1.2	0.9	79.8
4000	75.9	1.7	0.8	75.6	2.1	0.8	75.7
5000	73.7	1.7	0.7	72.4	2.1	0.7	73.1
A-wtd	104.1			103.3			103.7

Table A.10. Cell 8 Driving Lane Run 1.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	82.8	4.5	0.6	82.4	5.1	0.5	82.6
315	87.0	1.4	0.8	89.2	-0.8	0.7	88.2
400	90.3	0.9	1.0	88.2	0.5	0.8	89.4
500	91.5	1.3	1.0	89.7	1.6	1.0	90.7
630	95.8	1.2	1.0	92.9	1.6	1.0	94.6
800	100.3	0.4	1.0	97.5	0.5	1.0	99.1
1000	95.3	0.9	1.0	96.9	0.8	1.0	96.2
1250	92.7	0.5	1.0	94.6	0.8	1.0	93.8
1600	89.4	0.8	1.0	90.1	0.8	1.0	89.7
2000	86.8	1.1	1.0	85.9	1.2	1.0	86.4
2500	83.9	1.1	1.0	83.3	1.3	1.0	83.6
3150	80.2	1.0	0.9	79.4	1.2	0.9	79.8
4000	76.4	1.3	0.8	75.8	1.6	0.8	76.1
5000	73.8	1.8	0.7	72.6	2.0	0.7	73.2
A-wtd	**103.6**			**102.6**			**103.1**

Table A.11. Cell 8 Driving Lane Run 2.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	78.0	9.2	0.7	86.5	1.2	0.6	84.0
315	88.0	0.4	0.9	86.8	1.0	0.8	87.5
400	90.5	1.1	1.0	88.1	0.8	0.9	89.4
500	92.1	1.0	1.0	89.3	1.8	1.0	90.9
630	96.5	1.2	1.0	93.5	1.6	1.0	95.2
800	100.6	0.4	1.0	97.9	0.6	1.0	99.5
1000	96.1	1.0	1.0	97.4	0.9	1.0	96.8
1250	93.1	0.6	1.0	95.1	0.8	1.0	94.2
1600	89.3	0.8	1.0	90.4	0.8	1.0	89.9
2000	87.2	1.1	1.0	86.6	1.1	1.0	86.9
2500	83.9	1.1	1.0	83.6	1.1	1.0	83.8
3150	80.0	0.9	0.9	79.5	1.1	0.9	79.7
4000	76.3	1.4	0.8	75.6	1.6	0.8	75.9
5000	73.9	1.8	0.7	72.5	1.8	0.7	73.2
A-wtd	**104.0**			**103.0**			**103.5**

Table A.12. Cell 8 Driving Lane Run 3.

Frequency	**Leading Edge**			**Trailing Edge**			**AVG**
Hz	**IL**	**PI**	**Coh**	**IL**	**PI**	**Coh**	**IL**
250	85.4	0.6	0.7	86.9	-0.4	0.6	86.2
315	85.3	2.4	0.9	83.0	4.1	0.8	84.3
400	89.7	1.1	1.0	86.2	1.8	0.9	88.3
500	91.1	0.9	1.0	88.8	1.5	1.0	90.1
630	95.8	1.3	1.0	93.1	1.5	1.0	94.6
800	100.3	0.4	1.0	97.9	0.5	1.0	99.3
1000	95.6	1.0	1.0	97.4	0.9	1.0	96.6
1250	93.1	0.5	1.0	95.0	0.7	1.0	94.1
1600	88.9	0.8	1.0	90.2	0.8	1.0	89.6
2000	87.1	1.1	1.0	86.5	1.1	1.0	86.8
2500	83.7	1.1	1.0	83.5	1.1	1.0	83.6
3150	79.6	0.9	0.9	79.6	1.0	0.9	79.6
4000	75.8	1.3	0.8	75.6	1.4	0.8	75.7
5000	73.3	1.7	0.7	72.1	1.8	0.7	72.8
A-wtd	**103.7**			**102.9**			**103.3**

APPENDIX B. PRE- AND POST-GRIND MAINLINE RIDE QUALITY

Table B.1. Cell 7 Pre-Grind Ride Statistics.

Cell	Lane	Wheel Path	IRI (in/mi)	PTRN (in/mi)	RN
Cell 7	Driving	Left	83.3	134.7	3.56
		Right	68.0	117.1	3.72
	Passing	Left	72.8	127.4	3.62
		Right	78.5	123.7	3.66

Table B.2. Cell 7 Pre-Grind Power Spectral Density Settings.

Input	Value
PSD Calculation	Slope
Use Point Reset	No
Frequency Averaging	Yes
Bands Per Octave	12
Pre-Processor Filter	None

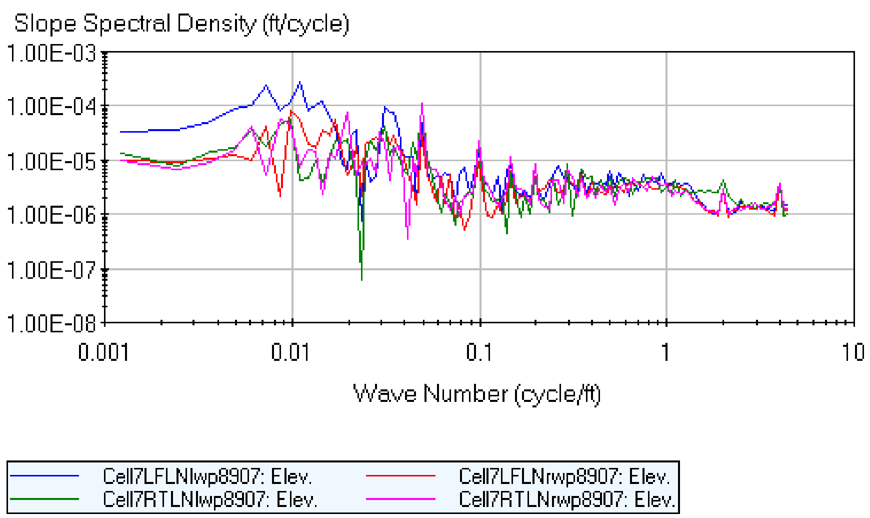

Figure B.1. Cell 7 pre-grind wave number.

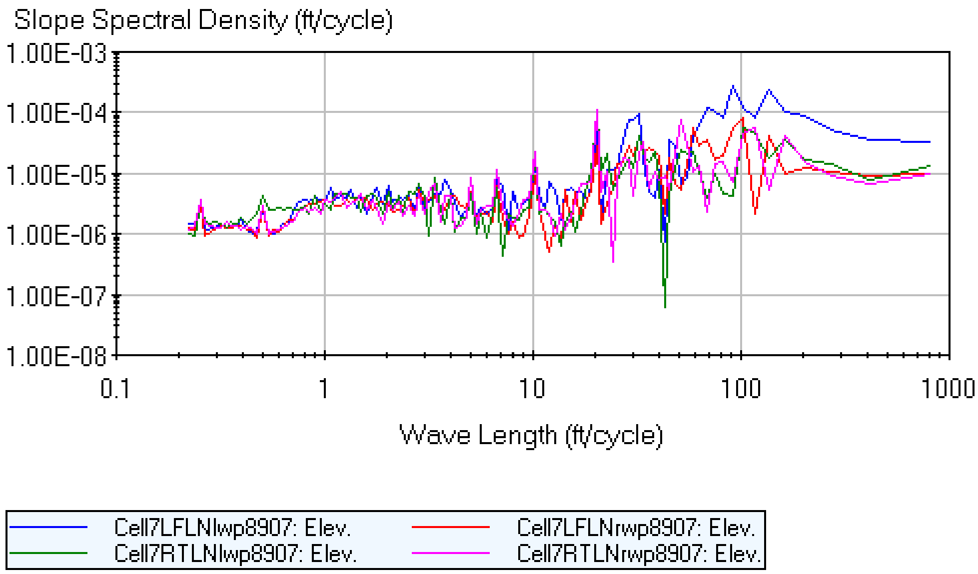

Figure B.2. Cell 7 pre-grind wavelength.

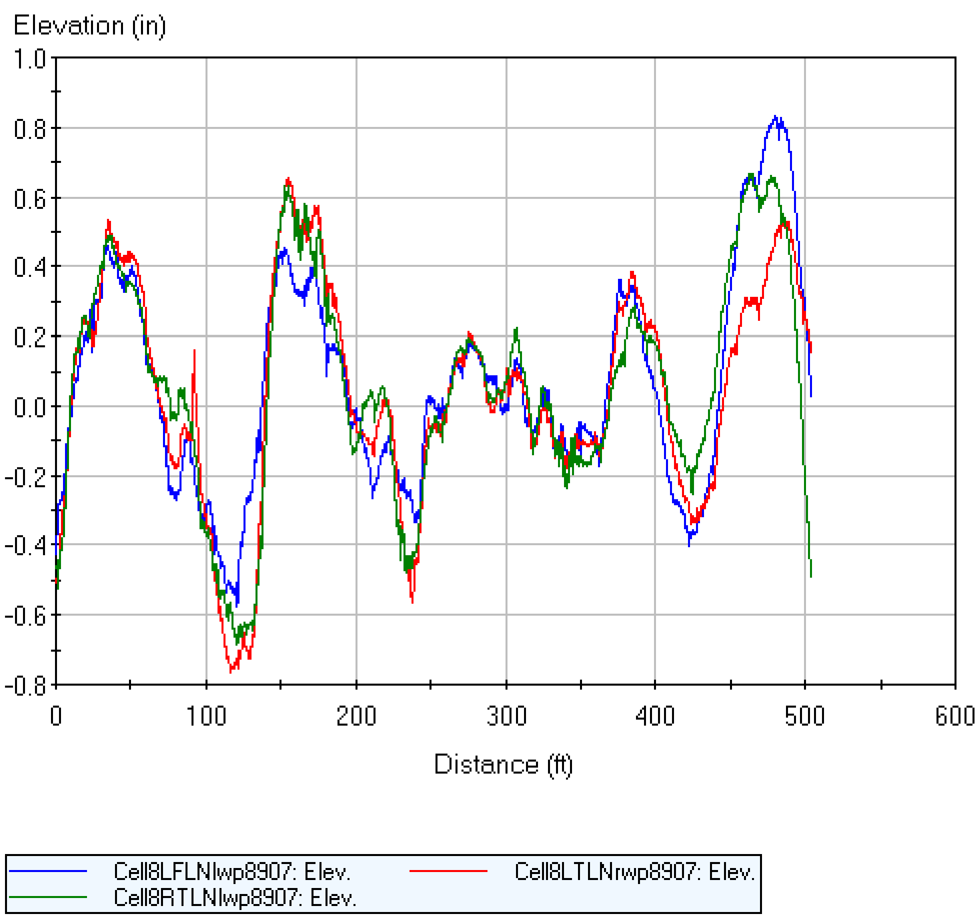

Figure B.3. Cell 8 pre-grind ProVAL report.

Table B.3. Cell 8 Pre-Grind Ride Statistics.

Cell	Lane	Wheel Path	IRI (in/mi)	PTRN (in/mi)	RN
Cell 8	Driving	Left	107.9	173.2	3.23
		Right	123.0	176.6	3.20
	Passing	Left	123.1	186.0	3.13
		Right	104.8	169.0	3.26

Table B.4. Cell 8 Pre-Grind Power Spectral Density Settings.

Input	Value
PSD Calculation	Elevation
Use Point Reset	No
Frequency Averaging	Yes
Bands Per Octave	12
Pre-Processor Filter	None

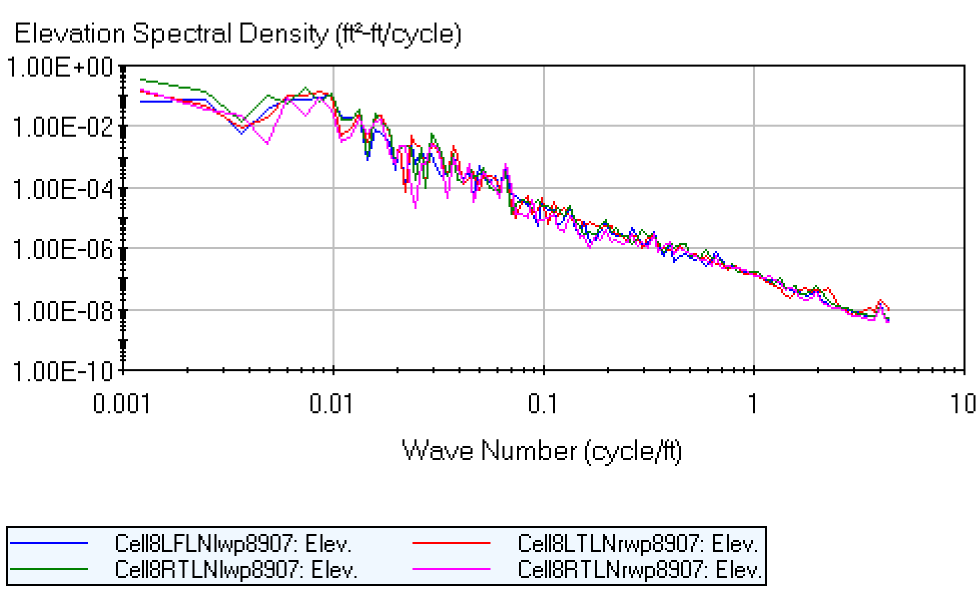

Figure B.4. Cell 8 pre-grind wave number.

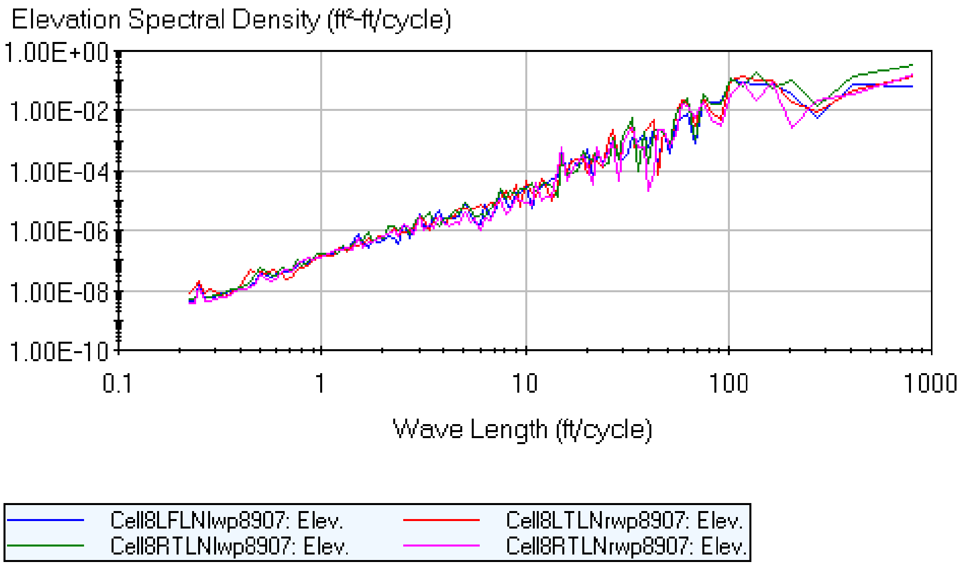

Figure B.5. Cell 8 pre-grind wavelength.

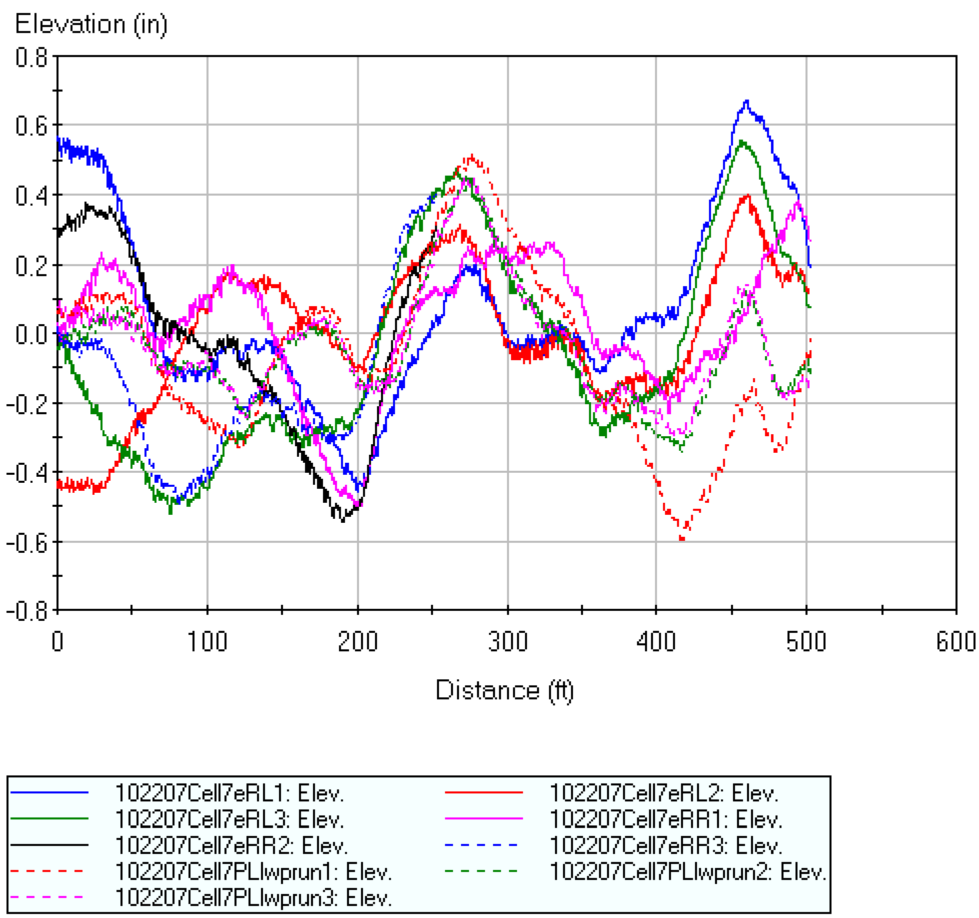

Figure B.6. Cell 7 post-grind ProVAL report.

Table B.5. Cell 7 Post-Grind Ride Statistics.

Cell	Lane	Wheel Path	IRI (in/mi)	PTRN (in/mi)	RN
Cell 7	Driving	Left	48.3	115.3	3.74
			44.5	112.5	3.76
			46.5	100.5	3.88
		Right	51.9	119.8	3.69
			55.4	117.8	3.71
			44.2	118.4	3.71
	Passing	Left	53.7	108.1	3.81
			47.5	95.1	3.93
			50.0	103.9	3.85
		Right	49.9	95.7	3.93
			43.2	87.8	4.01
			45.7	94.0	3.94

Table B.6. Cell 8 Post-Grind Ride Statistics.

Cell	Lane	Wheel Path	IRI (in/mi)	PTRN (in/mi)	RN
Cell 8	Driving	Left	70.4	167.7	3.27
			74.1	166.6	3.28
			74.9	207.8	2.96
		Right	74.2	198.7	3.03
			75.4	188.6	3.11
			75.3	189.8	3.10
	Passing	Left	70.7	173.1	3.23
			75.9	180.8	3.17
			66.0	184.2	3.14
		Right	81.7	202.8	3.00
			84.9	166.1	3.29
			73.7	213.3	2.92

APPENDIX C. ADDITIONAL FRICTION DATA

Table C.1. Cell 7 Pre-Grind Friction Data.

Cell	Grind Type	Lane	Tire Type	Date	Time	FN	Peak	Speed (mph)	Air Temp (°F)	Pavement Temp (°F)
Cell 7	Innovative	Driving	Ribbed	23-Jun-94		60				
			Ribbed	20-Sep-94		6.7				
			Ribbed	4-May-95		1.5				
			Ribbed	20-Jun-95		0.4				
			Ribbed	29-Oct-97	12:17	55.1	74.2	40.3	50	51
			Ribbed	20-Oct-98	9:33	47.7	69.8	39.7	44	
			Ribbed	31-Oct-01	13:49	38.1	57.2	40.2	69	55
			Ribbed	3-Nov-04	11:12	57.7	83.3	39.5	30	
			Ribbed	24-May-05	10:47	53.3	69.7	40.5	72	114.9
			Ribbed	19-Apr-06	11:08	55.7	82.81	40.4	59	
			Ribbed	24-Oct-06	1348	59.5	78.6	40	42	62.8
			Smooth	14-Oct-98	14:11	31	66.5	48.3	40.2	51
			Smooth	20-Oct-98	10:10	36.2	39.6	40.2	51	
			Smooth	19-Apr-06	11:32	26.2	45.26	40.5	60	
			Smooth	24-Oct-06	1404	35.9	51.97	40.2	43	63
		Passing	Ribbed	23-Jun-94		58.7				
			Ribbed	20-Sep-94		52.5				
			Ribbed	4-May-95		60.1				
			Ribbed	20-Jun-95		63.6				
			Ribbed	29-Oct-97	12:22	58.3	79.7	39.4	48	51
			Ribbed	14-Oct-98	15:01	56.7	87.8	40.3	44	
			Ribbed	20-Oct-98	9:48	53.4	76.4	40.1	41	
			Ribbed	31-Oct-01	14:39	42.1	64.4	40.3	60	55
			Ribbed	3-Nov-04	10:42	56.9	85.6	39.7	29	
			Ribbed	24-May-05	10:27	58.8	77.9	40.3	71	108.4
			Ribbed	19-Apr-06	11:49	57.5	81.56	40.4	60	
			Ribbed	24-Oct-06	1419	59.4	75.81	40	45	64
			Smooth	14-Oct-98	14:24	46	64	40.3	51	
			Smooth	20-Oct-98	10:27	41.9	63.1	40	46	
			Smooth	3-Nov-04	10:58	43.3	72.4	40.2	30	
			Smooth	19-Apr-06	12:10	40.4	78.95	40.2	62	

Table C.2. Cell 8 Pre-Grind Friction Data.

Cell	Grind Type	Lane	Tire Type	Date	Time	FN	Peak	Speed (mph)	Air Temp (°F)	Pavement Temp (°F)
Cell 8	Conventional	Driving	Ribbed	23-Jun-94		54.3				
			Ribbed	20-Sep-94		54.9				
			Ribbed	4-May-95		54.8				
			Ribbed	20-Jun-95		48.5				
			Ribbed	29-Oct-97	12:17	44.5	74.1	40.1	50	51
			Ribbed	14-Oct-98	14:47	46.2	66.7	40.2	51	
			Ribbed	20-Oct-98	9:33	37.7	66.7	40.1	39	
			Ribbed	31-Oct-01	13:50	38.7	57	40.3	69	55
			Ribbed	3-Nov-04	11:12	47.5	73.6	40.5	30	
			Ribbed	24-May-05	10:47	42.6	60.4	40.6	72	112.8
			Ribbed	19-Apr-06	11:08	60.7	81.89	40.5	59	
			Ribbed	24-Oct-06	1348	48	64.14	40.3	42	61.7
			Smooth	14-Oct-98	14:11	25.9	18.7	56.6	40.2	55
			Smooth	20-Oct-98	10:10	22.6	30.1	40.4	46	
			Smooth	19-Apr-06	11:32	30.2	37.58	40.5	61	
			Smooth	24-Oct-06	14:04	20.9	28.87	40.6	43	61
		Passing	Ribbed	23-Jun-94		56.4				
			Ribbed	20-Sep-94		47				
			Ribbed	4-May-95		57.7				
			Ribbed	20-Jun-95		55.4				
			Ribbed	29-Oct-97	12:21	52.8	76.7	40.4	48	51
			Ribbed	14-Oct-98	15:01	54.4	72.8	39.8	44	
			Ribbed	20-Oct-98	9:48	39.9	70.5	40.1	42	
			Ribbed	31-Oct-01	14:39	41.2	61.2	40.4	60	55
			Ribbed	3-Nov-04	10:42	50.4	85.8	40.1	29	
			Ribbed	24-May-05	10:27	46.8	65.7	40.6	73	106.6
			Ribbed	19-Apr-06	11:48	52.6	80.73	40	61	
			Ribbed	24-Oct-06	1419	47	68.09	40.1	44	63.3
			Smooth	14-Oct-98	14:23	41.3	48	40.2	50	
			Smooth	20-Oct-98	10:27	24.3	45.5	40.2	46	
			Smooth	3-Nov-04	10:58	29.7	41.6	40.5	30	
			Smooth	19-Apr-06	12:09	28	81.77	39.9	62	

APPENDIX D. TEXTURE DATA

Table D.1. Cell 7 Pre-Grind Texture Data.

Measured By Bernard Izevbekhai						Sand Patch ASTM E-965			
10/15/07, 10/16/07			Time 12:00pm			Temp 55 Deg °F			
	Location	**Wheelpath**	**Run 1**	**Run 2**	**Run 3**	**Average**	**Vol (mm3)**	**Texture (mm)**	**CTM Check**
Cell 7	BX8	RR	482.6	482.6	482.6	482.6	68300	0.37	0.35
	BX8	RL	431.8	431.8	431.8	431.8		0.47	0.45
	BX8	LR	431.8	457.2	457.2	448.7		0.43	0.54
	BX8	LL	431.8	406.4	431.8	423.3		0.49	0.54
	BX9	RR	457.2	457.2	482.6	465.7		0.40	
	BX9	RL	457.2	457.2	457.2	457.2		0.42	
	BX9	LR	431.8	457.2	431.8	440.3		0.45	
	BX9	LL	431.8	431.8	431.8	431.8		0.47	
	BX10	RR	482.6	482.6	457.2	474.1		0.39	0.39
	BX10	RL	457.2	482.6	254	397.9		0.55	0.45
	BX10	LR	431.8	482.6	431.8	448.7		0.43	0.55
	BX10	LL	431.8	457.2	431.8	440.3		0.45	0.55
	BX11	RR	508	482.6	457.2	482.6		0.37	
	BX11	RL	482.6	482.6	482.6	482.6		0.37	
	BX11	LR	431.8	406.4	406.4	414.9		0.51	
	BX11	LL	431.8	431.8	431.8	431.8		0.47	
	BX12	RR	431.8	406.4	431.8	423.3		0.49	
	BX12	RL	457.2	457.2	457.2	457.2		0.42	
	BX12	LR	431.8	482.6	431.8	448.7		0.43	
	BX12	LL	482.6	431.8	431.8	448.7		0.43	
	Bx13	RR	482.6	508	533.4	508.0		0.34	
	Bx13	RL	508	508	457.2	491.1		0.36	
	Bx13	LR	457.2	457.2	457.2	457.2		0.42	
	Bx13	LL	457.2	457.2	457.2	457.2		0.42	

Table D.2. Cell 8 Pre-Grind Texture Data.

Measured By Bernard Izevbekhai						Sand Patch ASTM E-965			
10/15/07, 10/16/07			Time 12:00pm			Temp 55 Deg °F			
	Location	**Wheelpath**	**Run 1**	**Run 2**	**Run 3**	**Average**	**Vol (mm3)**	**Texture (mm)**	**CTM Check**
Cell 8	BX1	RR	457.2	431.8	431.8	440.3	68300	0.45	0.5
	BX1	RL	457.2	457.2	457.2	457.2		0.42	0.51
	BX1	LR	406.4	406.4	457.2	423.3		0.49	0.52
	BX1	LL	457.2	457.2	431.8	448.7		0.43	
	BX2	RR	508	508	457.2	491.1		0.36	0.42
	BX2	RL	482.6	431.8	431.8	448.7		0.43	0.5
	BX2	LR	431.8	457.2	457.2	448.7		0.43	0.45
	BX2	LL	457.2	457.2	482.6	465.7		0.40	.
	BX3	RR	508	508	508	508.0		0.34	
	BX3	RL	482.6	457.2	457.2	465.7		0.40	
	BX3	LR	406.4	406.4	457.2	423.3		0.49	
	BX3	LL	406.4	406.4	406.4	406.4		0.53	
	BX4	RR	508	508	482.6	499.5		0.35	0.45
	BX4	RL	508	508	482.6	499.5		0.35	0.42
	BX4	LR	431.8	457.2	457.2	448.7		0.43	0.49
	BX4	LL	431.8	431.8	431.8	431.8		0.47	0.45
	BX5	RR	508	508	508	508.0		0.34	
	BX5	RL	482.6	482.6	482.6	482.6		0.37	
	BX5	LR	508	482.6	482.6	491.1		0.36	
	BX5	LL	457.2	457.2	508	474.1		0.39	
	BX6	RR	482.6	533.4	533.4	516.5		0.33	
	BX6	RL	482.6	508	508	499.5		0.35	
	BX6	LR	508	533.4	533.4	524.9		0.32	
	BX6	LL	457.2	508	304.8	423.3		0.49	
	Bx7	RR	482.6	482.6	508	491.1		0.36	
	Bx7	RL	482.6	508	508	499.5		0.35	
	Bx7	LR	482.6	457.2	457.2	465.7		0.40	
	Bx7	LL	508	482.6	482.6	491.1		0.36	
Cell 8 SH	Bx14	RR	330.2	304.8	304.8	313.3		0.89	0.91
	Bx14	RL	330.2	25.4	279.4	211.7		1.94	
	Bx15	RR	330.2	50.8	304.8	228.6		1.66	
	Bx15	RL	304.8	304.8	304.8	304.8		0.94	
	Bx16	RR	304.8	330.2	304.8	313.3		0.89	
	Bx16	RL	330.2	304.8	228.6	287.9		1.05	
	BX17	RR	355.6	304.8	304.8	321.7		0.84	0.74
	BX17	RL	330.2	279.4	304.8	304.8		0.94	
	Bx18	RR	330.2	304.8	330.2	321.7		0.84	
	Bx18	RL	304.8	279.4	330.2	304.8		0.94	
	BX19	RR	330.2	304.8	304.8	313.3		0.89	
	BX19	RL	330.2	304.8	304.8	313.3		0.89	0.77
	Bx20	RR	304.8	304.8	254	287.9		1.05	
	Bx20	RL	304.8	533.4	254	364.1		0.66	
	BX21	RR	304.8	279.4	254	279.4		1.11	
	BX21	RL	330.2	304.8	304.8	313.3		0.89	0.81

Table D.3. Cell 7 Post-Grind Texture Data.

Measured By Bernard Izevbekhai						Sand Patch ASTM E-965			
10/23/2007			Time 12:00pm			Temp 50 Deg °F			
	Location	**Wheelpath**	**Run 1**	**Run 2**	**Run 3**	**Average**	**Vol (mm3)**	**Texture (mm)**	**CTM Check**
Cell 7	BX8	RR	304.8	304.8	304.8	304.8	68300	0.94	1.1
	BX8	RL	304.8	304.8	304.8	304.8		0.94	1.24
	BX8	LR	304.8	304.8	279.4	296.3		0.99	1.09
	BX8	LL	304.8	330.2	304.8	313.3		0.89	1.09
	BX9	RR	304.8	330.2	304.8	313.3		0.89	
	BX9	RL	279.4	304.8	304.8	296.3		0.99	
	BX9	LR	304.8	304.8	304.8	304.8		0.94	
	BX9	LL	304.8	304.8	304.8	304.8		0.94	
	BX10	RR	304.8	279.4	279.4	287.9		1.05	1.03
	BX10	RL	304.8	279.4	279.4	287.9		1.05	1.11
	BX10	LR	304.8	304.8	304.8	304.8		0.94	0.94
	BX10	LL	304.8	304.8	279.4	296.3		0.99	1.11
	BX11	RR	304.8	279.4	279.4	287.9		1.05	
	BX11	RL	279.4	279.4	279.4	279.4		1.11	
	BX11	LR	304.8	304.8	304.8	304.8		0.94	
	BX11	LL	279.4	304.8	330.2	304.8		0.94	
	BX12	RR	304.8	304.8	330.2	313.3		0.89	
	BX12	RL	304.8	304.8	330.2	313.3		0.89	
	BX12	LR	304.8	304.8	279.4	296.3		0.99	
	BX12	LL	330.2	304.8	304.8	313.3		0.89	
	Bx13	RR	279.4	304.8	304.8	296.3		0.99	
	Bx13	RL	304.8	304.8	304.8	304.8		0.94	
	Bx13	LR	330.2	304.8	304.8	313.3		0.89	
	Bx13	LL	279.4	279.4	304.8	287.9		1.05	

Table D.4. Cell 8 Post-Grind Texture Data.

Measured By Bernard Izevbekhai						Sand Patch ASTM E-965			
10/23/2007			Time 12:00pm			Temp 50 Deg °F			
	Location	**Wheelpath**	**Run 1**	**Run 2**	**Run 3**	**Average**	**Vol (mm3)**	**Texture (mm)**	**CTM Check**
Cell 8	BX1	RR	228.6	228.6	254	237.1	68300	1.55	1.43
	BX1	RL	228.6	228.6	228.6	228.6		1.66	1.45
	BX1	LR	203.2	228.6	228.6	220.1		1.80	1.53
	BX1	LL	254	228.6	228.6	237.1		1.55	
	BX2	RR	254	254	254	254.0		1.35	1.45
	BX2	RL	254	254	254	254.0		1.35	1.2
	BX2	LR	254	254	254	254.0		1.35	1.32
	BX2	LL	254	254	254	254.0		1.35	1.43
	BX3	RR	254	254	254	254.0		1.35	
	BX3	RL	228.6	228.6	254	237.1		1.55	
	BX3	LR	228.6	228.6	279.4	245.5		1.44	
	BX3	LL	228.6	228.6	254	237.1		1.55	
	BX4	RR	254	254	228.6	245.5		1.44	1.42
	BX4	RL	254	254	228.6	245.5		1.44	1.3
	BX4	LR	254	228.6	228.6	237.1		1.55	1.52
	BX4	LL	228.6	228.6	228.6	228.6		1.66	1.4
	BX5	RR	228.6	228.6	228.6	228.6		1.66	
	BX5	RL	228.6	228.6	228.6	228.6		1.66	
	BX5	LR	228.6	228.6	228.6	228.6		1.66	
	BX5	LL	228.6	228.6	228.6	228.6		1.66	
	BX6	RR	228.6	228.6	228.6	228.6		1.66	
	BX6	RL	228.6	228.6	228.6	228.6		1.66	
	BX6	LR	228.6	228.6	228.6	228.6		1.66	
	BX6	LL	228.6	228.6	228.6	228.6		1.66	
	Bx7	RR	228.6	228.6	228.6	228.6		1.66	
	Bx7	RL	228.6	228.6	228.6	228.6		1.66	
	Bx7	LR	228.6	228.6	228.6	228.6		1.66	
	Bx7	LL	228.6	203.2	228.6	220.1		1.80	
Cell 8 SH	Bx14	RR	228.6	254	228.6	237.1		1.55	1.7
	Bx14	RL	228.6	228.6	228.6	228.6		1.66	
	Bx15	RR	228.6	228.6	228.6	228.6		1.66	
	Bx15	RL	228.6	228.6	228.6	228.6		1.66	
	Bx16	RR	228.6	228.6	228.6	228.6		1.66	
	Bx16	RL	228.6	228.6	228.6	228.6		1.66	
	BX17	RR	228.6	228.6	228.6	228.6		1.66	1.72
	BX17	RL	254	254	203.2	237.1		1.55	
	Bx18	RR	228.6	228.6	254	237.1		1.55	
	Bx18	RL	228.6	254	254	245.5		1.44	
	BX19	RR	228.6	254	254	245.5		1.44	
	BX19	RL	228.6	228.6	254	237.1		1.55	1.52
	Bx20	RR	228.6	254	254	245.5		1.44	
	Bx20	RL	254	228.6	228.6	237.1		1.55	
	BX21	RR	228.6	228.6	254	237.1		1.55	
	BX21	RL	228.6	228.6	228.6	228.6		1.66	1.5

APPENDIX E. MNROAD MAINLINE AND LOW VOLUME ROAD

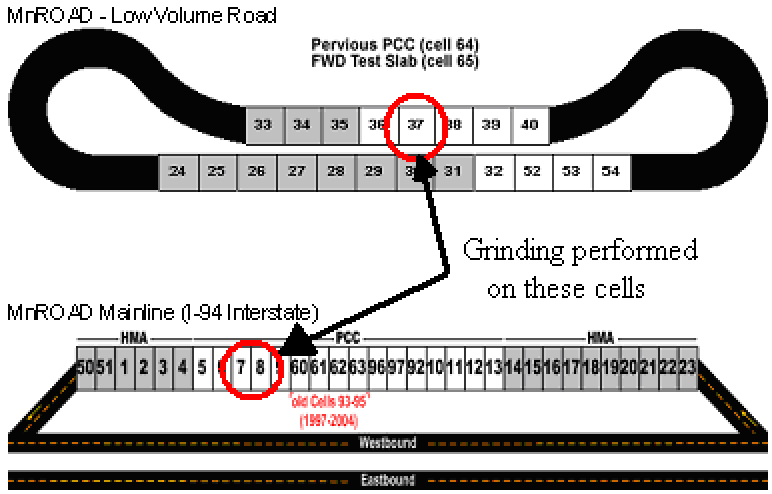

Figure E.1. MnROAD mainline and low volume road.

APPENDIX F. CELL 37 PRE- AND POST-GRIND RIDE REPORT

Table F.1. Cell 37 Pre-Grind Ride Statistics.

Cell	Test Code	IRI (in/mi)	PTRN (in/mi)	RN
Cell 37	TS21	101.8	228.7	2.81
	TS22	119.1	242.3	2.71
	TS31	136.3	305.6	2.31
	TS32	162.6	352.3	2.05
	TS33	119.8	266.4	2.55
	TS41	92.6	176.3	3.20

Table F.2. Cell 37 Pre-Grind Power Spectral Density Settings.

Input	Value
PSD Calculation	Elevation
Use Point Reset	No
Frequency Averaging	Yes
Bands Per Octave	12
Pre-Processor Filter	None

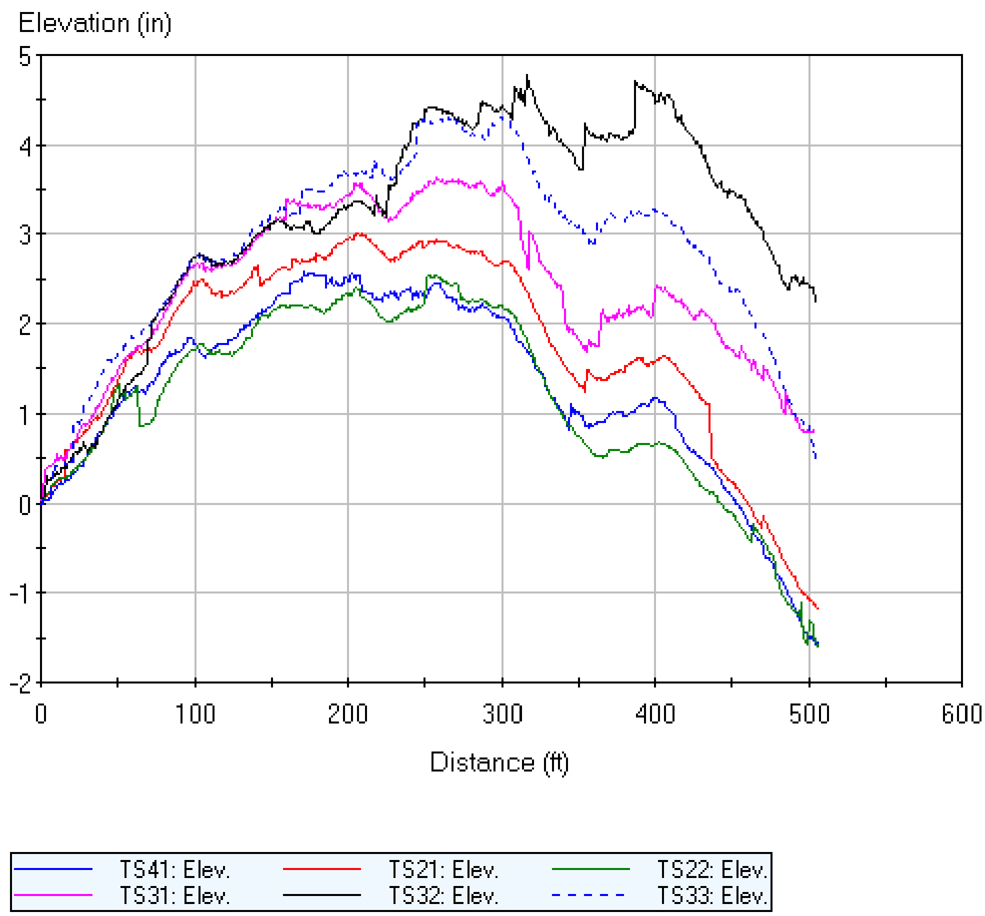

Figure F.1. Cell 37 pre-grind ride report.

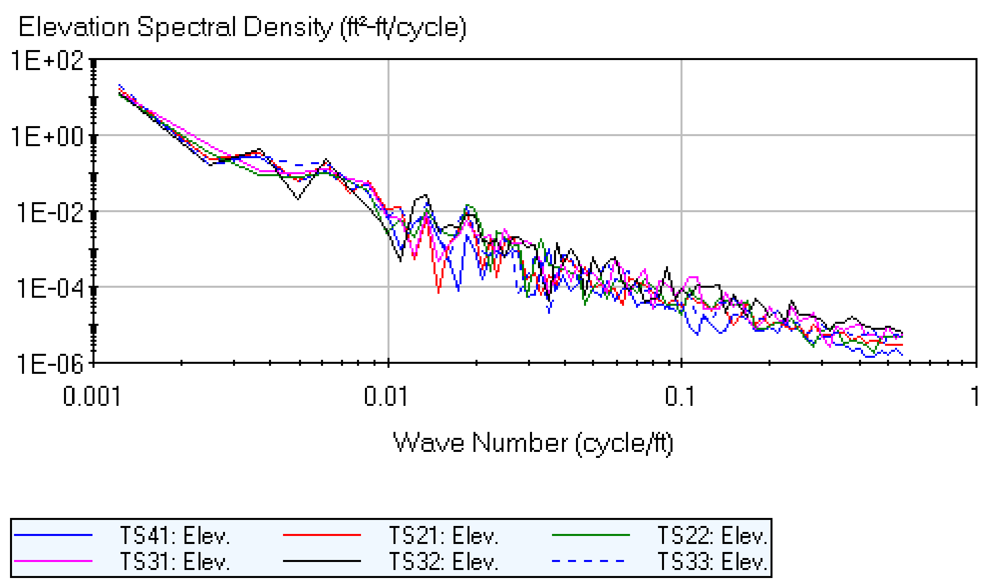

Figure F.2. Cell 37 pre-grind wave number.

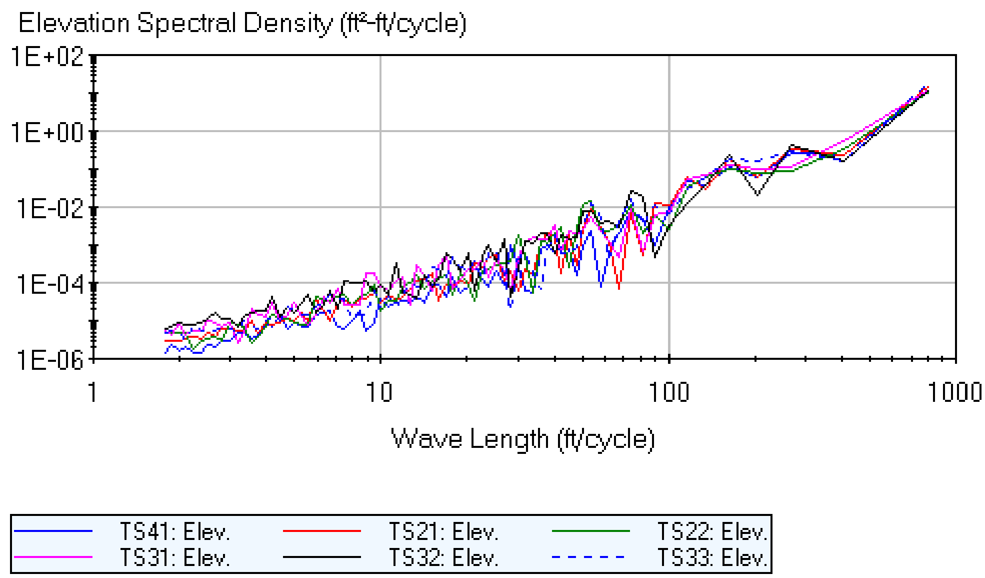

Figure F.3. Cell 37 pre-grind wavelength.

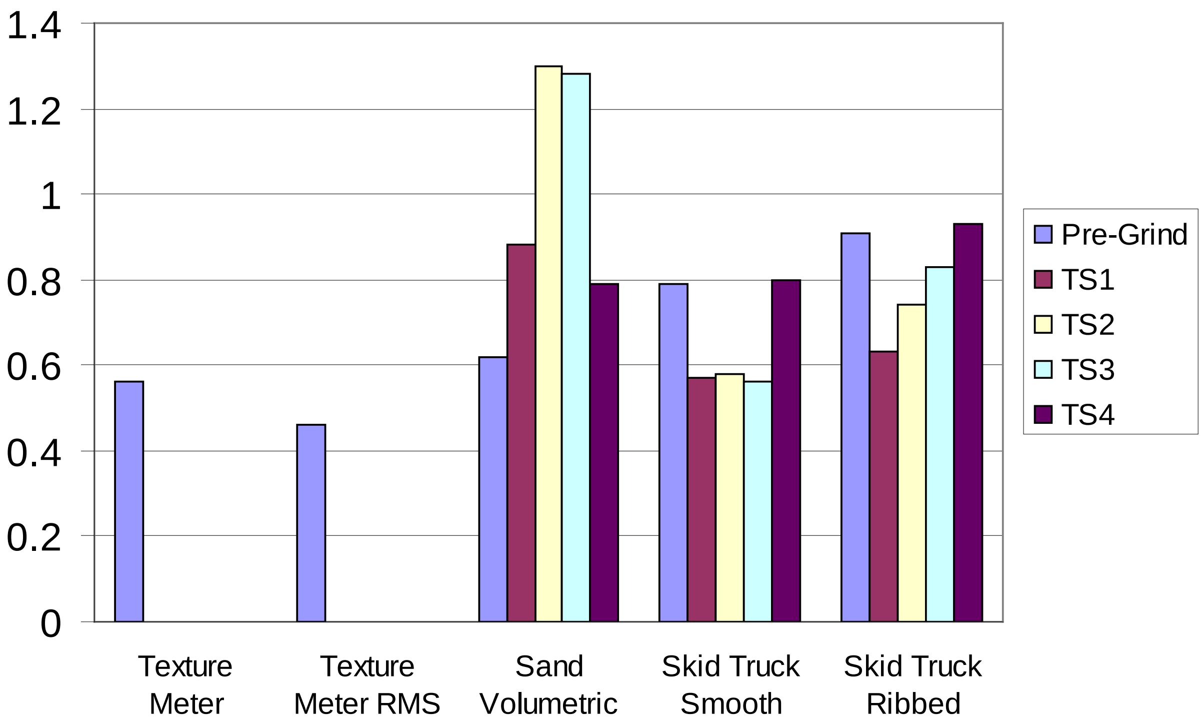

Figure F.4. Variability of post-grind texture with measurement procedure.

Table F.3. Cell 37 Texture Data.

Measured by:	Bernard Izevbekhai Arash Moin						Sand Patch ASTM E-965 Cell 37				
Station	**Date**	**Time**	**DIA 1**	**DIA 2**	**DIA 3**	**Run 1**	**Run 2**	**Run 3**	**Average**	**Volume (mm^3)**	**Texture (mm)**
TX9TS1	6/19/07	10:00 AM	16	16	15	408	408	382.5	399.5		0.546
TX9TS1			13	14	15	331.5	357	382.5	357		0.683
TX8TS1			13	13	12	331.5	331.5	306	323		0.834
TX7TS1			12.5	13	14	318.75	331.5	357	335.75		0.772
TX6TS1			17	15	14	433.5	382.5	357	391		0.569
TX5TS1			17.5	19.5	19.5	446.25	497.25	497.25	480.25		0.377
TX4TS1			14	15	16	357	382.5	408	382.5		0.595
TX3TS1			12	15	14	306	382.5	357	348.5		0.716
TX2TS1			13	14	15	331.5	357	382.5	357		0.683
TX1TS1			15	16	16	382.5	408	408	399.5		0.545
Average											**0.632**
TX9TS3	6/22/07	11:10 AM	11	11	10.5	280.5	280.5	267.74	276.25		1.140
TX8TS3			11.5	11.5	12	293.25	293.25	306	297.5		0.983
TX7TS3			11	10.5	10.5	280.5	267.75	267.74	272		1.176
TX6TS3			10	11	10.5	255	280.5	267.75	267.75		1.214
TX5TS3			10.5	10.5	9	267.75	267.75	229.5	255		1.338
TX4TS3			10.5	10	10.5	267.75	255	267.75	263.5		1.253
TX3TS3			10	9	9	255	229.5	229.5	238		1.536
TX2TS3			10	9	8.5	255	229.5	216.75	233.75		1.592
TX1TS3			9	10	10	229.5	255	255	246.5		1.432
Average											**1.296**
TX9TS2			11	12	12.5	280.5	306	318.75	301.75		0.956
TX8TS2			9	9.5	9.5	229.5	242.25	242.25	238		1.536
TX7TS2			9	9	9	229.5	229.5	229.5	229.5		1.662
TX6TS2			9.5	10.5	10.5	242.25	267.75	267.75	259.25		1.295
TX5TS2			10	11	11.5	255	280.5	293.25	276.25	68300	1.140
TX4TS2			12	12	12.5	306	306	318.75	310.25		0.904
TX3TS2			10.5	10	10	267.75	255	255	259.25		1.295
TX2TS2			11	10	10	280.5	255	255	263.5		1.253
TX1TS2			10	9	9.5	255	229.5	242.25	242.25		1.483
Average											**1.279**
TX9TS1			12	13	12.5	306	331.5	318.75	318.75		0.856
TX8TS1			12	12	13	306	306	331.5	314.5		0.880
TX7TS1			12	12.5	12.5	306	318.75	318.75	314.5		0.880
TX6TS1			12	13	13	306	331.5	331.5	323		0.834
TX5TS1			12	12.5	12.5	306	318.75	318.75	314.5		0.880
TX4TS1			12	12	12	306	306	306	306		0.929
TX3TS1			12	12	12.5	306	306	318.75	310.25		0.904
TX2TS1			13	12.5	13	331.5	318.75	331.5	327.25		0.812
TX1TS1			13	12.5	12.5	331.5	318.75	318.75	323		0.834
Average											**0.868**
TX9TS4			13	13.5	13	331.5	344.25	331.5	335.75		0.772
TX8TS4			13.5	13.5	14	344.25	344.25	357	348.5		0.716
TX7TS4			13	12.5	13	331.5	318.75	331.5	327.25		0.812
TX6TS4			12.5	12.5	13	318.75	318.75	331.5	323		0.834
TX5TS4			15	15	15.5	382.5	382.5	395.25	386.75		0.582
TX4TS4			14	15	14.5	357	382.5	369.75	369.75		0.636
TX3TS4			12	11.5	12	306	293.25	306	301.75		0.956
TX2TS4			12	10	12	306	255	306	289		1.042
TX1TS4			14	13	13	357	331.5	331.5	340		0.753
Average											**0.789**

Table F.4. Cell 37 Post-Grind Ride Statistics.

Cell	Test Code	IRI (in/mi)	PTRN (in/mi)	RN
Cell 37	TS31	65.6	126.6	3.63
	TS32	64.9	128.9	3.61
	TS33	64.7	127.5	3.62
	TS34	64.7	128.0	3.62
	TS35	63.9	125.2	3.64

Table F.5. Cell 37 Post-Grind Power Spectral Density Settings.

Input	Value
PSD Calculation	Slope
Use Point Reset	No
Frequency Averaging	Yes
Bands Per Octave	12
Pre-Processor Filter	None

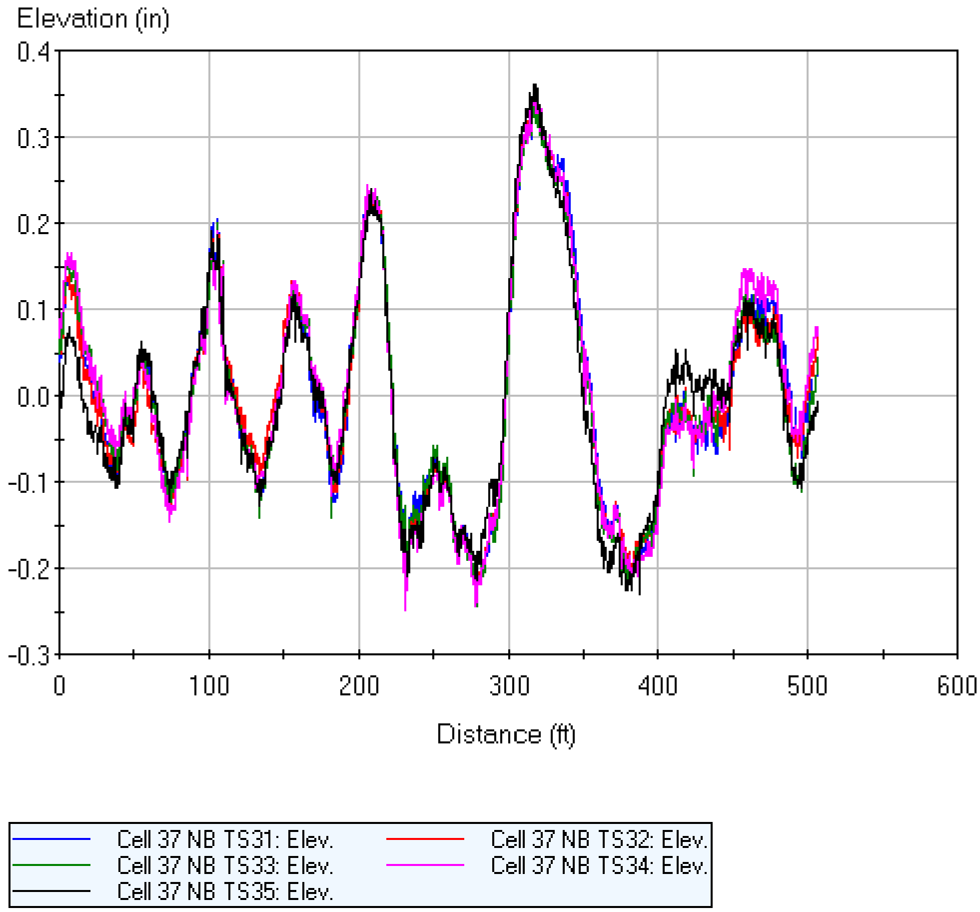

Figure F.5. Cell 37 pre-grind report (tested 6/18/07).

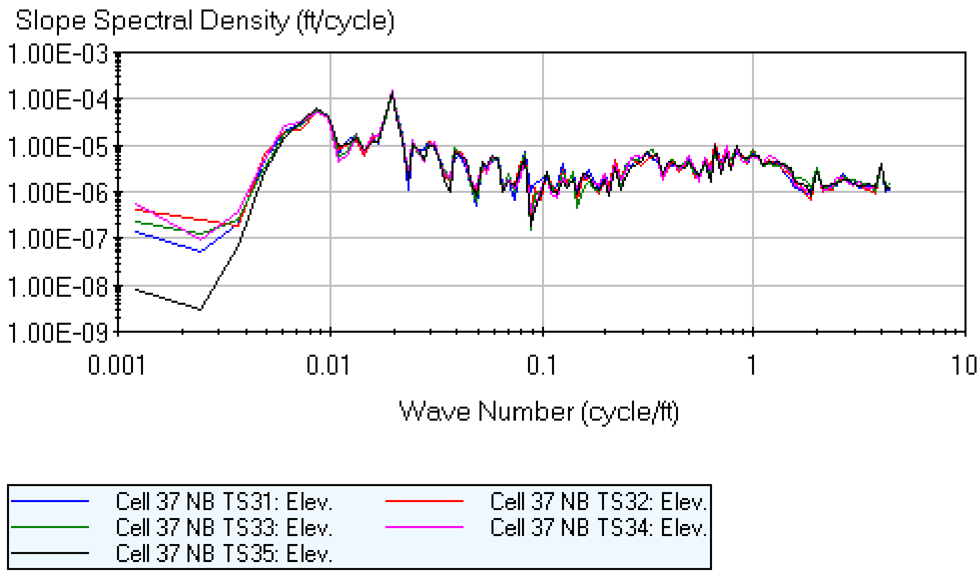

Figure F.6. Cell 37 post-grind wave number.

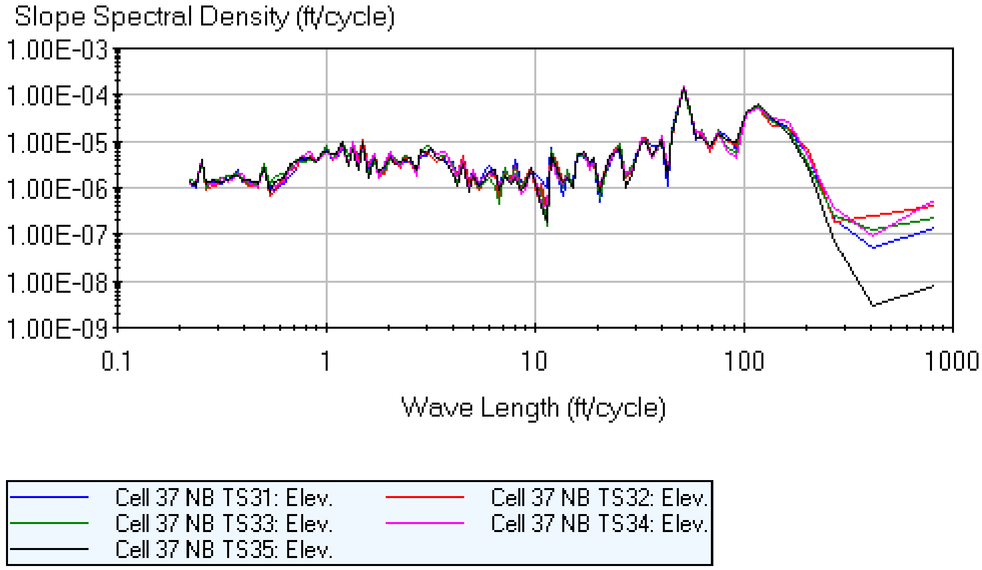

Figure F.7. Cell 37 post-grind wavelength.

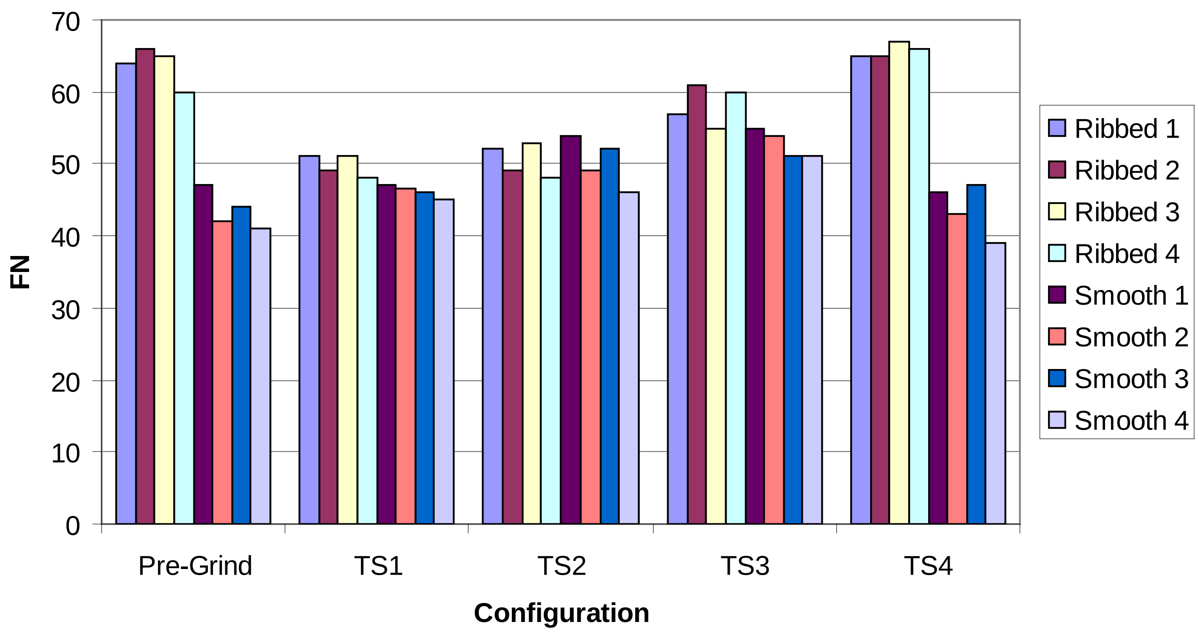

Figure F.8. Cell 37 friction.

Table F.6. Cell 37 Friction Data.

			Friction Number							
			Ribbed Tire				**Smooth Tire**			
Condition	**Date**	**Test Code**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Pre-Grind	6/18/2007		64.5	66.7	64.9	60.4	48.1	41.0	42.9	40.8
Post-Grind	6/22/2007	TS1	50.7	49.7	50.3	48.8	48.6	48.0	47.7	46.0
		TS2	51.2	49.4	52.7	48.7	52.9	49.5	51.5	46.7
		TS3	57.5	60.2	56.5	60.0	55.9	55.5	51.2	50.7
		TS4	65.1	65.1	66.3	65.5	46.9	43.3	47.9	39.1

Table F.7. Cell 37 Measurements from Skid Truck.

		Texture 10 mm												
		Location												
Test Code	**Tire**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Mean**
Pre-Grind	Ribbed	0.610	0.610	0.635	0.711	0.635	0.660	0.991	0.889	1.016	0.762	0.660	1.168	0.779
Pre-Grind	Smooth	0.889	0.889	0.889	1.067	1.168	1.397	0.838	0.762	0.762	0.838	0.686	0.762	0.912
TS1	Ribbed	0.787	0.483	0.432	0.483	0.483	0.356	0.686	0.813	0.660	0.559	0.483	0.508	0.561
	Smooth	0.838	0.838	0.711	0.432	0.483	0.533	0.711	0.686	0.610	0.610	0.610	0.635	0.641
TS2	Ribbed	0.838	0.838	0.838	0.483	0.406	0.406	0.635	0.610	0.457	0.533	0.406	0.406	0.572
	Smooth	0.737	0.737	0.737	0.711	0.787	0.737	0.711	0.914	0.940	0.762	0.660	0.711	0.762
TS3	Ribbed	0.635	0.406	0.406	0.406	0.483	0.508	0.559	0.533	0.737	0.762	0.660	0.533	0.552
	Smooth	0.965	0.940	1.397	0.584	0.711	0.711	0.838	0.864	0.838	0.711	0.660	1.041	0.855
TS4	Ribbed	1.143	1.041	1.397	0.584	0.559	0.656	0.787	0.787	0.838	0.838	0.483	0.483	0.802
	Smooth	1.118	1.118	0.991	0.991	0.838	0.762	0.940	1.016	1.067	1.118	0.711	0.686	0.946