Drainable Pavements at MnROAD Pervious Concrete and Porous Concrete Overlay Cells 39, 85, and 89

Minnesota Department of Transportation

RESEARCH SERVICES

Office of Policy Analysis, Research & Innovation

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Minnesota Department of Transportation
Office of Materials

April 2010

Research Project
Final Report #2010-16

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Technical Report Documentation Page

1. Report No. MN/RC 2010-16	2.	3. Recipients Accession No.
4. Title and Subtitle Drainable Pavements at MnROAD Pervious Concrete and Porous Concrete Overlay Cells 39, 85, and 89		5. Report Date April 2010 6.
7. Author Andrew Eller		8. Performing Organization Report No.
9. Performing Organization Name and Address Minnesota Department of Transportation Office of Materials and Road Research 1400 Gervais Maplewood, MN 55109		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. (c) LAB879
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services Section 395 John Ireland Boulevard, MS330 St. Paul, MN 55155-1899		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes http://www.lrrb.org/pdf/201016.pdf		

16. Abstract (Limit: 250 words)

This annual report details the testing and observations from Cells 39 Porous Concrete Overlay, 85 Pervious Concrete on Granular Subgrade, and 89 Pervious Concrete on Cohesive Subgrade of the LVR at MnROAD. Permeable pavements are useful to help solve some of the drainage problems that roadway facilities encounter. However, these pavements must also provide for other user needs in addition to the drainage aspect. Drainability should be measured along with friction, ride (IRI), noise, textural, and structural properties. Once these properties and their relation to service life are quantified, a design guide or recommendations can be made to optimize the pavement properties relative to the user's needs.

17. Document Analysis/Descriptors Permeability, Pervious concrete, Porous concrete, Concrete overlays, Pavement, MnROAD, Low volume roads, LVR, Drainable, Drainage, Sound absorption, Sound intensity, Noise, OBSI, Sound absorption, Circular test tracks, Circular track texture meter, CTM, Friction, Friction tests, Texture		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 27	22. Price

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Cells 39, 85, and 89

Final Report

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April 2010

Published by:

Minnesota Department of Transportation
Research Services Section
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

Table of Contents

List of Tables

List of Figures

Executive Summary

This report discusses research activities and test results from the Cell 39 Porous Concrete Overlay, Cell 85 Pervious Concrete on Granular Subgrade, and Cell 89 Pervious Concrete on Cohesive Subgrade during the 2009 calendar year. These cells are located on the MnROAD Low Volume Road (LVR) and were constructed in fall 2008.

The permeable pavement initiative at the MnROAD Research Facility is born partially of the need to mitigate the effects of increasing impervious surfaces as a result of continuing development of populated areas. Impervious surfaces, such as traditional concrete and asphalt commonly used in roadways, parking lots, and building infrastructure, do not allow water from precipitation events to infiltrate the ground and instead it becomes diverted directly to the city, county or state highway storm water system. Often times the water flowing through these systems remains largely untreated due to the unpredictable nature and volume of weather events. Unfortunately this means that contaminants are mainlined directly to surface waters, streams, and rivers without the filtration benefits that natural soils provide. Pervious pavements provide a means of reducing impervious surfaces in the urban environment while both maintaining the usability of the facility and allowing storm water to infiltrate the natural soils beneath the pavement surface.

Given the need to decrease impermeable surface area in the urban environment it is also imperative that the surface provide to the needs of the user, in this case the traveling public. A permeable pavement must provide adequate structural strength and durability, friction, ride quality, noise properties, and drainage/maintenance properties in order to remain a viable solution to this problem. The pervious and porous pavement cells at the MnROAD Research Facility provide an excellent venue to quantify these variables in a real world environment. An overall trend in the temporal change of these variables can be quantified from the data gathered so that the usable life of permeable pavements can be better understood. As such, the course of this permeable pavement research is ongoing. This report summarizes the testing and observations performed during 2009 to characterize Cells 39 (Porous Concrete Overlay), 85 (Pervious Concrete Pavement on Sand Subgrade), and 89 (Pervious Concrete Pavement on Clay Subgrade). This testing includes nuclear density testing, pore structure analysis, and flow tests; friction tests; ride quality; noise properties; textural properties; and FWD testing.

Permeable pavements must have a relatively uniform pore structure in order to drain properly across the entire pavement area. Water poured from buckets onto the pavement in different areas showed that the permeability of the pore structure varies significantly in these cells depending on roadway station and offset. Nuclear density tests and flow tests confirmed the presence of spatial anisotropy of the pore structure of these pavements. Flow tests showed that apparent permeability increased after vacuuming in Cell 89, however, no change in apparent permeability was evident after vacuuming Cell 85. Although the overall cause(s) of this variability is unknown, construction issues as well as debris in the pores are the leading causes identified at this time.

Friction is a property often measured for pavements to infer the level of traction a tire can achieve on that surface. No matter the drainage issues a permeable pavement mitigates, it must also provide adequate friction to remain a safe alternative to standard pavements. A Dynatest

1295 Friction Trailer (ASTM E-274) and Findlay Irvine Grip Tester (ASTM E-274) were both used to test for friction parameters. Smooth-tire runs with the Dynatest 1295 Friction Trailer showed Friction Numbers (FN) ranging from 45 to 55. These initial tests indicate that these permeable pavements have adequate friction; an FN of 25 or less would require mitigation. Ride quality, as quantified by the International Roughness Index (IRI), is a measure of how bumpy a road is to the end user. At this time, permeable PCC pavements require some amount of manual handwork in addition to the standard roller screed used to place it. However it is placed, a permeable pavement must attain an adequate IRI value throughout its intended service life. To measure this, the Mn/DOT Pathways Van (ASTM E-950) and the Lightweight Inertial Surface Analyzer (LISA) (ASTM E-950) are used to measure these properties at MnROAD. The Pathways Van utilizes multiple single-beam lasers to measure IRI, whereas the LISA is equipped with a three-beam laser and a Roline laser as well. IRI values measured by each method vary from 3.10 to 6.40 m/km depending on the time of year, wheel path measured, and method used.

Noise properties of pavements have become more critical as urban development and roadways encroach on each other. On Board Sound Intensity (OBSI) values ranged from 97 to 100.5 dBA depending on the wheel path measured. For comparison, Cell 40 (transverse tined) of the LVR attains an OBSI of 103.5 dBA. Sound absorption equipment (ASTM E-1050) was also used to quantify the noise attenuation properties of these pavements. Measurements taken in 2009 greatly exceeded those taken shortly after construction of the cells in November 2008. This phenomenon is thought to be due to the relatively early stage of hydration at which the measurement was taken.

Textural properties of pavements are closely related to both noise and friction properties of a pavement. The permeable cells were testing using the Circular Track Texture Meter (CTM) (ASTM E-2157) to measure the Mean Profile Depth (MPD). The MPD ranged from 1.74 to 2.04 mm depending on the lane, wheel path, and time of year. Some of the CTM tests in October 2009 were performed in different location from the April 2009 CTM tests.

Extensive FWD testing performed throughout the year will help characterize the structural properties of these cells. Testing is performed near the edges, corners, and at the center of the panels. Analysis of the deflection data is forthcoming in subsequent reports.

Data collection will continue on these cells with the goal of developing performance algorithms based on the various characteristics as measured by the data. Ultimately, the aim of studying permeable PCC Cells 39, 85, and 89 is to better understand the overall properties, structural behavior, and service life of a permeable pavement in order to develop a design guide or recommendations based on optimizing its properties to the needs of the user.

1. Introduction

This report discusses research activities and test results from the Cell 39 Porous Concrete Overlay, Cell 85 Pervious Concrete on Granular Subgrade, and Cell 89 Pervious Concrete on Cohesive Subgrade during the 2009 calendar year. These cells are located on the MnROAD Low Volume Road (LVR) and were constructed in fall 2008 (Figure 1). Since their construction, various activities helped to measure the properties of these drainable pavements. The cells were tested regularly during the year (FWD, flow tests, OBSI, sound absorption, texture, friction, etc.) and were also monitored with data collected from imbedded sensors (thermocouples, frost sensors, etc.). Routine maintenance also occurred regularly depending on the weather conditions; The LVR is plowed and salted in a manner similar to standard practice for low volume roads. In addition to plowing and salting, the pervious cells were also vacuumed in late fall 2009. Vacuuming is a maintenance practice used to improve the hydraulic properties of the pavement due to debris collecting in the pore structure. Normally, the LVR is loaded by a 5-axle semi truck trailer in an 80 kip configuration on the inner loop, while the outer loop portion of these cells experiences environmental factors only.

Initial tests were performed on Cells 39, 85, and 89 in the fall of 2008 following their construction. Since that time, several rounds of testing were performed during the calendar year 2009. Analysis of the data collected during this study will establish initial conditions and degradation patterns for each cell. Frequency, time domain, and spatial analysis of the data will then help determine relationships between parameters as a function of seasonal effects and traffic loading. The ultimate goal of this study is to develop global relationships between these parameters to establish a surface performance/survival algorithm that will be useful in pervious pavement design and management. This report will discuss the density tests, porosity analysis, flow tests, and surface characteristic tests performed to collect the data necessary to develop a surface performance/survival algorithm for the cells in this study.

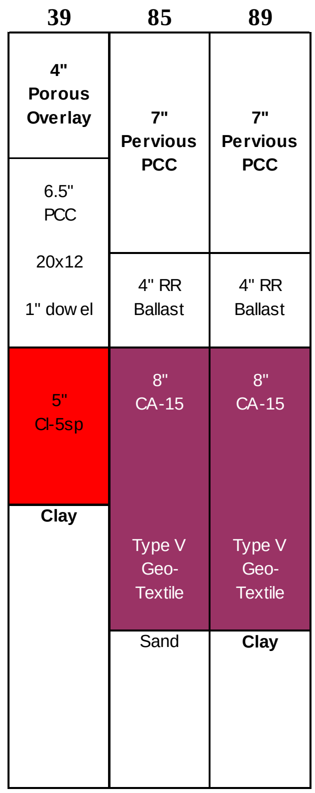

Figure 1. Cross Section of Permeable Pavement Cells 39, 85, and 89.

2. Pore Structure Analysis

Heterogeneities in the porous structure were evident after a simple test consisting of pouring a bucket of water over the pervious cells in different areas. The water surface flow of the inside lane traveled the entire width of the lane; whereas the water surface flow of the outer lane only traveled about half the width of the lane. The results of this simple test showed that there must be spatial differences in the porosity and/or permeability of the pervious concrete cells. Results from density and flow tests were used in conjunction with mathematical algorithms to examine any potential differences in porosity and permeability; these algorithms will be revealed in greater detail in the final report for this study. The next two sections discuss the density and flow tests used to quantify the pervious cells' porosity and permeability.

2.1 Nuclear Backscatter Density Testing

On June 4, 2009, a Nuclear Density gauge (Seaman Nuclear Instrumentation, Model C-200) using the backscatter method was used to obtain density values of the pavements in question (see Figure 1).

Figure 2. Nuclear backscatter density testing on Cell 39.

Three test stations per cell were designated for nuclear density testing. The four wheel paths corresponding to each test station were then designated as test locations. Four backscatter measurements were taken at each test location, two of the measurements with the density gauge aligned longitudinally to the road, and two measurements with the density gauge aligned transverse to the road. Statistical analyses (scatter plots, descriptive statistics, and Mann-Whitney Z-test) applied to the data showed that the densities of the inner and outer lane of the LVR were statistically different. Cell 39 showed the greatest difference between the inner and outer lane. The porosity of the cells was then calculated using the densities obtained from the testing. See Table 1 for calculated porosity values and measured density values.

Table 1. Nuclear density values with calculated porosities.

Cell – Location	Density (pcf)		Porosity	
	Mean	Standard Dev.	Mean	Standard Dev.
39 – Overall	118.6	5.53	0.19	0.038
39 – Inside	124	3.99	0.15	0.027
39 – Outside	115.9	4.02	0.21	0.028
85 – Overall	125.6	2.81	0.14	0.019
85 – Inside	125	1.62	0.14	0.011
85 – Outside	126.1	3.74	0.14	0.026
89 – Overall	126.4	6.53	0.13	0.045
89 – Inside	125.5	4.32	0.14	0.03
89 – Outside	127.2	8.57	0.13	0.059

2.2 Flow Testing

The pervious cells (Cells 85 and 89) were vacuumed on Nov. 4, 2009 using a Reliakor Vacuum Truck to determine possible changes in the pavement's hydraulic conductivity. The pores in the pervious pavement appeared clear of debris before the vacuuming was performed, and the brush on the vacuum truck was not used as to avoid introducing additional material into the pore structure (See Figure 2 for a photo of the Reliakor Vacuum Truck in operation). A flow test was performed using a Mn/DOT falling head permeability device the day before vacuuming, and also immediately after the vacuuming. Before beginning the flow test, the head was kept constant with a water tank source until steady flow developed. The time elapsed to drain the permeability device from the 37 cm mark to the 11 cm mark was recorded. Each cell was tested in one location in a chosen wheel path. The permeability device is shown in Figure 3. If possible, Mn/DOT will continue to vacuum and monitor the pervious/porous cells and record any changes to flow times.

Figure 3. Reliakor Vacuum Truck.

The times recorded from the permeability testing showed minor changes to flow times post-vacuuming. It is presumed that this is due to the fact that there was little visible distress in the cells (such as cracking or raveling) that would cause loose material to become clogged in the pores. The fact that a relatively small amount of material was recovered from the vacuum truck receptacle following vacuum operations supports this idea. See Table 2 for flow times measured before and after vacuum operations.

Figure 4. Mn/DOT Permeability Device.

Table 2. Flow times before and after vacuuming.

Cell No.	Type	Before Time (s)	After Time (s)	% Change
85	Pervious Concrete	6.0	6.0	0
89	Pervious Concrete	17.0	15.5	9

3. Surface Characteristics

Describing the surface characteristics of any pavement can be useful to determine various properties that ascribe some of its most important engineering aspects. Some of the methods used to measure surface characteristics for this study include On-Board Sound Intensity (OBSI) testing, sound attenuation testing, Circular Track Texture Meter (CTM) measurements, skid resistance and friction tests, and ride quality.

3.1 On-Board Sound Intensity (OBSI)

Tire-Pavement Interaction Noise (TPIN) is the acoustic effect a rolling tire has on a pavement surface. One way to quantify this effect is by using OBSI methods, which reports a decibel value for the TPIN as recorded by a set of microphones positioned near the tire. The Mn/DOT OBSI equipment consists of a Chevrolet Impala with 4 intensity meters connected via 4 communication cables to a Bruel and Kjaer Frontend Collector connected to a dell laptop computer. The intensity meters are mounted on a rig system attached to a Standard Reference Test Tire (SRTT) that is installed at the rear of the vehicle and maintained at a temperature of 30 degrees (See Figure 4). After recording temperature, 4 intensity meters are plugged in to the B & K Front End Unit, as well as 12v power supply and Ethernet (computer) cable. With this arrangement, the unit is capable of repeatable measurements of tire pavement interaction noise from the tire pavement contact patch at a speed of 60 miles per hour (Khazanovich and Izevbekhai, 2008).

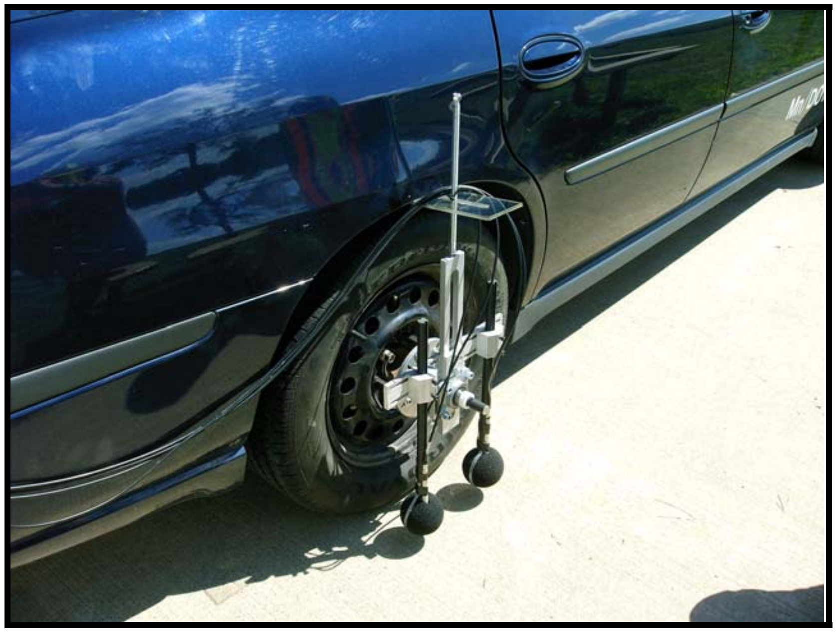

Figure 5. Chevrolet Impala with OBSI microphones attached.

OBSI is measured at MnROAD according to the interim standards adopted by AASHTO. OBSI was measured on 3.17.09 and 7.22.09. Figure 5 shows graphs of typical sound intensity data from Cell 39, and Table 3 shows the average values calculated for pervious Cells 39, 85, and 89. For comparison, OBSI testing on Cell 40 (transverse tined) of the LVR registered greater than 103.5 dBA.

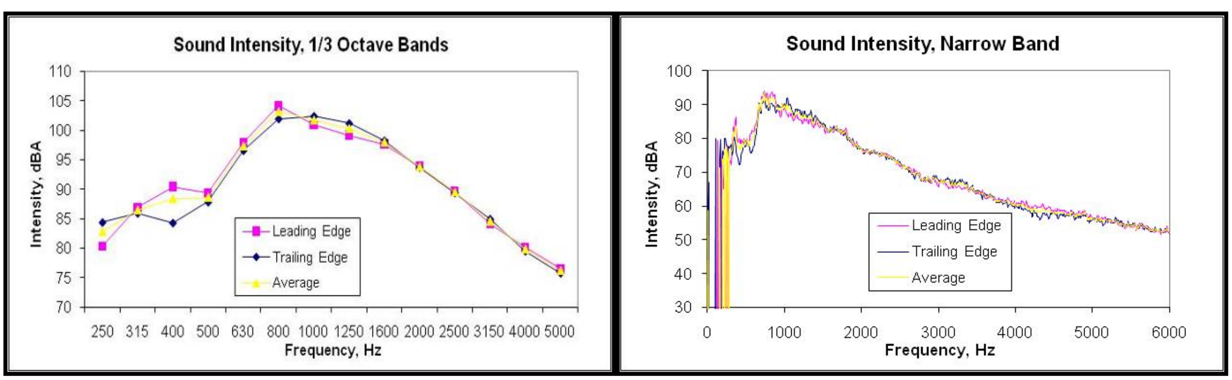

Figure 6. Typical sound intensity graphs from OBSI data, Cell 39.

Table 3. OBSI average values for Cells 39, 85, and 89.

OBSI data (decibels, dBA)			
Cell	**Mar-09**	**Jul-09**	**Sep-09**
39 – Inside Lane	100.4	100.1	100.5
39 – Outside Lane	97.9	97.6	96.8
85 – Inside Lane	99.3	99.4	98.5
85 – Outside Lane	100.0	99.1	98.2
89 – Inside Lane	100.1	98.2	98.0
89 – Outside Lane	99.0	99.3	98.9

3.2 Sound Absorption and Attenuation

Sound absorption attenuation is measured at MnROAD using a Mn/DOT BSWA 435 device and following a modified ASTM E-1050 (Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System). The sound absorption test is a static test in the sense that the white noise is not generated by the interaction between the rolling tire and pavement surface as in the OBSI test. In this case, the white noise is produced by an impedance tube device placed on the pavement (Figure 7). The sound produced within the impedance tube is a random audio signal with a flat power spectral density that contains noise at the same level at all frequencies. The signal's spectral density has equal power in any band and at any frequency in a given bandwidth. The noise is transmitted to the pavement surface through a projection distance d_1 and is reflected to a set of microphones at a distance d_2 from the source. The reflected noise is received by a set of microphones that are connected to an analyzer that identifies and records the actual reflection or absorption of each frequency from zero to 2000 Hz. The absorption ratio for 315, 400 500, 750, 1000, 1250, 1650 hertz are then isolated for a broadband analysis and plotted against frequency (Izevbekhai, 2008). Absorption is reported as a percentage on these plots; the higher the absorption value, the more sound is being absorbed by the material. Figure 8 shows a plot of absorption values versus frequency for pervious/porous cells in addition to other MnROAD cells for comparison. Sound absorption values measured on August 24, 2009 were taken at two separate stations in each wheel path for the inner and outer lanes of the LVR. The data taken in November 2008 shows a marked difference from the data taken in August 2009. It is believed this is because the cells were still wet and hydrating at the time of the sound absorption testing.

Figure 7. Mn/DOT BSWA 435 sound absorption testing device, Cell 89 (ASTM E-1050).

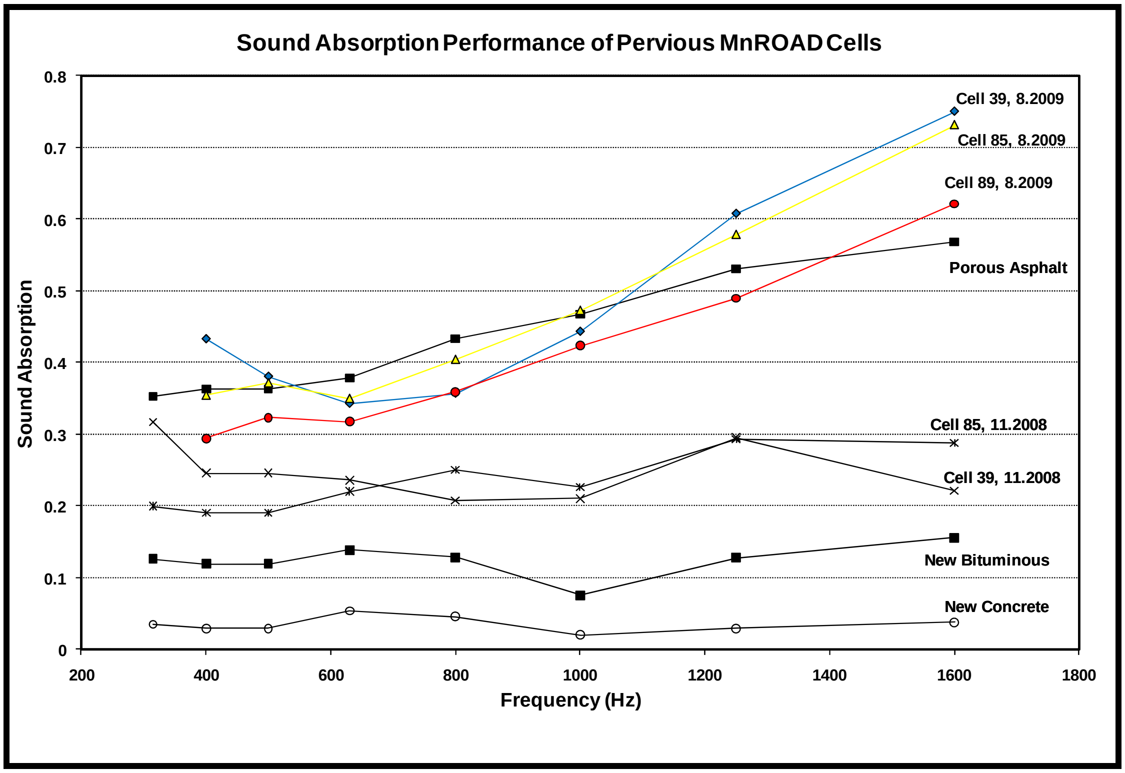

Figure 8. Absorption value plot for various MnROAD cells.

3.3 Circular Track Texture Meter (CTM)

The CTM uses a laser to measure the profile of a circle 284 mm (11.2 in) in diameter or 892 mm (35 in) in circumference. The profile is divided into eight segments of 111.5 mm (4.4 in). The average mean profile depth (MPD) is determined for each of the segments of the circle. The reported MPD is the average of all eight segment depths. Three measurements are taken at each test location, and an average mean profile depth (MPD) and root mean square (RMS) is recorded for that test location. Temperature, concrete surface moisture, and concrete distress at the test location are also noted. All CTM testing follows the procedures as set forth in ASTM E-2157. See Figure 9 for a photo of the CTM.

Cells 39, 85, and 89 were tested in April and October of 2009 (Table 4). Some of the tests were not taken in the same spot from the spring versus the fall measurements; they are as noted in the table.

Figure 9. CTM Device (ASTM E-2157).

Table 4. MPD measurements from CTM data.

Cell	MPD measurement (mm) Apr-09	Oct-09
39 – Inside Lane	1.9	1.97*
39 – Outside Lane	2.04	2.01
85 – Inside Lane	2.01	1.74*
85 – Outside Lane	1.93	1.94*
89 – Inside Lane	1.88	1.89
89 – Outside Lane	1.81	1.94

*indicates different test location from April 2009 tests

3.4 Friction Tests

Measuring friction resistance is a useful way to characterize pavement texture. Friction resistance is the force developed when a tire is prevented from rotating, and slides along the surface of the pavement. ASTM E-867 (Standard Terminology Relating to Traveled Surface Characteristics) defines friction resistance as "the ability of the traveled surface to prevent the loss of traction." In some sense, friction tests are analogs to how skid-prone a pavement is relative to another pavement type, or to its age. However, friction testing cannot determine stopping distances or threshold speeds that might cause loss of vehicle control. Nonetheless, friction data is critical for describing characteristics of a pavement that are undoubtedly related to texture.

The friction testing at MnROAD was performed using the KJ Law (Dynatest 1295) Friction Trailer (Figure 10) as well as a Findlay Irvine Grip Tester (Figure 11). The KJ Law Friction Trailer is a piece of equipment used for MnROAD's standard battery of friction tests, however, the Findlay Irvine Grip Tester was only temporarily on loan from the FHWA. Friction tests followed ASTM E-274 (Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire) in conjunction with ASTM E 501 and ASTM E 524. Both pieces of equipment were used to measure friction at MnROAD; however, tabulated Grip Tester data is not yet available (see Figure 12 for an example of Grip Tester data). Friction Numbers (FN), as measured by the KJ Law Friction Trailer in June and November of 2009, can be seen in Table 5.

Figure 10. KJ Law (Dynatest 1295) Friction Trailer (ASTM E-274).

Figure 11. Findlay Irvine Grip Tester on loan from FHWA (ASTM E-274).

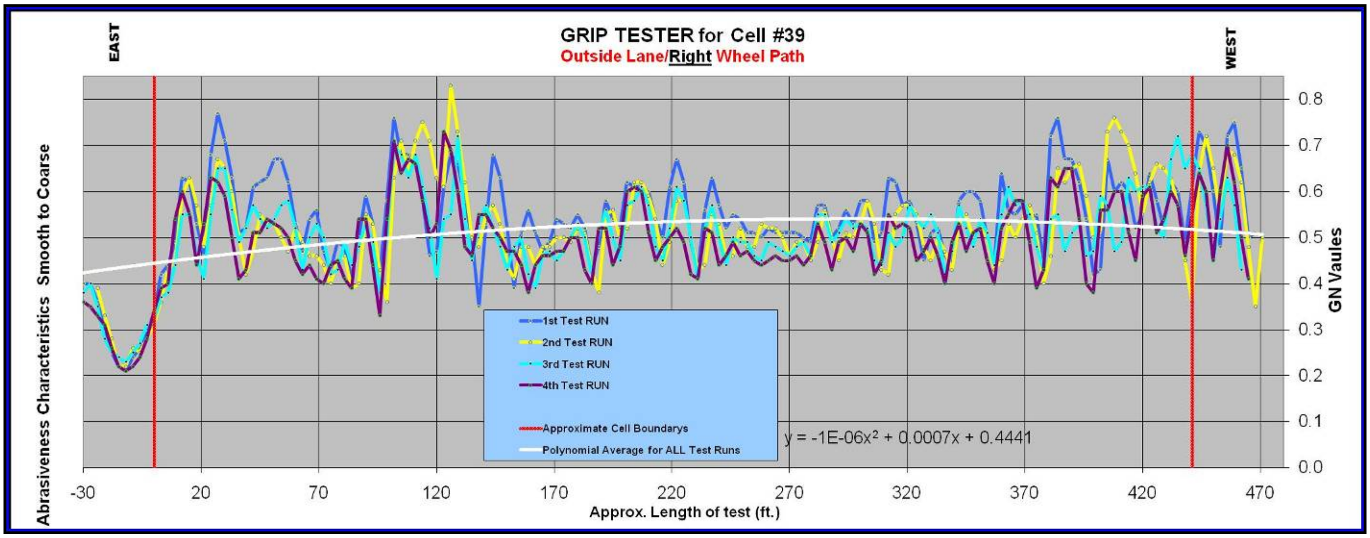

Figure 12. Findlay Irvine Grip Tester data.

Table 5. KJ Law (Dynatest 1295) Friction Trailer data.

KJ Law (Dynatest 1295) Friction Trailer (Friction Number, FN)				
	ribbed tire		smooth tire	
Cell	Jun-09	Nov-09	Jun-09	Nov-09
39 – Inside Lane	48.7	51.2	50.1	54.9
39 – Outside Lane	43.9	55.6	45.2	45.0
85 – Inside Lane	37.6	44.8	46.9	45.0
85 – Outside Lane	52.4	51.2	61.3	51.1
89 – Inside Lane	41.7	41.7	45.4	48.3
89 – Outside Lane	57.6	45.0	55.0	45.0

The KJ Law Friction Trailer is the main skid-test performed at MnROAD, and it is usually performed twice annually. The friction trailer is pulled behind a truck at 40 mph and sprays water on the tire-pavement interface before data measurements are taken. Once water is applied, a brake activates that causes the wheel to lock so that drag and load (horizontal and vertical forces) can be measured by sensors at the wheel assembly. Both ribbed and smooth tires are used to take the friction measurements in both wheel paths of the inner and outer lanes of the LVR. The Friction Number (FN) is calculated as the average coefficient of friction across the test interval of the cell lane in question. Friction Numbers theoretically range from 0-100. A FN above 25 on a smooth tire gives adequate friction, and a FN below 15 may need remediation.

3.5 International Roughness Index (IRI)

IRI is a test method that measures the amount that a vehicle's suspension deflects during a stretch of road due to irregularities in the pavement profile. IRI provides an end-user measurement in that it represents the amount of 'bumpiness' a road user feels. Some states already use an IRI based specification for their pavement evaluations, while many other states will be implementing a specification in the near future (Wilde, 2007).

Figure 13. Pathways High Speed Laser Equipped Surface Evaluation Device (ASTM E-950).

IRI is measured on the LVR using two pieces of equipment following ASTM E-950 (Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference). The Mn/DOT Pavement Management unit has a Pathways High Speed Laser Equipped Surface Evaluation Device (Figure 13) that measures IRI in the left wheel path by a laser mounted to the front bumper of the van. The Pathways vans are used statewide to monitor the trunk highway and county state aid system, so IRI measurements are taken at MnROAD once per year. The second piece of equipment used to measure IRI at MnROAD is the Lightweight Inertial Surface Analyzer (LISA) (Figure 14). The LISA measures IRI from two separate laser sources mounted on the side of the vehicle. One laser source takes three discrete measurements using three laser beams that measure profile over a 4" path width, each laser dot being 2" apart. The second laser source takes continuous measurements across the same 4" path width. The LISA is used to collect IRI data 3-4 times per year; however, the DVI remains the primary source for IRI data due to its repeatability. IRI data from the LISA and DVI are presented in Table 6.

Figure 14. Lightweight Inertial Surface Analyzer (LISA) (ASTM E-950).

3.6 Falling Weight Deflectometer (FWD) Testing

FWD testing is performed regularly at MnROAD on both the LVR and I-94 Mainline portions of the facility. Individual concrete panels within a cell are numbered and designated for deflection testing at the panel's center, mid edge, and corner; Concrete panel joint efficiency is also tested (Figure 15). FWD tests may be performed up to 7 times per year depending on equipment and personnel availability, and time scheduling issues.

A large quantity of FWD data has been collected during 2009, and it would be inefficient to present all the graphs in this report. However, Figure 16 shows a representative deflection basin for each cell in this study. Figure 17 shows a deflection basin for a TH 100 pavement of similar thickness design.

Table 6. IRI data from LISA and Pathways Van.

CELL	DAY	LANE	LISA 3-Beam IRI (M-KM)	LISA Roline IRI (M-KM)	Pathways Van IRI (M-KM)
39	4/2/2009	*LVR-Inside*	3.355	--	--
		LVR-Outside	3.685	--	--
	4/27/2009	*LVR-Inside*	--	--	3.66
		LVR-Outside	--	--	3.99
	6/30/2009	*LVR-Inside*	3.42	--	--
		LVR-Outside	3.705	--	--
	10/28/2009	*LVR-Inside*	--	--	3.86
		LVR-Outside	--	--	4.35
	11/19/2009	*LVR-Inside*	3.48	3.49	--
		LVR-Outside	3.905	3.925	--
85	4/2/2009	*LVR-Inside*	4.125	--	--
		LVR-Outside	3.38	--	--
	4/27/2009	*LVR-Inside*	--	--	4.85
		LVR-Outside	--	--	5.01
	6/30/2009	*LVR-Inside*	4.06	--	--
		LVR-Outside	3.65	--	--
	10/28/2009	*LVR-Inside*	--	--	5.13
		LVR-Outside	--	--	5.28
	11/19/2009	*LVR-Inside*	4.38	4.705	--
		LVR-Outside	3.91	3.95	--
89	4/2/2009	*LVR-Inside*	4.46	--	--
		LVR-Outside	3.17	--	--
	4/27/2009	*LVR-Inside*	--	--	5.99
		LVR-Outside	--	--	4.06
	6/30/2009	*LVR-Inside*	4.655	--	--
		LVR-Outside	3.3	--	--
	10/28/2009	*LVR-Inside*	--	--	6.33
		LVR-Outside	--	--	4.44
	11/19/2009	*LVR-Inside*	5.7	5.87	--
		LVR-Outside	3.665	3.895	--

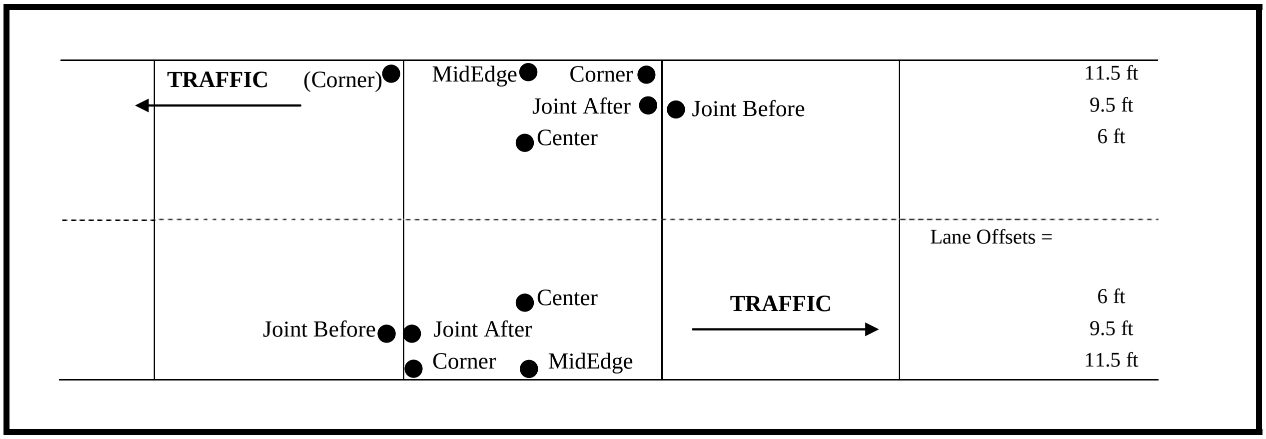

Figure 15. Diagram of FWD test points in a typical LVR cell.

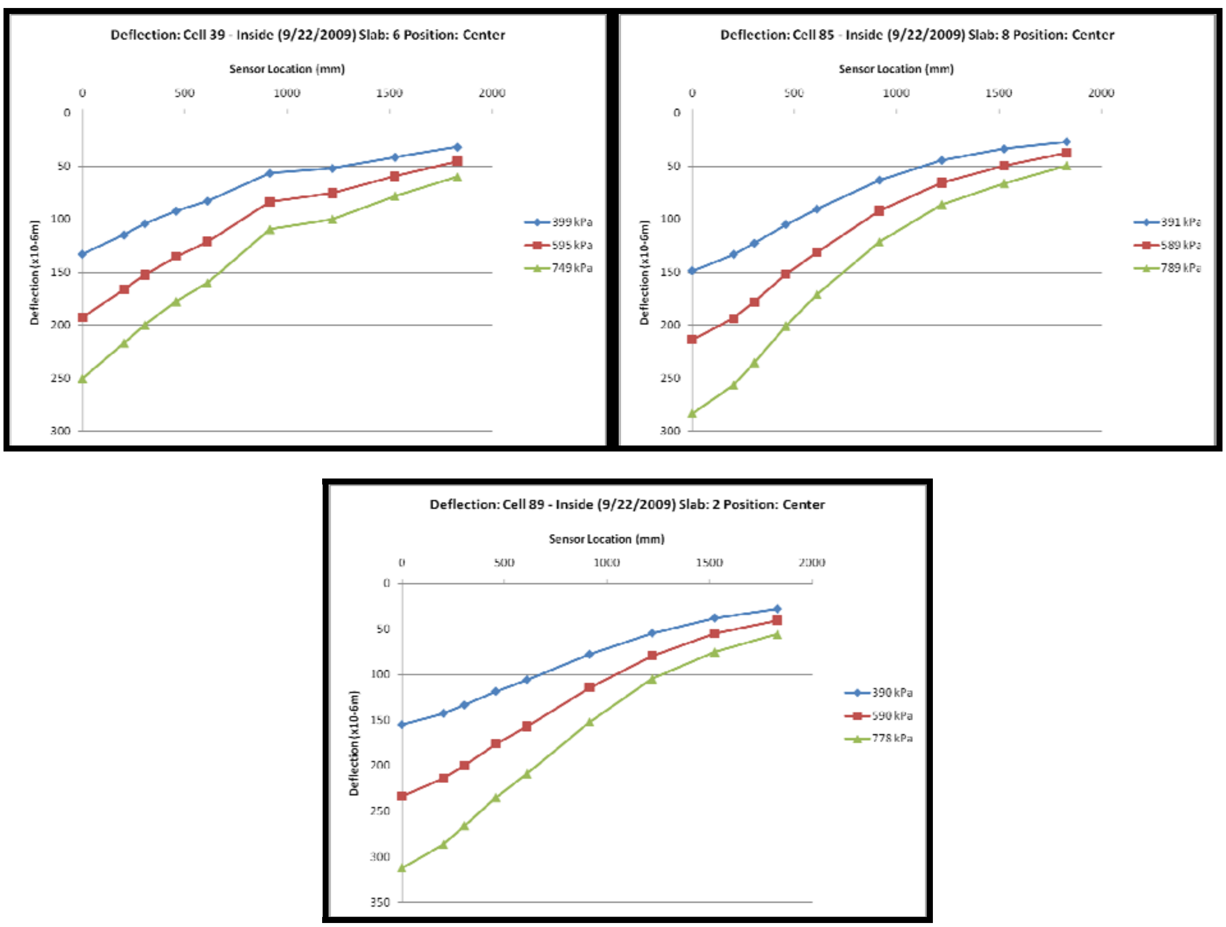

Figure 16. Representative deflection basins for Pervious Concrete Cells.

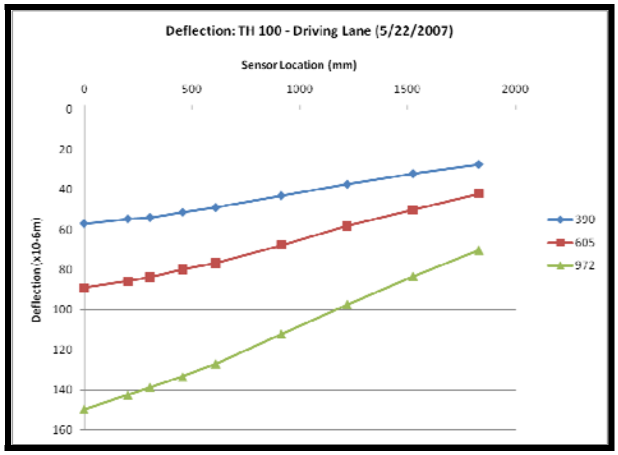

Figure 17. Deflection of a TH 100 Pavement of similar thickness design.

References

Khazanovich, L. and Izevbekhai, B. "Implications of Time-Dependent Texture Degradation on Pavement On-Board Sound Intensity Patterns in MnROAD Test Cells". Proceedings of the 2008 NoiseCon Conference, July 28-30, 2008 Dearborn, MI, obtained from author, CD-ROM. (Also available at http://www.mrr.dot.state.mn.us/research/pdf/2008MRRDOC025.pdf.)

Izevbekhai, B. *Pavement Surface Characteristics MnROAD Studies: Task 2: Construction and Initial Test Records of New and Innovative Textures*. Minnesota Department of Transportation, St. Paul, MN, November 2008, MPR 6-021.

Izevbekhai, B. *Construction Report of Pervious Concrete Cells in MnROAD Low Volume Road: Cell 39 Porous Concrete Overlay, Cell 85 Pervious Concrete on Granular Subgrade, Cell 89 Pervious Concrete on Cohesive Subgrade*. Minnesota Department of Transportation, St. Paul, MN, December 31, 2008, MPR 6-021.

Wilde, W.J. *Implementation of an International Roughness Index for Mn/DOT Pavement Construction and Rehabilitation*. Minnesota Department of Transportation, St. Paul, MN, 2007, Final Report MN/RC-2007-09.

Rohne, R. and Izevbekhai, B. *Early Performance of Pervious Concrete Pavement*. Transportation Research Board, Washington, D.C., 2005.

Schaefer, V.R. "Construction and Performance of the Pervious Concrete Overlay at MnROAD". CD-ROM. Proceedings of the 2010 TRB Annual Meeting, Washington, D.C., 2010.

Rohne, R. and Lebens, M. *Subgrade Temperatures and Freezing Cycles in Pervious Pavements*. Minnesota Department of Transportation, St. Paul, MN, 2009.

Rohne, R. and Lebens, M. *Exploring Pervious Pavement Management Strategies*. Minnesota Department of Transportation, St. Paul, MN, 2009.