Minnesota Department of Transportation

RESEARCH SERVICES

Office of Policy Analysis, Research & Innovation

Construction Report for MnROAD Thin Unbonded Concrete Overlay Test Cell 5 (Sub-Cells 105-405)

Mark Watson, Primary Author
Minnesota Department of Transportation

MnROAD
Office of Materials

June 2010

Research Project
Final Report #2010-30

Your Destination...Our Priority

CONSTRUCTION REPORT FOR MnROAD THIN UNBONDED CONCRETE OVERLAY TEST CELL 5 (Sub-Cells 105 - 405)

Final Report

Prepared by

Mark J. Watson, MS

Thomas R. Burnham, PE

Minnesota Department of Transportation
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109-2043

June 2010

Published by

Minnesota Department of Transportation
Office of Policy Analysis, Research and Innovation
Research Services
395 John Ireland Boulevard, MS 330
St. Paul, MN 55155

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Minnesota Department of Transportation at the time of publication. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
MN/RC – 2010-30		

4. Title and Subtitle	5. Report Date
CONSTRUCTION REPORT FOR MNROAD THIN UNBONDED OVERLAY TEST CELL 5 (SUB-CELLS 105 - 405)	June 2010
	6.

7. Author(s)	8. Performing Organization Report No.
Mark J. Watson, Thomas R. Burnham	T9RC0500

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Minnesota Department of Transportation Office of Materials and Road Research 1400 Gervais Avenue Maplewood, MN 55109	11. Contract © or (G)rant No. LAB016

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul,, MN 55155	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

http://www.lrrb.org/pdf/201030.pdf

16. Abstract (Limit: 200 words)

In the summer of 2008, after roughly fourteen years of service many of the pavement test cells at the Minnesota Road Research project (MnROAD) required rehabilitation or reconstruction. This massive construction effort was also known as "Phase II" (SP 8680-157). Among the cells that were rehabilitated was Cell 5, which is located on the mainline or interstate 94 section of the research facility. Cell 5 received a thin (4 to 5") unbonded concrete overlay. This cell was heavily instrumented with electronic sensors designed to collect environmental and load response data. In addition the pavement in this cell will be thoroughly evaluated and rigorously tested at various times during the year. The thin design, and consequently shorter life, of this overlay should produce valuable data over the life of the sensors. This report describes the physical characteristics of the new thin unbonded concrete overlay test cell 5 (sub-cells 105-405). Included in the report are the construction plans (including sensor layouts), quantities and bid prices, as well as the special provisions. The report also summarizes the results from the initial material tests, various surface characteristics measurements and other initial test results.

17. Documentation Analysis/Descriptors	18. Availability Statement
Concrete Pavements, Thin Unbonded Concrete Overlay, interlayer, MnROAD project, Pavement Instrumentation	No restrictions. Document available from: National Technical Information Services, Springfield, VA 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. Of Pages	22. Price
Unclassified	Unclassified	62	

ACKNOWLEDGMENTS

The authors would like to thank the many Minnesota Department of Transportation employees, whose activities and contributions were instrumental to the successful construction and material testing of the new MnROAD test cell 5 (sub-cells 105-405).

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION **1**

Minnesota Road Research Project (MnROAD) 1
Objectives of Report and Research 1
State of the Practice 2
Construction Contract 2

CHAPTER 2. INSTRUMENTATION AND DATA COLLECTION **4**

Introduction 4
Data Collection System Layout 5

CHAPTER 3. CONSTRUCTION AND MATERIALS **10**

Existing Conditions (Prior to Overlay Placement) 10
Test Cell Description & Design, Cell 5 (sub-cells 105-405) 11
Mix Designs 12
Construction Sequence 14
Material Sampling and Testing 16
Concrete Material Testing During Paving (Mn/DOT Quality Assurance) 16
Laboratory Testing Results 16
Rapid Chloride Ion Permeability 16
Compressive Strength and Flexural Strength 16

CHAPTER 4. INITIAL TESTING **18**

Early Age Testing 18
FWD Testing 18
Pavement Surface Characteristics 23
Texture Measurements 23
Sound Measurements 24
Ride Measurements 25

CHAPTER 5. CONCLUSIONS **27**

REFERENCES **28**

Appendix A: Project Specific Selected Special Provisions

Appendix B: Sensor Locations

Appendix C: Documentation of Distressed Joints Prior to PCC OL

List of Figures

Figure 1.1. Location of Cell 5 on MnROAD Mainline (Interstate) 1
Figure 2.1. Installation of Dynamic and Environmental Strain Sensors 4
Figure 2.2. As-Built Sensor Layout for Cell 105 (Driving Lane) 6
Figure 2.3. As-Built and Design Sensor Layout for Cell 205 (Driving Lane) 7
Figure 2.4. As-built and Design Sensor layout for Cell 305 (driving lane) 8
Figure 2.5. As-built and Design Sensor Layout for Cell 405 (Driving Lane) 9
Figure 3.1. Condition Prior to Overlay (Right), Road Warrior Pavement Breaker (Left) 10
Figure 3.2. Pavement Cracking Detail (2) 11
Figure 3.3. Cross-section of MnROAD Test Cell 5 (2) 12
Figure 3.4. Cross Section of MnROAD Test Cells 105 - 405 12
Figure 3.7. Delivery of Fresh Concrete Mix to the Paver 14
Figure 3.8. Texturing of the Freshly Placed Concrete Mix (Note 1” spacing) 14
Figure 3.9. Curing Compound Application 15
Figure 3.10. Diamond Grinding (CDG + LT) 15
Figure 4.1. Pavement Automated Profiling System (PALPS) 18
Figure 4.2. As-Built FWD Testing Locations for MnROAD ‘Old’ Cell 5 20
Figure 4.3. Joint 23 (Left) and Joint 26 (Right) after Distress Treatment 21
Figure 4.4. As-Built FWD Testing Locations for Cell 5 – After Overlay 21
Figure 4.5. Typical Invar (IV) Reference Rod Design 23
Figure 4.6. Circular Texture Meter (CTM) 24
Figure 4.7. On Board Sound Intensity (OBSI) Testing Apparatus 24
Figure 4.8. On Board Sound Intensity Testing Results 25
Figure 4.9. Lightweight Inertial Surface Analyzer (LISA) 26

List of Tables

Table 1.1. Cell 5 Material Quantity and Bid Prices 3
Table 2.1. Sensor Types and Quantities for Test Cell 5 (Sub-Cells 105-405) 4
Table 2.2. Data Collection Equipment used in Test Cell 5 (Sub-Cells 105-405) 5
Table 3.4. Concrete Grade Classification (6) 13
Table 3.5. Concrete Slump Classification (6) 13
Table 3.6. Concrete Mix Gradation Classification (7) 13
Table 3.1. Friction Test (ASTM E-274) Prior to and after Diamond Grinding 15
Table 3.2. Mn/DOT Quality Assurance Tests 16
Table 3.3. Rapid Chloride Ion Permeability Test Results 17
Table 3.4. Compressive Strength and Flexural Strength Test Results 17
Table 4.1. Cell 5 LTE Results - Prior to Distress Treatment and Overlay 19
Table 4.2. Cell 5 Average LTE Results - Prior to Overlay and After Distress Treatment 22
Table 4.3. Cell 5 LTE Results - After Overlay 22
Table 4.4. Cell 5 OBSI Testing Locations 24
Table 4.5. Lightweight Inertial Surface Analyzer (LISA) Results – 11/2008 and 3/2009 26

Executive Summary

In the summer of 2008, after roughly fourteen years of service, the Minnesota Road Research project (MnROAD) underwent a massive effort involving the re-construction and rehabilitation of many of its pavement test cells, known as "Phase II" (SP 8680-157). Cell 5, located on the mainline (interstate 94); was rehabilitated with a thin (4 – 5" thick) unbonded concrete overlay (UBOL) as part of a state funded (MPR-6(016)) research project, "Performance of Thin Unbonded Concrete Overlays on High Volume Roads". Unbonded concrete overlays are generally used to rehabilitate pavements by restoring lost ride and structural capacity. The thin overlay design of cell 5, placed on a high volume interstate highway, is approximately half the thickness recommended by conventional Minnesota State design practice.

Cell 5 was originally constructed in 1993, and consisted of 7.1" of PCC placed over 3" of class 4 aggregate base and 27" class 3 aggregate subbase on a clay subgrade. At the time of the MnROAD phase II project (SP 8680-157), cell 5 was in better condition than a typical unbonded overlay candidate pavement, so selected transverse joints of the cell were distressed with a Road Warrior pavement breaking hammer. The resulting condition was characterized with falling weight deflectometer (FWD) testing. The cell was then overlaid with a Permeable Asphalt Stabilized Stress Relief Course (PASSRC) 1" thick. Then a network of electronic sensors, designed to collect environmental and load response data, were installed above the PASSRC interlayer layer. The sensors were held in place with wooden dowels, which allowed them to be embedded at various depths within the concrete overlay. The overlay consisted of concrete 4 – 5" thick placed with a slipform paver, over the PASSRC interlayer. The concrete was a standard Mn/DOT paving mixture, which met standard slump and air content quality assurance tests. The pavement had longitudinal tie bars, and relied on the underlying pavement for load transfer (no dowels due to thin slab). The concrete slab was cut to form panels 15 feet long by 13 (passing lane) or 14 (driving lane) feet wide. Compressive and flexural strength tests on cylinders and beams met Mn/DOT specifications for concrete pavements. After approximately one month, the pavement was diamond ground due to low skid numbers, caused by improperly spaced longitudinal tines (1" vs. ½"). The cell, along with the rest of the MnROAD mainline (interstate), was open to live traffic in early February 2009.

The location of cell 5 in the MnROAD facility affords it the opportunity to be thoroughly evaluated and rigorously tested in accordance with the research project work plan. Early age characterization of the concrete panel deformation, or "warp and curl", was performed using an innovative profiling device; these results will be analyzed in a separate contract. Initial baseline testing included: distress surveys, ride, surface characteristics (texture, noise and friction), as well as structural testing (falling weight deflectometer). These initial measurements will be invaluable in measuring performance over time. Electronic sensors will provide useful data on the mechanical performance of the pavement, which will aid in the eventual development of mechanistic empirical design methods. The information gathered, and lessons learned from this research project will help to improve the design and construction of unbonded concrete overlays.

CHAPTER 1. INTRODUCTION

Minnesota Road Research Project (MnROAD)

The Minnesota Road Research Project (MnROAD), located approximately 40 miles northwest of Minneapolis, near Albertville, Minnesota, was constructed by the Minnesota Department of Transportation (Mn/DOT) between 1990 and 1993 (1). The mainline or interstate section of MnROAD is 3.5 miles long and carries the "live traffic" of west bound Interstate 94 which has an ADT of 28,000 with 13% trucks (1). Traffic is typically diverted from the MnROAD research section back to the original west bound section for three days per month to allow for safe and careful execution of pavement testing and evaluation.

During the summer and fall of 2008 MnROAD was undergoing its' phase 2 reconstruction project. Cell 5 was among the many cells which were reconstructed. The original cell 5 consisted of a 7 inch jointed plain concrete pavement (JPCP) over 30" of granular base on a clay subgrade. This cell was in relatively good functional and structural condition at the time of reconstruction. Cell 5 received a thin unbonded PCC overlay (4-5 in thick PCC over 1 in thick bituminous interlayer) placed over the existing 7.1 inch thick concrete pavement constructed in 1992 (2).

The unbonded overlay test cells were placed on the interstate portion of MnROAD in an attempt to accelerate their response to heavy traffic volumes and loadings. Figure 1.1 shows the location of cell 5 relative to other mainline test cells, noting that the white cells denote concrete test cells, and gray cells denote bituminous test cells.

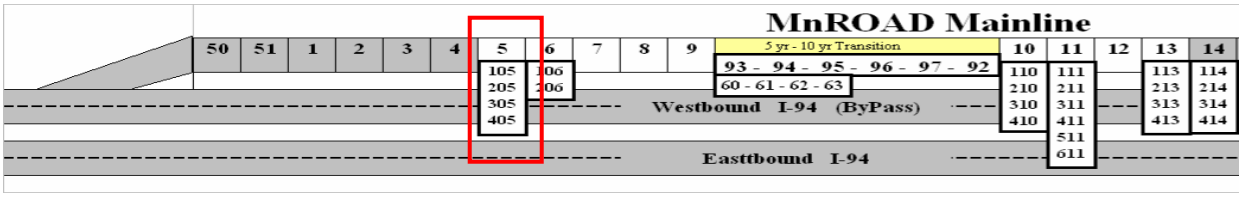

Figure 1.1. Location of Cell 5 on MnROAD Mainline (Interstate)

Objectives of Report and Research

This report will focus exclusively on Cell 5. For a more complete report on the phase 2 reconstruction projects at MnROAD see Johnson, Worel and Clyne (1). This report will document the: cell layout, pavement design, research plan, sensor types and locations, as well as mix design and material testing. Additional test results, as-built sensor locations as well as detailed pavement evaluation will follow in a future report "First Year Monitoring and Performance Report".

The research objectives for Cell 5 (Sub-Cells 105-405) include the following:

- Construct and instrument a thin (variable slab thickness) unbonded concrete overlay on MnROAD test Cell 5.
- Facilitate the development of performance data to improve the understanding of thin unbonded concrete overlays especially with regard to: maturity, slab warp and curl, thermal expansion, and repair techniques. This data will be used in the

development of better distress and life prediction models leading to a rational design method.

- Provide possible design recommendations and changes to Mn/DOT standard specifications, special provisions, manuals for constructing thin unbonded concrete overlays.

State of the Practice

Mn/DOT currently designs and constructs a large number of unbonded PCC overlays and has experienced good to excellent performance from these projects (3). Standard Mn/DOT practice involves the use of a one inch thick drainable HMA stress relief interlayer, and a concrete layer thickness of at least 7, but usually 8 to 9 inches (4). NCHRP Synthesis Report No. 415 conducted a literature review, a survey of state highway agencies, and obtained data from the LTPP database in an attempt to establish a relationship between site condition and design factors on overlay performance. They noted some general characteristics that contributed to good UBOL performance such as: thicknesses of at least 7 in., an bituminous interlayer at least 1 in. thick and doweled joints (5). Mn/DOT and other agencies have historically used conservative thicknesses of 7.5 to 8 inches of doweled PCC placed on a 1 – 1.5" thick HMA interlayer. The new MnROAD thin UBOL test cells are designed to test the limits of commonly accepted rules and design procedures, with the construction of a thin UBOL of 4-5 inches subjected to interstate loading. The drainable bituminous interlayer has historically had good performance in Minnesota.

The literature review conducted earlier (4) concluded that the current design and instrumentation of the new Mn/ROAD thin UBOL test cells will incorporate both proven design and construction techniques, as well as new experimental features that will help to advance the state of the art of thin unbonded overlays (TUBOL). The PASSRC interlayer, joints and construction methods to be used have provided success on past UBOL projects. The use of transverse orientated strip/wick drains on a thin UBOL subjected to interstate traffic and harsh weather conditions was not found in the literature. This experiment will either validate current design thicknesses, or provide evidence that current practices are overly conservative.

Construction Contract

The construction of this cell was part of a much larger Phase II reconstruction effort that involved the reconstruction of more than 20 cells at MnROAD. This project (Mn/DOT state project number: S.P. 8680-157) was let on January 25, 2008 and awarded to Progressive Contractors, Inc. (PCI) of St. Michael, MN for the amount of $2,092,828.30. The cost of cell 5 materials was approximately $94,423.65, see Table 1.1. Note that mobilization is included in the full contract, and the price for cell 5 reflects a lower cost due to the large number of cells being reconstructed.

Construction on Cell 5 began on June 18, 2008 with the distressing the joints by means of a Road Warrior pavement breaking hammer on sub-cells 105 and 405. The permeable asphalt stabilized stress relief layer was placed over the existing PCC surface on September 19, 2008, and paving of the concrete layer took place on October 8, 2008. The surface was diamond ground on November 18, 2008 due to insufficient initial texture and skid resistance resulting from insufficient spacing of the longitudinal tining (spaced at 1 inch instead of specified ½ inch).

Table 1.1. Cell 5 Material Quantity and Bid Prices

ITEM DESCRIPTION MPR-6(016) CELL 5	**QTY.**	**UNITS**	**UNIT PRICE**	**EXTENSION**
WICK DRAIN	126	L F	$9.95	$1,253.70
AGGREGATE SHOULDERING (CV) CLASS 5	121	C Y	$20.00	$2,420.00
PAVEMENT CRACKING	36	L F	$50.00	$1,800.00
CONCRETE PAVEMENT STANDARD WIDTH 4"	829	S Y	$28.20	$23,377.80
CONCRETE PAVEMENT STANDARD WIDTH 5"	949	S Y	$23.20	$22,016.80
STRUCTURAL CONCRETE	224	C Y	$118.00	$26,432.00
CONCRETE CORING	2	EACH	$100.00	$200.00
BITUMINOUS MIXTURE FOR PASSRC	98	TON	$77.65	$7,609.70
ASPHALT CEMENT FOR MIXTURE	3	TON	$417.75	$1,253.25
BITUMINOUS MATERIAL FOR TACK COAT	175	GAL	$2.00	$350.00
BITUMINOUS MATERIAL FOR SHOULDER TACK	71	GAL	$2.00	$142.00
TYPE SP 12.5 WEARING COURSE MIXTURE (4,B)	119	TON	$63.60	$7,568.40
TOTAL COST ($)				**$94,423.65**

CHAPTER 2. INSTRUMENTATION AND DATA COLLECTION

Introduction

An important feature of the MnROAD project is the extensive infrastructure available to support the instrumentation of pavement sections. New test cell 5 (Sub-Cells 105-405) was all built with electronic sensors embedded within the pavement structure to measure the pavement's response to load and environmental effects. Figure 2.1 shows sensors secured to wooden dowels prior to concrete overlay placement. The locations of these sensors were surveyed prior to and after overlay placement. Note that wooden dowels were used in an effort to minimize any reinforcing effects to the pavement slab. Table 2.1 summarizes the type and number of sensors in each of the new cells.

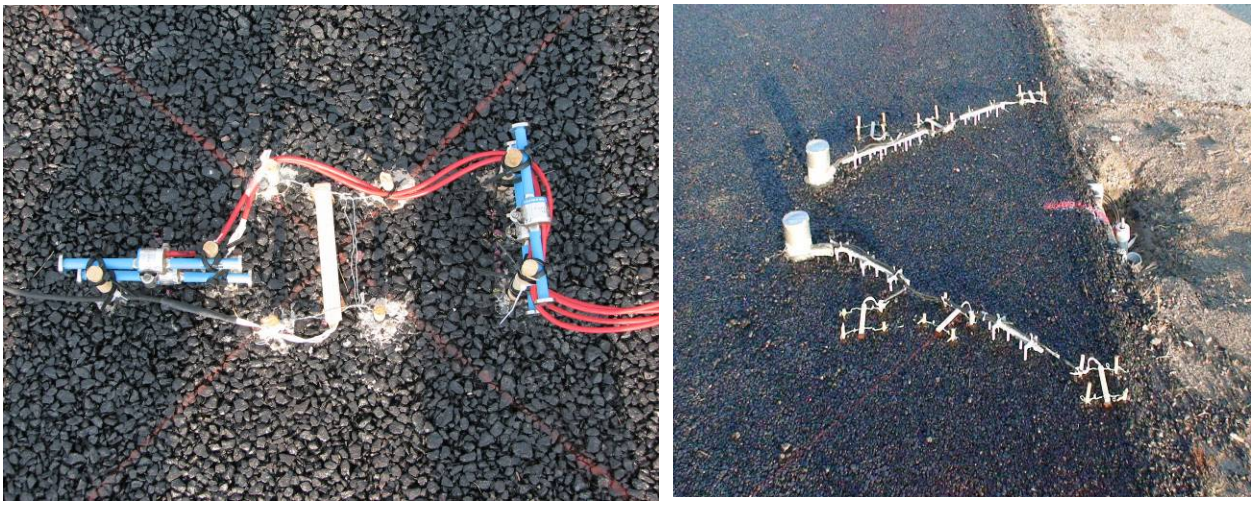

Figure 2.1. Installation of Dynamic and Environmental Strain Sensors

Table 2.1. **S**ensor Types and Quantities for Test Cell 5 (Sub-Cells 105-405)

Sensor Code	Sensor Type	Manufacturer	Measurement Type	Quantities			
				Cell 105	Cell 205	Cell 305	Cell 405
CE	PML-60-20	Tokyo Sokki	Strain	16	15	15	16
IV	Invar Reference Rod	Mn/DOT	Elevation	1	3	3	1
TC	Thermocouple (T-Type)	Omega	Temperature		24	16	
VW	4200 Vibrating Wire	Geokon	Strain		16	16	
HC	Horizontal Clip (PI-5S Displacement Transducer)	Tokyo Sokki	Joint Opening		4 (PI-5S-50)	4 (PI-5S-50&100)	
IK	Maturity Loggers	IntelliRock	Maturity		9	9	
XV	Thermistor on VW	Geokon	Strain		16	16	
DT	LVDT	Macro	Deflections	2	4	4	2

For further information on installation techniques, please contact the Road Research Section in the Mn/DOT Office of Materials.

Data Collection System Layout
Table 2.1 lists the equipment being utilized to gather data from the sensors installed in the test Cell.

Table 2.2. Data Collection Equipment used in Test Cell 5 (Sub-Cells 105-405)

Equipment	Purpose
Optim Electronics MEGADAC®	Collect dynamic strain data from sensors.
Campbell Scientific CR23X datalogger	Collect temperature and static strain data from thermocouple and vibrating wire sensors.

Figure 2.2 - Figure 2.5 show the design sensor layouts in each sub-cell of cell 5. Note that "T" denotes a sensor location at the Top of the slab only, a "B" denotes a bottom location only and no letter indicates that there are sensors at both the top and bottom locations. Additional sensor location details can be found in Appendix B. Note the as-built sensor locations are only shown for Cell 305, as this was the only cell that was different from the design (denoted with orange highlight).

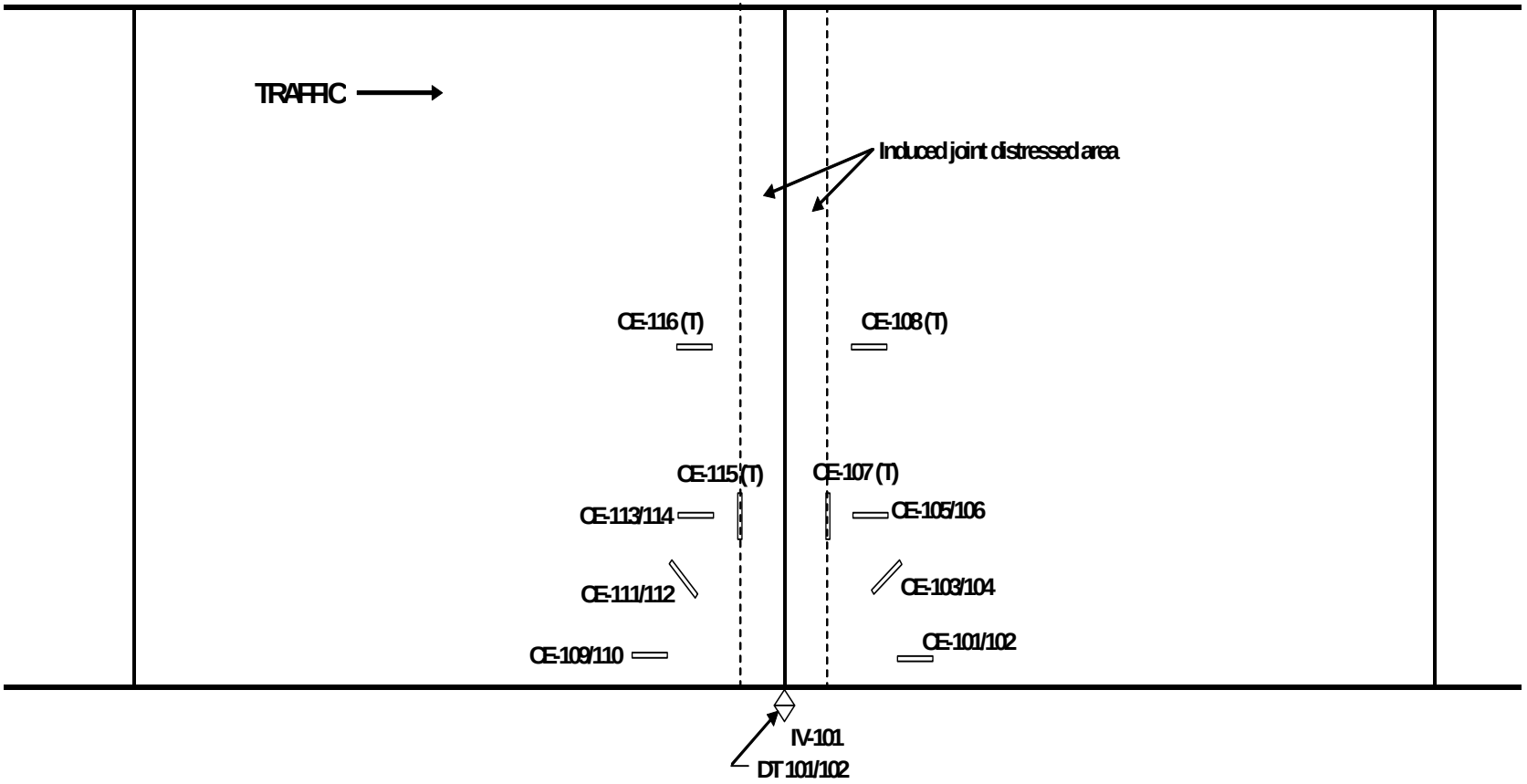

Figure 2.2. As-Built Sensor Layout for Cell 105 (Driving Lane)

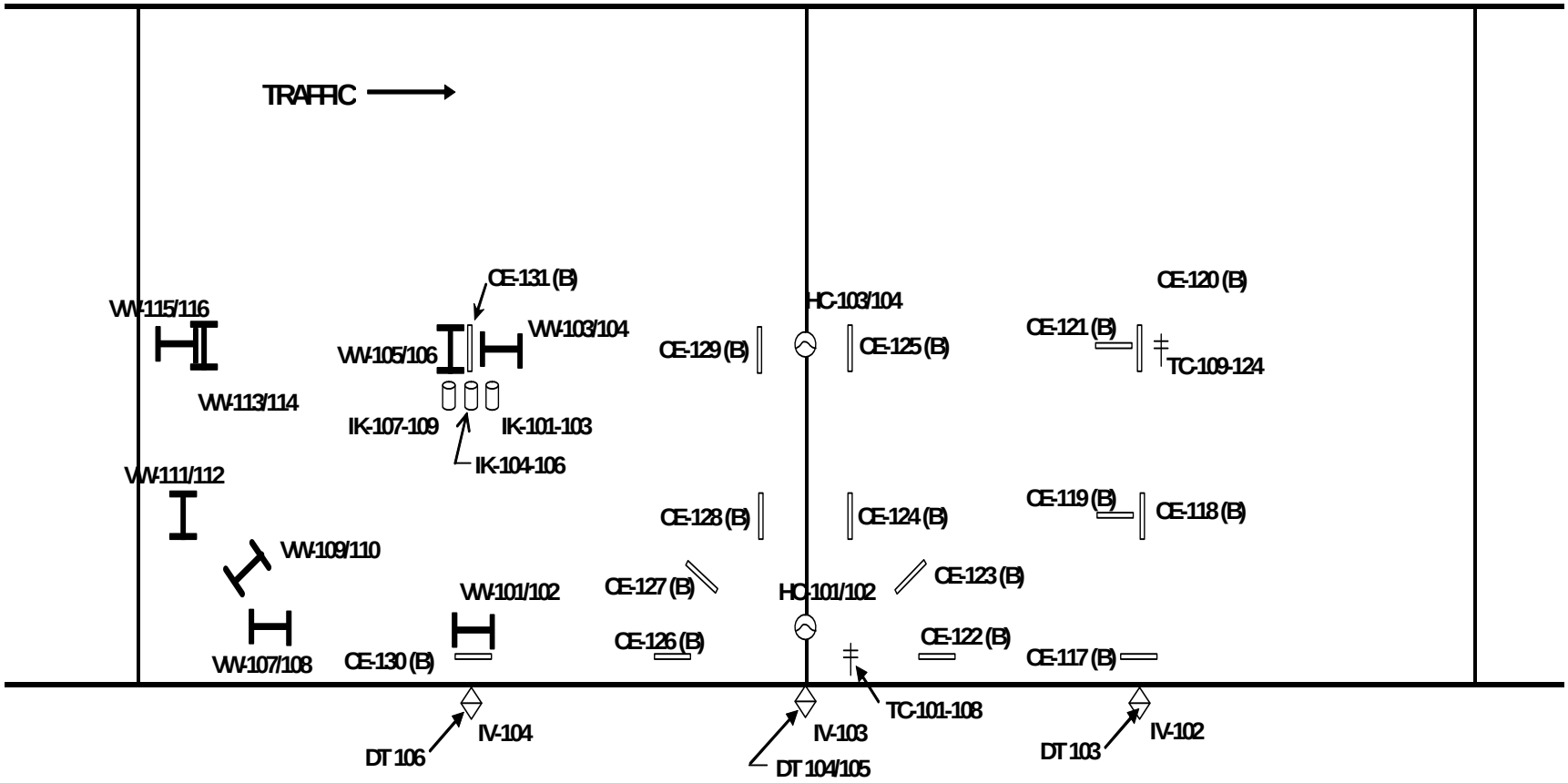

Figure 2.3**.** As-Built and Design Sensor Layout for Cell 205 (Driving Lane)

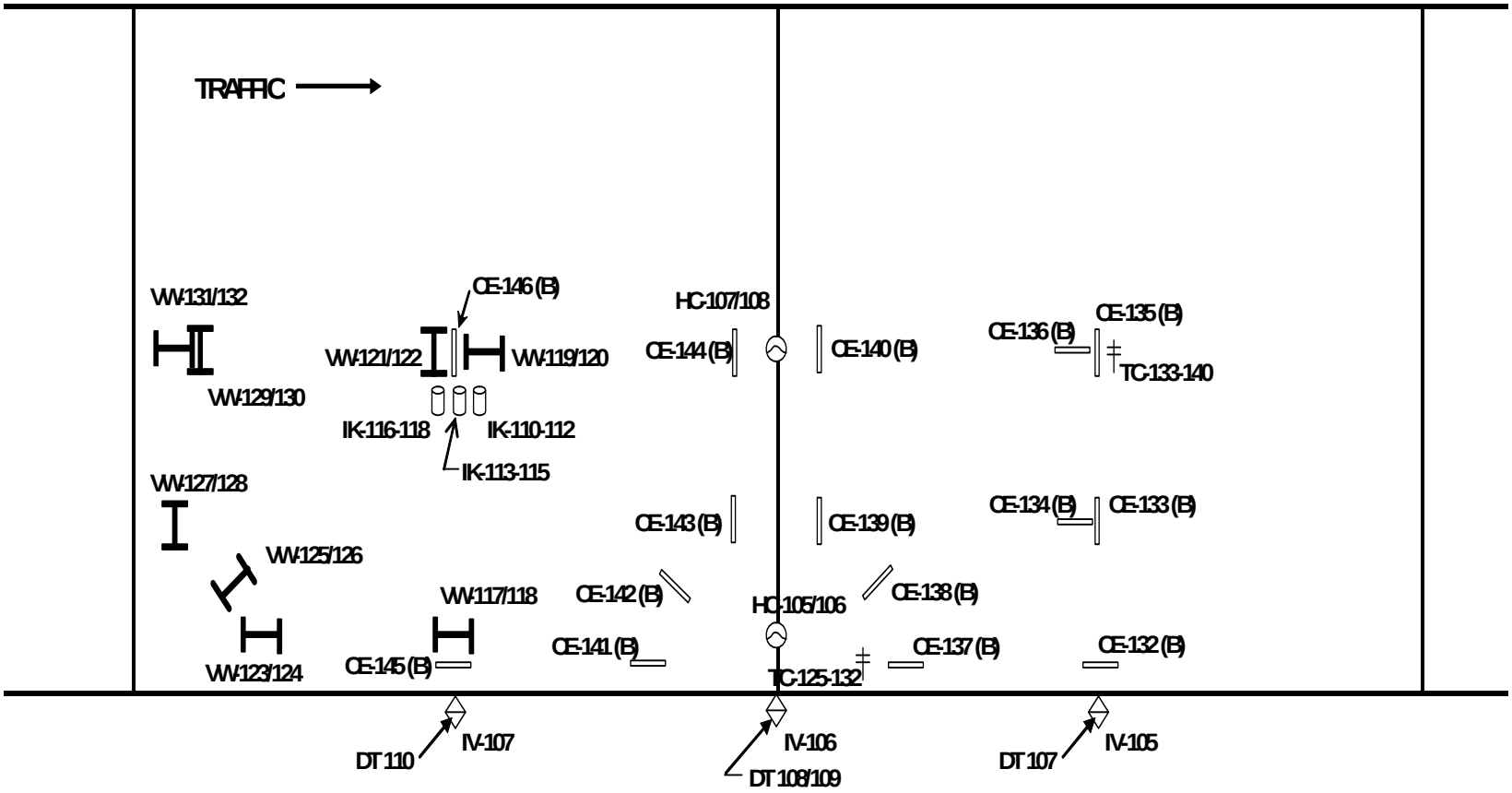

Figure 2.4. As-built and Design Sensor layout for Cell 305 (driving lane)

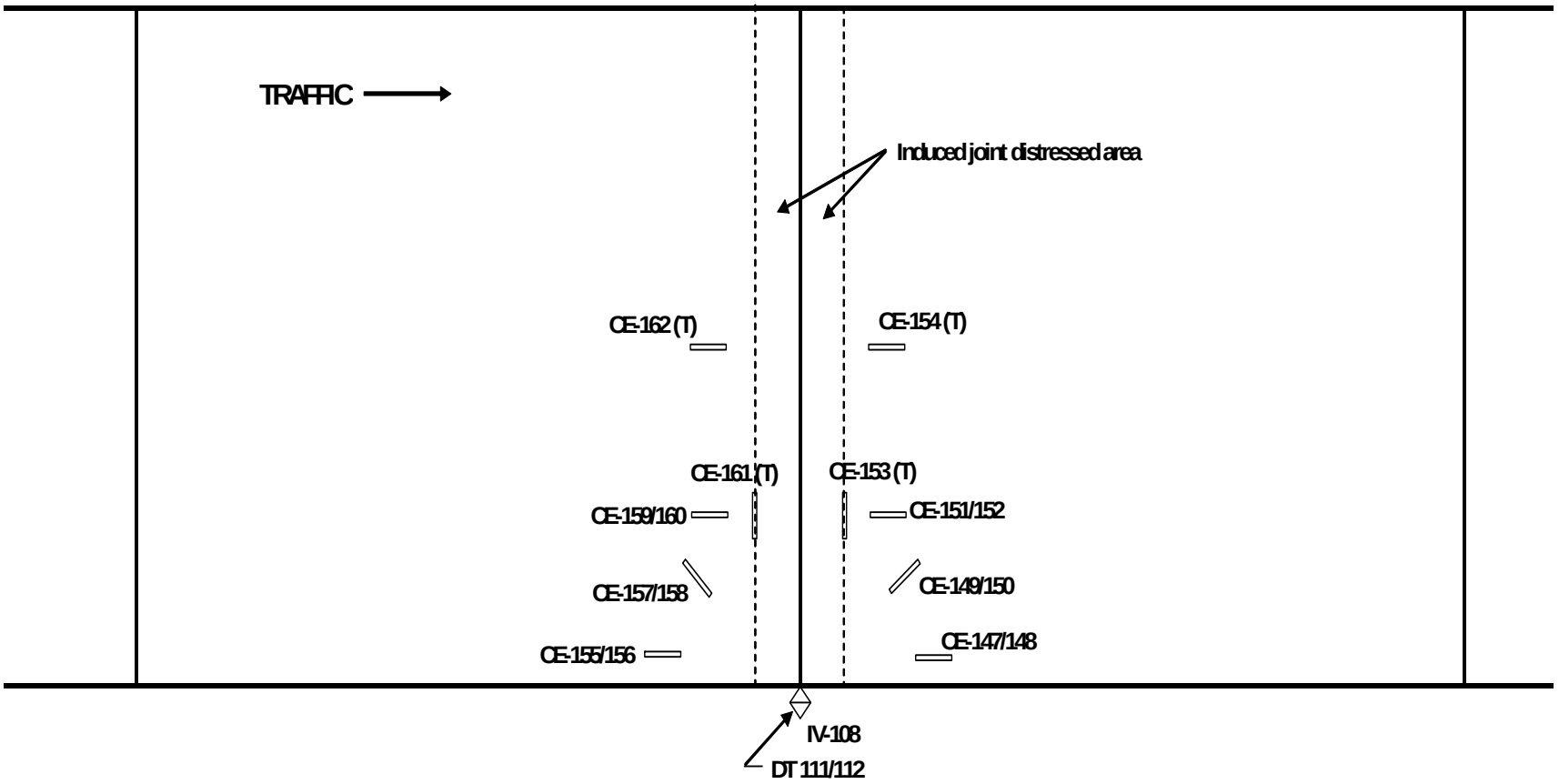

Figure 2.5. As-built and Design Sensor Layout for Cell 405 (Driving Lane)

CHAPTER 3. CONSTRUCTION AND MATERIALS

Existing Conditions (Prior to Overlay Placement)

The original pavement in Cell 5 was constructed in 1993 and consisted of 7.1" of PCC placed over 3" class 4 aggregate base over 27" class 3 aggregate subbase over a clay subgrade, see Figure 3.4. This pavement had 20' long by 13' (passing lane) or 14' (driving lane) wide panels and bituminous shoulders. The longitudinal joints were reinforced and sealed with bituminous hot pour sealant. The transverse joints were skewed (2' over 12' width) had 1" x 15" long dowels spaced at 12" center to center and were sealed with silicone sealant.

Cell 5 was in relatively good structural condition as illustrated by Figure 3.1, and had moderate load transfer efficiency (LTE) between adjacent joints, the FWD testing results are shown in chapter 4. Unbonded concrete overlays are typically placed on badly deteriorated PCC pavements, oftentimes with poor L.T.E. so in order to mirror field practice more closely the joints of 2 sub-cells (105 and 405) were artificially distressed using a Road Warrior pavement breaking hammer, see Special Provisions in Appendix C. This "treatment" was performed on June 18, 2008 on eight of the existing joints in two of the sub-cells at a rate of 4 drops at each joint location, with 4 passes to cover the entire 27' wide joint (see Figure 3.2).

Figure 3.1. Condition Prior to Overlay (Right), Road Warrior Pavement Breaker (Left)

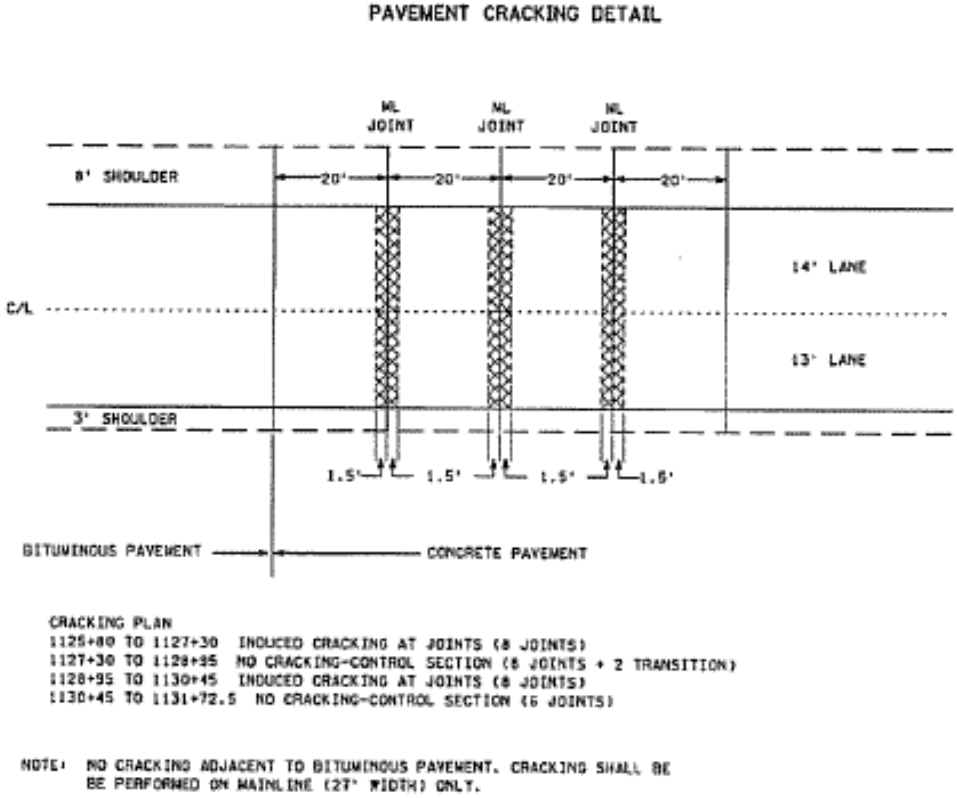

Figure 3.2. Pavement Cracking Detail (2)

Test Cell Description & Design, Cell 5 (sub-cells 105-405)

The final designs for cell 5 incorporated one panel size (13' or 14' wide and 15' long), two different unbonded thicknesses (4 and 5 inches of PCC over 1 inch drainable HMA stress relief layer), and two different pavement joint conditions (distressed vs. non-distressed). Figure 3.3 and 3.4 and show cross-section details of the test cell designs. Note that the joints in the overlay (15 feet) may line up with the joints in the underlying pavement (20 ft spacings) at approximately 60 foot intervals (15'*4 = 20'*3 = 60') as no special effort was made to mismatch the joints. The contraction joints were not sealed, no longitudinal tie bars were used, and due to the thin panels, dowel bars were not used. All cells were constructed using Mn/DOT's concrete pavement mix specifications for 2008. The bituminous shoulders were also reconstructed during the project using Mn/DOT SPWEB440B. To accommodate these variables, four shorter length test cells 105, 205, 305, 405 were incorporated into cell 5, see Figure 3.4. Total length of cells 105 and 205 were 150 feet and 165 feet respectively. Total length of cells 305 and 405 were 120 feet and 157.5 feet respectively.

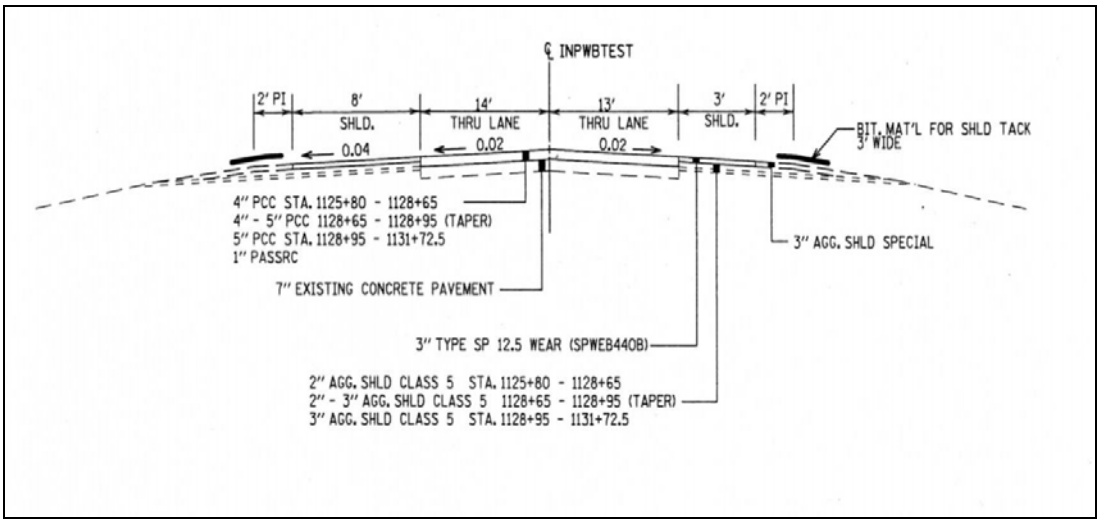

Figure 3.3. Cross-section of MnROAD Test Cell 5 (2)

Unbonded PCC Overlay

105	**205**	**305**	**405**
5	5	5	5
4"	**4"**	**5"**	**5"**
1" PSAB	1" PSAB	1" PSAB	1" PSAB
7.1" cracked '93 PCC	7.1" '93 PCC	7.1" '93 PCC	7.1" cracked '93 PCC
3"cl4sp	**3"cl4sp**	**3"cl4sp**	**3"cl4sp**
27" Cl3sp Orig 20x14 20x13 HMA Should 1" dowel	**27" Cl3sp** Orig 20x14 20x13 HMA Should 1" dowel	**27" Cl3sp** Orig 20x14 20x13 HMA Should 1" dowel	**27" Cl3sp** Orig 20x14 20x13 HMA Should 1" dowel
Clay LTine	**Clay** LTine	**Clay** LTine	**Clay** LTine
Oct 08	**Oct 08**	**Oct 08**	**Oct 08**
Current	**Current**	**Current**	**Current**

Figure 3.4. Cross Section of MnROAD Test Cells 105 - 405

Mix Designs

In addition to the materials sampled for research purposes, Mn/DOT inspectors sampled material for standard QA/QC tests. These tests which were conducted in accordance to the 2005 Minnesota Department of Transportation Standard Specifications for Construction and include: Slump test, Air Content and Modulus of Rupture. The structural concrete and bituminous interlayer (PASSRC) used in cell 5 were not experimental and not specified any differently than a standard Mn/DOT production concrete paving mixture. MnROAD cell 5 was constructed using Mn/DOT's concrete pavement mix specifications for 2008 (6). The concrete mix was type

3A41, denoted according to Mn/DOT's current specifications for structural PCC, 2461 (http://www.dot.state.mn.us/pre-letting/spec/2005/2401-2481.pdf).The concrete mixture was type 3 (air entrained) and strength grade A (Table 3.1), had a maximum allowable slump of 4 inches (Table 3.2), and had a specified gradation of CA 50 and CA 15 inclusive defined in Table 3.3. The mixture had a target air content of 7% (+/- 1.5%) and a water-to-cementitious materials ratio (w/c_m) of 0.37.

Table 3.1. Concrete Grade Classification (6)

CONCRETE CLASSIFICATION

	Type 1 Concrete		Type 3 Concrete	
Grade of Concrete	Cement-Void Ratio	Anticipated Compressive Strength Mpa (psi)	Cement-Void Ratio	Anticipated Compressive Strength Mpa (psi)
U	0.80	43 (6300)	0.70	39 (5600)
V	0.76	41 (6000)	0.66	37 (5300)
W	0.72	39 (5700)	0.62	34 (5000)
X	0.68	37 (5400)	0.58	32 (4700)
Y	0.62	34 (5000)	0.54	30 (4300)
A	0.56	31 (4500)	0.50	27 (3900)
B	0.52	28 (4100)	0.46	23 (3400)
C	0.44	22 (3200)	0.40	19 (2700)

Table 3.2. Concrete Slump Classification (6)

SLUMP RANGE DESIGNATION

Slump Designation	Maximum Slump	Slump Range
1	25 mm (1 inch)	0-25 mm (0-1 inch)
2	50 mm (2 inches)	25-50 mm (1-2 inches)
3	75 mm (3 inches)	50-75 mm (2-3 inches)
4	100 mm (4 inches)	75-100 mm (3-4 inches)
5	125 mm (5 inches)	100-125 mm (4-5 inches)
6	150 mm (6 inches)	125-150 mm (5-6 inches)

Table 3.3. Concrete Mix Gradation Classification (7)

COARSE AGGREGATE DESIGNATION FOR CONCRETE

Percent by mass (weight) **passing square opening sieves** ***(A)***

Aggregate Designation	50 mm (2 in.)	37.5 mm (1 ½ in.)	31.5 mm (1 ¼ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	16.0 mm (⅝ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (# 4)
CA-00				100	95-100				0-10
CA-15	100	90-100			35-65			5-25	0-7
CA-25 or 2M6	100	95-100			50-80			20-40	0-7
CA-35 or 3M6		100	95-100		55-85			20-45	0-7
CA-45 or 4M6			100	95-100	65-95			25-55	0-7
CA-50				100	85-100			30-60	0-12
CA-60					100	85-100		40-70	0-12
CA-70						100	85-100	50-100	0-25
CA-80 *(A)*								100	55-95

The PASSRC interlayer used an asphalt performance graded binder (PG) of 64-22 and conformed to the CA-70 gradation specification (Table 3.3).

Construction Sequence

All construction activities took place in 2008 beginning on June 18, with the artificial distressing of the joints. On September 19 the PASSRC layer was paved. The sensors were installed over the course of approximately 4 – 5 days starting on September 24. The 4 – 5" thick, 27' wide concrete overlay was machine placed over the PASSRC layer and electronic sensors in one pass on October 8, 2008 starting at approximately 8:40am and ending at approximately 11:00am. Figure 3.5 shows fresh concrete mix being delivered to the concrete paver. Figure 3.8 shows longitudinal texturing and Figure 3.9 shows application of the curing compound to the newly textured surface.

Figure 3.5. Delivery of Fresh Concrete Mix to the Paver

Figure 3.6. Texturing of the Freshly Placed Concrete Mix (Note 1" spacing)

Figure 3.7. Curing Compound Application

The concrete surface of cell 5 was diamond ground by Diamond Surface Inc. of Maple Grove on November 18, 2008. Initial skid resistance testing indicated a low skid resistance resulting from the insufficient texture of the 1" spaced longitudinal tines. Table 3.4 shows the dramatic change in skid resistance (ASTM E-274) resulting from the diamond grinding operation. Also note that ASTM E 965 indicated a mean texture depth of 0.442. The diamond grinding pattern was the conventional configuration (CDG) with approximately 1/8*1/8*1/8" groove kerf depth and width. This was superimposed onto the existing longitudinal tine (LT) without any prior flush grinding, see Figure 3.10.

Figure 3.8. Diamond Grinding (CDG + LT)

Table 3.4. Friction Test (ASTM E-274) Prior to and after Diamond Grinding

Lane	Date	Time	Fn	Peak	Speed	Air Temp	Pvt Temp	Tire Type
ML - Driving	10/31/2008	10:53	24.6	52.47	38.1	68	61.6	Ribbed
ML - Driving	10/31/2008	11:10	16.9	40.19	40.1	68	67.1	Smooth
ML - Driving	6/16/2009	10:13	39.4	64.88	40.6	68	88.1	Ribbed
ML - Driving	6/16/2009	11:23	46.5	73.15	40.5	68	92.5	Ribbed
ML - Driving	6/16/2009	10:29	49.9	84.13	40.0	68	88.8	Smooth
ML - Driving	6/16/2009	11:40	45.7	82.21	40.2	68	89.5	Smooth

Material Sampling and Testing

Concrete Material Testing During Paving (Mn/DOT Quality Assurance)

Concrete slump and air content tests were performed as the concrete was being placed. Test results are summarized in table 3.2 below. The percent air stayed within the allowable design range of +/- 1.5% of 7.0%, the maximum allowable slump was 3", which was not exceeded, note again that this concrete mix was placed using a slipform paver. The water to cementitious materials ratio was designed to be 0.35, the actual placed mix appears to be slightly lower.

Table 3.5. Mn/DOT Quality Assurance Tests

Time	% Air	Slump (in)	Total Act. H_2O (lb./CY)	Air Temp (ºF)	Concrete Temp (ºF)	Water Ratio	W/C Ratio
8:40 AM	7.6%	2 1/4"	187	50	60	0.91	0.32
10:00 AM	6.8%	1 1/2"	171	55	60	0.84	0.29
11:00 AM	6.0%	1 1/2"	179	57	60	0.87	0.31

A Core sample taken from the pavement at station 1130+70 on 10/28/08 indicated a thickness of 5.25", which is 0.25" greater than the thickness indicated in the plans. In addition the 61 day strength was 6810 P.S.I.

Flexural strength beams were broken at 7 and 28 days, indicating a modulus of rupture of 550 PSI and 520 PSI respectively. The Mn/DOT standard on flexural strength pertains to pavements at least 6" thick, and is related to when traffic can be allowed on the pavement, allowing a maximum 7 day cure period. Cell 5 wasn't opened to traffic February 2009, a few months after construction.

Laboratory Testing Results

This section summarizes the results of the laboratory testing performed by American Engineering and Testing, Inc. (AET) which tested the concrete samples for rapid chloride ion permeability, compressive strength and flexural strength.

Rapid Chloride Ion Permeability

The rapid chloride ion permeability test was performed on twenty-eight (28) day samples; Table 3.5 provides a summary of the results. Mn/DOT does not currently have a specification on chloride ion permeability of concrete mixtures.

Compressive Strength and Flexural Strength

Table 3.7 depicts the results from the compressive strength and flexural strength testing done in accordance with ASTM C39 and ASTM C78 respectively. The concrete mix was the same for all of the test cells. Mn/DOT specifies that the 28 day compressive strength of laboratory cured specimens should be at least 4500 PSI for class A concrete having a cement-void ratio of 0.56, the mix appears to have met this standard.

Table 3.6. Rapid Chloride Ion Permeability Test Results

Rapid Chloride Ion Permeability at 28 Days		
	Coulombs	**Milliamps (Max.)**
Trial 1:	2,100	118.5
Trial 2:	2,080	121.4
Trial 3:	1,940	108.4
Average:	2,040	116.1

Table 3.7. Compressive Strength and Flexural Strength Test Results

Test Summary		
Age	**Compressive Strength**	**Flexural Strength**
(Days)	(PSI)	(PSI)
1		490
1		490
3	2,430	570
3	2,390	560
3	2,520	
3	2,830	
7	3,700	580
7	3,670	630
7	4,040	620
7	3,620	640
21	4,600	
21	4,480	
21	4,470	
21	4,580	
28	5,230	890
28	5,100	1,000
28	5,300	1,010
28	5,170	830
28 Day Avg	5,200	933
28 Day Std. dev	85.24	87.32

CHAPTER 4. INITIAL TESTING

This chapter describes the testing that was undertaken after placement of the thin unbonded concrete pavement in cell 5 (sub-cells 105-405) at the MnROAD test facility. One of the research objectives for the new test cells was the characterization of the early age behavior of thin-unbonded concrete slabs, particularly related to slab curl and warp.

Early Age Testing

A measurement of interest was the profile shape of the pavement slabs over time. The profile shapes of 4 slabs in sub-cells 205 and 305 were measured using the newly developed Pavement Automated Profiling System (PALPS), see Figure 4.1. This device measures elevation differences between points along predetermined paths across the slabs. To fully characterize the slab curl and warp however, fixed elevation reference points are needed. To accomplish that, 12 foot (3.6 m) long invar (Type 36) rods were installed beside the pavement at transverse joint locations in the sensor areas. See Figure 2.2 - Figure 2.5 for their location (labeled as "IV" sensors) in Cell 5. The design of a typical invar reference rod installation is shown in Figure 4.5. The raw data will not be included in this report as it is currently being analyzed by Michigan Tech in a built-in curl and warp study (Contract No. 89258).

Figure 4.1. Pavement Automated Profiling System (PALPS)

FWD Testing

Falling Weight Deflectometer (FWD) testing was conducted with a Dynatest model before, and shortly following, construction of Cell 5 (sub-cells 105-405). Testing before the placement of the concrete was done to characterize the strength and condition; average load transfer efficiency (LTE) of the existing cell 5, taken during Fall 2007 are summarized in Table 4.1 below.

Table 4.1. Cell 5 LTE Results - Prior to Distress Treatment and Overlay

TEST DATE	EAST OF JT	WEST OF JT	TEST DATE	EAST OF JT	WEST OF JT
18-Mar-93		74	15-Sep-99	84	82
26-May-93		70	20-Oct-99	78	74
6-Aug-93		66	22-Mar-00	86	79
3-Sep-93		66	30-Mar-00	91	90
29-Sep-93		65	17-Apr-00	90	86
15-Mar-94	61	60	18-Jul-00	75	78
25-Mar-94	63	64	11-Sep-00	81	78
5-Apr-94	69	67	1-Mar-01	55	56
28-Apr-94	78	81	28-Mar-01	70	64
11-May-94	92	91	25-Apr-01	75	72
23-Jun-94	87	85	20-Jun-01	92	91
28-Sep-94	83	78	22-Oct-01	80	75
17-May-95	85	81	12-Mar-02	84	71
15-Jun-95	93	87	18-Mar-02	92	83
20-Sep-95	81	79	15-Apr-02	92	90
16-Nov-95	88	85	12-Jul-02	93	92
10-Apr-96	85	78	18-Sep-02	73	72
17-Apr-96	90	88	3-Oct-02	73	69
1-May-96	81	74	4-Nov-02	83	76
21-May-96	89	88	11-Dec-02	88	85
16-Oct-96	78	74	24-Mar-03	86	81
17-Mar-97	73	76	17-Apr-03	67	68
28-Mar-97	92	81	12-May-03	89	85
16-Apr-97	82	78	15-Mar-04	83	83
7-May-97	94	88	21-Apr-04	70	66
8-Jul-97	90	85	14-Apr-05	92	91
27-Aug-97	93	89	18-Apr-06	79	78
22-Sep-97	87	86	19-Jul-06	65	69
9-Oct-97	77	73	25-Sep-06	74	63
2-Mar-98	82	76	14-Nov-06	81	74
13-Apr-98	88	85	13-Mar-07	92	87
20-May-98	86	85	12-Apr-07	90	84
15-Jul-98	95	92	14-May-07	85	62
30-Sep-98	76	73	16-May-07	74	47
19-Mar-99	92	90			
21-Apr-99	92	90			
27-Jul-99	75	74			

Figure 4.2 shows the FWD testing locations of the ‘old’ cell 5 and the FWD testing of the distressed joints (2-7 and 22-26 denoted with red lines).

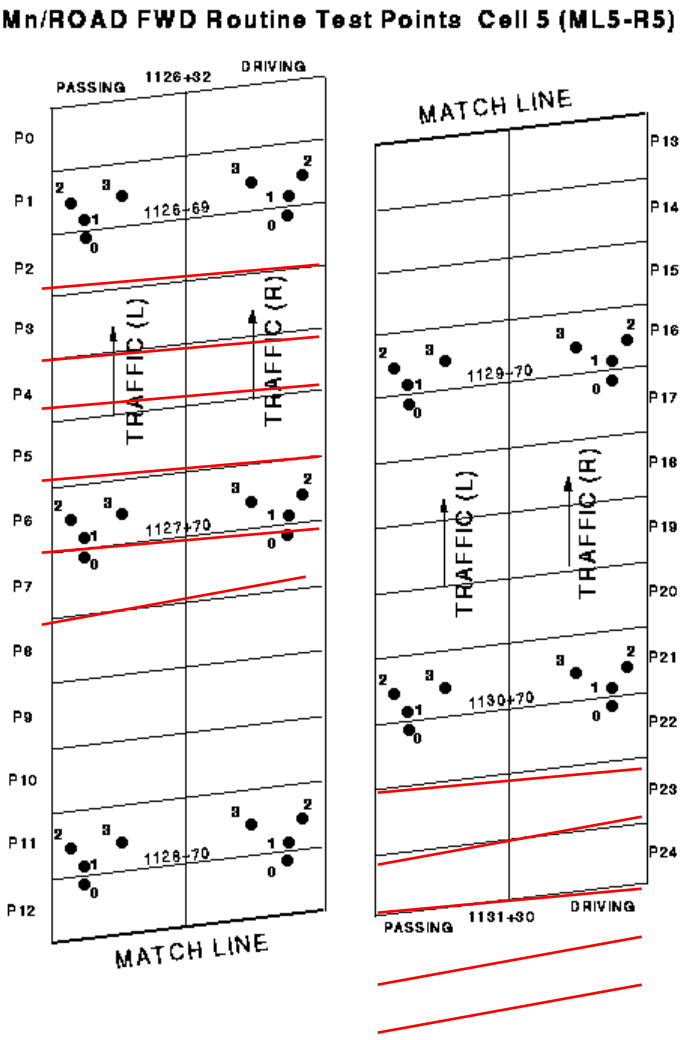

Figure 4.2. As-Built FWD Testing Locations for MnROAD 'Old' Cell 5

Figure 4.3 shows the condition of joints 23 and 26 shortly after the distress "treatment", Appendix C shows the condition of the remaining 9 joints. Figure 4.4 shows the corresponding approximate location of the underlying distressed joints in the unbonded overlay, as well as the routine FWD testing locations in the four sub-cells. Note that testing locations include: joints, center and edge slab locations both in the driving lane and the passing lane.

Figure 4.3. Joint 23 (Left) and Joint 26 (Right) after Distress Treatment

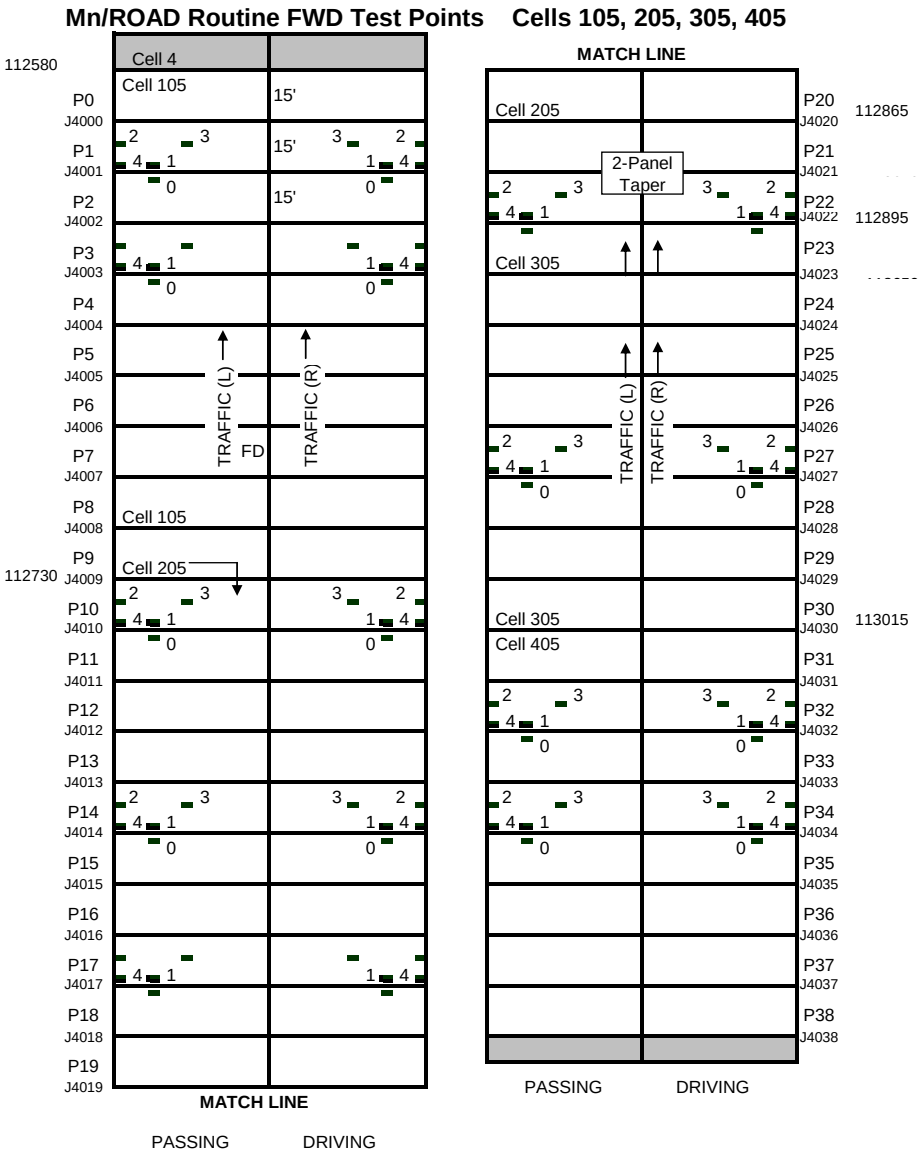

Figure 4.4. As-Built FWD Testing Locations for Cell 5 – After Overlay

Table 4.2 compares the LTE of distress treated joints (CRKD) with those that did not receive the distress treatment (control). The joints were tested at the edge of the panel in the driving lane, "East or West of the Joint" refer to the position of the load in relation to the joint being tested. The LTE results appear high due, most likely, to the high pavement surface temperatures on the day of testing. The pavement temperatures appear to have influenced the joint performance more than the distress treatments.

Table 4.2. Cell 5 Average LTE Results - Prior to Overlay and After Distress Treatment

	EAST OF JT			**WEST OF JT**			**OVERALL**		
	LTE	TEMP	n	LTE	TEMP	n	LTE	TEMP	n
CRKD	80.2	35.8	36	77.4	36.2	36	78.8	36.0	72
CTRL	76.5	35.9	56	78.5	35.9	51	77.5	35.9	107

FWD testing was also performed as soon as the concrete would safely support the FWD testing machine. Figure 4.4 shows the routine FWD testing locations in the four sub-cells. Note that testing locations include: joints, center and edge slab locations both in the driving lane and the passing lane. The LTE results from the spring testing are shown in Table 4.3. Note that overall, the average LTE did not decrease, even though the pavement temperature was much lower. The new cell 5 will be load tested seasonally in accordance with the work plan.

Table 4.3. Cell 5 LTE Results - After Overlay

	EAST OF JT			**WEST OF JT**			**OVERALL**		
	LTE	TEMP	n	LTE	TEMP	n	LTE	TEMP	n
CELL 5	72.9	17.7	96	83.6	18.0	96	78.2	17.9	192.0

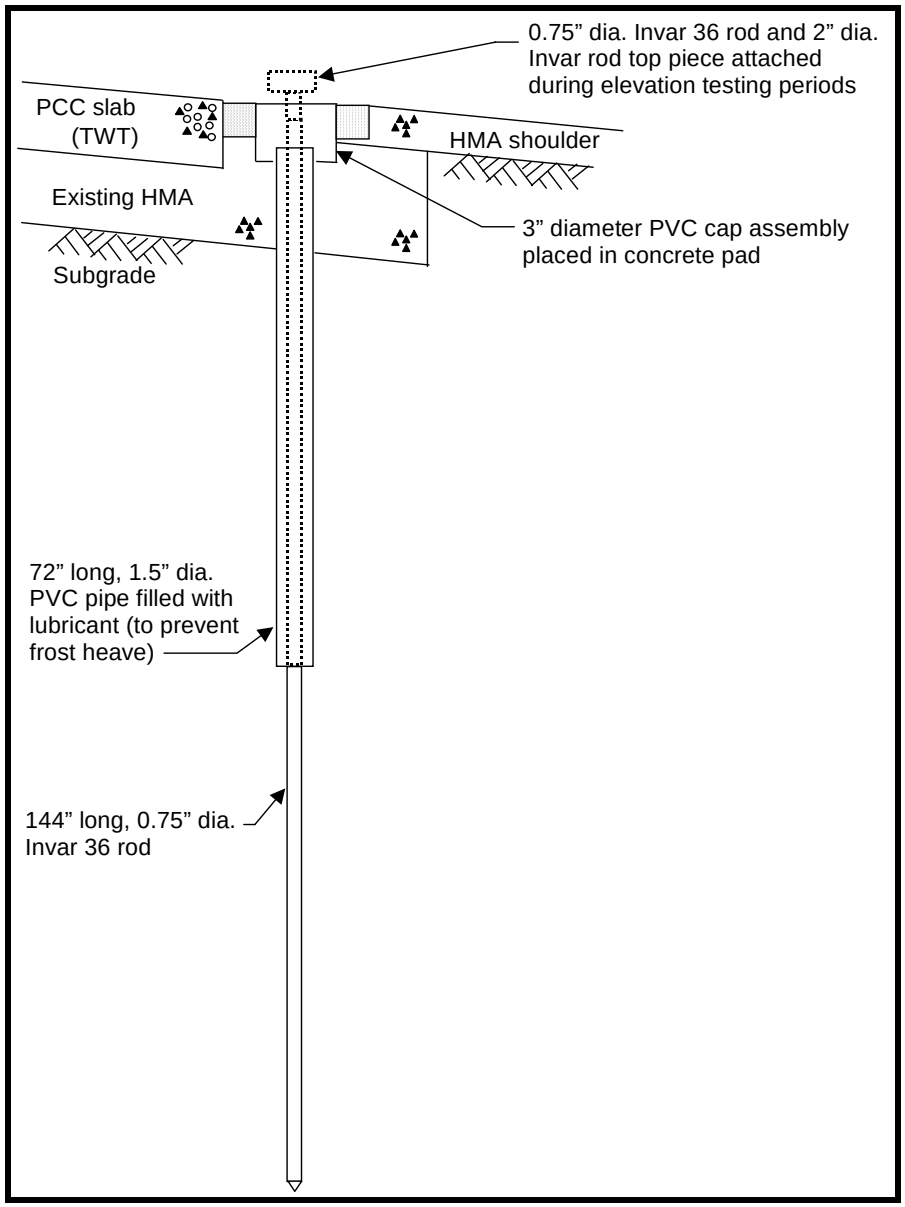

Figure 4.5. Typical Invar (IV) Reference Rod Design

Pavement Surface Characteristics

Texture Measurements

Texture measurements were taken after the diamond grinding operation using the Circular Texture Meter (ASTM E2157), see Figure 4.6. This test will be performed four times annually in accordance with the workplan.

Figure 4.6. Circular Texture Meter (CTM)

Sound Measurements

Sound was measured using an On Board Sound Intensity Device (OBSI), as shown in Figure 4.7. This test measures the tire-pavement interaction noise and was performed in accordance with the standard protocol at 60 miles per hour in both the passing and driving lanes. See Table 4.4 for testing locations and Figure 4.8 for testing results. This test will be performed four times annually in accordance with the work plan.

Figure 4.7. On Board Sound Intensity (OBSI) Testing Apparatus

Table 4.4. Cell 5 OBSI Testing Locations

Cell	STATION	OFFSET
105	112669	10
105	112669	-10
205	112827	10
205	112827	-10
305	112970	10
305	112970	-10
405	113101	10
405	113101	-10

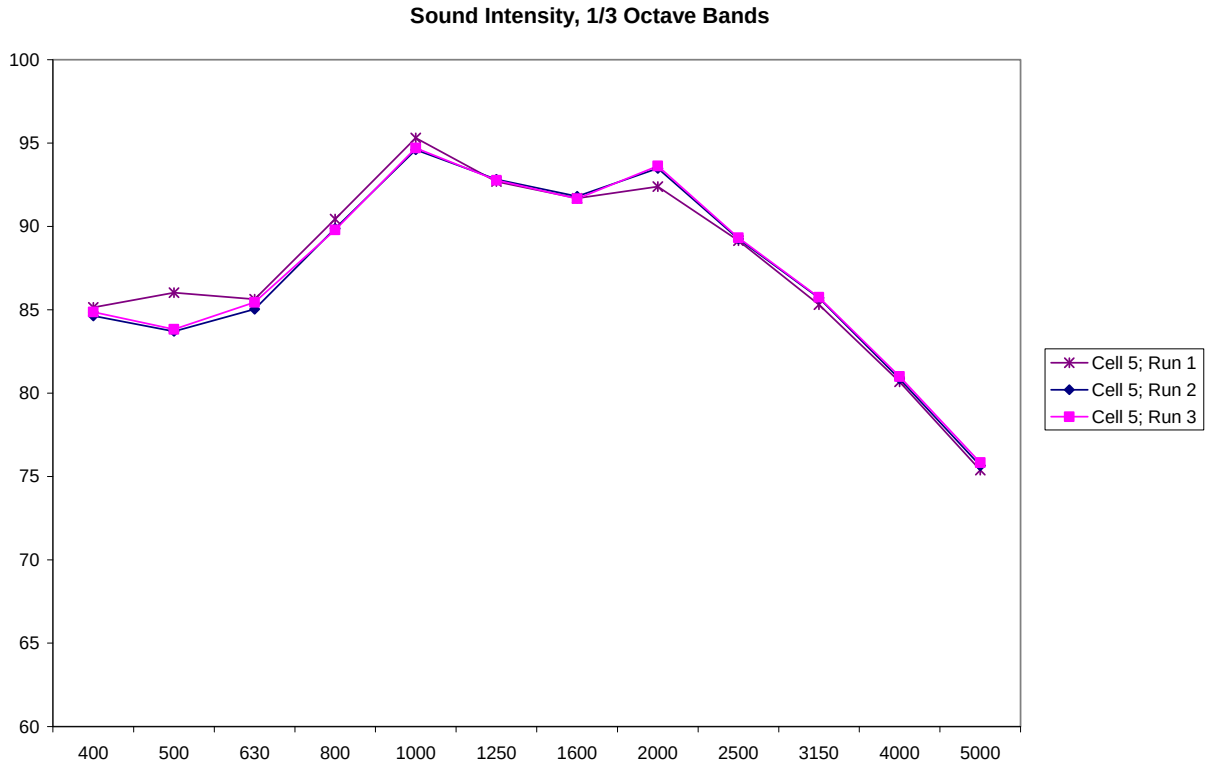

Figure 4.8. On Board Sound Intensity Testing Results

The sound absorption of cell 5 will be measured twice annually. The measurements will be accomplished in accordance with ISO10534-2, using an impedance tube manufactured by BSWA Tech (Model SW 422).

Ride Measurements

Ride was measured using a light weight inertial surface analyzer (LISA) as shown in Figure 4.9. Measurements were taken in both the left and right wheel paths of the driving and passing lanes as shown in Table 4.5 below. Note that testing took place in fall 2008 and spring 2009 immediately following construction. The routine monitoring plan calls for measurements to be taken four times annually.

Figure 4.9. Lightweight Inertial Surface Analyzer (LISA)

Table 4.5. Lightweight Inertial Surface Analyzer (LISA) Results – 11/2008 and 3/2009

DAY	LANE	WHEELPATH	IRI_RUN(M-KM)
11/19/2008	Driving	LWP	0.80
11/19/2008	Driving	RWP	0.85
11/19/2008	Driving	RWP	0.86
11/19/2008	Driving	SHLDR	3.36
11/19/2008	Driving	SHLDR	3.44
11/19/2008	Passing	LWP	0.73
11/19/2008	Passing	LWP	0.74
11/19/2008	Passing	RWP	0.63
11/19/2008	Passing	RWP	0.64
3/17/2009	Driving	LWP	0.72
3/18/2009	Driving	LWP	0.81
3/17/2009	Driving	RWP	0.77
3/17/2009	Driving	RWP	0.73
3/18/2009	Passing	LWP	0.76
3/18/2009	Passing	LWP	0.75
3/18/2009	Passing	RWP	0.65
3/18/2009	Passing	RWP	0.70

CHAPTER 5. CONCLUSIONS

During the MnROAD Phase II reconstruction project (SP 8680-157), Cell 5, located on the mainline (interstate 94); was rehabilitated with a thin (4 – 5" thick) unbonded concrete overlay (UBOL) as part of a state funded (MPR-6(016)) research project, "Performance of Thin Unbonded Concrete Overlays on High Volume Roads". The thin overlay is approximately half the thickness of a conventional unbonded concrete overlay (8" thick), and has panels 15 feet long by 13' (passing lane) or 14' (driving lane) wide. The pavement has no dowels, relying on the underlying pavement for support, and incorporated an innovative wick drain system for drainage. The concrete mixture and pavement met Mn/DOT standard specifications for construction.

A network of electronic sensors designed to measure environmental and load responses was installed concurrently with construction. Data from the sensors will be analyzed by a team from the University of Minnesota to model unbonded overlay behavior. Falling weight deflectometers (FWD) testing was carried out both prior to, and after construction, to evaluate pavement joint condition. Early age measurements of pavement slab deformation "warp and curl" were gathered. Initial baseline measurements of surface characteristics (noise, texture and friction) and ride were also made. Distresses were not present at construction, and annual distress survey results will be presented in later reports.

REFERENCES

1. Ann Johnson, Ben Worel and Tim Clyne. 2008 MnROAD Phase II Construction Report. Minnesota Department of Transportation, St. Paul, MN, May 2009.

2. Tim Clyne. Construction Plan for Reconstruction of MnROAD Mainline and Low Volume Road. State Project No. 8680-157 (No Fed. Proj. No.) Unpublished Project Design Plans, Minnesota Department of Transportation, St. Paul, MN, December 2007.

3. Erland Lukanen. Unpublished Charts from Mn/DOT Pavement Management System Data. Minnesota Department of Transportation, St. Paul, MN, June 2008.

4. Mark Watson and Tom Burnham. Thin Unbonded PCC overlay of PCC Pavements on High Volume Roads. Task 1 Report: Literature Review, Unpublished. June 2008.

5. ERES Consultants. Evaluation of Unbonded Portland Cement Concrete Overlays. Transportation Research Board, National Research Council, NCHRP Report No. 415, Washington, D.C. 1999.

6. Minnesota Department of Transportation. Standard Specifications for Construction. Minnesota Department of Transportation, Saint Paul, MN, 2005.

7. Tom Burnham and Mark Watson. Thin Unbonded PCC overlay of PCC Pavements on High Volume Roads. Task 2 Report: Test Cell Design, Materials Sampling, and Pavement Performance Monitoring Plans, Unpublished. July 2008.

Appendix A: Project Specific Selected Special Provisions

(2231) PAVEMENT CRACKING

SP2005-99 - mod

This work shall consist of fracturing the existing concrete pavement in Cell No. 5, at the locations indicated in the plans. The work shall be performed in accordance with the applicable Mn/DOT Standard Specifications, the Plan Details and the following:

Fracturing shall be accomplished with equipment (breaker/hammer) mounted on a vehicle capable of controlled forward and transverse movement and fracturing the pavement to the full depth, capable of cracking the pavement as detailed in the plan, yet maintain aggregate interlock in the fractured faces. The Contractor shall provide the Engineer with information on the equipment and method intended to accomplish the cracking for Engineers approval.

The concrete shall be cracked transversely at each designated transverse pavement joint for the full width of the mainline pavement, and longitudinally for a distance of approximately **1 foot (+/- 4'')** each side of the joints. No other fracturing of the panels shall occur, unless so directed by the Engineer.

Before routine fracturing operations begin, the Contractor shall perform the cracking on a test joint on the Project to demonstrate that the operation is satisfactory to the Engineer.

The Contractor shall be responsible for core drilling samples of sufficient size to permit determination of the extent and type of mechanical cracking of the concrete pavement. The Contractor should anticipate multiple coring locations of the concrete pavement when so directed by the Engineer. All coring locations shall be under the supervision of the Engineer. Analysis of the cores to determine extent of fracturing shall be determined by the Engineer.

MEASUREMENT AND PAYMENT

Pavement cracking will be measured separately by meters [**linear feet**] along the centerline of the roadbed where such work is performed.

Payment will be made under Item 2231.603 (Pavement Cracking) at the Contract bid price per meter [**linear foot**], which shall be compensation in full for all costs incidental thereto, including but not limited to: (1) mechanically fracturing the pavement and (2) core drilling samples of the concrete for mechanical cracking analyses.

CONCRETE CURING

SP2005-108.1 - mod

Mn/DOT specifications: 2301.3M2, 2401.3G, 2404.3C3, 2521.3C3b, 2531.3G2 are hereby modified to include the following provision:

The Contractor shall place all types of membrane cure material homogeneously to provide a uniform solid white opaque coverage on all exposed concrete surfaces (equal to a white sheet of typing paper). The membrane cure shall be placed within ½ hour of concrete placement unless otherwise directed by the Engineer. Failure to comply with these provisions will result in a price reduction for the concrete item involved in accordance with Mn/DOT 1503.

S-46.1 Cells 10 & 11 will require a curing compound and a wet burlap cure for a minimum of 24 hours after paving to prevent built-in curling. Concrete may not be placed in extreme hot or cold temperatures, as determined by the Engineer.

(2301) CONCRETE PAVEMENT

PAVEMENT TEXTURE – SURFACE FINISH

The following final surface finishes shall be applied to the proposed concrete pavements as detailed in the table below. The Contractor shall provide to the Engineer for approval, his/her proposed method for achieving each specific surface finish.

PSC CODE	**FINISHING**	**Cell/Location Allocation**	**Performance Specification**
AST.D	Astro -Turf / Hessian Drag	13 heavy 14 light	Minimum of 1.2 mm Spot mean texture depth behind the paver. Uniformity of 1.2 to 1.5 is the desired setting. The texturing will not proceed until the engineer certifies that texture lies within this range. This shall be maintained by the acceptable bristle density and uniform distributed load (UDL) achieved with a metal chain. Aggregate shall not be accepted, as UDL The surface should be void of scrapings unless the contractor guarantees that subsequent removal of the scrapings shall not result in tearing of the surface.
BLP.D	Burlap or light Hessian Drag	10	Minimum of 0.8 mm Spot tests behind the Paver. Uniformity of 0.8 to 1.0 is the desired setting. The texturing will not proceed until the engineer certifies that texture lies within this range. This shall be maintained by the acceptable bristle density and uniform distributed load(UDL) achieved with a metal chain. Aggregate shall not be accepted as UDL The surface should be void of scrapings unless the contractor guarantees that subsequent removal of the scrapings shall not affect result in tearing of the surface.
BRM.D	Broom Drag	11	Minimum of 1.2 mm Spot tests behind the paver. Uniformity of 1.2 to 1.5 is the desired setting. The texturing will not proceed until the engineer certifies that texture lies within this range. This shall be maintained by the acceptable bristle density and uniform distributed load (UDL) achieved with a metal chain. Aggregate shall not be accepted as UDL The surface should be void of scrapings unless the contractor guarantees that subsequent removal of the scrapings shall not affect result in tearing of the surface.
STP.C	Stamped Concrete	53	This shall be built to the texturing configuration specification obtained from the FHWA Office Of Pavement Technology at the time of paving. Stamped concrete shall maintain the desired imprint and should be void of tearing due to suction or other phenomena.

TRA.T	Transverse tining	TBD	To be achieved with a rake or other device that will imprint sufficient texture as would guarantee an MTD of 1.2 to 1.5mm behind the paver. The tining spacing shall be 1 inch from groove to groove and shall be perpendicular to the direction of travel. The tining depth shall be chosen to ensure sufficient friction but shall in no case be less than ¼ " in depth.
LON.T	Longitudinal tining	5	To be achieved with a rake or other device that will imprint sufficient texture as would guarantee an MTD of 1.2 to 1.5mm behind the paver. The tining spacing shall be1 inch from groove to groove and shall be parallel to the direction of travel. The tining depth shall be chosen to ensure sufficient friction but shall in no case be less than ¼ " in depth.
DIA.T	Diagonal Tining	TBD	To be achieved with a rake or other device that will imprint sufficient texture as would guarantee an MTD of 1.2 to 1.5mm behind the paver. The tining spacing shall be 1 inch from groove to groove and shall be oriented at 60 degrees to the direction of travel. The tining depth shall be chosen to ensure sufficient friction but shall in no case be less than ¼ " in depth.
RAN.T	Random Tining	TBD	To randomize the noise spectrum in the frequency domain, the interval of the tining shall stagger in this order 1 chosen to ensure sufficient friction but shall in no case ½" ; ½ " ;1" ; ½";1 ½ ". The groove depth shall be less than ¼ ".
HYD.B	Hydraulic Blasting/ Exposed Aggregate	39	Mean texture depth of 1.2 to 1.5 achieved by acceptable methods. Exposed aggregate shall be constructed with suitable mix design to assure aggregate exposure by use of a retarder and power-washing or other methods that will establish an exposed aggregate finish to meet prevailing industry standard.

PAVEMENT TEXTURE

Remove Mn/DOT 2301.3L and any other references to tining in the concrete pavement and replace with the following:

After the concrete has been consolidated, screeded, and floated, the pavement surface shall be given a final finish texture. Pavement texture shall be constructed to the performance specification in the table above. Each test shall be conducted not more than 24 hours after construction for acceptance. The acceptance tests include the test method for measuring average texture depth by the Sand Volumetric Technique ASTM E-965- 87 or the Circular Track Meter ASTM E-2157 (2005). If the contractor elects to check the texture by the sonic method behind the paver, it will be acceptable in so far as corrective measures are taken when failing textures are observed. The rate of sampling shall be 2 samples per panel, (one foot off the leave edge and mid point of the slab on a line defined at 3 ft from the outside edge).

Textures are specified for research purposes and may require removal and replacement when failing textures are observed. A failing texture in this respect is one in which a a localized measurement falls below the specified mean texture depth and one adjacent spot 3 ft

before or 3 ft after that spot fails also. Grinding is not therefore an acceptable corrective measure in that situation.

The tined segments are not only held to the texture depth standard but also the spacing as this influences the noise level being researched.

2350) BITUMINOUS MIXTURE FOR PERMEABLE ASPHALT STABILIZED STRESS RELIEF COURSE
SP2005-135 - mod

This work shall consist of constructing a Permeable Asphalt Stabilized Stress Relief Course (PASSRC) of hot plant-mixed bituminous aggregate mixture on the inplace concrete and/or bituminous (shoulder) pavement. The purpose of the PASSRC is to act as a separation layer and to more rapidly drain water from beneath the unbonded concrete overlay and thus provide greater service life.

The PASSRC shall be produced and placed in accordance with the requirements of Mn/DOT 2350, the Plan details and these Special Provisions.

MATERIALS

(A) Aggregate

The aggregate shall comply with the following requirements:

(1) General

The requirements of Mn/DOT 3139 are waived, except where specifically noted herein.

The use of recycled materials will not be permitted in the production of PASSRC mixtures. Recycled materials shall include, but are not limited to: glass, recycled asphaltic pavement, crushed concrete, and roofing shingles.

(2) Gradation

Materials for PASSRC shall meet the gradation requirements of Mn/DOT 3137, gradation CA-70, (modified to add 0-5 percent passing the 2.00 mm [**No. 10**] sieve).

The CA-70 gradation limits of Mn/DOT 3137 shall be the JMF limits.

(3) Crushing

The Fine Aggregate Angularity (FAA) requirement of Mn/DOT 2350 is waived.

(4) Quality

The aggregate shall consist of sound, durable particles of gravel, quarry rock or combinations thereof. The aggregate shall be free of matter such as metal, glass, plastic, brick, rubber, and any other objectionable material. Crushed concrete or bituminous mixtures shall not be used for PASSRC.

The Los Angeles Rattler loss on the coarse aggregate fraction (material retained on the 4.75 mm [**No. 4**] sieve) shall not exceed 40% for any individual source used within the mix. An aggregate proportion which passes the 4.75 mm [**No. 4**] sieve and exceeds 40% LAR loss on the course aggregate fraction is prohibited from use in the mixture. The Loss Angeles Rattler test procedure shall be that described by AASHTO T96, Mn/DOT modified.

Spall is defined as shale, iron oxide, unsound cherts, pyrite, highly weathered and/or soft phyllite and argilite (may be scratched with a brass pencil), and other materials having similar characteristics. The total of all spall materials, by weight of the total composite sample, shall not exceed 3 percent, based on a lithological count**. Shale content of the fraction passing the 4.75 mm [No. 4] shall not exceed 5.0 percent. Lumps in the fraction retained on the 4.75 mm [No. 4] shall not exceed 0.5 percent.**

(5) Aggregate Class

Aggregate for PASSRC shall meet the classification requirements of Mn/DOT 3137, as modified below.

(a) Class A - No changes

(b) Class B - For carbonate aggregate (limestone and dolostone) the minus 75 μm [**200**] sized portion of the insoluble residue shall not exceed 8 percent by weight. The insoluble residue test procedure is on file in the chemical laboratory, Office of Materials and Road Research.

(c) Class C - 95 percent 1-face crushing - If carbonate particles in the plus 4 aggregate exceed 40 percent by weight, the minus 75 μm [**200**] sized portion of the insoluble residue for the plus 4 carbonate fraction shall not exceed 8 percent by weight.

(d) Combinations of the above, provided each fraction meets the requirements shown above for Class A, B or C.

(B) Asphalt

The asphalt cement shall be Performance Grade (PG) 64-22 meeting AASHTO MP-1.

MIXTURE DESIGN

Mn/DOT 2350.3 is replaced with the following:

PASSRC Mixture Design and Approval

At least 15 days prior to the beginning of the mixture production, the Contractor shall submit representative samples of the aggregate and the asphalt cement, along with the production gradations, and the percentage of each aggregate component to be used in the mixture, to the Bituminous Engineer for determination of the asphalt content for the mixture. The sample shall be 35 kg [**80 pounds**] of aggregate retained in the 4.75 mm [**No. 4**] sieve and 15 kg [**35 pounds**] of aggregate passing the 4.75 mm [**No. 4**] sieve.

The percentage of asphalt to be incorporated into the mixture shall generally be between 2 and 4 percent based on the total weight of the mixture. The actual asphalt percentage will be based on the aggregate sample(s) submitted to the laboratory for testing. An acceptable asphalt content shall provide 100 percent coating of the aggregate particles with no excess run-off or puddling. The Engineer will issue a Mixture Design Report which shall include requirements for gradation and asphalt cement content The Air Void, Marshall Stability, Voids in the Mineral Aggregate, Fines to Effective Asphalt, Fine Aggregate Angularity, and Tensile Strength Ratio requirements of Mn/DOT 2350 are waived.

The aggregate used will have a large effect on the required AC content. The Contractor may wish to perform the procedure used by the Agency to determine an estimate of the AC content that will be required.

The drainage of the PASSRC layer shall be accomplished using horizontal strip wick drains at specified locations. The strip wick drain shall be made of materials capable of withstanding compaction forces of shoulder construction consisting of a minimum of 3” of Class 5 aggregate material and overlying bituminous surface, while capable of passing sufficient water from the PASSRC layer to the ditch. Choice of strip/wick drain material shall be approved by the Engineer prior to installation

CONSTRUCTION REQUIREMENTS

(A) The required construction sequence is as follows:

(1) Build PASSRC layer

(2) Construct pavement

(3) Install horizontal strip/wick drains on top of existing HMA shoulders at specified locations.

(4) Install variable depth Class 5 shoulder aggregate (do not remove the inplace bituminous shoulders)

(5) Place new bituminous shoulder structure

(B) Handling and Placement

Aggregate stockpiles shall be constructed in a manner that minimizes segregation.

Mixture production temperature, as measured at the plant site, shall not exceed 157^0 C [**315^o F**]. However, mix temperatures at the time of production shall, in the opinion of the Engineer, be high enough to ensure 100 percent coating of the aggregate particles.

Prior to the placement of the bituminous stress relief course, the pavement shall be cleaned by power sweeping and air blowing (including removing material from joints, cracks and bituminous patched areas) with 690 kPa [**100 p.s.i.**] (nominal) air pressure as directed by the Engineer. Tack surface of inplace pavement in accordance with Mn/DOT 2357.

Equipment for placing the PASSRC shall be capable of uniformity depositing and spreading the material, without segregation, to the required thickness. The placement equipment shall have an oscillatory or vibrating type screed capable of screeding the full width of material placed. It shall be the responsibility of the Contractor to place the PASSRC to a grade and tolerance such that the overlaying concrete thickness will meet minimum requirements. The material shall be placed to the width and compacted depth shown on the typical section.

The use of petroleum distillates such as kerosene and fuel oil in truck beds, paver hoppers, or rolling equipment is hereby prohibited and will be rigidly enforced.

The requirement for an asphalt tack coat, per Mn/DOT 2350.4D, is waived.

The horizontal strip/wick drains shall be placed on the existing HMA shoulder surface and protected during shoulder construction. The filter fabric cover shall be repaired to the satisfaction of the Engineer if damaged before the Class 5 placement. The drains shall be placed to pass sufficient water from the PASSRC layer to the ditch. Choice of strip/wick drain material shall be approved by the Engineer prior to installation.

(C) Maintenance

After placement and compaction, material used for PASSRC shall be dense and stable enough so that it will not be displaced or rutted during the placement of the overlay concrete. A cure period shall be provided which, in the opinion of the Engineer, will be adequate to allow the PASSRC to "firm up" before the overlaying concrete is placed.

Concrete hauling units, either loaded or empty, will be permitted on the PASSRC. If contamination of the PASSRC occurs, the Contractor shall remove and replace or clean the surface to the satisfaction of the Engineer to assure drainage capacity as designed. If rutting or other damage occurs to the PASSRC or underlying structure, the Contractor will be required to repair and level the areas prior to placement of the concrete overlay/pavement. No additional compensation will be made for corrective action.

If concrete hauling units turn around on the PASSRC, the Contractor shall protect the PASSRC from deformation by any method acceptable to the Engineer. No additional compensation will be made for protecting the PASSRC.

The PASSRC shall be kept free of fine soils or other contaminants during construction. Contaminated material shall be removed and replaced at no cost to the Agency. Prior to placement of the shoulders,
water shall be free to drain from the PASSRC to the ditch.

(D) PCC Pavement Placement

Within two hours prior to constructing the concrete overlay, the bituminous stress relief layer shall be coated with a whitewash of hydrated lime and water. The proportions used in the whitewash mixture and the rate of application shall be such that a uniform color, not darker than uncoated concrete after curing, will be produced on the surface of the stress relief layer. The purpose of the whitewash is to reduce the heat generated from the black surface of the PASSRC, and thus give an even curing temperature within the pavement depth. If the whitewash should wear off due to construction operations, it shall be replaced or the surface cooled with water prior to paving.

Damage to the PASSRC layer shall be repaired promptly by the Contractor, as directed by the Engineer, at no expense to the Agency.

MIXTURE QUALITY MANAGEMENT

The requirements for "Mixture Quality Management" under Mn/DOT 2350.5 shall be modified as follows:

Quality control (QC)

Sampling, testing, and documentation shall be limited to aggregate qualities, course aggregate angularity, belt sample gradations, and asphalt cement content spot checks. Aggregate belt samples shall be 15 kg [**35 pounds**].

Testing rates and documentation are as follows.

(1) Percent passing on sieves of Mn/DOT 3137, gradation CA-70, modified to add 0-5 percent passing the 2.00 mm [**No. 10**] sieve. (1 test per 1000 metric tons [**1000 tons**])

(2) Coarse Aggregate Angularity (1 test per 1000 metric tons [**1000 tons**])

(3) Asphalt spot checks (test as needed to control production/ minimum of one per day)

(4) Metric tons [**tons**] where sampled

(5) Cumulative metric tons [**tons**]

The control limits described in Table 2350-4 shall be waived with the exception of the limit on asphalt cement content. The JMF limits for the Asphalt Cement content shall be _ 0.3%.

During production, aggregate quality testing will be at the Engineers discretion.

PAVEMENT DENSITY

The density of all bituminous courses, shall be subject to the requirements of Mn/DOT 2350.6C Ordinary Compaction Method, or as directed by the Engineer.

Contractor is advised that it may be necessary to permit the PASSRC to cool sufficiently before compaction rolling to prevent rutting and shoving. Cooling to 65.5^0 C [**150^0 F**] may be appropriate for crushed gravel aggregates, but temperatures above 65.5^0 C [**150^0 F**] may be needed to maintain workability of crushed quarry rock aggregates. In no case shall the mix be less than 43^0 C [**110^0 F**] at time of compaction. Water may <u>not</u> be used to hasten the cooling process.

Steel-wheeled and/or vibratory roller(s) meeting the requirements of Mn/DOT 2350.6C2 shall be used for compaction, with the exception that <u>vibratory compaction will NOT be allowed</u>. Rollers must be steel-wheeled both front and back. When the amount of mixture placed exceeds 100 metric tons [**100 tons**] per hour, at least two rollers shall be used. Adequacy of compaction to provide stability will be judged by the Engineer. Two roller passes should provide adequate compaction, depending on roller size. Overrolling, to the extent that aggregate particles degrade, will not be permitted.

THICKNESS AND SURFACE SMOOTHNESS REQUIREMENTS

CONTRACTOR SURVEY METHOD FOR PAVEMENT PROFILE CONTROL

(1) The Contractor shall place the Permeable Asphalt Stabilized Stress Relief Course (PASSRC) layer to the width and compacted depth shown on the typical section in the plans.

(2) Subsequent to the complete placement of all of the (PASSRC), the Contractor shall survey the pavement surface at 15 m [**50 foot**] maximum intervals (7 m [**25 feet**] in transitions) at the centerline and 3.6 m [**12 feet**] left and right of centerline and place hubs at 15 m [**50 foot**] intervals on

both sides of roadway. The Contractor shall use these results to establish a recommended paving profile for review by the Engineer. The Engineer will approve or disapprove the Contractor's recommended paving profile within 3 working days. Approval will be based on establishing a concrete paving profile that closely follows the old profile to control concrete quantity but has no abrupt changes.

(3) The Contractor will be required to set and use stringlines for grade control on both sides of the roadway during their paving operations.

(4) The Contractor will be paid for all of the Structural Concrete produced and placed up to 102 percent of the approved amount computed by the Contractors survey crew in their determination of the profile and resulting estimated structural concrete quantity, unless otherwise approved by the Engineer. The quantity shall be determined based on computerized printouts from the Contractor's plant as verified by cement cutoffs with the consideration of any waste as determined by the Engineer.

(5) The Contractor shall not make claim for any additional ride incentive or a reduction in the ride disincentive due to Mn/DOT selecting the finished profile of the concrete overlay.

(6) All concrete cores shall be taken at 0.6 m [**2 feet**] from the outside pavement edge.

MEASUREMENT AND PAYMENT

Method of measurement for PASSRC will be in accordance with Mn/DOT 2350.8, modified as follows. Bituminous mixture and bituminous material for mixture will be paid for separately.

(A) Measurement will be made by the weight of bituminous mixture for PASSRC. Payment will be made under Item 2350.609 (Bituminous Mixture for Permeable Asphalt Stabilized Stress Relief Course) at the Contract bid price per metric ton [**ton**]. Payment for the accepted bituminous mixture shall be payment in full for all costs of constructing the PASSRC surface, including the costs of the mixture production, aggregate incorporated, placement, and compaction. Cost for Asphalt Cement is specifically excluded.

(B) Measurement will be made by the weight of Asphalt Cement incorporated into the PASSRC bituminous mixture. Payment will be made under Item 2350.609 (Asphalt Cement for Mixture) at the Contract bid price per metric ton [**ton**]. Payment for the asphalt cement, based on the acceptance of the PASSRC bituminous mixture, will be payment in full for asphalt cement, any additives, and the incorporation of the cement into the mixture.

(C) Measurement will be made by the Linear Foot of Wick Drain installed as specified on the existing bituminous shoulders. Payment will be made under Item 2105.603 (Wick Drain) at the Contract bid price per meter [**linear foot**]. Which will be payment in full for

costs of constructing and replacing damaged drains if necessary, as specified and approved by the Engineer.

Appendix B: Sensor Locations

Table B.1. Cell 105 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	SN	ORIENTATION	DEPTH (in)	STATION	OFFSET (FT)	NORTHING	EASTING	ELEVATION
105	CE	101	236	LONGITUDINAL	0.25	1126+64.28	-13.7	207372.274	539896.21	
105	CE	102	231	LONGITUDINAL	3.76	1126+64.28	-13.7	207372.274	539896.21	949.19
105	CE	103	233	39o	0.25	1126.65.14	-12.0	207370.401	539895.85	
105	CE	104	105	39o	3.76	1126.65.14	-12.0	207370.401	539895.85	949.22
105	CE	105	237	LONGITUDINAL	0.25	1126+65.27	-11.2	207369.707	539895.48	
105	CE	106	102	LONGITUDINAL	3.76	1126+65.27	-11.2	207369.707	539895.48	949.21
105	CE	107		TRANSVERSE	0.25	1126+66	-11.0			
105	CE	108		LONGITUDINAL	0.25	1126+66	-7.0			
105	CE	109	97	LONGITUDINAL	0.25	1126+70.21	-13.6	207368.626	539900.88	
105	CE	110	165	LONGITUDINAL	3.76	1126+70.21	-13.6	207368.626	539900.88	949.28
105	CE	111	96	39o	0.25	1126+69.53	-12.0	207367.787	539899.38	
105	CE	112	163	39o	3.76	1126+69.53	-12.0	207367.787	539899.38	949.26
105	CE	113	95	LONGITUDINAL	0.25	1126+69.26	-11.1	207367.216	539898.60	
105	CE	114	76	LONGITUDINAL	3.76	1126+69.26	-11.1	207367.216	539898.60	949.27
105	CE	115		TRANSVERSE	0.25	1126+68	-11.0			
105	CE	116		LONGITUDINAL	0.25	1126+68	-7.0			
105	DT	101		VERTICAL	0.75	1126+67	-14.2			
105	DT	102		VERTICAL	0.75	1126+67	-14.2			
105	IV	101			8.00	1126+67	-14.3	207370.979	539898.97	948.96

Table B.2. Cell 205 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (in)	STATION	OFFSET (FT)	Northing	Easting	Elevation
205	CE	117	LONGITUDINAL	3.76	1128+42.61	-13.7	207263.785	540037.736	951.38
205	CE	118	TRANSVERSE	3.76	1128+42.50	-11.1	207261.846	540036.113	951.44
205	CE	119	LONGITUDINAL	3.76	1128+43.03	-11.2	207261.607	540036.592	951.46
205	CE	120	TRANSVERSE	3.76	1128+42.6	-7.1	207258.594	540033.743	951.51
205	CE	121	LONGITUDINAL	3.76	1128+43.07	-7.1	207258.322	540034.120	951.51
205	CE	122	LONGITUDINAL	3.76	1128+47.00	-13.6	207261.095	540041.200	951.72
205	CE	123	39°	3.76	1128+47.84	-12.1	207259.375	540040.944	951.54
205	CE	124	TRANSVERSE	3.76	1128+49.04	-11.2	207257.888	540041.310	951.44
205	CE	125	TRANSVERSE	3.76	1128+49.12	-6.6	207254.253	540038.629	951.48
205	CE	126	LONGITUDINAL	3.76	1128+53.05	-13.7	207257.444	540046.032	951.52
205	CE	127	39°	3.76	1128+52.22	-12.1	207256.73	540044.427	951.6
205	CE	128	TRANSVERSE	3.76	1128+51.1	-11.2	207256.633	540042.949	951.53
205	CE	129	TRANSVERSE	3.76	1128+51.11	-6.6	207253.052	540040.219	951.54
205	CE	130	LONGITUDINAL	3.76	1128+57.55	-13.6	207254.643	540049.552	951.54
205	CE	131	TRANSVERSE	3.76	1128+57.58	-7.2	207249.518	540045.659	951.62
205	DT	103	VERTICAL	0.75	1128+42.5	-14.2			
205	DT	104	VERTICAL	0.75	1128+50	-14.2			
205	DT	105	VERTICAL	0.75	1128+50	-14.2			
205	DT	106	VERTICAL	0.75	1128+57.5	-14.2			
205	HC	101	HORIZONTAL	1.00	1128+50	-13.0			
205	HC	102	HORIZONTAL	3.00	1128+50	-12.5			
205	HC	103	HORIZONTAL	1.00	1128+50	-7.0			
205	HC	104	HORIZONTAL	3.00	1128+50	-6.5			
205	IK	101	VERTICAL	1.00	1128+58.67	-13.6	207253.932	540050.416	951.87
205	IK	102	VERTICAL	2.00	1128+59.2	-13.6	207253.615	540050.844	951.8
205	IK	103	VERTICAL	3.00	1128+58.68	-13.5	207253.878	540050.390	951.74
205	IK	104	VERTICAL	1.00	1128+59.44	-12.1	207252.322	540050.151	951.9
205	IK	105	VERTICAL	2.00	1128+59.87	-12.2	207252.127	540050.548	951.81
205	IK	106	VERTICAL	3.00	1128+59.51	-12.1	207252.274	540050.203	951.75
205	IV	102		8.00	1128+42.67	-14.4	207264.358	540038.248	951.24
205	IV	103		8.00	1128+50.4	-14.4	207259.874	540044.100	951.6
205	IV	104		8.00	1128+57.18	-14.5	207255.555	540049.777	951.71
205	TC	101	VERTICAL	0.50	1128+35.67	-13.4	207267.803	540032.064	954.55
205	TC	102	VERTICAL	1.00	1128+35.67	-13.4	207267.803	540032.064	

Table B.3. Cell 205 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (in)	STATION	OFFSET (FT)	Northing	Easting	Elevation
205	TC	103	VERTICAL	1.50	1128+35.67	-13.4	207267.803	540032.064	
205	TC	104	VERTICAL	2.00	1128+35.67	-13.4	207267.803	540032.064	
205	TC	105	VERTICAL	3.00	1128+35.67	-13.4	207267.803	540032.064	
205	TC	106	VERTICAL	4.00	1128+35.67	-13.4	207267.803	540032.064	
205	TC	107	VERTICAL	5.00	1128+35.67	-13.4	207267.803	540032.064	
205	TC	108	VERTICAL	8.00	1128+35.67	-13.4	207267.803	540032.064	
205	TC	109	VERTICAL	0.50	1128+41.04	-7.1	207259.545	540032.502	954.55
205	TC	110	VERTICAL	1.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	111	VERTICAL	2.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	112	VERTICAL	2.50	1128+41.04	-7.1	207259.545	540032.502	
205	TC	113	VERTICAL	3.50	1128+41.04	-7.1	207259.545	540032.502	
205	TC	114	VERTICAL	4.50	1128+41.04	-7.1	207259.545	540032.502	
205	TC	115	VERTICAL	6.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	116	VERTICAL	9.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	117	VERTICAL	11.50	1128+41.04	-7.1	207259.545	540032.502	
205	TC	118	VERTICAL	15.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	119	VERTICAL	18.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	120	VERTICAL	24.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	121	VERTICAL	36.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	122	VERTICAL	48.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	123	VERTICAL	60.00	1128+41.04	-7.1	207259.545	540032.502	
205	TC	124	VERTICAL	72.00	1128+41.04	-7.1	207259.545	540032.502	
205	VW	101	LONGITUDINAL	1.00	1128+57.54	-12.1	207253.44	540048.614	951.4
205	VW	102	LONGITUDINAL	3.00	1128+57.48	-12.1	207253.511	540048.589	951.57
205	VW	103	LONGITUDINAL	1.00	1128+57.09	-7.1	207249.774	540045.236	951.85
205	VW	104	LONGITUDINAL	3.00	1128+57.13	-7.1	207249.768	540045.279	951.72
205	VW	105	TRANSVERSE	1.00	1128+58.16	-7.2	207249.18	540046.133	951.95
205	VW	106	TRANSVERSE	3.00	1128+58.14	-7.2	207249.212	540046.124	951.78
205	VW	107	LONGITUDINAL	1.00	1128+62.07	-13.1	207251.48	540052.821	951.95
205	VW	108	LONGITUDINAL	3.00	1128+62.08	-13.1	207251.484	540052.840	951.81
205	VW	109	39°	1.00	1128+62.90	-12.1	207250.224	540052.905	951.93
205	VW	110	39°	3.00	1128+62.09	-12.1	207250.234	540052.905	951.977
205	VW	111	TRANSVERSE	1.00	1128+64.05	-11.1	207248.722	540053.203	951.95
205	VW	112	TRANSVERSE	3.00	1128+64.04	-11.1	207248.756	540053.210	951.77

Table B.4. Cell 205 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (in)	STATION	OFFSET (FT)	Northing	Easting	Elevation
205	VW	113	TRANSVERSE	1.00	1128+63.53	-7.7	207246.299	540050.691	951.96
205	VW	114	TRANSVERSE	3.00	1128+63.53	-7.6	207246.267	540050.666	951.81
205	VW	115	LONGITUDINAL	1.00	1128+64.08	-7.7	207245.958	540051.125	952.02
205	VW	116	LONGITUDINAL	3.00	1128+64.05	-7.7	207245.988	540051.105	951.87
205	XV	101	LONGITUDINAL	1.00	1128+57.54	-12.1	207253.44	540048.614	951.4
205	XV	102	LONGITUDINAL	3.00	1128+57.48	-12.1	207253.511	540048.589	951.57
205	XV	103	LONGITUDINAL	1.00	1128+57.09	-7.1	207249.774	540045.236	951.85
205	XV	104	LONGITUDINAL	3.00	1128+57.13	-7.1	207249.768	540045.279	951.72
205	XV	105	TRANSVERSE	1.00	1128+58.16	-7.2	207249.18	540046.133	951.95
205	XV	106	TRANSVERSE	3.00	1128+58.14	-7.2	207249.212	540046.124	951.78
205	XV	107	LONGITUDINAL	1.00	1128+62.07	-13.1	207251.48	540052.821	951.95
205	XV	108	LONGITUDINAL	3.00	1128+62.08	-13.1	207251.484	540052.840	951.81
205	XV	109	39°	1.00	1128+62.90	-12.1	207250.224	540052.905	951.93
205	XV	110	39°	3.00	1128+62.09	-12.1	207250.234	540052.905	951.977
205	XV	111	TRANSVERSE	1.00	1128+64.05	-11.1	207248.722	540053.203	951.95
205	XV	112	TRANSVERSE	3.00	1128+64.04	-11.1	207248.756	540053.210	951.77
205	XV	113	TRANSVERSE	1.00	1128+63.53	-7.7	207246.299	540050.691	951.96
205	XV	114	TRANSVERSE	3.00	1128+63.53	-7.6	207246.267	540050.666	951.81
205	XV	115	LONGITUDINAL	1.00	1128+64.08	-7.7	207245.958	540051.125	952.02
205	XV	116	LONGITUDINAL	3.00	1128+64.05	-7.7	207245.988	540051.105	951.87
205	EC	101		11.50	1128+41.04	-7.1	207259.545	540032.502	
205	EC	102		15.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	103		18.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	104		24.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	105		36.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	106		48.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	107		60.00	1128+41.04	-7.1	207259.545	540032.502	
205	EC	108		72.00	1128+41.04	-7.1	207259.545	540032.502	

Table B.5. Cell 305 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (FT)	STATION	OFFSET (FT)	NORTHING	EASTING	ELEVATION
305	CE	132	LONGITUDINAL	0.396	1129+32.43	-13.6	207209.1	540108.988	952.48
305	CE	133	TRANSVERSE	0.396	1129+32.38	-11.1	207207.176	540107.45	952.55
305	CE	134	LONGITUDINAL	0.396	1129+32.92	-11.2	207206.872	540107.896	952.53
305	CE	135	TRANSVERSE	0.396	1129+32.47	-7.1	207203.947	540105.092	952.57
305	CE	136	LONGITUDINAL	0.396	1129+33	-7.2	207203.638	540105.523	952.58
305	CE	137	LONGITUDINAL	0.396	1129+37.03	-13.6	207206.323	540112.656	952.65
305	CE	138	39°	0.396	1129+37.81	-12.1	207204.653	540112.357	952.66
305	CE	139	TRANSVERSE	0.396	1129+38.99	-11.2	207203.186	540112.717	5952.61
305	CE	140	TRANSVERSE	0.396	1129+38.99	-7.2	207200.034	540110.306	952.64
305	CE	141	LONGITUDINAL	0.396	1129+43	-13.6	207202.706	540117.406	952.66
305	CE	142	39°	0.396	1129+42.09	-12.1	207202.002	540115.722	952.74
305	CE	143	TRANSVERSE	0.396	1129+40.97	-11.2	207201.978	540114.282	952.69
305	CE	144	TRANSVERSE	0.396	1129+40.97	-7.2	207198.836	540111.874	952.7
305	CE	145	LONGITUDINAL	0.396	1129+47.63	-13.6	207199.842	540121.046	952.69
305	CE	146	TRANSVERSE	0.396	1129+47.47	-7.1	207194.802	540116.977	952.77
305	DT	107	VERTICAL	0.0625	1129+32.5	-14.2			
305	DT	108	VERTICAL	0.0625	1129+40	-14.2			
305	DT	109	VERTICAL	0.0625	1129+40	-14.2			
305	DT	110	VERTICAL	0.0625	1129+47.5	-14.2			
305	HC	105	HORIZONTAL	0.083	1129+40	-13.0			
305	HC	106	HORIZONTAL	0.33	1129+40	-12.5			
305	HC	107	HORIZONTAL	0.083	1129+40	-7.0			
305	HC	108	HORIZONTAL	0.33	1129+40	-6.5			
305	IK	110		0.083	1129+31.43	-13.5	207209.628	540108.133	952.82
305	IK	111		0.208	1129+31.05	-13.5	207209.86	540107.825	952.72
305	IK	112		0.33	1129+31.41	-13.5	207209.625	540108.104	952.59
305	IK	113		0.083	1129+31.45	-12.1	207208.518	540107.305	952.86
305	IK	114		0.208	1129+30.99	-12.1	207208.776	540106.925	952.73
305	IK	115		0.33	1129+31.49	-12.1	207208.516	540107.35	952.63
305	IV	105		0.667	1129+32.56	-14.5	207209.753	540109.647	952.02
305	IV	106		0.667	1129+40.01	-14.0	207205.147	540115.509	951.86
305	IV	107		0.667	1129+47.47	-14.5	207200.645	540121.45	952.42
305	TC	125		0.042	1129+38.02	-13.3	207205.464	540113.239	952.97
305	TC	126		0.083	1129+38.02	-13.3	207205.464	540113.239	

Table B.6. Cell 305 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (FT)	STATION	OFFSET (FT)	NORTHING	EASTING	ELEVATION
305	TC	127		0.125	1129+38.02	-13.3	207205.464	540113.239	
305	TC	128		0.208	1129+38.02	-13.3	207205.464	540113.239	
305	TC	129		0.375	1129+38.02	-13.3	207205.464	540113.239	
305	TC	130		0.458	1129+38.02	-13.3	207205.464	540113.239	
305	TC	131		0.708	1129+38.02	-13.3	207205.464	540113.239	
305	TC	132		0.958	1129+38.02	-13.3	207205.464	540113.239	
305	TC	133		0.042	1129+34.52	-6.6	207202.292	540106.396	953.02
305	TC	134		0.083	1129+34.52	-6.6	207202.292	540106.396	
305	TC	135		0.125	1129+34.52	-6.6	207202.292	540106.396	
305	TC	136		0.208	1129+34.52	-6.6	207202.292	540106.396	
305	TC	137		0.375	1129+34.52	-6.6	207202.292	540106.396	
305	TC	138		0.458	1129+34.52	-6.6	207202.292	540106.396	
305	TC	139		0.708	1129+34.52	-6.6	207202.292	540106.396	
305	TC	140		0.958	1129+34.52	-6.6	207202.292	540106.396	
305	VW	117	LONGITUDINAL	0.083	1129+47.54	-13.1	207199.478	540120.644	952.75
305	VW	118	LONGITUDINAL	0.33	1129+47.55	-13.0	207199.42	540120.621	952.86
305	VW	119	LONGITUDINAL	0.083	1129+46.92	-7.1	207195.155	540116.549	953.06
305	VW	120	LONGITUDINAL	0.33	1129+46.89	-7.2	207195.207	540116.558	952.84
305	VW	121	TRANSVERSE	0.083	1129+47.99	-7.2	207194.523	540117.417	953.17
305	VW	122	TRANSVERSE	0.33	1129+48.04	-7.1	207194.478	540117.442	952.92
305	VW	123	LONGITUDINAL	0.083	1129+52.02	-13.1	207196.747	540124.203	953.17
305	VW	124	LONGITUDINAL	0.33	1129.+52.05	-13.0	207196.691	540124.19	952.95
305	VW	125	39°	0.083	1129+52.79	-12.1	207195.485	540124.206	953.13
305	VW	126	39°	0.33	1129+52.83	-12.1	207195.459	540124.233	952.89
305	VW	127	TRANSVERSE	0.083	1129+53.97	-11.1	207194.014	540124.559	953.14
305	VW	128	TRANSVERSE	0.33	1129+53.97	-11.1	207194.021	540124.57	952.91
305	VW	129	TRANSVERSE	0.083	1129+53.37	-7.2	207191.312	540121.741	953.2
305	VW	130	TRANSVERSE	0.33	1129+53.41	-7.2	207191.241	540121.728	952.95
305	VW	131	LONGITUDINAL	0.083	1129+53.92	-7.2	207190.981	540122.18	953.24
305	VW	132	LONGITUDINAL	0.33	1129+53.93	-7.2	207190.975	540122.187	953.01
305	XV	117	LONGITUDINAL	0.083	1129+47.54	-13.1	207199.478	540120.644	952.75
305	XV	118	LONGITUDINAL	0.33	1129+47.55	-13.0	207199.42	540120.621	952.86
305	XV	119	LONGITUDINAL	0.083	1129+46.92	-7.1	207195.155	540116.549	953.06
305	XV	120	LONGITUDINAL	0.33	1129+46.89	-7.2	207195.207	540116.558	952.84

Table B.7. Cell 305 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (FT)	STATION	OFFSET (FT)	NORTHING	EASTING	ELEVATION
305	XV	121	TRANSVERSE	0.083	1129+47.99	-7.2	207194.523	540117.417	953.17
305	XV	122	TRANSVERSE	0.33	1129+48.04	-7.1	207194.478	540117.442	952.92
305	XV	123	LONGITUDINAL	0.083	1129+52.02	-13.1	207196.747	540124.203	953.17
305	XV	124	LONGITUDINAL	0.33	1129.+52.05	-13.0	207196.691	540124.19	952.95
305	XV	125	39°	0.083	1129+52.79	-12.1	207195.485	540124.206	953.13
305	XV	126	39°	0.33	1129+52.83	-12.1	207195.459	540124.233	952.89
305	XV	127	TRANSVERSE	0.083	1129+53.97	-11.1	207194.014	540124.559	953.14
305	XV	128	TRANSVERSE	0.33	1129+53.97	-11.1	207194.021	540124.57	952.91
305	XV	129	TRANSVERSE	0.083	1129+53.37	-7.2	207191.312	540121.741	953.2
305	XV	130	TRANSVERSE	0.33	1129+53.41	-7.2	207191.241	540121.728	952.95
305	XV	131	LONGITUDINAL	0.083	1129+53.92	-7.2	207190.981	540122.18	953.24
305	XV	132	LONGITUDINAL	0.33	1129+53.93	-7.2	207190.975	540122.187	953.01

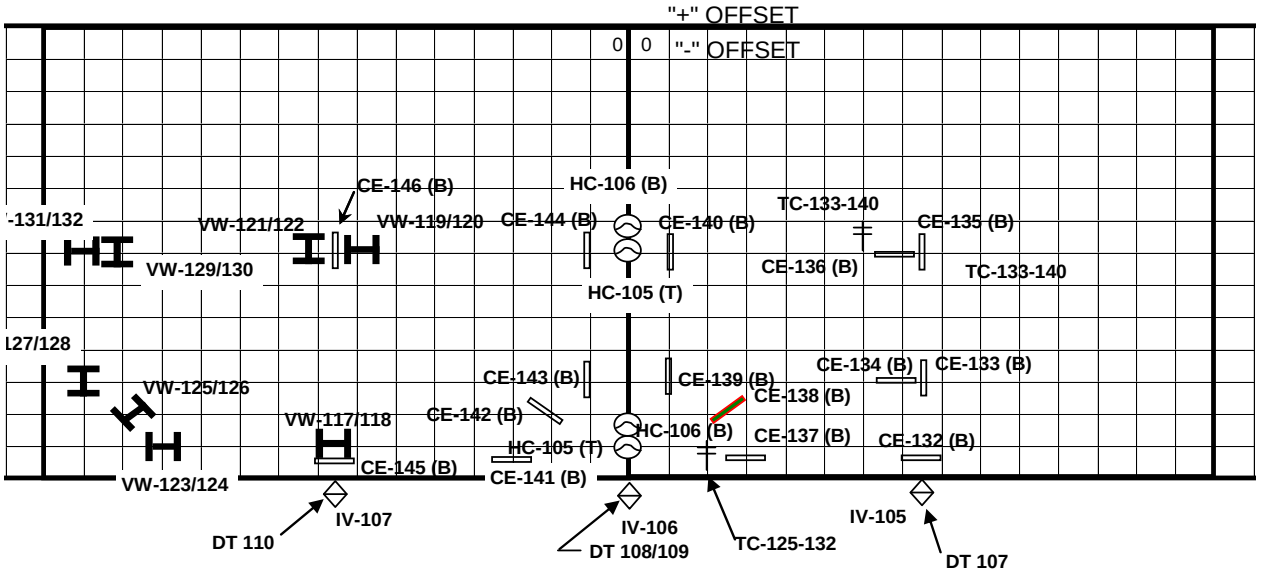

Figure B.1. Cell 305 As-Built Sensor Locations

Table B.8. Cell 405 Sensor Plan and As-Built Locations

CELL	MODEL	SEQ	ORIENTATION	DEPTH (FT)	STATION	OFFSET (FT)	NORTHING	EASTING	ELEVATION
405	CE	147	LONGITUDINAL	0.021	1130+85.12	-13.6	207116.229	540230.19	
405	CE	148	LONGITUDINAL	0.396	1130+85.12	-13.6	207116.229	540230.19	953.02
405	CE	149	39°	0.021	1130+85.95	-12.0	207114.433	540229.85	
405	CE	150	39°	0.396	1130+85.95	-12.0	207114.433	540229.85	954.31
405	CE	151	LONGITUDINAL	0.021	1130+86.08	-11.1	207113.616	540229.39	
405	CE	152	LONGITUDINAL	0.396	1130+86.08	-11.1	207113.616	540229.39	954.47
405	CE	153	TRANSVERSE	0.021	1130+87	-11.0			
405	CE	154	LONGITUDINAL	0.021	1130+87	-7.0			
405	CE	155	LONGITUDINAL	0.021	1130+91.10	-13.6	207112.547	540234.9	
405	CE	156	LONGITUDINAL	0.396	1130+91.10	-13.6	207112.547	540234.9	954.5
405	CE	157	39°	0.021	1130+90.18	-12.1	207111.934	540233.27	
405	CE	158	39°	0.396	1130+90.18	-12.1	207111.934	540233.27	954.51
405	CE	159	LONGITUDINAL	0.021	1130+90.07	-11.2	207111.289	540232.63	
405	CE	160	LONGITUDINAL	0.396	1130+90.07	-11.2	207111.289	540232.63	954.55
405	CE	161	TRANSVERSE	0.021	1130+89	-11.0			
405	CE	162	LONGITUDINAL	0.021	1130+89	-7.0			
405	DT	111	VERTICAL	0.0625	1130+88.17	-14.2			
405	DT	112	VERTICAL	0.0625	1130+88.17	-14.2			
405	IV	108		0.667	1130+88.17	-14.4	207115.022	540233.1	953.26

Appendix C: Documentation of Distressed Joints Prior to PCC OL

Figure C.1. Joint No. 2 (Underlying PCC, prior to OL)

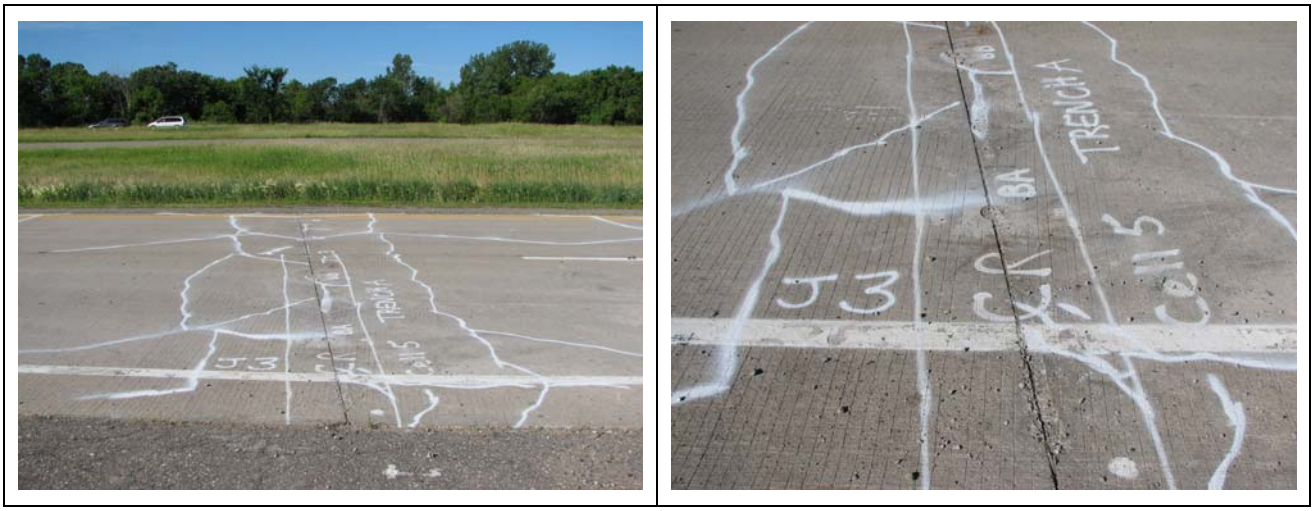

Figure C.2. Joint No. 3 (Underlying PCC, prior to OL)

Figure C.3. Joint No. 4 (Underlying PCC, prior to OL)

Figure C.4. Joint No. 5 (Underlying PCC, prior to OL)

FigureC.5. Joint No. 6 (Underlying PCC, prior to OL)

Figure C.6. Joint No. 7 (Underlying PCC, prior to OL)

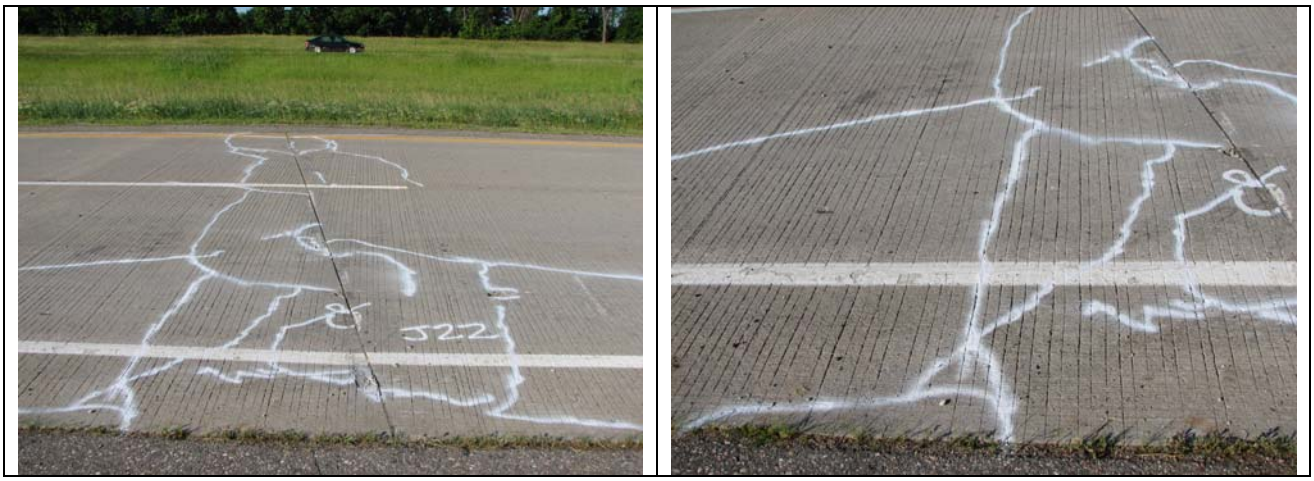

Figure C.7. Joint No. 22 (Underlying PCC, prior to OL)

Figure C.8. Joint No. 23 (Underlying PCC, prior to OL)

Figure C.9. Joint No. 24 (Underlying PCC, prior to OL)

Figure C.10. Joint No. 25 (Underlying PCC, prior to OL)

Figure C.11. Joint No. 26 (Underlying PCC, prior to OL)