Minnesota Road Research Project

2007 Low Volume Road & Farm Loop
Cells 33, 34, 35, 77, 78, 79, 83, 84

Construction Report

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This report represents the results of research conducted by the authors and does not necessarily represent the view or policy of the Minnesota Department of Transportation. This report does not contain a standard or specified technique.

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ABSTRACT

The purpose of this report is to provide details on the 2007 reconstruction of several cells on MnROAD's Low Volume Road. As MnROAD enters Phase II of its existence several research projects were initiated that necessitated the reconstruction of pavement test sections. The first research study plans to test various configurations of heavy farm equipment (manure tankers in particular) and assess the resulting damage in comparison to a typical 80,000 lb truck. A new "Farm Road" was built in the MnROAD stockpile area and is comprised of Cells 83 and 84. The second consists of stabilizing a full-depth reclamation base material with off-spec fly ash and comparing its performance to both a non-stabilized FDR and a conventional aggregate base. This study removed Cells 29 and 30 on the LVR and replaced them with Cells 77, 78, and 79. The third study is a field validation of previous laboratory work on polyphosphoric acid modified asphalt binders. It is located on Cells 33, 34, and 35. A fourth study involved innovative diamond grinding of concrete pavements to optimize their surface characteristics (noise, ride, texture, friction, splash and spray). Cells 37, 7, and 8 were ground during the summer of 2007.

These projects are the result of partnerships between the Minnesota Department of Transportation and private industry (Bloom Consultants, Innophos, MTE Services, DuPont, Paragon Technical Services, ICL Performance Products LP, and the Professional Nutrient Applicators Association of Wisconsin, among others), government agencies (Federal Highway Administration, Department of Energy, and the Minnesota Local Road Research Board), and other state DOTs (Wisconsin and Iowa) through the Transportation Pooled Fund Program.

This report documents the previous pavement condition, pavement structural and mix designs, instrumentation plan, field construction activities, material sampling, and initial laboratory test results.

INTRODUCTION

MnROAD Facility

The Minnesota Department of Transportation (Mn/DOT) constructed the Minnesota Road Research Project (MnROAD) between 1990 and 1993. MnROAD is located 40 miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments originally containing 40 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 herein, 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 are shown in Appendix A. Additional information on MnROAD can also be found on its web site at http://mnroad.dot.state.mn.us/research/mnresearch.asp.

Mainline

The MnROAD Mainline is a 3.5-mile 2-lane interstate roadway carrying "live" traffic. The Mainline consists of both 5-year and 10-year pavement designs. Originally, a total of 23 cells were constructed consisting of 14 hot mix asphalt (HMA) cells and 9 Portland cement concrete (PCC) test cells. Superpave and whitetopping cells were added in 1997 and 2004, and many of the HMA cells have received various maintenance treatments over the years.

Traffic on the Mainline comes from the traveling public on westbound I-94. Typically the Mainline is closed for three days per month and the traffic is rerouted to the original interstate highway to allow MnROAD researchers the ability to safely collect data and record test cell performance. The traffic volume has increased dramatically since the test facility first opened, from an estimated 14,000 vehicles per day in 1994 to over 26,000 vehicles per day today. The Mainline equivalent single axle loads (ESALs) are determined from two weigh-in-motion (WIM) devices located at MnROAD. An IRD Inc. hydraulic load scale was installed in 1989 east of the mainline test cells, and a Kistler quartz WIM was installed in 2000 between PCC cells 10 and 11. Over time the Mainline has received over 6 million flexible ESALs and 10 million rigid ESALs.

Low Volume Road

Parallel and adjacent to the Mainline is the Low Volume Road (LVR). The LVR is a 2-lane, 2 ½-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/trailer with two different loading configurations. The "heavy" load configuration results in a gross vehicle weight of 102 kips (102K configuration) that operates on the outside lane one day per week. The "legal" load configuration has a gross vehicle weight of 80 kips (80K configuration) that operates on the inside lane four days per week. This results in a similar number of ESALs being delivered to both lanes even though the number of passes differs. From this point forward, loading on the LVR will be done exclusively by the 80K truck five days per week on the inside lane. This will allow researchers to isolate the environmental effects on pavement performance.

MnROAD Instrumentation and Performance Database

Data collection at MnROAD is accomplished with a variety of methods to help describe the pavement response to loads and the environment and the actual pavement performance. Layer data is collected from a number of different types of sensors (initially numbering 4,572) located throughout the pavement surface and sub-layers. The sensors measure variables such as temperature, moisture, strain, deflection, and frost depth. Data flows 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. MnROAD staff also monitors

pavement performance on a regular basis, and the data is input into the database. Monitoring data includes ride, distress, rutting, faulting, friction, FWD, forensic trenches, and material laboratory testing. Data from the sensors or monitoring activities can be requested from the MnROAD database by contacting Mn/DOT researchers. For more details on MnROAD data please visit:
http://www.mrr.dot.state.mn.us/research/MnROAD_Project/MnROADReports/MnRoadOnlineReports/MNROADDBDescriptions.pdf

PROJECT BACKGROUND

Existing Pavement Condition

Cells 33-35 were constructed in 1999 for a Superpave study with the goal of evaluating different asphalt binder grades for their low temperature cracking susceptibility. They consisted of 4" HMA over 12" Class 6 sp. aggregate base over clay subgrade. The PG 58-28 binder (Cell 33) exhibited the typical thermal cracking pattern expected of evenly spaced thermal cracks straight across the pavement. The PG 58-34 binder (Cell 34) had virtually no cracks after 8 years in service. The PG 58-40 binder (Cell 35) has a shattered appearance of numerous small cracks spaced close together. These cracks appear to be more fatigue in nature, as there are few if any cracks that go straight across the 12-ft pavement lane. All three cells showed similar rutting behavior, with an average rut depth of about ½ inch. A forensic investigation in the spring of 2007 indicated that the rutting was primarily due to consolidation of the aggregate base material under heavy traffic loading.

Cells 29-30 were original MnROAD cells built in 1993 using a Pen 120/150 (PG 58-28) binder. Both cells had 5" HMA over an aggregate base (Cell 29 had 10" Class 4 sp. and Cell 30 had 12" Class 3 sp.) over clay subgrade. They exhibited a typical thermal cracking pattern and both had an average rut depth of about 1/3 inch. The west end of Cell 29 was beginning to exhibit moderate fatigue cracking and larger rut depths, but a microsurfacing application in September 2005 restored the ride quality of the cells significantly.

Acid Modified Binder Study

Polyphosphoric acid (PPA) has been used for some thirty years to stiffen asphalt for paving applications. Specifically, these additives have improved the pavement performance at high temperatures (i.e., rutting) without adversely affecting the low temperature properties (i.e., low temperature cracking). More recently PPA has been used to stiffen asphalts that may be marginal on the Superpave RTFOT test. This has been particularly so in the case of polymer modified binders. It was found more cost effective to add a small amount of acid, which could readily be dispersed in the binder rather than mill in additional quantities of more expensive polymer. It was then found that by adding polyphosphoric acid the amount of polymer could be reduced thereby saving cost for the contractor. The Federal Highway Administration, Office of Infrastructure, is completing a laboratory project to address the risks and benefits associated with the use of polyphosphoric acid as an asphalt modifier. This lab study aims clearly identify which grades can and cannot be used and the pitfalls associated with the use of polyphosphoric acid with certain antistrip compounds, such as amines and lime as well as asphalt binders from differing sources. The MnROAD study will build upon the findings of this study and conduct a field trial to assess the performance of PPA mixes over a 5 year period. This study is a joint venture between public agencies and private industry, as shown in Table 1.

Table 1. Acid Study Partners

Partner	Contribution
Minnesota Department of Transportation	Overall project management and administration; design, construction, QC/QA and performance testing; MnROAD operations, performance monitoring, and reporting
Federal Highway Administration	Asphalt binder and mixture performance testing; $150,000 for MnROAD instrumentation, monitoring, reporting, and general operations
MTE Services, Inc.	Asphalt blending and transport; asphalt binder and mixture performance testing
Innophos, Inc.	$75,000 for MnROAD construction; advice and guidance on the proper inclusion of PPA
Marathon Petroleum Company, LLC	Supply of neat PG xx-34 binder
DuPont	Support MTE's costs of binder production
Paragon Technical Services, Inc.	Support MTE with PPA + SBS blend
ICL Performance Products LP	PPA supply and funding
Western Research Institute	Chemical analysis of asphalt binders and mixtures

Construction of MnROAD Low Volume Road test cells to study the performance of asphalt mixtures modified with polyphosphoric acid was completed in 2007. The HMA mix designation was SPWEB340C, which indicates a 12.5 mm Superpave mix, Traffic Level 3 (1-3 Million ESALs), 4.0% design air voids, and PG 58-34 binder. No RAP was allowed in the mix, the quantity of limestone aggregates was limited to 10%, and hydrated lime was added at 1%. A liquid phosphate ester antistrip (Innovalt W) was added to each binder material at 0.5%. The job mix formula is shown in Figure 1. The cells include the following binder materials:

- 0.75% PPA only (Cell 33)
- 0.3% PPA + 1.0% SBS polymer (Cell 34)
- 2.0% SBS polymer only (Cell 35)
- 0.3% PPA + 1.1% Elvaloy polymer (Cells 77-79 – shared with Fly Ash Study)

BITUMINOUS PLANT MIX DESIGN REPORT
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FAX: (651) 366-5580

0-2007-196

Date: 7/12/2007

THIS MIX DESIGN REPORT IS NOT VALID UNTIL PLANT NO. INDICATED BELOW IS CERTIFIED.

TO BE FILLED IN BY CONTRACTOR

ENGINEER | FOR Mn/RD

PROJECT NUMBER SP8680-156

SPEC	2360
SPEC YEAR	2007
MIX TYPE	SPWEB340
AC GRADE	PER PROPOSAL

THIS MIXTURE HAS BEEN REVIEWED FOR VOLUMETRIC PROPERTIES ONLY, IT DOES NOT ASSURE THAT FIELD PLACEMENT AND COMPACTION REQUIREMENTS HAVE BEEN MET.

PLANT NO. 901204 - 2007 JOB MIX FORMULA

Begin With Test Number: SP WE 401

Sieve Size (mm)	(in.)	Composite Formula	JMF LIMITS		For Information Only Virgin Formula
37.5	(1 1/2)				
25.0	(1)				
19.0	(3/4)	100	100	100	
12.5	(1/2)	95	88	100	
9.5	(3/8)	84	77	90	
4.75	(#4)	61	54	68	
2.36	(#8)	46	40	52	
0.075	(#200)	2.7	2.0	4.7	
Spec. Voids		4.0	3.0	5.0	
Spec. VMA		14.0	13.7		
% AC		5.6	5.2		
		(TOTAL)			

PERCENT PASSING

%AC (NEW)

TM # 2007-083 Indicates a Gyratory Density of 147.7 (lbs/ft3) at 60 Design Gyrations
Use of anti-strip agent required: N

Proportions		Pit	Source of Material	Sp.G
5	%	73006	MARTIN MARIETTA ST CLOUD 3/4" UNWASHED (GRANITE)	2.701
24	%	73006	MARTIN MARIETTA ST. CLOUD CA-50 (GRANITE)	2.719
20	%	73006	MARTIN MARIETTA ST. CLOUD 1/2" CLEAR (GRANITE)	2.711
35	%	73006	MARTIN MARIETTA ST CLOUD WASHED SAND (GRANITE)	2.692
16	%	71002	BARTON ELK RIVER #1 WASHED SAND	2.657
1	%		CALCIUM HYDROXIDE (LIME)	2.300
	%			
	%			

Mix Aggregate Specific Gravity at the Listed Percentages = 2.697

Remarks MINUS #4 AGG SG AT THE LISTED PERCENTAGES = 2.678

Mix Design Reviewed by:

Mix Design Specialist

cc:
Contractor - COMMERCIAL ASPHALT #4
METRO INSPECTION

Figure 1. Acid Study HMA Mix Design

Fly Ash Study

High carbon fly ash is one of the by-products of burning coal in power generating facilities. Fly ash is frequently described as being composed of glassy, spherical particles that are primarily the size of silt. Fly ash within Mn/DOT specification is frequently included in concrete mixtures to improve durability. Due to the increasingly stringent environmental regulations promulgated by the U.S. Environmental Protection Agency and/or local authorities the power generation industry has taken measures to reduce the emission of NOx and SOx from burners fueled with coal. Low-NOx burners reduce emissions by changing the combustion characteristics of coal-fueled boilers. Fly ash produced from power plants operated to reduce

NOx emissions will produce ash that does not meet Mn/DOT specification. The resulting cementitious high carbon fly ash (CHCFA) has self-hardening properties in the presence of moisture, such as Class C fly ash, but cannot be used in concrete since the high carbon content absorbs air in the concrete and affects durability. Laboratory testing has shown high carbon fly ash to be a viable stabilizing material for base layers.

The material used in this study was produced by the combustion of coal at the Riverside electric power plant in North Minneapolis. Fly ash from the Riverside 8 plant is Class C high calcium high carbon cementitious ash but slightly off specification for use as a construction material in Mn/DOT construction projects. The higher than usual carbon content resulting from the addition of petroleum coke to the furnace feed stock for increased heat content results in a carbon content slightly higher than the Mn/DOT specified 5%. The fly ash installed at the MnROAD facility will have been fully characterized through annual ash characterizations required by the Minnesota Pollution Control Agency permit. Xcel Energy may be willing to share their fly ash characterization data with this study group.

The goal of this research project is to install a road base at the MnROAD facility with fly ash aggregate for long term monitoring of engineering and environmental characteristics and compare it to the performance of a non-stabilized recycled base as well as a crushed stone aggregate base. This study is a partnership between Mn/DOT and Bloom Consultants, LLC of Milwaukee, WI and will allow MnROAD to conduct a controlled long term evaluation of pavement base materials stabilized with high carbon fly ash. This work is a portion of Phase II of a fly ash stabilization project performed by Bloom Consultants, LLC and is sponsored by the U.S. Department of Energy. Phase II is a $750,000 project entitled Use of High Carbon Fly Ash to Stabilize Recycled Pavement as Base Course. It has a two year time requirement and will involve MnROAD test sections constructed in 2007. The estimated service life of this proposed MnROAD test cell will be 10 years. It is proposed that the monitoring and evaluation protocol established during DOE Phase II shall be continued through the test cell service life.

The construction of the test cells occurred during the summer of 2007 at MnROAD. The cells include one 10 foot by 10 foot lysimeter installed in the subgrade for the collection and channeling of leachate from the road base to a collection point off the shoulder. Monitoring of the leachate from each cell will occur during at various times of the year depending on rainfall events and budgetary limits.

Farm Equipment Study

Over the past few decades, there have been significant changes in both farm size and farm equipment. Combined with a regulatory emphasis that has encouraged farmers to store manure as a liquid and apply it in a short time frame, the farm equipment industry has responded by producing larger and larger manure hauling and application equipment.

The shift to larger and heavier equipment has occurred at a faster rate than both pavement design technology and the state regulatory approach to larger farm equipment. Innovations such as steer able axles, flotation tires, and tire design changes are not reflected in state DOT regulations. In the minds of some manure applicators and farmers, this has forced the adoption of equipment and practices that, while complying with the letter of the law, actually create more pavement damage.

The objectives of this study are to determine pavement response under various types of agricultural equipment (including the impacts of different tires and additional axles), to compare this response to that produced by a typical 5-axle tractor-trailer, and to calibrate the analytical models for prediction of relative damage caused by heavy farm equipment. Based on these results, it may be possible to provide recommendations on tire and axle configurations that would reduce pavement damage from agricultural

equipment. In addition, this study will provide basic information for use by the state transportation agencies for potential legislative uses. This research will allow policy and design decisions to be driven by direct experimental results rather than by models that may not have been validated for the types of loadings and tire configurations of current and evolving agricultural equipment.

The objectives of this project will be accomplished by constructing new instrumented test sections at MnROAD and retrofitting instrumentation into an existing concrete test section. This project was initiated as a pooled fund study, with contributions from Mn/DOT, Minnesota Local Road Research Board, Iowa DOT, Illinois DOT, and the Professional Nutrient Applicators Association of Wisconsin (PNAAW). The PNAAW has enlisted the support (both cash and in-kind) of several private industries and associations as shown in Table 2.

Table 2. PNAAW Industry Partners

Organization	Cash	In-Kind
Professional Nutrient Applicators Association of Wisconsin	$10,000	$5000 labor on site, equipment transport
John Deere		1 180 hp tractor, 1 250 hp tractor, total 240 hours per year
Professional Dairy Producers of Wisconsin	$500	
Husky Farm Equipment	$2500	$2500 equipment, transport
Minnesota Custom Manure Applicators Association		$5000 labor on site, equipment transport
Michelin Tire		$20,000 in tires, changing services
Harlon Oil		Diesel fuel for tractors
Midwest Manure Applicator Association (Ohio)		Technical and logistical support

Diamond Grinding Study

One option is for rehabilitating Portland cement concrete pavements without the need to restore structural capacity is to diamond grind the surface. This process removes much of the pavement roughness and restores texture and friction. Many variables play into the grinding operation, such as blade spacing, depth of cut, kerf configuration, etc. With an increased awareness of pavement surface characteristics it was expedient re-examine how the diamond grinding process can be improved to enhance quietness, safety, and ride comfort. An attempt to define the scope without re-inventing the wheel led to collaboration with the Institute for Safe, Quiet, and Durable Highways (SQDH) at Purdue University, Federal Highway Administration (FHWA), 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 juncture that a MnROAD study would create an opportunity to validate the Purdue results.

This study was put forth as a pooled fund study with participation from Mn/DOT, TXDOT and FHWA. ACPA and IGGA agreed to perform the diamond grinding as an in-kind match. Mn/DOT made two cells available on the MnROAD Mainline (Cells 7 and 8) for this study, as well as a proof-of-concept on the Low Volume Road (Cell 37) to increase the comfort level of performing unconventional grind before proceeding to the Mainline.

The proof of concept grinding was performed on Cell 37 during the week of June 18, 2007. The mainline Cells 7 and 8 grinding was done by Diamond Services Inc. at their expense during the week of October 18, 2007. The scope of work includes monitoring of friction, noise, texture and ride quality over time. Development of a protocol for splash and spray may also be considered. Durability and benefit/cost will also be documented and reported.

No further documentation of this project will be recorded in this report. The reader should refer to reference [1] for more information.

MnROAD 2007 RECONSTRUCTION

Pavement Design

A "typical" pavement design for a low volume road in Minnesota was chosen for the MnROAD test sections. Being somewhat constrained by existing conditions, the pavement structural and geometrical designs were based on normal low volume roads in Minnesota. An analysis with MnPAVE, Mn/DOT's mechanistic-empirical pavement design procedure, shows that each of the pavement sections has a 5 to 10 year design life, which is within the parameters of each study.

Cells 33-35 (Acid Study)

The original Cells 33-35 were constructed in 1999 with 4" HMA over 12" Class 6 sp. aggregate base over clay subgrade. For the current study the 4" HMA was removed and replaced with a new 4" HMA layer. The HMA lanes were each 14 feet wide with aggregate shoulders from an existing MnROAD stockpile. The asphalt mixtures on all three cells were designed exactly the same, with the only difference being the asphalt binder material used.

Cells 77-79 (Fly Ash Study)

For this study the in place cells were reclaimed to a depth of 10 inches. This reclaimed material was set aside on the shoulders and stockpile area for later use. The underlying aggregate base was subcut to the existing subgrade, and the base material in the middle portion (Cell 78) was removed. Clay borrow material was added 5" thick in order to reduce the total pavement thickness. The aggregate or reclaimed base material was put back 8" thick, Cell 79 was stabilized with high carbon fly ash, and 4" HMA was paved using the same mix design as for Cells 33-35. The base materials consisted of:

- Full-depth reclamation of 50% HMA + 50% Class 4 sp. (non-stabilized)
- Class 6 sp. crushed stone aggregate base (from on-site stockpile)
- Full-depth reclamation of 50% HMA + 50% Class 3 sp. (stabilized with 14% fly ash)

Cell 78 used the same Class 6 sp. base as in Cells 33-35, so this served as a control section for both the Acid and Fly Ash studies. The pavement lanes were 14' wide each, and the shoulders used aggregates from existing stockpiles as well as leftover reclaimed material.

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1 Izevbekhai, Bernard Igbafen, Report of Diamond Grinding on Cells 7 and 8 MnROAD Mainline Interstate Highway I-94, Final Report, Minnesota Department of Transportation, November 2007.

Cells 83-84 (Farm Equipment Study)

For this study an entirely new road was built in the MnROAD stockpile area. See Figure 2 for a sketch of the general layout. A long stretch parallel to the Mainline came off an existing concrete pad in front of our Weigh-In-Motion building. The topsoil in this area was stripped off and roughly 2' of clay borrow was added to build up the existing grade. Cell 83 was the "thin" section representing a typical 7-ton road in Minnesota, and Cell 84 was the "thick" section representing a typical 10-ton road. Cell 83 consisted of 8" Class 5 aggregate base imported by the contractor followed by 3.5" HMA, and Cell 84 consisted of 9" Class 5 aggregate base and 5.5" HMA. The mix design for the HMA used on the farm road is shown in Figure 3. The pavement lanes were each 12' wide with 6' shoulders (Cell 83 was aggregate and Cell 84 was paved) on each side. A gravel road 8" thick was built to complete the loop and meet back up with existing aggregate roads in the stockpile area.

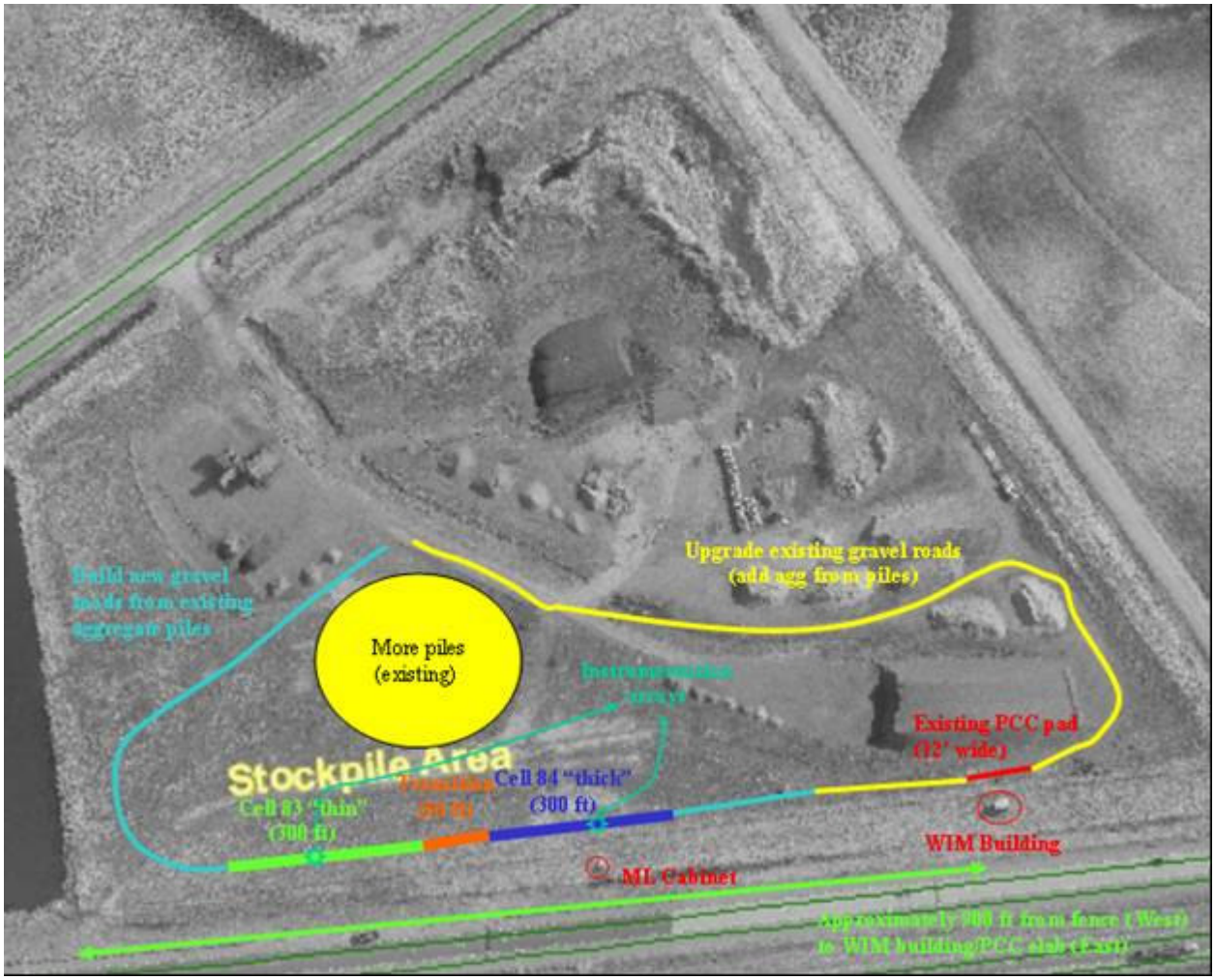

Figure 2. Farm Road Layout

BITUMINOUS PLANT MIX DESIGN REPORT
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FAX: (651) 366-5580

Farm ROAD
 # 0-2007-059
Date: 5/7/2007

THIS MIX DESIGN REPORT IS NOT VALID UNTIL PLANT NO. INDICATED BELOW IS CERTIFIED.

TO BE FILLED IN BY CONTRACTOR	
ENGINEER	FOR
PROJECT NUMBER	
CONTRACTOR SIGN.	
FOR ALL STATE, COUNTY, AND CITY PROJECTS, CONTRACTORS MUST FAX A COPY TO MNDOT TWO WORKING DAYS PRIOR TO PRODUCTION AT (651) 366-5580	

SPEC	2360
SPEC YEAR	2007
MIX TYPE	SPWEB340
AC GRADE	PER PROPOSAL

THIS MIXTURE HAS BEEN REVIEWED FOR VOLUMETRIC PROPERTIES ONLY, IT DOES NOT ASSURE THAT FIELD PLACEMENT AND COMPACTION REQUIREMENTS HAVE BEEN MET.

PLANT NO. 901204 - 2007 JOB MIX FORMULA

Begin With Test Number: SP WE 301 / -- -- ---

Sieve Size (mm)	(in.)	Composite Formula	JMF LIMITS			For Information Only Virgin Formula
37.5	(1 1/2)			-		
25.0	(1)			-		
19.0	(3/4)	100	100	-	100	
12.5	(1/2)	93	86	-	100	
9.5	(3/8)	79	72	-	86	
4.75	(#4)	60	53	-	67	
2.36	(#8)	47	41	-	53	
0.075	(#200)	2.2	2.0	-	4.2	
Spec. Voids		4.0	3.0	-	5.0	
Spec. VMA		14.0	13.7			
% AC		5.7 (TOTAL)	5.3			%AC (NEW)

PERCENT PASSING

TM # 2007-026 Indicates a Gyratory Density of 147.6 (lbs/ft3) at 60 Design Gyrations
Use of anti-strip agent required: N

Proportions		Pit	Source of Material	Sp.G
48	%	71059	BARTON ELK RIVER #2 BA 3/4"	2.642
8	%	71002	BARTON ELK RIVER #1 WASHED SAND	2.657
24	%	19106	KRAEMER BURNSVILLE 9/16" CLEAR (LIMESTONE)	2.683
20	%	19106	KRAEMER BURNSVILLE WASHED SAND (LIMESTONE)	2.706
0	%	71059	BARTON ELK RIVER #2 SCREENED SAND	2.640
	%			
	%			
	%			

Mix Aggregate Specific Gravity at the Listed Percentages = 2.666
This Mix Design Report supersedes MDR/REC # 0-2003-173 Dated: 8/29/2003

Remarks MINUS #4 AGGREGATE SPG AT THE LISTED PERCENTAGES = 2.664

Mix Design Reviewed By:

cc:
Contractor - COMMERCIAL ASPHALT #4
Metro Inspection

Mix Design Specialist

Figure 3. Cell 83 & 84 HMA Mix Design

Construction Contract

The project was assigned SP # 8680-156 and let on June 8, 2007. Three local contractors submitted bids, and Midwest Asphalt Corporation was awarded the contract based on their low bid of $389,857.43. The contract start date was July 16, 2007. The Contract number was S07104.

One of the challenges during the contracting process was keeping track of each individual funding source. Each of the three projects (Acid, Fly Ash, and Farm Equipment) had their own funding mechanisms, and we had to keep track of which pay items to pay for out of each fund. This made the accounting more straightforward while adding a level of complexity in the field.

Instrumentation Infrastructure

Given past experience with sensor failure and malfunction, it was decided to do as much as possible to protect sensor arrays from the construction process and operations practices. Prior to the actual placing of the sensors, a few instrumentation system development guidelines were identified to improve the performance of sensor arrays. These guidelines were developed as problems or questions came up. Some were not identified until well into the roadway construction. They are:

- Existing data collection/communications cabinets are to be utilized as much as possible.
- Sensor arrays are to be located as close as possible to data collection/communications cabinets.
- Sensors and sensor lead wires are to be protected as much as possible.
- Sensor arrays are to be located as near as possible to the center of the cell.
- Only the inside (80K) lane of the Low Volume Road is to be instrumented.

Sensor arrays were located near existing data collection/communications cabinets to minimize lead lengths. EMI and RFI are likely sources for noise. Long leads are more susceptible to EMI. Loops of excess lead in hand holes and vaults are likely candidates for induced currents. We decided to place all sensors arrays within 100 feet of existing and new cabinets.

Unprotected leads in an abrasive base are just asking for holes in the cable jackets, moisture intrusion, and corroded or broken wire. To provide more protection for lead wire, we installed a series of conduit laterals to bring the sensor leads across the pavement to the data collection/communications cabinets.

Cells 33-35

Existing cabinets were used with the exception of the cabinet in Cell 35, which was relocated to an existing alternate foundation nearer to the center of the cell. Hand hole (HH) and conduit grids were installed for each cabinet. The basic design for the grids is as shown in Figure 4. The figure also shows the general layout of sensors in each cell. We experimented with the construction sequence for the grids. First trenching the conduit laterals (six-inch wide trench approximately 2-feet deep) and then boring 3-foot diameter holes for the hand holes. We found it easier to bore for the hand holes and then trench for the conduit and go back to clean out the hand hole with the boring tool. It does not seem logical but it did work out better for time and labor.

Hand holes are 24-inch diameter polyethylene (PE) canisters, 42 inches deep. The hand holes have molded PE covers and cover frames. Hand hole bottoms have weeps and are to be installed on a gravel sump. Installing the hand hole to the correct finished elevation is the largest challenge. The best way to do so is to clean out the bore hole, backfill with some aggregate, drop in the canister, add more aggregate around the canister and slowly pull the canister to its final elevation with a twisting motion to allow the aggregate to flow under the canister and hold it at the proper elevation. The last steps include adding more aggregate to the inside bottom of the canister and to backfill and compact around the canister. Prior to backfilling the canister, the cover frame must be installed on the canister to keep the canister round. The PE canisters are quite flexible.

As soon as the existing pavement was removed hand hole bores were made on 20-foot centers in line with the cabinet, parallel to the centerline of the roadway. Existing vaults were utilized instead of hand holes whenever possible.

After the HH bores conduit laterals were trenched with care taken to have enough depth to allow for drainage of the conduit to the hand hole. Polyvinyl chloride conduit was then installed in lateral trenches. Risers were installed in the conduit at the centerline and at the inside lane edge line. Riser openings were

located just below the surface of the subgrade and just below the surface of the base. The lateral trenches were then backfilled and compacted with a SkidLoader-mounted trench compacting wheel.

Cells 77-79

Since existing Cells 29 and 30 were used to construct three new cells for the Fly Ash Study, two new cabinets were installed in Cells 77 and 79. The new cabinets were located near the center of the new cells. The foundations were constructed to fit a NEMA 334 cabinet 11 inches deep on six-inches of 0.75-inch aggregate. Concrete pads were constructed on either side of the cabinet. The construction of handholes and conduit was similar to that of Cells 33-35.

Cells 83-84

The two cells built for the Farm Study were new cells in new locations. No infrastructure was in place from existing cells to work with. Therefore, new cabinets were installed and the necessary power and communications networks were built to support Cells 83 and 84. Aside from creating this new infrastructure, the installation of cabinets, handholes, and conduits in Cells 83 and 84 proceeded much like those on the Low Volume Road.

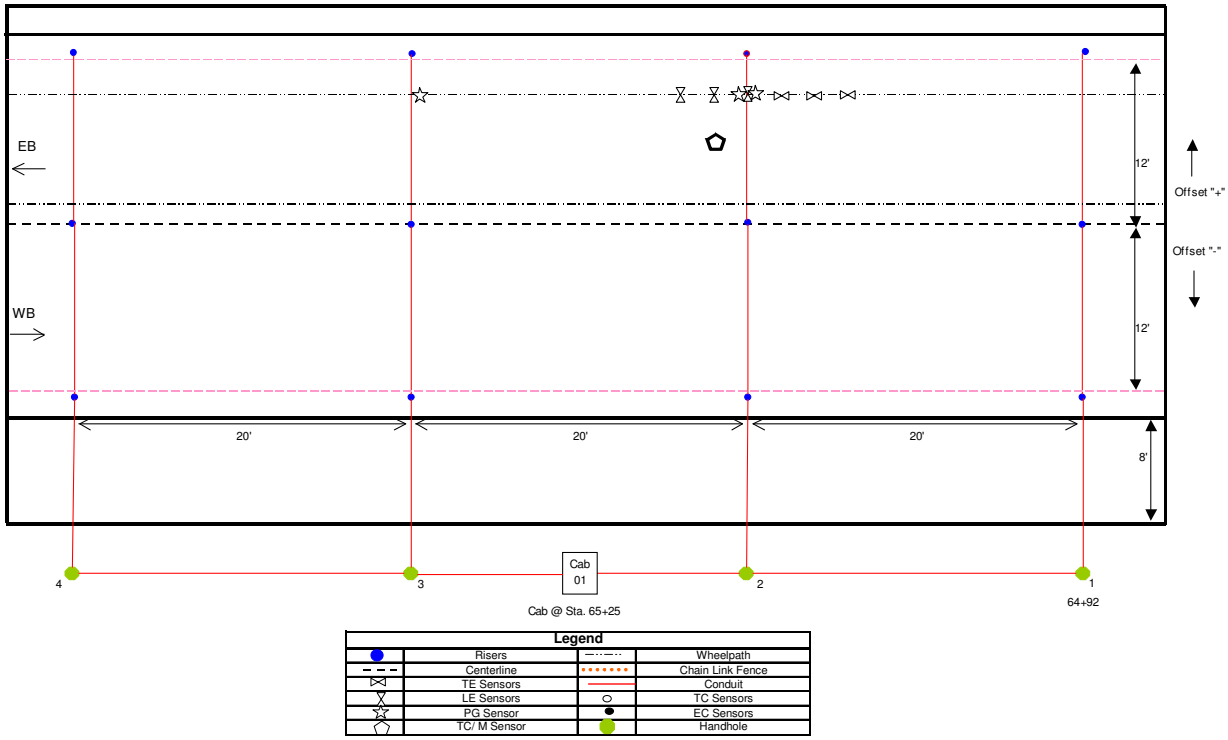


Figure 4. Instrumentation and Infrastructure Layout, Cell 33

Sensor Installation

Much of the instrumentation work was performed before the construction project began by MnROAD staff and several student workers. Sensors were calibrated in the laboratory, and lead wires were prepared. Every sensor and lead wire was marked to allow for easy installation in the field. Once each unbound layer (common borrow and aggregate base) was placed and compacted, researchers were ready to install the sensors. At each location, a hole was augured with a skid steer loader. Each sensor was placed at the

appropriate depth and its location was recorded. The hole was backfilled and compacted with a hand tamper. The lead wires were pulled through the conduits and into the cabinets, where they were wired into the appropriate data logging equipment.

Instrumentation for monitoring unbound material moisture content, temperature, soil pressure, aggregate base displacement, and asphalt strain were installed in the pavement layers during construction (see Table 3). Sensor arrays were installed within each cell at various predetermined locations. In each array, sensors were located at specific depths as shown in Figure 5. All instrumentation is connected to a data acquisition system so that the environmental data collection is automated. Data will be loaded to the MnROAD database on a daily basis. Dynamic data collected as the pavement response to a moving vehicle load will be collected manually at certain times throughout the year.

Table 3. Instrumentation Installed

Sensor	Description	Manufacturer	Total # of Sensors	Sensor Locations
Thermocouple	Measures temperature of pavement layers at various depths	Omega Type TX	144	one 16-TC tree in each of 8 cells (Cell 83 has 2 TC trees)
ECH2O Probe	Measures volumetric water content, electrical conductivity, and temperature	Decagon ECH2O TE	63	one 8-EC tree in each of 8 cells
Time Domain Reflectometer	Measures volumetric water content from 0% to saturation	Campbell TDR 100	8	one 8-TDR tree in Cell 83
Lysimeter	10 m x 10m 3-layer geosynthetic to collect leachate from base layer	Homemade	3	one lysimeter in each of Cells 77-79
Loop Detector	Detects truck and activates dynamic gauges	Never-Fail Inductive Loop	10	one loop in each of Cells 33-35 & 77-79, two loops in each of Cells 83-84
Soil Compression Gauge	Measures 3-D displacement at middle of base layer	Vishay Micro-Measurements LVDT	6	one X-Y-Z group in each of Cells 83-84
Soil Compression Gauge	Measures 2-D displacement (X-Y) at middle of base layer	CTL Potentiometer	6	one X-Y group in each of Cells 77-79
Dynamic Pressure Cell	Measures normal stress at base/subgrade interface	Geokon 3500	24	3 PK sensors in each of 8 cells
Asphalt Dynamic Strain Gauge	Measures transverse or longitudinal strain at the bottom of HMA layer	CTL ASG-152	72	3 longitudinal & 3 transverse sensors in each of Cells 33-35 & 77-79; 6 longitudinal, 6 transverse, & 6 @ 45° in each of Cells 83-84

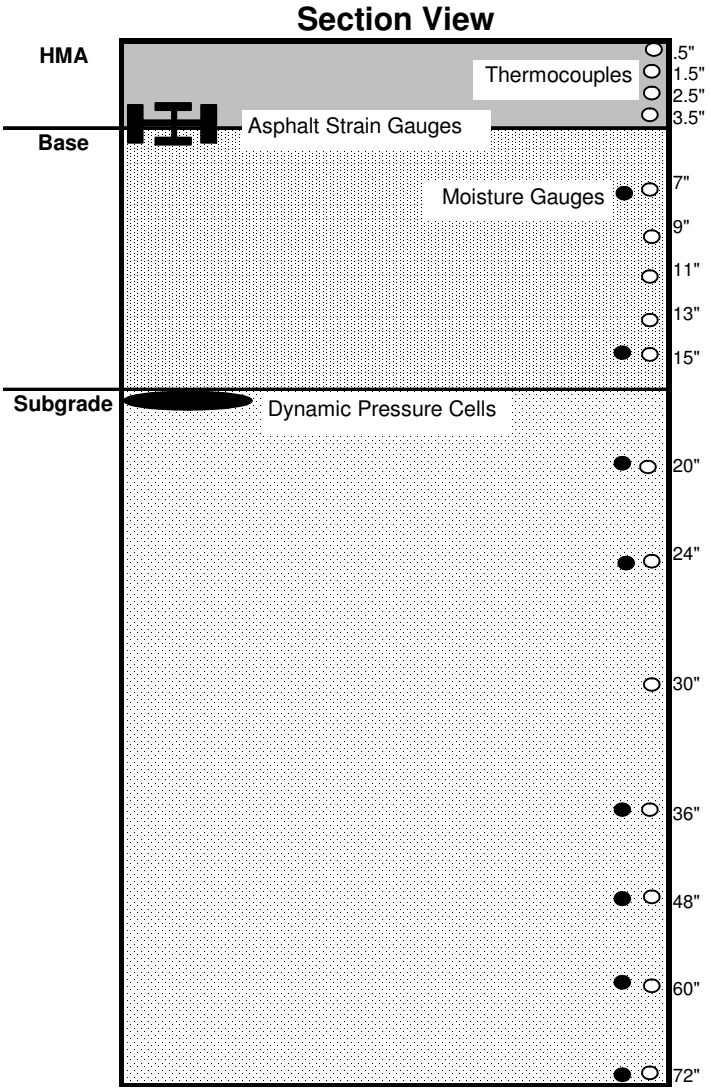


Figure 5. Sensor Depth Schematic, Cell 33

Lysimeter Installation

One of the requirements by the Minnesota Pollution Control Agency (MPCA) for the fly ash study was that the leachate be monitored in each test section to monitor the concentrations of several regulated chemicals. To this end, a pan lysimeter was installed in each cell to monitor the quantity of water percolating from the pavement and the concentration of trace elements in the leachate. MPCA has requested continuous monitoring of leachate until 2017.

The lysimeter was installed by University of Wisconsin researchers with assistance from MnROAD staff. The lysimeter is 10 ft wide, 10 ft long, and 3 inches deep and is lined with 1.5-mm-thick linear low density polyethylene geomembrane. The base of the lysimeter was overlayed by a geocomposite drainage layer (geonet sandwiched between two non-woven geotextiles) in order to freely drain the water and to keep aggregate particles from clogging the system. MnROAD staff excavated a hole at the top of the subgrade in each cell. The lysimeter was installed, and a drainage pipe was also installed off to the shoulder (see Figure 6). Class 6 aggregate material was placed in each lysimeter and compacted prior to adding the base layer in each cell.

The environmental monitoring program consists of monitoring the volume of water draining from the pavement and concentrations of trace elements in the leachate. Water collected in the drainage layer will be directed to a sump plumbed to a 30-gallon polyethylene collection tank buried adjacent to the roadway. The collection tank will be insulated with extruded polystyrene to prevent freezing. Leachate that accumulates in the collection tank will be removed periodically with a pump. The volume of leachate removed will be recorded with a flow meter, a sample for chemical analysis will be collected, and the pH, Eh, and electrical conductivity of the leachate are recorded. Leachate samples will be collected by the "clean hands/dirty hands" technique described in detail in EPA Method 1669. Samples will be filtered, preserved, and analyzed. Water samples for inorganic analysis will be collected following the generation of at least 1 quart of leachate after precipitation events. Inorganic water samples will be collected in polyethylene bottles of the appropriate size and preserved with the appropriate chemicals for transport and storage at the analytical laboratory. All samples will be delivered to the analytical laboratory within the same day of collection or stored over night in a refrigerator. The analytical laboratory will observe all appropriate water sample holding times as specified by the US EPA.

Leachate samples will be collected each month for the first quarter following construction and at least once quarterly thereafter for the duration of the project. Following the collection of leachate the collection tanks will be totally pumped out after each sampling event and the quantity of water recorded.

Figure 6. Lysimeter Installation at MnROAD

Fly Ash Stabilization

Stabilization of the reclaimed base in Cell 79 with off-spec fly ash was one of the crucial operations of the construction project. The research partners, Bloom Consultants and the University of Wisconsin, had prior experience with fly ash stabilization, so their oversight was helpful in successfully completing the operation. The basic operations are shown in Figure 7 and described below.

1. The fly ash was transported from the Riverside 8 plant in North Minneapolis to MnROAD in a 5-axle truck. Once at MnROAD the transport truck transferred the fly ash to the vane feeder truck. The supplier only provided one transport truck, so there was a lot of down time waiting for 3 loads of fly ash.
2. The vane feeder truck spread out the fly ash at the pre-determined rate of 14%. The vane feeder truck was brought in from across Lake Michigan because there are not very many trucks available like we required in the contract. The rate was calculated by measuring the weight of fly ash deposited on a 1-square-yard mat and adjusting the vanes to the proper setting. The fly ash was spread out on the grade approximately 3.5" deep. All of the fly ash was spread out on the roadway before mixing commenced.
3. The reclaimer ran through and mixed to a depth of 8", being careful not to get too deep and into the clay subgrade. A water truck was hooked up to the reclaimer and added about 1% water to the base while mixing.
4. A blade followed close behind the reclaimer and immediately began shaping the base to the required depth and cross-slope.
5. A vibratory padfoot roller was used to achieve adequate compaction because of the increased fines added to the base.

Once mixing operations commenced, the contractor had to work quickly to blade the stabilized material within tolerance. The fly ash caused the base to set up like a lean concrete. MnROAD staff attempted to install pressure gauges and other instrumentation right behind the reclaimer. Once it became apparent that the material was setting up to quickly, we got out of the way and let the contractor finish his work. MnROAD staff came back the next day and dug holes with a pickaxe and shovels to install the remaining instrumentation.

Figure 7. Fly Ash Stabilization

Intelligent Compaction

Intelligent compaction (IC) was performed at MnROAD as a partnership between Mn/DOT, Midwest Asphalt Corporation, and Caterpillar Global Paving (CAT). The aggregate base compaction was written in as part of the construction contract, but the HMA compaction was added after the fact. The aggregate base specification required that "once the base course is compacted and approved by the Engineer the Contractor shall provide a final pass with an Intelligent Compaction Vibratory roller to map the surface 'for information only'. This shall be considered incidental work." The objective of using intelligent compaction at MnROAD was to collect IC data on the aggregate base and bituminous pavement layers, provide a visual record of material stiffness and other parameters over the entire cell, analyze the data, and store a complete record of each test cell for future.

CAT provided both rollers for use out at MnROAD – the CS683E for aggregate base and the CB534D for asphalt pavements (see Figure 8). The CS683E used the Machine Drive Power method with the CCV arbitrarily set to a target of 130 and a maximum of 150. All IC data on the aggregate base was collected on September 5, 2007.

Figures 9-12 show maps of material stiffness over each cell. It appears that the machine was calibrated a bit low, because a large portion of the maps show CCV values greater than 150, especially on Cell 79. On Cells 83 and 84 it can be seen that the outside edges were softer than the middle of the pavement, especially on Cell 84. This was due in part to the presence of standing water in the ditches at those locations. The pictures from the Fly Ash study show that Cell 79 has the stiffest base layer out of the three cells, followed by Cell 77 and then Cell 78. Within each cell one can also see the relative stiffness of one area over another. These maps are helpful in analyzing layer stiffness, as shown in the next section.

The CB534D roller collected temperature data in front of each pass of the roller. The roller is equipped with one infrared camera in front and behind the roller so that it records the temperature before the water from the drum comes in contact with the pavement. This allows researchers and practitioners to see how uniform (or not) the temperature profile is across the pavement. Temperature segregation within the hot mix can create soft spots or areas with higher air voids that may be prone to premature failures. Collecting HMA mix temperature data from the rollers is still in its infancy, but this project got some exposure for the technology. Only one of the three rollers on the project was outfitted with IC technology; future projects at MnROAD and around Minnesota hope to have each roller as well as the paver outfitted with temperature measuring devices in order to record a complete temperature profile throughout the entire paving process. Intelligent compaction data on the asphalt pavement was collected September 11 and 13, but subsequent HMA paving did not use this technology. The temperature data collected with the IC roller is not available for this report.

Figure 8. Intelligent Compaction Rollers - Aggregate Base (Top) & HMA (Bottom)

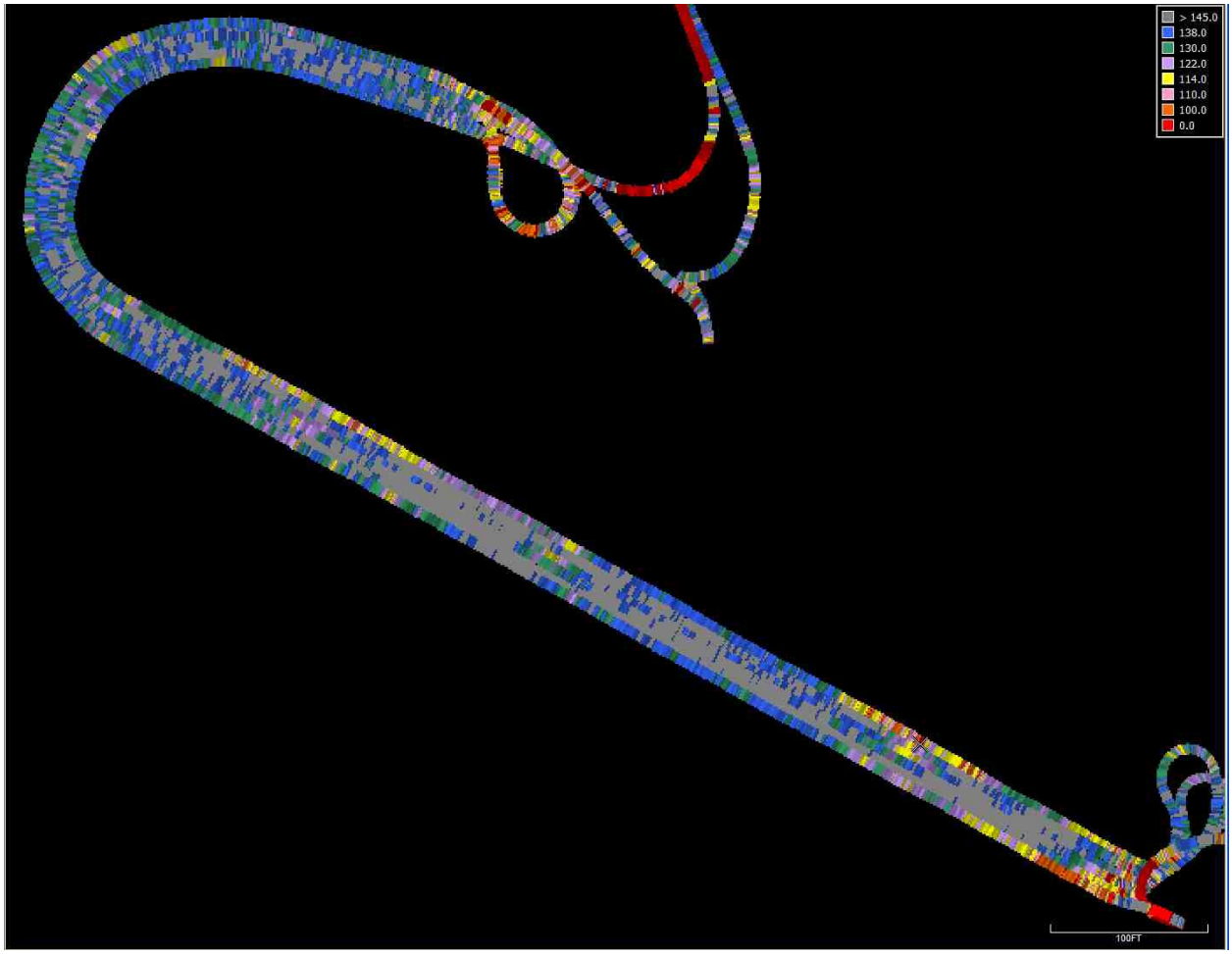


Figure 9. Intelligent Compaction on Aggregate Base, Cells 83-84

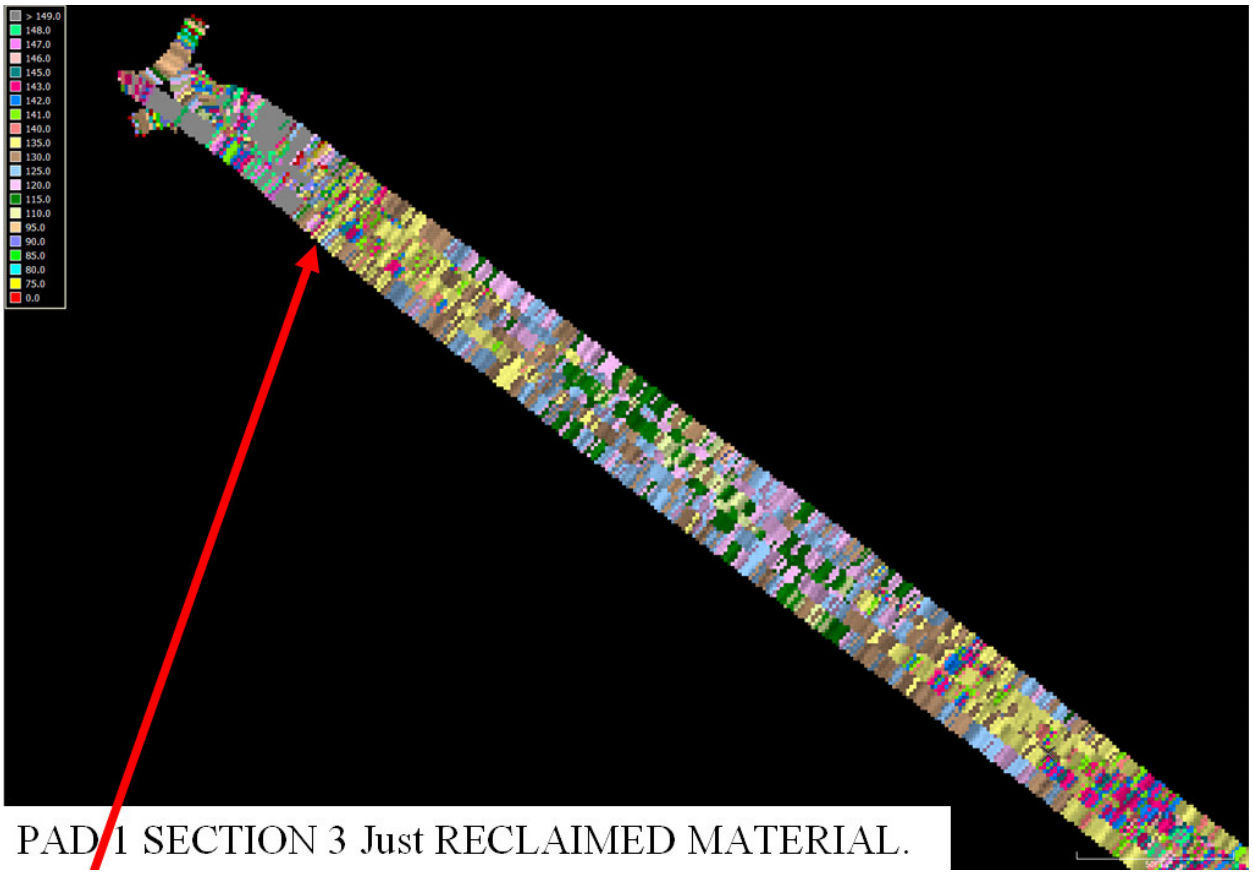


Figure 10. Intelligent Compaction on Aggregate Base, Cell 77

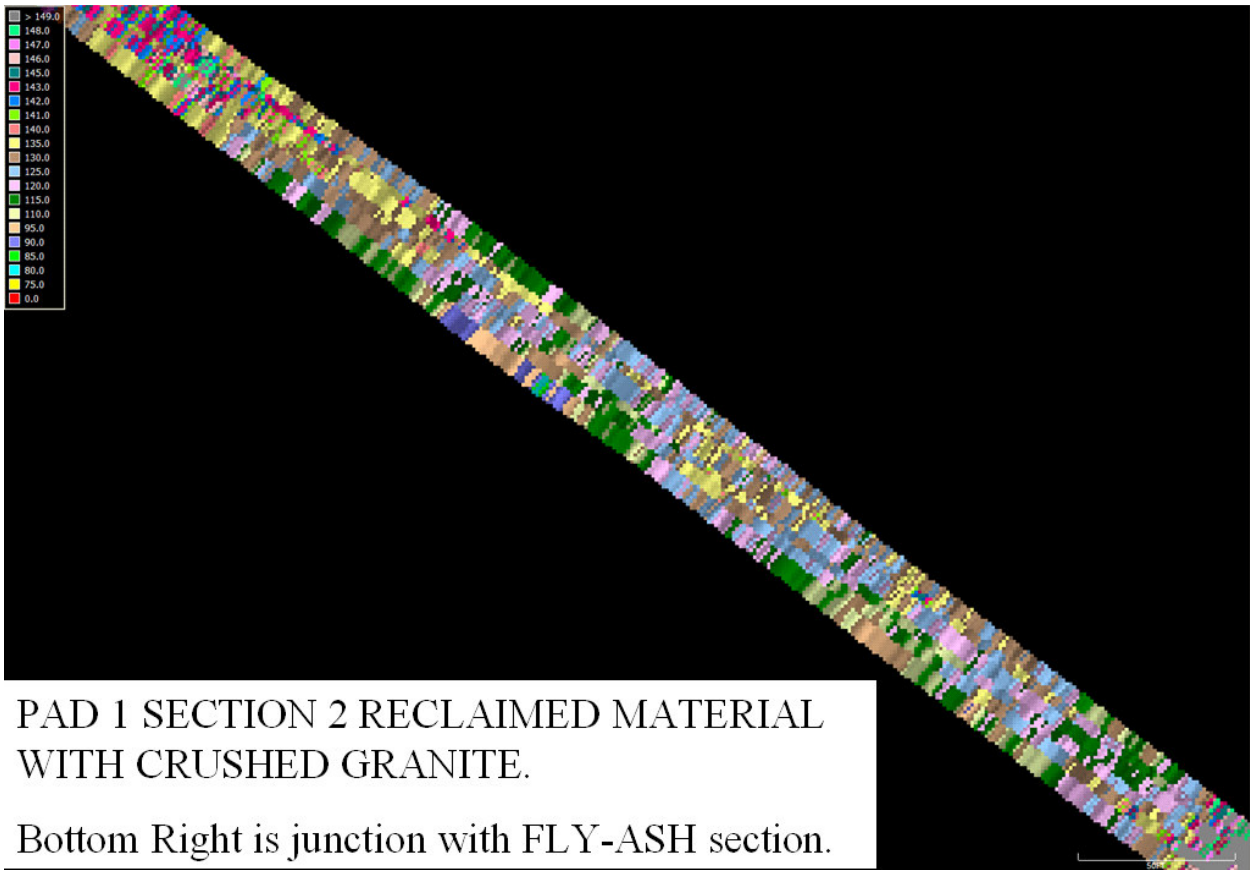


Figure 11. Intelligent Compaction on Aggregate Base, Cell 78

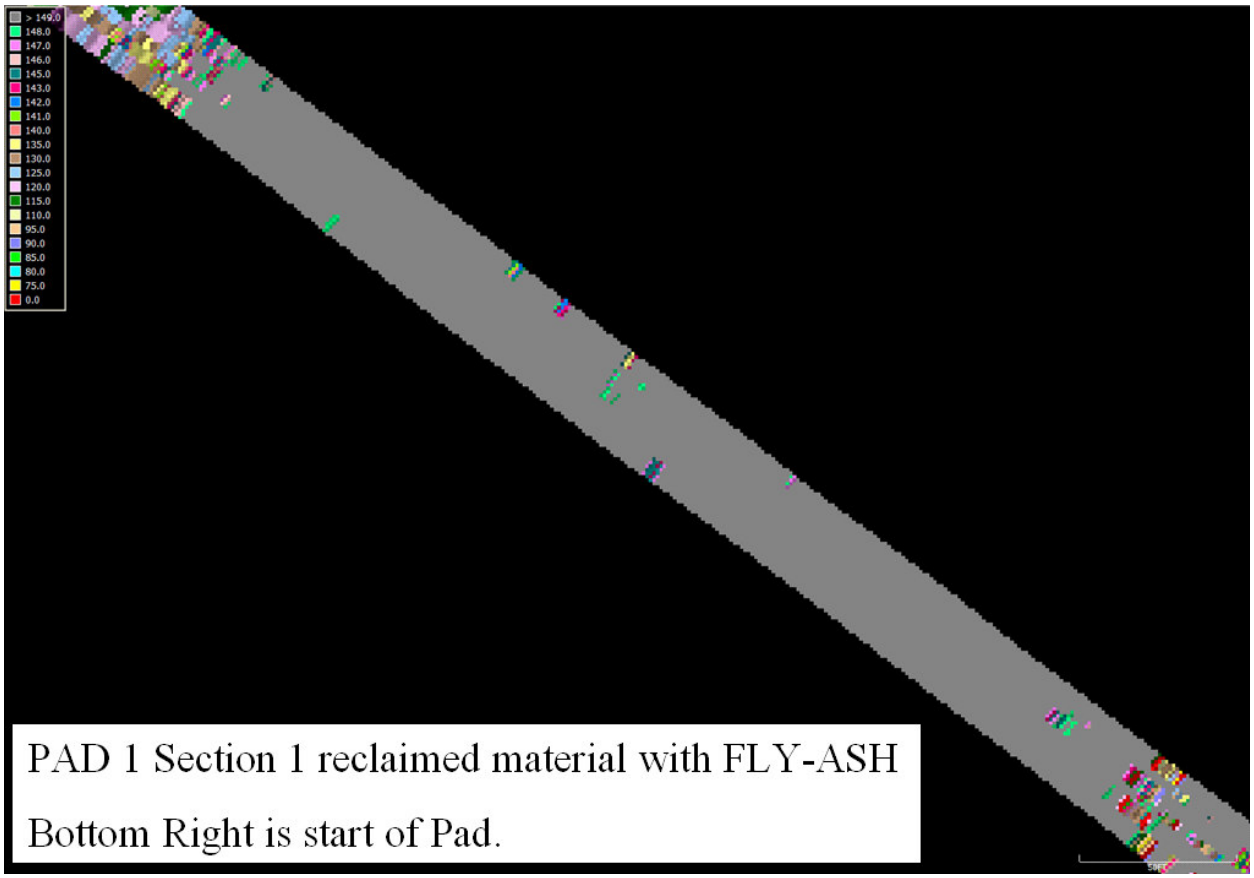


Figure 12. Intelligent Compaction on Aggregate Base, Cell 79

Challenges Faced

The summer/fall of 2007 was marked with extreme weather patterns. At the beginning of the project the weather was bone-dry, which made it rather easy to do the grading work. Then from mid-August to mid-October we set a record for the amount of rainfall in the Twin Cities. Immediately after that it was very dry again. See the two stories from the local newspaper below for documentation.

> *Will it ever stop raining? October has seen particularly gray skies, with rainfall totals averaging more than an inch and a half above the norm. In fact, Thursday evening's showers busted at least one all-time rainfall record for the Twin Cities metro area. The previous precipitation record for August through October, set in 1900, was 18.63 inches. At exactly 8:53 p.m. Thursday that record was beat at the Minneapolis-St. Paul International Airport, where weather watchers tallied an extra .04 inches for the prior hour - topping off a total of 18.66 inches since August. And most meteorologists expect more to come. But there could be a break in the clouds. According to the National Weather Service, the showers should ease by tonight, and Saturday will be relatively sunny. Alas, come Saturday night, the clouds are expected to creep back in, bringing with them a slight chance of rain that will threaten the region through Monday. From Oct. 1 to Oct. 18, 16 days were cloudy or partly cloudy, and enough rain fell on 10 of those days to record at least a fraction of an inch of precipitation, according to data gathered by the Minnesota Climatology Working Group.* [2]

2 Vezner, Tad, "Thursday's rain breaks state record," *Pioneer Press*, October 18, 2007.

> *After a very wet start to the fall, we have dried out over the past few weeks with virtually no rain. More than 6 inches fell in September, double what we average, and 3.55 inches fell in the first half of October. Since Oct. 18, we haven't had more than 0.01 inches on any given day. Today, that adds up to 26 days with dry conditions. The last time we had a stretch with rainfall less than 0.1 inches was a year ago, in November 2006.* [3]

As might be expected, the record rainfall soaked into the exposed aggregate base and subgrade and caused quite soft conditions. When we attempted to pave Cells 77 and 78 on September 11, the HMA trucks sunk into the base and created ruts in excess of 4" in some cases (see Figure 13 below). After several weeks of waiting for the rain to stop for more than a few days in a row in order to dry out the base & subgrade, more drastic measures needed to be taken. Work progressed under a Force Account Work Order per Mn/DOT Specification 1904. Midwest excavated 8" of the reclaimed and Class 6 bases in Cells 77 and 78 respectively. They spent 2 days in mid-October running a chisel plow continuously to dry the subgrade. The weather finally cooperated with sunny skies, moderate winds, and temperatures in the upper 60s. The moisture content in the subgrade dropped from 20% to the target of 15%, and the base was replaced and prepared to pave. MnROAD staff worked quickly to re-install the sensors that were removed for the plowing operation. At the end of the day Mn/DOT spent an extra $20,563.49 on the force account work, but the base and subgrade were better able to handle the construction traffic.

Figure 13. Ruts in Aggregate Base During Paving

One curiosity of the construction contract was that Midwest overran the quantity of HMA by 12.7%. The contract quantity of HMA was 2405 tons throughout all eight cells, and a total of 2711 tons was paved. No matter how many "inspectors" seem to be present during paving at MnROAD, there is still a lot of variability within a cell. There could be several possible reasons for the extra HMA including:

3 Jensen, Belinda, "Quite a Dry Stretch," *Pioneer Press*, November 14, 2007.

1. Inaccurate estimates of unit weight from the start. MnROAD used 110 lbs per square yard per inch as an estimate, while the Mn/DOT Bituminous Office uses 112 or 113 lbs.
2. Increased unit weight of the granite aggregates used over a "typical" aggregate.
3. Increased width of paving. Isolated spot checks after construction showed that the widths were as specified in the plans. However, any deviation from these plans (increased width) would lead to increased HMA quantities.
4. Increased thickness of paving. Isolated ruts in the wheel path caused by the soft, wet base materials would lead to thicker HMA lifts in those areas. Table 4 below shows the thickness of 3 cores taken per cell. These results were used to deduct $2624.48 for excess thickness from the contract per Mn/DOT Specification 2360.7.A. The contractor is allowed ¼" above the lift thickness shown in the plans, which was 2.0" in most cases.

Table 4. HMA Core Thicknesses

MnROAD_ID	Cell	Station	Offset	Total Thickness	Top Lift	Bottom Lift
3307BC004	33	6512	6	5	2.25	2.75
3307BC005	33	6751	-2.2	4.375	2.25	2.125
3307BC006	33	6562	8.9	4.375	2	2.375
3407BC006	34	7203	6	4.875	2.5	2.375
3407BC007	34	7052	-6	4	2.25	1.75
3407BC008	34	7401	-1	4.25	2.125	2.125
3507BC004	35	7723	6	4.5	2.125	2.375
3507BC005	35	7702	4.9	4	2.125	1.875
3507BC006	35	7551	11	4.25	2.25	2
7707BC001	77	18763	-6	5.125	2.875	2.25
7707BC002	77	18781	-12.1	7.25	3	4.25
7707BC003	77	18758	7.1	3.25	2	1.25
7807BC001	78	19185	-6	4	2.25	1.75
7907BC004	79	19554	-2	4.25	2.5	1.75
7907BC005	79	19436	3.6	4.875	2.5	2.375
7907BC006	79	19717	2.3	4.25	2.25	2
8307BC004	83	100176	-6	3.5	1.5	2
8307BC005	83	100134	-6	3.875	1.75	2.125
8307BC006	83	100116	8.7	3.75	1.675	2.075
8307BC007	83	100302	-3.4	4	1.75	2.25
8407BC004	84	100517	-6	5	2.125	2.875
8407BC005	84	100557	10.8	5.875	3.25	2.625
8407BC006	84	100591	-6.5	5.25	2.5	2.75

Construction Field Notes

Table 5 is a summary of Mn/DOT's field notes taken during reconstruction. The notes basically reflect the main activities by the contractors that occurred each day.

Table 5. Field Construction Notes

Date	Notes
July 23	Midwest began reclaiming Cells 29 & 30 (pavement and shoulders). They also began stripping topsoil in the stockpile area for the new Farm Road.
July 24	Midwest began hauling clay from piles in the stockpile area to build up the subgrade for the Farm Road. They also stripped the reclaimings with a backhoe and Cells 29 & 30. The reclaimings were piled up on the shoulders and hauled to the stockpile area for later use.
July 25	Midwest continued hauling reclaimed material to the stockpile, and they hauled clay from the stockpile area back to Cells 29 & 30. They also continued hauling clay from the stockpile for the Farm Road.
July 26	Midwest finished hauling the reclaimed material to the stockpile area. They continued to haul clay from the stockpile for Cells 29 & 30 and the Farm Road.
July 27	Midwest continued subgrade work on the Farm Road, hauling clay from the stockpile.
July 30	Midwest continued subgrade work on the Farm Road, hauling clay from the stockpile.
July 31	Midwest continued subgrade work on the Farm Road, hauling clay from the stockpile.
August 1	Midwest continued grading the clay on the Farm Road. G.L. Contracting, Inc. (subcontractor) installed the 12" reinforced concrete pipe and aprons to drain water underneath the Farm Road. They had to come back out and reinstall the pipe after their first attempt was off by about 9" in elevation.
August 7	Midwest replaced the reclaimed material in Cells 77 & 79.
August 8	Midwest placed Class 6 sp. aggregate base in Cell 78. They graded Cells 77 & 79.
August 9	Midwest placed high carbon fly ash in Cell 79 to stabilize the base. See the operation described in detail above.
August 13	Midwest began placing Class 5 aggregate base on Cells 83 & 84. The material was hauled in by Dennis Fehn Gravel & Excavating, Inc. out of a local pit.
August 17	Midwest finished grading the subgrade on the East end of the Farm Road (Cell 84).
August 24	Midwest removed the HMA from Cells 33, 34, and 35 with a backhoe.
August 27	Midwest placed Class 5 aggregate base on Cell 84.
September 4	Midwest placed Class 6 sp. aggregate surface around the cabinet (instrument pad) on Cell 83. They toleranced the Class 5 on the Farm Road.
September 5	Midwest ran the intelligent compaction roller over the aggregate base on Cells 77, 78, 79, 83, 84, 33, 34, and 35. See the intelligent compaction section above for more information.

September 11	Midwest paved Cells 79 (Elvaloy + PPA) and 35 (SBS only). While trying to pave Cells 77 and 78, the hot mix trucks created significant ruts in the base while backing up. This was primarily due to the record amount of rainfall MnROAD received during late summer and early fall. The Contractor was not allowed to continue paving here until the base problem was rectified.
September 12	Midwest was on site with a vacuum excavator to check the aggregate base thickness on Cells 77 and 78. There was concern that it was thin in some instances, but multiple spot checks at each hub and in between hubs showed only a slight deficiency on the East end of Cell 78. Midwest regraded the cells in an attempt to prepare them for paving.
September 13	Midwest paved Cells 34 (SBS + PPA) and 33 (PPA only) in the morning and went on to pave the first lift of Cells 83 and 84 in the afternoon. There was a heavy downpour and hailstorm in the morning, but they were able to work through it and lay down the HMA without any troubles.
September 22	Midwest cleaned up the shoulders on Cells 33, 34, and 35. They added Class 6 sp. aggregate when necessary. They also pumped water from the ditches along the Farm Road.
September 25	Midwest cut density cores for Lots 1-5, corresponding to Cells 79, 35, 34, 33, 83-84.
October 3	Midwest continued to pump water from the ditches along the Farm Road.
October 10	Midwest paved the top lift on Cells 83 and 84. They graded the slopes inside the Farm Road, on the north side of the cells.
October 11	Midwest cut density cores for Lot 6, the top lift of Cells 83-84.
October 12	Midwest graded the shoulders on Cells 83 and 84, using Class 6 sp. aggregates from the stockpile.
October 15	Work proceeded under a Force Account Work Order to dry out the subgrade and base on Cells 77 and 78. MnROAD staff removed all of the instrumentation possible in the base and subgrade, leaving only 1 thermocouple/moisture gauge tree in each cell. Midwest excavated the Class 6 and reclaimed materials from Cells 77 and 78 and stockpiled them on the North side of the Low Volume Road for later use. The subgrade was exposed.
October 17	Midwest cut weep holes along the shoulders in Cells 77 and 78. They were told several times throughout the project to do so, but did not until this time. This allowed the water on the subgrade to drain out to the ditches.
October 22	Midwest began farming the subgrade on Cells 77 and 78. They used a tractor with a chisel plow to dig up the subgrade to a depth of approximately 1 ft, allowing the air and sunshine to dry out the clay. The moisture content was at approximately 20% when they began, and we were looking for an optimum moisture content of about 15%.
October 23	Midwest continued farming the subgrade on Cells 77 and 78. By 3:00 pm the moisture content of the clay was at approximately 15%, which was the target. The Engineer decided that this was acceptable, and plans were made to put the cells back together.
October 24	Midwest finished compacting and tolerancing the subgrade with a motor grader. They added the base material to Cells 77 and 78 and started tolerancing the East end of Cell 78. They also graded the backslopes on the Farm Road.

October 25	Midwest finished grading the base materials on Cells 77 and 78 in the morning. MnROAD staff worked quickly to replace all of the sensors before paving would commence shortly after noon. The Force Account work was deemed complete. Midwest paved Cells 77 & 78 (Elvaloy + PPA). The HMA trucks created a few minor ruts in the base, but they were much better than the first time and deemed acceptable. Included in this paving was also a small patch in Cell 28 (to fix a failed area) and a 2" overlay on Cell 53 (for a composite pavement study).
October 29	Midwest finished shaping the ditch on the South side of the Farm Road after the Mn/DOT survey crew set grade stakes for them. They added Class 6 sp. aggregate shouldering material on Cells 77, 78, and 79. All of the major items for LVR and Farm Road construction were complete, leaving only turf establishment for a later date.
November 7	R.D.N. Contracting Inc. (subcontractor) seeded and spread hay for turf establishment on the Farm Road. THE PROJECT IS COMPLETE.

Unbound Material Stiffness Testing

Several field stiffness tests were performed at MnROAD during construction using the Lightweight Deflectometer (LWD) and Dynamic Cone Penetrometer (DCP). Each cell contained six or seven test points spaced approximately 50 feet apart in each lane. Cells 33, 34, and 35 were not tested with the DCP or LWD during construction. These portable, lightweight field devices give an indication of the stiffness/strength of the aggregate base and clay subgrade materials during construction. Figures 14-18 show the results of DCP testing on the clay subgrade of each cell immediately before placing the aggregate base. The graphs for Cells 77, 78, and 79 show a spike in the "depth per blow" at approximately 8", which roughly corresponds to the thickness of additional clay borrow material that was added to the existing subgrade. The graphs for Cells 83 and 84 do not show this spike, as approximately 2' of clay borrow was added on top of the existing subgrade.

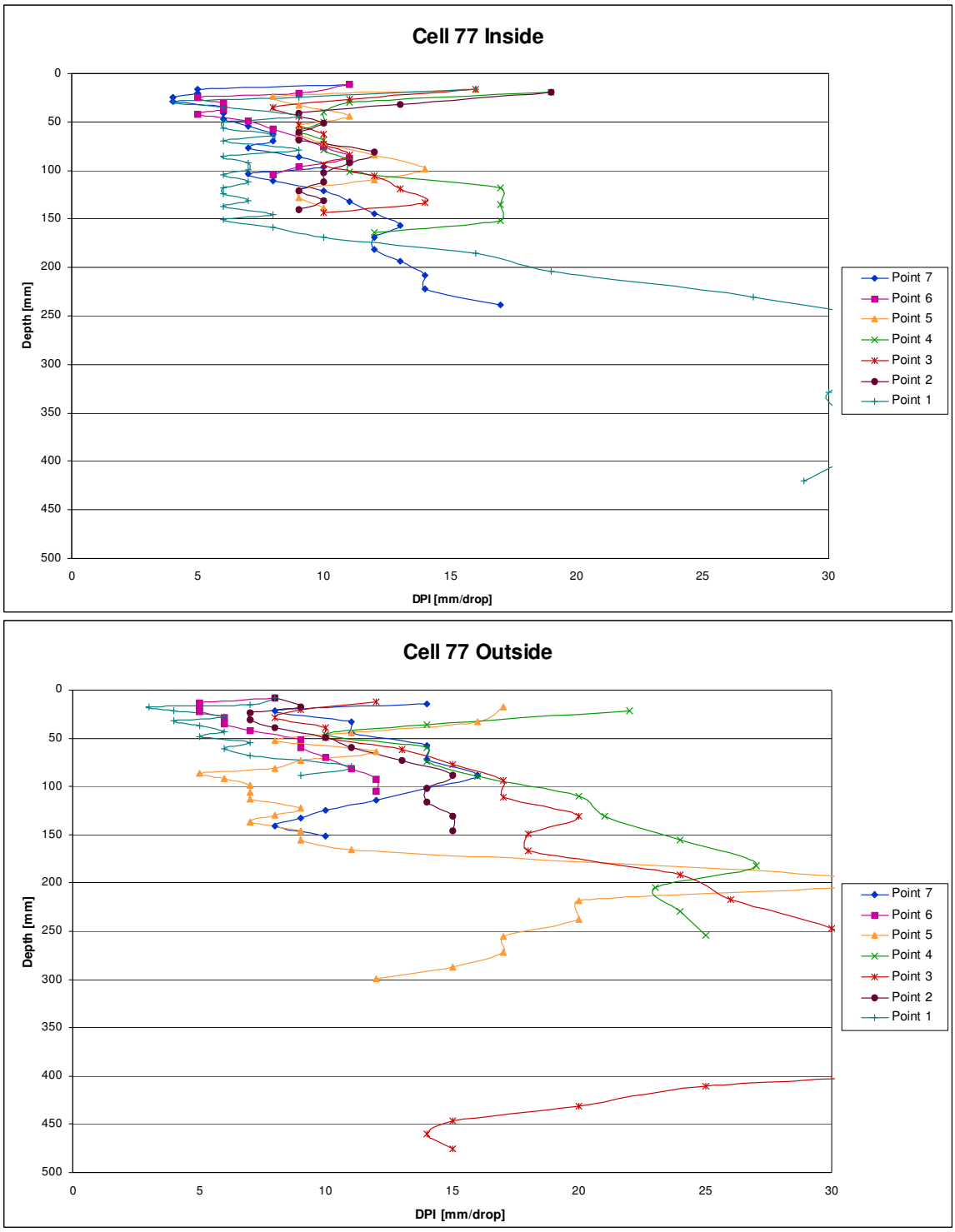


Figure 14. Dynamic Cone Penetrometer Results, Cell 77 Subgrade

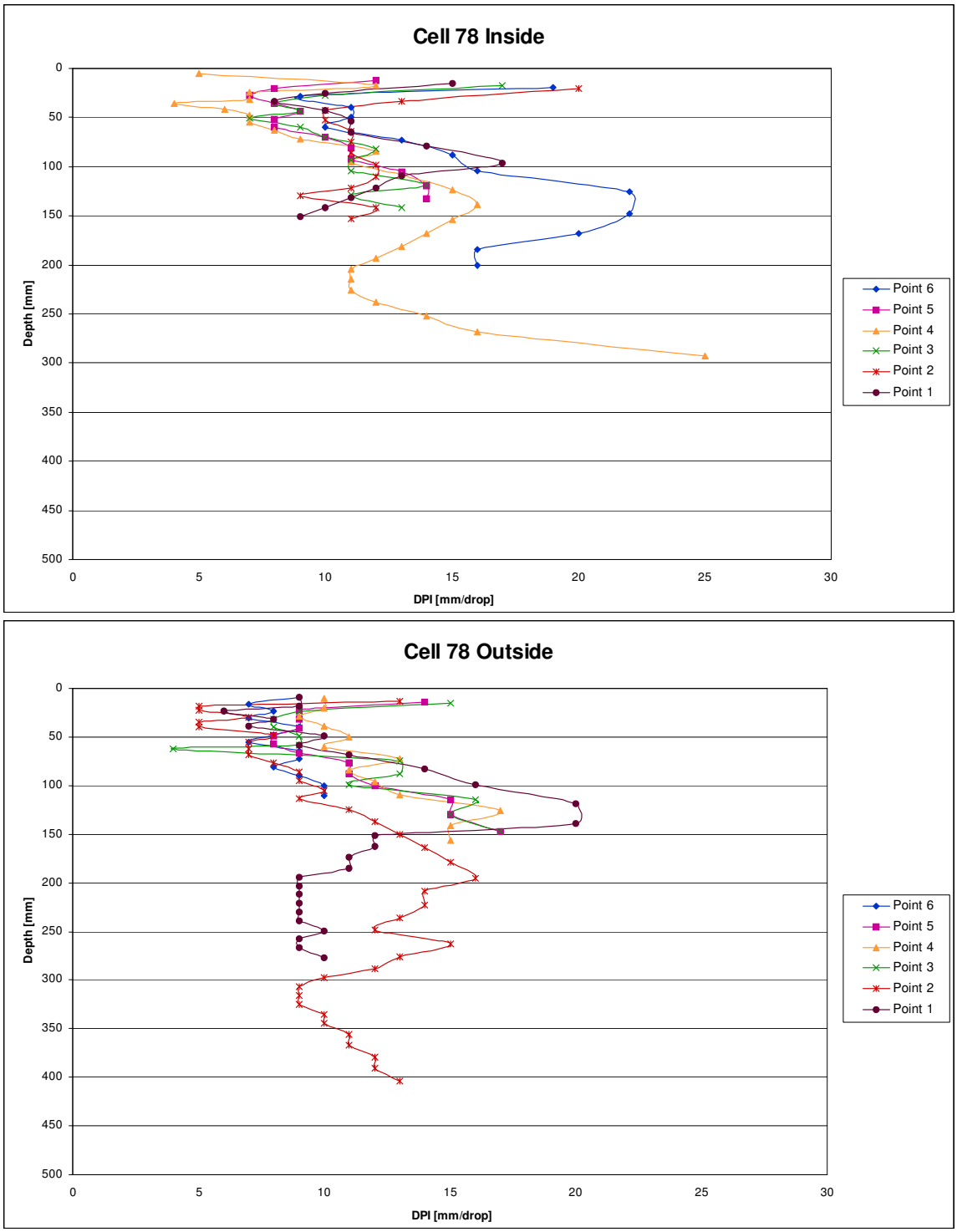


Figure 15. Dynamic Cone Penetrometer Results, Cell 78 Subgrade

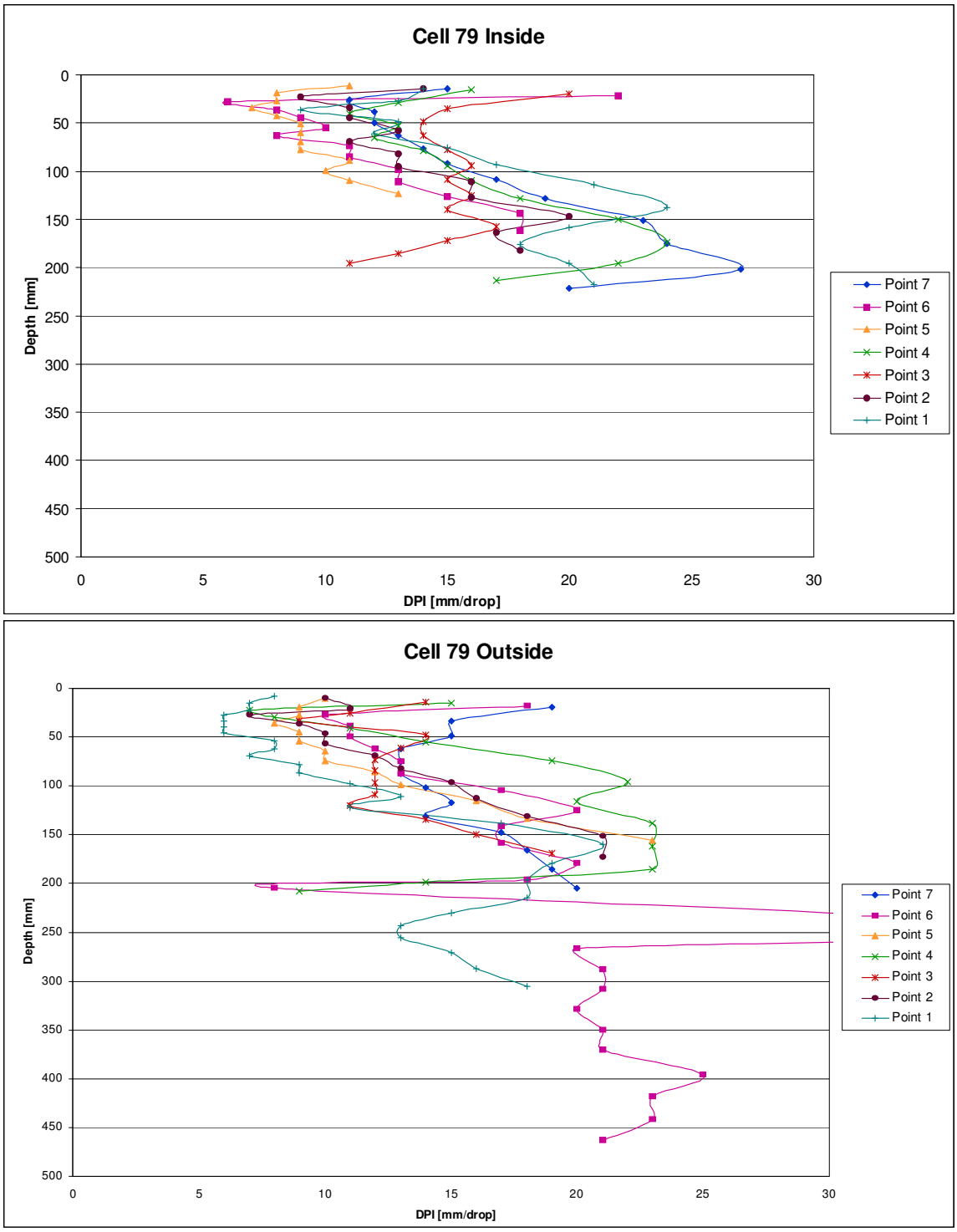


Figure 16. Dynamic Cone Penetrometer Results, Cell 79 Subgrade

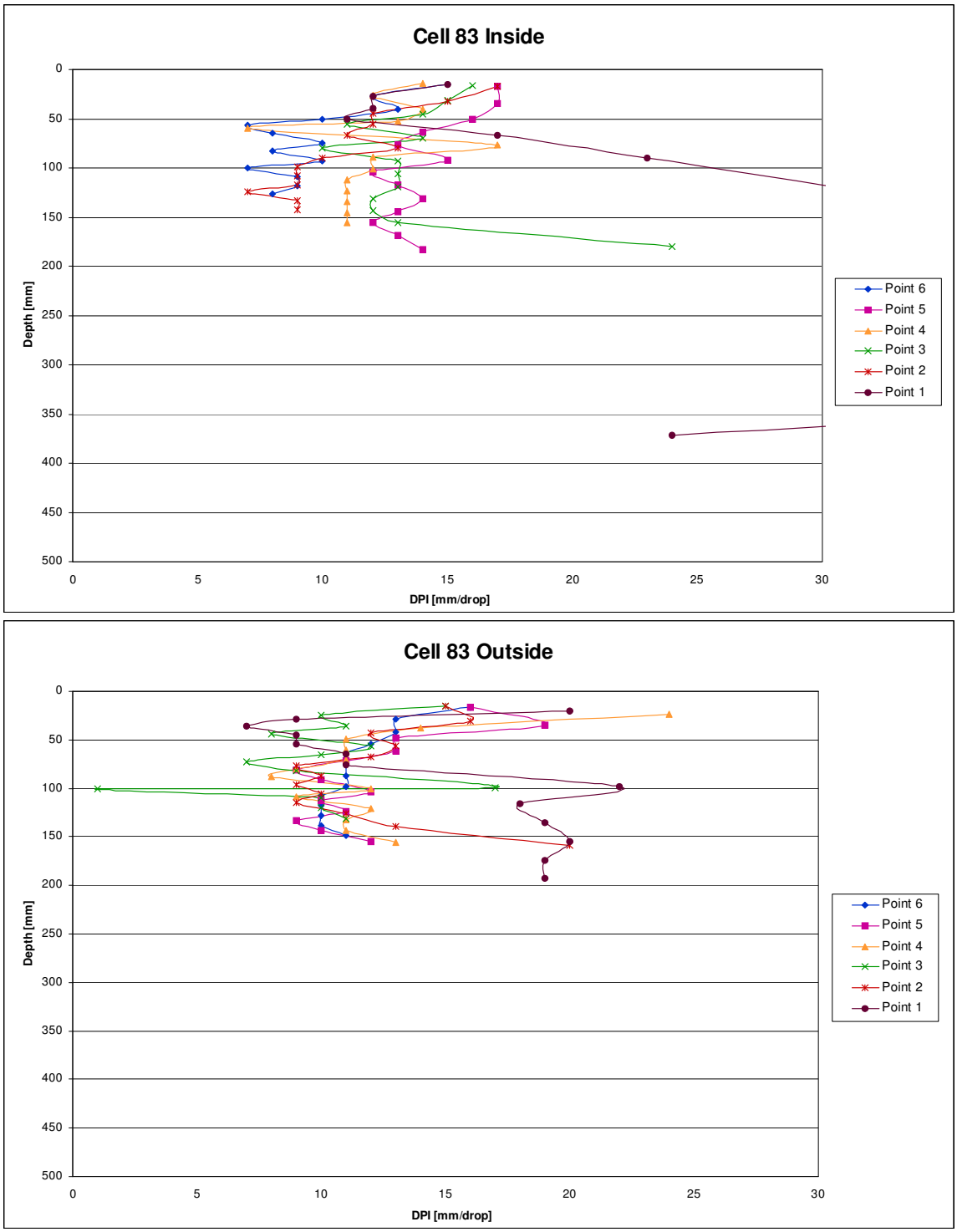
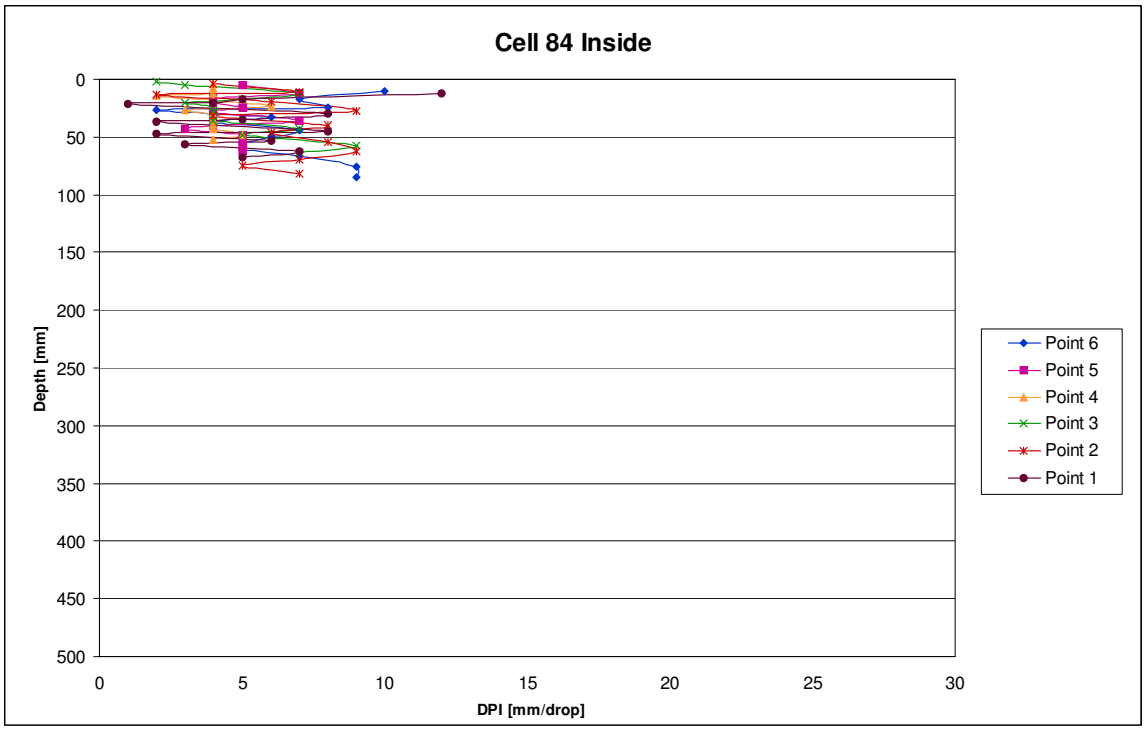


Figure 17. Dynamic Cone Penetrometer Results, Cell 83 Subgrade



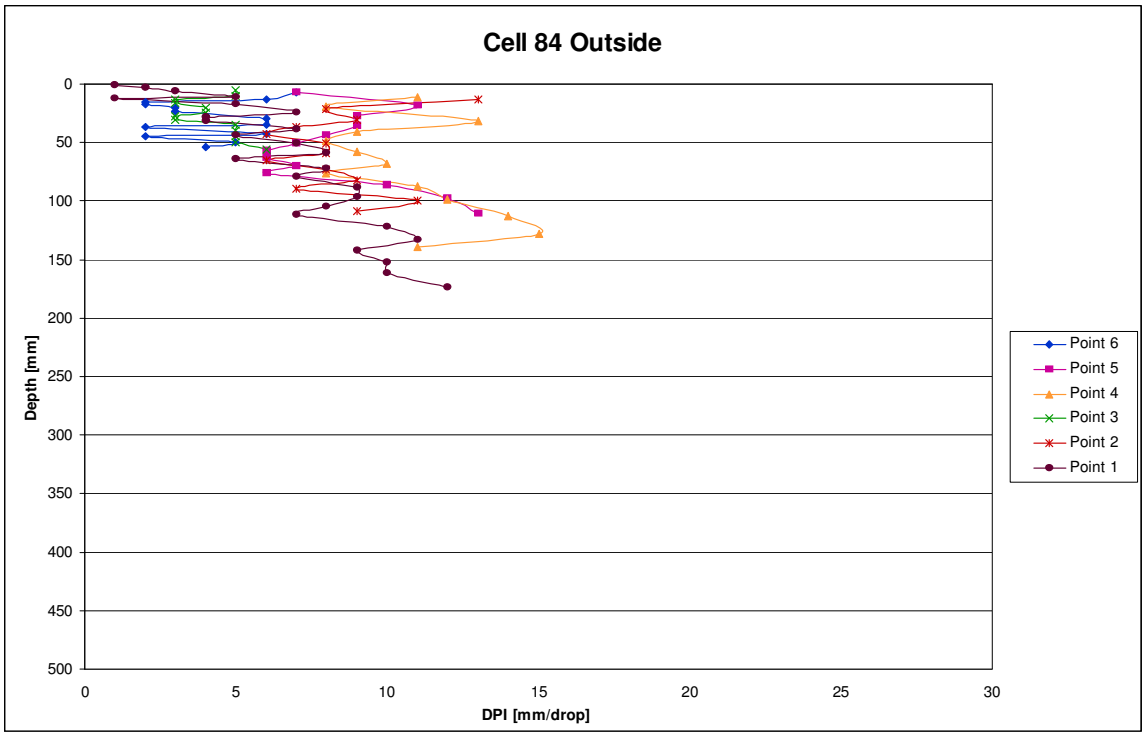
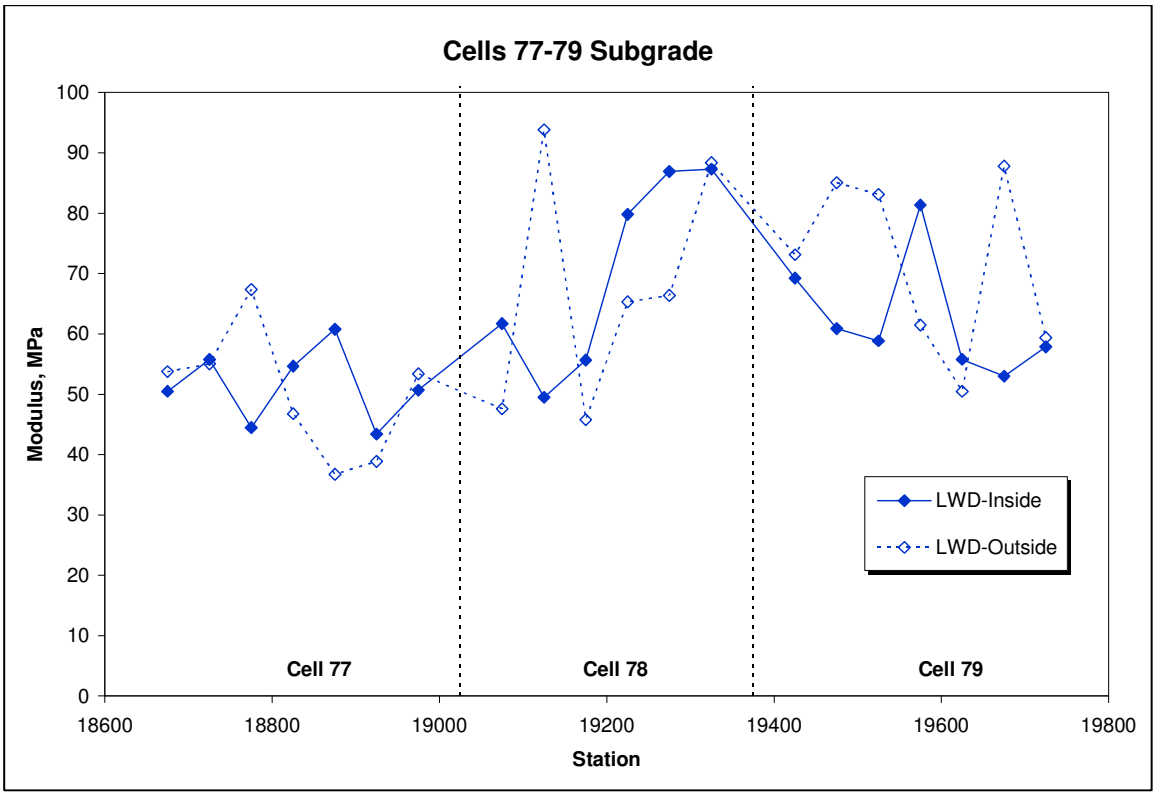


Figure 18. Dynamic Cone Penetrometer Results, Cell 84 Subgrade

Figures 19-21 show LWD stiffness results for each cell by station along the roadway. The subgrade is rather variable within each cell and also between cells. The only notable difference is that the subgrade for Cell 84 is significantly stiffer than in the other cells. Figure 20 shows that the aggregate base in Cell 79 is significantly stiffer than that of Cells 77 or 78, a result of the fly ash stabilization. The aggregate base is quite soft on the East end of Cell 84, which possibly resulted from standing water in the ditches on either side of the roadway in that area. Figure 21 shows the results of multiple LWD tests taken on the same points over a period of time on Cells 77 and 78. In mid-August the aggregate base material in those cells was relatively stiff. Then after significant rainfalls over the summer, LWD tests taken in early October show that the base weakened considerably. Shortly afterward the force account work to dry the subgrade in these cells commenced.



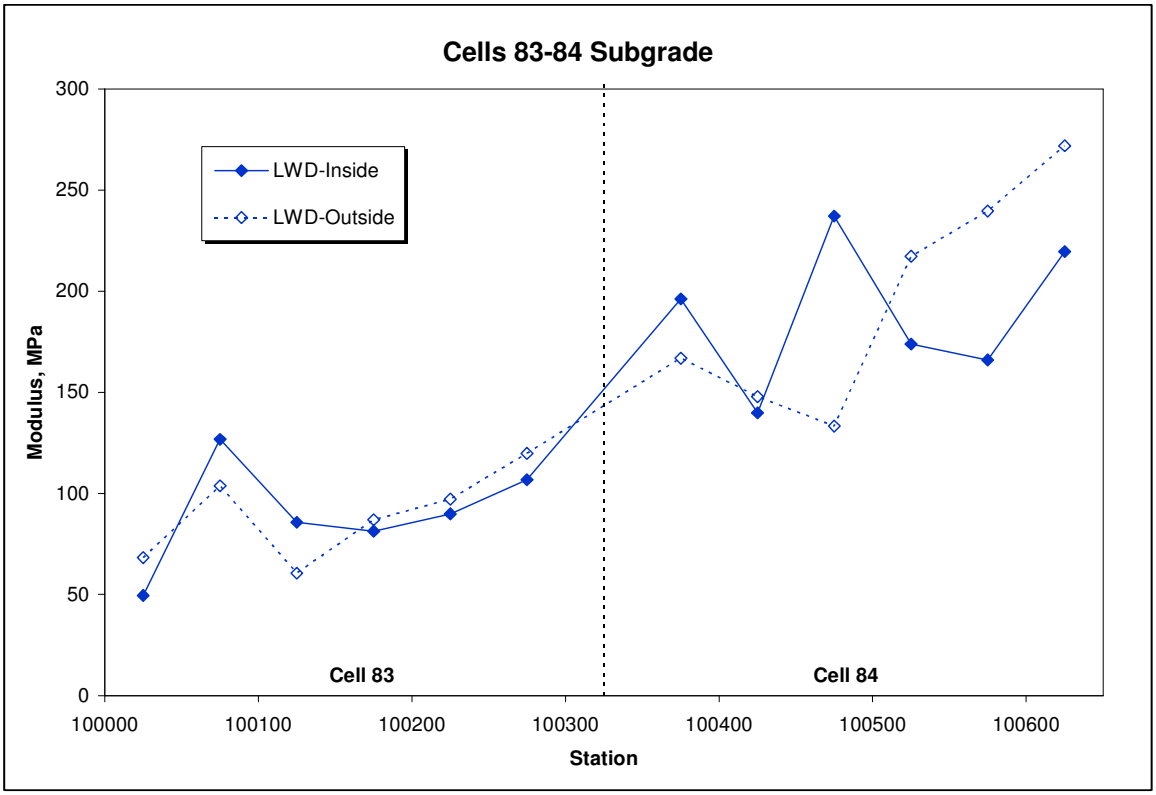
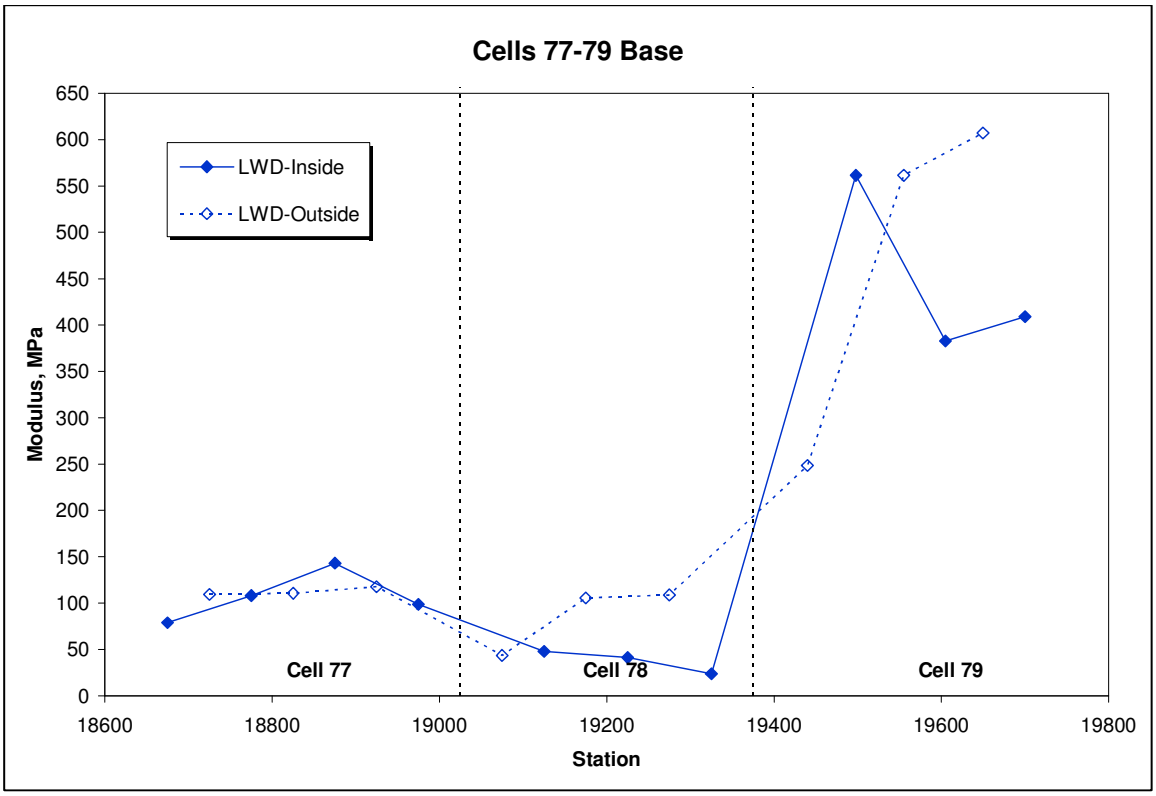


Figure 19. Lightweight Deflectometer Results, Subgrade



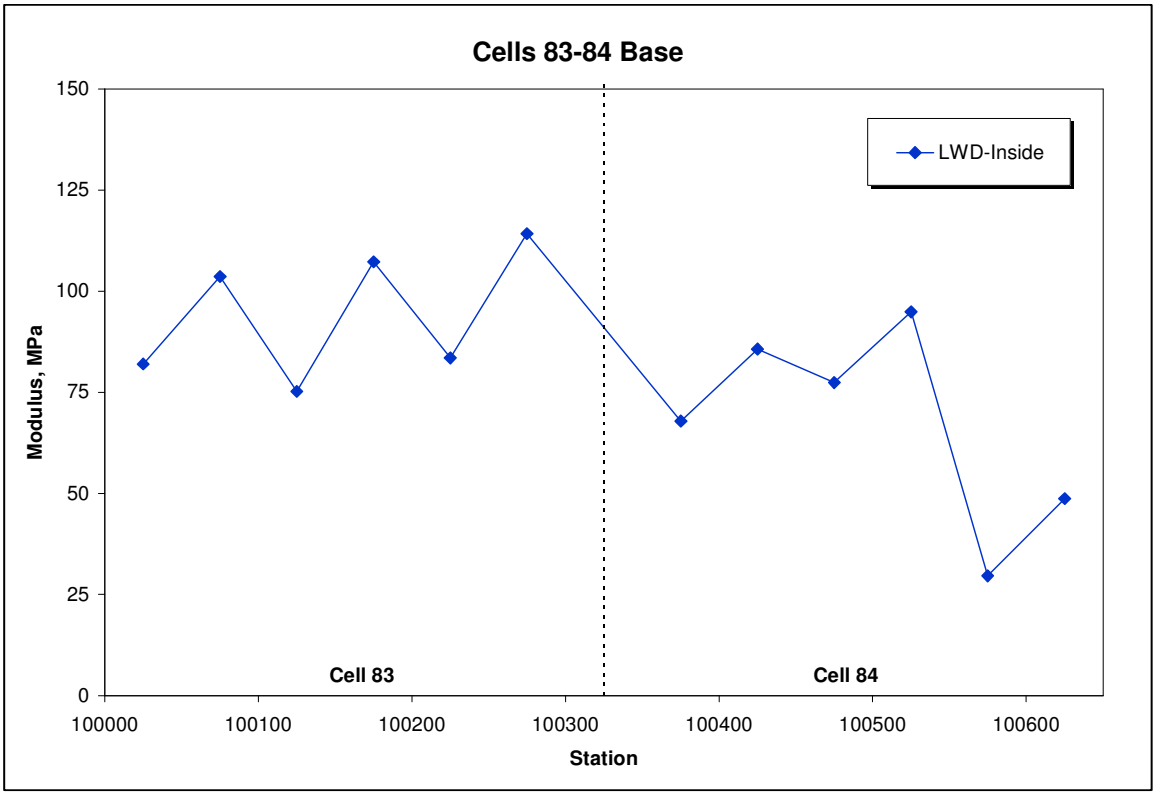
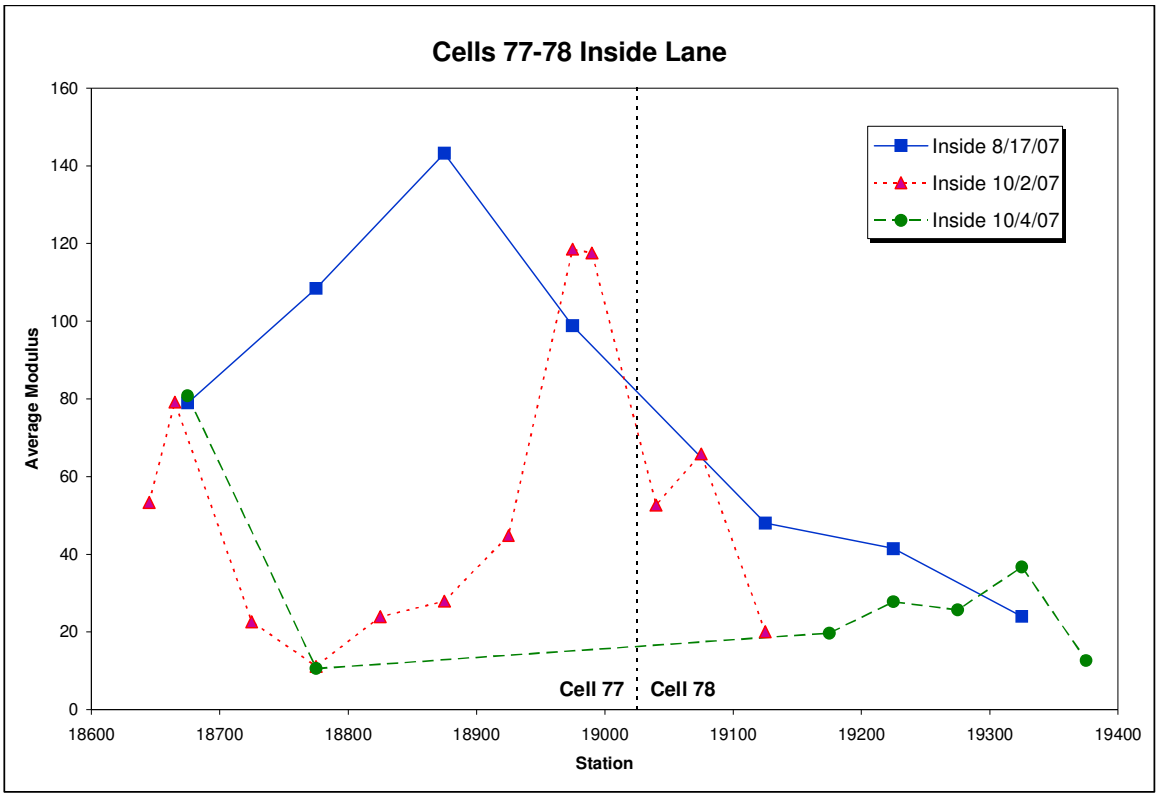


Figure 20. Lightweight Deflectometer Results, Base



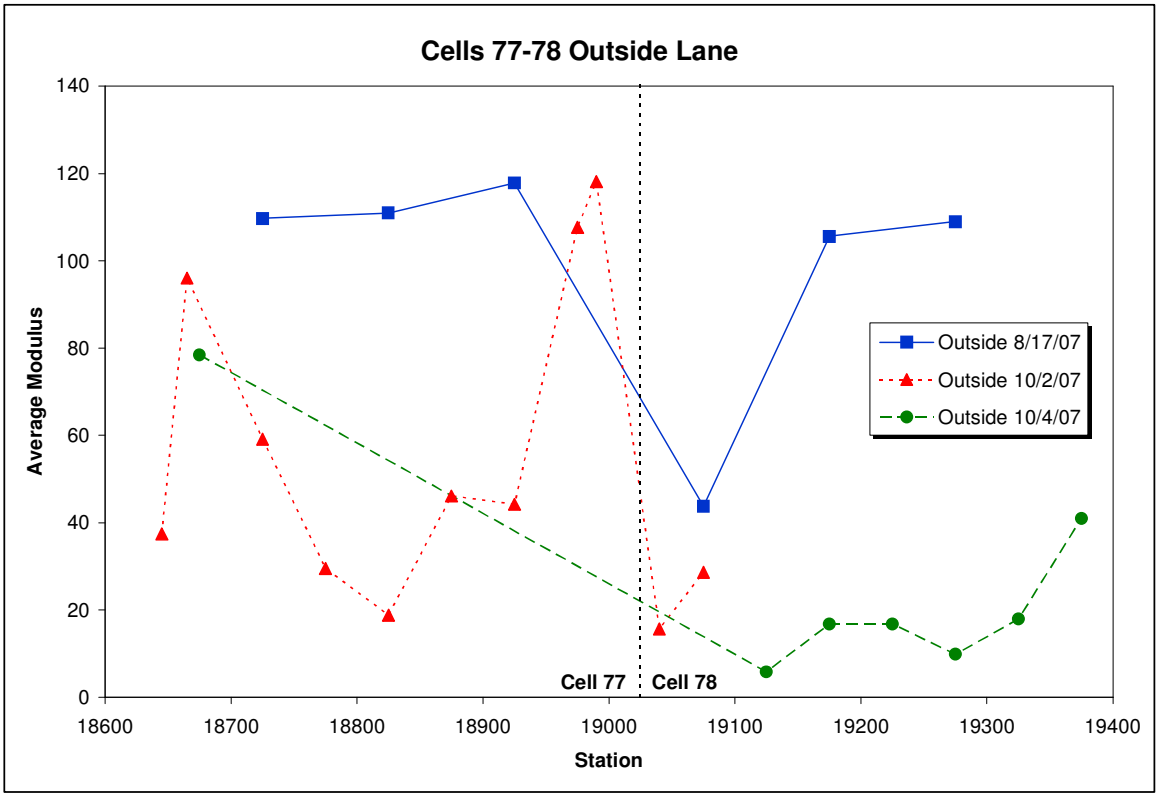


Figure 21. Lightweight Deflectometer Results Over Time

Falling Weight Deflectometer (FWD) testing was also performed throughout the duration of the project. Data was collected on the subgrade (when available), aggregate base, and HMA pavement layers. The FWD data is stored in the MnROAD database for future analysis by the researchers. Table 6 shows forward-calculated stiffness values for Cells 33-35 based on the method described by Stubstad et al[4]. The data was collected October 3, 2007, shortly after HMA paving, and it shows that the three cells are quite similar in their layer stiffness values.

Table 6. Falling Weight Deflectometer Results, Cells 33-35

		Average Stiffness, MPa	Coefficient of Variation
Cell 33	**Subgrade**	56.4	15.1%
	Base	147.9	15.1%
	HMA	1331.3	13.7%
Cell 34	**Subgrade**	52.3	11.2%
	Base	137.4	11.2%
	HMA	1250.8	17.7%
Cell 35	**Subgrade**	58.5	15.2%
	Base	153.6	15.2%
	HMA	1380.3	12.2%

Construction Samples Taken

The following samples listed in Table 7 were collected during construction. Tables 8-12 show the testing results from each of these materials.

4 Stubstad, R., Jiang., Y. J., and E. Lukanen, "Forwardcalculation of Pavement Moduli with Load-Deflection Data," *Transportation Research Record 2005*, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 104-111.

Table 7. Material Samples Taken During Construction

Sample Material	Sample No. & Type	Group	Test Type
Clay Borrow	(15) 5 gallon buckets	Mn/DOT, Bloom, U-WI	Research
Class 3 Sp. Aggregate	(1) 30 lb bag	Mn/DOT	Gradation
Class 6 Sp. Aggregate	(1) 30 lb bag	Mn/DOT	Gradation
	(15) 5 gallon buckets	Bloom, U-WI	Research
Class 5 Aggregate	(1) 30 lb bag	Mn/DOT	Gradation
Reclaimed Base	(2) 30 lb bags	Mn/DOT	Gradation
	(30) 5 gallon buckets	U-WI	Research
Fly Ash	(7) 5 gallon buckets	Mn/DOT, Bloom, U-WI	Research
HMA Aggregates (5 sources)	(10) 30 gallon drums	MTE	Moisture Susceptibility
	(12) 5 gallon buckets	Paragon	Research
	Stockpile	Mn/DOT	Research
Hydrated Lime	(3) 5 gallon buckets	Paragon, MTE, Mn/DOT	Research
HMA Cores	(21) 4" cores	Mn/DOT	QC/QA Testing
	(23) 6" cores	Mn/DOT, MTE	Thickness, Research
HMA Mix	(8) plastic cylinders	Mn/DOT	QC/QA Testing
	(125) 2.5 gallon buckets (41) 5 gallon buckets (30) cardboard boxes	Mn/DOT, MTE, Bloom, Innophos, WRI	Research

Table 8. Aggregate Base Gradations

Sieve Size		Reclaimed	Class 6	Reclaimed	Class 5	Class 3
mm	**U.S.**	**Cell 77**	**Cell 78**	**Cell 79**	**Cell 83**	**Farm Rd**
50	2"	100		100		
37.5	1 1/2"	98.4*		97.1*		
31.5	1 1/4"	97.1	100	97.1	100	100
25	1"	93.0	100	92.6	99.6	99.3
19	3/4"	87.1	97.3	86.4	96.7	97.5
16	5/8"	83.6	93.0	81.4	93.0	96.6
12.5	1/2"	77.6	83.8	76.0	88.8	95.6
9.5	3/8"	68.6	72.4	69.4	83.8	93.9
4.75	#4	49.2	49.6	52.9	71.2	84.7
2.36	#8	31.9	34.2	38.0	58.6	75.5
2.00	#10	28.4	31.5	35.1	55.5	72.9
1.18	#16	19.8	24.1	26.1	46.5	63.1
0.600	#30	11.3	17.4	16.0	32.0	42.5
0.425	#40	7.9	14.6	11.8	22.3	31.3
0.300	#50	5.5	12.4	9.1	14.4	23.5
0.150	#100	3.2	8.9	5.8	7.0	13.3
0.075	#200	2.5	6.1	4.5	5.0	8.8
% AC		4.58	-	4.10	-	0.56
% Crushed		-	-	-	18.8	-

* Value does not meet Specification

Table 9. HMA Aggregate Gradations (Contractor Results)

Sieve Size							Bottom	Top
mm	U.S.	Cell 33	Cell 34	Cell 35	Cell 77	Cell 79	Cell 83	Cell 83
19	3/4"	100	100	100	100	100	100	100
12.5	1/2"	93	91	92	89	92	95	94
9.5	3/8"	83	82	83	81	87	80	84
4.75	#4	62	62	63	68	65	64	67
2.36	#8	49	49	50	46	52	49	51
1.18	#16	35	35	35	33	37	38	40
0.600	#30	23	23	23	22	24	27	28
0.300	#50	13	13	13	13	14	14	15
0.150	#100	6	6	7	7	7	7	7
0.075	#200	3.9	3.9	4.1	4	4	3.6	3.9

* Value beyond warning limit

Table 10. Fly Ash Lab Test Results

Physical Test Results	Test Result	Spec Requirements
Reported SPG	2.72	2.67 +/- 0.12
% Retained on #325	28.5	Max 30%
Autocl Expan	0.06	Max 0.80
Strength Activity 7 Day	80	75% of Control

Chemical Analysis %	Test Result	Spec Requirements
Silicon Dioxide	19.86	
Aluminum Oxide	12.96	
Iron Oxide	6.16	
Sum of 3	38.98*	Min 50%
Calcium Oxide	26.98	Max 40%
Magnesium Oxide	5.44	
Sulfer Trioxide	7.59*	Max 5.0%
Sodium Oxide	1.65	
Potassium Oxide	0.37	
Available Alkali	1.89	Max 3.0%
Loss on Ignition	15.15*	Max 3.0%

* Value does not meet Specification

Table 11. HMA Field Testing Data (Contractor Results)

	Test	Cell 33	Cell 34	Cell 35	Cell 77	Cell 79	Bottom Cell 83	Top Cell 83
Loose Mix	Ig Oven AC%	5.4	5.5	5.4	5.2	5.3	5.5	5.5
	%FAA	46	46		46	45	42	42
	% Coarse Agg Ang	100/-	100/-	100/-	100/-	100/-	90/-	86/-
	Gmm	2.478	2.474	2.471	2.484	2.478	2.476	2.494
	Gmb @ N-design	2.378	2.389	2.379	2.403	2.355	2.411	2.405
	%Air Voids @ N-design	4.0	3.4	3.7	3.3	5.0	2.6	3.6
	VMA	16.4	16.2	16.5	15.6	17.2	14.5	14.8
	VFA	75.4	78.8	77.4	78.8	71.1	81.9	75.9
Field Cores	% Max Density	94.2	93.5	93.6	92.2	92.1	93.9	94.2
	% Air Voids	5.8	6.5	6.4	7.8	7.9	6.1	5.8
	Bonus	4%	0%	4%	0%	0%	0%	4%

Table 12. Fly Ash Stabilized Base Lab Test Results

Test Point	Station	Offset	Unconfined Compressive Strength, kPa		Elastic Modulus, MPa		CBR Ratio, %		Resilient Modulus, MPa	
			7 Day	28 Day	7 Day	28 Day	7 Day	28 Day	7 Day	28 Day
1	19440	-6	333		54		76	70	204	
2	19498	-6		612		61	76	96		215
3	19555	-6	382		79		39	171	222	
4	19605	-6		353		31	82	64		109
5	19650	-6	334		58		50	89	241	
6	19700	-6		330		72	50	124		204

CONSTRUCTION SUMMARY

Initial field reviews of the pavement sections show that all the cells are smooth with no cracks and negligible rutting. Tables 13-15 show initial ride quality, rutting, and friction measurements. Since Cells 83 and 84 are in the MnROAD Stockpile Area and they are loaded only twice each year, the performance

data for those cells is collected on a different schedule than the other LVR cells.

Table 13. MnROAD Post-Construction Ride Quality Data

Cell	Lane	IRI, m/km	RQI	SR
33	80K	1.31	3.2	4.0
	102K	1.14	3.4	4.0
34	80K	1.40	3.2	4.0
	102K	1.22	3.3	4.0
35	80K	1.56	3.0	4.0
	102K	1.09	3.5	4.0
77	80K	1.55	3.0	4.0
	102K	1.47	3.1	4.0
78	80K	1.36	3.2	4.0
	102K	1.34	3.2	4.0
79	80K	2.05	2.6	4.0
	102K	1.88	2.8	4.0

Table 14. MnROAD Post-Construction Rutting Data (inches)

Cell	Lane	Max	Min	Average
33	80k	0.05	0	0.02
	102k	0.09	0	0.03
34	80k	0.07	0	0.02
	102k	0.07	0	0.02
35	80k	0.07	0	0.03
	102k	0.13	0	0.03
77	80k	0.10	0	0.04
	102k	0.21	0.003	0.08
78	80k	0.10	0	0.03
	102k	0.12	0.001	0.04
79	80k	0.06	0	0.02
	102k	0.08	0	0.04
83	WB	0.14	0.005	0.06
	EB	0.09	0	0.04
84	WB	0.14	0.001	0.04
	EB	0.10	0	0.04

Table 15. MnROAD Post-Construction Friction Data (Ribbed Tire)

Cell	Lane	Friction Number	Speed mph	Air Temp, °C	Pavement Temp, °C
33	80K	70.4	39.1	37	51.6
34	80K	68.8	40.4	37	51.1
35	80K	69.8	40.2	37	51.1
77	80K	54.1	40.6	38	51.6
78	80K	51.6	40.8	37	50.8
79	80K	64.5	40.3	37	50.1

MnROAD staff and their research partners will carry out the research on each of these cells over the next several years. The MnROAD Operations staff will conduct regular pavement performance monitoring. Table 16 shows the type of monitoring activities scheduled and the frequency of measurements.

Table 16. MnROAD Performance Monitoring Schedule

MnROAD Monitoring Activity	Collection Frequency	Comment
Manual Distress Survey	2 / year	Modified LTPP Survey (April, October).
ALPS Rutting Measurements	3 / year	Advanced Laser Profile System collected every (50'). Collects profiles using a 12.5' beam for measuring ruts.
Pathways Longitudinal Profile	3 / year	Pavement Management office collects ride data summaries and ERD files. Digital images are evaluated for distress calculations to determine a Surface Rating and Pavement Quality Index once per year.
Friction Pavements Office	2 / year	Summer runs to determine skid on smooth & ribbed tires.
Falling Weight Deflectometer	Varies per Cell	Test frequency varies throughout the year, but FWD data is typically collected 6 times per year, including during Spring Thaw. Time histories are collected but the data is stored offline.
LISA - Lightweight Profiler	TBD	Light Weight Profiler (golf cart) used to collect ride (IRI and ERD) files at a high frequency during the year.
Surface Texture – Sand Patch	TBD	Two locations per cell per lane unless part of a surface characteristics study which will increase the number of points.
Surface Texture – Texture Meter	TBD	One location per cell per lane unless part of a surface characteristics study which will increase the number of points.
Tire/Pavement Noise – OBSI	TBD	On Board Sound Intensity (OBSI) measurements will be conducted with a Mn/DOT owned system.
Ground Penetrating Radar	As needed	Various air-coupled and ground-coupled antennas available to collect data such as pavement layer thickness.

The entire construction process from plan preparation through final completion was a learning experience for everyone involved. Challenges included developing the proper bid items and special provisions as well as dealing with inevitable weather and other delays. Accomplishments included installing the instrumentation and coordination between the researchers and the Contractor. Overall this was a successful construction project.

This report presents a summary of the research and construction activities undertaken at MnROAD in 2007. Several important lessons were learned including:

- Partnerships between Mn/DOT and other entities ultimately made all of this work possible. MnROAD would not have been able to develop the research projects or fund the test section construction without significant contributions from our partners.
- Oversight by Mn/DOT of the Contractor's construction activities is not to be taken lightly. Weather played a large role in some of the difficulties encountered during construction, but some of the problems could have been avoided with more attention to detail by the inspectors.
- Overall the construction experiences with each of the pavement materials were positive. The PPA modified binders behaved similar to "typical" HMA mixtures during laydown and compaction operations. The fly ash stabilization provided adequate stiffness in the base material and made it possible to pave on when the non-stabilized base materials were considerably softer.
- The falling-weight deflectometer and other devices can be used to gather important field performance data of pavement test sections.
- In-ground instrumentation is an essential tool in determining a pavement's response to environmental and traffic loading.

APPENDIX A

MNROAD TEST SECTION LAYOUTS

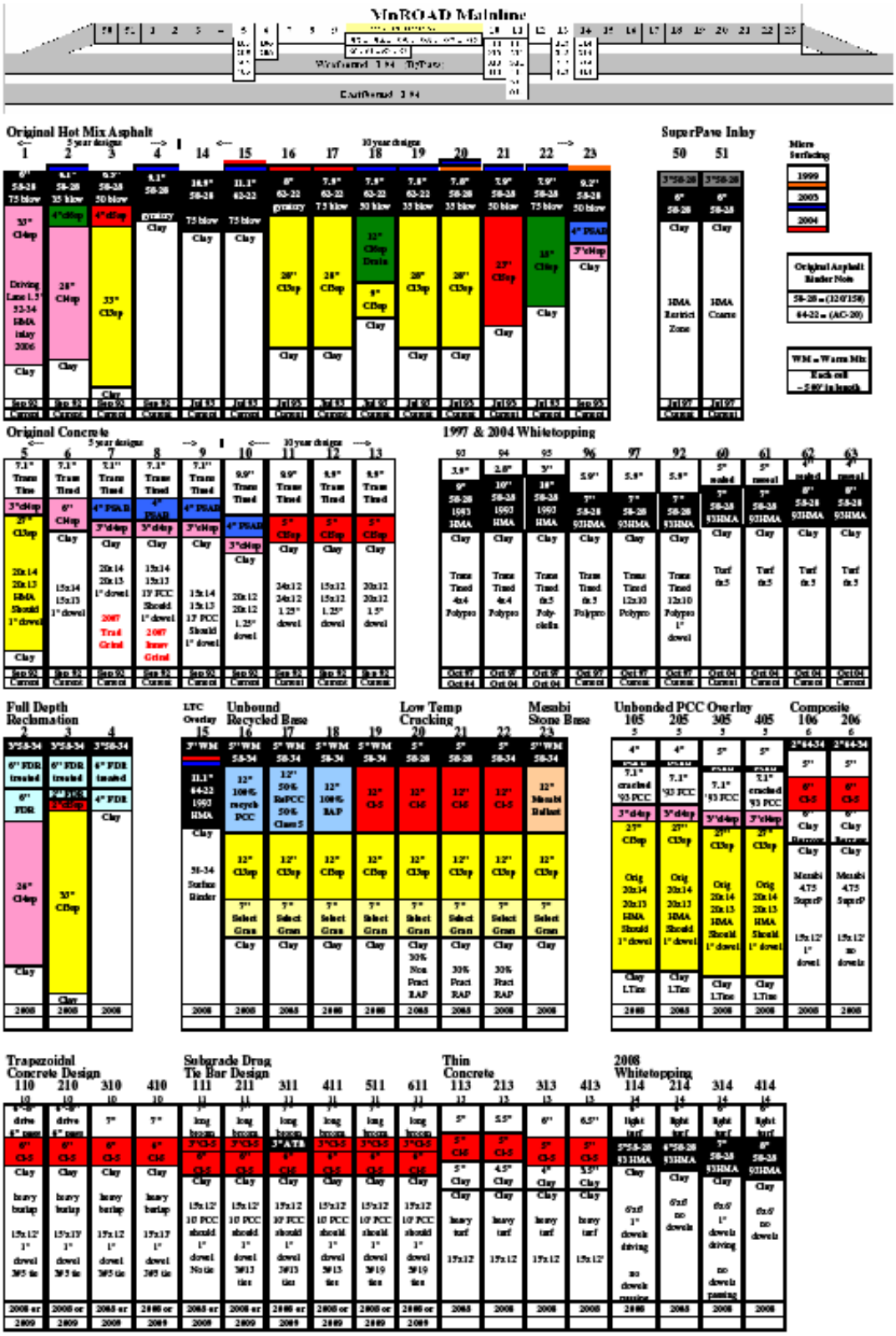


Figure A-1. MnROAD Test Cell Layout (Mainline)

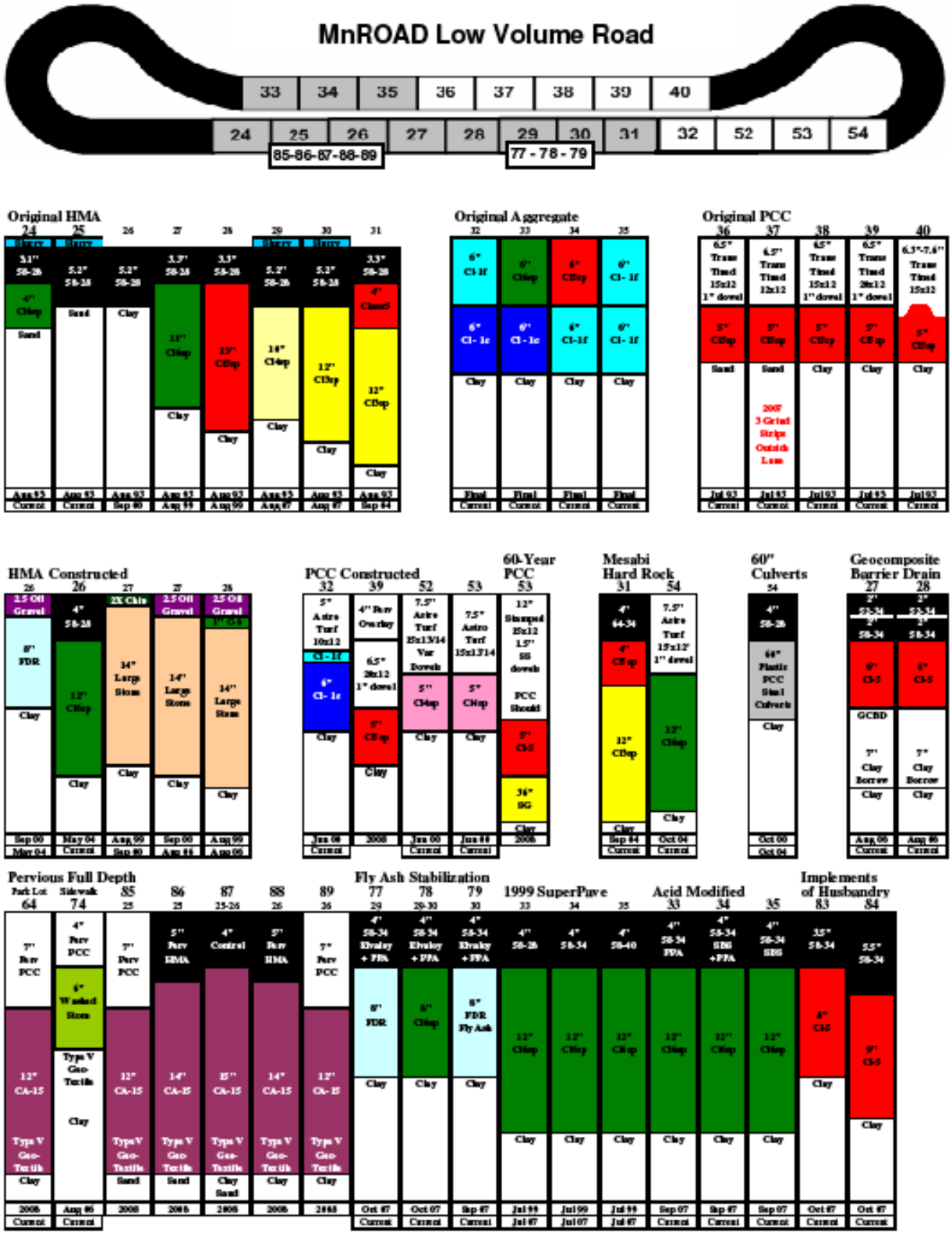


Figure A-2. MnROAD Test Cell Layout (Low Volume Road)