DEPARTMENT OF TRANSPORTATION

2022 MnROAD Construction Activities

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Minnesota Department of Transportation

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Research Project of the National Road Research Alliance
Final Report 2023-37

MnROAD
SAFER, SMARTER, SUSTAINABLE PAVEMENTS THROUGH INNOVATIVE RESEARCH

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16. Abstract (Limit: 250 words)

The 2022 construction season at the MnROAD facility saw construction of 39 new and unique pavement test sections and the repairs of 6 existing test sections. These sections were planned and designed by the National Road Research Alliance (NRRA) teams to address high-priority research needs. This report details development, design, and construction of each test section supporting the associated research studies developed by the teams. Individual study details are left to future reports generated by the individual research contracts and their respective NRRA teams. As a multi-state, pooled-fund program, the National Road Research Alliance (NRRA) provides strategic implementation of pavement engineering solutions through cooperative research.

For Phase II, NRRA focused on improving sustainability and resiliency of our national pavement system and studying and promoting intelligent construction technologies. Based on these goals, some test sections were rehabilitated to extend their life by recycling in-situ material and applying preventive maintenance techniques. Newly constructed tests sections used innovative materials such as plastic, rubber and fibers for asphalt pavements and alternative cementitious, alternative supplementary cementitious, and carbon injection for concrete pavements. Two test sections served perpetual pavement and wicking geotextile research projects. Both were designed and constructed as perpetual pavements one of them with a wicking geotextile on top of the subgrade for improving drainage and stiffness of road foundation and quantifying its long-term benefits. Six test sections were repaired using performance engineered mixes on the replacement panels and finished with diamond grinding to eliminate faulting.

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2022 MnROAD CONSTRUCTION ACTIVITIES

FINAL REPORT

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Illinois Tollway
Iowa DOT
Georgia DOT**
Michigan DOT
Minnesota DOT
Minnesota Local Road Research Board (LRRB)
Mississippi DOT
Missouri DOT
Nebraska DOT
New York State DOT**
North Dakota DOT
Wisconsin DOT

** States continuing involvement with the Veta Pooled fund, which is now part of NRRA research.

Associate Member Organizations

Academia
Auburn University's National Center for Asphalt Technology (NCAT)
Cal State LA

Iowa State University

- Institute for Transportation's National Concrete Pavement Technology Center
- Institute for Transportation's Asphalt Materials and Pavement Program (AMPP)

Michigan State University
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Minnesota State University Mankato Center for Transportation Research and Implementation
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North Dakota State University Upper Great Plains Transportation Institute (UGPTI)
South Dakota State, South Dakota Local Transportation Assistance Program
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University of Missouri - Columbia
University of Nevada - Reno
University of New Hampshire
University of North Dakota
University of Pittsburgh, Swanson Engineering
University of St. Thomas
University of Texas El Paso (UTEP) Center for Transportation Infrastructure Systems (CTIS)
Washington State University

Associations

Aggregate and Ready-Mix Association of Minnesota
Asphalt Pavement Alliance (APA)
Asphalt Recycling & Reclaiming Association (ARRA)
Indiana Soybean Alliance
Minnesota Asphalt Pavement Association (MAPA)
National Asphalt Pavement Association (NAPA)
National Stone Sand and Gravel Association (NSSGA)
Wisconsin Concrete Pavement Association

Private Industries

3M Transportation Safety Division
All States Materials Group
American Engineering Testing, Inc.
Astec Industries
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Bio-Based Spray Systems
Braun Intertec
CarbonCure

Cargill Industrial Specialties
Caterpillar Paving Products
Collaborative Aggregates, LLC
The Dow Chemical Company
Earth Science Systems, LLC
First State Tire Recycling and R.-T.E.A. Manufacturing
Flint Hills Resources
Flyereld Consulting
Leica Geosystems
Liberty Tire Recycling
Mathy Construction Co.
Midstate Reclamation and Trucking
Minnesota Paving and Materials (Formerly Hardrives)
MOBA Automation
Owens Corning
Pacific Geosource
Payne and Dolan, Inc.
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Infrasense, Inc.
IngevityWSB & Associates, Inc.
Ingios Geotechnics, Inc.
Tricor Refining
Trimble
Uberbinder
Wirtgen Group

Construction Operations

C.S. McCrossan Construction, Inc
PCi Roads, LLC
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Antigo Construction, Inc
Bolton & Menk

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Ingios Geotechnics, Inc.
Interstate Improvements, Inc
J & R Larson Grounds Maintenance, LLC
Mid-State Reclamation, Inc
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MnDOT St. Cloud
MnDOT Maplewood Lab
Michigan State University (MSU)
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On Call Pavement Sweeping, Inc
Reiner Contracting, Inc.
SOLMAX (Formerly TenCate)
The Transtec Group
University of Texas – El Paso (UTEP)
North Dakota State University (NDSU)
National Center for Asphalt Technology (NCAT)

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List of Abbreviations and Technology Terms

APLT ....Automated Plate Load Test
ASCM............................Alternative Supplementary Cementitious Materials
CIR ....Cold-In-Place Recycling
COA ....Concrete Overlay with Asphalt
CPR ....Concrete Pavement Rehabilitation
DCP...............................Dynamic Cone Penetrometer
DIV................................Digital Inspection Vehicle
DPI ....Dynamic Penetrometer Index
DPS ....Dielectric Profile System
ESAL..............................Equivalent Single Axle Load
FRC ....Fiber-reinforced Concrete
FWD..............................Falling Weight Deflectometer
GN ....Granular Number
HMA ....Hot Mix Asphalt Pavement
IRI ....International Roughness Index
LISA...............................Lightweight Inertial Surface Analyzer
LVR ....Low volume road at MnROAD
LWD..............................Lightweight Deflectometer
MnDOT..........................Minnesota Department of Transportation
MnROAD ....Minnesota Road Research Project
MIRA.............................Ultrasonic Pulse Echo Device
Mr-Values.....................Resilient Modulus Values
Mr-Composite ....Composite Resilient Modulus Values
MSU..............................Michigan State University
NCAT ....National Center for Asphalt Technology
NDSU ....North Dakota State University
NMAS ....Nominal Maximum Aggregate Size
NRRA ....National Road Research Alliance
PCC ....Portland Cement Concrete Pavement
PEM ....Performance Engineered Mixtures
RAB...............................Recycled Aggregate Base
RAP ....Recycled Asphalt Pavement
RCA...............................Recycled Concrete Aggregate
Road Doctor ....Road Survey Van with Innovative Technology
RSR ....Residual Strength Ratio
SCM ....Supplementary Cementitious Materials

SEAT ....First two blows of a DCP test
UTBWC..........................Ultra-thin Bonded Wearing Course
UTEP..............................University of Texas - El Paso
VMA ....Voids in Mineral Aggregate
TC ....Thermocouple Tree
TGA...............................Thermal Gravimetric Analysis
VW................................Vibrating Wire
XRD...............................X-Ray Diffraction
XRF ....X-Ray Fluorescence

EXECUTIVE SUMMARY

The National Road Research Alliance (NRRA), a multi-state pooled-fund project (TPF-5 (466)), is an innovative endeavor of the Minnesota Department of Transportation Office of Materials Road Research. The NRRA exists to:

- Evaluate pavement materials, equipment, and methods under real-world conditions.
- Leverage knowledge, skills, and resources from participating partners to advance pavement research and implementation efforts.
- Establish industry standards and develop performance measures for improving pavement performance.
- Develop and/or revise construction and materials specifications and recommendations.
- Study and promote innovative techniques and technologies that will save agencies resources, improve safety, and increase efficiency.
- Support the exchange of information and ideas through collaborative research efforts that provide opportunities for public agencies to share experiences.
- Support technology transfer that highlights the implementation of research results and the associated benefits.

Led by an Executive Committee of DOT and local agency partners, the NRRA consists of five technical projects teams: Flexible, Rigid, Geotechnical, Preventive Maintenance (PM), and intelligent construction technologies (ICT). NRRA membership also includes “associate members,” consisting of industry, academia, associations, and consultants who were instrumental in accomplishing both the research and the 2022 construction efforts.

For the 2022 MnROAD Construction (NRRA Phase II/MnROAD Phase IV), NRRA is narrowing focus to two primary objectives:

1. Improving long-term sustainability of the national pavement system through the study of optimized designs, innovative recycling methods, next generation materials, and associated construction methods.
2. Studying and promoting intelligent construction technologies that will increase construction efficiency, enhance pavement performance, and improve construction site safety.

The 2022 construction season at MnROAD saw the construction of 39 new and unique test sections and the repair of 6 test sections. These sections, designed to address NRRA high-priority sustainability focused research topics, were conceived and planned by members of the five NRRA technical teams.

This report details the development of the individual long-term research area projects, the pavement sections designed to meet those needs, and the construction of them. Each specific group of tests sections support long-term research contracts. Details and results of each individual study are left to future reports generated by the individual research contracts and their respective teams. Each of the research projects are discussed in individual chapters.

Chapter 1: Introduction

1.1 MnROAD Facility

The Minnesota Road Research Project (MnROAD) is a pavement test facility owned and operated by the Minnesota Department of Transportation (MnDOT). The facility, located on westbound I-94, northwest of the Twin Cities metropolitan area, was constructed in 1990-1993 and opened to traffic in 1994. With the 2022 construction described in this report, MnROAD now has four separate experimental roadways segments:

- 2.7-mile, two-lane, westbound I-94 mainline with live traffic. This segment averages 26,500 vehicles per day with 13 percent trucks and provides approximately 750,000 flexible and 1,000,000 rigid equivalent single axle loads (ESALs) per year.
- 2.5-mile, two-lane closed loop low-volume road (LVR). Traffic on the LVR is provided by an 80-kip, 5-axle, tractor/trailer combination. The combination averages approximately 70 laps a day and is restricted to the inside lane only. The outer lane of the LVR is preserved for the study of environmental effects alone.
- 1000-foot long, two-lane roadway in the MnROAD stockpile area. This area has been used for testing the impact of implements of husbandry on low-volume roads and is periodically used by contractors to test placement methods before proceeding to test sections on the mainline or LVR.
- A newly constructed in 2017 series of asphalt overlay and partial-depth concrete repair test sections on the original westbound concrete pavement lanes of I-94. This pavement segment, originally constructed in 1973, is 3.5 miles in length. These test sections receive the same traffic stream as mainline MnROAD test sections but only seven days per month, on average, when traffic is diverted from the MnROAD mainline for monitoring or construction. As a result, the cumulative ESALs on this roadway are about one-quarter of what the MnROAD mainline I-94 test sections experience.

MnROAD has progressed through four phases since it was originally constructed. Phase-I (1994-2007) primarily investigated concrete and asphalt structural (thickness) designs. Phase-II (2008-2015) focused on partnerships with government, academia, and industry, led by MnDOT through the former Transportation Engineering and Road Research Alliance. Phase III (2016-2021) focused on the creation of a partnership with the National Center for Asphalt Technology (NCAT) that resulted in the construction in 2016 of eight flexible pavement sections as part of a National Cracking Performance Test experiment and the addition of 39 new and unique concrete and asphalt test sections during the 2017 construction season at MnROAD.

For Phase IV, the 2022 construction season at MnROAD saw the addition of 39 new and unique test sections. These test sections were designed to address National Road Research Alliance (NRRA) high-priority sustainability-focused research topics. They were conceived and designed by NRRA Flexible, Geotechnical, Intelligent Construction, Preventive Maintenance, and Rigid team members.

1.2 National Road Research Alliance (NRRA)

The NRRA is a multi-state pooled-fund program led by MnDOT. The NRRA provided guidance for the 2022 MnROAD research construction with the objective of strategic implementation through cooperative pavement research. Led by an Executive Committee of DOT and local agency partners, NRRA is supported by numerous academia and industry partner representatives, as shown in Table 1.1. Together, representatives from these organizations provided their expertise to plan and oversee the MnROAD research initiated in 2022, from the selection of research topics to communication and implementation of results. The five NRRA project teams are: Flexible, Rigid, Geotechnical, Preventive Maintenance, and Intelligent Construction Technologies.

Table 1-1 NRRA Executive Committee Members

Agency	Members
California DOT (Caltrans)	Joe Holland and Tom Pyle
Illinois DOT	Brian Pfeifer and Charles Wienrank
Illinois Tollway	Dan Gancarz and Cindy Williams
Iowa DOT	Chris Brakke and Jeff De Vries
Georgia DOT**	John Hancock and Jacob Walker
Michigan DOT	Kevin Kennedy
Minnesota DOT	Duane Hill and Ben Worel*
Minnesota Local Road Research Board (LRRB)	Jim Foldesi (St. Louis County)
Mississippi DOT	Alex Middleton and Cindy Smith
Missouri DOT	Brett Trautman
Nebraska DOT	Oak Metcalfe and Matt Needham
New York State DOT**	Edward Collins, Brett Dean and Michael Heim
North Dakota DOT	Amy Beise and Aaron Perez
Wisconsin DOT	Eric Lyngdal and Barry Paye
Federal Highway Administration	Steve Cooper and Peter Eakman

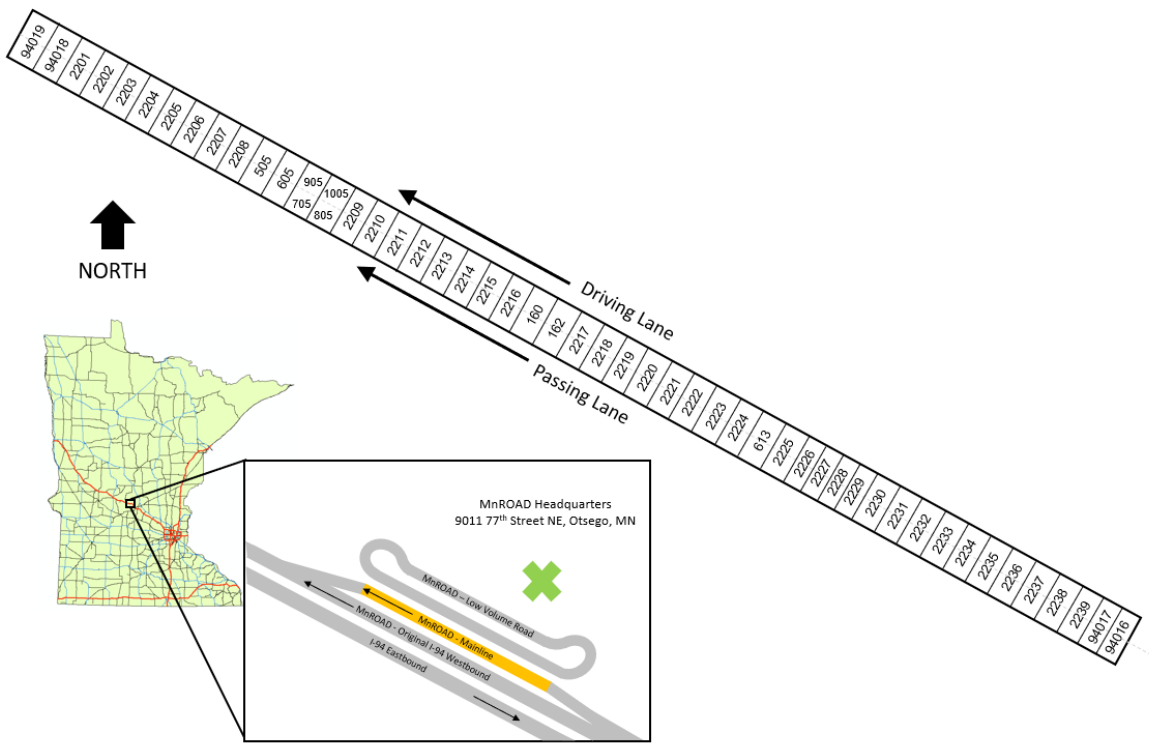
* Executive Committee Director

** States continuing involvement with the Veta Pooled fund, which is now part of NRRA research.

In addition to state DOT and local agency sponsors, NRRA associate members from industry and academic sectors provide key perspectives and expertise throughout the research planning process by giving input on long-term technology trends, identifying innovative solutions to research ideas, and determining the viability and successful approaches to implementation of research results. Associate members also have an opportunity to provide or obtain materials for testing and to propose design approaches based on laboratory or field experience.

Planning for the NRRA 2022 construction began in February 2021. During the experiment planning and design phase, the five NRRA project teams developed the high-priority research projects listed in Table 1.2. Sections constructed at MnROAD were designed to address some of these research topics. The maps in Figure 1.1 show the general location of the new and existing test sections on the MnROAD I-94 mainline.

Figure 1-1 MnROAD I-94 WB Mainline NRRA Test Sections



2022 HMA Reflective Cracking Challenge										Perpetual HMA		Concrete Overlay on Asphalt		WIM	Recycled PCC	Alternative Cementitious Concrete								Concrete Overlay on Asphalt		Alternative Cementitious Concrete								Concrete Overlay on Concrete (Thicklift HMA)				2022 Perpetual Recycling with Thinlays/Microsurfacing							
2239	2238	2237	2236	2235	2234	2233	2232	2231	2230	2229	2228	2227	2226	2225	613	2224	2223	2222	2221	2220	2219	2218	2217	162	160	2216	2215	2214	2213	2212	2211	2210	2209	805 1005	705 905	605	505	2208	2207	2206	2205	2204	2203	2202	2201

1.3 Report Objectives

This report documents the objectives of each research project, along with design considerations and construction experiences of the sections built to support them. Table 1.2 lists the supporting NRRA team, the title of the research project, and the principal investigators for each of the research contracts. The details and results of each individual study are left to future reports generated by the individual research contracts and their respective teams. In this report, each of the research projects are discussed in individual chapters. Chapter 15 describes the performance monitoring and instrumentation that are common among all the projects.

Table 1-2 NRRA Research Projects and Investigation

NRRA Team	Research Project	Principal Investigator
Flexible	MnROAD Reflective Cracking Challenge	Eshan Dave, University of New Hampshire
	Reclamation and Recycling Techniques to Achieve Perpetual Pavements Characteristics	Mohammad Sabouri, Braun Intertec
	Validation of Loose Mix Aging Procedures for Cracking Resistance Evaluation in Balanced Mix Design	Fan Yin, National Center for Asphalt Technology
	Perpetual Pavements in Wet-Freeze Climates	TBD
	Recycled Binder Availability	TBD
Rigid	Development of Concrete Mix Designs/Matrix of Materials, Performance Properties, and Construction Field Sampling and Testing Expectations During Construction	Thomas Van Dam, Nichols Consulting Engineers
	Use of Alternative Pozzolanic Materials Towards Reducing Cement Content in Concrete Pavements	Nicholas Weitzel, Nichols Consulting Engineers
	Use of Carbon Dioxide for Sustainable and Resilient Concrete Pavements	Peter Taylor, CP Tech Center at Iowa State University
	The Use of Alternative Cementitious Materials in Concrete Pavements	Prashant Ram, Applied Pavement Technologies, Inc.
	Evaluation of the Use of Early Loading to Increase Joint Deployment in Concrete over Asphalt	Michael Wallace, Minnesota DOT
	Concrete Overlay Test Section Repairs Utilizing PEM and Diamond Grinding	Tom Burnham, Minnesota DOT
Geotechnical	Performance Evaluation of Wicking Geotextiles for Improving Drainage and Stiffness of Road Foundation	Bora Cetin, Michigan State University
	Flooded Pavements App--Phase II	Majid Ghayoomi, University of New Hampshire
Preventive Maintenance	Thinlay as a PM Treatment	Andrea Blanchette, Terracon

1.4 Partnerships

Many MnROAD research efforts in 2022 were made possible by collaborating with partners that donated time, equipment, and materials to meet the objectives of the research projects. Of special note are the following organizations:

- Caterpillar (CAT) donated time and hot mix asphalt milling equipment to mill approximately 10,000 tons of asphalt from multiple existing test sections. CAT also donated time and roller equipment for intelligent compaction (IC) uniformity assessment of pavement foundation of Portland Cement Concrete Pavement (PCC) experiments.
- SOLMAX (Formerly TenCate) donated the geotextile wicking fabric for the Performance Evaluation of Wicking Geotextiles for Improving Drainage and Stiffness of Road Foundation project.
- Asphalt Materials, Inc. donated the void reducing asphalt membrane (VRAM) – J-Band materials used for the MnROAD Reflective Cracking Challenge project and the Cold-In-Place Recycling rejuvenator for the Reclamation and Recycling Techniques to Achieve Perpetual Pavements Characteristics project.
- The following companies donated materials for the 15-alternative cementitious, alternative supplementary cementitious and carbon sequestration concrete sections.
    - CarbonCure
    - Ultra High Materials
    - Continental Cement
    - Carbon Limit
    - Ash Grove
    - Carbon Upcycling
    - Hess Pumice
    - Urban Mining
    - TerraCo$_2$
    - 3M
    - Burgess Pigments
- North Dakota State University (NDSU) installed novel fiber optic (FO) sensors at its own expense. The NDSU team will compare the responses from the FO sensors to the conventional sensors installed by the MnROAD team in both concrete and asphalt test sections.
- Michigan State University (MSU), led by Dr. Nizar Lajnef, worked with the MnROAD team to install wireless asphalt strain gauges in test sections 2232 and 2228. Dr. Lajnef's team also designed novel pressure mats used in the PCC test sections. These sensors are currently under development by the MSU team and will be compared to responses measured from MnROAD's conventional pavement response sensors.
- University of Texas El Paso (UTEP) donated time and equipment for IC assessment of pavement foundation (i.e., base layer) of PCC experiments.
- Ingios Geotechnics partially donated time and equipment for IC assessment of pavement foundation of flexible experiments.

- MSU donated time for geotechnical testing and instrumentation installation of pavement foundations. Also, MSU donated two (2) Shape Array Accelerometers (SAA) for assessment of heaving in the wicking geotextile cells.
- The National Science Foundation (NSF) internship program provided funding to support a MSU graduate student working on geotechnical testing and instrumentation.

Chapter 2: MnROAD Pavement Milling and Concrete Removal Operations

2.1 Objectives

There is a growing concern among many U.S state and local agencies that current mill-and-fill asphalt pavement rehabilitation and preservation projects do not last as long as their intended design life. For this reason, the need to develop tools to better predict and quantify the performance properties of asphalt overlays on existing asphalt pavements has been recognized as a priority by NRRA members. This chapter covers the milling efforts donated in kind by our partners at Caterpillar (CAT). These efforts not only allowed MnROAD to have all sections milled at no cost, but it provided opportunities for CAT to test new technologies and train their staff on operating the different pieces of equipment they brought to the site. This opportunity allowed for the NRRA project on “Asphalt Pavement Milling Best Practices through Enhanced Understanding of Milling Process” to collect materials for testing that will aid in answering important questions generated under the scope of this research project.

A total of 186 cores and 19 Recycled Asphalt Pavement (RAP) samples were collected during the milling operations. These samples, together with others collected for this research project, will provide information to be able to: (1) quantitatively determine changes to physical and mechanical properties of asphalt pavements from milling operations, (2) identify factors that have the most significant impacts on milling induced changes to the existing pavement; and (3) develop best practices guidance for use in milling, design, and construction specifications.

2.2 Milling Operations

Before initiating milling operations, Bio-logs were delivered and installed by J.R. Larson as part of the Erosion Prevention and Sediment Control plan during the week of May 16th and weep trenches were excavated on May 26th and May 27th. Milling operations for the sections associated with the research project occurred from May 23 to June 2, 2022. Table 2.1 presents the milled test section locations and their length.

Table 2-1 Milled Test Sections Locations and Lengths

Test Section	Start Station	End Station	Length, ft
101	1102+85	1105+60	275
201	1105+60	1108+40	280
2	1108+40	1111+20	560
3	1116+92	1119+85	585
4	1119+85	1125+85	600
115	1194+45	1197+30	285
215	1197+30	1200+18	288
16	1200+18	1205+90	572
17-20*	1205+90	1228+50	2260
21	1228+50	1234+35	585
22	1234+35	1240+15	580
23	1240+15	1245+80	580

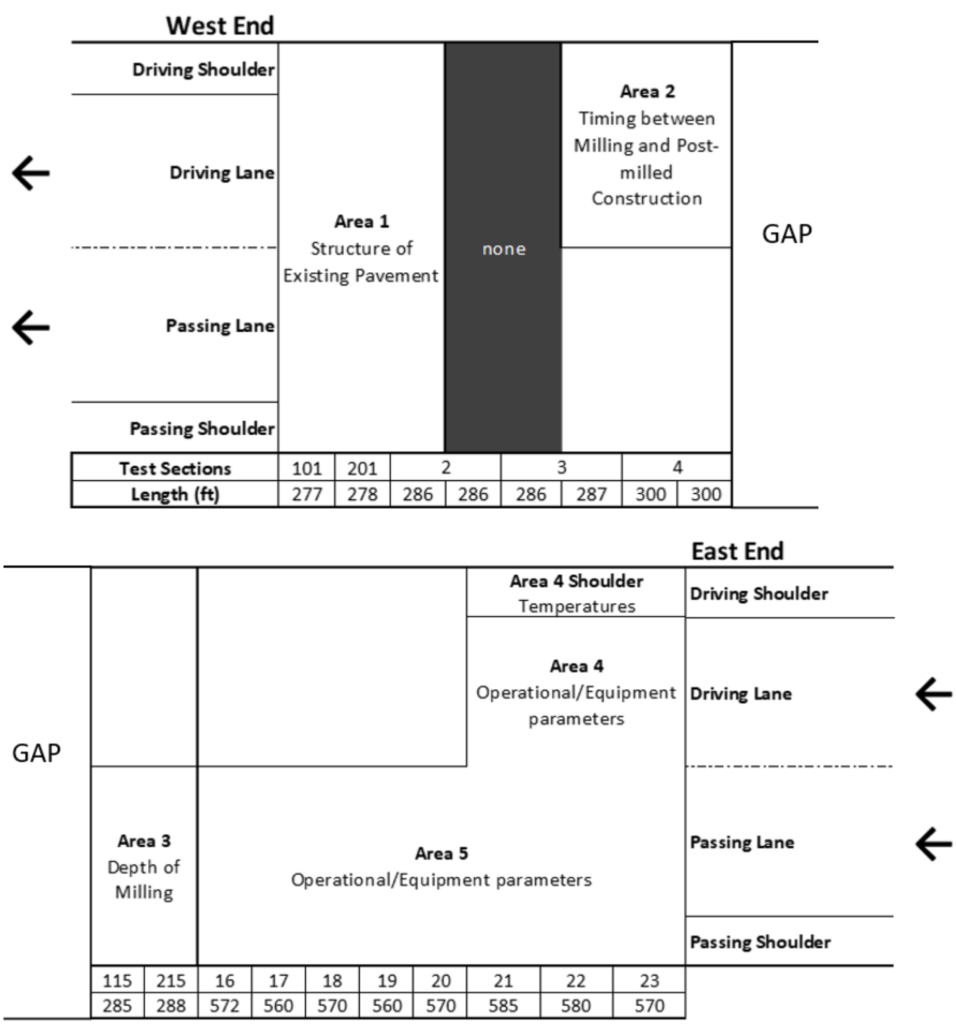
* Test sections 17 to 20 were milled but no sample taken as part of the research effort

During the milling operation, CAT utilized 3 different types of milling machines to remove approximately 10,000 tons of in-place asphalt layers. The cold planers that CAT used during milling operations were models PM312 and PM622. Figure 2.1 shows the pictures of the cold planers on-site.

The research team, CAT and MnROAD staff developed a plan to perform milling with different equipment features, taking into consideration different milling depths, types of rotors and temperatures. The plan categorized MnROAD test sections into different areas, as shown in Figure 2.2, and these areas were assigned a research variable to evaluate. The gap corresponds to concrete test sections.

Figure 2-1 CAT Cold Planer Models PM312 (Left) and PM622 (Right) Used at MnROAD

Figure 2-2 Plan Views Showing Areas with Different Milling Parameters



2.3 Concrete Pavement Removal Operations

During the week of June 6, 2022, Antigo Construction provided pavement breaking services as preparation for removal of existing concrete pavement test sections by C.S. McCrossan during the week of June 13th. Figure 2.3 shows the operation of the concrete breaker and how the test sections looked after the breaking process was conducted. C.S. McCrossan removed rubblized concrete with excavators and tandem axle haul trucks. To reduce carbon footprint, some of the concrete was crushed and processed into Class 5Q to be used as aggregate base during re-construction.

Figure 2-3 Existing Test Sections Concrete Removal

The removal of the 6-inch-thick concrete overlay on former test sections 614 to 914 required careful handling, because the underlying asphalt layer needed to remain in place for the construction of new concrete overlay on asphalt test sections 2226 and 2227. Figure 2.4 presents the removal operation for these test sections.

Figure 2-4 Concrete Removals Over HMA Layer in Former Test Sections 614 to 914

2.4 Additional HMA Removal

In areas where HMA was an underlying layer that could not be removed during surface milling (former test sections 414, 314, 214, 114, and 96) the HMA material was broken up with the excavator and removed with the rubblized concrete.

2.5 Sampling and Testing

The sampling and testing for this effort were also determined by coordination between the University of New-Hampshire research team, CAT personnel and MnROAD staff. Table 2.2 presents the research details for the milling operations on the existing test section as they reached their end of life. The areas are shown in Figure 2.2 The test results will be part of the final report for the NRRA project Understanding and Improving Pavement Milling Operations. This report is available upon request to MnROAD staff.

Table 2-2 2022 MnROAD Milling Research Details on Existing Test Sections

Existing Test Sections	Area	Milling Dates	Testing Parameters	Sampling
101, 201, 2	1	May 23, 24	Compare Properties Over Different Cross-sectional Designs	48 cores
3, 4	2	May 23, 24, 25	Measure Changes Over Few Weeks’ Time as Exposed Interface Experiences Traffic	26 cores
115, 215	3	May 26, 27	Test Various Depths Relative to a Layer Interface at: (1) Interface, (2) Halfway Through Interface, (3) Three-quarters Depth Through Interface	24 cores 2 RAP samples
21, 22, 23	5	May 31 to June 2nd	Testing Changes in Drum Diameters, Speed and Spacing	24 cores 5 RAP samples
16, 21, 22, 23	4, 5	May 31 to June 2nd	Mill Sections at Different Periods of the Day to Test Temperature Changes.	64 cores 5 RAP samples
17, 18, 19, 20	5	May 31 to June 2nd	No Cores Collected from These Test Sections	8 RAP samples

Chapter 3: MnROAD Grading and Base Operations and Testing

3.1 Objectives

This chapter covers the activities related to grading and base operations conducted during the 2022 construction season at MnROAD. After asphalt milling and concrete removal operations were completed, several test sections required grading and base work existing layers to meet project specifications and research requirements.

Contractor quality control and department quality assurance testing for grading and base operations followed 2020 MnDOT standard specifications 2111 Test Rolling, 2112 Subgrade Preparation, 2211 Aggregate Base and 3138 Aggregate for Surface and Base Course. Frequency of sampling and testing followed the 2020 Schedule of Materials Control (MnDOT, 2020). Department aggregate samples were collected from the temporary stockpiles created by CSM and sent to MnDOT's Metro or St. Cloud material lab for testing. For contract purposes, material was tested as submitted (i.e., the same material was submitted as a Class 3 and a Class 5)

NRRA partners, Ingios, University of El Paso – Texas (UTEP) and Transtec, conducted planned research testing on MnROAD test sections to evaluate various spatial uniformity of pavement foundation layers. Ingios used the Automated Plate Load Testing (APLT) device and conducted Dynamic Cone Penetrometer (DCP) and COMP-Score® RT mapping tests to provide documentation of engineering support parameter values for the remaining asphalt layers after milling, for the exposed shoulder base aggregate for test sections 2201, 2202, 2207 and 2208, and for the existing and reworked unbound aggregate base layers for test sections 2230 to 2239.

UTEP, Transtec and MnDOT staff conducted advanced intelligent compaction measurement values (ICMV) testing. Intelligent compaction (IC) is a roller-based innovative technology that provides real time compaction monitoring and control. IC was used to monitor roller passes, machine vibration frequencies/amplitudes, and stiffness related values of compacted foundation materials for the subgrade and base layers in new concrete test sections 2209 to 2224, perpetual asphalt pavement test section 2228, and wicking geotextile test section 2229. This technology uses an accelerometer (mounted on roller) to estimate the level of compaction and calculate ICMV. These two efforts by Ingios and UTEP, helped to quantitatively measure pavement foundation uniformity and record it using intelligent compaction.

Spot testing for pavement foundations included moisture, Light Weight Deflectometer (LWD), Dynamic Cone Penetrometer (DCP), and Nuclear Density (NDG) tests. Further, as part of an NRRA research project (i.e., Continuous Moisture Measurement during Pavement Foundation Construction, continuous moisture measurements were attempted with a prototype developed by UTEP. Michigan State University (MSU) research staff provided geotechnical support for pavement foundation construction and performance monitoring. This effort included installation of moisture sensors and thermocouples on subgrade, subbase, and base layers, spot testing for quality assurance using standard equipment (e.g., Light Weight Deflectometer, Dynamic Cone Penetrometer) and electrical density gauges (EDG-e), installation of wicking geotextile and installation of shape arrays (SAA) for frost heave monitoring.

To accommodate future material requests, a representative sample with a minimum size of 3 cubic yards was provided for each of the aggregate materials placed on site. These samples were stored at the MnROAD stockpile area and are available upon request. In addition, 10 cubic yards of clay subgrade that was removed from test section 2228 was stockpiled.

3.2 Quality Control (QC) and Quality Assurance (QA) Sampling and Testing

Contractor Quality Control (QC) and Department Quality Assurance (QA) testing followed MnDOT Standard Specifications and project Special Provisions. The MnROAD project engineer was responsible for acceptance testing in accordance with the MnDOT Schedule of Materials Control. MnDOT and MnROAD engineers also ensured that the construction complied with the plans and special provisions. Testing included: proofrolling, density, moisture, gradation, classification, dynamic cone penetrometer (DCP), LWD, FWD, and gas permeameter. Samples were collected and shipped to MnDOT/MnROAD partner and research contractor’s testing labs.

Table 3.1 presents the timeline for subgrade preparation and aggregate base placement for each test section.

Table 3-1 Schedule for Subgrade Preparation, Aggregate Base Placement, Geotechnical Foundation Testing and Sensor Installation at MnROAD in 2022

		June				July					August			
Grading activity	**Test Sections**	**5**	**12**	**19**	**26**	**3**	**10**	**17**	**24**	**31**	**7**	**17**	**21**	**28**
Fine grading existing aggregate base layer	2230 to 2239	X	X	X										
Install Aggregate Base Moisture Sensors	2230 to 2239	X	X											
Ingios - Research Mapping Pavement Foundation	2201 to 2208, 2230 to 2239		X											
Install Aggregate Base Dynamic Load Sensors	2230 to 2239			X										
Foundation Layer Field Tests (LWD, DCP, Density)	2230 to 2239			X										
Subgrade excavation	2228 to 2229		X											
Aggregate Subbase and Base Placement	2228 to 2229			X	X									
Install Foundation Layer Moisture	2228 to 2229			X	X									
Install Foundation Layer Dynamic Sensors	2228 to 2229													
Foundation Layers Field Tests (LWD, DCP, Density)	2228 to 2229			X	X									
Installation of Wicking Geotextile	2229			X										
Installation of Shape Array Accelerometer sensors	2228, 2229				X									
Grading of Aggregate Base Layers	2228 to 2229				X									
Removal of Existing Aggregate Base materials	2209 to 2225				X	X								
Excavation of Subgrade	2209 to 2225			X	X									
Placement of Aggregate Subbase and Base layers	2209 to 2225					X	X							
Foundation Layer Field Tests (LWD, DCP, Density, EDG-e)	2209 to 2224					X								
Install Foundation Layer Moisture Sensors	2209 to 2224					X	X		X					
Install Foundation Layer Dynamic Load Sensors	2209 to 2224													
Fine Grading of Aggregate Base Layers	2209 to 2225								X					
Stabilization/regrade of shoulders using RAP									X	X		X	X	
Install conduit for future Weigh-In-Motion equipment	2225								X					
Placement of aggregate base for shoulders										X	X	X		

Table 3.2 presents the granular and non-granular layers that required work per test section. The aggregate base was placed and compacted in lifts using Equipment per Table 2211.3-2 in section 2211 of 2020 MnDOT Standard Specifications. The MnROAD construction inspector observed the contractor performing proofrolls with subsequent construction operations not allowed until conformance was achieved. Due to concerns with the possible moisture conditioning of the clay subgrade, the contractor limited the exposed clay subgrade to what they could cover with aggregate base prior to any weather events. As such, proof-rolled subgrades were covered prior to the need for any additional testing. In general, granular material was placed with dual axle dump trucks and rough graded with CAT 259D3 skid

loaders. Fine grading was performed with a CAT 12 M3 AWD grader and compaction was performed with a CAT PS-150C rubber tire roller and a CAT CS 563D vibratory smooth drum roller.

Table 3-2 Granular and Non-granular Layer Work and Material Type per Test Section

Test Sections	Subgrade	Aggregate Subbase	Aggregate Base	Aggregate for Shoulder
2201 to 2208				Existing*
2209 to 2224	Clay	Class 5	Class 5Q	Class 5Q
2225	Clay		Class 5Q	Class 5Q
2226 to 2227				Existing
2228 to 2229	Clay	Class 3	Class 5Q	Class 5Q
2230 to 2239		Select Granular + Class 3	Existing Class 6	Existing Class 6

* Small areas were supplemented with Class 5Q to meet elevation differences in milling

Table 3-3 Grading and Base Quality Assurance (QA) Requirements for Sampling Frequency

Material	Subgrade	Class 3	Class 4	Class 5*	Class 5Q**
Quantity	-	535 yd3	912 yd3	3,388 yd3	2,646 yd3
Compaction Tests	LWD	DCP Index	DCP Index	DCP Index	DCP Index
Min. Test Rate	1/25 Stations	1/1500 yd3	1/1500 yd3	1/1500 yd3	1/1500 yd3
No. of Tests Required	2	2	2	2	2
Moisture Min. Test Rate	-	1/1000 yd3	1/1000 yd3	1/1000 yd3	1/1000 yd3
No. of Tests Required	0	2	2	4	3
Gradation Min. Test Rate	-	2 Random Samples	2 Random Samples	2/2000 yd3	2/2000 yd3
No. of Tests Required	0	2	2	4	4
Moisture Density (Proctor) Tests Required				1	1

* MnDOT 3138 Class 5 2020 specification was used for special provisions material "Special – RAB"
**MnDOT 3138 Class 5Q 2018 specification was used for special provisions material "Special"

Lightweight Deflectometer (LWD) tests were conducted, and field density and moistures contents were collected for the exposed/excavated clay subgrade layer of test sections 2209 to 2225, 2228 and 2229. The clay subgrade was prepared before placement of the overlain layer. A total of 86 LWD tests were conducted on the in-place subgrade. A total of 164 nuclear density tests were also conducted to collect field density and moisture contents for the clay subgrade, Class 3 subbase, and Class 5Q base of test sections 2228 and 2229. Test results for this effort will be summarized under a separate report and will be shared upon request to MnROAD staff.

Gradations, moisture and-density (Proctor) tests, field density test and field moisture test were used to determine compliance with the aggregate subbase and base specifications for test sections noted in Table 3.2. Close visual inspection of the entire operation was performed by an inspector from MnROAD. Aggregate samples were collected from at least three areas in the MnROAD stockpile area nearest to the middle of the stockpile as possible, while standing on the ground.

Gradation tests results are presented on Tables 3.4 to 3.7. Gradations tests conducted for Class 3, Class 4, and Class 5 aggregates met the gradation specifications requirements. As presented in Table 3.6, gradation tests for Class 5Q aggregate show that the material is finer than the requirements in several sieve sizes. This is likely due to the nature of the material and the challenges that the Contractor had in preventing the segregation of material during stockpiling and placing operations. Due to time constraints, MnROAD engineers decided to accept the material as placed based on DCP and proof-roll results.

Proctor tests were conducted on Class 5 and Class 5Q aggregates. Class 5 aggregate sub-base has a maximum dry density of 124.5 pcf and optimum moisture content of 10.7%. Class 5Q aggregate base has a maximum dry density of 124.5 pcf and optimum moisture content of 9.6%.

Table 3-4 Gradation Test Results for Class 3 Subbase Aggregate

		% Passing		Specifications	
Sieve No.	Sieve Size (mm)	Test 1	Test 2	Min	Max
2”	50.800	100	100	100	
¾”	19.050	99	98		
5/8”	15.875	95	94		
½”	12.700	87	85		
3/8”	9.525	79	76		
No. 4	4.750	63	57	35	100
No. 10	2.000	47	45	20	100
No. 20	0.841	33	-		
No. 40	0.420	21	20	5	50
No. 50	0.300	12	-		
No. 100	0.150	8	8		
No. 200	0.075	5.0	6.2	5.0	10.0

Table 3-5 Gradation Test Results for Class 4 Subbase Aggregate

		% Passing		Specifications	
Sieve No.	Sieve Size (mm)	Test 1	Test 2	Min	Max
2”	50.800	100	100	100	
¾”	19.050	97	97		
5/8”	15.875	92	92		
½”	12.700	84	85		
3/8”	9.525	78	77		
No. 4	4.750	62	61	35	100
No. 10	2.000	51	45	20	100
No. 20	0.841	40	31		
No. 40	0.420	28	20	5	50
No. 50	0.300	17	12		
No. 100	0.150	13	8		
No. 200	0.075	8.4	5.1	4.0	10.0

Table 3-6 Gradation Test Results for Class 5Q Base Aggregate

		% Passing				Specifications	
Sieve No.	Sieve Size (mm)	Test 1	Test 2	Test 3	Test 4	Min	Max
2”	50.800	100	100	100	100	100	
1”	25.400	97	92	94	83	65	95
¾”	19.050	90	84	87*	61	45	85
5/8”	15.875	85	79	82	51		
½”	12.700	79	73	76	38		
3/8”	9.525	72*	66	70	28*	35	70
No. 4	4.750	57*	51*	55*	17	15	45
No. 10	2.000	43*	38*	40*	11	10	30
No. 20	0.841	31	26	28	8		
No. 40	0.420	19	16	17	5	5	50
No. 50	0.300	11	10	10	3		
No. 100	0.150	7	6	7	2		
No. 200	0.075	4.4	3.8	4.1	1.3	0.0	10.0

* Does not meet specifications

Table 3-7 Gradation Test Results for Class 5 Base Aggregate

		% Passing					Specifications	
Sieve No.	Sieve Size (mm)	Test 1	Test 2	Test 3	Test 4	Test 5	Min	Max
1 ½”	50.800	100	100	100	100	100	100	
¾”	19.050	98	98	97	98	98	70	100
½”	12.700	88	87	87	86	85		
3/8”	9.525	81	81	79	77	76	45	90
No. 4	4.750	65	65	63	59	57	35	80
No. 10	2.000	50	50	46	43	45	20	65
No. 40	0.420	25	24	24	17	20	10	35
No. 100	0.150	11	10	11	7	8		
No. 200	0.075	6.9	6.9	6.3	4.9	6.0	0.0	10.0

Each lift of the unbound granular materials placed were uniformly compacted to meet the requirements of MnDOT specification 2211.3D.2.c, “Penetration Index Method,” for aggregate base and subbase. Dynamic Cone Penetrometer (DCP) tests were conducted at the finish elevation for each layer. The requirements for the maximum seating (SEAT) and DCP penetration index (DPI) are related to the Gradation Number (GN) of the material tested along with the moisture content of the material. In most cases, moisture testing was not required as the DCP tests met the requirements for the GN with a maximum allowable SEAT of 40 mm and DPI of 10 mm. Test 8 required a moisture test to be performed, where the moisture content of 7.8 % indicated a maximum DPI of 12. Table 3.8 presents a summary of the Penetration Index Method test results. All tests conducted pass the requirements for SEAT and DPI.

Table 3-8 Dynamic Cone Penetrometer (DCP) Index Test Results for Unbound Granular Aggregate

Test No.	Date	Test Section	Layer	Station	Offset	Test Layer Depth (mm)	GN	SEAT (mm)	DPI (mm/blow)
1	6/17/22	2239	Base	1242+25	-9.5	305	3.7	17	5
2	6/17/22	2239	Base	1245+25	-9.5	305	3.7	16	5
3	6/17/22	2239	Base	1245+00	-18	305	3.7	29	5
4	6/23/22	2231	Base	1206+40	4	305	3.7	14	5
5	6/23/22	2232	Base	1213+04	-2	305	3.7	16	6
6	6/23/22	2232	Base	1212+70	-12	305	3.7	28	7
7	6/30/22	2229	Base	1199+80	-9	241	3.1	33	9
8	6/30/22	2229	Base	1199+50	-5	241	3.1	39	12
9	7/1/22	2218	Sub-Base	1166+00	-5	140	4.0	36	6
10	7/1/22	2222	Sub-Base	1176+31	9	140	4.0	19	6
11	7/5/22	2216	Sub-Base	1152+15	-10	140	4.0	35	10
12	7/5/22	2216	Sub-Base	1150+85	2	140	4.0	33	7
13	7/6/22	2213	Sub-Base	1143+92	8	140	4.0	35	10
14	7/6/22	2214	Sub-Base	1145+01	6	140	4.0	39	10

A total of 63 gas permeameter tests were conducted on the aggregate base layer for test sections 2228 and 2229. Test results can be shared upon request to MnDOT and MnROAD staff.

3.3 Research Testing and Instrumentation

3.3.1 Ingios Pavement Foundation Intelligent Compaction Mapping

From June 13 to June 16, 2022, Ingios Geotechnics mobilized a CAT CS56B smooth drum roller enabled with COMP-Score® RT mapping system (Figure 3.1), to assess foundation uniformity and the Automated Plate Load Testing (APLT) to perform in-situ testing to determine the resilient modulus (M_r) and permanent deformation (δ_p) of the test section subsurface pavement layers (Figure 3.2).

Figure 3-1 Ingios CS56B Vibratory Smooth Drum Roller Enabled with COMP-Score® RT Mapping System (White & Vennapusa, 2022)

Figure 3-2 Ingios Automated Plate Load Testing (Top) Setup with 18 in. Diameter Loading Plate (Middle) and 12 in. Diameter Loading Plate with Layered Analysis Sensor Kit (Bottom) to Determine In-situ Modulus Measurement Values (White & Vennapusa, 2022)

Ingios documented engineering properties for pavement foundation layers for the remaining hot mix asphalt (HMA) milled surface layer for test sections 2201, 2202, 2207 and 2208. Two APLTs tests, A and B, were performed using 1,550 cycles and cyclic stress of 5, 10, 20, 30 and 40 psi with a minimum stress of 2 psi. Test A used the 12-inch diameter plate on the bound material of test sections 2201, 2202, 2207 and 2208.

Testing was also performed on the shoulder aggregate base of tests sections 2201 to 2208 and on the existing and reworked base aggregate of test sections 2230 to 2239. Test B used the 18-inch diameter plate on the unbound material for the shoulder of test sections 2201 to 2208 and for test sections 2231 to 2239. Test B was selected to match MnDOT's concurrent falling weight deflectometer (FWD) testing being performed using an 18 in. diameter loading plate.

A dynamic cone penetrometer (DCP) test was performed per ASTM D6951 at each APLT location to assess penetration resistance profile and layer thicknesses. A ¾ in. diameter hole was drilled in the bound test sections (2201, 2202, 2207, and 2008) to about 4 to 8 inches below the surface to perform the DCP test in the foundation layers.

Key observations from the APLT results were reported by Ingios as follows:

- Resilient modulus (Mr-values) on unbound materials in test sections 2230, 2234, 2235, and 2239 exhibited stress-hardening behavior, where Mr-values increased with increasing stress up to 40 psi. This is typical behavior for stiff granular materials. DCP profiles at the test locations indicated CBR values ranging from 20 to > 100 in the top 24 inches.
- Mr-Comp values on unbound materials in the shoulder lane in test sections 2201 to 2208 exhibited stress weakening behavior, where the Mr-values decreased with increasing stress up to 40 psi. This is typical behavior for cohesive materials. DCP profiles at the test locations indicated low CBR values (< 10) at 5 to 6 inches below the surface.
- Mr-Comp values on the bound materials in test sections 2207 and 2208 with stabilized FDR layers at the surface exhibited stress-weakening behavior, where the Mr-values slightly decreased with increasing stress up to 40 psi or remained constant. Backcalculated top layer Mr-values (Mr-FDR) and underlying subgrade layer Mr-values (Mr-Subgrade) also followed the same trend of stress-weakening behavior. This is typical behavior for a layered case with stiff top layer over softer cohesive materials. DCP profiles at the test locations indicated CBR values decreased beneath the stabilized FDR layer at about 17 inches below the surface at all locations except for L19. Test point L19 was located near the east edge of test section 2208 and the DCP profile at the test location encountered refusal at about 15 inches below surface.
- Mr-Comp values on the bound materials in test sections 2201 and 2202 exhibited stress-hardening behavior, where the Mr-values increased with increasing stress up to 40 psi. This is typical behavior for a layered case with stiff underlying granular materials. DCP profiles at the test locations indicated CBR values > 40 up to about 33 inches below surface.

The complete results from Ingios are contained in a separate report that can be provided upon request to MnROAD and MnDOT staff.

3.3.2 UTEP, Transtec, and MSU Pavement Foundation Geotechnical Support

Research related pavement foundation testing on test sections 2228 and 2229 was conducted with the collaboration of research teams from UTEP, Transtec, Michigan State University (MSU), MnDOT/MnROAD staff. Geotechnical support for pavement foundation construction and performance monitoring included installation of TEROS 10 volumetric water content sensors, TEROS 21 matric suction sensors, T type thermocouples, recently developed electrical density gauges (EDG-e) sensors, and shape arrays (SAA) for frost heave monitoring. In addition, thermocouple trees, spot testing for quality assurance using standard equipment (e.g., Light Weight Deflectometer, Dynamic Cone Penetrometer, Nuclear Gauge Density), intelligent compaction (IC) mapping for assessment of foundation uniformity, and a prototype of the continuous moisture measurement (CMM) was used by the teams and installation of shape arrays (SAA) for frost heave monitoring.

From the week of June 6th to July 25th the MSU team worked with MnDOT staff to install moisture sensors in pavement foundation layers on test sections 2209, 2214, 2222, 2228, 2229, 2232, 2234, 2236 and 2239. A total of 54 TEROS 10 sensors to monitor volumetric water content change during the design life of the test sections and 54 TEROS 21 sensors to monitor the change in matric suction levels of pavement foundation layers were installed. Details of exact locations of the moisture sensors and material-specific calibration functions can be shared upon request.

Installation of these moisture sensors was novel, as there has been limited research available in the literature on how to install these sensors, designed for agricultural soils, into compacted granular bases containing complex recycled geomaterials (Aydin, et al., 2023). Figure 3.3 shows both moisture sensors in the base layer of one of the test sections where they were installed.

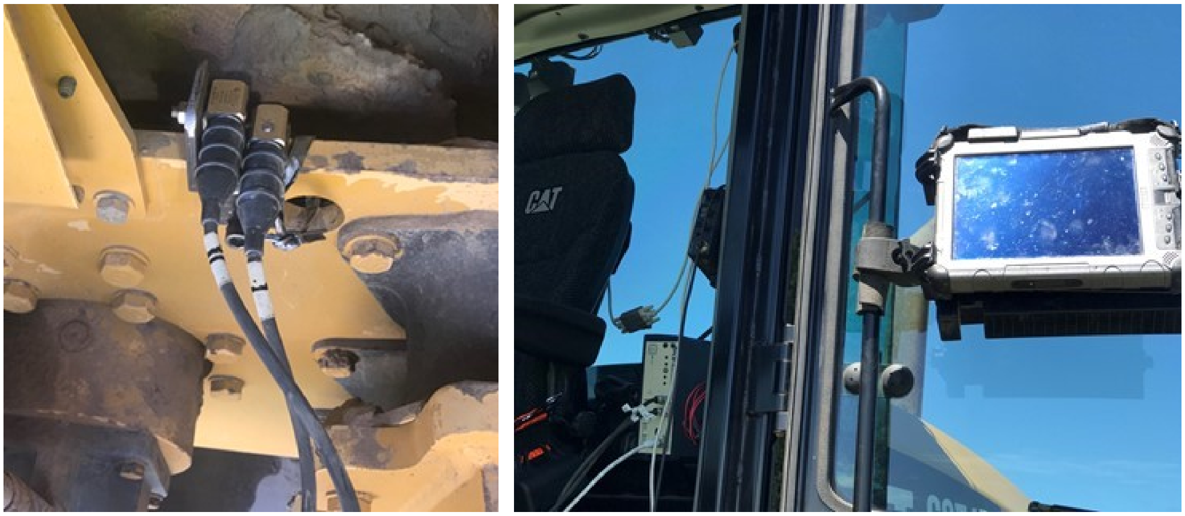
Figure 3-3 TEROS 10 and TEROS 21 Moisture Sensors Installation

Concurrently with the efforts by MSU, the UTEP and Transtec teams worked with MnDOT staff to start installation of geophones in the clay subgrade and Class 3 subbase to monitor advanced intelligent compaction (IC) activities and determine intelligent compaction measurement values (ICMV) for test sections 2228 and 2229 as part of an active NRRA study (i.e., Evaluation of Levels 3-4 intelligent compaction measurement values (ICMV) for Soils Subgrade and Aggregate Subbase Compaction). The ICMV system, shown in Figure 3.4, consists of a data acquisition box, an accelerometer mounted on the roller drum, a GPS antenna and receiver, a power supply, geophone sensors (embedded in-ground), and a laptop computer. A CS74B model CAT roller compactor was provided to MnROAD and UTEP research team by Caterpillar to collect the ICMVs (Figure 3.5). This roller compactor was retrofitted with the original manufacturer (OEM) IC roller system. One accelerometer was mounted near the drum to measure the CMV and the onboard computer display was installed to measure, record, and export data files containing information such as date and time, coordinates, number of roller passes, speed and direction, vibration frequency and amplitude, and ICMV (Figure 3.6).

Figure 3-4 UTEP Moduli ICMV Components and Data Acquisition System (Nazarian, et al., 2020)

Figure 3-5 CAT Roller Used for ICMV Measurements

Figure 3-6 UTEP Moduli ICMV Accelerometer (Left) and Onboard Display (Right) (Chang, et al., 2023)



The pavement foundation of test sections 2228 and 2229 consist of a Class 5Q aggregate base over a Class 3 aggregate subbase over a clay subgrade. A step-by-step description of the IC procedure which included pre-mapping the existing subgrade, placing and compaction subbase or base foundation materials, and performing spot tests within the test sections is reported under a separate report (Chang, et al., 2023).

The results of the IC testing showed that test section 2229 (a test section with a wicking geotextile) had poor subgrade conditions, where the Compaction Measurement Values (CMV_{UTEP}) were observed to be smaller than test section 2228 (control test section). It was also observed that intelligent compaction technology was able to capture the effect of stress history on the subgrade layer of test section 2229 as the driving lane had higher CMV_{UTEP} than the passing lane because of the exposed higher volume of traffic loading during the previous service life. In addition, CMV_{UTEP} of the subbase and base layers of test section 2229 also yielded poor support conditions following the subgrade layer, emphasizing the importance of ensuring the quality and uniformity of each pavement foundation layer, as overall performance depends on each component of the foundation layer.

UTEP also performed IC mapping of compacted base layer for several PCC experiments (Cells 2209-2224). In general, results indicate some non-uniformity of pavement foundation for these experiments. The complete results of this IC effort can be shared upon request to MnDOT personnel.

A wicking geotextile donated by SOLMAX was installed on test section 2229 as part of the research project these test sections belong to. Figure 3.6 presents the installation of the wicking geotextile. The test sections layouts are presented under Figure 12.1 in Chapter 12.

Figure 3-7 Wicking Geotextile Installation

An attempt to continuously estimate moisture conditions in test sections 2228 and 2229 was completed using a prototype developed by UTEP and Mark Baker (Private Consultant) as part of a current NRRA study (i.e., Continuous Moisture Measurement during Pavement Foundation Construction). Results of this continuous moisture assessment effort can be found in NRRA report Continuous Moisture Measurement during Pavement Foundation Construction (Baker, et al., 2023). Also, LWD, DCP and Nuclear Density spots tests were conducted for test sections 2228 to 2239.

A recently published research paper on Geotechnical Aspects of MnROAD 2022 Reconstruction details the improvements in installation guidelines and calibration procedures for moisture and water potential (suction) sensors when used in foundation layers containing recycled asphalt pavement (RAP) and recycled asphalt concrete (RCA) as well as the challenges and suggested improvements for large scale usage of electrical density gauges for quality assurance. It also shows how MnROAD is using IC mapping of foundation layers to improve performance ranking of current experiments and how near real time IC mapping was used to proactively address poor subgrade conditions (Velasquez, et al., 2023).

Test sections 2228 and 2229 were equipped with Shape Array Accelerometer (SAA) sensors for the real-time measurement of deformation of the pavement foundation. The SAA sensors were chosen due to their versatility and ability to be used in different orientations to monitor various types of deformation. Specifically, the sensors could be used horizontally to monitor settlement or heave in roadways and embankments, vertically to monitor lateral deformation, and in an arc to monitor changes in convergence, such as those that occur in tunnels and sewers. Two SAA sensors were installed in the shoulder and passing lane using 2-inch (5 cm) diameter schedule 80 PVC casings placed in a 6-inch (15 cm) trench at the center of the base layer. The PVC pipes were joined using PVC primer and cement, and a fishing rope was used to guide the SAAs into the PVC (Figure 3.7). The end closest to the cable at the edge of the shoulder was designated as the reference point, while the end that was embedded into the pavement was designated as the far end. The reference end was fixed with a clamp attached to two embedded vertical 6-foot steel bars (Figure 3.8), while the far end was free to accommodate deformation. Given the maximum frost penetration depth observed in the MnROAD test sections from 2017 to 2019 was 5.52 feet (Cetin, et al., 2021), the 6-foot steel bars were used to ensure stability against heaving. The holes for steel rods were filled with the fast-setting concrete mix at the bottom 1 foot and gravel at the top to reduce the adhesion of the steel bars with the surrounding materials. A horizontal installation kit was mounted on the near end of the SAA, and a PVC cap was attached to the far end to prevent water intrusion. Finally, the trench was backfilled with base materials after installing the SAA.

Figure 3-8 Installation of SAA in PVC Casings

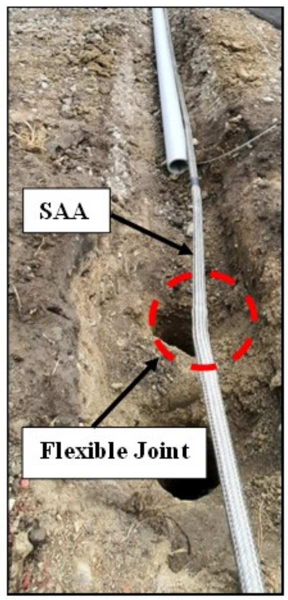


Figure 3-9 Fixing the Reference Point of SAA

Chapter 4: Reclamation and Recycling Techniques to Achieve Perpetual Pavements

4.1 Objectives

The use of reclamation and recycling techniques to achieve perpetual pavements has gained traction with agencies around the United States due to the sustainability benefits of reclamation in addition to a longer life pavement. The test sections constructed for this project support the implementation of such techniques on actual pavement and addresses multiple components of the current NRRA emphasis towards sustainability and intelligent construction. Sustainability is directly addressed by utilizing in-place reclamation techniques to achieve long-lasting pavements.

The main objective of this project is to identify and apply the proper techniques to sustainably reuse the materials within stabilized full depth reclamation (SFDR) test sections constructed at MnROAD in 2008. The selected techniques, based on discussion with the TAP members, intend to extend the good performance and continue the perpetual pavement behavior of original MnROAD test sections 2 and 3. MnROAD original test sections 1 and 4 required a deeper rehabilitation and presented additional challenges from the original full-depth asphalt structure.

Historically, these original sections at MnROAD have been used to promote benefits of reclamation and under this research can continue to serve as an example of effective, long-lasting Stabilized Full Depth Reclamation (SFDR). The research effort supported by this construction will also address rehabilitation techniques for full-depth asphalt pavements using modern techniques and materials.

4.2 Pavement Design

Four in-place recycling and four preventive maintenance test sections were planned, designed, and constructed to extend the life of former SFDR test sections as part of the 2022 NRRA MnROAD construction. The new test sections were constructed in an area previously occupied by test sections 101, 201, 2, 3 and 4 on the MnROAD I-94 WB mainline. Test sections 1-4 were originally constructed in 1994. Test section 1 was resurfaced in 2017 and split into two test sections: 101 and 201. In this case, the existing asphalt surface, aggregate base, and subgrade layers were maintained from when they were originally constructed in 1994. On the other hand, test sections 2, 3 and 4 were rehabilitated using a SFDR technique in 2008 and maintained their original subbase and subgrade layers from 1994. Typical sections for test sections before reconstruction in 2022 are presented in Figure 4.1. Typical sections for the test sections constructed for this study are presented in Figure 4.2. The test sections have widths of 9 ft for driving shoulder, 13 ft for driving lanes, 12 ft for passing lane, and 4 ft for passing shoulder.

Figure 4-1 Typical Sections for Test Sections Before Reconstruction

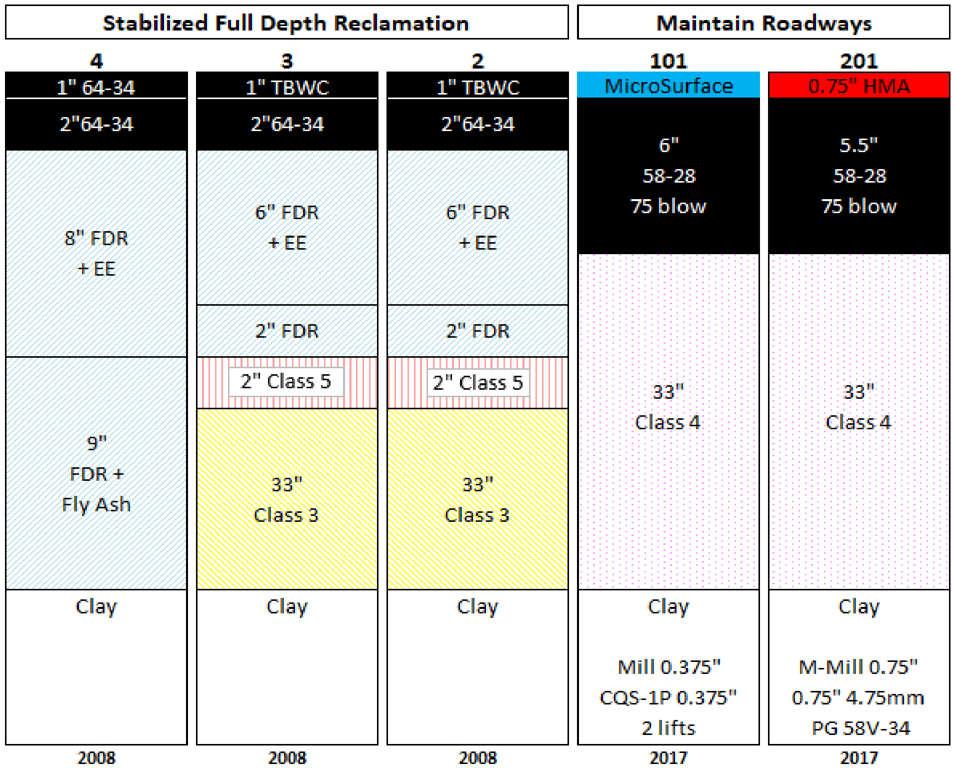
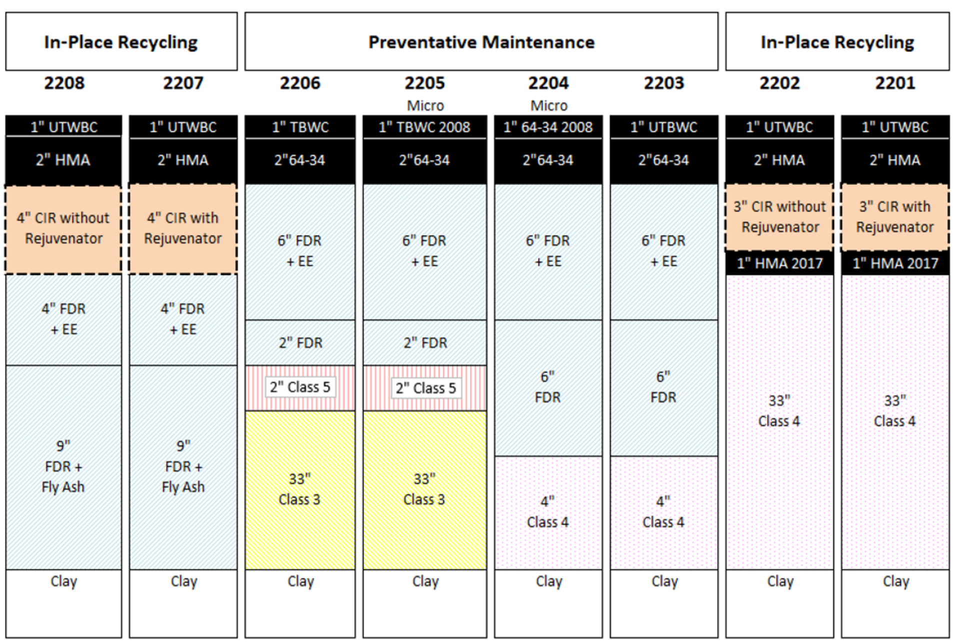


Figure 4-2 Typical Sections for Test Sections 2201 Through 2208



Design details for each constructed test section are summarized in Table 4.1.

Table 4-1 Perpetual Recycling Test Section Design

Test Section	Start Station	End Station	Length (ft)	Wear Layer	Non-Wear Layers
2201	1103+05	1105+54	249	UTBWC	2" HMA PG58-34 20% RAP + 3" CIR
2202	1105+94	1107+71	177	UTBWC	2" HMA PG58-34 20% RAP + 3" CIR
2203	1108+61	1111+06	245	UTBWC	Existing SFDR
2204	1111+46	1113+92	246	Microsurface	Existing SFDR
2205	1114+32	1116+77	245	Microsurface	Existing SFDR
2206	1117+17	1119+63	246	UTBWC	Existing SFDR
2207	1120+03	1122+68	265	UTBWC	2" HMA PG58-34 20% RAP + 4" CIR
2208	1123+08	1125+64	256	UTBWC	2" HMA PG58-34 20% RAP + 4" CIR

The Minnesota Department of Transportation (MnDOT) through its partnership with Asphalt Materials, Inc. provided the emulsion and rejuvenator to the mix design consultant selected by the Contractor to prepare the CIR mix designs for test sections 2201, 2202, 2207 and 2208 in accordance with specifications described in section 5-692.291 of the 2021 MnDOT Grading and Base Manual. Standard specifications stipulating the performance requirements are summarized in Table 4.2.

Table 4-2 Requirements for Emulsion CIR Mix Design (MnDOT Grading and Base Manual)

Property	Criteria	Purpose
Compaction effort, Superpave Gyratory Compactor, 1.16° internal angle, 600 kPa stress, gyrations	30 gyrations	Density Indicator
Density, ASTM D 2726 or equivalent	Report	Compaction Indicator
Gradation for Design Millings, ASTM C117	Report	--
Marshall Stability*, ASTM D 1559 Part 5, 40°C	1,250 lbs. min.	Stability Indicator
Retained Stability Based on Cured Stability * £	70 % min.	Ability to withstand moisture damage

Indirect Tensile Test, AASHTO T 322, Modified	Report	Thermal Cracking
Raveling Test, Method Attached, Ambient, Modified	2% max.	Raveling Resistance

CIR specimens were prepared using a gyratory compactor at internal compaction angle of 1.16 degrees and 30 gyrations. The target moisture content of 2.0% was added to process the milling in the laboratory. This is assumed to be “free” or pre-wet water that corresponds with the amount of water added at the milling head in the field.

For test sections 2201 and 2022, MnROAD staff provided cores and millings from previous test sections 101 and 201. The existing surface was milled, leaving about 2 to 2.5 inches of HMA remaining. The 2 to 2.5 inches of remaining HMA was reclaimed with added millings into a 3-inch CIR layer.

For test sections 2207 and 2008, MnROAD staff provided cores from previous test section 4. Test section 4 had 3 inches of HMA surface layers that were milled previously by CAT and left the 8-inch SFDR base layer exposed. Four inches out of the 8-inch SFDR base layer was then reclaimed into a 4-inch CIR layer. It is very important to highlight these sections because the CIR technique was employed on existing SFDR recycled material. In other words, the SFDR base layer underwent a second round of recycling.

Based on the results of the CIR mix design report, MnDOT requested our partners at Asphalt Material, Inc. to develop the amount of rejuvenator to add to the engineering emulsion (EE) for the tests sections in this research study. The rejuvenator was delivered to the mix design consultant, which was used to combine at 98% EE and 2% rejuvenator to produce six Marshall stability specimens to investigate retained stability in mixtures using the specially modified EE.

A summary of the mixtures design results performed at the optimum emulsion content are shown in Table 4.3. The complete CIR mix design report is in Appendix A.

Table 4-3 CIR Mix Design Results Summary

Test Section	Emulsion Content (%)	Dry Marshall Stability (lb)	Retained Stability	Raveling, Mass Loss (%)	Critical Low Pavement Temperature (°F)	Bulk Density (lb/ft^3)	Air Voids (%)
2201	2.2	1574	0.73	-	-	130.1	16.8
2202	2.2	1341	0.88	1.22	-20	132.8	15.1
2207	1.7	1411	0.77	-	-	130.6	15.7
2208	1.7	1279	0.85	0.56	-23	132.5	13.8

4.3 Construction

Existing asphalt layers were removed by cold milling performed by CAT at no cost through the NRRA partnership during the week of May 23rd to May 27th. During milling operations for test sections 101 and

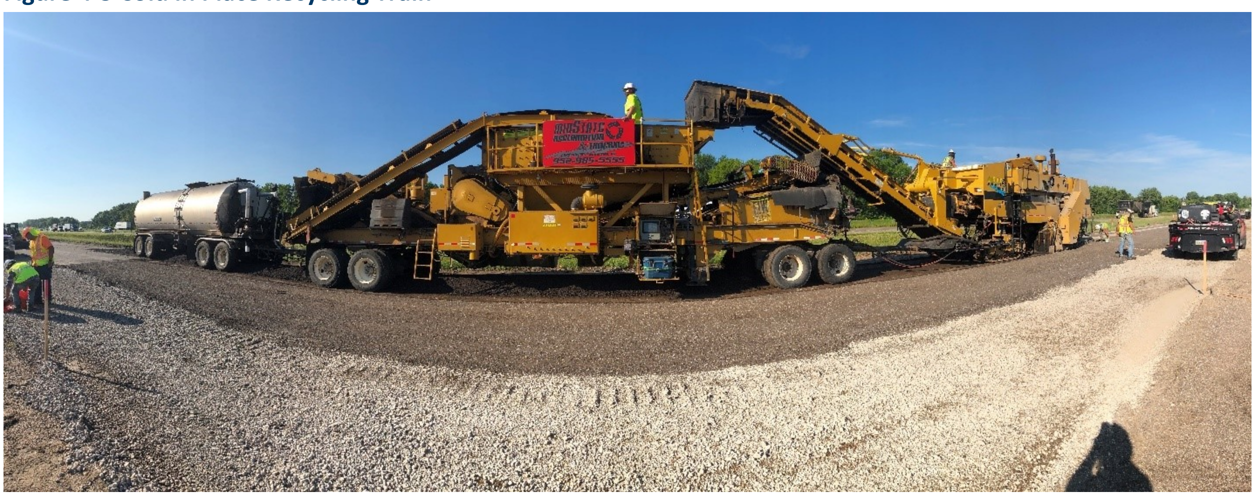
201, an extra inch of in-place material was unintentionally removed. For milling operation details refer to Chapter 2 of this report.

Table 4.4 presents the construction schedule for test sections under this research effort. CIR construction took place on August 22nd, HMA placement took place on August 25th, the microsurfacing was placed on September 12, and the UTBWC was placed on September 16. Figure 4.3 shows the CIR train used in the construction of these test sections at MnROAD.

Table 4-4 Construction Schedule for Test Sections under this Research Effort

Pavement Layer	Dates	Test Sections
CAT Milling	May 23 to May 27	2201 to 2208
3" CIR	August 22	2201 and 2202
4" CIR	August 22	2207 and 2208
2" HMA	August 25	2201, 2202, 2207 and 2208
Microsurface	September 12	2204 and 2205
UTBWC	September 16	2201, 2202, 2205, 2206 2207 and 2208

Figure 4-3 Cold in Place Recycling Train



Test sections 101 and 201 are now identified as 2201 and 2202. Tests sections 101 and 201 had a total length of 555 feet. Each new test section was intended to be approximately 277 feet in length. Approximately 3 to 3.5 inches of asphalt were milled leaving in place 2 to 2.5 inches of existing milled asphalt layer underlain by 33 inches of Class 4 aggregate subbase and clay subgrade. Two inches of RAP millings from MnROAD stockpile area were placed on top of the remaining milled asphalt to perform cold-in-place recycling on the top 3 inches (1" existing asphalt + 2" RAP millings). One-inch ultra-thin bonded wearing course (UTBWC) and 2" of hot mix asphalt (HMA) with PG58-34 binder and 20% RAP were placed on top of the 3" CIR layer.

The test section 2201 CIR layer incorporates an emulsion plus a rejuvenator to compared with the test section 2202 CIR that only incorporates an emulsion. During placement of the 2" HMA layer for test section 2202, the CIR layer between station 1105+94 and station 1108+61 was removed to correct for elevation and allow for a smooth transition between test section 2202 and 2203. This resulted in test section 2202 being reduced to 177 feet from starting station 1105+94 to ending station 1107+71. Figure 4.3 presents the cold in place recycling process.

Test sections 2 and 3 were divided in half to form 4 new test sections each with a length of approximately 286 feet. These new 4 test sections are now identified as 2203, 2204, 2205 and 2206. One inch of asphalt was removed, and a 1-inch-thick ultra-thin bonded wearing course (UTBWC) was placed for new test sections 2203 and 2206. Figure 4.4 shows the placement of the UTBWC.

Figure 4-4 UTBWC Placement on Test Sections 2201, 2202, 2203, 2206, 2207 and 2208

A microsurface layer was applied to test sections 2204 and 2205. Figure 4.5 shows the application of the microsurface layer.

Figure 4-5 Application of Microsurfacing on Test Sections 2204 and 2205

Test sections 2207 and 2208, previously test section 4, had 3 inches of asphalt over 8 inches of in-place full depth reclamation layer with engineered emulsion (FDR + EE) underlain by 9 inches of FDR + fly ash, and clay subgrade. These test sections have a length of 300 feet each. The top 3 inches of asphalt were milled leaving exposed the 8” FDR + EE layer. The top 4” of the FDR + EE layer were cold-in-place recycled. Similarly, to test sections 2201 and 2202, test section 2207 CIR layer incorporates an emulsion plus a rejuvenator to compare with test section 2208 CIR that only incorporates an emulsion. A one-inch-thick ultra-thin bonded wearing course (UTBWC) and 2” of hot mix asphalt (HMA) with a PG58-34 binder and 20% RAP were placed on top of the 4” thick CIR layer.

The previous design described the shoulders for test sections 2201 to 2208 as 4” of HMA over 33 inches of Class 4 aggregate subbase underlain by clay subgrade. The actual thickness of HMA shoulder varied from 4-5 inches in the driving lane shoulder and 4-9 inches in the passing lane shoulder. Class 5Q was used to bring the shoulders to final elevation. In general, Class 5 Q was added to balance during grading operations. In the passing lane shoulder of test sections 2203 and 2204, 5 inches of Class 5Q was placed with a Blaw-Knox RW-195D road widener and compacted with vibratory plate compactor.

4.4 Sampling and Testing

For research purposes, 3 buckets per test section were filled with CIR material during construction. Also, 2 gallons of emulsion and 2 gallons of rejuvenator were collected and shipped to the University of New Hampshire for further testing based on the workplan for this research project. The research also included the collection of smaller field samples of approximately 5000 grams per test section to conduct extraction and recovery. Details on the testing proposed for this project are listed on the project’s website, with results to be compiled in a separate report.

The Contractor retained the services of a consultant to conduct quality assurance testing. The results were submitted to MnROAD engineers, and the report can be provided upon request to MnROAD staff.

This field report includes rolling patterns, observations, sieve analysis, CIR compaction report, CIR depth report, CIR yield bitumen report and moisture test results.

Rolling patterns were establish by creating a control strip at two randomly selected points using smooth drum and rubber tires rollers. To achieve a maximum wet density of 132.7 pcf, it was established that for test sections 2201 and 2202, 4 passes of the smooth drum roller and 3 passes of the rubber tire roller were required. On the other hand, for test sections 2207 and 2208, 4 passes of the smooth drum roller and 4 passes of the rubber tire roller were required to achieve a maximum wet density of 136.9 pcf. Four nuclear density tests were conducted per test section. Table 4.5 presents a summary of the measured nuclear density results. All tests conducted met or exceeded the 98% compaction requirement.

Table 4-5 Summary of CIR Measured Nuclear Density Quality Assurance Results

Test Section	Station	Test Wet Density (PCF) From Nuclear	Relative Compaction (%)	Pass/Fail
2201	1103+40	133.2	100	Pass
	1103+40	133.4	101	Pass
	1105+24	133.5	101	Pass
	1105+24	133.9	101	Pass
2202	1106+01	143.2	108	Pass
	1106+01	139.1	105	Pass
	1107+17	136.4	103	Pass
	1107+17	137.1	103	Pass
2207	1120+03	139.2	102	Pass
	1120+03	140.8	103	Pass
	1121+15	138.2	101	Pass
	1121+15	139.0	102	Pass
2208	1123+07	133.6	98	Pass
	1123+07	137.6	101	Pass
	1124+95	139.0	102	Pass
	1124+95	136.0	99	Pass

Results on samples collected to perform sieve analyses are presented in Table 4.6.

Table 4-6 Summary of Sieve Analysis Conducted on CIR Field Samples

	% Passing			
Sieve Sizes	Section 2201	Section 2202	Section 2207	Section 2208
1.5”	100	100	100	100
1”	98.1	-	95.7	96.4
¾”	95.4	82.3	90.6	94.1
3/8”	69.8	59.0	67.4	79.0
#4	46.9	40.8	42.0	56.9
#10	28.5	25.8	25.7	37.0
#30	11.2	11.4	10.6	16.0

Light weight deflectometer (LWD) tests were conducted on the CIR layers at approximately 2, 24, 48 and 60 hours after construction. Table 4.7 presents a summary of the LWD results. The results show CIR layer modulus values increasing with time.

Table 4-7 Light Weight Deflectometer (LWD) Results for CIR Layers

Test Section	Station	Lane	Modulus (MPa)			
			8/22/2022	8/23/2022	8/24/2022	8/25/2022
2201	1103+85	Passing	69	105	145	168
		Driving	-	94	112	145
	1105+00	Passing	96	119	122	149
		Driving	-	91	113	145
2202	1106+42	Passing	93	122	129	179
		Driving	89	105	120	135
	1107+75	Passing	74	94	117	166
		Driving	109	114	128	171
2207	1120+70	Passing	66	93	114	-
		Driving	-	107	124	-
	1122+22	Passing	71	101	113	-
		Driving	-	104	120	-
2208	1123+58	Passing	71	97	121	-
		Driving	112	140	156	-
	1124+90	Passing	89	82	105	-
		Driving	78	105	135	-

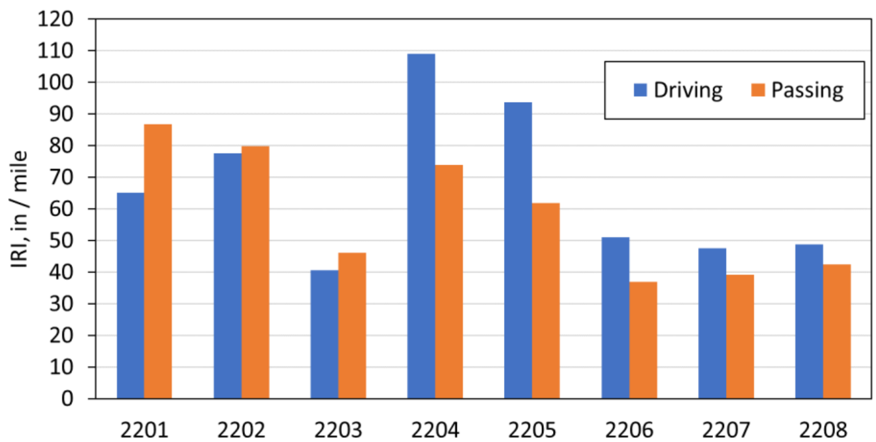
Nuclear density and moisture measurements were performed bituminous surface as part of construction of test sections 2201, 2202, 2207 and 2208. Table 4.8 presents the results of the conducted tests.

Table 4-8 Average In-place Nuclear Density

Test Section	Paving Layer	Layer %Gmm	Stdev	N
2201	12.5 mm (5C) over CIR w/ Rejuvenator	91.5	1.04	17
2202	12.5 mm (5C) over CIR w/o Rejuvenator | Existing FDR	92.5	0.89	20
2207	12.5 mm (5C) over CIR w/ Rejuvenator	90.9	1.87	11
2208	12.5 mm (5C) over CIR w/o Rejuvenator | Existing FDR	92.1	0.92	20

International Roughness Index (IRI) was measured on the final HMA layers at approximately after construction. Figure 4.6 presents a summary of the IRI results.

Figure 4-6 IRI Measurements for Test Sections 2201 to 2208



4.5 Instrumentation and Sensors

No new sensors were installed for these test sections. These sections only had thermocouples originally installed and those remaining in the newly constructed test sections. Table 4.9 presents the number of working thermocouples (TC) on test sections 2201 through 2008. Appendix B lists the as-built locations of the sensors.

Table 4-9 Thermocouple Trees (TC) in Each Test Section

Test Section	Number of Working TC sensors
2202	8
2203	11
2206	14

Chapter 5: Concrete Overlay Test Section Repairs Utilizing Performance Engineered Mixes (PEM) and Diamond Grinding

5.1 Objectives

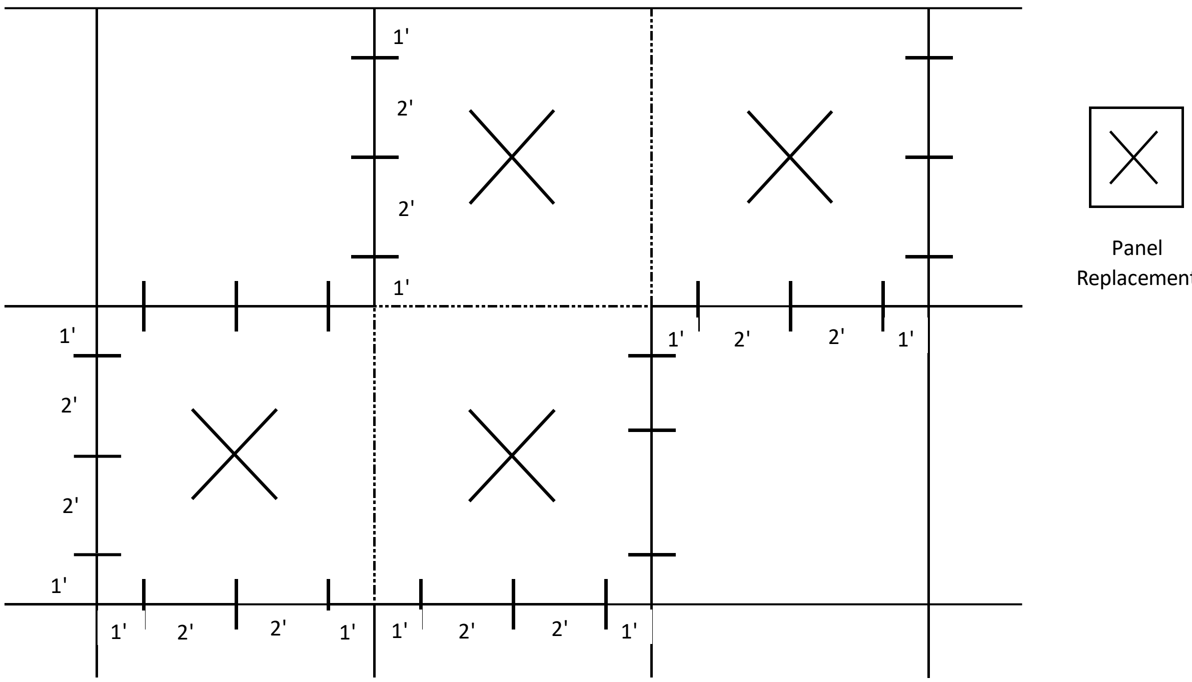
Thin (undoweled) concrete overlays, on concrete or asphalt, develop cracked panels and transverse joint faulting when subject to heavy truck loadings. The primary objective of this research is to diamond grind existing thin concrete overlay test sections at MnROAD, along with other roadway segments in the state and local county network, that have developed low to moderate levels of joint faulting. The results of this research hope to establish how long the improved ride quality will take to reach the pre-ground levels. Concrete pavement repairs for test sections 160-162 and 505-805 were carried out prior to the grinding, utilizing performance engineered mixtures (PEM) and associated test methods during installation.

This research evaluates the feasibility of using PEM materials and test methods for concrete pavement rehabilitation (CPR), and the longevity of improved ride quality of thin concrete overlays after diamond grinding. Repairs and diamond grinding of two existing concrete overlays on asphalt (COA) and 4 existing concrete overlays on concrete (COC) test sections at MnROAD were performed, and their performance will be monitored over a minimum 3-year period. Data collected by MnROAD during the evaluation period includes visual distress surveys, joint opening and fault measurements, joint load transfer performance using the Falling Weight Deflectometer (FWD), ride quality profiling, ultrasonic tomography (MIRA), curling and warping measurements, and extracted cores.

5.2 Design

Existing test sections 160-162 and 505-805 were utilized for testing of PEM mix repairs and diamond grinding. In each of these sections, approximately 20% of the panels were removed and replaced. The replacement included saw cutting and removal of panels. Panel sizes were 6-foot by 6-foot. Holes were drilled and blown out for reinforcement bar with a maximum spacing of 2-feet. Reinforcement bars were anchored in place using an epoxy adhesive. See figure 5.1 for detailed panel replacement plan. Concrete mix was placed using the optimized mixture from CP Tech Center. Cell maps displaying which panels were replaced are shown in Appendix C. Bond breaker fabric material was placed under the repairs shown in Figure 5.3. After panel replacement was complete, diamond grinding took place on all cells.

Figure 5-1 Typical Panel Replacement and Tie Bar Detail (bottom)



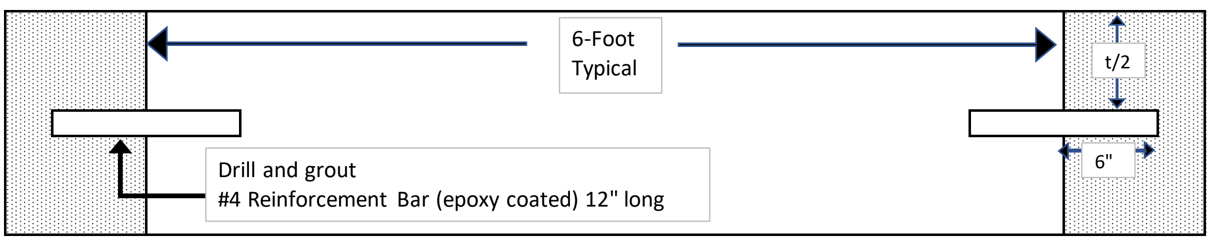
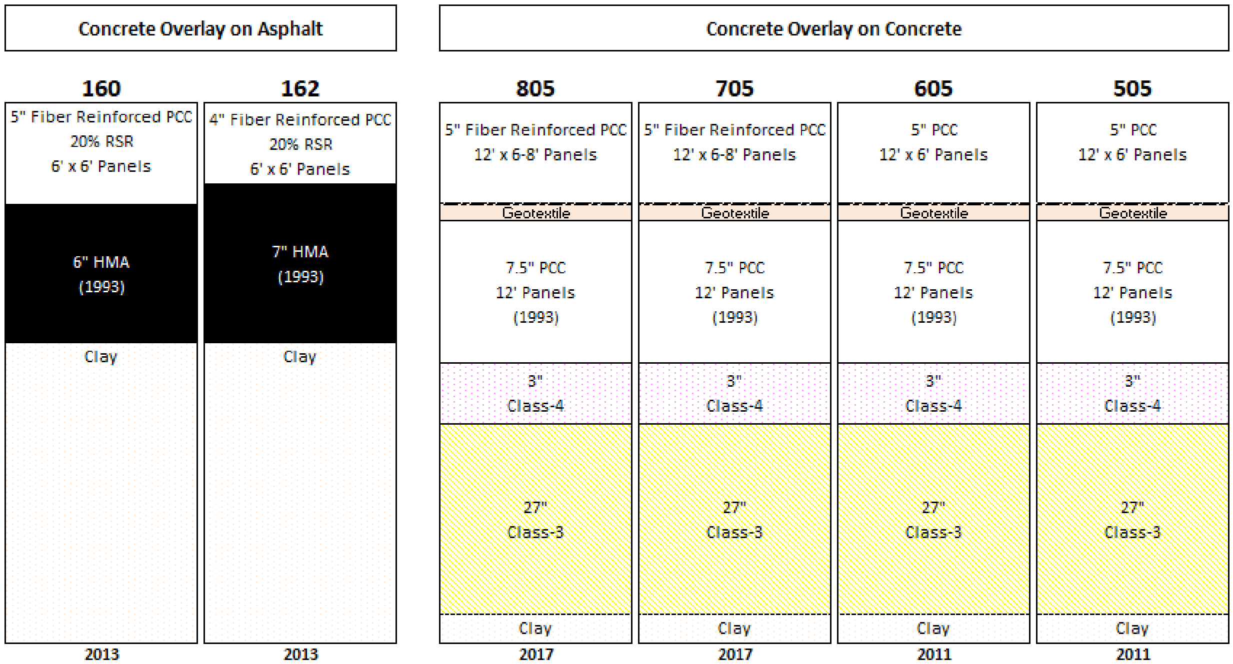


Figure 5-2 Cross-section Design of Concrete Repair Test Sections



5.3 Construction

Table 5.1 shows the construction schedule for test sections under this research study.

Table 5-1 Construction Schedule

	August 2022				September 2022			
Activities	**7**	**14**	**21**	**28**	**4**	**11**	**18**	**25**
Prep. Full Depth Repair Panels	X							
Place Concrete in Repair Panels		X						
Diamond Grinding					X			

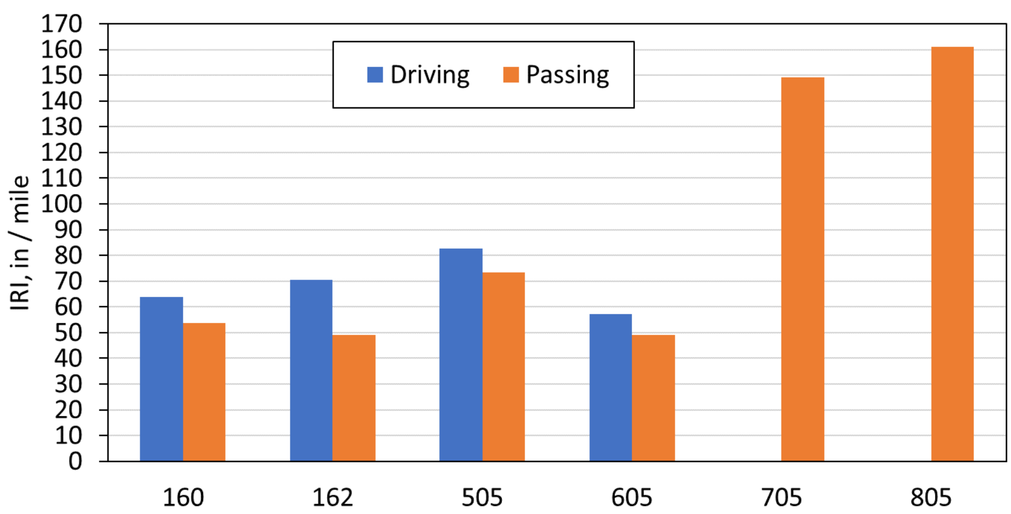
Figure 5-3 Preparation of Repair Panels for Concrete Placement with Tie Bars and Bond Breaking Fabric Material for Test Section 160

Figure 5.4 shows the placement of concrete in the repaired panels. Concrete was placed with tie bars and bond breaking fabric material.

Figure 5-4 Placement of Concrete in Repair Panels in Test Section 160

Figure 5.5 presents a summary of the International Roughness Index (IRI) results on these repaired test sections.

Figure 5-5 IRI Measurements for Test Sections 160-162 and 505-805



5.4 Sampling and PEM related Testing

Compressive strength tests were conducted at 28 days and flexural strength tests were conducted at 1, 3, 7 and 28 days. In addition to optimization of the concrete mixtures, there are several newer fresh and hardened concrete tests developed for PEM. These tests are designed to better predict the future performance of the concrete. Table 5.2 shows the PEM tests performed on these test sections.

Table 5-2 Performance Engineered Mixtures Tests

Tests	Measurement
Box Text	Surface void rating
Super Air Meter	Air content and SAM number
Concrete Resistivity	Permeability
Vibrating Kelly Ball (V Kelly)	Rate of Penetration

5.5 Instrumentation and Sensors

The tests sections in this study did not have any new sensors installed during the 2022 construction event. A review of the sensors currently present took place to determine how many were functioning properly. Sections 505-805 did not contain any sensors. The list of existing sensors that were functioning properly during the time of construction in sections 160 and 162 are shown in Table 5.3.

Table 5-3 Existing Sensors in Repaired Test Sections

Test Section	Sensor Type		No. of Sensors
160	TC	Omega, Thermocouple	16
	VW	Geokon, 4200A-2 Vibrating Wire Strain Gauge	5
162	TC	Omega, Thermocouple	8
	VW	Geokon, 4200A-2 Vibrating Wire Strain Gauge	6

Chapter 6: Use of Alternative Pozzolanic Materials Towards Reducing Cement Content in Concrete Pavements

6.1 Objectives

Replacement of cement in concrete with pozzolans translates to a significant reduction of carbon footprint. This substitution must be done without compromising the strength and durability of the concrete. Using higher percentages of limestone or natural pozzolanic substitution without compromising durability or long-term mechanical strength translates into a sustainable practice. Although much research has gone into pozzolanic substitution, there is a lack in the knowledge base regarding the sustainable limits in the use or inclusion of limestone in cementitious blends. Additionally, there is a missing link between limestone content and its actual influence on the porosity of the mix, including absorption and possible desorption within the matrix.

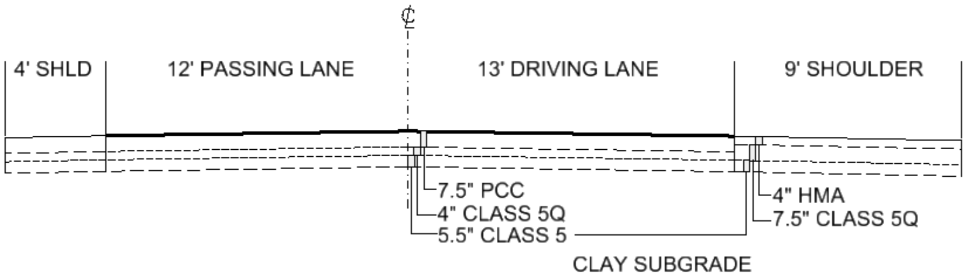
The main goal of this research is to investigate the factors impacting production and placement of concrete pavement utilizing alternative pozzolanic materials, as well as determine the field performance when exposed to heavy traffic loading and extreme climatic conditions.

6.2 Design

Due to the renewed interest seen nowadays in using natural and recycled materials-such as pozzolans as a replacement for Portland cement this research project was designed to investigate the sustainability and resiliency of alternative pozzolanic materials within pavements and help increase confidence in the usage of ternary or quaternary blends of cementitious materials.

Concrete mixes containing six alternative pozzolanic materials were placed on test sections 2215, 2219, 2220, 2221, 2222 and 2224 as part of the 2022 NRRA MnROAD construction. As presented in Figure 6.1, the typical section for each of these test sections is 7.5 inches of concrete placed on 4 inches of Class 5Q aggregate base over 5.5 inches of Class 5 subbase. The test sections have widths of 9 ft for driving lane shoulder, 13 ft for driving lanes, 12 ft for passing lane, and 4 ft for passing shoulder. The 9 ft driving lane shoulder was paved with a 4-inch-thick hot mix asphalt surface. The concrete panels are 15 ft long, and the passing lane concrete shoulder was paved monolithically with the passing lane, then sawcut to the 4-foot width. The transverse joints contain eleven 1.25-inch diameter by 15-inch-long epoxy coated steel dowel bars space at 12 inches on center. The final surface was first created using Astro turf drag, but sections 2215, 2219, 2220, and 2224 had to be diamond ground shortly after construction due to inadequate texture. Panels containing sensors in each of these sections were not diamond ground to retain at least a portion of the original texture that was created and to protect the sensors from damage.

Figure 6-1 Typical Section for Alternative Pozzolanic Test Sections



Design details for each constructed test section are summarized in Table 6.1. All concrete mixes with Portland limestone cement (PLC) were manufactured to meet ASTM C595 with 10% limestone (Type IL(10)). The Urban Mining -Ground Glass alternative pozzolanic material placed in test section 2215 is composed of Portland limestone cement (PLC) and 30% ground glass pozzolan replacement. The optimized mix designed by the CP Tech Center placed in test section 2219 is composed of Portland limestone cement (PLC) and 30% fly ash with a total reduced cementitious content. The Burgess Pigments natural pozzolan placed on test section 2220 is composed of Portland limestone cement (PLC), 18% fly ash and 12% Metakaolin replacement. The 3M natural pozzolan placed in test section 2221 is composed of Portland limestone cement (PLC), 15% Prairie State fly ash and 15% natural pozzolan for 30% total replacement. The Hess Pumice natural pozzolan placed in test section 2222 is composed of Portland limestone cement (PLC) and 30% natural pozzolan replacement. The Carbon limit blended alternative supplementary cementitious material (SCM) placed in test section 2224 is composed of a natural pozzolan mix plus a catalyst at a 30% total replacement.

Table 6-1 Alternative Pozzolanic Materials Test Section Design Details

Section	Material	Start Station	End Station	Length (ft)
2215	Urban Mining - Ground Glass	1148+70	1149+94	127
2219	Optimized Mix - CPTech	1167+99	1170+67	268
2220	Burgess Pigments - Natural Pozzolan	1170+67	1172+62	195
2221	3M - Natural Pozzolan	1172+62	1174+96	234
2222	Hess Pumice - Natural Pozzolan	1175+35	1177+65	230
2224	Carbon Limit - Blended ASCM	1181+13	1182+82	169

Selection of the final concrete mix designs were determined under a separate project responsible for the development of concrete mix designs/matrix of materials, performance properties, and construction field sampling and testing expectations during the 2022 MnROAD construction. Mix design trials for this study were conducted by AET and Braun Intertec. Trial mixing incorporated the latest Performance Engineered Mixture (PEM) tests including air content, Super Air Meter (SAM), box test, unit weight, slump test and paste content for fresh properties and compressive and flexural strength for hardened properties. Project specific paving mix designs (JMF) are presented in Appendix D.

Final mixes used to construct the alternative pozzolanic materials test sections were produced and delivered to MnROAD by Aggregate Industries.

6.3 Construction and Observations

Table 6.2 presents the concrete mix designations, placement time and quantities placed at MnROAD for the alternative pozzolanic test sections. Construction of these sections began with test section 2215 on August 1st. Construction followed MnDOT Specification 2301 Concrete Pavement and the project specification special provisions. For all test sections, a central batch plant was used to produce the concrete, and the material was delivered to MnROAD in concrete mixing trucks for placement using a standard slip-form paver. In all test sections Joint sawing occurred approximately 4-6 hours after placement.

Table 6-2 Alternative Pozzolanic Concrete Mix Designations, Placement Time, Quantities and Weather Conditions

Test Section	Mix ID	Day Placed	Time Start	Time Stop	Quantity (cy)	Weather Conditions
2215	3A21-RGM1	8/1/2022	8:38 am	10:05 am	97	67°F, Sunny
2219	3A21-RGI1	8/5/2022	10:00 am	12:34 pm	196	76°F, Sunny
2220	3A21-RGB1	8/5/2022	7:21 am	9:56 am	185	69°F, Sunny
2221	3A21-RG31	8/4/2022	9:28 am	11:21 am	176	69°F, Sunny
2222	3A21-RGP1	8/4/2022	7:15 am	9:02 am	178	60°F, Sunny
2224	3A21-RGL1	8/3/2022	7:51 am	9:33 am	125	74°F, Sunny

6.3.1 Test Section 2215: Urban Mining - Ground Glass

The first truck arrived around 7:00 am on July 29, 2022. The first few loads appeared dry and not workable. These trucks had 2 oz of water reducer and no viscosity modifying admixture (VMA). They increased the water reducer on the next couple trucks and added water on site. The paver got stuck in the concrete about 15 feet from the header due to the unworkable dry concrete from the first couple loads. They tried to back the paver up to revibrate and bent the vibrators. They had to lift the paver out of the concrete and fix the vibrators. The paver moved ahead past the dry concrete to start paving again. The Ready-mix plant then broke down. The finished surface was not acceptable. Decision was made to move past this cell to the next and repave this cell at the end of the project. This material was completely removed from the cell.

The second attempt to pave this cell began on August 1, 2022. The control mix was placed for the first 100 yards. The mix arrived at 8:45am using 5 oz of water reducer instead of the 1-3 oz dosage as shown on the mix design. Slump appeared to be within the acceptable range. The mix placed and finished well. There was a 20-minute delay between the third and fourth truck. The surface at that location required water at the surface to assist with finishing. About 100 yards was placed. The final 30 yards were a control mix. At the transition between the next mix, the Contractor lifted the paver and removed the grout box material before starting the next cell. Figure 6.2 shows the concrete being placed for test section 2215.

Figure 6-2 Concrete Placement for Urban Mining Ground Glass Test Section 2215

6.3.2 Test Section 2224: Carbon Limit - Blended ASCM

Super sacks of the Carbon Limit - Blended ASCM material were loaded into a pneumatic tanker at MnROAD prior to delivery to the ready-mix plant. This material was delivered in supersacks to MnROAD prior to construction. Loading the material from the supersacks into the pneumatic tanker was difficult. During placement of the concrete in Cell 2224, there was downtime of up to 30+ minutes between concrete trucks. Once the concrete mixture was placed, color variation was obvious behind the paver. It was later discovered that the blended material was delivered in three layers in the supersacks and was not actually uniformly blended. The concrete mixtures placed in this section had extremely high-water demand. The mix design called for 1-4 oz of water reducer (WR). The first mixtures started with 4 oz of WR, but quickly went to 7, and then to 9 oz. For the mixture with 4 oz., 50-gal of water had to be added to the truck between the plant and placement. Even with 9 oz of WR, trucks were adding 20 gallons of water. The mix was very stiff. The final surface texture was poorly consolidated and extremely smooth.

Raveling occurred, as saw operators reported a hard upper surface with a softer sub-surface. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 6.3 shows the concrete being placed for test section 2224.

Figure 6-3 Concrete Placement for Carbon Limit Blended ASCM Test Section 2224

6.3.3 Test Section 2222: Hess Pumice - Natural Pozzolan

During placement of the mixed concrete, there was downtime of up to 30+ minutes between deliveries. Delays were due to both transport between the plant and MnROAD, as well as the need to stop at a sampling station set up nearby where several crews made test specimens for production and research purposes. When the material was hit with a vibrator, pronounced bleed water resulted, more than observed for other mixtures. The mix placed well and finished well overall throughout the section. The final Astro turf drag surface met minimum texture requirements and did not need grinding. Figure 6.4 shows the concrete being placed for test section 2222.

Figure 6-4 Concrete Placement for Hess Pumice Natural Pozzolan Test Section 2222

6.3.4 Test Section 2221: 3M - Natural Pozzolan

There was downtime of up to 15+ minutes between concrete deliveries. Delays were due primarily to sampling. The first few loads were "wet." When the material was vibrated, pronounced bleed water resulted, more than observed for other mixtures. The mix placed well and finished well overall throughout the cell. There are no signs of clumps on the finished surface of the slabs. The final Astro turf drag surface met minimum texture requirements and did not need grinding. Figure 6.5 shows the concrete being placed for test section 2221.

Figure 6-5 Concrete Placement for 3M Natural Pozzolan Test Section 2221

6.3.5 Test Section 2220: Burgess Pigments - Natural Pozzolan

Fifty-pound sacks had to be manually emptied into the truck at the plant. Downtime of up to 30+ minutes between deliveries occurred. Delays were due to both transport and sampling. Aggregate Industries was having difficulty mixing the burgess pigments material into the concrete when added either before the truck was loaded, or after the truck was loaded. Large (up to 1”) clumps were seen in the discharged concrete. The mixtures were very dry and required water to be added at the site during paving. Extended mixing time was required for this mix. There are no signs of the clumps in the finished slabs. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 6.6 shows the concrete being placed for test section 2220.

Figure 6-6 Concrete Placement for Burgess Pigments Natural Pozzolan Test Section 2220

6.3.6 Test Section 2219: Optimized Mix - CPTech Center

There was downtime of up to 15+ minutes between deliveries. Delays were due primarily to sampling. Extended mixing time was required for this mix. The mix placed and finished well throughout the cell. Slump looked within acceptable range. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 6.7 shows the concrete being placed for test section 2219.

Figure 6-7 Concrete Placement for CPTech Center Optimized Mix Test Section 2219

6.4 Sampling and Testing

A comprehensive sampling and testing program were implemented for these new test sections. This was a combined effort that included Federal Highway Administration (FHWA) Mobile Concrete Technology Center (MCTC) mobile laboratory, American Engineering Testing (AET), and Turner Fairbanks Highway Research Center (TFHRC).

A total of 186 fresh concrete specimens were collected. A list of the fresh concrete testing can be found in Table 6.3. MnDOT collected samples of cementitious materials and aggregates at the batch plants to satisfy MnDOT contract quality assurance requirement. In addition, the contractor also tested the surface texture after paving. Delays occurred in concrete placement due to both transport between the plant and MnROAD, as well as the need to stop at a sampling station set up nearby where several crews made test specimens for production and research purposes. Tests results can be shared upon request to MnDOT personnel and will be documented under a summary document.

Table 6-3 Number of Test Specimens Taken to Determine Properties of Fresh Concrete for Alternative Pozzolanic Materials Test Sections

		Test Sections					
Tests	**Test Method**	**2215**	**2219**	**2220**	**2221**	**2222**	**2224**
Slump, in	AASHTO T119	4	3	5	5	5	3
Air content, %	ASTM C231 / AASHTO T152	4	3	5	5	5	3
Super Air Meter, SAM No.	AASHTO TP118	4	3	4	4	4	3
Hardened Air Content, %	ASTM C457	3	2	3	3	3	2
Unit Weight, pcf	ASTM C138	4	3	5	5	5	3
Temperature, °F	ASTM C1064	4	3	5	5	5	3
Box Test	AASHTO TP137	2	2	4	2	2	2
Phoenix, w/c	AASHTO T152	2	1	2	2	2	1
V-Kelly Index	AASHTO TP129	1	1	3	1	1	1
Microwave, w/c	AASHTO TP23	2	1	2	2	2	1
Calorimetry	ASTM C1753	1	1	1	1	1	1

To determine the hardened concrete properties of the materials in the test sections, a total of 719 specimens were cast on site. The testing on these specimens was conducted by FHWA and AET. Table 6.4 presents the tests that were conducted on the collected hardened specimens, the standard test method, age, specimen type and size. It should be noted that for some test procedures, raw materials were collected and provided to AET for trial batching and testing.

Test results and analysis of these materials will be discussed in the research project construction report and analysis. All test results for both fresh and hardened properties are part of the MnROAD database and available upon request. For test section 2219, the Poisson's ratio test was not performed.

Table 6-4 Hardened Concrete Properties Tests for Alternative Pozzolanic Materials Test Sections

Tests	Test Method	Testing Age (days)
Compressive Strength	ASTM C39	1, 3, 7, 14, 28, 42 and 56
Flexural Strength	ASTM C78	1, 3, 7, 14, 28 and 56
Resistivity	AASHTO T358	1, 3, 7, 14, 28, 42, 56, 91 and 120
Maturity	ASTM C1074	Up to 56
Bulk Resistivity	ASTM C1876	7, 28, 56, 91 and 120
Formation Factor	AASHTO R101	28, 56, 91, 120
Critical Saturation Time	ASTM C1585	120
Deicing Salt Damage	AASHTO T365	28
Rapid Chloride Permeability	ASTM C1202	56
Freeze Thaw	ASTM C666	15
Poisson's Ratio and Elastic Modulus	ASTM C469	28
Coefficient of Thermal Expansion	AASHTO T336	-
Drying Shrinkage	ASTM C157	35
Autogenous Shrinkage	ASMT C1698	7
TGA	E1131 NIST TFHRC	28 and 56
Carbon Sequestration	E1131 NIST TFHRC	28 and 56
Carbon Uptake and pH	-	-
XRD and XRF	-	-
Pore Solution Expression	-	28 and 56
Blended Cement	ASTM C595	28
Performance Spec for Hydraulic Cement	ASMT C1157	28
Fly Ash or Natural Pozzolans	ASTM C311	28
Expansion of Mortar Bars	ASTM C1038	14
	ASTM C1012	365
Concrete Prism	ASTM C1293	730
Alkali Silica Reactivity	ASMT C1567	28
	ASTM C1260	28
R3 Testing	ASTM T1897	7
Aggregate Stability	TFAST	-
Semi-adiabatic Calorimetry	ASTM C1679	-
Set Time	ASTM C403	

To characterize all aspects of the new test sections, several test procedures were performed by MnROAD research staff within the first few weeks after paving. Surface profiling was conducted using the MnROAD Lightweight Inertial Surface Profiler (LISA) and baseline faultmeter measurements were taken. Results from this testing will be used by the principal investigator of the research contract. Others can obtain the data from the MnROAD website, or by contacting MnROAD staff.

Thickness was measured throughout each test section using the MIT-Scan-T2 device. Figure 6.8 shows the final concrete thickness measured from the T2 plates.

Figure 6-8 Final Concrete Thickness Measured by MIT-Scan-T2

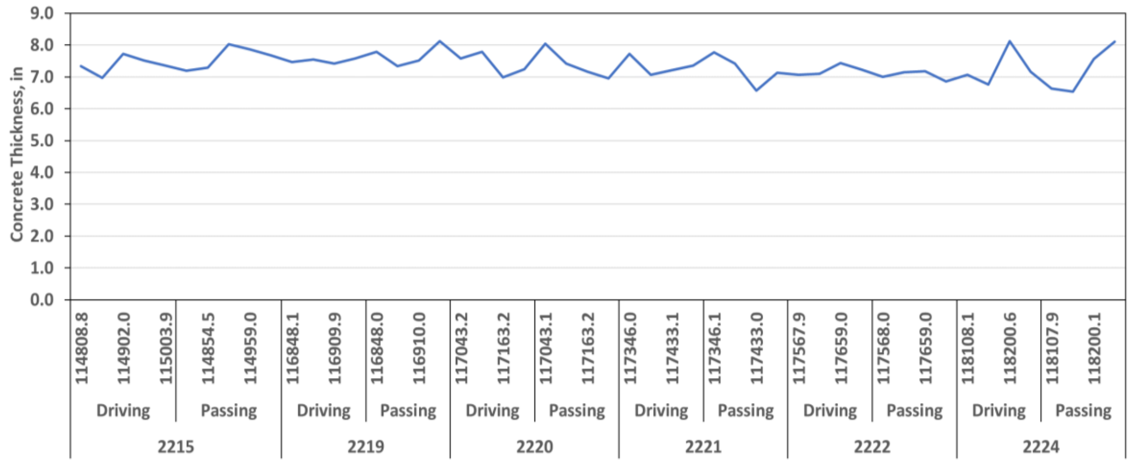


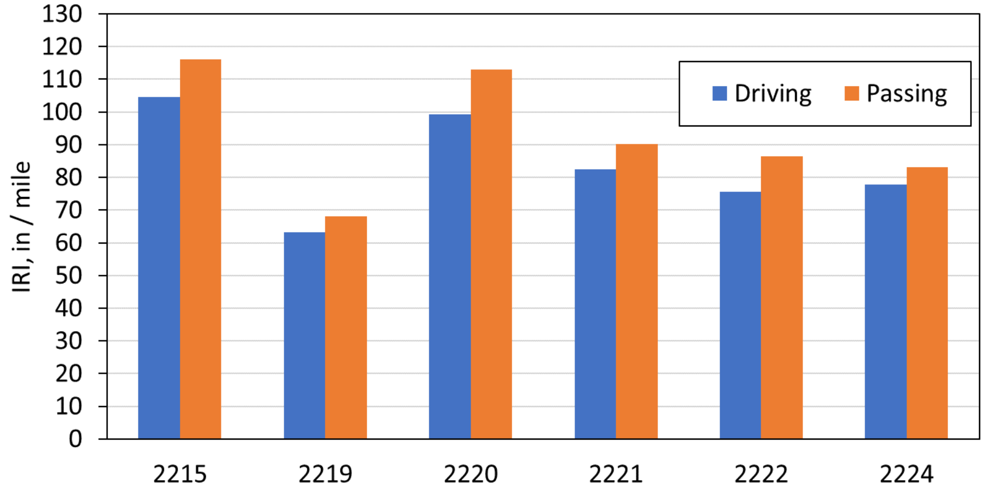
Table 6.5 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 6-5 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Thickness, in	Std. Dev.
2215	7.79	0.120
2219	7.73	0.184
2220	7.14	0.142
2221	7.30	0.241
2222	7.09	0.125
2224	7.88	0.194

Figure 6.9 presents a summary of the International Roughness Index (IRI) results for the test sections under this research study.

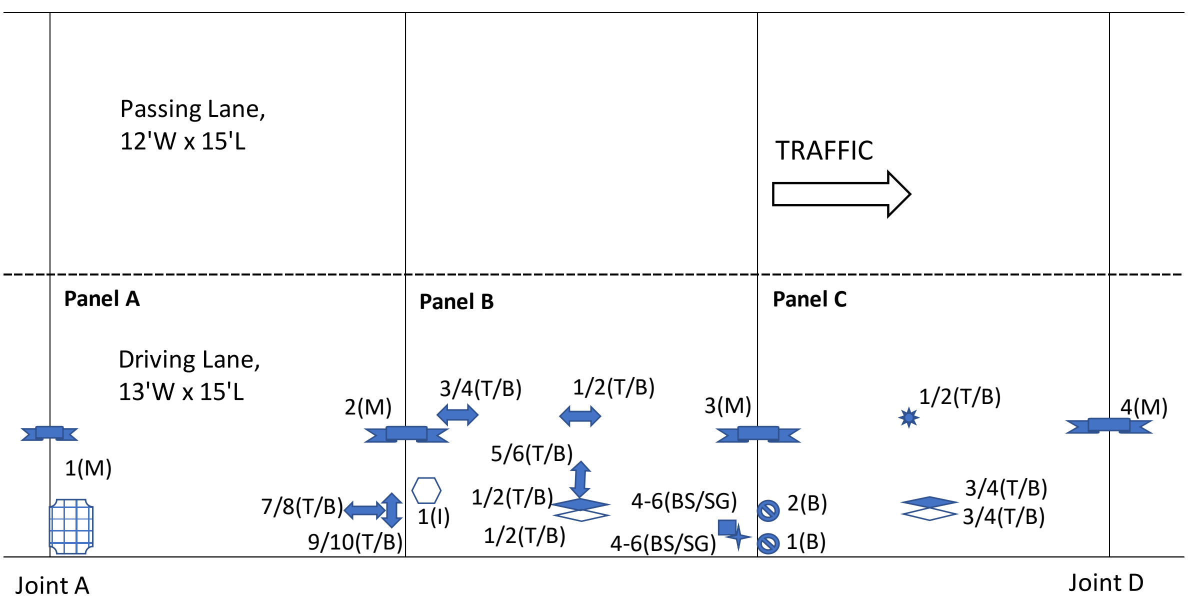
Figure 6-9 IRI Measurements for Alternative Pozzolanic Materials Test Sections



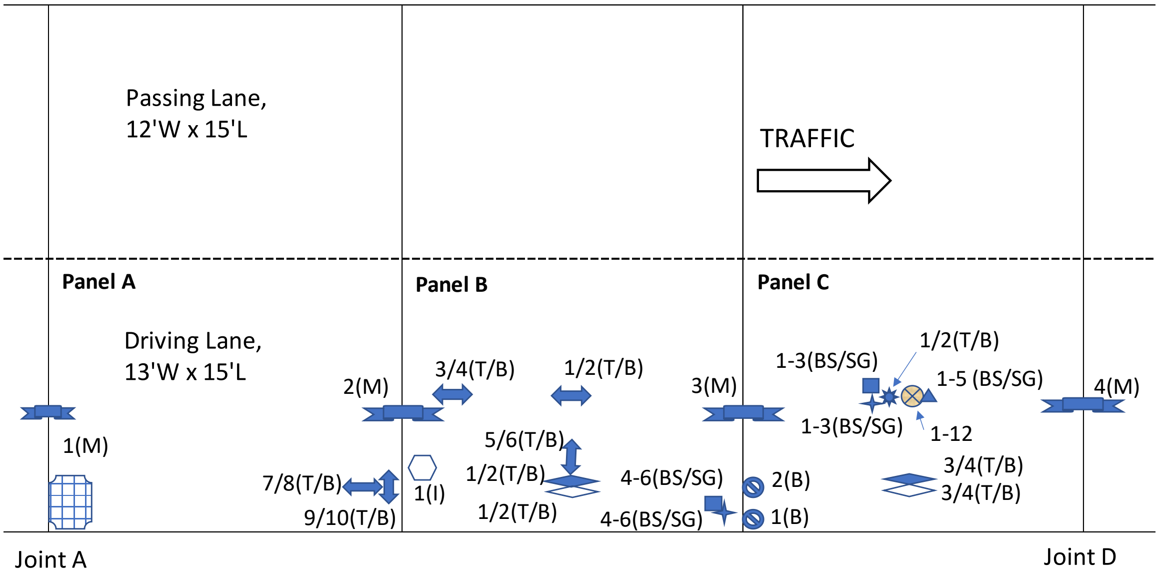
6.5 Instrumentation and Sensors

For test sections 2215, 2219, 2220, 2221 and 2222 environmental strains gauges, joint opening, vibrating wire, TEROS 12 moisture sensors, pressure plates and grids, magneto induction sensors were installed (Figure 6.10a). Test section 2224 had all the sensors previously mentioned plus new thermocouples (TC) and TEROS 10 and TEROS 21 moisture sensors (Figure 6.10b). For description of new sensors installed during this construction effort refer to Chapter 14. For sensors that have been installed by MnROAD staff in previous construction efforts please refer to MnROAD website. Appendix B lists the as-built locations of the sensors.

Figure 6-10 Sensor Installation Layout



(a)



(b)

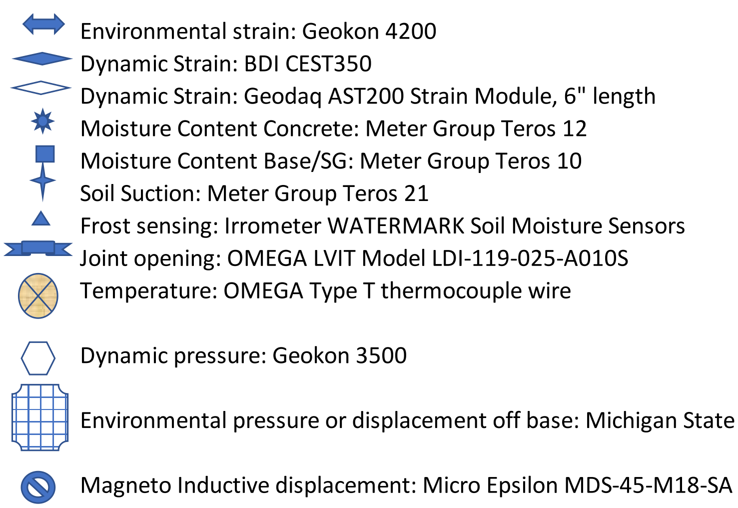


Table 6.6 shows the instrumented joints and stations for each test section under this study.

Table 6-6 Instrumented Joints and Stations per Test Sections

Test Section	Joint A #	Joint A Station	Joint D #	Joint D Station
2215	3019	1149+53	3016	1149+08
2219	3246	1169+32	3243	1168+87
2220	3260	1171+42	3257	1170+97
2221	3277	1173+97	3274	1173+52
2222	3294	1176+37	3291	1175+92
2224	3331	1182+07	3328	1181+62

Table 6.7 shows the number of maturity sensors installed per lane in each test section. A total of 41 wireless maturity sensors were installed in the test sections under this research study. As shown in

Figure 6.11 the maturity sensors installed collected temperature at two points, within the body of the maturity sensors and at the tip of the cable. Maturity sensors were installed with zip ties on the dowel bar basket assemblies. More details on the type of maturity sensors can be found in Chapter 14. Maturity sensors data is available upon request to MnROAD staff.

Table 6-7 Number of Maturity Sensors Installed

Test Section	Lane	
	Driving	Passing
2215	4	3
2219	4	3
2220	4	2
2221	4	3
2222	4	3
2224	4	3

Figure 6-11 Maturity Sensors Installation for Alternative Pozzolanic Materials Test Sections

Chapter 7: Use of Carbon Dioxide for Sustainable and Resilient Concrete Pavements

7.1 Objectives

In 2016, world cement production generated around 2.2 billion tons of CO_2. More than half of the emissions associated with cement manufacturing arise from the calcination process. Together with thermal combustion, 90% of the sector's emissions could be attributed to the production of clinker. It is therefore necessary to explore alternative options for cement and concrete production used in public infrastructure to achieve decarbonization goals.

In terms of sustainability, this initiative approaches the carbon footprint reduction by utilizing the CO_2 captured from post-industrial sources and mixing it into fresh concrete, and by creating the potential to reduce Portland cement usage with a concrete mix without compromising durability. Additionally, the Carbon in Concrete initiative is hypothesized to enhance resiliency by the proof of concept of durability through the reduction or elimination of oxychloride formation.

This initiative performs the long-term monitoring in a real-life real-time scenario. It will give users the information needed to deploy carbon sequestration in their agencies towards sustainable and resilient concrete pavements. If demonstrated to be effective for paved road applications, widespread adoption of CO_2 mineralized concrete will create an opportunity for significant emissions reductions within the NRRA member States, nationwide and internationally.

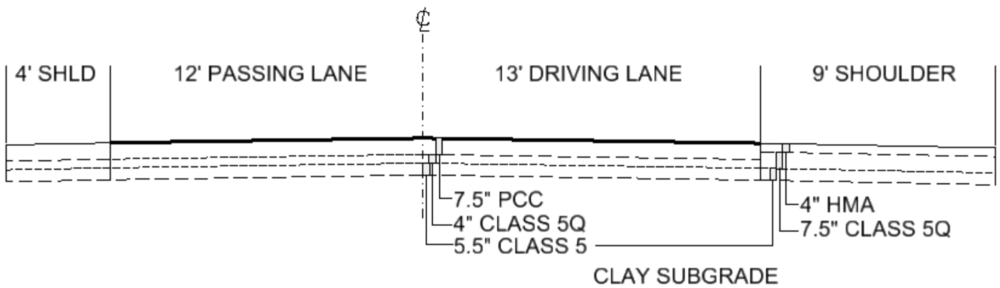
The goal of this research is to examine through testing, measurements and observation, the performance of concrete made with the carbon sequestration mineralization technology. It will generally entail an evaluation of the sustainability of mineralized concrete when the concrete is used for pavement purposes by collecting information on paved road applications. The aim is also to ascertain if the sustainability properties associated with carbon injected concrete are retained when this technology is used in pavements where the concrete is subjected to traffic and environmental exposure.

7.2 Design

This research project was designed to investigate sustainable CO_2 utilization technologies under development and deployment. Five test sections were constructed under this study as part of the 2022 NRRA MnROAD construction. Test sections 2210, 2211 and 2212 have carbon injected into the concrete, test section 2213 has carbon injected as part of the processing of the fly ash and then incorporated into the concrete and test section 2217 was not injected with carbon to serve as a control section.

As presented in Figure 7.1, the typical section for each of these test sections is 7.5 inches of concrete placed on 4 inches of Class 5Q aggregate base over 5.5 inches of Class 5 subbase. The test sections have widths of 9 ft for driving lane shoulder, 13 ft for driving lanes, 12 ft for passing lane, and 4 ft for passing shoulder. The 9 ft driving lane shoulder was paved with a 4-inch-thick hot mix asphalt surface. The concrete panels are 15 ft long, and the passing lane concrete shoulder was paved monolithically with the passing lane, then sawcut to the 4-foot width. The transverse joints contain eleven 1.25-inch diameter by 15-inch-long epoxy coated steel dowel bars spaced at 12 inches on center. The final surface was first created using Astro turf drag, but sections 2210, 2211, 2212, and 2217 had to be diamond ground shortly after construction due to inadequate texture. Panels containing sensors in each of these sections were not diamond grind to retain at least a portion of the original texture that was created and to protect the sensors from damage.

Figure 7-1 Typical Section for Carbon Dioxide (CO2) Test Sections



Design details for each constructed test section are summarized in Table 7.1. All concrete mixes with Portland limestone cement (PLC) were designed to meet ASTM C595 with 10% limestone. The CarbonCure RGC1 material placed on test section 2210 is composed of Portland limestone cement (PLC), 30% fly ash and optimized with CarbonCure and a contractor declared dosage of 6 oz per cubic yard of concrete. The CarbonCure RGC2 material placed on test section 2211 is not optimized composed of CarbonCure added at the same dosage used in the 2210 test section and scaled to cement content of the CarbonCure control mix placed in 2217. The CarbonCure RGC3 material placed in test section 2212 is composed of Portland limestone cement (PLC), 30% fly ash and no CarbonCure. Test section 2212 is a control for test section 2210. The Carbon Upcycling material placed on test section 2213 is composed of a Portland limestone cement (PLC) and 30% processed fly ash as an alternative supplementary cementitious material (ASCM). The control material placed on test section 2217 is composed of Portland limestone cement (PLC) plus 30% fly ash. Test section 2217 is a control for test section 2211.

Table 7-1 Carbon dioxide (CO2) Materials Test Section Design Details

Test Section	Material	Start Station	End Station	Length, ft
2210	CarbonCure RGC1	1134+38	1137+08	270
2211	CarbonCure RGC2	1137+08	1139+71	263
2212	CarbonCure RGC3	1139+71	1142+43	272
2213	Carbon Upcycling - Processed Fly Ash	1142+43	1144+73	230
2217	CarbonCure Control	1162+43	1164+97	254

Selection of the final concrete mix designs were determined under a separate project responsible for the development of concrete mix designs/matrix of materials, performance properties, and construction field sampling and testing expectations during the 2022 MnROAD construction. Mix design trials batching for the CarbonCure test sections in this study were conducted at Cemstone facilities in Dayton, MN under the observation of MnDOT personnel. Trial mixing incorporated the latest Performance Engineered Mixture (PEM) tests including air content, Super Air Meter (SAM), box test, unit weight, slump test and paste content for fresh properties and compressive and flexural strength for hardened properties. Project specific paving mix designs (JMF) are presented in Appendix D.

Final mixes used to construct the carbon mineralization test sections 2210, 2211, 2212, and 2217 were produced and delivered to MnROAD by Cemstone. Test section 2213 was produced and delivered to MnROAD by Aggregate Industries at Maple Grove.

7.3 Construction

Table 7.2 presents the concrete mix designations, placement time and quantities placed at MnROAD for the carbon mineralization concrete test sections. Construction of these sections began with test section 2210 on July 27th. Construction followed MnDOT Specification 2301 Concrete Pavement and the project specification special provisions. For all test sections, a central batch plant was used to produce the concrete. Infrastructure in the plant was used to add CO_2 during mixing. Thermogravimetric analysis (TGA) was performed to determine the exact amount of CO_2 in the concrete specimen. The material was delivered to MnROAD in concrete mixing trucks for placement using a standard slip-form paver. In all test sections Joint sawing occurred approximately 4-6 hours after placement.

Table 7-2 Carbon Mineralization Concrete Mix Designations, Placement Time, Quantities and Weather Conditions

Test Section	Mix ID	Day Placed	Time Start	Time Stop	Quantity (cy)	Weather Conditions
2210	3A21-RGC1	7/27/2022	10:18 am	12:58 pm	207	72°F, Sunny
2211	3A21-RGC2	7/28/2022	9:03 am	11:51 am	197	NR*, Sunny
2212	3A21-RGC3	7/28/2022	11:58 am	2:52 pm	209	NR*, Sunny
2213	3A21-RGU1	7/29/2022	7:11 am	9:34 am	180	56°F, Sunny
2217	3A21-RGCC	8/8/2022	9:25 am	12:54 pm	194	NR*

* NR = exact air temperature was not recorded

7.3.1 Test Section 2210: CarbonCure RGC1

The fresh concrete appeared to be on the stiff side. During placement of the concrete, there was downtime of up to 30+ minutes between deliveries. Many times, after the paving machine had passed, finishing crew members had to use a float to close noticeable tears in the surface. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 7.2 shows the concrete being placed for test section 2210.

Figure 7-2 Concrete Finishing for CarbonCure RGC1 Test Section 2210

7.3.2 Test Section 2211: CarbonCure RGC2

The fresh concrete appeared to be on the stiff side. There was downtime of up to 30+ minutes between deliveries. Many times, after the paving machine had passed, finishing crew members had to use a float to close noticeable tears in the surface. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 7.3 shows the concrete being placed for test section 2211.

Figure 7-3 Concrete Placement for CarbonCure RGC2 Test Section 2211

7.3.3 Test Section 2212: CarbonCure RGC3

The fresh concrete appeared to be on the stiff side. There was downtime of up to 30+ minutes between deliveries. Many times, after the paving machine had passed, finishing crew members had to use a float to close deep voids, as well as repair poorly consolidated edges. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Figure 7.4 shows the concrete being placed for test section 2212.

Figure 7-4 Concrete Placement for CarbonCure RGC3 Test Section 2212

7.3.4 Test Section 2213: Carbon Upcycling / Processed Fly Ash

A 95% relative humidity was measured for the concrete placement of this test section. A pneumatic tanker was used to transport material and loading the super sacks took approximately 5 hours. The concrete appeared to be on the stiff side. There was downtime of up to 30+ minutes between deliveries. Batching took place at Aggregate Industries – Maple Grove due to the Rogers plant being down. The first load delivered to MnROAD was dry because the quantity of water reducer (WR) was held back due to concerns of high slump. Additional WR and water was added to the remaining loads. The mix placed and finished well throughout the cell. The final Astro turf drag surface met texture specification requirements. Figure 7.5 shows the concrete being placed for test section 2213.

Figure 7-5 Concrete Placement for Carbon Upcycling Processed Fly Ash Test Section 2213

7.3.5 Test Section 2217: CarbonCure Control

This section was placed as a control. It was not injected with CO_2. The slump looked within the acceptable range. The mix placed and finished well throughout the cell. The final Astro turf drag surface met texture specification requirements. Figure 7.6 shows the concrete being finished for test section 2217.

Figure 7-6 Concrete Finishing for CarbonCure Control Test Section 2217

7.4 Sampling and Testing

A comprehensive sampling and testing program were implemented for these new test sections. This was a combined effort that included Federal Highway Administration (FHWA) Mobile Concrete Technology Center (MCTC) mobile laboratory, American Engineering Testing (AET), and Turner Fairbanks Highway Research Center (TFHRC).

A total of 185 fresh concrete specimens were collected for this study. A list of the fresh concrete testing can be found in Tables 7.3. MnDOT collected samples of cementitious materials and aggregates at the batch plants to satisfy MnDOT contract quality assurance requirements. In addition, the contractor also tested the surface texture after paving. Delays occurred in concrete placement due to both transport between the plant and MnROAD, as well as the need to stop at a sampling station set up nearby where several crews made test specimens for production and research purposes. Tests results can be shared upon request to MnDOT personnel and will be documented under a summary document.

Table 7-3 Number of Test Specimens Taken to Determine Properties of Fresh Concrete for Carbon Mineralization Test Sections

		Test Sections				
Tests	**Standard**	**2210**	**2211**	**2212**	**2213**	**2217**
Slump, in	AASHTO T119	5	5	5	5	5
Air content, %	ASTM C231 / AASHTO T152	5	5	5	5	5
Super Air Meter, SAM No.	AASHTO TP118	4	5	4	4	4
Hardened Air Content, %	ASTM C457	3	5	3	2	3
Unit Weight, pcf	ASTM C138	5	5	5	5	5
Temperature, °F	ASTM C1064	5	5	5	5	5
Box Test	AASHTO TP137	2	5	2	2	2
Phoenix, w/c	AASHTO T152	1	5	2	1	2
V-Kelly Index	AASHTO TP129	2	5	2	1	1
Microwave, w/c	AASHTO TP23	1	2	2	1	2
Calorimetry	ASTM C1753	1	1	1	1	1

To determine the hardened concrete properties of the materials in the test sections, a total of 690 specimens were cast on site. The testing on these specimens was conducted by FHWA and AET. Table 7.4 presents the tests that were conducted on the collected hardened specimens, the standard test method, age, specimen type and size. It should be noted that for some test procedures, raw materials were collected and provided to AET for trial batching and testing. Test results and analysis of these materials will be discussed in the research project construction report and analysis. All test results for both, fresh and hardened properties, are part of the MnROAD database and available upon request.

Table 7-4 Hardened Concrete Properties Tests for Carbon Mineralization Test Sections

Tests	Test Method	Testing Age (days)
Compressive Strength	ASTM C39	1, 3, 7, 14, 28, 42 and 56
Flexural Strength	ASTM C78	1, 3, 7, 14, 28 and 56
Resistivity	AASHTO T358	1, 3, 7, 14, 28, 42, 56, 91 and 120
Maturity	ASTM C1074	Up to 56
Bulk Resistivity	ASTM C1876	7, 28, 56, 91 and 120
Formation Factor	AASHTO R101	28, 56, 91, 120
Critical Saturation Time	ASTM C1585	120
Deicing Salt Damage	AASHTO T365	28
Rapid Chloride Permeability	ASTM C1202	56
Freeze Thaw	ASTM C666	15
Poisson's Ratio and Elastic Modulus	ASTM C469	28
Coefficient of Thermal Expansion	AASHTO T336	-
Drying Shrinkage	ASTM C157	35
Autogenous Shrinkage	ASMT C1698	7
TGA	E1131 NIST TFHRC	28 and 56
Carbon Sequestration	E1131 NIST TFHRC	28 and 56
Carbon Uptake and pH	-	-
XRD and XRF	-	-
Pore Solution Expression	-	28 and 56
Blended Cement	ASTM C595	28
Performance Spec for Hydraulic Cement	ASMT C1157	28
Fly Ash or Natural Pozzolans	ASTM C311	28
Expansion of Mortar Bars	ASTM C1038	14
	ASTM C1012	365
Concrete Prism	ASTM C1293	730
Alkali Silica Reactivity	ASMT C1567	28
	ASTM C1260	28
R3 Testing	ASTM T1897	7
Aggregate Stability	TFAST	-
Semi-adiabatic Calorimetry	ASTM C1679	-
Set Time	ASTM C403	

To characterize all aspects of the new test sections, several test procedures were performed by MnROAD research staff within the first few weeks after paving. Surface profiling was conducted using the MnROAD Lightweight Inertial Surface Profiler (LISA). Results from this testing will be used by the principal investigator of the research contract. Others can obtain the data from the MnROAD website, or by contacting MnROAD staff.

Thickness was measured throughout each test section using the MIT-Scan-T2 device. Figure 7.7 shows the final concrete thickness measured from the T2 plates.

Figure 7-7 Final Concrete Thickness Measured by MIT-Scan-T2

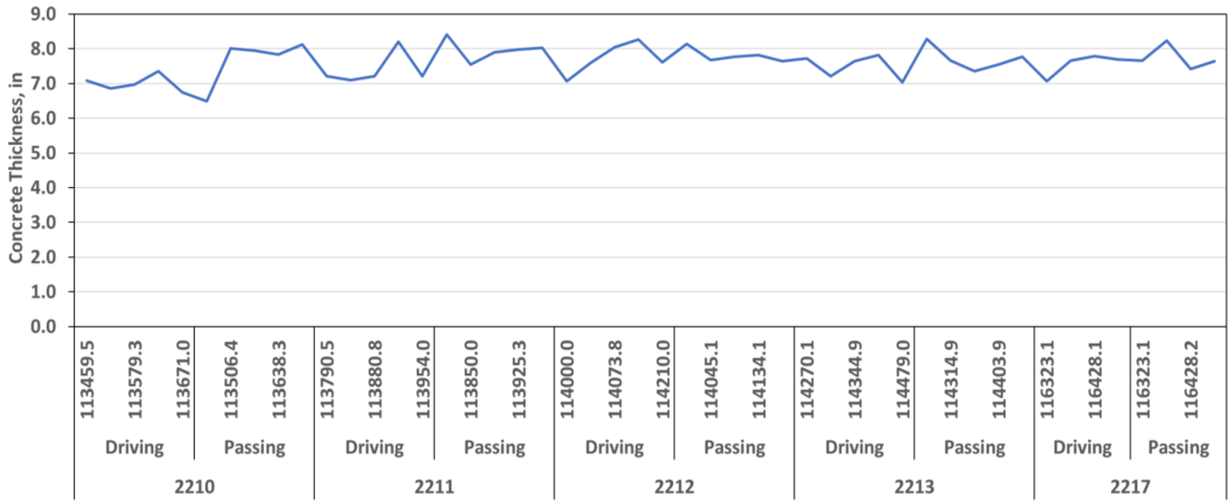


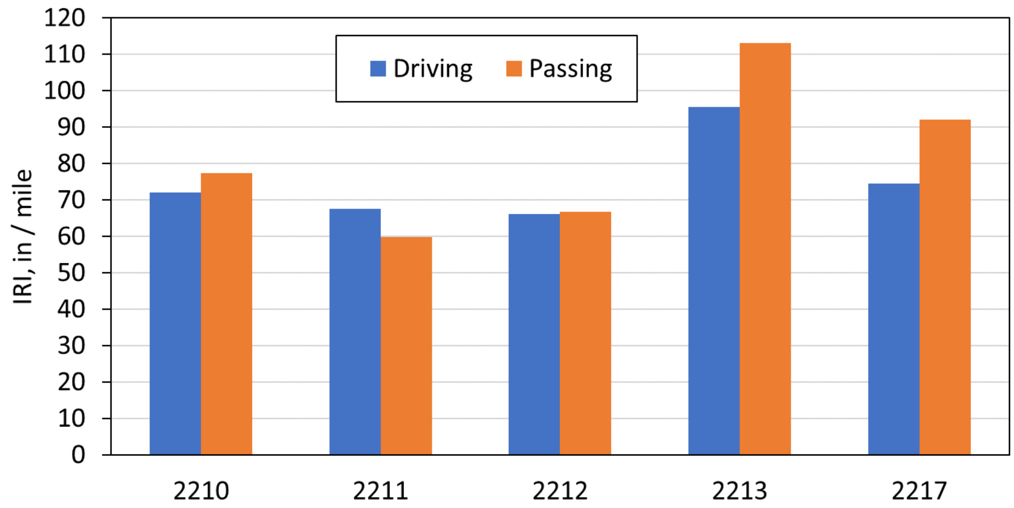
Table 7.5 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 7-5 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Thickness (in)	Std. Dev.
2210	Not Measured	Not Measured
2211	8.02	0.172
2212	7.88	0.134
2213	7.66	0.122
2217	7.73	0.135

Figure 7.8 presents a summary of the International Roughness Index (IRI) results for the test sections under this research study.

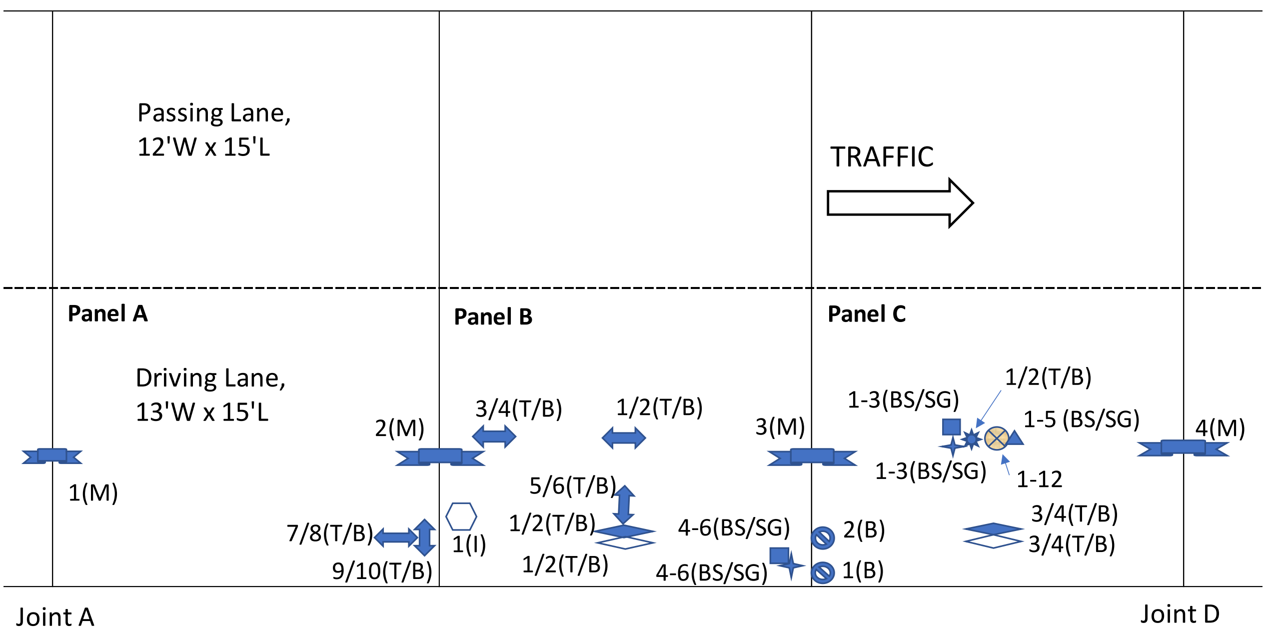
Figure 7-8 IRI Measurements for Carbon Dioxide Test Sections



7.5 Instrumentation and Sensors

For test sections 2210, 2211, 2212, 2213 and 2217 environmental strains gauges, joint opening, vibrating wire, TEROS 12 moisture sensors, pressure plates and grids, magneto induction sensors (Figure 7.10). For description of new sensors installed during this construction effort refer to Chapter 14. For sensors that have been installed by MnROAD staff in previous construction efforts please refer to MnROAD website. Appendix B lists the as-built locations of the sensors.

Figure 7-9 Sensor's Installation Layout



Environmental strain: Geokon 4200
Dynamic Strain: BDI CEST350
Dynamic Strain: Geodaq AST200 Strain Module, 6" length
Moisture Content Concrete: Meter Group Teros 12
Moisture Content Base/SG: Meter Group Teros 10
Soil Suction: Meter Group Teros 21
Frost sensing: Irrometer WATERMARK Soil Moisture Sensors
Joint opening: OMEGA LVIT Model LDI-119-025-A010S
Temperature: OMEGA Type T thermocouple wire

Dynamic pressure: Geokon 3500

Environmental pressure or displacement off base: Michigan State

Magneto Inductive displacement: Micro Epsilon MDS-45-M18-SA

Table 7.6 shows the instrumented joints and stations for each test section under this study.

Table 7-6 Instrumented Joints and Stations per Test Sections

Test Section	Joint A #	Joint A Station	Joint D #	Joint D Station
2210	3031	1136+33	3028	1135+88
2211	3050	1139+18	3047	1138+73
2212	3064	1141+28	3061	1140+83
2213	3082	1143+98	3079	1143+53
2217	3085	1164+22	3209	1163+77

A total of 32 wireless maturity sensors were installed in the test sections under this research study. As shown in Figure 7.3 the maturity sensors installed collected temperature at two points, within the body of the maturity sensors and at the tip of the cable. Maturity sensors were installed with zip ties attached to the dowel bar basket assemblies. More details on the type of maturity sensors can be found in Chapter 14. Maturity sensors data is available upon request to MnROAD staff.

Table 7-7 Number of Maturity Sensors Installed

Test Section	Lane	
	Driving	Passing
2210	3	1
2211	4	3
2212	4	3
2213	4	3
2217	4	3

Figure 7-10 Maturity Sensors Installation for Carbon Dioxide Test Sections

Chapter 8: The Use of Alternative Cementitious Materials in Concrete Pavements

8.1 Objectives

In recent years, there has been a concerted effort to reduce greenhouse gas (CO_2) emissions to prevent climate change. For every metric ton of Portland cement produced, 0.9 metric tons of CO_2 is produced. According to Emission Database for Atmospheric Research, in 2016 2.3 billion tons of CO_2 was produced by the cement industry. This accounted for 7 percent of the CO_2 emitted into the atmosphere that year.

This research project focuses on studying the performance of concrete pavement test sections incorporating alternative cementitious materials. Geopolymer concrete is one type of such material, although others are also of interest. As regulatory agencies begin to ask transportation departments to reduce greenhouse gas emissions generated during the construction of needed transportation infrastructure, geopolymer concrete or other materials could provide a viable option.

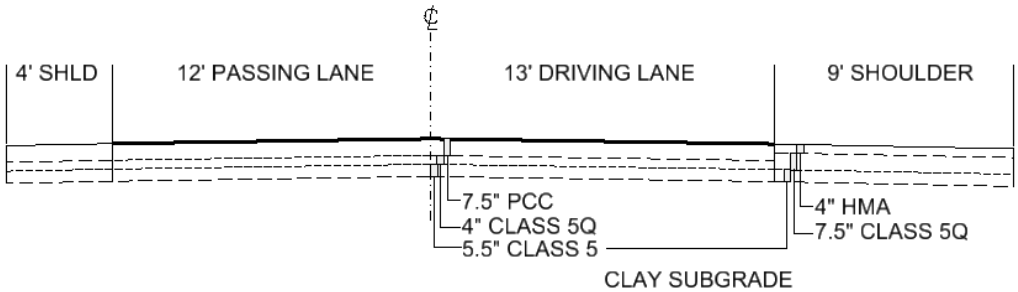
The goal of this research proposal is to investigate the factors impacting production and placement of concrete pavement utilizing alternative cementitious materials, as well as determine the field performance when exposed to heavy traffic loading and extreme climatic conditions.

8.2 Design

This research project was design to investigate and provide information on characteristics that need to be considered when selecting alternative cementitious materials and on factors that need to be considered when designing concrete mixtures using these materials. These test sections will aid in developing guidelines for successfully producing and placing concrete mixes with alternative cementitious materials in the field and determining the tests that must be performed during paving and acceptance after hardening.

Concrete mixes containing four alternative cementitious materials were placed in test sections 2209, 2214, 2216, 2223 as part of the 2022 NRRA MnROAD construction. This study also included the construction and performance evaluation of control section 2218, which will be used by all the other studies associated with concrete sections constructed in 2022. As presented in Figure 8.1, the typical section for each of these test sections is 7.5 inches of concrete placed on 4 inches of Class 5Q aggregate base over 5.5 inches of Class 5 subbase. The test sections have widths of 9 ft for driving lane shoulder, 13 ft for driving lanes, 12 ft for passing lane, and 4 ft for passing shoulder. The 9 ft driving lane shoulder was paved with a 4-inch-thick hot mix asphalt surface. The concrete panels are 15 ft long, and the passing lane concrete shoulder was paved monolithically with the passing lane, then sawcut to the 4-foot width. The transverse joints contain eleven 1.25-inch diameter by 15-inch-long epoxy coated steel dowel bars space at 12 inches on center. The final surface was first created using Astro turf drag, but sections 2209, 2214, and 2216 had to be diamond ground shortly after construction due to inadequate texture. Panels containing sensors in each of these sections were not diamond grind to retain at least a portion of the original texture that was created and to protect the sensors from damage.

Figure 8-1 Typical Section for Alternative Cementitious Materials Test Sections



Design details for each constructed test section are summarized in Table 8.1. Concrete mixes with Portland limestone cement (PLC) were designed to meet ASTM C595 with 10% limestone. The Ultra High Materials placed in test section 2209 is composed of hydraulic non-Portland cement at 100% replacement. The Ash Grove material placed on test section 2214 is composed of a Type IP 30 cement with calcined clay pozzolan. The TerraCO2 manufactured fly ash material placed in test section 2216 is composed of Portland limestone cement (PLC) and 30% alternative supplementary cementitious materials. The control mix material placed in test section 2218 is composed of Portland limestone cement (PLC) and 30% fly ash. The Continental Cement high limestone material placed in test section 2223 is composed of blended Portland limestone cement (PLC) containing 20% limestone and 30% fly ash.

Table 8-1 Alternative Cementitious Materials Test Section Design Details

Test Section	Material	Start Station	End Station	Length (ft)
2209	ACM - Ultra High Material	1131+63	1133+77	14
2214	Ash Grove - ACM	1145+03	1147+28	225
2216	TerraCO$_2$ - Manufactured Fly Ash	1150+32	1152+75	243
2218	Control Mix	1164+97	1167+99	302
2223	Continental Cement - High Limestone	1178+56	1181+13	257

Selection of the final concrete mix designs were determined under a separate project responsible for the development of concrete mix designs/matrix of materials, performance properties, and construction field sampling and testing expectations during the 2022 MnROAD construction. Mix design trials were conducted by AET and Braun Intertec. Trial mixing incorporated the latest Performance Engineered

Mixture (PEM) tests including air content, Super Air Meter (SAM), box test, unit weight, slump test and paste content for fresh properties and compressive and flexural strength for hardened properties. Project specific paving mix designs (JMF) are presented in Appendix D.

Final mixes used to construct the alternative cementitious materials and control test sections were produced and delivered to MnROAD by Aggregate Industries.

8.3 Construction

Table 8.2 presents the mix designation and construction details for the alternative cementitious concrete test sections. Construction of these sections began with test section 2214 on July 29th. Construction followed MnDOT Specification 2301 Concrete Pavement and the project specification special provisions. For the test sections containing alternative cementitious materials, a pneumatic tanker was used to transport the materials to the central batch plant, loading the super sacks into the tanker taking approximately 5 hours. After batching at the batch, the concrete was delivered to MnROAD in concrete mixing trucks for placement using a standard slip-form paver.

Table 8-2 Alternative Cementitious Material Concrete Mix Designations, Placement Time, Quantities and Weather Conditions

Test Section	Mix ID	Day Placed	Time Start	Time Stop	Quantity (cy)	Weather Conditions
2209	3A21-RGH1	8/9/2022	8:50 am	9:38 am	44	NR*
2214	3A21-RGC1	7/29/2022	9:55 am	2:00 pm	179	56°F, Sunny
2216	3A21-RGT1	8/1/2022	10:58 am	1:23 pm	189	72°F, Sunny
2218	3A21-RGSC	8/8/2022	6:58 am	9:22 am	235	NR*
2223	3A21-RGO1	8/3/2022	10:07 am	11:57 am	200	74°F, Sunny

* NR = exact air temperature was not recorded

8.3.1 Test Section 2209: Ultra High Material - ACM

The first two loads were control mix. The first Ultra High mix was very dry and appeared like gravel coming out of the truck. The second truck was better but still too dry to place properly. These loads were rejected. The next few loads placed appeared to have too much slump but after going through the paver, the edge stood up fine. The paver then got stuck due to another stiff load. The Contractor had to lift the paver out and back in again causing a bump in the surface that will likely have to be ground. Finished with a few more loads and switched back to the control mix to finish the cell. The last set of sensors did not get covered with the Ultra High material. You could walk on the Ultra High directly behind the paver without causing indentations. The final surface was first created using Astro trf drag but had to be diamond ground shortly after construction due to inadequate texture. Joint sawing occurred approximately 4-6 hours after placement. Figure 8.2 shows the concrete being placed for test section 2209.

Figure 8-2 Concrete Placement for Ultra High Material ACM Test Section 2209

8.3.2 Test Section 2214: Ash Grove – ACM

A 95% relative humidity was measured for the concrete placement of this test section. The concrete started out dry but improved quickly. There was downtime of up to 30+ minutes between deliveries. Delays were due to both transport and sampling. A second pneumatic tanker arrived late, causing a 2.5-hour delay in delivery of batched concrete. A cold joint was created within the test section rather than putting in a header. An additional 20 cubic yards of control mix was needed to finish this section. Batching took place at Aggregate Industries-Maple Grove due to the Rogers plant being down. The mix placed and finished well throughout the cell. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Joint sawing occurred approximately 4-6 hours after placement. Figure 8.3 shows the concrete being placed for test section 2214.

Figure 8-3 Concrete Placement for Ash Grove ACM Test Section 2214

8.3.3 Test Section 2216: $TerraCO_2$ - Manufactured Fly Ash

The first truck appeared to have an acceptable slump. The mix then appeared to be on the wetter side, but the edge was standing up fine. About ¾ of the way through the cell the inside shoulder edge started slumping and boards were needed to establish a vertical edge until the end of the cell. It appears the concrete paste was getting funneled to the inside shoulder along the edge. The Contractor attempted to remove and replace as much as they could but appeared to be unsuccessful in removing a good portion of the unsuitable material along the edge. The final surface was first created using Astro turf drag but had to be diamond ground shortly after construction due to inadequate texture. Joint sawing occurred approximately 4-6 hours after placement. Figure 8.4 shows the concrete being finished for test section 2216.

Figure 8-4 Concrete Finishing for Terra CO2 Manufactured Fly Ash Test Section 2216

8.3.4 Test Section 2223: Continental Cement - High Limestone

There were downtimes of up to 30+ minutes between deliveries. Delays were due to both transport and sampling. The concrete mix set quickly once placed. A significant amount of water was added. The final Astro turf drag surface met texture requirements and did not need grinding. Joint sawing occurred approximately 4-6 hours after placement. Figure 8.5 shows the concrete being placed for test section 2223.

Figure 8-5 Concrete Placement for Continental Cement High Limestone Test Section 2223

8.3.5 Test Section 2218: Control Mix

This mix appeared to have a higher slump but placed well after going through the paver. There appeared to be lots of bleed water at the surface during the first 6 loads. A delay of approximately 1.5 hours occurred before curing the surface to wait for some of the bleed water to evaporate. The mix was adjusted, and no bleed water was present at the surface during the remaining loads. The mix placed and finished well thereafter. The final Astro turf drag surface met texture requirements. Figure 8.6 shows the concrete being finished for test section 2218.

Figure 8-6 Concrete Finishing for Control Test Section 2218

8.4 Sampling and Testing

A comprehensive sampling and testing program were implemented for these new test sections. This was a combine effort that included Federal Highway Administration (FHWA) Mobile Concrete Technology Center (MCTC) mobile laboratory, American Engineering Testing (AET), and Turner Fairbanks Highway Research Center (TFHRC).

A total of 137 fresh concrete specimens were collected. A list of the fresh concrete testing can be found in Table 8.3. MnDOT collected samples of cementitious materials and aggregates at the batch plants to satisfy MnDOT contract quality assurance requirements. In addition, the contractor also tested the surface texture after paving. Tests results can be shared upon request to MnDOT personnel and will be documented under a summary document.

Table 8-3 Number of Test Specimens Taken to Determine Properties of Fresh Concrete for Alternative Cementitious Materials and Control Test Sections

		Test Sections				
Tests	**Standard**	**2209**	**2214**	**2216**	**2218**	**2223**
Slump, in	AASHTO T119	3	5	5	2	5
Air content, %	ASTM C231 / AASHTO T152	3	5	5	2	5
SAM No., in.lb	AASHTO TP118	3	4	4	2	4
Hardened Air Content, %	ASTM C457	2	3	3	1	3
Unit Weight, pcf	ASTM C138	3	5	5	2	5
Temperature, °F	ASTM C1064	3	5	5	2	5
Box	AASHTO TP137	3	2	2	1	2
Phoenix, w/c	AASHTO T152	0	2	2	0	2
V-Kelly Index	AASHTO TP129	0	1	1	0	1
Microwave, w/c	AASHTO TP23	0	2	1	0	2
Calorimeter	ASTM C1753	1	1	1	0	1

A total of 593 hardened concrete specimens were cast on site. The testing on these specimens was conducted by FHWA and AET. Table 7.4 presents the tests that were conducted on the collected hardened specimens, the standard test method, age, specimen type and size. It should be noted that for some test procedures, raw materials were collected and provided to AET for trial batching and testing.

Test results and analysis of these materials will be discussed in the research project construction report and analysis. All test results for both, fresh and hardened properties, are part of the MnROAD database and available upon request. Test section 2218 did not have Poisson's ratio, elastic modulus, coefficient of thermal expansion.

Table 8-4 Hardened Concrete Properties Tests for Alternative Cementitious Materials and Control Test Sections

Tests	Test Method	Testing Age (days)
Compressive Strength	ASTM C39	1, 3, 7, 14, 28, 42 and 56
Flexural Strength	ASTM C78	1, 3, 7, 14, 28 and 56
Resistivity	AASHTO T358	1, 3, 7, 14, 28, 42, 56, 91 and 120
Maturity	ASTM C1074	Up to 56
Bulk Resistivity	ASTM C1876	7, 28, 56, 91 and 120
Formation Factor	AASHTO R101	28, 56, 91, 120
Critical Saturation Time	ASTM C1585	120
Deicing Salt Damage	AASHTO T365	28

Tests	Test Method	Testing Age (days)
Rapid Chloride Permeability	ASTM C1202	56
Freeze Thaw	ASTM C666	15
Poisson's Ratio and Elastic Modulus	ASTM C469	28
Coefficient of Thermal Expansion	AASHTO T336	-
Drying Shrinkage	ASTM C157	35
Autogenous Shrinkage	ASMT C1698	7
TGA	E1131 NIST TFHRC	28 and 56
Carbon Sequestration	E1131 NIST TFHRC	28 and 56
Carbon Uptake and pH	-	-
XRD and XRF	-	-
Pore Solution Expression	-	28 and 56
Blended Cement	ASTM C595	28
Performance Spec for Hydraulic Cement	ASMT C1157	28
Fly Ash or Natural Pozzolans	ASTM C311	28
Expansion of Mortar Bars	ASTM C1038	14
	ASTM C1012	365
Concrete Prism	ASTM C1293	730
Alkali Silica Reactivity	ASMT C1567	28
	ASTM C1260	28
R3 Testing	ASTM T1897	7
Aggregate Stability	TFAST	-
Semi-adiabatic Calorimetry	ASTM C1679	-
Set Time	ASTM C403	

To characterize all aspects of the new test sections, several test procedures were performed by MnROAD research staff within the first few weeks after paving. Surface profiling was conducted using the MnROAD Lightweight Inertial Surface Profiler (LISA) and baseline faultmeter measurements were taken. Results from this testing will be used by the principal investigator of the research contract. Others can obtain the data from the MnROAD website, or by contacting MnROAD staff.

Thickness was measured throughout each test section using the MIT-Scan-T2 device. Figure 8.7 shows the final concrete thickness measured from the T2 plates.

Figure 8-7 Final Asphalt Thickness Measured by MIT-Scan-T2

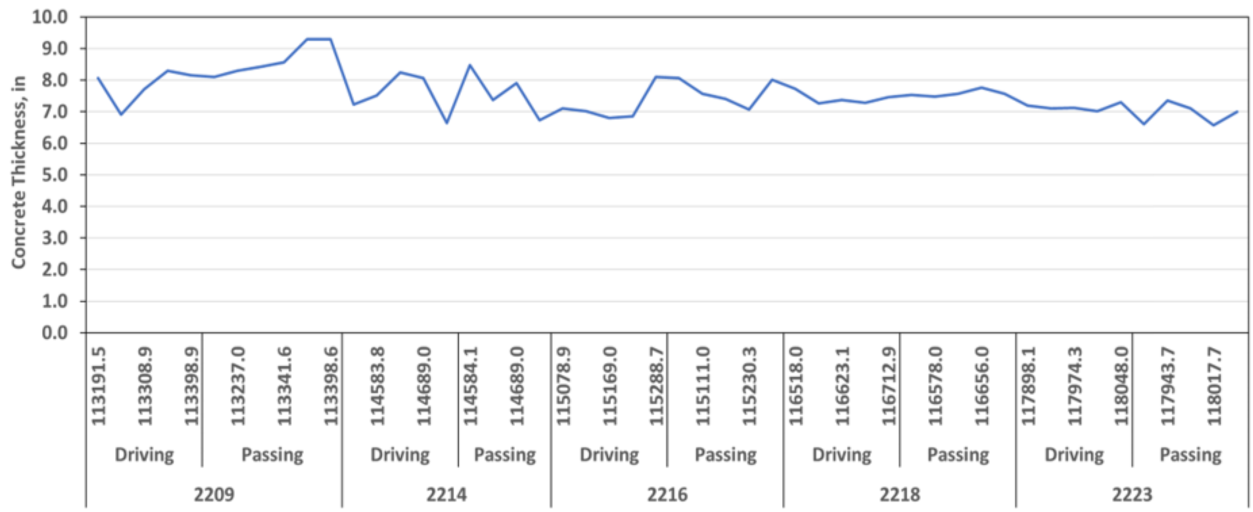


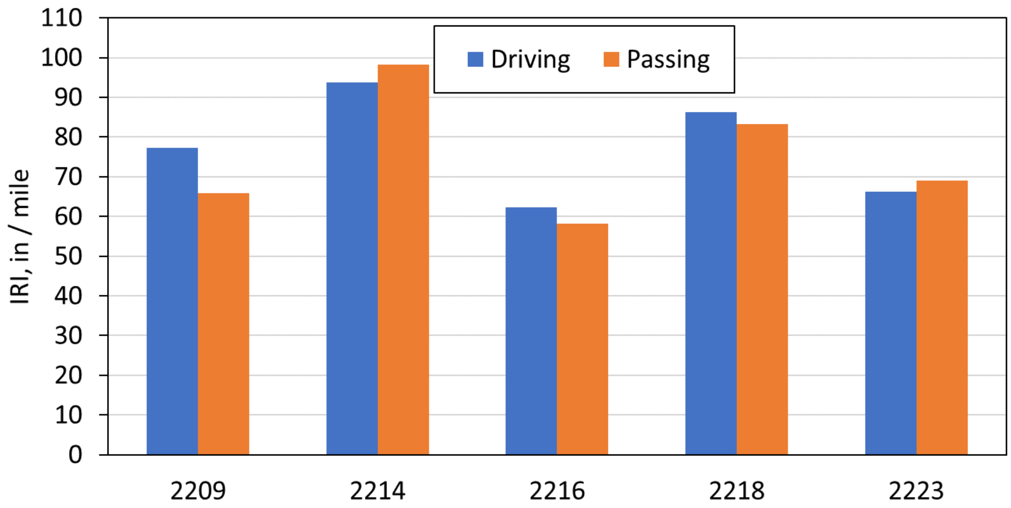
Table 8.5 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 8-5 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Thickness, in	Std. Dev.
2209	8.34	0.143
2214	7.92	0.139
2216	7.24	0.148
2218	7.48	0.131
2223	6.98	0.126

Figure 8.8 presents a summary of the International Roughness Index (IRI) results for the test sections under this research study.

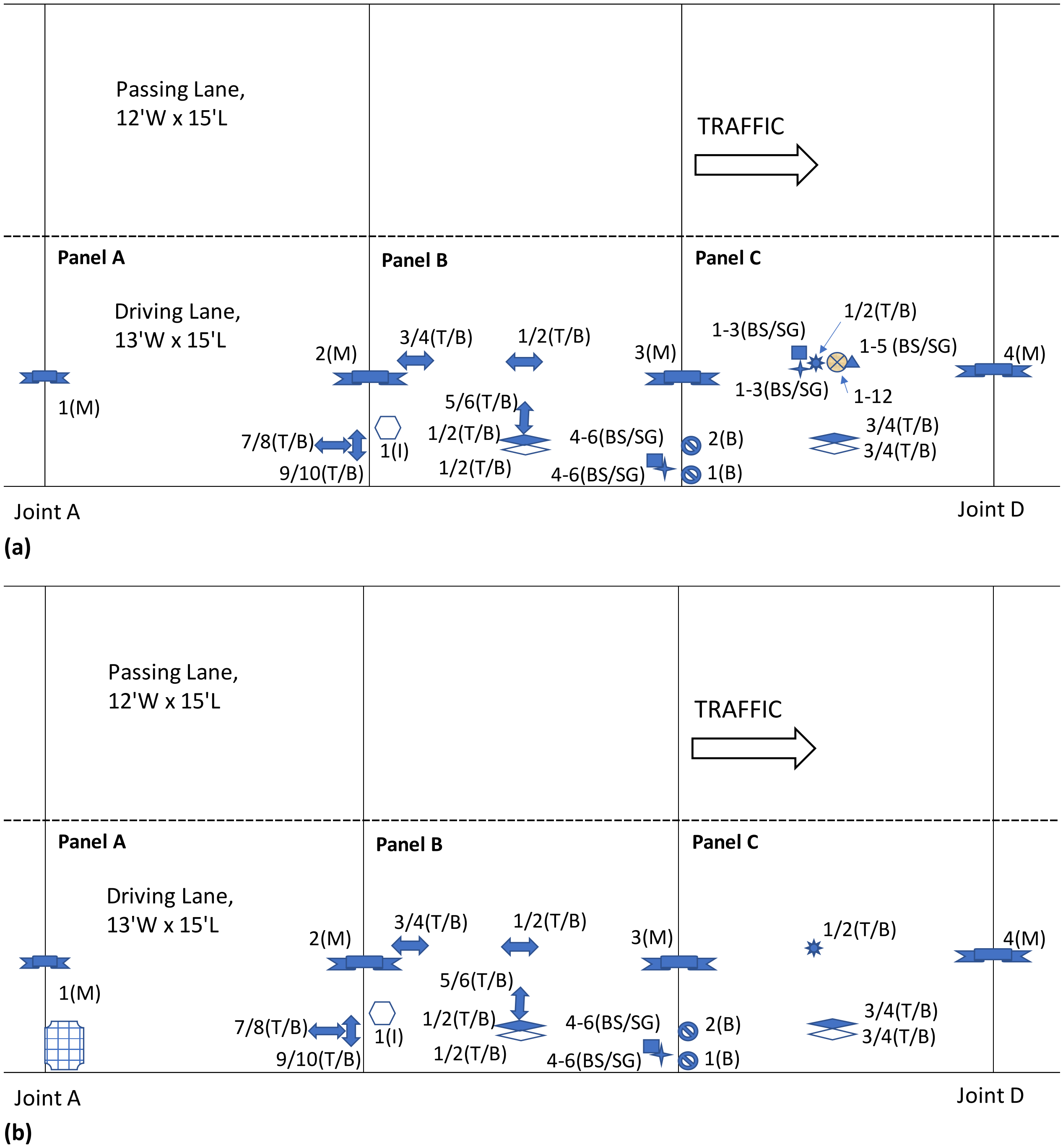
Figure 8-8 IRI Measurements for Carbon Dioxide Test Sections



8.5 Instrumentation and Sensors

For test sections 2216, 2218 and 2223 environmental strains gauges, joint opening, vibrating wire, TEROS 12 moisture sensors, pressure plates and grids, magneto induction sensors were installed (Figure 8.9a). Test sections 2209 and 2214 had all the sensors previously mentioned plus new thermocouples (TC) and TEROS 10 and TEROS 21 moisture sensors (Figure 8.9b). For description of sensors that have been installed by MnROAD staff in previous construction please refer to MnROAD website. Appendix B lists the as-built locations of the sensors.

Figure 8-9 Sensor's Installation Layout



Environmental strain: Geokon 4200
Dynamic Strain: BDI CEST350
Dynamic Strain: Geodaq AST200 Strain Module, 6" length
Moisture Content Concrete: Meter Group Teros 12
Moisture Content Base/SG: Meter Group Teros 10
Soil Suction: Meter Group Teros 21
Frost sensing: Irrometer WATERMARK Soil Moisture Sensors
Joint opening: OMEGA LVIT Model LDI-119-025-A010S
Temperature: OMEGA Type T thermocouple wire

Dynamic pressure: Geokon 3500

Environmental pressure or displacement off base: Michigan State

Magneto Inductive displacement: Micro Epsilon MDS-45-M18-SA

Table 8.6 shows the instrumented joints and stations for each test section under this study.

Table 8-6 Instrumented Joints and Stations per Test Sections

Test Section	Joint A #	Joint A Station	Joint D #	Joint D Station
2209	3014	1133+78	3011	1133+33
2214	3101	1146+83	3098	1146+38
2216	3133	1151+63	3130	1151+18
2218	3231	1167+07	3228	1166+62
2223	3319	1180+27	3316	1179+82

A total of 26 wireless maturity sensors were installed in the test sections under this research study. As shown in Figure 7.3 the maturity sensors installed collected temperature at two points, within the body of the maturity sensors and at the tip of the cable. Maturity sensors were installed with zip ties and attached to the dowels bar basket assemblies. More details on the type of maturity sensors can be found in Chapter 14. Maturity sensors data is available upon request to MnROAD staff.

Table 8-7 Number of Maturity Sensors Installed

Test Section	Driving Lane	Passing Lane
2209	1	1
2214	4	3
2216	4	2
2218	2	2
2223	4	3

Figure 8-10 Maturity Sensors Installation Alternative Cementitious Materials Test Sections

Chapter 9: Weigh-In-Motion (WIM) Equipment Evaluation

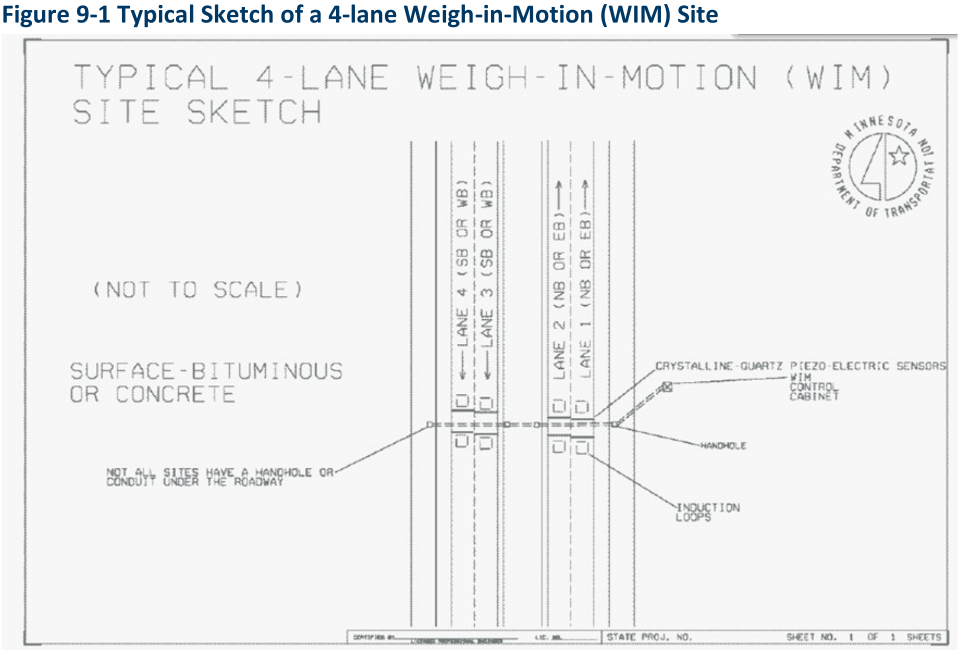
9.1 Introduction

Historically the Weigh-In-Motion (WIM) equipment at MnROAD has been located right before I-94 WB splits into the MnROAD Mainline and the MnROAD Original Westbound test tracks. It was not cost effective to install sensors in every test section to directly record Equivalent Single Axle Loads (ESALs), a measure of the amount of damage to the pavement incurred by vehicle loads. MnROAD has possessed and operated a Weigh-In-Motion (WIM) sensor at the site since 1994 to record data such as vehicle type, approximate weight, speed, and numerous other data. Throughout the history of MnROAD three WIMs have been used: WIM #4 – July 15, 1994, to September 08, 2001; WIM #25 – August 20, 2000, to April 29, 2008; and WIM #37 – July 14, 2009, to present time. This data was used to estimate the amount of ESALs incurred on the MnROAD Mainline and the MnROAD Original Westbound.

9.2 Description of WIM system currently used by MnROAD

Weigh-in-motion (WIM) devices are designed to record data such as axle weights and gross vehicle weights from vehicles travelling either at reduced or fast speeds over the WIM location. A typical site sketch of the WIM system used at MnROAD is shown below in Figure 9.1. Please note that MnROAD only has a WIM system in the Westbound direction and not in the Eastbound direction.

Figure 9-1 Typical Sketch of a 4-lane Weigh-in-Motion (WIM) Site



The WIM system at MnROAD is configured first with a lead 6' x 6' induction loop followed by a 2' to 3' gap in each lane. Behind the gap is a Kistler crystalline quartz piezo-electric WIM sensor that covers both the right and left wheel path. Next a second Kistler crystalline quartz piezo-electric WIM sensor covering both the right and left wheel path follows the first one with a space of 10’ to 12’. Lastly, the lagging 6’ x 6’ induction loop follows 2’ to 3’ after the second Kistler sensor.

9.3 WIM location on Mainline at MnROAD

Since the Old Westbound test track will be converted into three lanes by the end of 2025, use of the location before the split of Old Westbound and the Mainline Test Tracks will be discontinued for WIM use starting in Fall 2023. Thus, a new location for WIM installation and use needed to be decided. To meet the requirements of ASTM standards in WIM use a test section needs to be a certain length for there to be sufficient space before (200 ft) and after (100 ft) the WIM site to minimize impacts of road roughness and transitions on vehicle to WIM dynamics.

New concrete test Section 2225, with a length of 279 ft, was chosen as the site for WIM installation which will take place in Summer 2023. Constructed in 2022, test section 2225 is located in an area previously occupied by test sections 114, 214, 314 and 414 on MnROAD I-94 WB mainline. Portions of the test sections before and after 2225 (approximately 50 ft of new test section 2226, and 45 ft of existing test section 613) were diamond ground in addition to the entire length of 2225 to make it so there was 200 ft of smooth pavement before the WIM devices and 100 ft of smooth length after the site location. The structure of the pavement system is shown in Figure 9.2. Design details for test section 2225 are summarized in Table 9.1.

Figure 9-2 Pavement Structures of WIM Test Section 2225

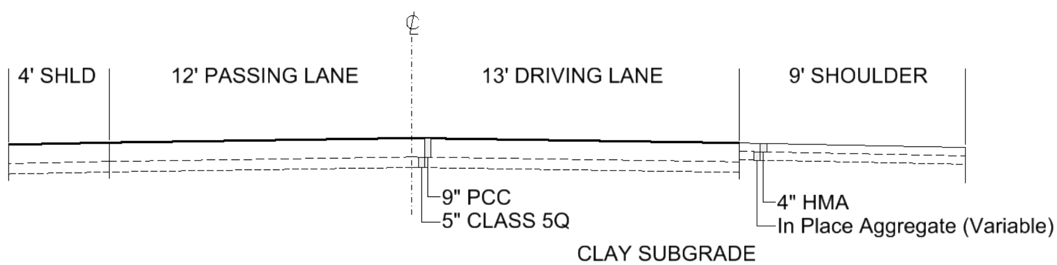


Table 9-1 WIM test section design details

Test Section	Station		Length (ft)	Mix ID	Surface	Base
	Start	End				
2225	1189+08	1191+87	279	3A21-RGSC	9” PCC Concrete	5” Class 5Q

9.4 WIM test section construction

A summary of the construction schedule of test section 2225 is presented in Table 9.2. Construction started on the week of July 11th with 6 inches of PCC concrete removal followed by milling of 5 to 6 inches of the HMA under the PCC concrete.

After removal of PCC concrete and HMA, C.S. McCrossan excavated around 2" of clay subgrade for test section 2225 on the week of June 19th. On the week of July 3^{rd}, the contractor finished excavating clay subgrade and placed the Class 5Q aggregate base. During the week of July 24^{th}, C.S. McCrossan installed conduit from the driving shoulder to the passing shoulder for future installation of Weigh in Motion equipment, and PCI trimmed the Class 5Q aggregate base in preparation for concrete paving during the week of July 31^{st}.

Table 9-2 Construction Schedule

	June 2022				July 2022				
Activities	**5**	**12**	**19**	**26**	**3**	**10**	**17**	**24**	**31**
Concrete and HMA Removal		X							
Clay Subgrade Removal			X		X				
Place Class 5Q Base Aggregate					X				
Fine Grading								X	
PCC Concrete									X

Figure 9.3 shows the concrete being finished for test section 2218.

Figure 9-3 Concrete Finishing for WIM Test Section 2225

9.5 Sampling and Testing

Two hundred and thirty-three (233) cubic yards of PCC concrete were placed on test section 2225 on August 2^{nd} from 9:34am to 12:05pm. Thirteen (13) fresh concrete samples were collected and tested, and thirty-four (34) hardened concrete samples were collected for testing. Test results can be shared upon request and will be documented under a summary document.

To characterize all aspects of the new test sections, several test procedures were performed by MnROAD research staff within the first few weeks after paving. Surface profiling was conducted using the MnROAD Lightweight Inertial Surface Profiler (LISA) and baseline faultmeter measurements were taken. Results from this testing will be used by the principal investigator of the research contract. Others can obtain the data from the MnROAD website, or by contacting MnROAD staff.

Thickness was measured throughout each test section using the MIT-Scan-T2 device. Figure 9.4 shows the final asphalt thickness measured from the T2 plates.

Figure 9-4 Final Concrete Thickness Measured by MIT-Scan-T2

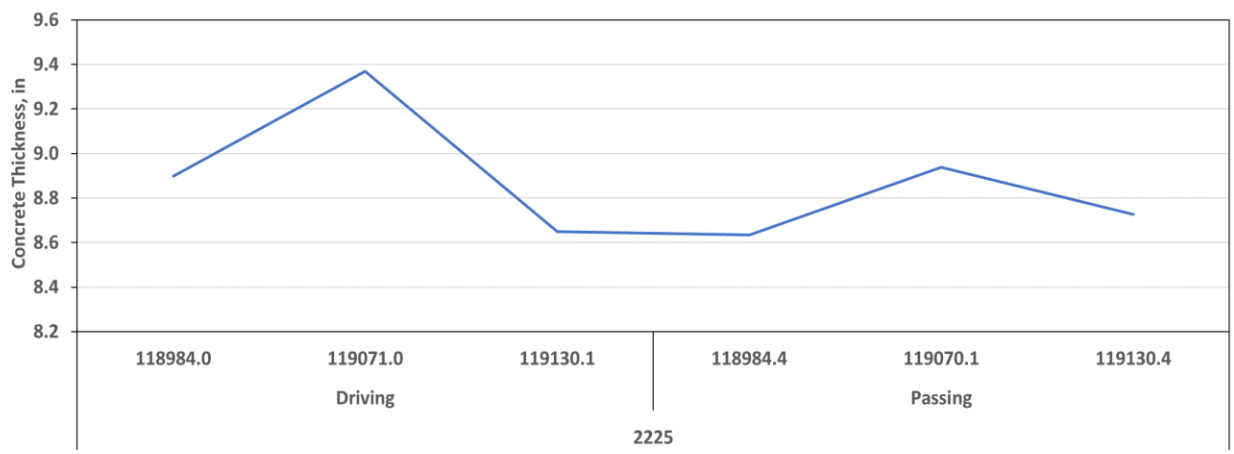


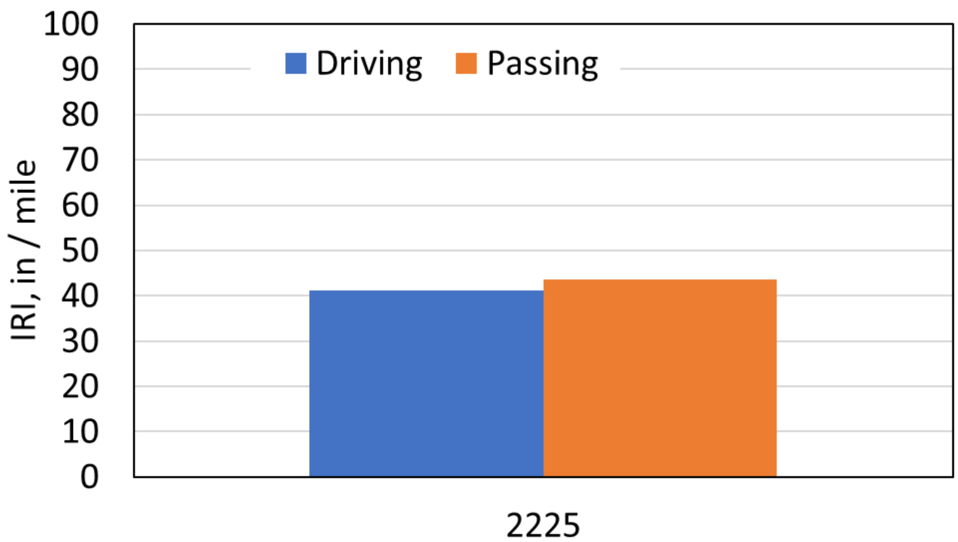
Table 9.3 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 9-3 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Thickness, in	Std. Dev.
2225	8.76	0.159

Figure 9.5 presents a summary of the International Roughness Index (IRI) results for the test sections under this research study.

Figure 9-5 IRI Measurements for WIM Test Sections



9.6 WIM System Layout & Installation

The layout of the new WIM to be installed in Summer 2023 in Test Section 2225 is shown in Figure 9.6. The WIM will contain 14 sensors and 4 loops of which 2 will be in the passing lane for measuring standard double threshold traffic data. The 2 loops and 10 sensors located in the driving lane will be spaced apart such that several spacing length effects on traffic data accuracy can be investigated in double, triple, quadruple, and quintuple threshold. In addition, a vector sensor array will be installed with three sensors and two loops in the driving lane just downstream of the 2 loops and 10 sensors in the driving lane. This array is used to determine wheel wander, tire type and pressure/footprint of tire. A camera and illuminator light system is positioned such that pictures of vehicles going over the vector sensor array and the 10-sensor layout in the driving lane can be collected as well. Installation of the new WIM system on test section 2225 took place during the weeks of July 10th and July 17th with the combined efforts of MnDOT, and International Road Dynamics Corporation staff and the installation contractor Design Electric, Inc. Pictures of the installation are shown in Figure 9.7. Calibration of the new system is scheduled to take place the week of September 25th using the MnROAD truck which is a Class 9 vehicle with 80k lbs of total weight.

Figure 9-6 Schematic of WIM System Installed in the Summer 2023 in Test Section 2225

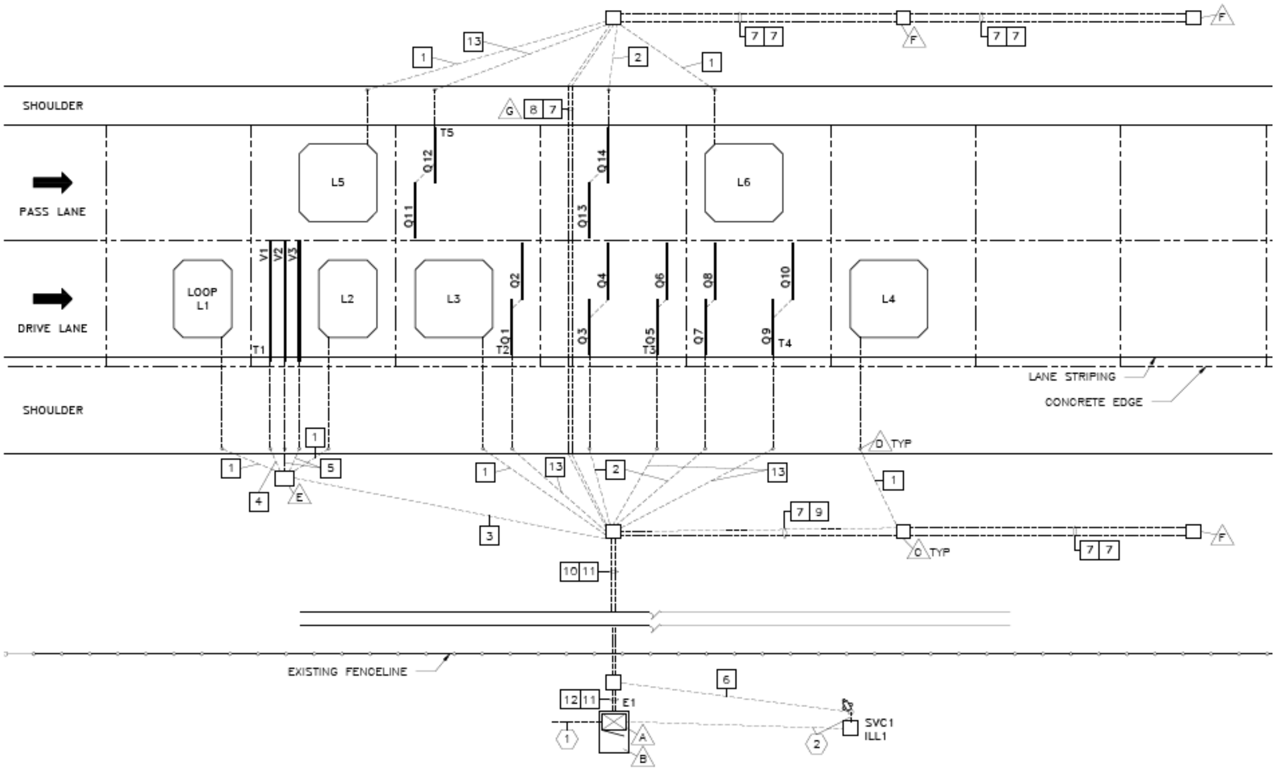
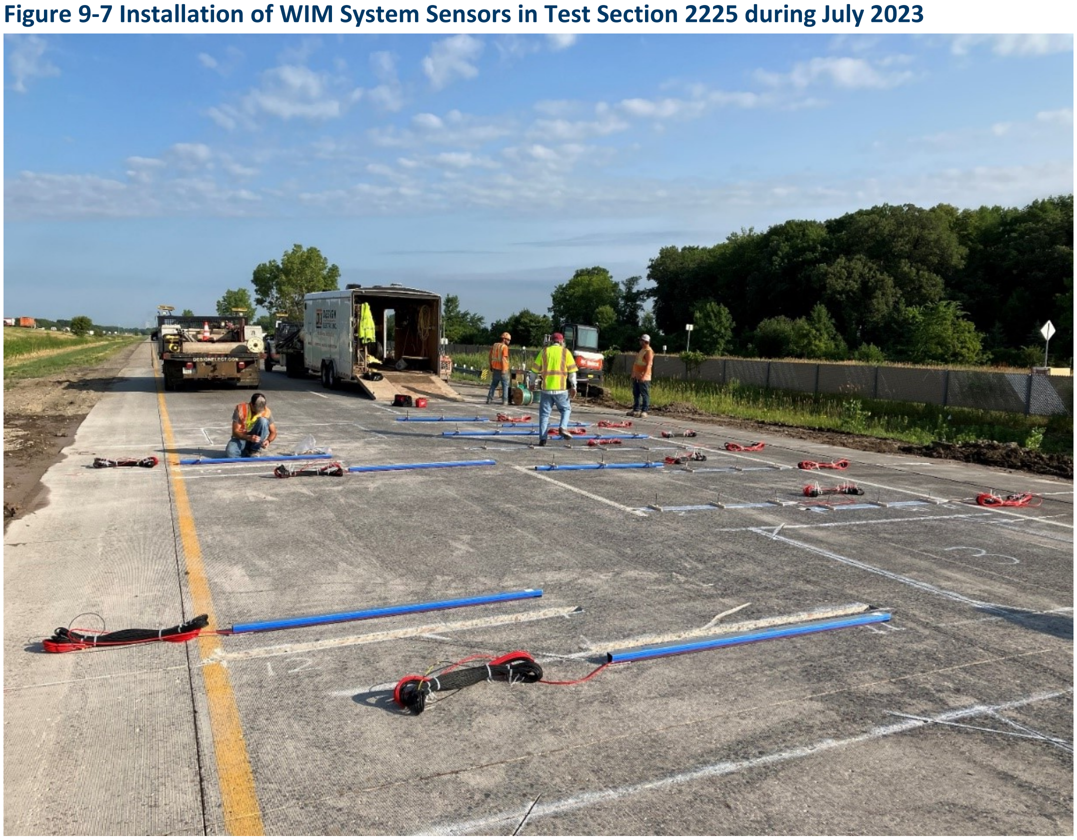


Figure 9-7 Installation of WIM System Sensors in Test Section 2225 during July 2023



Chapter 10: Use of early loading to increase joint deployment in concrete overlays on asphalt

10.1 Objectives

Thin concrete overlays on asphalt (COA) are designed with small panels (typically 6 feet long) to reduce curling, warping and load related distresses. Recent performance observations in Minnesota have highlighted though that many of these closely spaced transverse contraction joints are not deploying. Lack of deployment can result in several concerning phenomenon, including wider joints spaced up to 60 feet apart, and a reduction in ride quality from joints deployed at an average spacing of 12 ft. The longer-term effects on performance of COAs due to these features are still being determined.

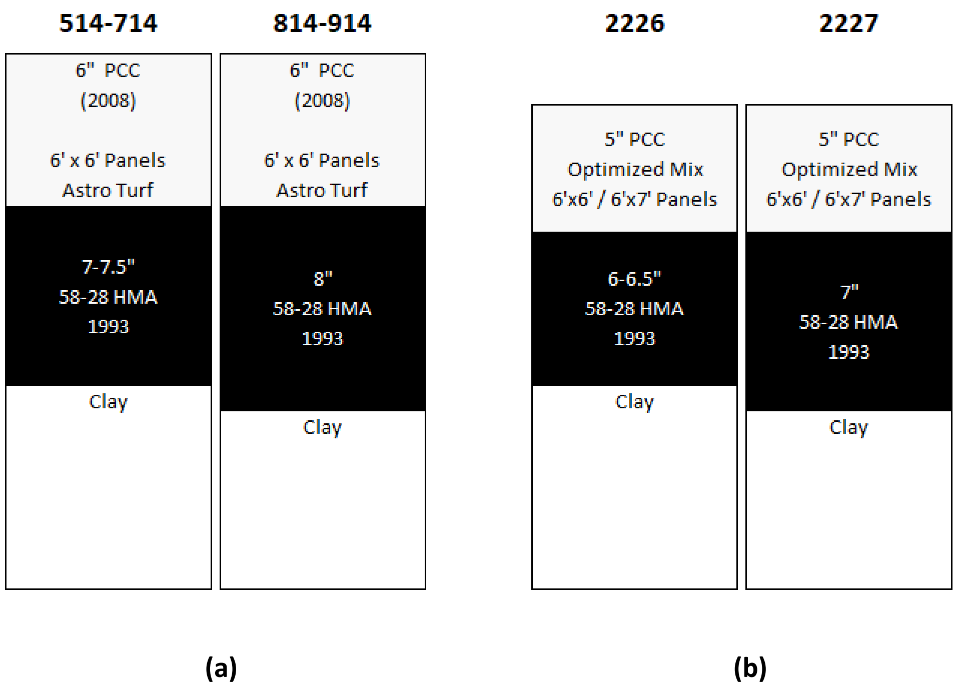
There are several features of COAs that create challenges when trying to deploy saw-cut joints. To deploy transverse joints, the concrete must be placed on a material that has sufficient friction to grab the concrete as it shrinks, but not so much friction that it restrains the frictional forces. To remove near surface distresses and/or lower the increase in grade associated with overlays, most COA projects involve removal of a portion of the asphalt using diamond grinding. Diamond grinding, however, results in a rough surface which the concrete bonds very well to. This bond provides structural benefits to the concrete overlay, but also significantly increases the frictional forces during the time of shrinkage. In addition, the increasing use of structural fibers in concrete overlays can add further restraint to joint deployment. The application of traffic loads eventually increases the number of deployed joints, but often not 100% of them. To fully meet the intended design of the overlay, all joints should deploy as early as possible.

The objective of this NRRA research project is to replace existing concrete overlay on asphalt (COA) test sections 514 through 914 at MnROAD with two new COA test sections that will explore the efficacy of early loading on increasing joint deployment under controlled conditions. In addition to two early loading periods, another variable was added in the form of two different transverse joint saw-cut depths, to establish whether that might affect early joint deployment. Following construction and early loading, the new test sections will be monitored for joint deployment and overall performance over the first 3 years of life. During the same time, additional COA projects throughout Minnesota (and other NRRA member states) will also be studied as they receive early loading intended to increase joint deployment.

10.2 Design

The test sections for this study were designed to evaluate the feasibility of using early loading and variable saw-cut depths to increase the number of deployed transverse joints in thin concrete overlays on asphalt. Mechanisms to increase the number of early deployed joints are limited. Adjusting the saw-cut depth may encourage earlier deployment but might come at the expense of reducing the already small amount of aggregate interlock available within the joint faces of thin concrete overlays. The earlier application of traffic loads seems to be a more logical choice; this must however be balanced with limiting potential damage to the thin concrete panels. Figure 10.1 presents the cross-section of the pavement design for the two new test sections constructed at MnROAD. The new test sections are 5 inches thick, 135 feet long, with 6 x 6/6 x 7 foot panels. The existing asphalt layer, paved in 1993, was milled 1 inch before the overlay was placed. No tie bars or reinforcing steel was included in these test sections.

Figure 10-1 Pavement Structures (a) Previous Test Sections 514-914 and (b) After Construction of New Test Sections 2226 and 2227



Design details for each constructed test section are summarized in Table 10.1. The concrete placed in these sections utilized optimized gradation and reduced cementitious content mixture designed by the CPTech Center (Iowa State University) and was also used in the construction of test section 2219. The mix design details for the optimized PCC concrete are covered in Chapter 6 (Section 6.2) and the work conducted to prepare the pavement foundation of these two test sections is covered under Chapter 3 MnROAD Grading and Base of this report.

Table 10-1 Early Loading Test Section Design

Test Section	Station Start	Station End	Length (ft)	Mix ID	Surface	Base / Subbase
2226	1191+87	1193+07	120	3A21-GRI1	Optimized PCC	5” Class 5Q / 5.5” Class 5
2227	1193+07	1194+46	139	3A21-GRI1	Optimized PCC	5” Class 5Q / 5.5” Class 5

Figure 10.2 shows the layout of the variable joint saw-cut depths for the test sections on this study.

Figure 10-2 Layout of the Variable Joint Saw-cut Depths

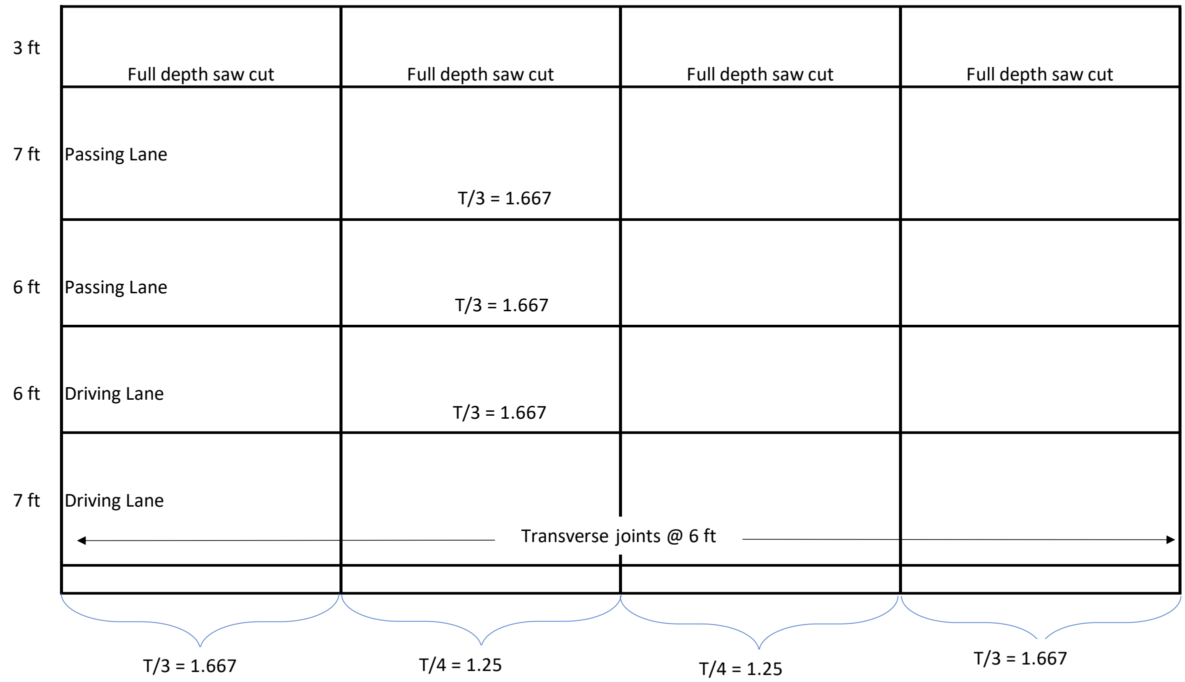
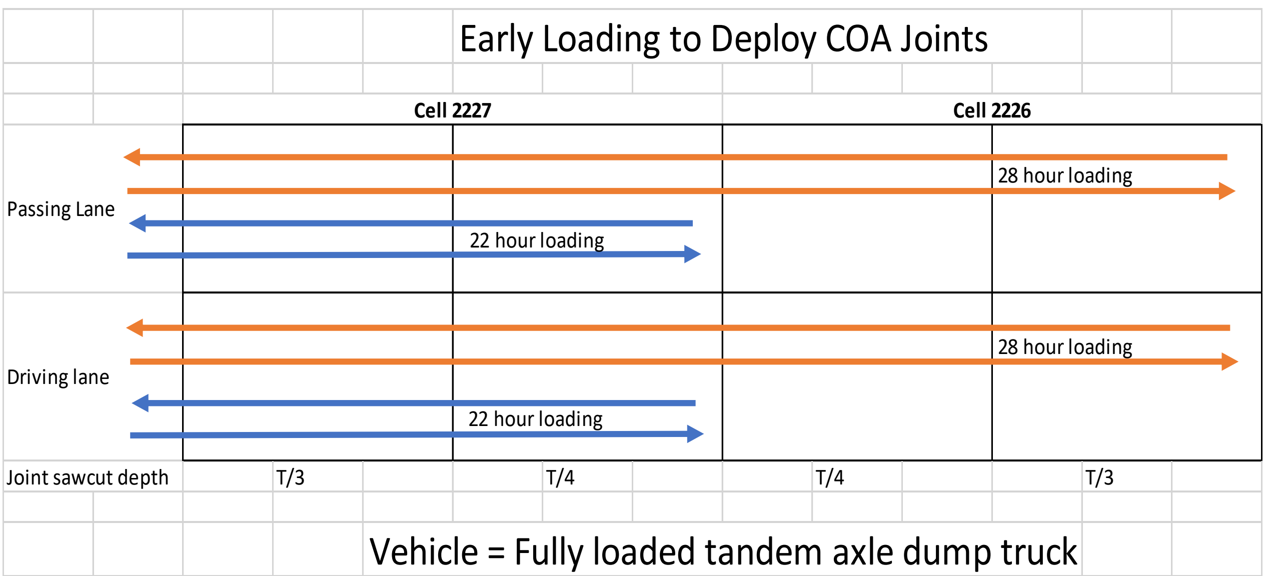


Figure 10.3 shows the tandem axle dump truck used for loading these test section for joint activation. Figure 10.4 depicts the timing and sequence of early loading. A 52,000 pound tandem axle dump truck was utilized for loading. 22 hours after paving, five slow (approx. 5 mph) passes were made on the driving and passing lane of cell 2227. 28 hours after paving, five slow (approximately 5mph) passes were made on the driving lane and five fast (approximately 30 mph) passes were made on the passing lane.

Figure 10-3 Tandem Axle Dump Truck Used for Loading Section 2226 and 2227

Figure 10-4 Timing and Sequence of Early Loading



10.3 Construction

A summary of the construction schedule of test sections 2226 and 2227 is presented in Table 10.2. Construction started on the week of July 10th with 6 inches of PCC concrete slabs removed with care as to not damage the underlying HMA layer. The concrete slab removals (See section 2.3) were followed by milling of 1 inch of the original 1993 HMA layer under the PCC concrete. PCI paved test sections 2226 and 2227 on August 2nd as indicated on Table 10.2. Grinding was performed in section 2227 and 2226 by

Interstate Improvement on Aug 8th and 9th as part of the smoothing operation for the WIM. For exact locations of diamond grinding, reach out to MnDOT staff.

Figure 10-5 Placement of Concrete Test Sections 2226 and 2227

Table 10-2 Construction Schedule

	July 2022					Aug
Activity	3	10	17	24	31	7
Concrete Slab Removal and HMA Milling		X				
Place Optimized PCC Concrete					X	
Diamond Grinding						X

Table 10.3 presents the date and time of placement of the optimized PCC concrete for test sections 2226 and 2227 and the total quantity placed.

Table 10-3 Concrete Placement

Test Section	Day Placed	Time Start	Time Stop	Quantity (cy)
2226 and 2227	8/2/2022	7:30 AM	9:31 AM	147

10.4 Sampling and Testing

A comprehensive sampling and testing program were implemented for these new test sections conducted by Federal Highway Administration (FHWA) Mobile Concrete Technology Center (MCTC) mobile laboratory and American Engineering Testing (AET).

A total of 18 fresh concrete specimens and 81 hardened concrete specimens were cast for test section 2227. No tests were conducted on test section 2226. A list of the fresh concrete testing, as well as the hardened tested specimens can be found in Tables 10.4 and 10.5. MnDOT collected samples of cementitious materials and aggregates at the batch plants to satisfy MnDOT contract quality assurance requirements. Tests results can be shared upon request to MnDOT personnel and will be documented under a summary document.

Table 10-4 Number of Test Specimens taken to Determine Properties of Fresh Concrete for Early Loading of COA Test Sections

Test	Standard	Specimens
Slump, in	AASHTO T119	2
Air content, %	ASTM C231 / AASHTO T152	2
Super Air Meter, SAM No.	AASHTO TP118	2
Hardened Air Content, %	ASTM C457	2
Unit Weight, pcf	ASTM C138	2
Temperature, °F	ASTM C1064	2
Box Test	AASHTO TP137	2
Phoenix, w/c	AASHTO T152	1
V-Kelly Index	AASHTO TP129	1
Microwave, w/c	AASHTO TP23	1
Calorimetry	ASTM C1753	1

Table 10-5 Hardened Concrete Properties Tests for Early Loading of COA Test Sections

Tests	Test Method	Testing Age (days)
Compressive Strength	ASTM C39	1, 3, 7, 28 and 56
Flexural Strength	ASTM C78	1, 3, 7 and 28
Resistivity	AASHTO T358	1, 3, 7, 28, 42, 56, 91 and 120
Maturity	ASTM C1074	Up to 56
Bulk Resistivity	ASTM C1876	7, 28, 56, 91 and 120
Formation Factor	AASHTO R101	28, 56, 91, 120
Critical Saturation Time	ASTM C1585	120
Deicing Salt Damage	AASHTO T365	28
Rapid Chloride Permeability	ASTM C1202	56
Freeze Thaw	ASTM C666	15
Poisson's Ratio and Elastic Modulus	ASTM C469	28
Coefficient of Thermal Expansion	AASHTO T336	-
Drying Shrinkage	ASTM C157	35
Autogenous Shrinkage	ASMT C1698	7
TGA	E1131 NIST TFHRC	28 and 56
Carbon Sequestration	E1131 NIST TFHRC	28 and 56
Carbon Uptake and pH	-	-
XRD and XRF	-	-
Pore Solution Expression	-	28 and 56
Blended Cement	ASTM C595	28

Tests	Test Method	Testing Age (days)
Performance Spec for Hydraulic Cement	ASMT C1157	28
Fly Ash or Natural Pozzolans	ASTM C311	28
Expansion of Mortar Bars	ASTM C1038	14
	ASTM C1012	365
Concrete Prism	ASTM C1293	730
Alkali Silica Reactivity	ASMT C1567	28
	ASTM C1260	28
R3 Testing	ASTM T1897	7
Aggregate Stability	TFAST	-
Semi-adiabatic Calorimetry	ASTM C1679	-
Set Time	ASTM C403	

To characterize all aspects of the new test sections, several test procedures were performed by MnROAD research staff within the first few weeks after paving. Surface profiling was conducted using the MnROAD Lightweight Inertial Surface Profiler (LISA) and baseline faultmeter measurements were taken. Results from this testing will be used by the principal investigator of the research contract. Others can obtain the data from the MnROAD website, or by contacting MnROAD staff.

Thickness was measured throughout each test section using the MIT-Scan-T2 device. Figure 10.6 shows the final concrete thickness measured from the T2 plates.

Figure 10-6 Final Asphalt Thickness Measured by MIT-Scan-T2

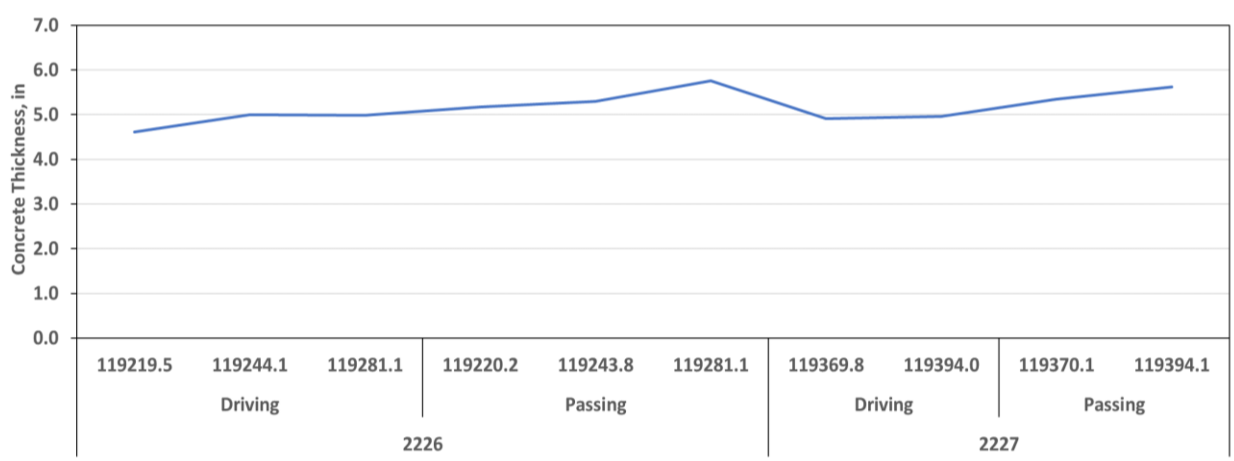


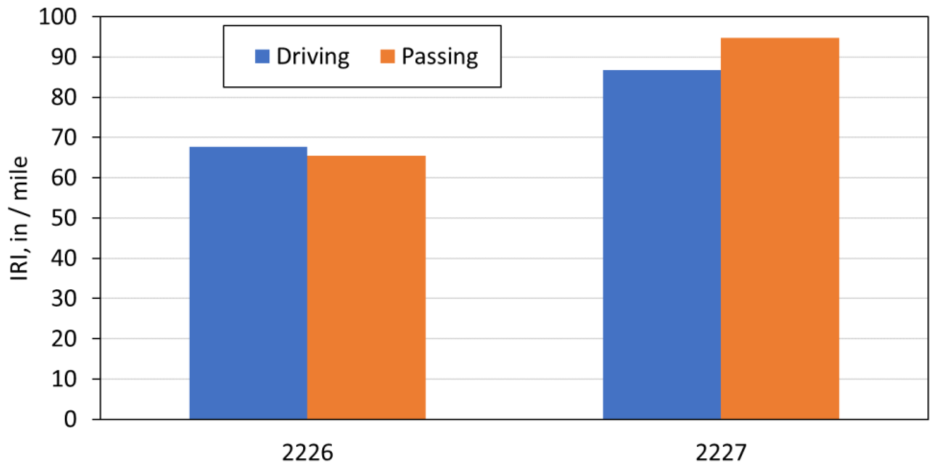
Table 10.6 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 10-6 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Material	Thickness, in	Std. Dev.
2226	PCC	5.60	0.238
	HMA	3.97	0.313
2227	PCC	5.52	0.184
	HMA	5.15	0.217

Figure 10.7 presents a summary of the International Roughness Index (IRI) results for the test sections under this research study.

Figure 10-7 IRI Measurements for Test Sections 2226 and 2227



10.5 Instrumentation and Sensors

For test sections 2226 and 2227 joint opening, dynamic strain gauges and TEROS 12 moisture sensors were installed (Figure 10.8). For description of sensors that have been installed by MnROAD staff in previous construction please refer to MnROAD website.

Figure 10-8 Sensor's Installation Layout

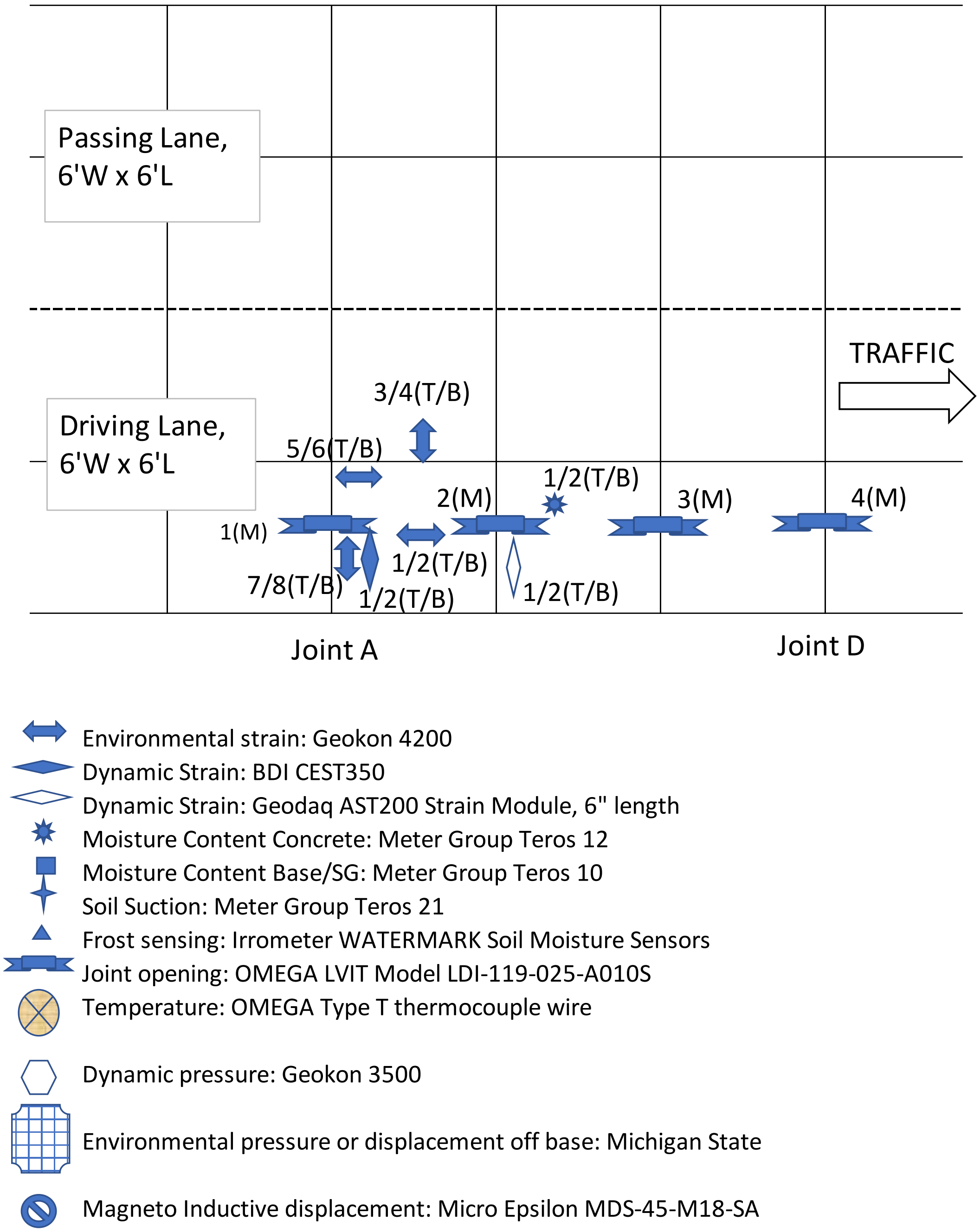


Table 10.7 shows the instrumented joints and stations for each test section under this study.

Table 10-7 Instrumented Joints and Stations per Test Sections

Test Sections	Joint A #	Joint A Station	Joint D #	Joint D Station
2226	3430	1192+41	3427	1192+23
2227	3455	1193+91	3452	1193+73

A total of 8 wireless maturity sensors were installed in the test sections under this research study. As shown in Figure 10.9 the maturity sensors installed collected temperature at two points, within the body of the maturity sensors and at the tip of the cable. Maturity sensors were installed with zip ties and attached to the dowels bar basket assemblies. More details on the type of maturity sensors can be found in Chapter 14. Maturity sensors data is available upon request to MnROAD staff.

Table 10-8 Number of Maturity Sensors Installed

Test Section	Lane Driving
2226	4
2227	4

Figure 10-9 Maturity Sensors Installation Alternative Cementitious Materials Test Sections

Chapter 11: Perpetual Pavements in Wet-Freeze Climates

11.1 Objectives

Perpetual pavements (PP) are asphalt and concrete pavement structures that are designed to provide long pavement life with limited surface repairs. This is accomplished by a well-designed structure including the unbound granular materials. The asphalt layers are also uniquely designed to withstand the stresses at each location; the bottom layer is a strain tolerant layer usually achieved with a low-air void or high binder asphalt mix design or highly modified asphalt binder. The middle asphalt lift or lifts are stiff layers to reduce the amount of tensile stress that is induced on the HMA layer. The surface layer is a high-quality layer that provides a long lasting, smooth surface with good friction properties.

Test sections 2228 and 2229 were constructed as part of the NRRA study “Perpetual Pavements in Wet Freeze Climates.” The study was initiated by the NRRA Flexible Team. The objectives are to update perpetual pavement design procedures, especially for the region and to evaluate the impact of thickness and modern mix design tools and material. Test sections are also being constructed on I-94 near Osseo, Wisconsin in collaboration with Wisconsin Department of Transportation (WisDOT). Test section 2229 used a wicking geotextile fabric above the clay subgrade and is discussed further in the Chapter 12.

The PP concept and design tools, a sustainable design alternative, have been widely available but the use of PPs in the upper mid-west states of the U.S. is still limited. This project strives to provide NRRA member agencies another sustainable pavement design strategy that can be implemented.

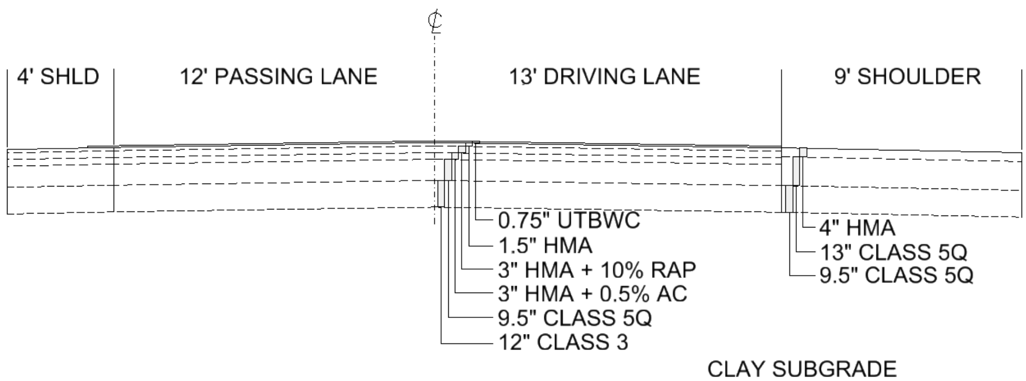
The objective of this project is to provide NRRA agency members guidance on PP designs by developing/updating the fatigue transfer function for the PerRoad software (version 4.4) and validating the new PerRoad design philosophy (using the cumulative strain distribution) under freeze-thaw conditions. The two sections in Wisconsin will be deep-strength asphalt pavements and will be instrumented with the same array of strain gauges and pressure cells to capture the structural response to vehicle loads as the MnROAD sections. Environmental conditions within the sections at both locations will be monitored using thermocouples and moisture gauges throughout the depth of the pavement structure.

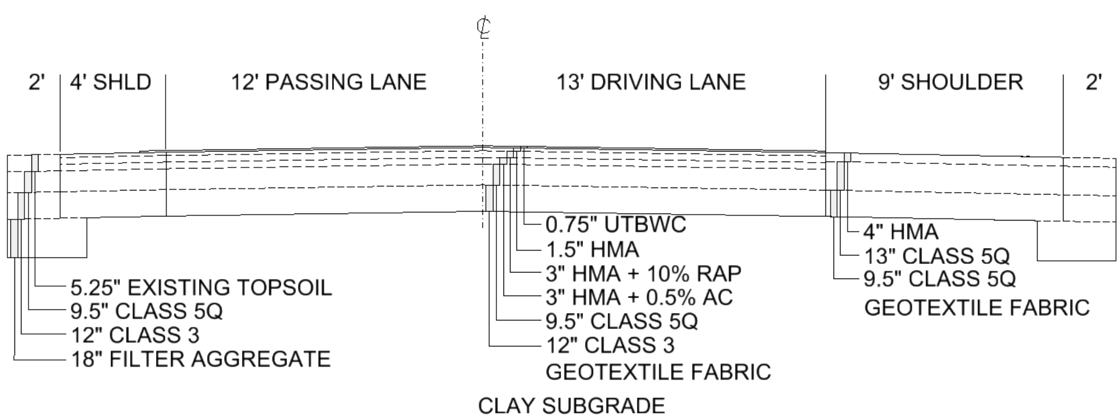
11.2 Design

The cross section of sections 2228 and 2229 are shown in Figures 11.1. Previous test sections 115 and 215 were removed for 2228 and 2229; additional native clay subgrade was removed. The difference between 2228 and 2229 is the wicking geotextile fabric in cell 2229 covering the clay-loam subgrade. Above the subgrade (or wicking geotextile in 2229), 12 inches of MnDOT class 3 material was placed and MnDOT Class 5 Special Base was placed 9.5 inches thick. The top of the Class 3 material was 18 inches from surface, matching the materials and instrumentation locations of 2230 and 2239. This provides a direct comparison to be made between the perpetual pavement designs at MnROAD and a conventional design. The total hot mix asphalt was placed in 4 lifts as listed below with 1 being closest to the surface. The design intention behind selecting each mix type is discussed.

1. 5/8 inch Ultra Thin Bonded Wearing Coarse (UTBWC). *This mix was selected provide a high-friction and high-quality surface.*
2. 1.5 inch (MnDOT SPEWB540C) PG 58H-34, 19 mm NMAS, MnDOT traffic level 5, ≈20% RAP. *This mix is the MnDOT recommend mix for the traffic level (westbound I-94) and climate (Monticello, MN).*
3. 3.0 inch (MnDOT SPEWB540B) PG 58S-28, 19 mm NMAS, MnDOT traffic level 5, ≈30% RAP. *RAP content was increased in this mix to stiffen asphalt structure and reduce strains at lower HMA layer.*
4. 3.0 inch (MnDOT SPEWB540C) PG 58H-34, 19 mm NMAS, MnDOT traffic level 5, ≈20% RAP, +0.5% asphalt cement. *Polymer modified binder was selected and the binder content was increased 0.5% to increase flexibility at the location of maximum tensile strain*.

Figure 11-1 Cross-Section of Test Sections 2228 (Top) and 2229 (Bottom)





11.3 Construction

Construction began in May 2022 with the removal of the existing HMA in previous cells 115 and 215. The in-place MnDOT class 4 aggregate was removed. Extensive instrumentation installed throughout the pavement structure to evaluate the wicking geotextile and perpetual responses is covered in sub-section

11.5. More details of the wicking geotextile fabric and unbound material placement are covered in Chapter 12.

The overall construction schedule is shown in table 11.1. A material transfer device (MTD) was used for all HMA paving.

Void Reducing Asphalt Member (VRAM) was applied on the centerline of test sections 2228 and 2229. The total length of application was 592 ft.

Table 11-1 Construction Schedule for 2228 and 2229

	June 2022				July 2022					August 2022			
Activities	**5**	**12**	**19**	**26**	**3**	**10**	**17**	**24**	**31**	**7**	**17**	**21**	**28**
Existing Pavement Removal		X											
Wicking Geotextile Installation			X										
Class 3 Subbase Aggregate													
Class 5Q Base Aggregate													
Fine Grading				X									
VRAM Application						X							
HMA Paving					X	X				X			

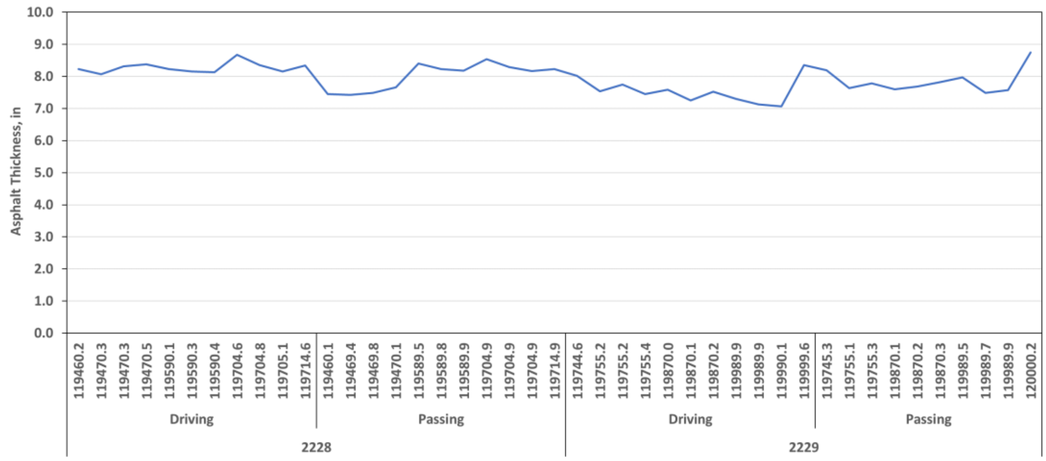
11.4 Sampling and Testing

The HMA was mixed and paved by C.S. McCrossan. All three HMA mixes used had pavement trials paved at the contractor's plant in Maple Grove, Mn. Plant mixed HMA samples were collected for each mix. MnDOT personnel attended the trial paving, took samples for volumetric testing, measured nuclear density.

During paving at MnROAD, plant produced HMA was collected for future sampling and testing. This was done by the MnDOT engineer randomly selecting a truck for sampling during paving of each mix. Half of the selected truck was dumped into the paver and the other half was dumped into a pile on a clear flat area for sampling. 3.5-gallon buckets were manually filled from the pile. Over 100 buckets per mix were sampled to facilitate laboratory testing and long-term retention at MnROAD. The asphalt binder was sampled. One dump-truckload each of the constituent aggregates and RAP were obtained from C.S. McCrossan for long-term storage in the MnROAD stockpile area.

Thickness was measured throughout each test section using the MIT-Scan-T2. Ten plates were placed in each lane of each test section. Figure 11.3 shows the final asphalt thickness measured from the T2 plates. It can be seen that the driving lane of 2229 is closer to 7.0 inches thick while the passing lane and both lanes of 2228 are mainly thicker than 8.0 inches.

Figure 11-2 Final Asphalt Thickness Measured by MIT-Scan-T2



Thickness was also measured continuously using GPR on MnDOT's Road Doctor. The Road Doctor, described in detail in Chapter 14, was used throughout the project to monitor thickness of the pavement structure as the project developed. Table 11.2 shows the thickness value for 2228 and 2229 averaged from the continuous GPR measurements. Similar trends as the T2 data were observed showing that 2229 was slightly thinner than 2228.

Table 11-2 Average Asphalt Thickness Measured by Road Doctor

Test Section	Material	Thickness (in)	Std. Dev.
2228	UTWBC	0.83	0.119
	HMA	7.47	0.184
2229	UTWBC	0.84	0.153
	HMA	6.81	0.161

In-place density of the HMA was measured using MnDOT's Density Profile System (DPS) and traditional nuclear gauge testing. Nuclear testing was conducted by the MnROAD research team in addition to conventional MnDOT contractual quality control testing. The average in-place nuclear density measurements are presented in Table 11.3.

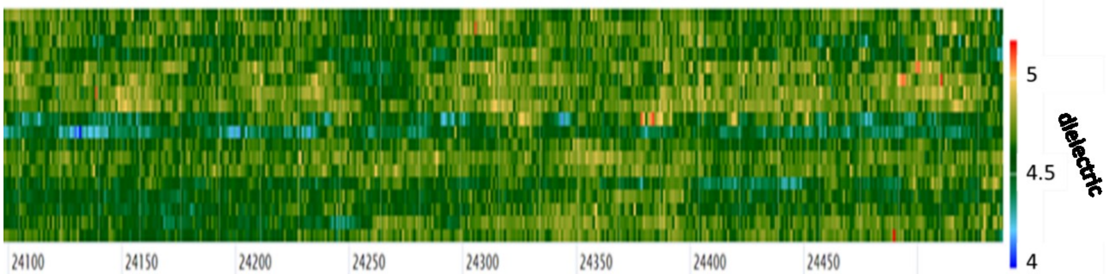
Table 11-3 Average In-place Nuclear Density

Test Section	Paving Layer	Layer %Gmm	Stdev	N
2228	Lift 1: 12.5 mm (5C) over Aggregate Base	89.5	1.52	9
2228	Lift 2: 12.5 mm (5C) over Lift 1	93.3	0.88	23
2228	Lift 3: 12.5 mm (5C) over Lift 2	91.8	1.37	17
2229	Lift 1: 12.5 mm (5C) over Aggregate Base	92.8	1.20	12

Test Section	Paving Layer	Layer %Gmm	Stdev	N
2229	Lift 2: 12.5 mm (5C) over Lift 1	94.0	0.77	19
2229	Lift 3: 12.5 mm (5C) over Lift 2	92.9	0.60	16

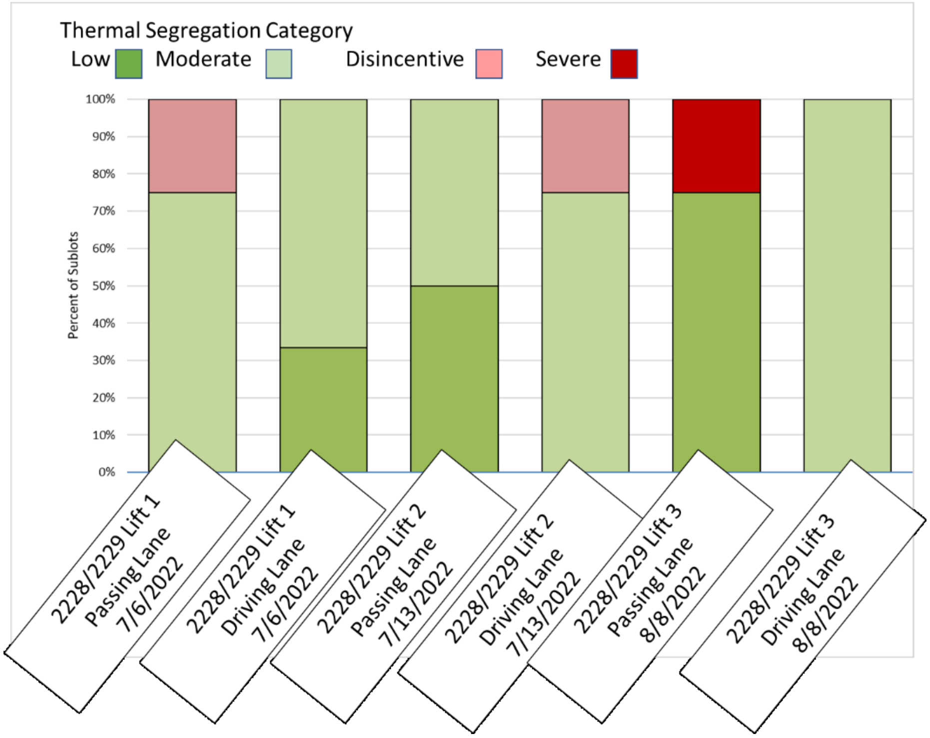
The DPS measures the dielectric of the HMA mat to correlate to an in-place density value. The DPS provides a complete assessment of the entire HMA mat and thus a map is generated showing the spatial variability of the mat density. An example for test section 2229 is shown in Figure 11.4. After complete processing and correlation to each unique mix, a density profile will be developed for each test section similar to the thermal profile. Thus, for each section a map will be generated in which thickness, density, and thermal profile data will be established to be overlayed with future distress surveys.

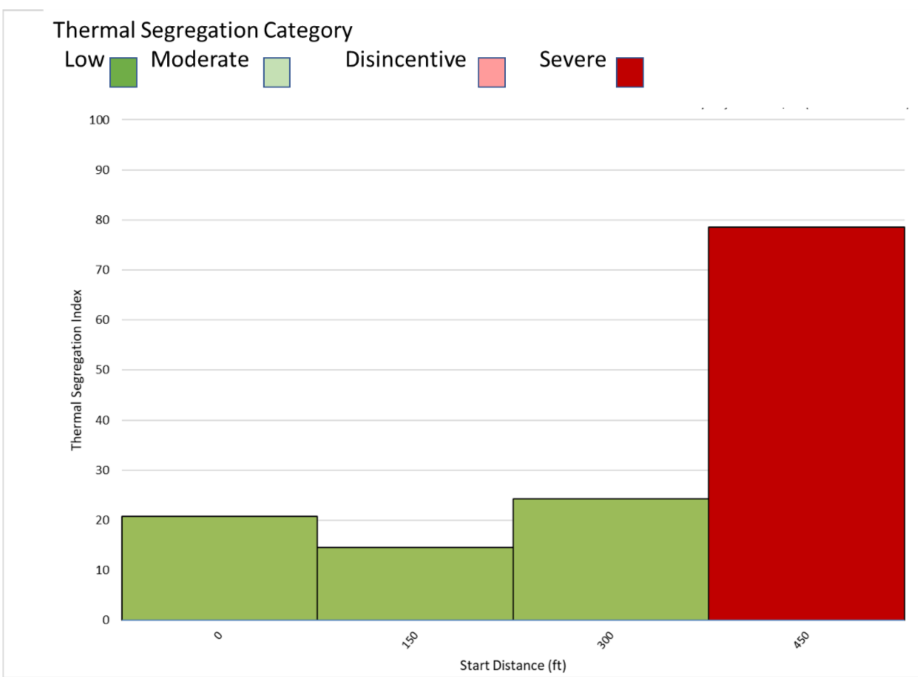
Figure 11-3 Example Spatial Variability of the Mat Density Measure with the Density Profile System



The thermal profile of the HMA mat and roller coverage was monitored following MnDOT specifications. In this process, the thermal profile from behind the paver is measured by the contractor and a VETA file is submitted to MnDOT's Advanced Materials and Testing office for incentive/disincentives adjustments. The summarized thermal segregation results are present in Figure 11.5. The red disincentive shown for lift 3 was in the final portion of the passing lane paved and was less than 100 ft.

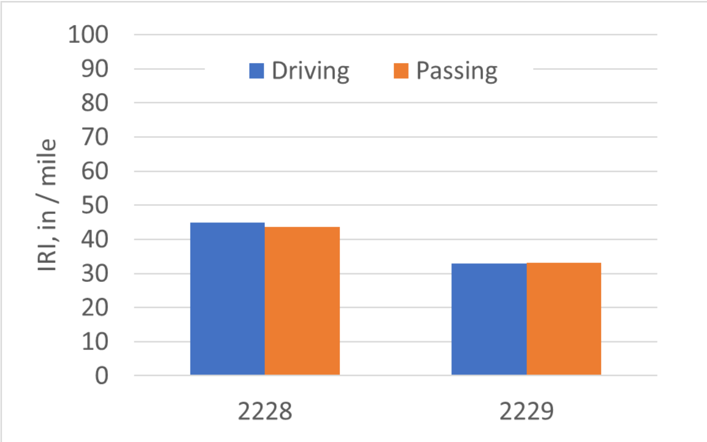
Figure 11-4 Thermal Profile of the HMA Mat and Roller Coverage





International Roughness Index (IRI) was measured on the final HMA layers after construction. Figure 11.6 presents a summary of the IRI results.

Figure 11-5 IRI Measurements for Test Sections 2228 and 2229



11.5 Instrumentation and Sensors

The instrumentation installed in 2228 was designed to measure the critical pavement responses that are utilized in the Perpetual pavement design process and to measure the environmental factors that influences the responses. Additionally, an array of moisture content and moisture potential were installed in both 2228 and 2229 to measure the effectiveness of the wicking geotextile fabric utilized above the clay subgrade in 2229.

The instrumentation array is shown in Figure 11.7 and the cross sections are shown in 11.8. Strain at the bottom of the asphalt layer is measured to assess the HMA's susceptibility to bottom-up fatigue cracking. Asphalt strain gauges were placed in longitudinal and transverse directions.

Figure 11-6 Sensor's Installation Layout

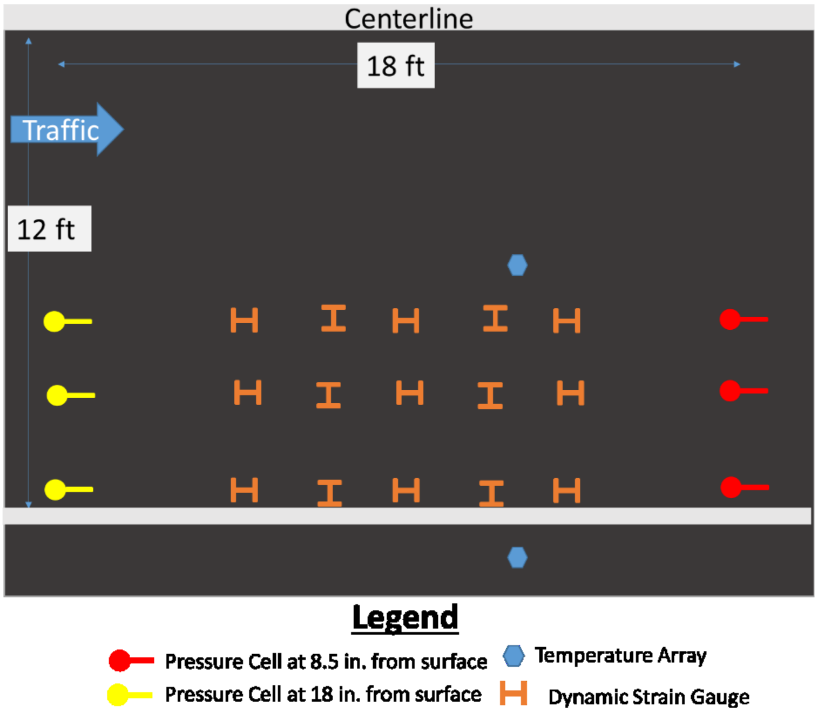
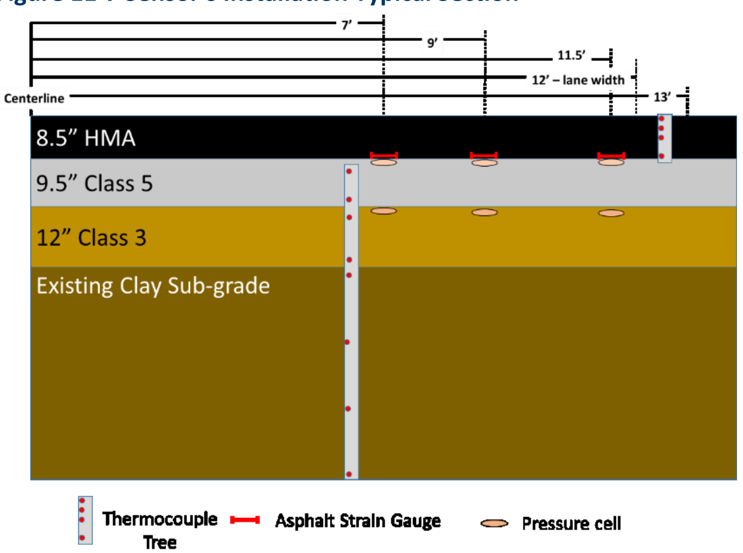


Figure 11-7 Sensor's Installation Typical Section



Chapter 12: Performance Evaluation of Wicking Geotextiles for Improving Drainage and Stiffness of Road Foundation

12.1 Objectives

Research studies completed on recently developed wicking geotextiles (with nanofiber technology) are limited and available results focus on their drainage capabilities and on short-term performance only. Wicking geotextiles, if used properly, offer the potential for enhanced pavement foundation performance that can extend the design life of a pavement.

A sustainable and resilient pavement structure requires a foundation with a robust drainage system. Roadways have frequently employed geotextiles for drainage, filtration, separation, and reinforcing needs. In general, nonwoven geotextiles are utilized for filtration, drainage, and separation (Han, 2015), but woven geotextiles are frequently employed in roads for reinforcing due to their greater tensile strengths. The focus of a woven geotextile's design for practical applications is primarily on its reinforcing effect; its hydraulic behaviors, on the other hand, are not key design factors, and the impact of hydraulic characteristics on the reinforcing effect is frequently disregarded. Woven geotextile can end up acting as a capillary barrier and can result in the water induced pavement deterioration due to moisture accumulation. Wicking geotextile is a woven geotextile that has the capacity to drain excess water off a highway laterally in both saturated and unsaturated conditions.

The test sections constructed under this effort will be used to evaluate the performance of wicking geotextiles for improving drainage and stiffness of road foundation. The results from this project will be used to quantify the long-term benefit of wicking geotextiles and to improve construction guidelines and specifications.

12.2 Design

The test sections for this research effort were designed to evaluate short- and long-term performance benefits (e.g., maintaining stiffness, improving drainage, and stabilizing moisture profile) of recently developed single-layer wicking geotextile using accelerated laboratory loading testing and MnROAD test sections to identify best practices for placing wicking geotextiles in road foundation and improve related specifications.

Two identical roadway sections (2229 with wicking geotextile and 2228 without wicking geotextile), each 250 feet in length, were constructed in I-94 highway at MnROAD facility. The wicking geotextile was installed in test section 2229, which is also a test section under the Perpetual Pavement in Freeze and Wet Climates research project covered in Chapter 11. This requires coordination between the research teams leading these NRRA efforts. The test sections have widths of 10 ft for driving shoulder, 13 ft for driving lanes, 12 ft for passing lane, and 4 ft for passing shoulder. The wicking geotextile was placed right on top of the clay subgrade layer. The is presented in Figure 12.2. The thickness of subbase, base, and asphalt courses are 12’’, 9.5’’, and 8.25’’, respectively. The wicking geotextile (Mirafi® H2Ri) was placed at the interface of the subgrade and subbase layer.

Figure 12-1 Constructed typical section for this study

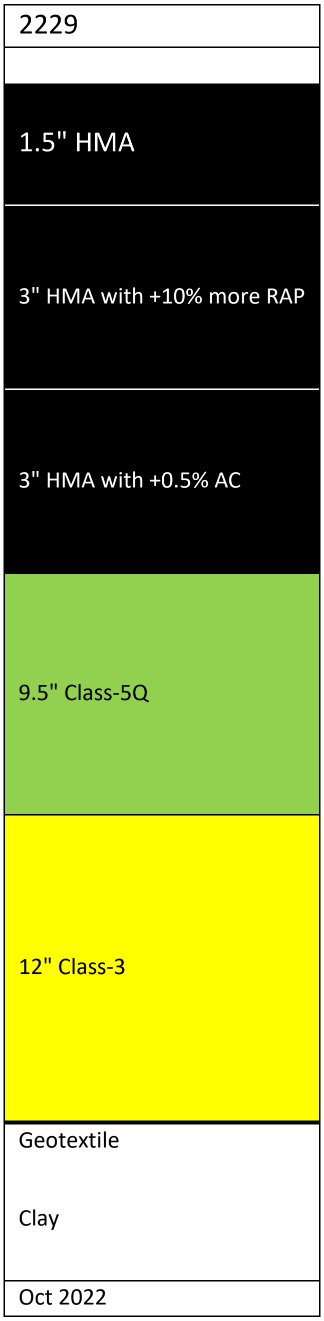
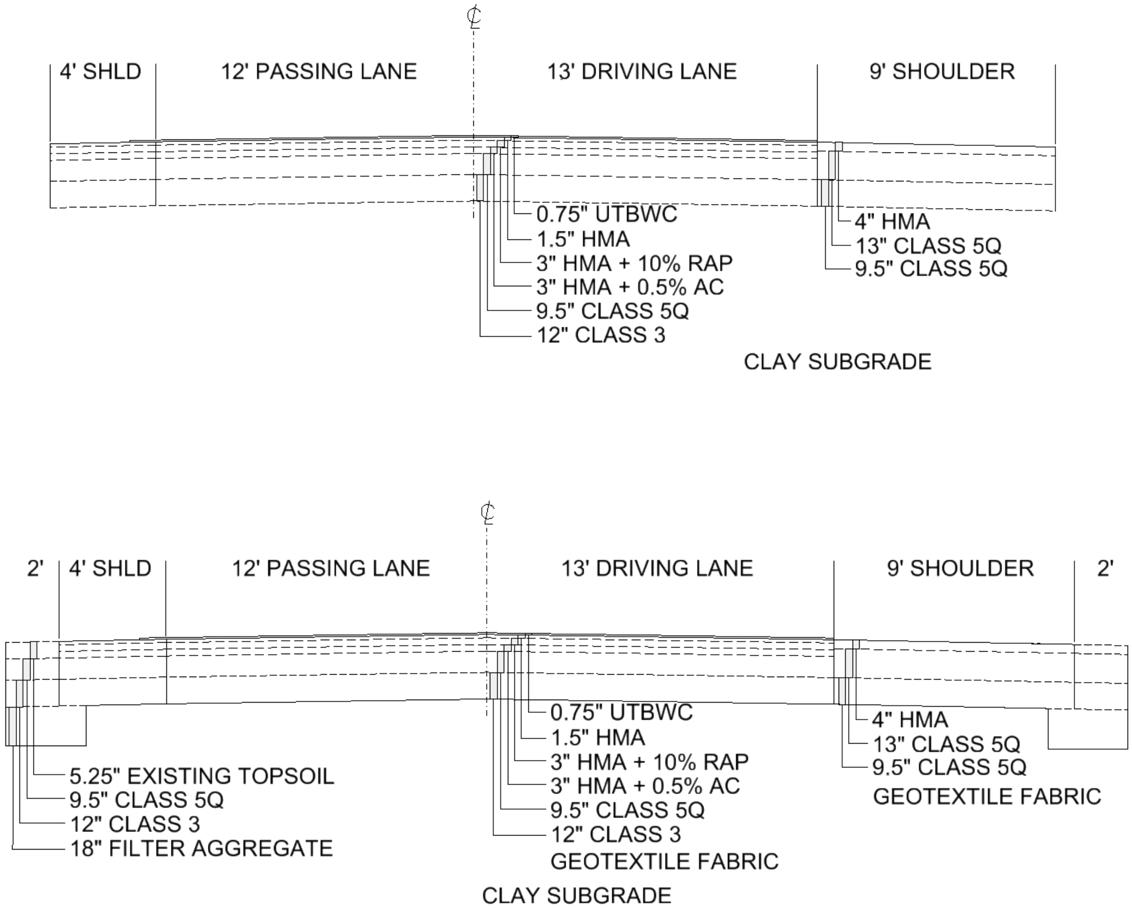
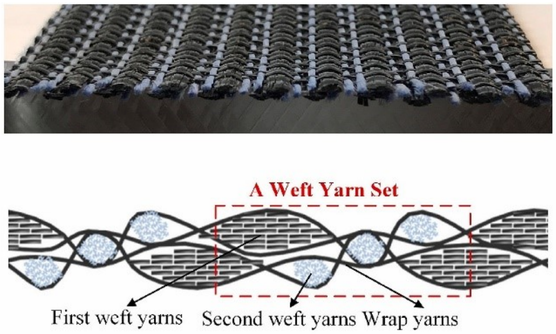


Figure 12-2 Typical Sections for Wicking Geotextile Test Section 2228 (top) and 2229 (bottom)



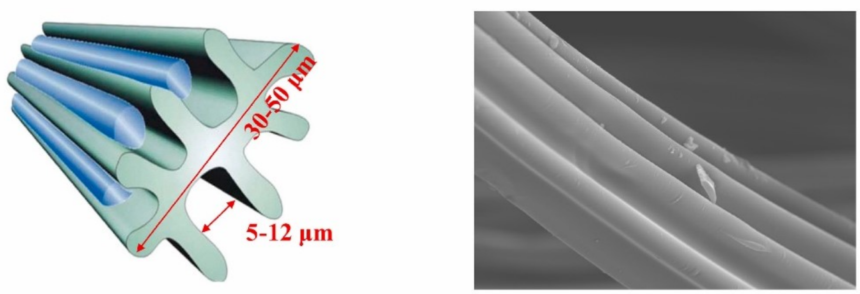
The wicking geotextile is made up of polyethylene yarns (black) which serve the traditional reinforcing purpose while the specially designed hydrophilic and hygroscopic nylon fiber yarns (blue) provide enhanced drainage along the plane of the geosynthetic. This results in a unique capability to drain water from roads and other buildings in saturated and unsaturated circumstances. The schematic plot of the cross-section of the wicking geotextile is shown in Figure 12.2 (Lin et al., 2022). Its application can range from enhanced lateral drainage/pavement reinforcement, frost heave mitigation, and surficial intrusion. Overlapped layers of Mirafi H2Ri should be shingled in a similar manner to roof tiles, to allow water to shed onto the adjacent lower layer(s). Adjacent rolls should be overlapped a minimum 12” (300 mm) and a maximum 36” (900 mm) along their sides and ends as a function of subgrade strength (Installation guidelines installation guidelines for Mirafi H 2 RI moisture management system, 2020).

Figure 12-3 The Schematic Plot of the Cross Section of the Wicking Geotextile (Lin et al., 2022)



The first kind of yarns in a set of weft yarns that run cross-machine have a higher cross-sectional area. The threads of the wicking fiber are arranged at the top, middle, and bottom of the wicking geotextile in parallel with the initial yarns. The wicking geotextile can absorb water from both underlying and overlaying soils because of the weaving structure. Depending on the temperature, pressure, and humidity, the geosynthetic can wick water without the help of gravity for up to 8" (200 mm). To keep the weaving pattern consistent, additional warp yarns are woven with the initial weft yarns and wicking fiber strands in the machine-direction. A single wicking fiber's microstructure is shown in Figure 12.3. The aperture of each groove varies from 5 to 12 µm, while the average diameter spans from 30 to 50 µm.

Figure 12-4 Microstructure of a Single Wicking Fiber (Lin et al., 2022)



12.3 Construction

Construction schedule for these test sections is covered under Chapter 3 for base grading and Chapter 11 for HMA mixes. A summary of the activities for this test section are presented under Table 12.1

Table 12-1 Construction Schedule for Test Sections 2228 and 2229

	June 2022				July 2022					August 2022			
Activities	**5**	**12**	**19**	**26**	**3**	**10**	**17**	**24**	**31**	**7**	**17**	**21**	**28**
Existing Pavement Removal		X											
Wicking Geotextile Installation			X										
Class 3 Subbase Aggregate			X	X									
Class 5Q Base Aggregate			X	X									
Fine grading				X									
HMA Paving					X	X				X			

As stated above, test section 2229 only differs from 2228 in the installation of the wicking geotextile on top of the clay subgrade layer. The initial design consisted of daylighting the wicking geotextile beyond the shoulders towards the ditch, but it had to be modified due to site constraints related to the differences in elevation between the top subgrade layer and the pavement edge level as shown in Figure 12.4. The modifications were suggested after a meeting between MnDOT staff, the research team and onsite wicking geotextile supplier representative. The wicking geotextile (Mirafi® H2Ri) is placed at the interface of subgrade and subbase layer as shown in Figure 12.5. An overlapping of 4' was provided in between the geotextiles, as shown in Figure 12.6, following the recommendation of the geotextile supplier representative.

Figure 12-5 Difference in Elevation between the Top Subgrade Layer and the Pavement Edge Level

The modifications consisted of the construction of two trenches to adequately install the wicking geotextile and allow it to wick water and drain properly. The excavated trenches were 3 ft wide by 1.5 ft deep under the edge of the shoulders and filled with open graded granular material. The geotextile was terminated to the trenches with a drop of 15 inches (Figure 12.7). The trench was filled with large size gap graded aggregates and a nonwoven geotextile (Mirafi-140N-15x360) was placed above the gap graded aggregates to minimize the intrusion of fines from the subbase layer (Figure 12.8).

Figure 12-6 Installation of Wicking Geotextile at the Interface of Subgrade and Subbase

Figure 12-7 Overlapping of Geotextile

Figure 12-8 Figure 12.8 Width and Depth of the Trench

Figure 12-9 Trench with Gap Graded Aggregate and Non-woven Geotextile.

12.4 Sampling and Testing

Sampling and testing for this test section is covered under Chapter 3 for base grading and Chapter 11 for HMA mixes.

12.5 Instrumentation and Sensors

Both test sections 2228 and 2229 were extensively instrumented to measure the volumetric water content, matric potential, temperature, and frost heave-thaw settlement of the base layers. The volumetric water content of soils at different depths and locations were measured using twelve Teros 10 sensors from the Meter Group. Similarly, twelve Teros 21 (Meter Group) were also installed alongside the Teros 10 sensors to measure the matric potential and temperature of the soil. Five pairs of sensors (Teros 10 and Teros 21) sensors were installed at 3 inches above the wicking geotextile (in the subbase) and 3 inches below the wicking geotextile (in the subgrade) along the pavement section. A pair of sensors was placed 3 inches below the top of the subbase layer at the center of pavement. Finally, a pair of sensors was placed 4.5 inches below the top base at the center of the pavement. For test section 2228, a thermocouple tree was built with 12T-type thermocouples placed at regular intervals up to 6 feet below the surface to measure the soil temperature for determining the temperature variation with depth, as well as to determine the frost penetration depth during winter. To avoid puncturing the wicking geotextile in test section 2229, three thermocouple trees measuring 8.25 inches, 21.5 inches and 36 inches were placed, two above and one below the geotextile. Shape Array Accelerometer sensors were installed at a depth of 4.5 inches from the top of the base to measure the frost heave and thaw settlement. The shape arrays were installed under the passing lane and its shoulder. The shape array consisted of 10 segments of 19.7 inches each covering a total length of 16.4 feet. The schematic diagram of test section 2229 along with sensor locations is given in Figure 12.9. The installation of moisture (Teros 10) and matric potential (Teros 21) sensors are presented in Figure 12.10. The installation of shape array sensors is depicted in Figure 12.11.

Figure 12-10 Sensor's Installation Typical Section

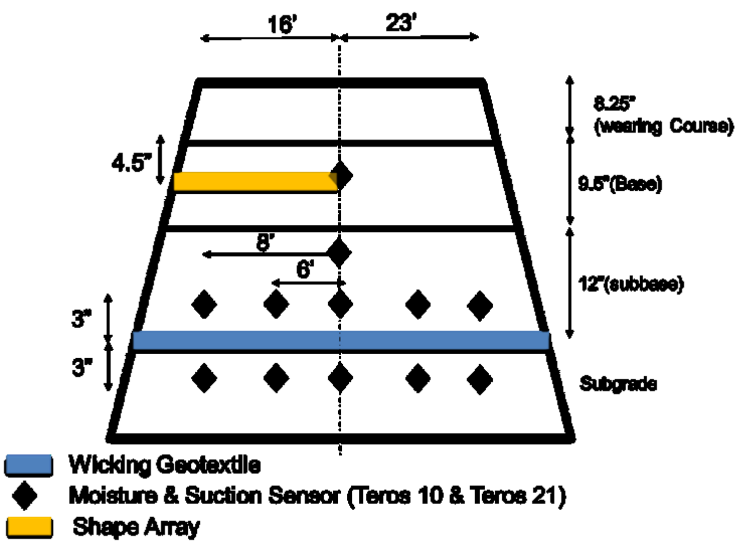


Figure 12-11 Installation of Teros 10 and Teros 21

Figure 12-12 Installation of Shape Array Sensors

Chapter 13: MnROAD Reflective Cracking In Asphalt Challenge

13.1 Objectives

Asphalt overlays comprise a vast majority of asphalt paving projects for state agencies. For example, as shown in Figure 13.1, in 2023 48% of MnDOT's network (6,796 miles) was bituminous over bituminous (BOB) pavements (i.e., asphalt mill and overlay projects) (MnDOT Pavement Management, 2023). Asphalt over concrete overlays (BOC) make up another 21% of MnDOT's network. The harsh winter climate of upper mid-western states, like Minnesota, provide additional challenges due to low-temperature transverse cracking throughout the pavement structure. Thus, most of the asphalt overlays are being applied to asphalt pavements that have been milled to remove the surface distress but still have transverse cracks in the remaining asphalt layers.

Figure 13-1 MnDOT Network in 2019

Statewide (All Districts)

Pavement	Percent	Miles
BIT	14%	1,951
BOB	48%	6,796
BOC	21%	2,983
CON	18%	2,538
CRCP	0%	2
All	**100%**	**14,271**

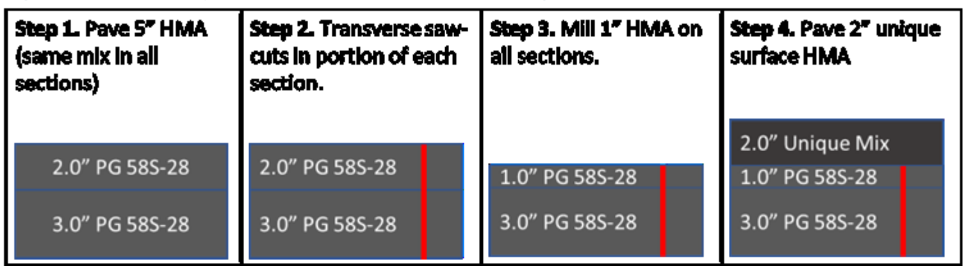
Pavement	PQI	RQI	SR
BIT	3.7	3.6	3.7
BOB	3.4	3.4	3.5
BOC	3.4	3.4	3.5
CON	3.7	3.5	3.9
CRCP	3.8	3.8	4.0
All	**3.5**	**3.4**	**3.6**

Specialized asphalt binders, mix designs and additives have been utilized to improve reflective cracking resistance and increase sustainability. However, in MN, due to the large range of temperatures and extreme low temperatures, reflective cracking from underlying transverse thermal cracks is often considered inevitable. Asphalt binder grade is the critical mix component related resistance to reflective and thermal cracking. Thus, this study includes four binder grades available in Minnesota, along with four recycled binder additives. The binder grades included in the study are PG 58S-28, PG 58H-34, PG 58V-34 (Superpave 5.0), and PG 52-34. The recycled additives included wet plastic from Dow Chemical, dry plastic from Avangard, wet ground tire–rubber (GTR) from Entech, and dry GTR from Liberty Tire. Dry additives were introduced into the HMA at the plant and the wet additives were blended at the asphalt distribution terminal. Aramid fibers were added for two test sections using a blower that was brought to the plant by the manufacturer.

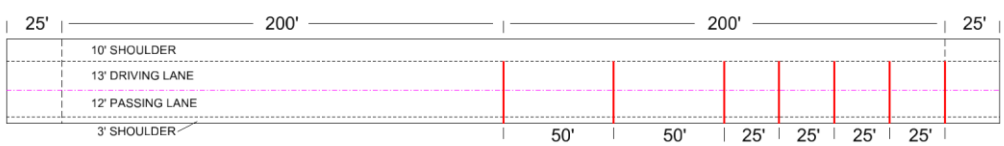
In 2017, the NRRA funded research on asphalt over PCC overlays (Van Deusen, 2018) showed that Superpave 5.0 was one of the best performing mixes. Superpave 5.0 has been used heavily in Indiana, and MnDOT also has a provisional specification for Superpave 5.0 mixes.

To better represent current asphalt network conditions, during the MnROAD 2022 construction an asphalt mill and overlay experiment was created with artificial transverse cracks in the non-surface hot-mix asphalt (HMA) layers following the steps outlined in Figure 13.2. After preparation of the base layer, construction began by paving five inches of consistent asphalt concrete designed for MnROAD's traffic and climatic condition. Transverse saw-cuts were then cut into a portion of each section to simulate underlying transverse thermal cracks in a consist manner than allows for even evaluation of the overlays placed above. The saw-cuts went through the entire width of the travel lanes (24 ft wide) and through the full five inches of asphalt. The asphalt surface was then milled. A unique, two-inch surface layer was then placed in each of the 10 test sections. More design and construction details are provided in Sections 13.2.

Figure 13-2 (a) Steps to Create Reflective Cracking Test Sections. (b) Plan View of MRCC Sections.



(a)



(b)

The objective of the MnROAD Reflective Cracking Challenge (MRCC) is to evaluate the field performance of asphalt overlays, using consistently formed cracks in test sections at MnROAD, that accurately represent the high-volume network conditions in MN. To help accomplish that objective, this construction supports NRRA Flexible Team project funded in 2021 and the NCAT MnROAD Additive Group Study. Extensive laboratory and field testing is planned to meet project goals for both research efforts.

The NRRA contract was awarded to a research team lead by Dr. Eshan Dave at the University of New Hampshire (UNH). HMA samples have also been distribute to NRRA agency members for testing. Results will be shared with the research team for analysis. A critical focus of the NRRA effort is the continuation of characterizing overlay performance in a similar manner to the 2017 NRRA Flexible team project (Dave, et al., 2019).

An integral component of the MRCC is the partnership with the National Center for Asphalt Technology (NCAT) and their NCAT MnROAD Additive Group Experiment (AG). The objective of the AG is to evaluate the impact of premium (aramid fiber) and recycled (ground tire rubber and recycled plastic) additives on the resulting laboratory and field performance of the HMA. Additionally, NCAT is developing a framework to incorporate innovative materials into HMA in a similar balanced-mix-design (BMD) type approach (Technology). In phase 1 of the AG study, NCAT evaluated 11 additives in a BMD framework. Based on this initial BMD testing, the study sponsors selected the additives to be constructed on the NCAT Test Track in Opelika, Alabama in 2021. A similar process was followed for the companion MnROAD sections, and the same products used on the NCAT Test Track were also utilized at MnROAD.

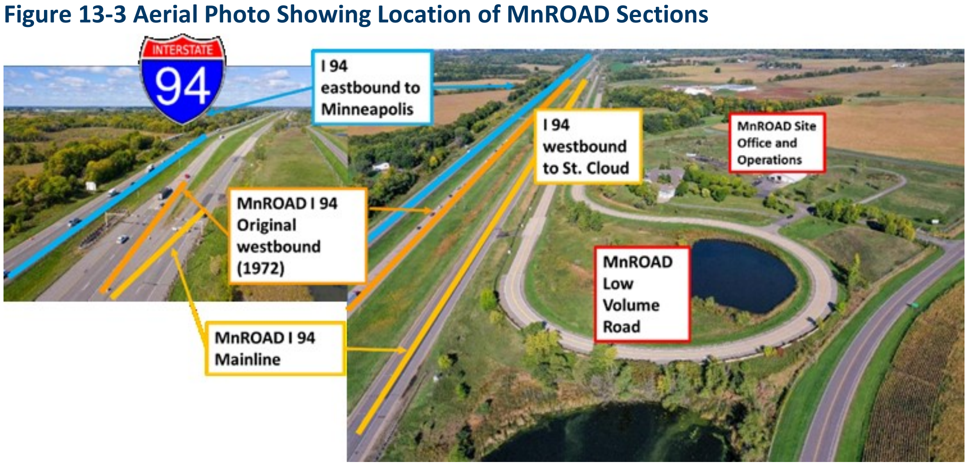
Another collaborative component of this study will be with the Missouri Center for Transportation Innovation (MCTI). The Missouri DOT (NRRA Agency Member) will be constructing additional companion test sections in south-eastern Missouri in 2023. The MCTI sections will also focus on incorporating recycled plastic and ground tire rubber into HMA overlays placed on Portland cement concrete pavements.

13.2 Design

The MRCC sections were constructed on westbound I-94 MnROAD Mainline. As shown in Figure 13.3, MnROAD Mainline parallels the original I-94 westbound alignment and live interstate traffic is switched between the MnROAD Mainline test sections and the original I-94 alignment to allow for periodic inspection, testing, and repair on MnROAD Mainline sections.

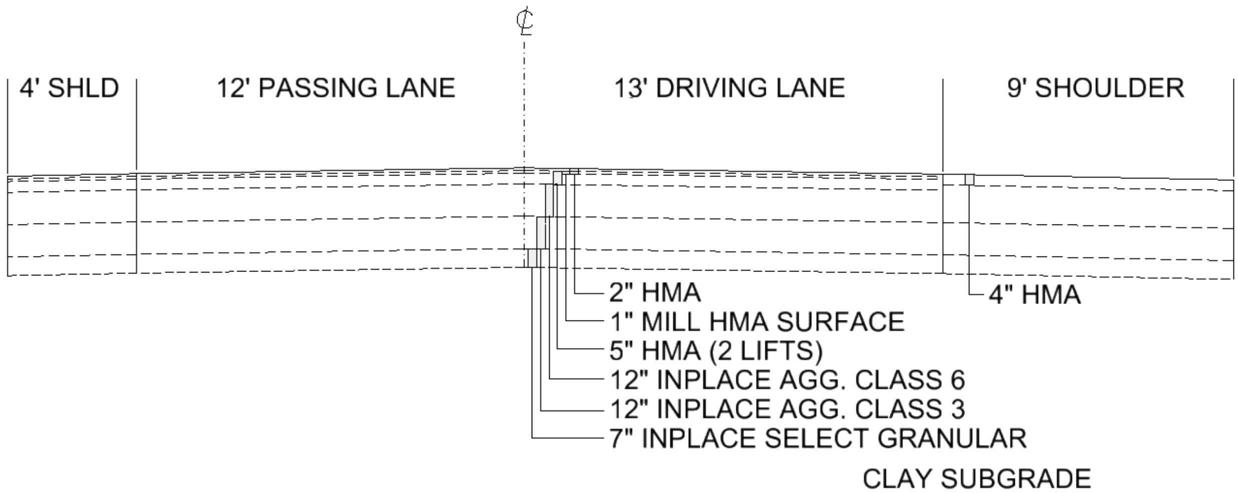
The 10 MRCC test sections, 2230 -2239, are in the same location as previous 2016 test sections 16-23 associated with the MnROAD NCAT Cracking Group Study. Test section 2239 is the first test section on MnROAD Mainline that the westbound I-94 live traffic travels over.

Figure 13-3 Aerial Photo Showing Location of MnROAD Sections



The pavement cross section from the construction plans is shown in Figure 13.4. All sections as part of this study were constructed over unbound material that was left in-place from 2016 construction. As shown in the details of Figure 13.44, each section consists of aa total of 6 in of asphalt over 12 inches of MnDOT Class 6 Aggregate over 12 inches of MnDOT Class 3 Aggregate over seven inches of select granular material over the native clay-loam subgrade.

Figure 13-4 Typical Section for Reflective Cracking



The 2016 Cracking Group sections had delamination between the asphalt layers that led to distress forming in the top two inches of the asphalt. A forensic investigation identified water intrusion through the longitudinal construction joints as the cause of the delamination. To avoid confounding issues from asphalt layer delamination, multiple actions were taken during the construction of 2022 MnROAD test sections:

1. The paving width of the driving lane was increased from 12 ft to 13 ft. The lane was still painted 12 ft wide from centerline; thus the longitudinal construction joint is moved further away from traffic wheel loads.
2. A longitudinal joint treatment (J-band) was used to help with joint density and water intrusion.
3. All sections were milled prior to placing of the final surface lift. Milling increases the potential bond strength between the asphalt layers.

The mix design process for the 2022 test MRCC sections began in earnest in fall 2021 when MnDOT sampled the aggregates and sequestered RAP stockpile, followed by developing a base mix design. The sampled aggregate and mix design information were sent to NCAT for balanced mix design testing and additives dosing. Through the Additive Group (AG), NCAT was responsible for developing mix-design for eight test sections at MnROAD, including all additive (six) sections and two control sections. All NCAT designed mixes were produced by Martin Marietta's Elk River plant and furnished by MnDOT directly to C.S. McCrossan for paving. The Martin Marietta plant used a Dillman counterflow drum.

C.S. McCrossan was the prime contractor for 2022 MnROAD construction and was responsible for all asphalt paving. Additionally, C.S. McCrossan designed all asphalt mixes except the eight AG mixes. The

AG mixes were furnished separately so MnDOT and NCAT could begin mix design in fall 2021 prior to the spring 2022 construction contract letting. This allowed for adequate time for mix designs and additives to be evaluated. To ensure consistent RAP properties from sampling in fall 2021 to construction in July 2022, Martin Marietta isolated a 500-ton RAP pile specifically for this project.

A MnDOT mix designation of SPWEB540C was required for the conditions, and a mix design provided by Martin Marietta that fell into this designation was provided to NCAT as the base mix design. This was a Superpave based design for wearing course mix at traffic level 5 with 4.0% design air voids and C oil (PG 58H-34).

The additives included in the study were recycled plastic, ground tire rubber, and aramid fibers. The mix details for each section are provided in Table 13.1. The recycled plastic and GTR had both "wet-process" and "dry-process" test sections. The "dry-process" additives (dry plastic and dry GTR) were added at the plant with a Hi-Tech Asphalt Solutions feed system. Both aramid fiber products utilized portable, dry-delivery systems brought by the manufacturer to the plant.

Table 13-1 Mix Details for Reflective Cracking Project HMA Mixes

Section	2239	2238	2237	2236	2235
Description	Control	Control	Dry Rubber	Dry Plastic	Wet Rubber
Product/Mfg			Smart Mix, Liberty	Avangard	Entech
Additive Delivery Method	NA	NA	Blown in at plant	Blown in at plant	Tanker
Binder	58H-34	XX-34	XX-34	XX-34	Mathy 52-34
MnDOT Mix ID	SPWEAB540C	SPWEAB540A	SPWEAB540A	SPWEAB540A	SPWEAB540A
HMA Plant	Martin Marietta	Martin Marietta	Martin Marietta	Martin Marietta	Martin Marietta
Surface Pave Date	18-Jul-22		19-Jul-22		20-Jul-22

Section	2234	2233	2232	2231	2230
Description	Fiber 1	Fiber 2	Wet Plastic	Superpave 5.0	Control
Product/Mfg	Forta Fi Fiber	Ace Fiber	Dow		
Additive Delivery Method	Blown in at plant	Blown in at plant	Tanker		
Binder	58H-34	58H-34	Mathy 52-34	58V-34	PG 58S-28
MnDOT Mix ID	SPWEAB540C	SPWEAB540C	SPWEAB540A	SPWEAB550F	SPWEAB540B
HMA Plant	Martin Marietta	Martin Marietta	Martin Marietta	C.S. McCrossan	C.S. McCrossan
Surface Pave Date	20-Jul-22	21-Jul-22	22-Jul-22		8-Aug-22

During the design process at NCAT, discussions occurred with the project team and product manufacturers to determine the proper design for each MnROAD test section. NCAT tried to stay as close as possible to the original mix design supplied by MM and "drop-in" each additive into the same mix design and aggregate structure. The low temperature grade and polymer modification of the asphalt were main points of discussion. Based on these discussions, the unmodified base asphalt in the PG58H-34 binder was included in the experiment as an additional control section. This binder is sold as a XX-34 unmodified asphalt that is produced by Flint Hills Resources. The XX designates that no high-temperature grading is provided. This asphalt typically has a high temperature grade of 49-52 but does not consistently meet PG 52-34 specifications. A high temperature PG of 58 is required for the portion of Minnesota that MnROAD is located based on LTPPBind. However, PG 52-34 mixes have shown very good performance in previous MnROAD studies including the NCAT Cracking Group.

C.S. McCrossan designed, produced, and paved the two lifts of asphalt underlying all 2022 MnROAD MRCC sections. A MnDOT mix designation SPWEB540B was specified. The same MnDOT mix designation was used except a PG 58S-28 (MnDOT B oil) was selected to create greater susceptibility to thermal cracking in the underlying layers, inducing a more severe test of the surface mixes placed above.

13.3 Construction

Construction began after a late, wet spring with the removal of the existing MnROAD sections in May 2022. The existing HMA in MnROAD sections 16-23 from the 2016 MnROAD NCAT Cracking Group experiment were milled. The MnDOT Class 5 base installed in 2016 was left in-place with only the requisite regrading and blue-topping being conducted.

To ensure base uniformity under the future test sections, falling weight deflectometer (FWD) testing was conducted by the MnROAD team. Ingios performed Automated Plate Load Testing (APLT) and COMP-Score® RT (intelligent compaction) mapping tests. This effort was summarized under Chapter 3 of this report and the report from Ingios is available upon request to MnDOT and MnROAD staff.

The overall construction schedule is shown in Table 13.2. In the days leading up to paving at MnROAD, the contractor paved trial mixes at their plant. A material transfer device (MTD) was required for all HMA paving at MnROAD but was not required for the test strips. Instrumentation in the MnROAD test sections was installed prior to paving the first lift of HMA.

Table 13-2 2022 MnROAD Reflective Cracking Test Section Construction Schedule

Activity	Date
Remove existing HMA	May 23-June 8
Regrade Base and Test	June 8-22
Install Instrumentation	June 20-21
Pave HMA Lift 1	June 23-24
Pave HMA Lift 2	June 27
Saw-cut HMA	July 11
Mill HMA	July 13
VRAM Application	July 15
Pave Unique Surface Lifts	July 18-22; August 8

After paving the first two lifts of PG 58S-28 in all test sections, transverse saw-cuts were made in the HMA. The saw-cuts were five inches deep (full-depth) and extended 24 ft wide (full travel width of I-94;

saw-cut not daylighted through shoulders). Then, one inch of the second lift of the new HMA was milled off the surface of the entire set of test sections. Figure 13.5 shows side by side comparison of a saw-cut and the HMA surface before and after milling. A material transfer device (MTD) was required for all HMA.

Figure 13-5 Pavement Surface Appearance after Saw-cut and Partial mill

Void Reducing Asphalt Member (VRAM) was applied on the centerline and shoulders of test sections 2230 to 2239. The total length of application was 9,080 ft. Figure 13.6 shows the application of VRAM on the perpetual pavement and wicking geotextile test sections.

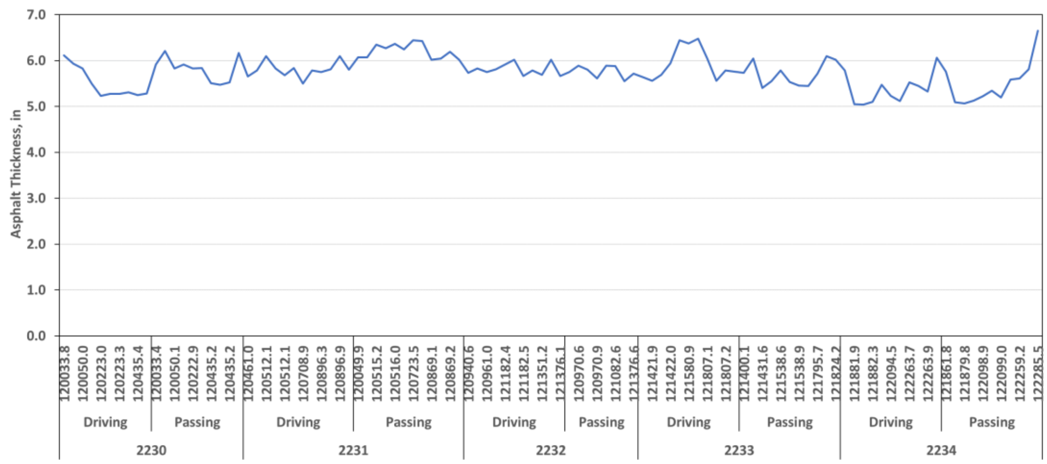
Figure 13-6 VRAM Application on the Centerline of Test Sections 2230 to 2239

13.4 Sampling and Testing

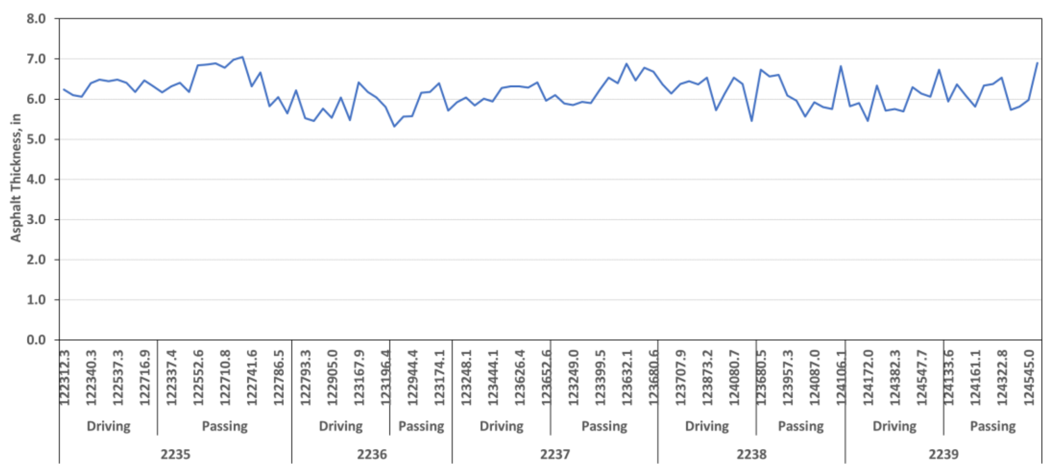
Plant mixed HMA samples were collected for each mix. During paving, a truck was randomly selected for sampling by the MnDOT engineer. Half of the selected truck was dumped into the paver and the other half was dumped into a pile for sampling. 3.5-gallon buckets were manually filled from the pile. Over 100 buckets per mix were sampled to facilitate laboratory testing and long-term retention at MnROAD. Each unique asphalt binder was sampled. One dump-truckload each of the constituent aggregates and RAP were obtained from Martin Marietta and C.S. McCrossin for long-term storage in the MnROAD stockpile area.

Thickness was measured throughout each test section using the MIT-Scan-T2 device which reports the distance to a thin, calibrated metal plate on top of the aggregate base immediately prior to paving. Ten plates were placed in each lane of each test section. The average final thickness of each test section is shown in Figure 13.7 (a) and (b). All points measured had a thickness greater than five inches.

Figure 13-7 Final thickness of each test section from MIT-Scan-T2 plates



(a)



(b)

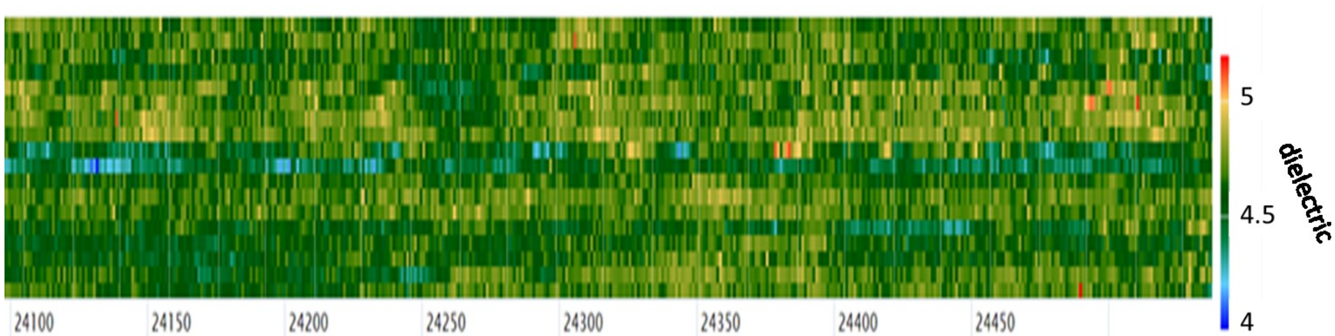
Table 13.3 presents a summary of the thickness measured with Road Doctor's Ground Penetrating Radar (GPR) for the test sections under this research study.

Table 13-3 Road Doctor Ground Penetrating Radar Thickness Measurements

Test Section	Layer	Thickness, in	Std. Dev.
2230	HMA	5.34	0.167
	Class 6 Base	13.17	0.289
2231	HMA	6.00	0.201
	Class 6 Base	10.81	0.791
2232	HMA	5.91	0.204
	Class 6 Base	12.49	0.424
2233	HMA	5.65	0.187
	Class 6 Base	13.30	0.210
2234	HMA	5.47	0.190
	Class 6 Base	13.97	0.246
2235	HMA	6.77	0.208
	Class 6 Base	13.58	0.456
2236	HMA	5.62	0.222
	Class 6 Base	-	-
2237	HMA	6.37	0.240
	Class 6 Base	13.50	0.189
2238	HMA	6.02	0.209
	Class 6 Base	14.71	0.355
2239	HMA	6.21	0.264
	Class 6 Base	-	-

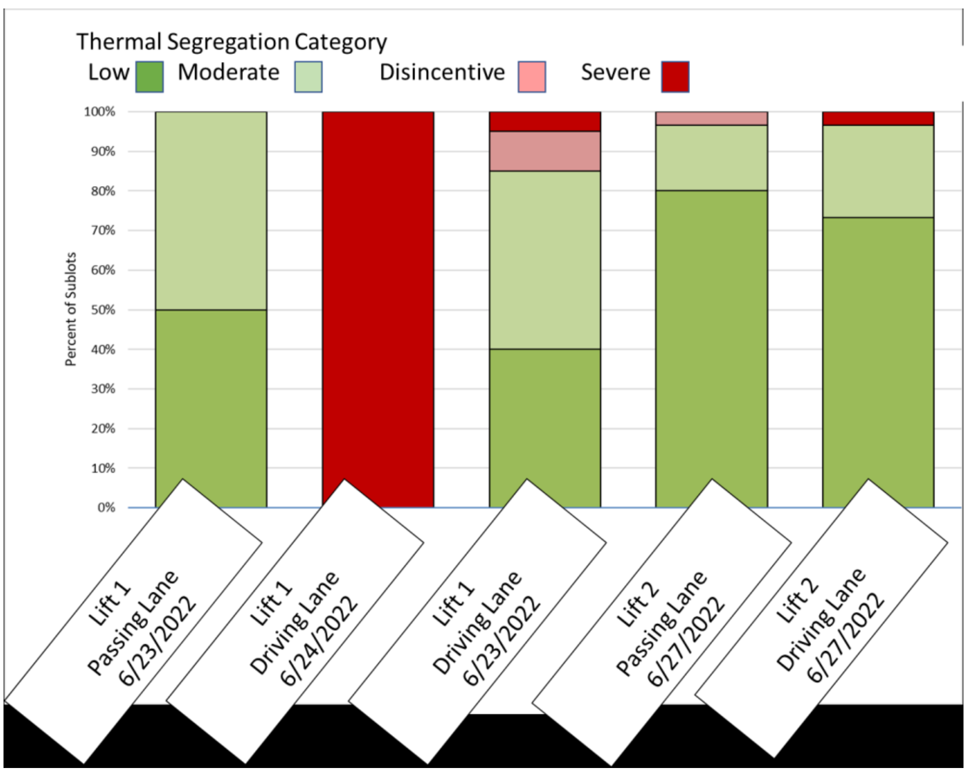
In-place density of the HMA was measured using MnDOT's Density Profile System (DPS) and traditional nuclear gauge testing. The DPS measures the dielectric of the HMA mat to correlate to an in-place density value. The DPS provides a complete assessment of the entire HMA mat and thus a map is generated showing the spatial variability of the mat density. An example for test section 2239 is shown in Figure 13.8. After complete processing and correlation to each unique mix, a density profile will be developed for each test section similar to the thermal profile.

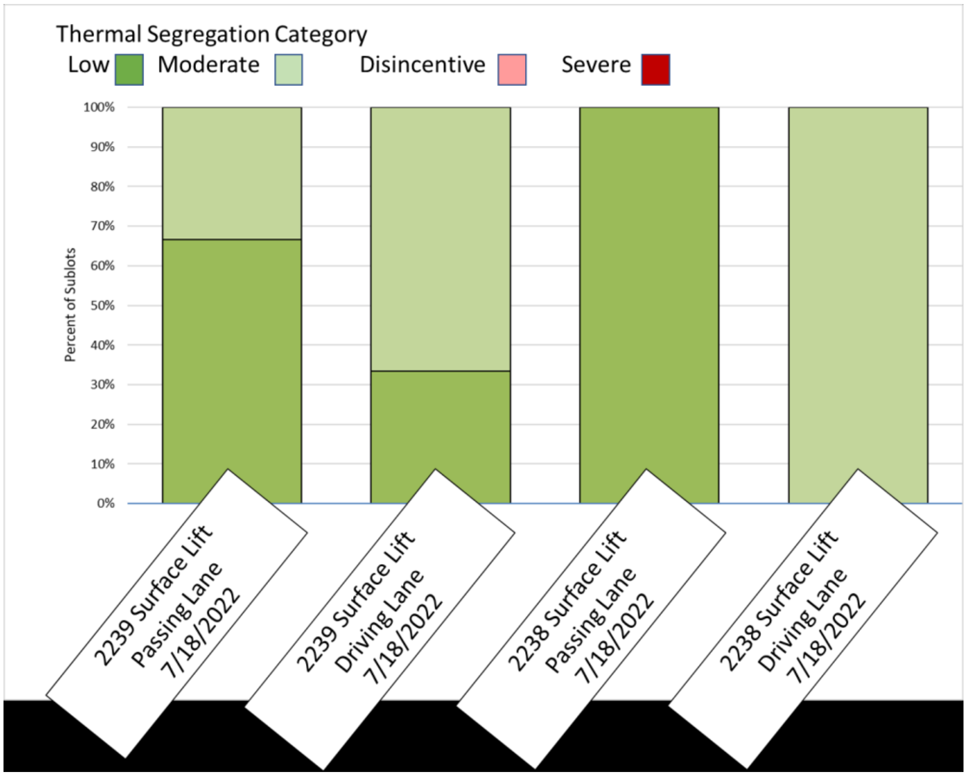
Figure 13-8 Example Spatial Variability of the Mat Density Measure with the Density Profile System

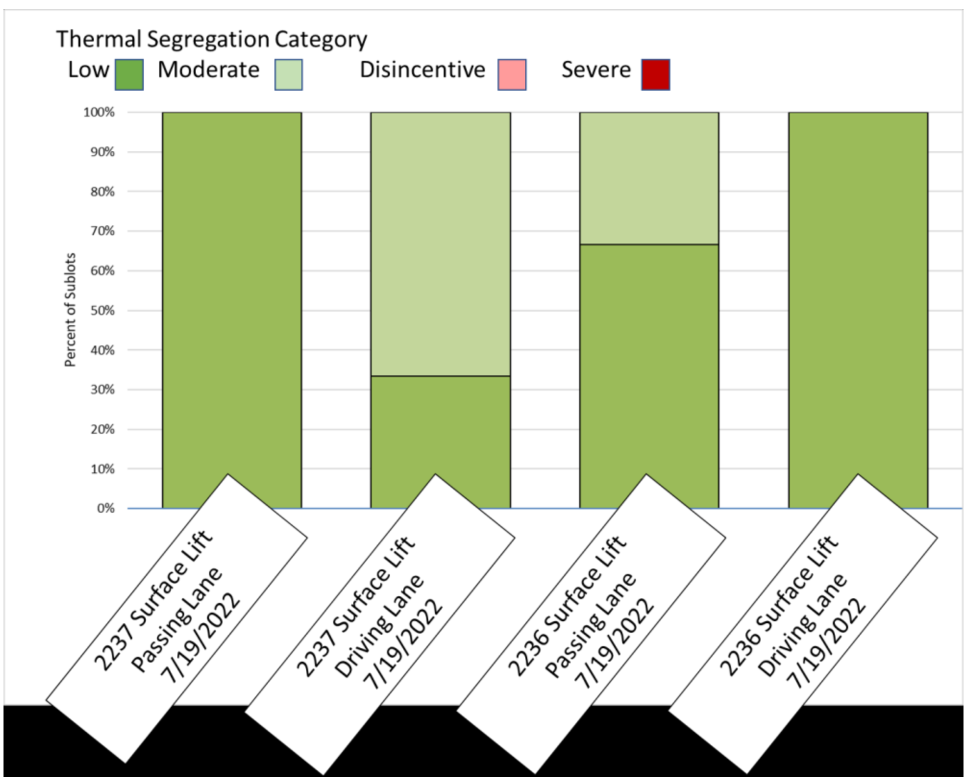


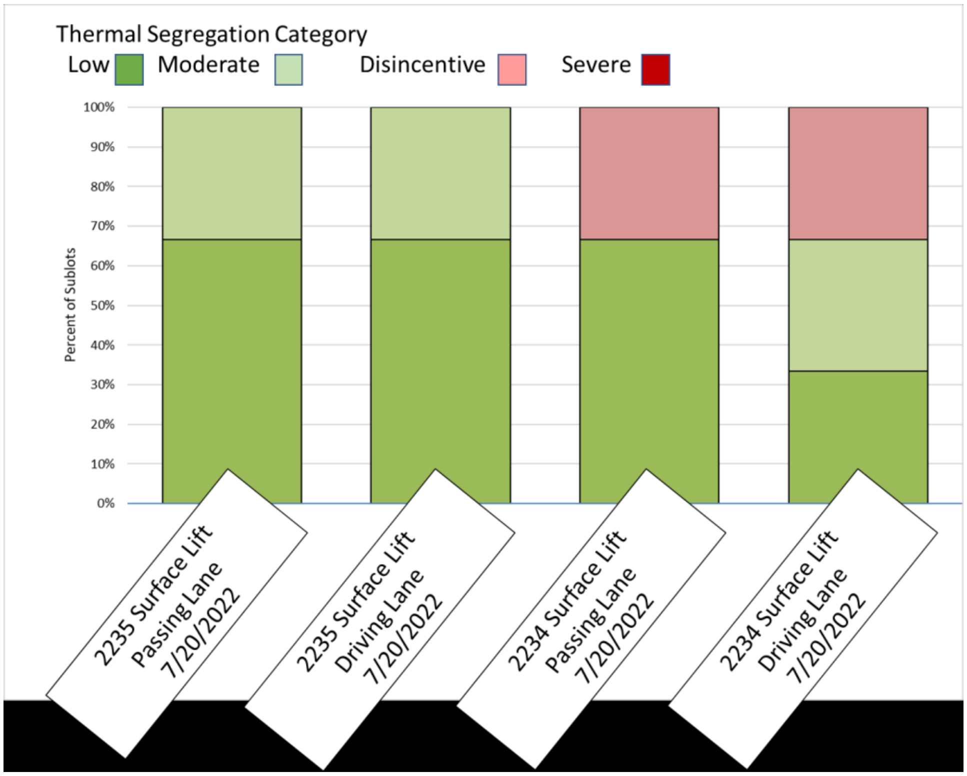
The thermal profile of the HMA mat and roller coverage was monitored following MnDOT specifications. In this process, the thermal profile from behind the paver is measured by the contractor and a VETA file is submitted to MnDOT's Advanced Materials and Testing office for incentive/disincentives adjustments. Figure 13.9 (a) shows the reported thermal segregation index (TSI) for the lower HMA layers that were paved uniformly for all sections. The severe thermal segregation that occurred on June 24 was due to mechanic failure of the material transfer device (MTD) that the contractor was unable to repair. The MnDOT engineer allowed the remain HMA onsite to be paved without the MTD (approximately 8 trucks) but stopped further production and paving for the day. The contractor had a different MTD onsite the following day and no further issues were encountered from the MTD. The TSI did not reach the severe category again on the project. Figures 13.8 (b)-(g) shows the individual section and lane results.

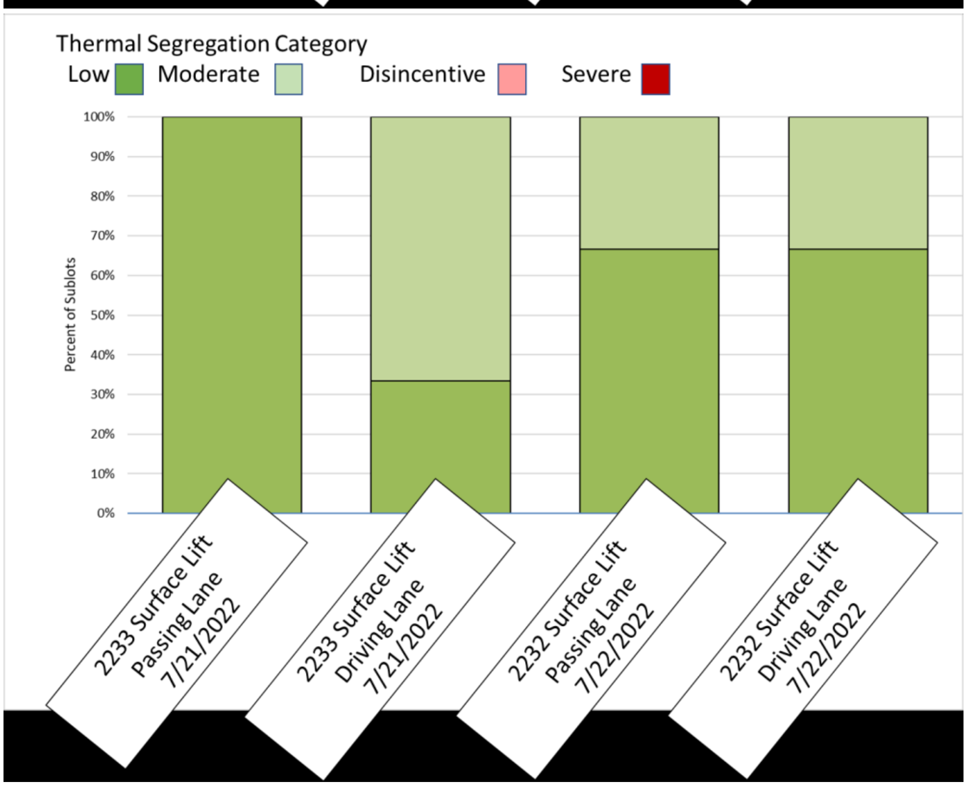
Figure 13-9 Thermal Segregation Index (TSI) for the HMA layers

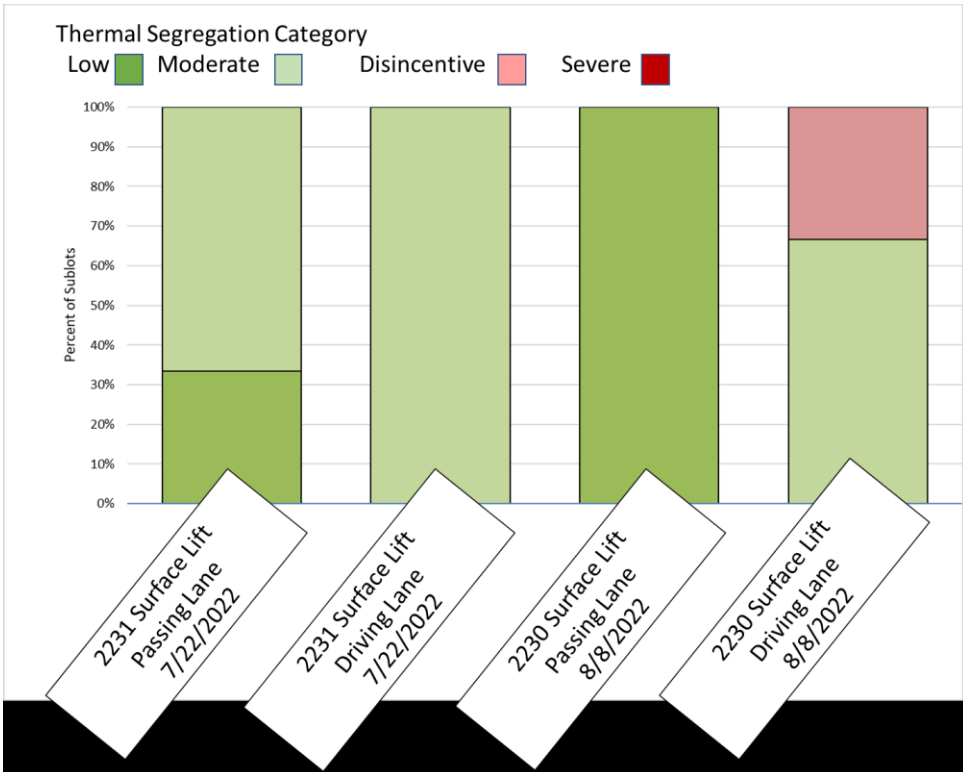



Thermal Segregation Category
Low
Moderate
Disincentive
Severe
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of Sublots
2239 Surface Lift Passing Lane 7/18/2022
2239 Surface Lift Driving Lane 7/18/2022
2238 Surface Lift Passing Lane 7/18/2022
2238 Surface Lift Driving Lane 7/18/2022


Thermal Segregation Category
Low
Moderate
Disincentive
Severe
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of Sublots
2237 Surface Lift Passing Lane 7/19/2022
2237 Surface Lift Driving Lane 7/19/2022
2236 Surface Lift Passing Lane 7/19/2022
2236 Surface Lift Driving Lane 7/19/2022

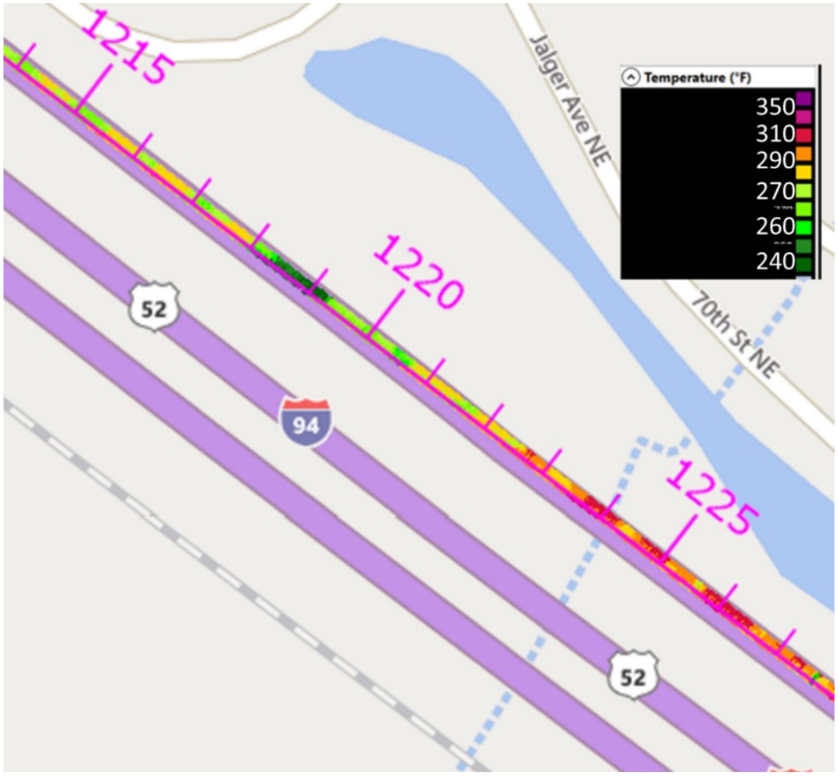

Thermal Segregation Category
Low
Moderate
Disincentive
Severe
Percent of Sublots
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2235 Surface Lift Passing Lane 7/20/2022
2235 Surface Lift Driving Lane 7/20/2022
2234 Surface Lift Passing Lane 7/20/2022
2234 Surface Lift Driving Lane 7/20/2022


Thermal Segregation Category
Low
Moderate
Disincentive
Severe
Percent of Sublots
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2233 Surface Lift Passing Lane 7/21/2022
2233 Surface Lift Driving Lane 7/21/2022
2232 Surface Lift Passing Lane 7/22/2022
2232 Surface Lift Driving Lane 7/22/2022



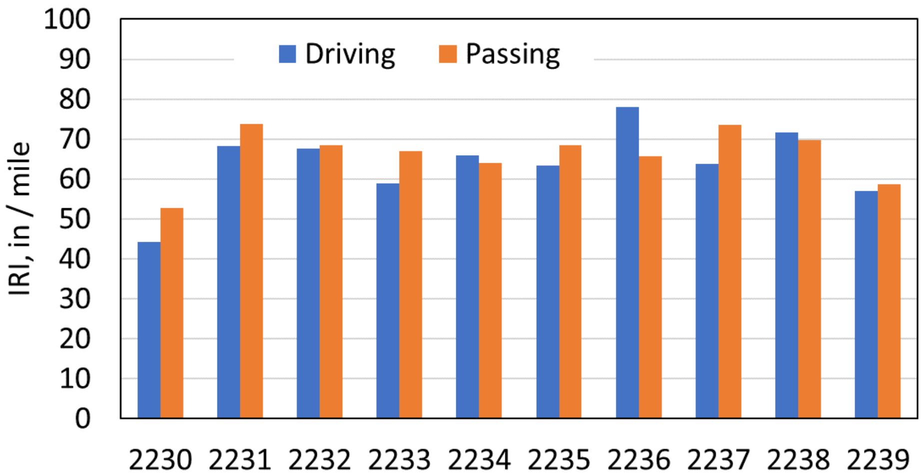
The impact of the MTD breakdown is shown in thermal map in Figure 13.10. After station 1223+00 the temperature of the mat strays below 290°F. Similar data and detailed maps for each paving layer were created but only this section is shown. A comprehensive report utilizing the construction technologies at MnROAD is being generated by the UNH team and will document the extent of all construction activities that may impact future performance.

Figure 13-10 Material Transfer Vehicle (MTD) Breakdown



International Roughness Index (IRI) was measured on the final HMA layers after construction. Figure 13.11 presents a summary of the IRI results.

Figure 13-11 IRI Measurements for Test Sections 2230 to 2231



13.5 Instrumentation and Sensors

Thermocouples were installed throughout the depth of the pavement structure in sections 2232, 2234, 2236, and 2238. Sections 2232, 2234, and 2236 had 12 strain gauges and 4 earthen pressure cells installed at the bottom of the asphalt to measure dynamic response under loading as show in Figures

13.12 and 13.13. All strain gauges were oriented in the longitudinal (travel) direction. Earthen pressure cells installed in 2016 construction at 18 in. below the surface were left in place. Moisture content and moisture potential sensors were also installed. This effort is covered under Chapter 3 of this report.

Figure 13-12 Sensor Layout (Plan View)

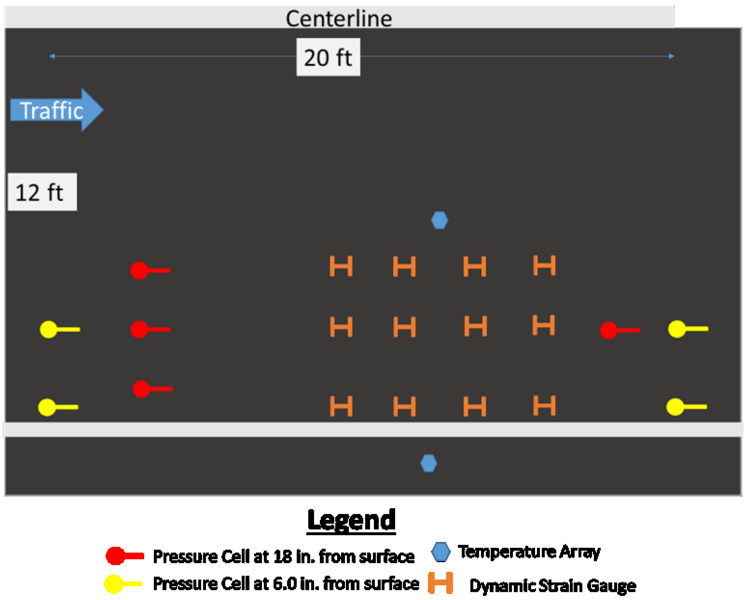
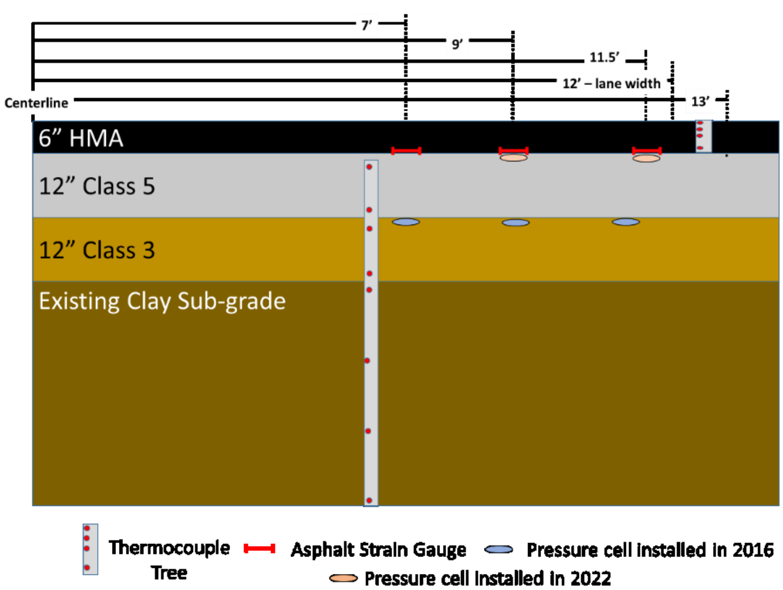


Figure 13-13 Cross-section with Instrumentation Locations



Chapter 14: Instrumentation and Performance Monitoring

14.1 Background

Characterizing pavement response to environmental and vehicle loads is the primary mission of the test sections at MnROAD. This is accomplished by gathering routine data from embedded instrumentation and a variety of performance monitoring tools over the life of each section. All the sections constructed during 2022 included instrumentation and will be monitored for a minimum of 3 years using various equipment. Table 14.1 shows the performance monitoring tests conducted and instrumentation devices installed.

Table 14-1 Performance Monitoring and Instrumentation Devices

Performance Monitoring	Seasonal Ride Quality (Pathway Van and LISA)
	Manual Distress Surveys
	Faultmeter
	MIRA
	Warping and Curling
	Friction
	Extracted Cores
	Falling Weight Deflectometer (FWD)
Instrumentation	Temperature
	Moisture
	Joint Opening (automated and manual)
	Strain (environmentally induced)
	Dynamic Strain
	Shape array accelerometer
	Maturity

The prescribed monitoring for each test section has been tailored to the research objectives of each study. This section provides a general summary of the monitoring being conducted and the frequency. It is not intended to be a comprehensive review of each activity. Further documentation on each activity can be found at www.dot.state.mn.us/mnroad/data/index.html.

14.2 Surface and Subsurface Characteristics Monitoring

Surface monitoring is comprised of visual distress surveys, automated distress and ride surveys, rutting, faulting measurements, warp and curl profiling, and friction measurements. This section focusses on documenting technologies that were used for the first time in MnROAD 2022 Construction. Technologies used in previous construction efforts and additional detailed information on these sensors can be found on MnROAD website.

On concrete sections, a MnROAD modified version of the Georgia Faultmeter is used to measure the amount of faulting between panels. Faulting measurements are taken at least twice per year (typically in the spring and fall) but the frequency may be increased if an increase in faulting is noticed. Friction is measured several times per year using a Dynatest locked-wheel skid trailer. Testing is done with a standard ribbed tire with the pavement in wet condition (water supplied by testing trailer) according to ASTM E274. Figure 14.1 shows a picture of the MnROAD faultmeter.

Figure 14-1 MnROAD Faultmeter

The Road Doctor Survey Van (RDSV) is an advanced non-destructive road survey technology currently being evaluated by MnDOT's Office of Road Research & Materials. The RDSV collects continuous surface and subsurface measurements by integrating state-of-the-art hardware and advanced software to process, synchronize, and visualize large and complex data. The system comprises eight different sensors, including a LIDAR laser scanner, a high-resolution 3D-accelerometer, two high-definition video cameras, a thermal camera, and three types of ground penetrating radar (GPR) technologies: GSSI 400 MHz ground-coupled (GC), GSSI 2 GHz horn antenna, and the 3D-Radar's step-frequency geoscope radar. All these sensors are linked to a single Global Position System (GPS) referencing system. This approach allows efficient synchronization and fusion of data from different sources and comprehensive root-cause investigation of pavement distress conditions. A photo of the device can be seen in Figure

14.1. Additional detailed information on this technology can be found on the Road Doctor website at https://www.dot.state.mn.us/materials/nde-stripping-evaluation/.

Figure 14-2 Road Doctor Survey Van

Dielectric (a.k.a. Density) Profiling Systems (DPS) is a means of collecting continuous dielectric measurements that have been used by various State Agencies as a means of evaluating compaction of freshly placed asphalt pavements. More recently, this has been the subject of a National Pooled Fund effort, "Continuous Asphalt Mixture Compaction Assessment using Density Profiling System (DPS) [TPF-5(443)], with the general objectives of further advancing the systems based on the needs from participants, supporting communication, providing training and technical assistance, and conducting marketing efforts to make industry aware of the current capabilities. For the Minnesota Department of transportation, with full implementation of paver mounted thermal profile systems (PMTP) as well as other intelligent construction technologies (ICT) like intelligent compaction (IC) the value ultimately comes down to the ability to geospatially assess the DPS density results and compare with other ICT giving insight into improved practices leading to process improvements for consistent properly compacted longer lasting pavements that improved the sustainability of the road network. A photo of the device can be seen in Figure 14.2. Additional detailed information on this technology can be found on the DPS website at mndot.gov/materials/dps.

Figure 14-3 Dielectric Profile System (DPS)

14.3 Environmental and Static Response Sensors

Environmental conditions are captured by thermocouples and moisture sensors within the pavement sections as well as by external weather stations. Environmental response sensors measure the movement within the pavement structure that result from the environmentally induced responses. These sensors are used in concrete test sections and include joint opening sensors and vibrating wire strain gauges. This section focusses on documenting technologies that were used for the first time in MnROAD 2022 Construction. Technologies used in previous construction efforts and additional detailed information on these sensors can be found on MnROAD website.

MnROAD has two weather stations to record environmental conditions at the site. The stations record air temperature, atmospheric pressure, precipitation, relative humidity, solar radiation, wind speed, and wind direction.

TEROS 10 sensors provide raw value in millivolts which are then converted to volumetric water content by calibration equations specifically developed for the materials. TEROS 10 uses stainless steel needles to measure the apparent dielectric permittivity (ε) of the surrounding medium by using the electromagnetic field. The stainless-steel needles are supplied by a 70 MHz oscillating wave to charge the surrounding medium (base, subbase, subgrade materials) according to the dielectric of the material. The microprocessor measures the charging time which is specific to the material and proportional to the dielectric of the material and outputs the raw value which is then converted to the volumetric water content by a calibration equation developed for the material. More detail can be found in METER Group TEROS 10 Manual.

TEROS 21 sensors consist of two engineered ceramic discs sandwiched between stainless steel screens and the circuit board which helps measure the matric suction through the solid matrix equilibration technique which introduces a solid material (ceramic discs) with a known soil water characteristics curve (relationship between the volumetric water content and matric suction) into the soils and allow hydraulic equilibrium between the materials and soil according to the Second Law of Thermodynamics.

As a result, the matric suction of the soil is obtained through hydraulic equilibrium. Like TEROS 10 sensors, TEROS 21 sensors also use the dielectric permittivity properties of the materials. TEROS 21 sensors originally measure the dielectric permittivity of the ceramic discs which are then converted to volumetric water content. Then matric suction of the ceramic discs is inferred from volumetric water content using the soil water characteristics curve of the ceramic discs which is in equilibrium with the surrounding soil. More detailed information can be found in METER Group, TEROS 21 manual.

Figure 14.4 presents pictures and schematics of both moisture sensors.

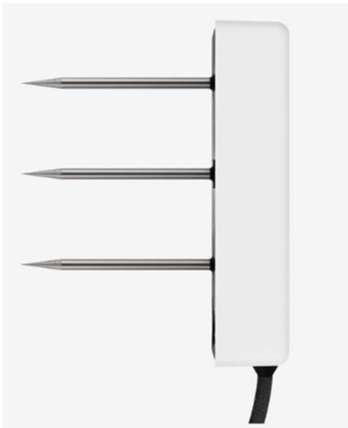
Figure 14-4 Moisture Sensors Installed (a) TEROS 10 Volumetric Water Content (b) TEROS 21 Matric Suction

(a)

(b)

The TEROS 12 moisture sensor consists of an enclosed epoxy body with three stainless steel prongs that measure the apparent dielectric permittivity and temperature. These sensors provide a raw value in millivolts which are then converted to volumetric water content. The volumetric water content range is dependent on the media the sensor is measuring. This requires a specific calibration equation to be developed for each material. More detail can be found in METER Group TEROS 12 Manual. Figure 14.5 shows a picture of the TEROS 12 sensor.

Figure 14-5 Teros 12 Moisture Sensors Installed to Measure Temperature and Volumetric Water Content



A new type of sensor system was developed by MnROAD researchers to directly measure the movement that occurs at the joints between concrete panels. A linear position sensor (OMEGA LDI-119-025-A010S) is used to measure the change in joint opening due to environmental conditions. A block out apparatus was installed prior to paving to create the cavity where the sensor would be installed and to secure bolts into the slabs, as shown in Figure 14.6. After paving, the block outs were removed, and the final installation of the sensors were performed. The sensors are suspended and fixed by two rods in a cavity that spans across the joint, as shown in Figure 14.7. As the panels expand and contract, the sensor will show a response output change in voltage. Each rod is fixed to one side of the joint.

Figure 14-6 Schematic Diagram of a Joint Gauge (JG) Sensor

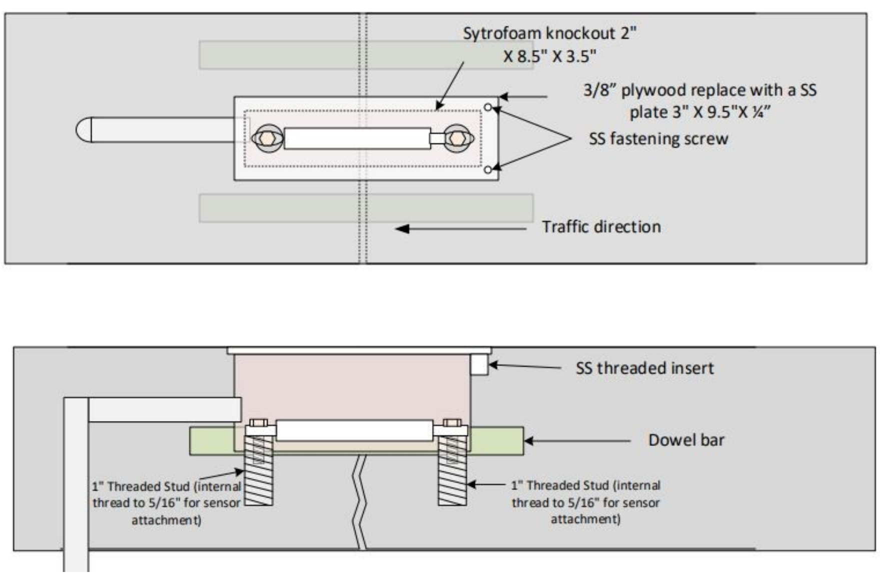


Figure 14-7 Joint Gauge (JG) Block Out

Another new sensor developed by MnROAD researchers measures concrete slab movement in the vertical direction. This sensor consists of a magneto-inductive displacement sensor (Micro Epsilon MDS-45) enclosed in a plastic pipe that is fixed to the base material. A magnet connected to a bolt is fixed to the concrete slab and positioned directly above the sensor, as shown in Figure 14.8. The bolt was reinforced by two dowels connected to a thin metal wire to prevent damage during paving. A piece of fabric was secured at the base of the bolt to prevent a bond between the slab and the base of the sensor, as shown in Figure 14.9. Slab movement generates a change in sensor output voltage through magnetic induction which corresponds to a known displacement.

Figure 14-8 Schematic Diagram of a Magnetic Induction (MI) Sensor

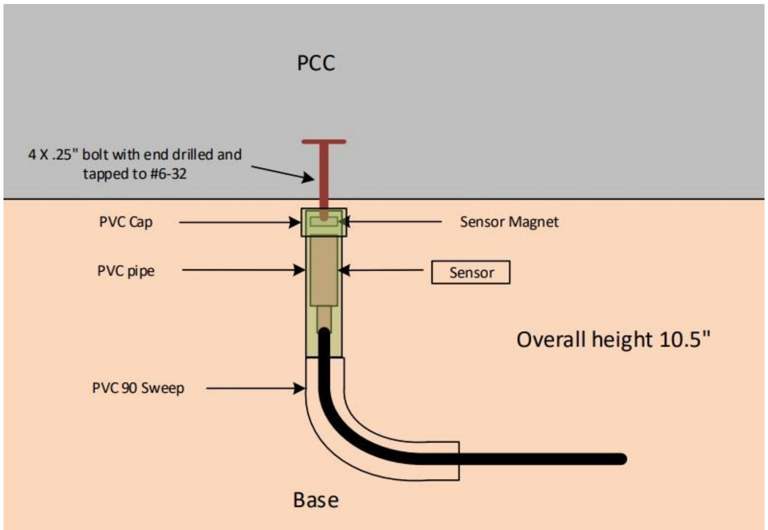


Figure 14-9 Magnetic Induction Sensor Installed in Base Material

The Shape Array sensors comprise a linear sequence of instrumented rigid stainless steel tube segments interconnected by flexible joints made from hydraulic hoses, allowing for bending, as shown in Figure 14.10. Each rigid segment contains three Micro-Electro-Mechanical Systems (MEMS) accelerometers that measure the accelerations of the segments relative to gravity in the x, y, and z directions, enabling measurement of tilt in each direction. Multiplying the tilt by the known length of each segment, relative deformation can be calculated from one end of the segment to the other. The segmental displacements can then be summed from a fixed reference point in the array to calculate the deflected shape of the entire SAA. In test sections 2228 and 2229, SAAs consisting of 10 segments were used, with each segment being 19.7 inches (50 cm) in length. Figure 14.11 presents the wiring diagram for SAA. The SAA232 is used to connect a single Shape Array to a single COM port on a Data Logger.

Figure 14-10 Shape Array Accelerometer (SAA)

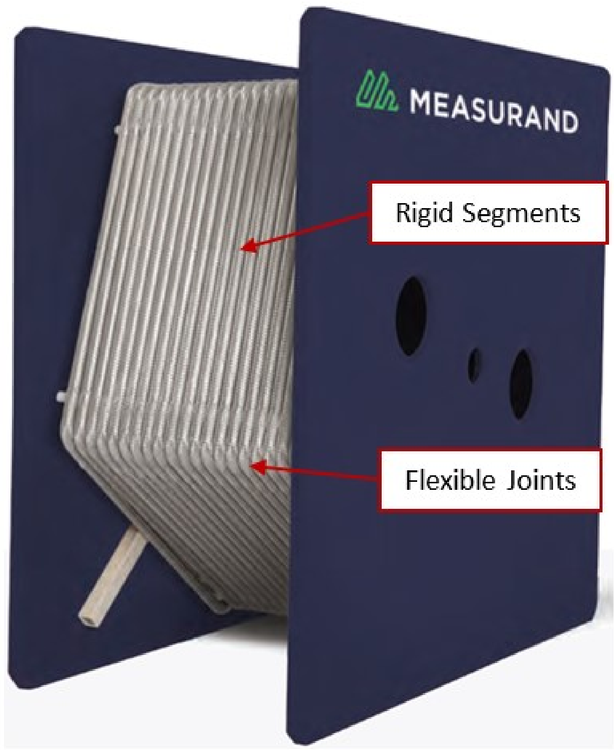
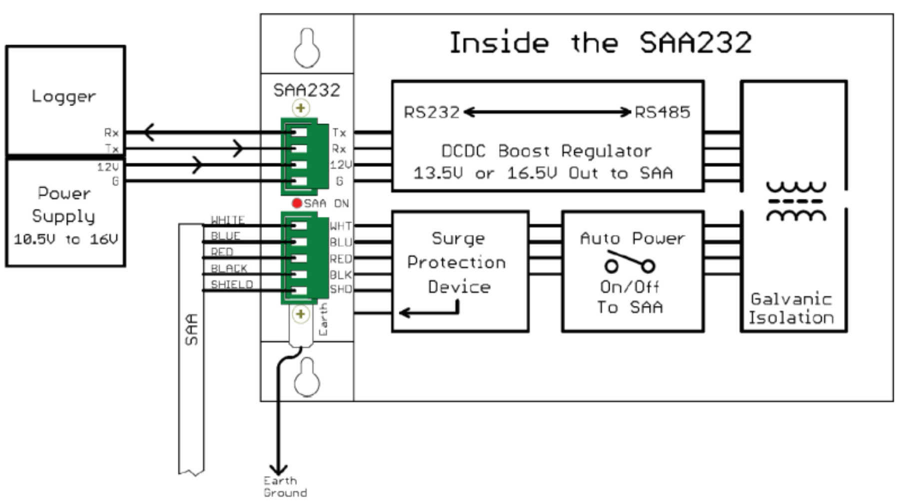


Figure 14-11 Wiring Diagram for Shape Array Accelerometer (SAA)



14.4 Dynamic Pavement Response Monitoring

The dynamic sensors included in asphalt test sections are the pressure cells, asphalt strain gauges and shape array accelerometer. Dynamic responses in concrete test sections are captured by the concrete strain gauges, accelerometers, and pressure plates.

Concrete dynamic strain gauges were installed to measure the dynamic response to loading. The gauges used were Geodaq AST200 and BDI Concrete Embedded Strain Transducer (BDI CEST350) These gauges are typically placed at the top and bottom of the concrete. A schematic of a typical gauge setup is shown in Figure 14.12.

Figure 14-12 Schematic of Concrete Dynamic Load Strain Gauge

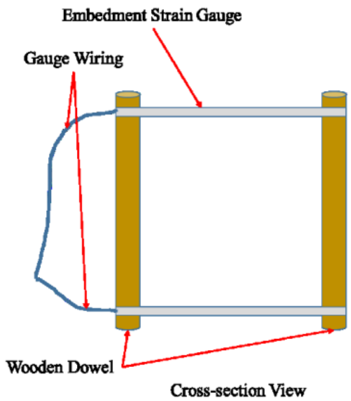


Figure 14.13 shows the setup with fiber glass dowels that were used to hold the gauges in position during paving. Data will be collected from these sensors during dynamic load testing of concrete sections. These gauges are referred to as “CE” in MnROAD data tables.

Figure 14-13 Concrete Embedded Strain Gauges used in MnROAD 2022 Construction

Dynamic pavement response data are collected four times per year (early spring, late spring, summer, and fall) to measure how the pavements are responding to vehicle loads over time. The MnROAD truck, loaded to 80,000 lbs total weight, is used for vehicle load testing data generated on NRRA test sections. Load responses are captured at targeted truck speeds of 5 and 40 mph. The testing time (morning or afternoon) is varied to ensure that load responses are gathered at a variety of pavement temperatures.

14.5 Concrete Curing and Hardening Sensors

Wireless concrete maturity sensors were installed to monitor concrete curing and hardening. The SmartRock maturity sensors was used for this construction effort. This sensor collects temperature data from two points independently: (1) the probe at the tip of the cable and (2) from inside the sensor body. These sensors have a reading range from -22 to +181°F (-30 to 85°C) with a measurement accuracy and resolution of ±1.8°F (±1°C) and ±0.18°F (±0.1°C), respectively. It has a battery life of up to 60 days and records data every 15 minutes with a wireless signal range of up to 40 ft (12m). Figure 14.14 presents maturity sensor.

Figure 14-14 GiaTec SmartRock Concrete Maturity Meter

Chapter 15: Summary and Future Work

For Phase II, NRRA goals are focused on improving long-term sustainability of our national pavement system and studying and promoting intelligent construction technologies. The 2022 construction season at MnROAD saw construction of 39 new and unique test sections and repair of 6 test sections. These sections were planned and designed by NRRA teams to address NRRA high-priority research topics and achieve Phase II goals.

During construction, numerous field and laboratory tests were performed, and many pieces of data were collected. MnROAD personnel will continue to monitor the performance of the sections until either the pavement sections fail, or it is determined no more research value can be obtained from them. The data generated from these efforts will be used by researchers performing work for each specific project.

This report details development, design, and construction of each research project and the test sections supporting them. Individual study details are left to future reports generated by the individual research contracts and their respective teams.

Interested readers are encouraged to stay up to date with the latest results of each MnROAD NRRA research team at mndot.gov/mnroad/nrra

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Appendix A
Cold in Place Recycle (CIR) Mix Design Report

August 8, 2022

Midstate Reclamation and Trucking
21955 Grenada Ave
Lakeville, MN 55044

Attn: Mike Swing <mikes@midstatecompanies.com>
CC: Emil Bautista (MnDOT) <Emil.Bautista@state.mn.us>
RE: Cold In-place Recycling Mix Design with Emulsion
I-94 MnROAD 2022 Construction, Cell 1-2
AET Report No. P-0014222B

Dear Mr. Swing,

American Engineering Testing, Inc. (AET) is pleased to present to Midstate Reclamation and Trucking ("Midstate") a Cold In-place Recycling (CIR) Engineered Emulsion (EE) Mix Design for the planned Cell 1-2 test sections along the Minnesota Road Research facility (MnROAD) in Wright County, Minnesota. This cover letter to our mix design reports summarizes the laboratory information.

MATERIAL INFORMATION

Minnesota Department of Transportation (MnDOT) engineers provided AET with a binder sample labeled "CIRTEC" and core samples from existing test sections at MnROAD. Cell 1-2 materials were cores and millings from the existing Cells 101 and 201. MnDOT had previously milled the existing surface, and MnDOT estimated that 2 to 2.5 inches of HMA remain. MnDOT intends to reclaim the remaining HMA surface, with added millings, into a 3-inch CIR layer. Therefore, AET trimmed the top of provided cores to produce samples roughly 2 inches in thickness. These cores were processed and supplemented with millings supplied by MnDOT.

MIX DESIGN SUMMARY AND MIX PERFORMANCE

AET performed the mix design according to specifications described in Section 5-692.291 of the 2021 MnDOT *Grading and Base Manual*, which we understand to be the specification for this project.

- The material was 100% RAP obtained from cores and millings provided to AET by MnDOT. The cores were frozen and crushed to provide the material for the mix design. The combined reclaimed materials were processed to resemble the "Medium" target gradation described in the MnDOT *Grading and Base Manual*. The final gradation of processed materials is provided in the attached CIR mix design report.

550 Cleveland Avenue North | Saint Paul, MN 55114
Phone (651) 659-9001 | (800) 972-6364 | Fax (651) 659-1379 | teamAET.com | AA/EEO

- The results for the RAP Coating Test (AASHTO T 59 Modified) were "Good."
- Based on a request from MnDOT, AET prepared mix design samples using 0.5% cement filler.
- We performed mix testing at 1.7%, 2.2%, 2.7%, and 3.2% EE contents.
- Mixtures at all tested EE contents met MnDOT requirements for performance in dry Marshall stability, retained stability, and raveling.
- The specification requires that low-temperature creep and tensile strength tests be performed according to AASHTO T 322. These tests were performed at 2.2% EE content at -4°F, -22°F, and -40°F. Analysis of low-temperature creep data identified the critical pavement temperature as -20°F.
- For this mixture, air void content (AVC) ranges between 16.3% and 12.8%.

OPTIMUM FOAMED ASPHALT CONTENT

The CIR mix designs met the MnDOT performance specification at all tested EE contents. We judge that 2.2% EE content provides an optimal combination of performance and cost. While we observe that added EE benefited the laboratory mixtures by reducing AVC, improvements to mix performance in Marshall stability are arguable at levels beyond 2.2% EE.

Finally, your practices may include adjusting the emulsion content downward to compensate for increasing pavement temperatures (over 100°F), which may affect stability characteristics of the reclaimed mix during construction. Our mix design report provides more detail on these and other adjustments.

ADDITIONAL TESTS USING EMULSION MODIFIED WITH REJUVENATOR

Following the initial round of mix design testing in the laboratory, AET provided a preliminary mix design report to Midstate and MnDOT for review. Based on the results of that report, MnDOT requested that Meigs develop the amount of rejuvenator to add to the EE for Cells 1-2. This rejuvenator was delivered to AET, which was used to combine at 98% EE and 2% rejuvenator to produce six Marshall stability specimens to investigate retained stability in mixtures using the specially modified EE. These tests determined that the modification of the EE appears to have the following effects on the CIR mixtures.

- Increased stiffness in dry (unconditioned) Marshall samples by 17%
- Negligible effect on wet (conditioned) Marshall samples (reduction by 3%)
- Decreased retained stiffness ratio in Marshall stability from 0.88 to 0.73.
- Increased air void content from 15.1% to 16.8%

As noted above, these conclusions are based on limited laboratory investigations of mixtures using the modified EE. Additional tests may provide more information on the performance of CIR mixtures featuring asphalt rejuvenator products.

Please contact us if you have questions or require additional information.

Sincerely,

American Engineering Testing

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Principal Civil Engineer
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651-999-1789

Jacob O. Michalowski, PE
Manager, Pavement Department
jmichalowski@amengtest.com
651-283-2481

Attachments:

a. Engineered Emulsion CIR Mix Design, AET Mix Design Report (4 Pages)

AMERICAN ENGINEERING TESTING	AET P-0014222	CIR MIX DESIGN SUMMARY

Client Midstate / MnDOT

Attn Mike Swing
AET Contact Jacob Michalowski

Project	MnROAD Cell 1-2	From	--
		To	--

Target Emulsion Content	2.2%
Gal/SY (Assumes 3 in depth)	0.77
Target Moisture Content	2.0%

Relevant Specification *2021 MnDOT Grading & Base Manual, CIR EE Mix Design*

Materials

MnDOT provided emulsion labeled "CIRTEC" and Type IL cement filler. Bituminous cores were collected from the MnROAD section by MnDOT and provided to AET. AET trimmed and crushed cores to resemble MnDOT field operations and target gradation. The CIR mix was composed of 100% RAP (produced by crushing frozen cores). Cement filler (0.5% by dry weight of materials) was used for all four EE contents. The rejuvenator-modified EE was tested in Marshall stability samples at 2.2% EE

Mix Preparation

Sampling and testing was performed according to the specification for CIR mix designs using engineered emulsion stabilization in the MnDOT specification cited above. CIR specimens were prepared using a gyratory compactor at internal compaction angle of 1.16 degrees and 30 gyrations.

Comments from Testing

The mixes exceeded all spec performance limits at EE contents tested. Low-temperature tests of the mixture were performed at 2.2% EE for information only, as required by the relevant specification

Special Notes

Field adjustments to the emulsion content may be required:

1) The emulsion content was determined based on the laboratory manufactured gradation. If reclaiming operations cannot be adjusted to create field materials resembling the target gradation, we recommended that the as-produced mixture be tested in the laboratory.

2) If the temperature of the existing pavement surface during the reclaiming operation is above 100 deg F, the emulsion content may need to be reduced to maintain workability.

3) The "target moisture content" indicated above is moisture added to processed millings in our lab procedure, which assumed "free" or pre-wet water of 2.0%. In the field, this added water would correspond with water added at the milling head.

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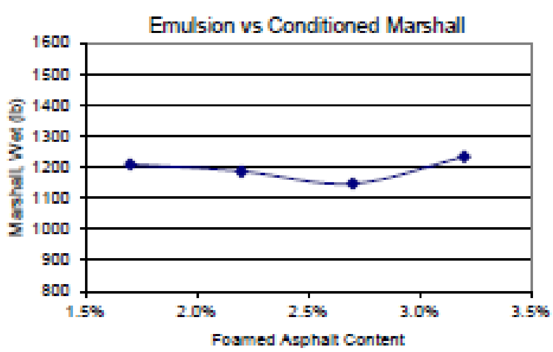
AET P-0014222	Midstate / MnDOT	COLD IN-PLACE RECYCLED MIX DESIGN (EE) TEST RESULTS

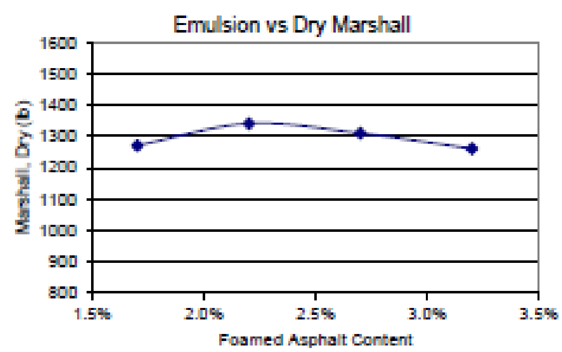
Sample number MnROAD Cell 1-2 **Date** 8/8/2022

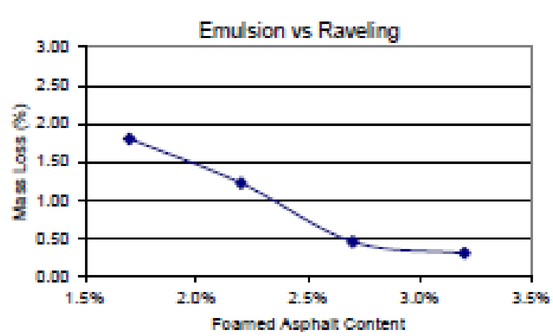
Material	RAP	Base	Bitumen	Filler
Location / Source	Cores/Millings	--	MnDOT Provided	MnDOT Provided
Extracted Binder (%)	3.7	--	*"CIRTEC"*	*0.5% Type IL Cem*
Prewet Water (%)	2.0			

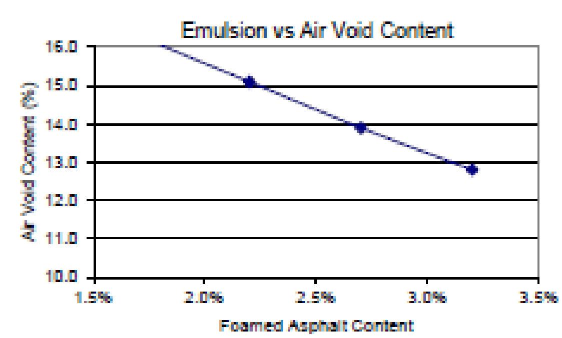
Emulsion treated material characteristics

					Rejuvenator	*Comments*
Emulsion content	1.7%	2.2%	2.7%	3.2%	2.2% R	
Filler added	0.5%	0.5%	0.5%	0.5%	0.5%	
Gradation	*Med*	*Med*	*Med*	*Med*	*Med*	*Target blend*
Bulk Density, lb/ft3	132.0	132.8	133.7	134.4	130.1	
Bulk Spec Grav (Gmb)	2.119	2.132	2.146	2.158	2.088	
Theo Max Spec Grav (Gmm)	2.530	2.511	2.493	2.475	2.511	
Air voids (%)	16.3	15.1	13.9	12.8	16.8	
Marshall Stability, soaked (lb)	1209	1186	1147	1233	1155	
Marshall Stability, dry (lb)	1271	1341	1310	1261	1574	*Min 1250*
Retained stability	0.95	0.88	0.88	0.98	0.73	*Min 0.70*
Critical low temp, pavement (F)	--	-20	--	--	--	*AASHTO T 322, see results*
Raveling, Mass Loss (%)	1.80	1.22	0.45	0.30	--	*Max 2%*

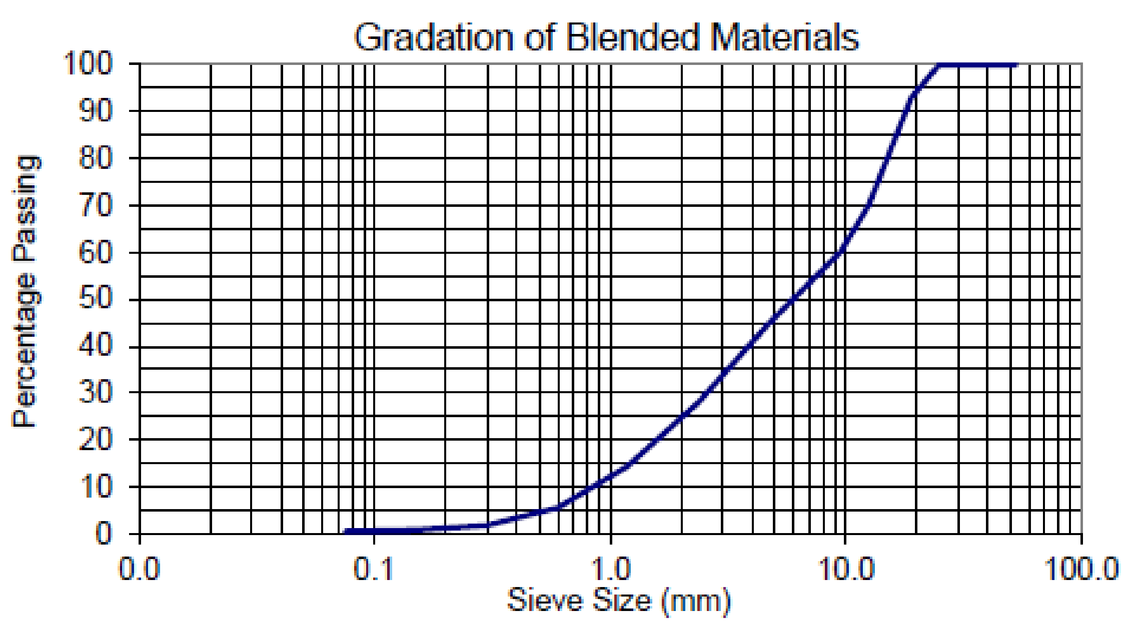








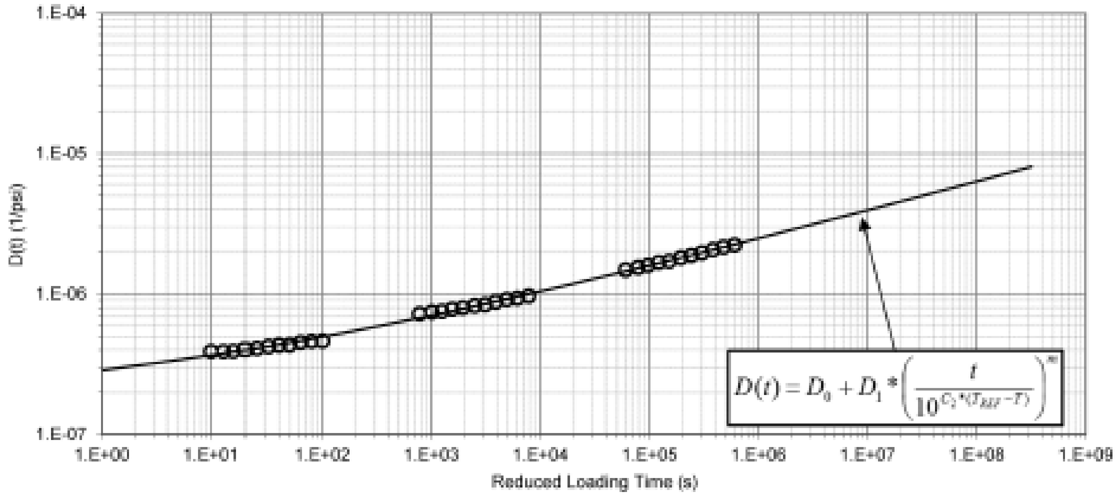
AET P-0014222	COLD IN-PLACE SIEVE ANALYSIS					ASTM C136		
Client		Midstate / MnDOT						
Project		MnROAD Cell 1-2						
		1		2		3		
Location		Processed Cores						Total Percent in Blend
Description		RAP						
Sample No.		1						
Date sampled		--						
Percentage in Blend		100						100
Mass of sample (g)								
Sieve size		Weight	%	Weight	%	Weight	%	Combined
mm	inch	Retained	Pass.	Retained	Pass.	Retained	Pass.	Grading
53.0	2		100.0					100.0
37.5	1½		100.0					100.0
25.0	1		100.0					100.0
19.0	¾		93.0					93.0
12.5	½		70.0					70.0
9.5	⅜		60.0					60.0
4.75	# 4		45.0					45.0
2.36	# 8		28.0					28.0
2.00	# 10							
1.18	# 16		14.3					14.3
0.600	# 30		5.6					5.6
0.425	# 40							
0.300	# 50		1.8					1.8
0.150	# 100		0.8					0.8
0.075	# 200		0.6					0.6



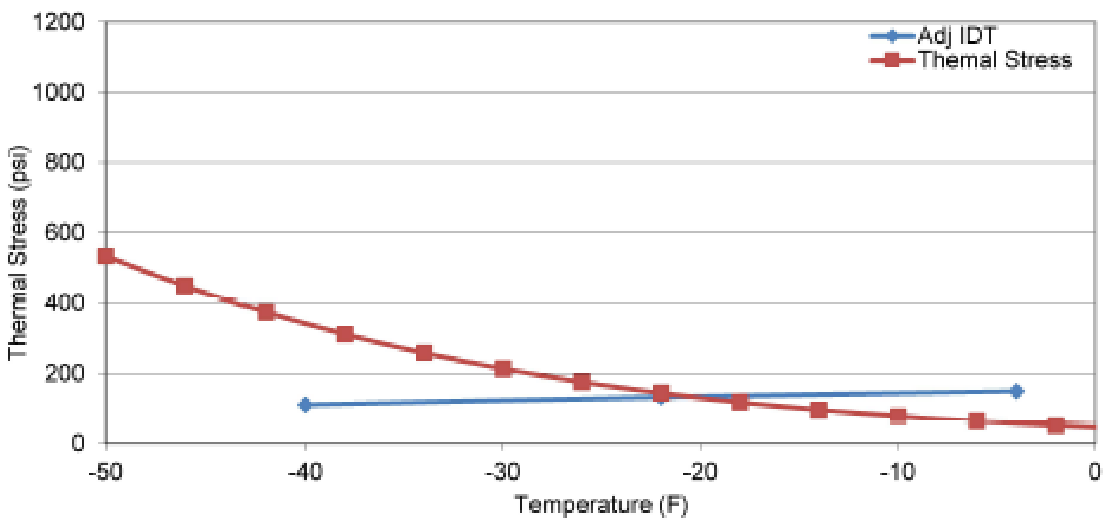
AET P-0014222	Strength and Creep Compliance Using Indirect Tensile (IDT) Test	AASHTO T 322

Client	Midstate / MnDOT								
Project	MnROAD Cell 1-2								
Emulsion Content		2.2%							
Temperature (F)	-4	-22	-40	-4	-22	-40	-4	-22	-40
IDT Strength (psi)	199.2	176.5	148.0	--	--	--	--	--	--
Adjusted IDT (psi)	149.4	132.4	111.0	--	--	--	--	--	--

Creep Compliance @ Emulsion Content **2.20%**



Critical Low Temperature @ Emulsion Content **2.20%**



August 8, 2022

Midstate Reclamation and Trucking
21955 Grenada Ave
Lakeville, MN 55044

Attn: Mike Swing <mikes@midstatecompanies.com>
CC: Emil Bautista (MnDOT) <Emil.Bautista@state.mn.us>
RE: Cold In-place Recycling Mix Design with Emulsion
I-94 MnROAD 2022 Construction, Cell 7-8
AET Report No. P-0014222A

Dear Mr. Swing,

American Engineering Testing, Inc. (AET) is pleased to present to Midstate Reclamation and Trucking ("Midstate") a Cold In-place Recycling (CIR) Engineered Emulsion (EE) Mix Design for the planned Cell 7-8 test sections along the Minnesota Road Research facility (MnROAD) in Wright County, Minnesota. This cover letter to our mix design reports summarizes the laboratory information.

MATERIAL INFORMATION

Minnesota Department of Transportation (MnDOT) engineers provided AET with a binder sample labeled "CIRTEC" and core samples from existing test sections at MnROAD. Cell 7-8 materials were cores from the existing Cell 4, which has a 3-inch HMA surface layer on an 8-inch SFDR base layer. MnDOT intends to reclaim the top four inches of the SFDR layer into a 4-inch CIR layer. Therefore, AET trimmed the provided cores to provide a 4-inch sample of the top of the SFDR layer for mix design samples.

MIX DESIGN SUMMARY AND MIX PERFORMANCE

AET performed the mix design according to specifications described in Section 5-692.291 of the 2021 MnDOT *Grading and Base Manual*, which we understand to be the specification for this project.

- The material was 100% RAP obtained from cores and millings provided to AET by MnDOT. The cores were frozen and crushed to provide the material for the mix design. The combined reclaimed materials were processed to resemble the "Medium" target gradation described in the MnDOT *Grading and Base Manual*. The final gradation of processed materials is provided in the attached CIR mix design report.
- The results for the RAP Coating Test (AASHTO T 59 Modified) were "Good."

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- Based on a request from MnDOT, AET prepared mix design samples using 0.5% cement filler.
- We performed mix testing at 1.2%, 1.7%, 2.2%, 2.7%, and 3.2% EE contents.
- Mixes at 1.2% and 1.7% EE content exceeded MnDOT requirements for dry Marshall stability of 1250 lb and retained stability of 0.70 (or 70%).
- Because the sets at 1.2% were added to investigate lower EE contents, raveling tests were not performed. We do not judge this to be a design concern as all other mixtures met MnDOT raveling requirements.
- The specification requires that low-temperature creep and tensile strength tests be performed according to AASHTO T 322. These tests were performed at 1.7% EE content at -4°F, -22°F, and -40°F. Analysis of low-temperature creep data identified the critical pavement temperature as -23°F.
- For this mixture, air void content (AVC) ranges between 15.8% and 11.1%.

OPTIMUM FOAMED ASPHALT CONTENT

The CIR mix designs met the MnDOT performance specification at 1.2% and 1.7% emulsion. We judge that 1.7% emulsion provides an optimal combination of performance in strength/stiffness performance and long-term durability. The following items provide more information on our selection of an optimum emulsion content.

- The mixtures at 2.2%, 2.7%, and 3.2% EE content did not meet MnDOT requirements for dry Marshall stability.
- The addition of 0.5% FAC from 1.2% to 1.7% EE content reduced AVC from 15.8% to 12.9%. We judge this reduction in AVC to be very beneficial to the long-term durability of the CIR structural layer in terms of resistance to environmental effects.

Finally, your practices may include adjusting the emulsion content downward to compensate for increasing pavement temperatures (over 100°F), which may affect stability characteristics of the reclaimed mix during construction. Our mix design report provides more detail on these and other adjustments.

ADDITIONAL TESTS USING EMULSION MODIFIED WITH REJUVENATOR

Following the initial round of mix design testing in the laboratory, AET provided a preliminary mix design report to Midstate and MnDOT for review. Based on the results of that report, MnDOT requested that Meigs develop the amount of rejuvenator to add to the EE for Cells 7-8. This rejuvenator was delivered to AET, which was used to combine at 98% EE and 2% rejuvenator to produce six Marshall stability specimens to investigate retained stability in mixtures using the specially modified EE. These tests determined that the modification of the EE appears to have the following effects on the CIR mixtures.

- Increased stiffness in dry (unconditioned) Marshall samples by 10%
- Negligible effect on wet (conditioned) Marshall samples (reduction by 1%)
- Decreased retained stiffness ratio in Marshall stability from 0.85 to 0.77.
- Increased air void content from 13.8% to 15.7%

As noted above, these conclusions are based on limited laboratory investigations of mixtures using the modified EE. Additional tests may provide more information on the performance of CIR mixtures featuring asphalt rejuvenator products.

Please contact us if you have questions or require additional information.

Sincerely,

American Engineering Testing

Derek Tompkins, PhD, PE
Principal Civil Engineer
dtompkins@teamaet.com
651-999-1789

Jacob O. Michalowski, PE
Manager, Pavement Department
jmichalowski@amengtest.com
651-283-2481

Attachments:

a. Engineered Emulsion CIR Mix Design, AET Mix Design Report (4 Pages)

AMERICAN ENGINEERING TESTING	**AET P-0014222**	**CIR MIX DESIGN SUMMARY**

Client	**Midstate / MnDOT**	**Attn**	Mike Swing
		AET Contact	Jacob Michalowski

Project	***MnROAD Cell 7-8***	*From*	--
		To	--

Target Emulsion Content	*1.7%*
Gal/SY (Assumes 4 in depth)	*0.79*
Target Moisture Content	*2.0%*

Relevant Specification *2021 MnDOT Grading & Base Manual, CIR EE Mix Design*

Materials

MnDOT provided emulsion labeled "CIRTEC" and Type IL cement filler. Bituminous cores were collected from the MnROAD section by MnDOT and provided to AET. AET trimmed and crushed cores to resemble MnDOT field operations and target gradation. The CIR mix was composed of 100% RAP (produced by crushing frozen cores). Cement filler (0.5% by dry weight of materials) was used at all EE contents tested. The rejuvenator-modified EE was tested in Marshall stability samples at 1.7% EE

Mix Preparation

Sampling and testing was performed according to the specification for CIR mix designs using engineered emulsion stabilization in the MnDOT specification cited above. CIR specimens were prepared using a gyratory compactor at internal compaction angle of 1.16 degrees and 30 gyrations.

Comments from Testing

The mixes exceeded all spec performance limits at 1.2% and 1.7%. Low-temperature tests of the mixture were performed at 1.7% EE for information only, as required by the relevant specification

Special Notes

Field adjustments to the emulsion content may be required:

1) The emulsion content was determined based on the laboratory manufactured gradation. If reclaiming operations cannot be adjusted to create field materials resembling the target gradation, we recommended that the as-produced mixture be tested in the laboratory.

2) If the temperature of the existing pavement surface during the reclaiming operation is above 100 deg F, the emulsion content may need to be reduced to maintain workability.

3) The "target moisture content" indicated above is moisture added to processed millings in our lab procedure, which assumed "free" or pre-wet water of 2.0%. In the field, this added water would correspond with water added at the milling head.

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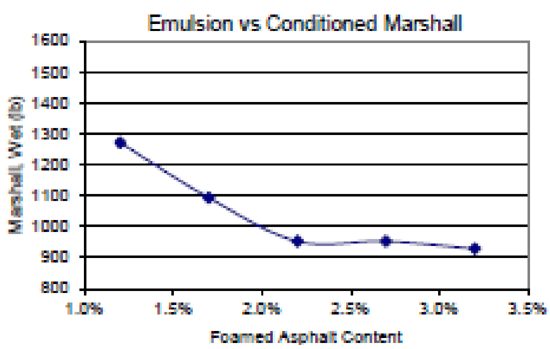
AET P-0014222	Midstate / MnDOT	COLD IN-PLACE RECYCLED MIX DESIGN (EE) TEST RESULTS

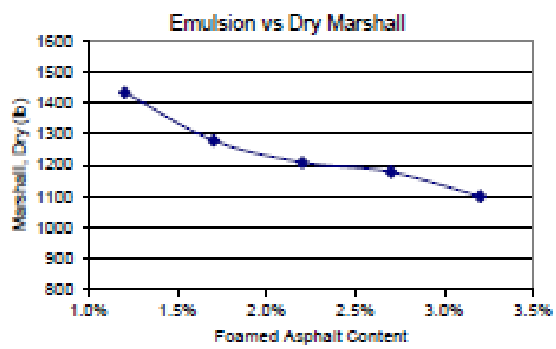
Sample number MnROAD Cell 7-8 **Date** 8/8/2022

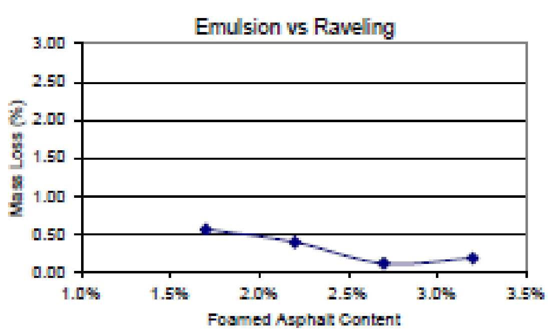
Material	RAP	Base	Bitumen	Filler
Location / Source	Roadway	--	MnDOT Provided	MnDOT Provided
Extracted Binder (%)	4.7	--	*"CIRTEC"*	*0.5% Type IL Cem*
Prewet Water (%)	2.0			

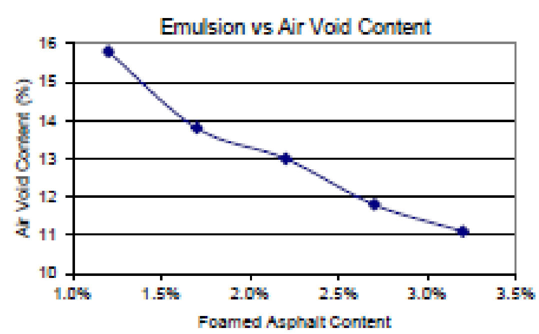
Emulsion treated material characteristics

						Rejuvenator	*Comments*
Emulsion content	1.2%	1.7%	2.2%	2.7%	3.2%	1.7% R	
Filler added	0.5	0.5%	0.5%	0.5%	0.5%	0.5%	
Gradation	*Med*	*Med*	*Med*	*Med*	*Med*	*Med*	*Target blend*
Bulk Density, lb/ft3	130.4	132.5	132.8	133.6	133.8	130.6	
Bulk Spec Grav (Gmb)	2.093	2.127	2.132	2.145	2.147	2.096	
Theo Max Spec Grav (Gmm)	2.485	2.467	2.450	2.433	2.416	2.487	
Air voids (%)	15.8	13.8	13.0	11.8	11.1	15.7	
Marshall Stability, soaked (lb)	1271	1093	953	953	929	1085	
Marshall Stability, dry (lb)	1434	1279	1209	1178	1100	1411	*Min 1250*
Retained stability	0.89	0.85	0.79	0.81	0.84	0.77	*Min 0.70*
Critical low temp, pavement (F)	--	-23	--	--	--	--	*T 322*
Raveling, Mass Loss (%)	--	0.56	0.39	0.11	0.18	--	*Max 2%*







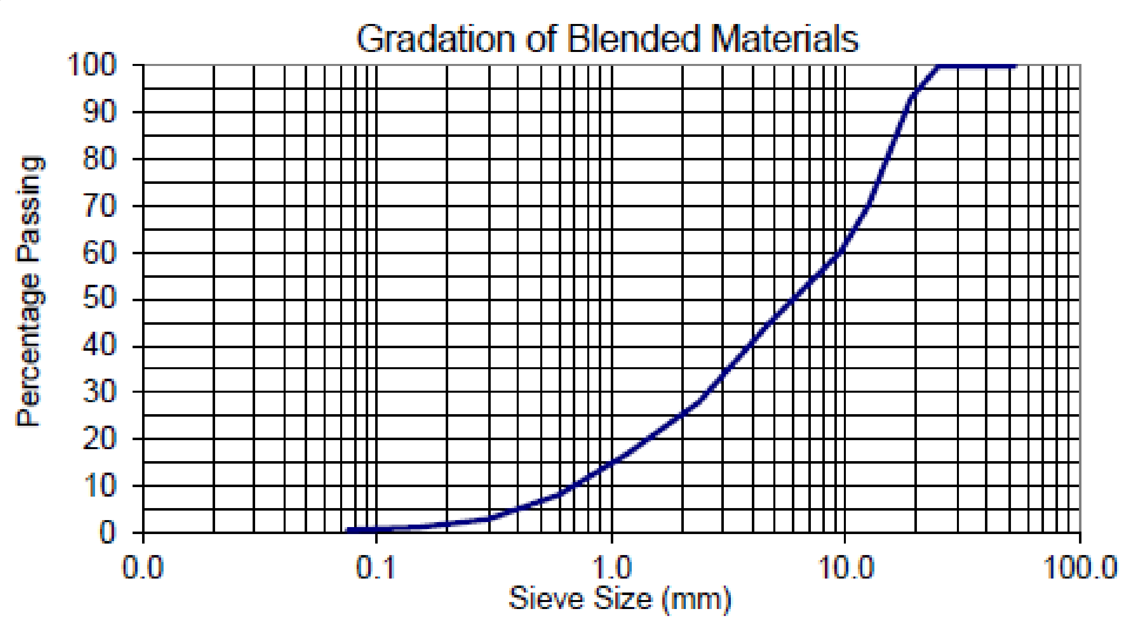


AET P-0014222	COLD IN-PLACE SIEVE ANALYSIS	ASTM C136

Client	Midstate / MnDOT
Project	MnROAD Cell 7-8

	1	2	3	Total Percent in Blend
Location	Processed Cores			
Description	RAP			
Sample No.	1			
Date sampled	--			
Percentage in Blend	100			100
Mass of sample (g)				

Sieve size		1		2		3		
mm	inch	Weight Retained	% Pass.	Weight Retained	% Pass.	Weight Retained	% Pass.	Combined Grading
53.0	2		100.0					100.0
37.5	1½		100.0					100.0
25.0	1		100.0					100.0
19.0	¾		93.0					93.0
12.5	½		70.0					70.0
9.5	⅜		60.0					60.0
4.75	# 4		45.0					45.0
2.36	# 8		27.9					27.9
2.00	# 10							
1.18	# 16		17.0					17.0
0.600	# 30		8.1					8.1
0.425	# 40							
0.300	# 50		2.9					2.9
0.150	# 100		1.1					1.1
0.075	# 200		0.6					0.6

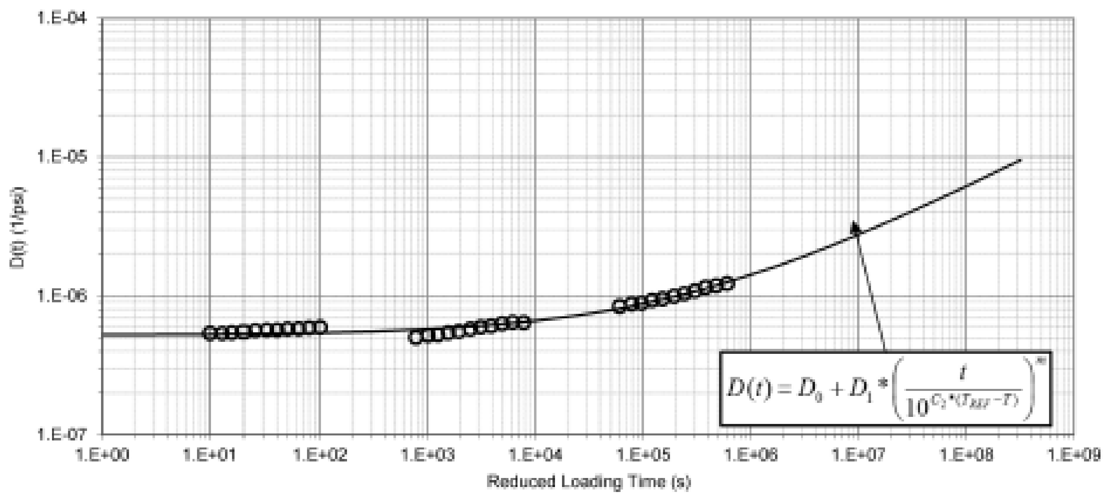


AET P-0014222	Strength and Creep Compliance Using Indirect Tensile (IDT) Test	AASHTO T 322

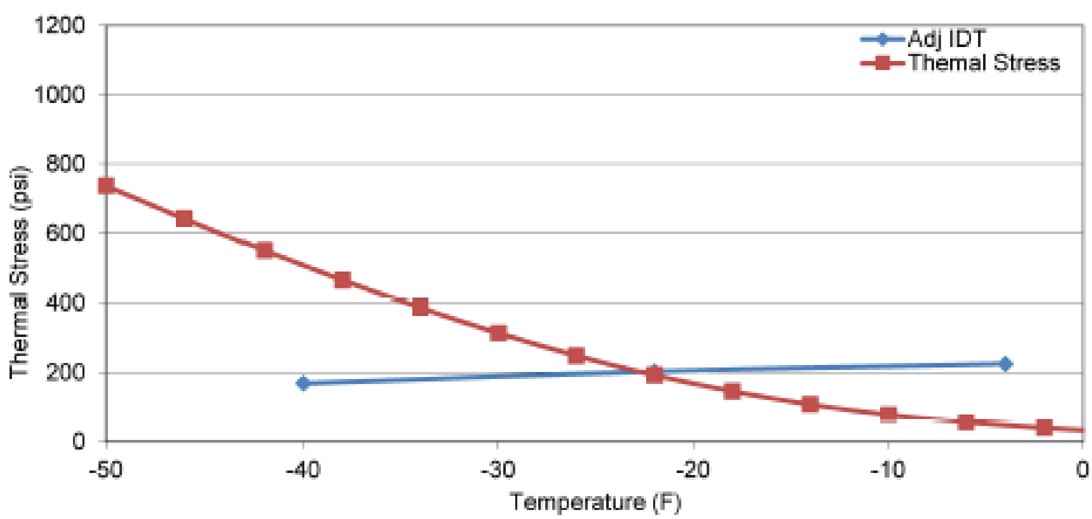
Client	Midstate / MnDOT
Project	MnROAD Cell 7-8

Emulsion Content	1.70%								
Temperature (F)	-40	-22	-4	-40	-22	-4	-40	-22	-4
IDT Strength (psi)	*225.0*	*271.1*	*300.2*	--	--	--	--	--	--
Adjusted IDT (psi)	*168.8*	*203.3*	*225.1*	--	--	--	--	--	--

Creep Compliance @ Emulsion Content **1.70%**



Critical Low Temperature @ Emulsion Content **1.70%**



Appendix B
As-Builts: Locations of Sensors

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2202	2202TC04	45.2751064	-93.7347758	110640.70	-9.760	7.56
2202	2202TC05	45.2751064	-93.7347758	110640.70	-9.760	11.52
2202	2202TC06	45.2751064	-93.7347758	110640.70	-9.760	17.52
2202	2202TC07	45.2751064	-93.7347758	110640.70	-9.760	23.52
2202	2202TC08	45.2751064	-93.7347758	110640.70	-9.760	35.52
2202	2202TC09	45.2751064	-93.7347758	110640.70	-9.760	47.52
2202	2202TC010	45.2751064	-93.7347758	110640.70	-9.760	59.52
2202	2202TC11	45.2751064	-93.7347758	110640.70	-9.760	95.52
2203	2203TC103	45.2745154	-93.7335319	111026.50	-5.930	2.50
2203	2203TC104	45.2745154	-93.7335319	111026.50	-5.930	3.50
2203	2203TC105	45.2745154	-93.7335319	111026.50	-5.930	5.00
2203	2203TC106	45.2745154	-93.7335319	111026.50	-5.930	7.00
2203	2203TC107	45.2745154	-93.7335319	111026.50	-5.930	9.00
2203	2203TC108	45.2745154	-93.7335319	111026.50	-5.930	11.00
2203	2203TC109	45.2745154	-93.7335319	111026.50	-5.930	13.00
2203	2203TC111	45.2745154	-93.7335319	111026.50	-5.930	24.00
2203	2203TC112	45.2745154	-93.7335319	111026.50	-5.930	28.00
2203	2203TC114	45.2745154	-93.7335319	111026.50	-5.930	48.00
2203	2203TC116	45.2745154	-93.7335319	111026.50	-5.930	72.00
2206	2206TC102	45.2732880	-93.7310688	111802.50	-5.900	1.50
2206	2206TC103	45.2732880	-93.7310688	111802.50	-5.900	2.50
2206	2206TC104	45.2732880	-93.7310688	111802.50	-5.900	3.50
2206	2206TC105	45.2732880	-93.7310688	111802.50	-5.900	5.00
2206	2206TC106	45.2732880	-93.7310688	111802.50	-5.900	7.00
2206	2206TC107	45.2732880	-93.7310688	111802.50	-5.900	9.00
2206	2206TC109	45.2732880	-93.7310688	111802.50	-5.900	13.00
2206	2206TC110	45.2732880	-93.7310688	111802.50	-5.900	15.00
2206	2206TC111	45.2732880	-93.7310688	111802.50	-5.900	24.00
2206	2206TC112	45.2732880	-93.7310688	111802.50	-5.900	28.00
2206	2206TC113	45.2732880	-93.7310688	111802.50	-5.900	36.00
2206	2206TC114	45.2732880	-93.7310688	111802.50	-5.900	48.00
2206	2206TC115	45.2732880	-93.7310688	111802.50	-5.900	60.00
2206	2206TC116	45.2732880	-93.7310688	111802.50	-5.900	72.00
2209	2209ME01	45.27068915	-93.72626511	113356.7	-5.558	9.50
2209	2209ME02	45.27068919	-93.72626447	113356.8	-5.669	13.50
2209	2209ME03	45.27068944	-93.72626476	113356.7	-5.696	20.00
2209	2209ME04	45.27068985	-93.72623003	113363.7	-11.269	9.50
2209	2209ME05	45.27069137	-93.72622979	113363.4	-11.745	13.50
2209	2209ME06	45.27068947	-93.72622933	113363.9	-11.270	20.00
2209	2209MG01	45.27069229	-93.72626630	113355.7	-6.278	1.00
2209	2209MG02	45.27069223	-93.72626606	113355.8	-6.298	6.50
2209	2209MS01	45.27068912	-93.72626257	113357.2	-5.949	9.50
2209	2209MS02	45.27069091	-93.72626593	113356.1	-5.937	13.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2209	2209MS03	45.27069103	-93.72626540	113356.2	-6.055	20.00
2209	2209MS04	45.27069191	-93.72622891	113363.4	-12.039	9.50
2209	2209MS05	45.27068998	-93.72622776	113364.1	-11.662	13.50
2209	2209MS06	45.27069130	-93.72622822	113363.7	-11.973	20.00
2209	2209PG01	45.27066583	-93.72619422	113376.3	-9.950	7.50
2209	2209TC03	45.27069398	-93.72626847	113354.9	-6.425	1.50
2209	2209TC04	45.27069398	-93.72626847	113354.9	-6.425	4.50
2209	2209TC05	45.27069398	-93.72626847	113354.9	-6.425	6.50
2209	2209TC06	45.27069398	-93.72626847	113354.9	-6.425	8.00
2209	2209TC07	45.27069398	-93.72626847	113354.9	-6.425	10.00
2209	2209TC08	45.27069398	-93.72626847	113354.9	-6.425	12.00
2209	2209TC09	45.27069398	-93.72626847	113354.9	-6.425	14.50
2209	2209TC10	45.27069398	-93.72626847	113354.9	-6.425	23.50
2209	2209TC11	45.27069398	-93.72626847	113354.9	-6.425	47.50
2209	2209TC12	45.27069398	-93.72626847	113354.9	-6.425	59.50
2209	2209VW01	45.27066856	-93.72622100	113370.2	-6.534	1.00
2209	2209VW02	45.27066850	-93.72622087	113370.3	-6.537	6.50
2209	2209VW03	45.27067598	-93.72621272	113370.3	-9.977	1.00
2209	2209VW04	45.27067596	-93.72621270	113370.3	-9.978	6.50
2209	2209VW05	45.27065895	-93.72620399	113375.9	-6.428	1.00
2209	2209VW06	45.27065892	-93.72620403	113375.9	-6.415	6.50
2209	2209VW07	45.27066274	-93.72618214	113379.5	-10.955	1.00
2209	2209VW08	45.27066262	-93.72618199	113379.5	-10.944	6.50
2209	2209VW09	45.27066212	-93.72618131	113379.8	-10.907	1.00
2209	2209VW10	45.27066219	-93.72618099	113379.8	-10.976	6.50
2209	2209MI02	45.27069052	-93.72623989	113361.5	-9.915	7.50
2209	2209MI01	45.27069317	-93.72623677	113361.6	-11.169	7.50
2210	2209CI01	45.27027659	-93.72547386	113609.9	-10.594	1.00
2210	2209CI02	45.27027604	-93.72547307	113610.1	-10.56	6.50
2210	2209CI03	45.27030172	-93.72552004	113594.9	-10.604	1.00
2210	2209CI04	45.27030238	-93.72552135	113594.4	-10.591	6.50
2210	2209CQ01	45.27027773	-93.72547297	113609.8	-11.065	1.00
2210	2209CQ02	45.27027730	-93.72547207	113610.1	-11.081	6.50
2210	2209CQ03	45.27030328	-93.72551937	113594.6	-11.161	1.00
2210	2209CQ04	45.27030299	-93.72551939	113594.7	-11.074	6.50
2210	2210JG001	45.27022849	-93.72541311	113633.0	-6.237	3.00
2210	2210JG002	45.27025350	-93.72545892	113618.0	-6.270	3.00
2210	2210JG003	45.27027846	-93.72550581	113602.9	-6.120	3.00
2210	2210JG004	45.27030413	-93.72555226	113587.7	-6.244	3.00
2210	2210MG001	45.27029298	-93.72552928	113594.9	-6.630	1.00
2210	2210MG002	45.27029287	-93.72552962	113594.9	-6.544	6.50
2210	2210MI001	45.27029205	-93.72549712	113601.7	-11.411	7.50
2210	2210MI002	45.27028864	-93.72550105	113601.6	-9.808	7.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2210	2210PG001	45.27026449	-93.72545508	113616.4	-10.050	7.50
2210	2210VW001	45.27027444	-93.72549546	113605.9	-6.583	1.00
2210	2210VW002	45.27027429	-93.72549544	113606.0	-6.542	6.50
2210	2210VW003	45.27025904	-93.72546692	113615.2	-6.615	1.00
2210	2210VW004	45.27025905	-93.72546710	113615.1	-6.589	6.50
2210	2210VW005	45.27027549	-93.72547525	113609.8	-10.059	1.00
2210	2210VW006	45.27027549	-93.72547535	113609.8	-10.044	6.50
2210	2210VW007	45.27026193	-93.72544290	113619.4	-11.221	1.00
2210	2210VW008	45.27026198	-93.72544328	113619.4	-11.177	6.50
2210	2210VW009	45.27026255	-93.72544441	113619.0	-11.164	1.00
2210	2210VW010	45.27026257	-93.72544448	113619.0	-11.157	6.50
2211	2211CI001	45.26977291	-93.72454855	113910.7	-10.360	1.00
2211	2211CI002	45.26977297	-93.72454861	113910.7	-10.368	6.50
2211	2211CI003	45.26979935	-93.72459545	113895.2	-10.634	1.00
2211	2211CI004	45.26979916	-93.72459543	113895.3	-10.582	6.50
2211	2211CQ001	45.26977398	-93.7245468	113910.8	-10.945	1.00
2211	2211CQ002	45.26977406	-93.72454689	113910.8	-10.953	6.50
2211	2211CQ003	45.26980038	-93.72459429	113895.2	-11.114	1.00
2211	2211CQ004	45.26980053	-93.72459403	113895.3	-11.197	6.50
2211	2211JG001	45.26972541	-93.72448756	113933.7	-6.212	3.00
2211	2211JG002	45.26975095	-93.72453494	113918.3	-6.151	3.00
2211	2211JG003	45.26977597	-93.72458161	113903.3	-6.053	3.00
2211	2211JG004	45.26980166	-93.72462799	113888.1	-6.190	3.00
2211	2211MG001	45.26978701	-93.72460122	113896.8	-6.162	1.00
2211	2211MG002	45.26978711	-93.72460115	113896.8	-6.202	6.50
2211	2211MI001	45.26979063	-93.72457321	113901.7	-11.608	7.50
2211	2211MI002	45.26978724	-93.72457679	113901.7	-10.067	7.50
2211	2211PG001	45.26976521	-93.72452796	113916.6	-11.370	7.50
2211	2211VW001	45.26976336	-93.72455623	113911.2	-6.395	1.00
2211	2211VW002	45.26976326	-93.72455625	113911.3	-6.363	6.50
2211	2211VW003	45.26975362	-93.72454034	113916.6	-6.076	1.00
2211	2211VW004	45.26975385	-93.72454034	113916.6	-6.140	6.50
2211	2211VW005	45.26977223	-93.72454962	113910.6	-9.997	1.00
2211	2211VW006	45.26977214	-93.72454990	113910.6	-9.926	6.50
2211	2211VW007	45.26975840	-93.72451695	113920.4	-11.131	1.00
2211	2211VW008	45.26975848	-93.72451716	113920.3	-11.12	6.50
2211	2211VW009	45.26975920	-93.72451872	113919.8	-11.082	1.00
2211	2211VW010	45.26975921	-93.72451907	113919.7	-11.033	6.50
2212	2212MI001	45.26946419	-93.72397358	114096.7	-11.446	7.50
2212	2212MI002	45.26946088	-93.72397727	114096.6	-9.910	7.50
2212	2212CQ001	45.26944850	-93.72394780	114105.4	-10.961	1.00
2212	2212CQ002	45.26944828	-93.72394777	114105.5	-10.902	6.50
2212	2212CQ003	45.26947349	-93.72399345	114090.5	-11.014	1.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2212	2212CQ004	45.26947346	-93.72399302	114090.6	-11.070	6.50
2212	2212CI001	45.26944749	-93.72394892	114105.4	-10.493	1.00
2212	2212CI002	45.26944747	-93.72394908	114105.4	-10.464	6.50
2212	2212CI003	45.26947232	-93.72399466	114090.6	-10.484	1.00
2212	2212CI004	45.26947240	-93.72399447	114090.6	-10.537	6.50
2212	2212MG001	45.26946304	-93.72400490	114090.5	-6.194	1.00
2212	2212MG002	45.26946303	-93.72400483	114090.5	-6.204	6.50
2212	2212JG001	45.26940003	-93.72388967	114128.0	-6.083	3.00
2212	2212JG002	45.26942492	-93.72393586	114113.1	-6.023	3.00
2212	2212JG003	45.26945027	-93.72398226	114098.0	-6.060	3.00
2212	2212JG004	45.26947617	-93.72402789	114082.9	-6.380	3.00
2212	2212JVW001	45.26943698	-93.72396219	114105.0	-5.371	1.00
2212	2212JVW002	45.26943678	-93.72396208	114105.1	-5.332	6.50
2212	2212JVW003	45.26942872	-93.72394219	114111.0	-6.127	1.00
2212	2212JVW004	45.26942884	-93.72394261	114110.8	-6.095	6.50
2212	2212JVW005	45.26944620	-93.72395061	114105.3	-9.854	1.00
2212	2212JVW006	45.26944632	-93.72395002	114105.4	-9.982	6.50
2212	2212JVW007	45.26943246	-93.72391853	114114.9	-10.923	1.00
2212	2212JVW008	45.26943248	-93.72391831	114115.0	-10.964	6.50
2212	2212JVW009	45.26943297	-93.72391998	114114.5	-10.842	1.00
2212	2212JVW010	45.26943318	-93.72391945	114114.6	-10.986	6.50
2213	2213JG001	45.26939989	-93.72388951	114128.1	-6.067	3.00
2213	2213JG002	45.26942487	-93.72393644	114113.0	-5.917	3.00
2213	2213JG003	45.26945026	-93.72398197	114098.0	-6.103	3.00
2213	2213JG004	45.26947604	-93.72402744	114083.0	-6.411	3.00
2213	2213MG001	45.26946303	-93.72400472	114090.6	-6.220	1.00
2213	2213MG002	45.26946310	-93.72400528	114090.4	-6.153	6.50
2213	2213CI001	45.26899632	-93.72311806	114375.3	-10.603	1.00
2213	2213CI002	45.26899616	-93.72311750	114375.4	-10.645	6.50
2213	2213CI003	45.26902080	-93.72316464	114360.3	-10.364	1.00
2213	2213CI004	45.26902092	-93.72316443	114360.3	-10.431	6.50
2213	2213CQ001	45.26899755	-93.72311682	114375.3	-11.155	1.00
2213	2213CQ002	45.26899741	-93.72311659	114375.3	-11.152	6.50
2213	2213CQ003	45.26902240	-93.72316323	114360.3	-11.048	1.00
2213	2213CQ004	45.26902241	-93.72316323	114360.3	-11.05	6.50
2213	2213JG001	45.26894960	-93.72305738	114398.0	-6.635	3.00
2213	2213JG002	45.26897447	-93.72310364	114383.1	-6.555	3.00
2213	2213JG003	45.26899983	-93.72315057	114367.9	-6.514	3.00
2213	2213JG004	45.26902456	-93.72319734	114352.8	-6.313	3.00
2213	2213MG001	45.26901238	-93.72317383	114360.3	-6.486	1.00
2213	2213MG002	45.26901200	-93.72317342	114360.5	-6.440	6.50
2213	2213MI001	45.26901320	-93.72314291	114366.5	-11.580	7.50
2213	2213MI002	45.26900995	-93.72314647	114366.4	-10.080	7.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2213	2213PG001	45.26898568	-93.72310010	114381.3	-10.352	7.50
2213	2213VW001	45.26898777	-93.72312708	114375.3	-6.718	1.00
2213	2213VW002	45.26898758	-93.72312691	114375.4	-6.691	6.50
2213	2213VW003	45.26897828	-93.72311004	114380.9	-6.652	1.00
2213	2213VW004	45.26897816	-93.72310979	114381.0	-6.656	6.50
2213	2213VW005	45.26899527	-93.72311937	114375.2	-10.096	1.00
2213	2213VW006	45.26899535	-93.72311897	114375.3	-10.182	6.50
2213	2213VW007	45.26898133	-93.72308701	114384.9	-11.150	1.00
2213	2213VW008	45.26898152	-93.72308689	114384.9	-11.225	6.50
2213	2213VW009	45.26898205	-93.72308837	114384.5	-11.144	1.00
2213	2213VW010	45.26898220	-93.72308843	114384.5	-11.177	6.50
2214	2214CI001	45.26851960	-93.72224066	114660.3	-10.647	1.00
2214	2214CI002	45.26851952	-93.72224033	114660.4	-10.676	6.50
2214	2214CI003	45.26854303	-93.72228862	114645.3	-9.886	1.00
2214	2214CI004	45.26854339	-93.72228867	114645.2	-9.980	6.50
2214	2214CQ001	45.26852064	-93.72223909	114660.4	-11.193	1.00
2214	2214CQ002	45.26852074	-93.72223925	114660.4	-11.198	6.50
2214	2214CQ003	45.26854522	-93.72228594	114645.4	-10.938	1.00
2214	2214CQ004	45.26854517	-93.72228563	114645.5	-10.973	6.50
2214	2214JG001	45.26847220	-93.72218119	114683.0	-6.290	3.00
2214	2214JG002	45.26849791	-93.72222707	114667.9	-6.513	3.00
2214	2214JG003	45.26852289	-93.72227300	114653.0	-6.518	3.00
2214	2214JG004	45.26854787	-93.72231982	114637.9	-6.383	3.00
2214	2214ME01	45.26853437	-93.72229640	114645.7	-6.160	9.50
2214	2214ME02	45.26853411	-93.72229734	114645.5	-5.937	13.50
2214	2214ME03	45.26853422	-93.72229729	114645.5	-5.977	20.00
2214	2214ME04	45.26853287	-93.72225677	114654.1	-11.951	9.50
2214	2214ME05	45.26853255	-93.72225714	114654.1	-11.799	13.50
2214	2214ME06	45.26853084	-93.72225676	114654.5	-11.367	20.00
2214	2214MG001	45.26853506	-93.72229729	114645.3	-6.221	1.00
2214	2214MG002	45.26853506	-93.72229729	114645.3	-6.221	6.50
2214	2214MI001	45.26853627	-93.72226514	114651.6	-11.619	7.50
2214	2214MI002	45.26853311	-93.7222684	114651.7	-10.193	7.50
2214	2214MS01	45.26853318	-93.72229891	114645.4	-5.422	9.50
2214	2214MS02	45.26853275	-93.72229763	114645.8	-5.500	13.50
2214	2214MS03	45.26853339	-93.72229603	114646.0	-5.935	20.00
2214	2214MS04	45.26853081	-93.72225933	114654.0	-10.955	9.50
2214	2214MS05	45.26853257	-93.72225847	114653.8	-11.595	13.50
2214	2214MS06	45.26853226	-93.72225845	114653.9	-11.512	20.00
2214	2214PG01	45.26851140	-93.72221983	114666.4	-11.551	7.50
2214	2214TC002	45.26853678	-93.72230049	114644.3	-6.215	0.50
2214	2214TC003	45.26853678	-93.72230049	114644.3	-6.215	1.50
2214	2214TC004	45.26853678	-93.72230049	114644.3	-6.215	4.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2214	2214TC005	45.26853678	-93.72230049	114644.3	-6.215	6.50
2214	2214TC006	45.26853678	-93.72230049	114644.3	-6.215	8.00
2214	2214TC007	45.26853678	-93.72230049	114644.3	-6.215	10.00
2214	2214TC008	45.26853678	-93.72230049	114644.3	-6.215	12.00
2214	2214TC009	45.26853678	-93.72230049	114644.3	-6.215	14.50
2214	2214TC010	45.26853678	-93.72230049	114644.3	-6.215	23.50
2214	2214TC011	45.26853678	-93.72230049	114644.3	-6.215	47.50
2214	2214TC012	45.26853678	-93.72230049	114644.3	-6.215	59.50
2214	2214VW001	45.26851102	-93.72224982	114660.4	-6.731	1.00
2214	2214VW002	45.26851087	-93.72224997	114660.4	-6.664	6.50
2214	2214VW003	45.26850151	-93.72223306	114665.9	-6.615	1.00
2214	2214VW004	45.26850151	-93.72223320	114665.9	-6.591	6.50
2214	2214VW005	45.26851870	-93.72224166	114660.3	-10.229	1.00
2214	2214VW006	45.26851859	-93.72224172	114660.3	-10.189	6.50
2214	2214VW007	45.26850429	-93.72221035	114669.9	-10.982	1.00
2214	2214VW008	45.26850449	-93.72221003	114669.9	-11.092	6.50
2214	2214VW009	45.26850501	-93.72221107	114669.6	-11.078	1.00
2214	2214VW010	45.26850510	-93.72221115	114669.6	-11.090	6.50
2215	2215CI01	45.26806732	-93.72140950	114930.5	-10.495	1.00
2215	2215CI02	45.26806743	-93.72140940	114930.5	-10.540	6.50
2215	2215CI03	45.26808898	-93.72144941	114917.6	-10.485	1.00
2215	2215CI04	45.26808901	-93.72144930	114917.6	-10.511	6.50
2215	2215CQ01	45.26806830	-93.72140831	114930.5	-10.964	1.00
2215	2215CQ02	45.26806837	-93.72140838	114930.5	-10.973	6.50
2215	2215CQ03	45.26809039	-93.72144794	114917.5	-11.123	1.00
2215	2215CQ04	45.26809017	-93.72144789	114917.6	-11.068	6.50
2215	2215JG01	45.26802081	-93.72134984	114953.0	-6.424	3.00
2215	2215JG02	45.26804582	-93.72139603	114938.0	-6.396	3.00
2215	2215JG03	45.26807089	-93.72144201	114923.1	-6.420	3.00
2215	2215JG04	45.26809592	-93.72148800	114908.1	-6.430	3.00
2215	2215MG01	45.26808256	-93.72146458	114915.9	-6.246	1.00
2215	2215MG02	45.26808265	-93.72146453	114915.9	-6.281	6.50
2215	2215PG01	45.26805616	-93.72139223	114936.5	-9.981	7.50
2215	2215PVW07	45.26805245	-93.72137917	114940.0	-10.96	1.00
2215	2215PVW08	45.26805225	-93.72137897	114940.1	-10.933	6.50
2215	2215PVW09	45.26805283	-93.72138028	114939.7	-10.894	1.00
2215	2215PVW10	45.26805304	-93.72138020	114939.7	-10.967	6.50
2215	2215VW01	45.26805886	-93.72141895	114930.5	-6.564	1.00
2215	2215VW02	45.26805871	-93.72141898	114930.5	-6.518	6.50
2215	2215VW03	45.26804946	-93.72140212	114936.0	-6.491	1.00
2215	2215VW04	45.26804960	-93.72140212	114936.0	-6.533	6.50
2215	2215VW05	45.26806646	-93.72141096	114930.4	-10.013	1.00
2215	2215VW06	45.26806624	-93.72141095	114930.5	-9.953	6.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2215	2215MI01	45.26808439	-93.72143327	114921.9	-11.693	7.50
2215	2215MI02	45.26808114	-93.72143718	114921.8	-10.139	7.50
2216	2216CQ001	45.26771737	-93.72076202	115140.5	-11.065	1.00
2216	2216CQ002	45.26771722	-93.72076167	115140.6	-11.077	6.50
2216	2216CQ003	45.26773918	-93.72080165	115127.5	-11.141	1.00
2216	2216CQ004	45.26773910	-93.72080183	115127.5	-11.090	6.50
2216	2216JG001	45.26766963	-93.72070349	115163.0	-6.461	3.00
2216	2216JG002	45.26769455	-93.72074981	115148.0	-6.385	3.00
2216	2216JG003	45.26771996	-93.72079569	115133.0	-6.525	3.00
2216	2216JG004	45.26774519	-93.72084211	115117.9	-6.525	3.00
2216	2216CI001	45.26771607	-93.72076308	115140.5	-10.521	1.00
2216	2216CI002	45.26771622	-93.72076325	115140.5	-10.538	6.50
2216	2216CI003	45.26773781	-93.72080301	115127.5	-10.533	1.00
2216	2216CI004	45.26773792	-93.72080316	115127.5	-10.539	6.50
2216	2216MG001	45.26773216	-93.72081831	115125.7	-6.496	1.00
2216	2216MG002	45.26773221	-93.72081863	115125.6	-6.462	6.50
2216	2216PG001	45.26770511	-93.72074573	115146.5	-10.079	7.50
2216	2216VW001	45.26770745	-93.72077253	115140.5	-6.547	1.00
2216	2216VW002	45.26770756	-93.72077283	115140.4	-6.533	6.50
2216	2216VW003	45.26769839	-93.72075604	115145.9	-6.518	1.00
2216	2216VW004	45.26769833	-93.72075595	115145.9	-6.515	6.50
2216	2216VW005	45.26771500	-93.72076483	115140.4	-9.937	1.00
2216	2216VW006	45.26771502	-93.72076459	115140.5	-9.981	6.50
2216	2216VW007	45.26770100	-93.72073280	115150.1	-10.923	1.00
2216	2216VW008	45.26770106	-93.72073307	115150.0	-10.896	6.50
2216	2216VW009	45.26770164	-93.72073413	115149.6	-10.899	1.00
2216	2216VW010	45.26770176	-93.72073395	115149.7	-10.960	6.50
2217	2217CI001	45.26560995	-93.71688812	116399.6	-10.581	1.00
2217	2217CI002	45.26561001	-93.71688834	116399.6	-10.561	6.50
2217	2217CI003	45.26563482	-93.71693549	116384.4	-10.326	1.00
2217	2217CI004	45.26563485	-93.71693552	116384.4	-10.329	6.50
2217	2217CQ001	45.26561103	-93.71688742	116399.5	-11.001	1.00
2217	2217CQ002	45.26561102	-93.71688754	116399.5	-10.979	6.50
2217	2217CQ003	45.26563613	-93.71693417	116384.4	-10.911	1.00
2217	2217CQ004	45.26563608	-93.71693432	116384.4	-10.872	6.50
2217	2217JG001	45.26556300	-93.71682923	116422.1	-6.264	3.00
2217	2217JG002	45.26558802	-93.71687526	116407.1	-6.262	3.00
2217	2217JG003	45.26561381	-93.71692212	116391.8	-6.356	3.00
2217	2217JG004	45.26563834	-93.71696780	116377.1	-6.267	3.00
2217	2217MG001	45.26562485	-93.71694198	116385.3	-6.426	1.00
2217	2217MG002	45.26562445	-93.71694249	116385.3	-6.229	6.50
2217	2217MI001	45.26562671	-93.71691426	116390.6	-11.316	7.50
2217	2217MI002	45.26562396	-93.71691747	116390.5	-10.018	7.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2217	2217PG001	45.26559811	-93.71687180	116405.6	-9.722	7.50
2217	2217VW001	45.26560124	-93.71689848	116399.4	-6.435	1.00
2217	2217VW002	45.26560120	-93.71689850	116399.4	-6.423	6.50
2217	2217VW003	45.26559217	-93.71688180	116404.9	-6.434	1.00
2217	2217VW004	45.26559207	-93.71688173	116404.9	-6.417	6.50
2217	2217VW005	45.26560867	-93.71689039	116399.4	-9.853	1.00
2217	2217VW006	45.26560869	-93.71689029	116399.5	-9.873	6.50
2217	2217VW007	45.26559468	-93.71685833	116409.1	-10.845	1.00
2217	2217VW008	45.26559489	-93.71685842	116409.0	-10.893	6.50
2217	2217VW009	45.26559553	-93.71685962	116408.6	-10.89	1.00
2217	2217VW010	45.26559558	-93.71685960	116408.6	-10.907	6.50
2218	2218CI001	45.26513333	-93.71601179	116684.4	-10.512	1.00
2218	2218CI002	45.26513332	-93.71601208	116684.4	-10.466	6.50
2218	2218CI003	45.26515859	-93.71605743	116669.5	-10.641	1.00
2218	2218CI004	45.26515864	-93.71605776	116669.4	-10.605	6.50
2218	2218CQ001	45.26513427	-93.71601054	116684.5	-10.981	1.00
2218	2218CQ002	45.26513417	-93.71601051	116684.5	-10.956	6.50
2218	2218CQ003	45.26515980	-93.71605633	116669.5	-11.166	1.00
2218	2218CQ004	45.26515979	-93.71605636	116669.5	-11.157	6.50
2218	2218JG001	45.26508649	-93.71595195	116707.1	-6.379	3.00
2218	2218JG002	45.26511177	-93.71599829	116692.0	-6.403	3.00
2218	2218JG003	45.26513654	-93.71604412	116677.1	-6.362	3.00
2218	2218JG004	45.26516162	-93.71609112	116662.0	-6.228	3.00
2218	2218MG001	45.26514836	-93.71606328	116670.6	-6.768	1.00
2218	2218MG002	45.26514812	-93.71606364	116670.6	-6.641	6.50
2218	2218MI001	45.26515035	-93.71603674	116675.6	-11.513	7.50
2218	2218MI002	45.26514696	-93.71604033	116675.6	-9.967	7.50
2218	2218PG001	45.26512182	-93.71599459	116690.5	-9.890	7.50
2218	2218VW001	45.26512458	-93.71602101	116684.5	-6.538	1.00
2218	2218VW002	45.26512453	-93.71602115	116684.5	-6.500	6.50
2218	2218VW003	45.26511518	-93.71600439	116690.0	-6.430	1.00
2218	2218VW004	45.26511504	-93.71600408	116690.1	-6.439	6.50
2218	2218VW005	45.26513207	-93.71601326	116684.4	-9.916	1.00
2218	2218VW006	45.26513196	-93.71601303	116684.5	-9.921	6.50
2218	2218VW007	45.26511847	-93.71598092	116694.0	-11.068	1.00
2218	2218VW008	45.26511836	-93.71598135	116694.0	-10.970	6.50
2218	2218VW009	45.26511890	-93.71598259	116693.6	-10.930	1.00
2218	2218VW010	45.26511891	-93.71598265	116693.6	-10.922	6.50
2219	2219CI001	45.26470637	-93.71522720	116939.5	-10.389	1.00
2219	2219CI002	45.26470626	-93.71522729	116939.5	-10.343	6.50
2219	2219CI003	45.26473041	-93.71527419	116924.6	-9.953	1.00
2219	2219CI004	45.26473067	-93.71527428	116924.5	-10.016	6.50
2219	2219CQ001	45.26470721	-93.71522583	116939.6	-10.847	1.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2219	2219CQ002	45.26470756	-93.71522614	116939.5	-10.899	6.50
2219	2219CQ003	45.26473168	-93.71527248	116924.6	-10.589	1.00
2219	2219CQ004	45.26473180	-93.71527276	116924.5	-10.581	6.50
2219	2219JG001	45.26465999	-93.71516710	116962.1	-6.429	3.00
2219	2219JG002	45.26468486	-93.71521358	116947.1	-6.313	3.00
2219	2219JG003	45.26470970	-93.71525999	116932.1	-6.201	3.00
2219	2219JG004	45.26473469	-93.71530605	116917.1	-6.185	3.00
2219	2219MG001	45.26472243	-93.71528363	116924.4	-6.167	1.00
2219	2219MG002	45.26472240	-93.71528385	116924.4	-6.123	6.50
2219	2219MI001	45.26472271	-93.71525274	116930.7	-11.097	7.50
2219	2219MI002	45.26471883	-93.71525637	116930.8	-9.407	7.50
2219	2219PG001	45.26469527	-93.71520927	116945.6	-9.999	7.50
2219	2219VW001	45.26469768	-93.71523657	116939.5	-6.407	1.00
2219	2219VW002	45.26469744	-93.71523644	116939.6	-6.356	6.50
2219	2219VW003	45.26468864	-93.71521956	116945.0	-6.466	1.00
2219	2219VW004	45.26468859	-93.71521965	116945.0	-6.437	6.50
2219	2219VW005	45.26469145	-93.71519621	116949.1	-10.944	1.00
2219	2219VW006	45.26469143	-93.71519628	116949.1	-10.928	6.50
2219	2219VW007	45.26469207	-93.71519743	116948.8	-10.932	1.00
2219	2219VW008	45.26469216	-93.71519764	116948.7	-10.927	6.50
2219	2219VW009	45.26470517	-93.71522846	116939.5	-9.844	1.00
2219	2219VW010	45.26470543	-93.71522850	116939.4	-9.914	6.50
2219	2219MI001	45.26773327	-93.72078739	115131.7	-11.673	7.50
2219	2219MI002	45.26773000	-93.72079119	115131.7	-10.133	7.50
2220	2220CI001	45.26440559	-93.71467273	117119.5	-10.578	1.00
2220	2220CI002	45.26440570	-93.71467289	117119.5	-10.584	6.50
2220	2220CI003	45.26443068	-93.71471949	117104.4	-10.483	1.00
2220	2220CI004	45.26443080	-93.71471958	117104.4	-10.503	6.50
2220	2220CQ001	45.26440668	-93.71467170	117119.5	-11.056	1.00
2220	2220CQ002	45.26440687	-93.71467185	117119.4	-11.087	6.50
2220	2220CQ003	45.26443178	-93.71471820	117104.4	-11.002	1.00
2220	2220CQ004	45.26443180	-93.71471839	117104.4	-10.978	6.50
2220	2220JG001	45.26435905	-93.71461297	117142.1	-6.518	3.00
2220	2220JG002	45.26438405	-93.71465939	117127.1	-6.448	3.00
2220	2220JG003	45.26440889	-93.71470575	117112.1	-6.346	3.00
2220	2220JG004	45.26443416	-93.71475172	117097.1	-6.425	3.00
2220	2220MG001	45.26442212	-93.71472858	117104.5	-6.581	1.00
2220	2220MG002	45.26442214	-93.71472883	117104.4	-6.548	6.50
2220	2220MI001	45.26442215	-93.71469831	117110.6	-11.345	7.50
2220	2220MI002	45.26441874	-93.71470162	117110.7	-9.839	7.50
2220	2220PG001	45.26439427	-93.71465553	117125.6	-10.009	7.50
2220	2220VW001	45.26439674	-93.71468226	117119.6	-6.525	1.00
2220	2220VW002	45.26439670	-93.71468222	117119.6	-6.518	6.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2220	2220VW003	45.26438784	-93.71466568	117124.9	-6.557	1.00
2220	2220VW004	45.26438752	-93.71466597	117124.9	-6.42	6.50
2220	2220VW005	45.26440474	-93.71467453	117119.4	-10.049	1.00
2220	2220VW006	45.26440450	-93.71467435	117119.5	-10.008	6.50
2220	2220VW007	45.26439229	-93.71464103	117129.0	-11.713	1.00
2220	2220VW008	45.26439235	-93.71464126	117128.9	-11.696	6.50
2220	2220VW009	45.26439286	-93.71464246	117128.5	-11.655	1.00
2220	2220VW010	45.26439300	-93.71464292	117128.4	-11.624	6.50
2220	2220ZZ001	45.26438047	-93.71462581	117134.7	-10.692	7.50
2220	2220ZZ002	45.26438068	-93.71462591	117134.6	-10.734	7.50
2220	2220ZZ003	45.26436270	-93.71464521	117134.7	-2.509	7.50
2220	2220ZZ004	45.26436312	-93.71464677	117134.3	-2.385	7.50
2220	2220ZZ005	45.26435554	-93.71458058	117149.5	-10.593	7.50
2220	2220ZZ006	45.26433799	-93.71459864	117149.7	-2.684	7.50
2220	2220ZZ007	45.26433783	-93.71459833	117149.8	-2.686	7.50
2221	2221CI001	45.26397864	-93.71388832	117374.6	-10.435	1.00
2221	2221CI002	45.26397873	-93.71388831	117374.5	-10.463	6.50
2221	2221CI003	45.26400414	-93.71393437	117359.5	-10.57	1.00
2221	2221CI004	45.26400437	-93.71393423	117359.5	-10.657	6.50
2221	2221CQ001	45.26397971	-93.71388693	117374.6	-10.961	1.00
2221	2221CQ002	45.26397972	-93.71388693	117374.6	-10.965	6.50
2221	2221CQ003	45.26400529	-93.71393346	117359.4	-11.042	1.00
2221	2221CQ004	45.26400534	-93.71393354	117359.4	-11.047	6.50
2221	2221JG001	45.26393189	-93.71382870	117397.1	-6.292	3.00
2221	2221JG002	45.26395674	-93.71387531	117382.1	-6.150	3.00
2221	2221JG003	45.26398200	-93.71392090	117367.2	-6.288	3.00
2221	2221JG004	45.26400777	-93.71396751	117351.9	-6.411	3.00
2221	2221MG001	45.26399393	-93.71394098	117360.4	-6.581	1.00
2221	2221MG002	45.26399377	-93.71394114	117360.4	-6.510	6.50
2221	2221MI001	45.26399555	-93.71391299	117365.8	-11.444	7.50
2221	2221MI002	45.26399198	-93.71391672	117365.8	-9.827	7.50
2221	2221PG001	45.26396724	-93.71387099	117380.6	-9.863	7.50
2221	2221VW001	45.26397013	-93.71389772	117374.5	-6.498	1.00
2221	2221VW002	45.26396999	-93.71389774	117374.6	-6.456	6.50
2221	2221VW003	45.26396065	-93.71388083	117380.1	-6.413	1.00
2221	2221VW004	45.26396071	-93.71388091	117380.1	-6.418	6.50
2221	2221VW005	45.26397749	-93.7138897	117374.5	-9.884	1.00
2221	2221VW006	45.26397753	-93.71388958	117374.6	-9.914	6.50
2221	2221VW007	45.26396350	-93.71385813	117384.1	-10.803	1.00
2221	2221VW008	45.26396354	-93.71385809	117384.1	-10.820	6.50
2221	2221VW009	45.26396413	-93.71385919	117383.7	-10.816	1.00
2221	2221VW010	45.26396399	-93.71385924	117383.8	-10.769	6.50
2221	2221ZZ001	45.26394657	-93.71381863	117395.9	-12.115	7.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2221	2221ZZ002	45.26394489	-93.71382010	117396.0	-11.400	7.50
2221	2221ZZ003	45.26394413	-93.71382092	117396.0	-11.051	7.50
2221	2221ZZ004	45.26394628	-93.71382050	117395.6	-11.737	7.50
2221	2221ZZ005	45.26394688	-93.71382177	117395.2	-11.710	7.50
2221	2221ZZ006	45.26394747	-93.71382299	117394.8	-11.690	7.50
2222	2222CI001	45.26357738	-93.71314981	117614.5	-10.505	1.00
2222	2222CI002	45.26357742	-93.71314975	117614.5	-10.527	6.50
2222	2222CI003	45.26360224	-93.71319592	117599.6	-10.446	1.00
2222	2222CI004	45.26360237	-93.71319592	117599.5	-10.482	6.50
2222	2222CQ001	45.26357862	-93.71314864	117614.5	-11.047	1.00
2222	2222CQ002	45.26357872	-93.71314871	117614.4	-11.066	6.50
2222	2222CQ003	45.26360338	-93.71319486	117599.5	-10.944	1.00
2222	2222CQ004	45.26360339	-93.71319482	117599.5	-10.952	6.50
2222	2222JG001	45.26353151	-93.71308998	117636.9	-6.653	3.00
2222	2222JG002	45.26355538	-93.71313632	117622.1	-6.268	3.00
2222	2222JG003	45.26358059	-93.71318215	117607.2	-6.354	3.00
2222	2222JG004	45.26360676	-93.71322945	117591.7	-6.483	3.00
2222	2222MG001	45.26359183	-93.71320264	117600.5	-6.381	1.00
2222	2222MG002	45.26359171	-93.71320274	117600.5	-6.332	6.50
2222	2222MI001	45.26359415	-93.71317440	117605.8	-11.488	7.50
2222	2222MI002	45.26359073	-93.71317787	117605.8	-9.954	7.50
2222	2222PG001	45.26356601	-93.71313260	117620.5	-9.926	7.50
2222	2222VW001	45.26356872	-93.71315911	117614.5	-6.544	1.00
2222	2222VW002	45.2635687	-93.71315913	117614.5	-6.533	6.50
2222	2222VW003	45.26355965	-93.71314171	117620.1	-6.655	1.00
2222	2222VW004	45.26355944	-93.71314190	117620.1	-6.565	6.50
2222	2222VW005	45.26357636	-93.71315110	117614.5	-10.009	1.00
2222	2222VW006	45.26357622	-93.71315115	117614.5	-9.959	6.50
2222	2222VW007	45.26356255	-93.71311889	117624.1	-11.078	1.00
2222	2222VW008	45.26356265	-93.71311913	117624.0	-11.069	6.50
2222	2222VW009	45.26356323	-93.71312015	117623.7	-11.078	1.00
2222	2222VW010	45.26356325	-93.71312018	117623.7	-11.080	6.50
2222	2222ZZ001	45.26354623	-93.71307843	117636.0	-12.719	7.50
2222	2222ZZ002	45.26354548	-93.71307941	117636.0	-12.348	7.50
2222	2222ZZ003	45.26354457	-93.71308039	117636.0	-11.93	7.50
2222	2222ZZ004	45.26354374	-93.71308121	117636.0	-11.563	7.50
2222	2222ZZ005	45.26354284	-93.71308212	117636.0	-11.161	7.50
2222	2222ZZ006	45.26354519	-93.71308151	117635.6	-11.934	7.50
2222	2222ZZ007	45.26354581	-93.71308275	117635.2	-11.919	7.50
2222	2222ZZ008	45.26354649	-93.71308396	117634.8	-11.925	7.50
2223	2223CI001	45.26292492	-93.71194935	118004.6	-10.570	1.00
2223	2223CI002	45.26292495	-93.71194951	118004.5	-10.553	6.50
2223	2223CI003	45.26295024	-93.71199612	117989.4	-10.539	1.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2223	2223CI004	45.26295037	-93.71199615	117989.4	-10.570	6.50
2223	2223CQ001	45.26292599	-93.71194825	118004.6	-11.053	1.00
2223	2223CQ002	45.26292600	-93.71194846	118004.5	-11.022	6.50
2223	2223CQ003	45.26295139	-93.71199497	117989.4	-11.053	1.00
2223	2223CQ004	45.26295155	-93.71199523	117989.3	-11.056	6.50
2223	2223JG001	45.26287840	-93.71188994	118027.1	-6.460	3.00
2223	2223JG002	45.26290343	-93.71193604	118012.1	-6.453	3.00
2223	2223JG003	45.26292825	-93.71198187	117997.2	-6.426	3.00
2223	2223JG004	45.26295354	-93.71202846	117982.1	-6.411	3.00
2223	2223MG001	45.26293869	-93.71200148	117990.9	-6.361	1.00
2223	2223MG002	45.26293858	-93.71200159	117990.9	-6.311	6.50
2223	2223MI001	45.26294201	-93.71197466	117995.6	-11.531	7.50
2223	2223MI002	45.26293880	-93.71197823	117995.6	-10.044	7.50
2223	2223PG001	45.26291353	-93.71193207	118010.6	-9.995	7.50
2223	2223VW001	45.26291629	-93.71195891	118004.5	-6.575	1.00
2223	2223VW002	45.26291616	-93.71195897	118004.6	-6.528	6.50
2223	2223VW003	45.26290695	-93.71194211	118010.1	-6.515	1.00
2223	2223VW004	45.26290691	-93.71194216	118010.1	-6.495	6.50
2223	2223VW005	45.26292387	-93.71195072	118004.5	-10.053	1.00
2223	2223VW006	45.26292392	-93.71195107	118004.5	-10.011	6.50
2223	2223VW007	45.26290993	-93.71191896	118014.1	-11.013	1.00
2223	2223VW008	45.26291010	-93.71191894	118014.1	-11.065	6.50
2223	2223VW009	45.26291045	-93.71192033	118013.7	-10.949	1.00
2223	2223VW010	45.26291054	-93.71192022	118013.7	-10.991	6.50
2223	2223ZZ001	45.26289394	-93.71187906	118025.8	-12.663	7.50
2223	2223ZZ002	45.26289307	-93.71188013	118025.8	-12.240	7.50
2223	2223ZZ003	45.26289221	-93.71188093	118025.8	-11.868	7.50
2223	2223ZZ004	45.26289126	-93.71188172	118025.9	-11.468	7.50
2223	2223ZZ005	45.26289044	-93.71188248	118025.9	-11.113	7.50
2223	2223ZZ006	45.26289274	-93.71188210	118025.5	-11.838	7.50
2223	2223ZZ007	45.26289334	-93.71188328	118025.1	-11.826	7.50
2223	2223ZZ008	45.26289393	-93.71188444	118024.7	-11.813	7.50
2224	2224CI001	45.26264878	-93.71144177	118169.6	-10.524	1.00
2224	2224CI002	45.26264891	-93.71144193	118169.5	-10.535	6.50
2224	2224CI003	45.26267350	-93.71148788	118154.7	-10.421	1.00
2224	2224CI004	45.26267364	-93.71148795	118154.6	-10.450	6.50
2224	2224CQ001	45.26264999	-93.71144058	118169.5	-11.060	1.00
2224	2224CQ002	45.26265013	-93.71144073	118169.5	-11.077	6.50
2224	2224CQ003	45.26267471	-93.71148674	118154.6	-10.951	1.00
2224	2224CQ004	45.26267491	-93.71148700	118154.5	-10.968	6.50
2224	2224JG001	45.26260224	-93.71138247	118192.0	-6.391	3.00
2224	2224JG002	45.26262740	-93.71142813	118177.1	-6.488	3.00
2224	2224JG003	45.26265210	-93.71147426	118162.2	-6.379	3.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2224	2224JG004	45.26267740	-93.71152077	118147.1	-6.381	3.00
2224	2224ME01	45.26266183	-93.71149026	118156.8	-6.677	9.50
2224	2224ME02	45.26266221	-93.71149016	118156.7	-6.802	13.50
2224	2224ME03	45.26266282	-93.71148932	118156.7	-7.108	20.00
2224	2224ME04	45.26266007	-93.71145643	118164.1	-11.482	9.50
2224	2224ME05	45.26266203	-93.71145876	118163.2	-11.682	13.50
2224	2224ME06	45.26266042	-93.71145702	118163.9	-11.489	20.00
2224	2224MG001	45.26266557	-93.71149419	118155.1	-7.139	1.00
2224	2224MG002	45.26266535	-93.71149446	118155.1	-7.034	6.50
2224	2224MI001	45.26266540	-93.71146682	118160.8	-11.39	7.50
2224	2224MI002	45.26266186	-93.71147056	118160.8	-9.778	7.50
2224	2224MS01	45.26266345	-93.71149239	118156.0	-6.810	9.50
2224	2224MS02	45.26266313	-93.71149209	118156.1	-6.762	13.50
2224	2224MS03	45.26266345	-93.71149180	118156.1	-6.903	20.00
2224	2224MS04	45.26265988	-93.71145738	118163.9	-11.279	9.50
2224	2224MS05	45.26266107	-93.71145886	118163.4	-11.390	13.50
2224	2224MS06	45.26266153	-93.71145796	118163.4	-11.664	20.00
2224	2224PG001	45.26263763	-93.71142459	118175.6	-10.000	7.50
2224	2224TC01	45.26266681	-93.71149656	118154.4	-7.125	1.00
2224	2224TC02	45.26266681	-93.71149656	118154.4	-7.125	1.50
2224	2224TC03	45.26266681	-93.71149656	118154.4	-7.125	2.50
2224	2224TC04	45.26266681	-93.71149656	118154.4	-7.125	5.50
2224	2224TC05	45.26266681	-93.71149656	118154.4	-7.125	7.50
2224	2224TC06	45.26266681	-93.71149656	118154.4	-7.125	9.00
2224	2224TC07	45.26266681	-93.71149656	118154.4	-7.125	11.00
2224	2224TC08	45.26266681	-93.71149656	118154.4	-7.125	13.00
2224	2224TC09	45.26266681	-93.71149656	118154.4	-7.125	15.50
2224	2224TC10	45.26266681	-93.71149656	118154.4	-7.125	24.50
2224	2224TC11	45.26266681	-93.71149656	118154.4	-7.125	48.50
2224	2224TC12	45.26266681	-93.71149656	118154.4	-7.125	60.50
2224	2224VW001	45.26264034	-93.71145129	118169.5	-6.588	1.00
2224	2224VW002	45.26264027	-93.71145137	118169.5	-6.557	6.50
2224	2224VW003	45.26263113	-93.71143448	118175.0	-6.569	1.00
2224	2224VW004	45.26263093	-93.71143445	118175.0	-6.516	6.50
2224	2224VW005	45.26264801	-93.71144321	118169.5	-10.075	1.00
2224	2224VW006	45.26264784	-93.71144326	118169.5	-10.017	6.50
2224	2224VW007	45.26263421	-93.71141143	118179.0	-11.078	1.00
2224	2224VW008	45.26263408	-93.71141138	118179.0	-11.050	6.50
2224	2224VW009	45.26263445	-93.71141256	118178.7	-10.971	1.00
2224	2224VW010	45.26263456	-93.71141253	118178.7	-11.007	6.50
2224	2224ZZ001	45.26261766	-93.71137102	118190.9	-12.644	7.50
2224	2224ZZ002	45.26261691	-93.71137191	118190.9	-12.291	7.50
2224	2224ZZ003	45.26261602	-93.71137271	118191.0	-11.907	7.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2224	2224ZZ004	45.26261526	-93.71137375	118190.9	-11.523	7.50
2224	2224ZZ005	45.26261435	-93.71137466	118190.9	-11.116	7.50
2224	2224ZZ006	45.26261674	-93.71137382	118190.6	-11.939	7.50
2224	2224ZZ007	45.26261736	-93.71137502	118190.2	-11.930	7.50
2224	2224ZZ008	45.26261794	-93.71137625	118189.8	-11.905	7.50
2226	2226CI001	45.26085648	-93.70814871	119240.2	-10.028	1.00
2226	2226CI002	45.26085654	-93.70814858	119240.2	-10.066	4.00
2226	2226CQ001	45.26086670	-93.70816661	119234.3	-10.169	1.00
2226	2226CQ002	45.26086671	-93.70816665	119234.3	-10.166	4.00
2226	2226JG001	45.26084947	-93.70815224	119241.0	-7.449	2.50
2226	2226JG002	45.26085982	-93.70817021	119235.1	-7.613	2.50
2226	2226JG003	45.26086981	-93.70818899	119229.0	-7.551	2.50
2226	2226JG004	45.26087920	-93.70820706	119223.2	-7.425	2.50
2226	2226MG001	45.26086157	-93.70817753	119233.2	-6.971	1.00
2226	2226MG002	45.26086161	-93.70817756	119233.2	-6.978	4.00
2226	2226VW001	45.26085814	-93.70815761	119238.0	-9.110	1.00
2226	2226VW002	45.26085832	-93.70815755	119238.0	-9.172	4.00
2226	2226VW003	45.26084992	-93.70816634	119238.1	-5.363	1.00
2226	2226VW004	45.26084973	-93.70816638	119238.1	-5.303	4.00
2226	2226VW005	45.26085056	-93.70815633	119240.0	-7.121	1.00
2226	2226VW006	45.26085044	-93.70815637	119240.0	-7.080	4.00
2226	2226VW007	45.26085593	-93.70814769	119240.5	-10.028	1.00
2226	2226VW008	45.26085588	-93.70814753	119240.6	-10.04	4.00
2227	2227CI001	45.26060508	-93.70768667	119390.4	-9.985	1.00
2227	2227CI002	45.26060493	-93.70768678	119390.4	-9.924	4.00
2227	2227CQ001	45.26061548	-93.70770500	119384.3	-10.11	1.00
2227	2227CQ002	45.26061503	-93.70770500	119384.4	-9.977	4.00
2227	2227JG001	45.26059841	-93.70769028	119391.1	-7.490	2.50
2227	2227JG002	45.26060874	-93.70770856	119385.1	-7.601	2.50
2227	2227JG003	45.26061833	-93.70772723	119379.2	-7.439	2.50
2227	2227JG004	45.26062864	-93.70774566	119373.1	-7.524	2.50
2227	2227MG001	45.26061125	-93.70771642	119383.0	-7.091	1.00
2227	2227MG002	45.26061107	-93.70771629	119383.0	-7.060	4.00
2227	2227VW001	45.26060714	-93.70769532	119388.2	-9.220	1.00
2227	2227VW002	45.26060695	-93.70769541	119388.2	-9.153	4.00
2227	2227VW003	45.26059828	-93.70770412	119388.3	-5.279	1.00
2227	2227VW004	45.26059828	-93.70770429	119388.3	-5.251	4.00
2227	2227VW005	45.26059910	-93.70769427	119390.2	-7.061	1.00
2227	2227VW006	45.26059904	-93.70769432	119390.2	-7.036	4.00
2227	2227VW007	45.26060474	-93.70768544	119390.7	-10.080	1.00
2227	2227VW008	45.26060457	-93.70768553	119390.7	-10.017	4.00
2228	2228LE01	45.26028371	-93.70711410	119578.7	-7.092	-8.50
2228	2228LE02	45.26028812	-93.70711006	119578.6	-9.002	-8.50

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2228	2228LE03	45.26029347	-93.70710393	119578.6	-11.509	-8.50
2228	2228LE04	45.26029124	-93.70712804	119574.2	-7.076	-8.50
2228	2228LE05	45.26029511	-93.70712326	119574.3	-8.947	-8.50
2228	2228LE06	45.26030063	-93.70711748	119574.3	-11.448	-8.50
2228	2228LE07	45.26029947	-93.70714282	119569.3	-7.133	-8.50
2228	2228LE08	45.26030321	-93.70713805	119569.5	-8.964	-8.50
2228	2228LE09	45.26030925	-93.70713322	119569.1	-11.467	-8.50
2228	2228TE01	45.26028749	-93.70712063	119576.5	-7.160	-8.50
2228	2228TE02	45.26029083	-93.70711556	119576.8	-8.920	-8.50
2228	2228TE03	45.26029616	-93.70710941	119576.9	-11.425	-8.50
2228	2228TE04	45.26029386	-93.70713320	119572.6	-7.024	-8.50
2228	2228TE05	45.26029780	-93.70712828	119572.7	-8.936	-8.50
2228	2228TE06	45.26030350	-93.70712269	119572.6	-11.459	-8.50
2228	2228PG01	45.26027658	-93.70710087	119583.0	-7.109	-18.00
2228	2228PG02	45.26028058	-93.70709622	119583.1	-8.999	-18.00
2228	2228PG03	45.26028595	-93.70708975	119583.2	-11.565	-18.00
2228	2228PG04	45.26030675	-93.70715620	119565.0	-7.134	-8.50
2228	2228PG05	45.26031043	-93.70715039	119565.4	-9.109	-8.50
2228	2228PG06	45.26031559	-93.70714460	119565.4	-11.512	-8.50
2228	2228PE01	45.26031797	-93.70717719	119558.2	-7.077	-8.50
2228	2228PE02	45.26032246	-93.70717293	119558.1	-9.046	-8.50
2228	2228PE03	45.26032857	-93.70716817	119557.7	-11.558	-8.50
2228	2228PE04	45.26032192	-93.70718437	119555.9	-7.092	-8.50
2228	2228PE05	45.26032623	-93.70717978	119555.9	-9.059	-8.50
2228	2228PE06	45.26033229	-93.70717492	119555.5	-11.571	-8.50
2228	2228WE01	45.26033176	-93.70719001	119552.5	-9.047	-8.50
2228	2228WE02	45.26033689	-93.70718372	119552.7	-11.517	-8.50
2228	2228WE03	45.26034162	-93.70719236	119549.9	-11.529	-8.50
2228	2228ME01	45.26027797	-93.70714186	119574.3	-1.072	-13.50
2228	2228ME02	45.26027424	-93.70714015	119575.6	-0.255	-20.00
2228	2228ME03	45.26030559	-93.70710468	119575.8	-14.887	-32.00
2228	2228ME04	45.26028544	-93.70712681	119575.8	-5.590	-32.00
2228	2228ME05	45.26027443	-93.70714195	119575.2	-0.029	-32.00
2228	2228ME06	45.26025850	-93.70715490	119576.1	6.608	-32.00
2228	2228ME07	45.26024254	-93.70717927	119574.6	15.048	-32.00
2228	2228ME08	45.26030480	-93.70710679	119575.5	-14.335	-28.00
2228	2228ME09	45.26028593	-93.70712772	119575.4	-5.594	-28.00
2228	2228ME10	45.26027462	-93.70714366	119574.7	0.179	-28.00
2228	2228ME11	45.26025944	-93.70715586	119575.6	6.481	-28.00
2228	2228ME12	45.26024272	-93.70717541	119575.3	14.383	-28.00
2228	2228MS01	45.26027613	-93.70714291	119574.5	-0.374	-13.50
2228	2228MS02	45.26027559	-93.70713931	119575.4	-0.778	-20.00
2228	2228MS03	45.26030547	-93.70710673	119575.4	-14.529	-32.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2228	2228MS04	45.26028616	-93.70712617	119575.8	-5.896	-32.00
2228	2228MS05	45.26027553	-93.70714001	119575.3	-0.651	-32.00
2228	2228MS06	45.26026018	-93.70715474	119575.7	6.097	-32.00
2228	2228MS07	45.26024376	-93.70717835	119574.5	14.550	-32.00
2228	2228MS08	45.26030547	-93.70710856	119575.0	-14.249	-28.00
2228	2228MS09	45.26028732	-93.70712647	119575.4	-6.191	-28.00
2228	2228MS10	45.26027509	-93.70714135	119575.1	-0.320	-28.00
2228	2228MS11	45.26026122	-93.70715505	119575.4	5.840	-28.00
2228	2228MS12	45.26024403	-93.70717402	119575.3	13.786	-28.00
2229	2229ME01	45.25981458	-93.70629702	119849.8	0.073	-13.50
2229	2229ME02	45.25981443	-93.70629545	119850.1	-0.132	-20.00
2229	2229ME03	45.25984711	-93.70626684	119848.7	-14.068	-32.00
2229	2229ME04	45.25982833	-93.70628119	119850.0	-6.387	-32.00
2229	2229ME05	45.25981293	-93.70629710	119850.1	0.561	-32.00
2229	2229ME06	45.25979945	-93.70631003	119850.5	6.489	-32.00
2229	2229ME07	45.25978272	-93.70632762	119850.6	14.085	-32.00
2229	2229ME08	45.25984493	-93.70626235	119850.1	-14.142	-28.00
2229	2229ME09	45.25982755	-93.70628267	119849.8	-5.930	-28.00
2229	2229ME10	45.25981428	-93.70629762	119849.7	0.253	-28.00
2229	2229ME11	45.25980024	-93.70631080	119850.2	6.379	-28.00
2229	2229ME12	45.25978267	-93.70632580	119851.0	13.815	-28.00
2229	2229MS01	45.25981250	-93.70629823	119850.0	0.863	-13.50
2229	2229MS02	45.25981345	-93.70629688	119850.1	0.377	-20.00
2229	2229MS03	45.25984815	-93.70626686	119848.5	-14.365	-32.00
2229	2229MS04	45.25982931	-93.70628112	119849.8	-6.682	-32.00
2229	2229MS05	45.25981339	-93.70629528	119850.4	0.142	-32.00
2229	2229MS06	45.25979940	-93.70630866	119850.8	6.287	-32.00
2229	2229MS07	45.25978314	-93.70632569	119850.9	13.662	-32.00
2229	2229MS08	45.25984380	-93.70626389	119850.1	-13.575	-28.00
2229	2229MS09	45.25982809	-93.70628028	119850.2	-6.459	-28.00
2229	2229MS10	45.25981558	-93.70629560	119849.9	-0.439	-28.00
2229	2229MS11	45.25980005	-93.70630836	119850.7	6.054	-28.00
2229	2229MS12	45.25978261	-93.70632680	119850.8	13.989	-28.00
2232	2232PG01	45.25786820	-93.70266080	121024.7	-8.934	-6.00
2232	2232PG02	45.25787393	-93.70265443	121024.8	-11.589	-6.00
2232	2232PG03	45.25790650	-93.70243333	121020.1	-6.993	18.00
2232	2232PG04	45.25791029	-93.70242952	121020.0	-8.684	-18.00
2232	2232PG05	45.25791574	-93.70242374	121020.0	-11.167	-18.00
2232	2232PG06	45.2579018	-93.70272240	121004.7	-8.962	-6.00
2232	2232PG07	45.25790782	-93.70271646	121004.6	-11.633	-6.00
2232	2232PG08	45.25793518	-93.70247506	121005.2	-8.719	-18.00
2232	2232LE01	45.25787891	-93.70269306	121015.8	-6.958	-6.00
2232	2232LE02	45.25788336	-93.70268805	121015.8	-9.031	-6.00

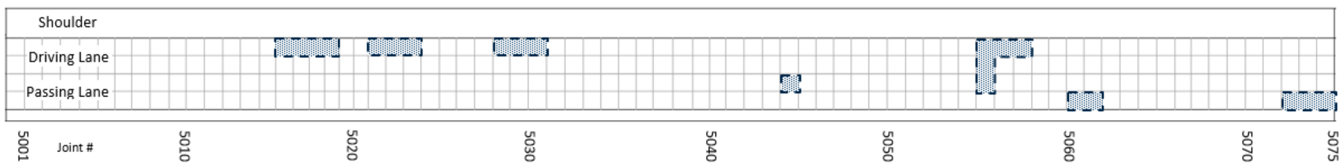
Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2232	2232LE03	45.25788857	-93.70268221	121015.8	-11.454	-6.00
2232	2232LE04	45.25788201	-93.70269859	121014.0	-6.983	-6.00
2232	2232LE05	45.25788647	-93.70269405	121013.9	-8.986	-6.00
2232	2232LE06	45.25789214	-93.70268849	121013.8	-11.498	-6.00
2232	2232LE07	45.25788536	-93.70270512	121011.9	-6.927	-6.00
2232	2232LE08	45.25789003	-93.70270037	121011.8	-9.024	-6.00
2232	2232LE09	45.25789443	-93.70269286	121012.4	-11.474	-6.00
2232	2232LE10	45.25788863	-93.70271057	121010.0	-7.016	-6.00
2232	2232LE11	45.25789332	-93.70270629	121009.9	-9.043	-6.00
2232	2232LE12	45.25789839	-93.70270023	121010.0	-11.459	-6.00
2232	2232ME01	45.25788625	-93.70271374	121009.9	-5.828	-8.00
2232	2232ME02	45.25788740	-93.70271584	121009.2	-5.832	-16.00
2232	2232ME03	45.25788680	-93.70271502	121009.5	-5.788	-20.00
2232	2232ME04	45.25788747	-93.70271542	121009.3	-5.917	-28.00
2232	2232MS01	45.25788824	-93.70271562	121009.1	-6.109	-8.00
2232	2232MS02	45.25788830	-93.70271498	121009.2	-6.228	-16.00
2232	2232MS03	45.25788803	-93.70271323	121009.6	-6.423	-20.00
2232	2232MS04	45.25788710	-93.70271319	121009.9	-6.161	-28.00
2234	2234PG01	45.25622783	-93.69964519	122005.0	-8.891	-6.00
2234	2234PG02	45.25623279	-93.69963863	122005.2	-11.356	-6.00
2234	2234PG03	45.25626422	-93.69941407	122001.5	-6.998	-18.00
2234	2234PG04	45.25626792	-93.69940955	122001.6	-8.775	-18.00
2234	2234PG05	45.25627318	-93.69940366	122001.7	-11.221	-18.00
2234	2234PG06	45.25626078	-93.69970573	121985.3	-8.898	-6.00
2234	2234PG07	45.25626683	-93.69970092	121985.0	-11.402	-6.00
2234	2234PG08	45.25629311	-93.69945572	121986.6	-8.800	-18.00
2234	2234LE01	45.25623675	-93.69967396	121997.2	-6.947	-6.00
2234	2234LE02	45.25624094	-93.69966839	121997.4	-9.035	-6.00
2234	2234LE03	45.25624596	-93.69966258	121997.4	-11.397	-6.00
2234	2234LE04	45.25623991	-93.69967928	121995.4	-7.024	-6.00
2234	2234LE05	45.25624393	-93.69967411	121995.5	-8.999	-6.00
2234	2234LE06	45.25624926	-93.69966904	121995.4	-11.335	-6.00
2234	2234LE07	45.25624233	-93.69968376	121993.9	-7.021	-6.00
2234	2234LE08	45.25624680	-93.69967940	121993.8	-8.995	-6.00
2234	2234LE09	45.25625190	-93.69967349	121993.9	-11.397	-6.00
2234	2234LE10	45.25624662	-93.69969155	121991.4	-7.035	-6.00
2234	2234LE11	45.25625103	-93.69968675	121991.4	-9.063	-6.00
2234	2234LE12	45.25625622	-93.69968088	121991.4	-11.485	-6.00
2234	2234ME01	45.25624652	-93.69969974	121989.7	-5.719	-8.00
2234	2234ME02	45.25624741	-93.69969914	121989.6	-6.070	-16.00
2234	2234ME03	45.25624762	-93.69970205	121989.0	-5.675	-20.00
2234	2234ME04	45.25624732	-93.69970177	121989.1	-5.632	-28.00
2234	2234MS01	45.25624720	-93.69970190	121989.1	-5.575	-8.00

Section	Sensor	Lat	Long	Station	Offset	Depth (in.)
2234	2234MS02	45.25624667	-93.69970063	121989.5	-5.623	-16.00
2234	2234MS03	45.25624710	-93.69969988	121989.6	-5.864	-20.00
2234	2234MS04	45.25624832	-93.69970026	121989.2	-6.157	-28.00
2236	2236PG01	45.25439161	-93.69625016	123106.4	-9.040	-6.00
2236	2236PG02	45.25439757	-93.69624460	123106.3	-11.638	-6.00
2236	2236PG03	45.25443655	-93.69600872	123103.2	-7.078	-18.00
2236	2236PG04	45.25443684	-93.69600810	123103.3	-8.841	-18.00
2236	2236PG05	45.25442740	-93.69601790	123103.3	-11.318	-18.00
2236	2236PG06	45.25442749	-93.69631741	123084.7	-9.174	-6.00
2236	2236PG07	45.25443303	-93.69631233	123084.6	-11.573	-6.00
2236	2236PG08	45.25445192	-93.69606508	123088.3	-7.130	-18.00
2236	2236LE01	45.25439936	-93.69627751	123099.1	-7.097	-6.00
2236	2236LE02	45.25440356	-93.69627276	123099.2	-9.056	-6.00
2236	2236LE03	45.25440844	-93.69626638	123099.4	-11.464	-6.00
2236	2236LE04	45.25440308	-93.69628485	123096.8	-7.052	-6.00
2236	2236LE05	45.25440722	-93.69627969	123096.9	-9.060	-6.00
2236	2236LE06	45.25441263	-93.69627402	123096.9	-11.513	-6.00
2236	2236LE07	45.25440565	-93.69629031	123095.1	-6.963	-6.00
2236	2236LE08	45.25440971	-93.69628473	123095.4	-9.010	-6.00
2236	2236LE09	45.25441572	-93.69627953	123095.1	-11.569	-6.00
2236	2236ME01	45.25440879	-93.69630233	123091.9	-6.031	-8.00
2236	2236ME02	45.25440884	-93.69630231	123091.9	-6.048	-16.00
2236	2236ME03	45.25440789	-93.69630163	123092.3	-5.874	-20.00
2236	2236ME04	45.25440831	-93.69630261	123092.0	-5.847	-28.00
2236	2236MS01	45.25440761	-93.69630083	123092.5	-5.916	-8.00
2236	2236MS02	45.25440791	-93.6963018	123092.2	-5.854	-16.00
2236	2236MS03	45.25440840	-93.69630034	123092.4	-6.222	-20.00
2236	2236MS04	45.25440949	-93.69630220	123091.8	-6.254	-28.00
2239	2239ME01	45.25276037	-93.69302304	124128.9	-5.903	-8.00
2239	2239ME02	45.25275998	-93.69302107	124129.4	-6.072	-16.00
2239	2239ME03	45.25276006	-93.69302127	124129.4	-6.067	-20.00
2239	2239ME04	45.25276125	-93.69302141	124129.1	-6.406	-28.00
2239	2239MS01	45.25276038	-93.69302179	124129.2	-6.087	-8.00
2239	2239MS02	45.25275986	-93.69302271	124129.1	-5.798	-16.00
2239	2239MS03	45.25276093	-93.69302274	124128.9	-6.118	-20.00
2239	2239MS04	45.25276127	-93.69302294	124128.8	-6.189	-28.00

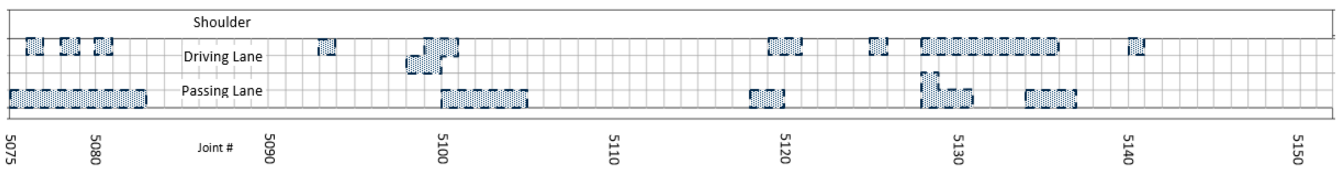
Appendix C - Concrete Overlay Test Sections Panels Replaced

Indicates Concrete Repair

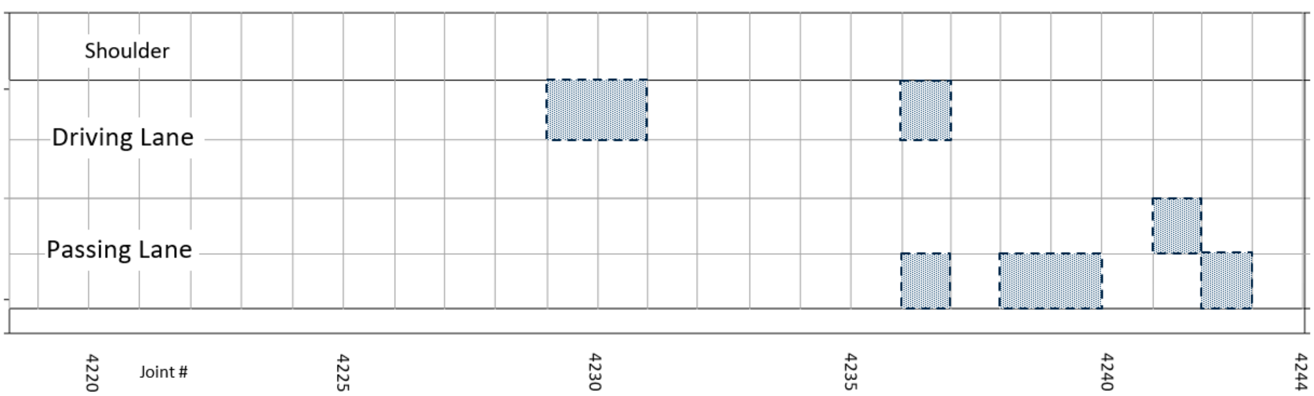
Test Section 160



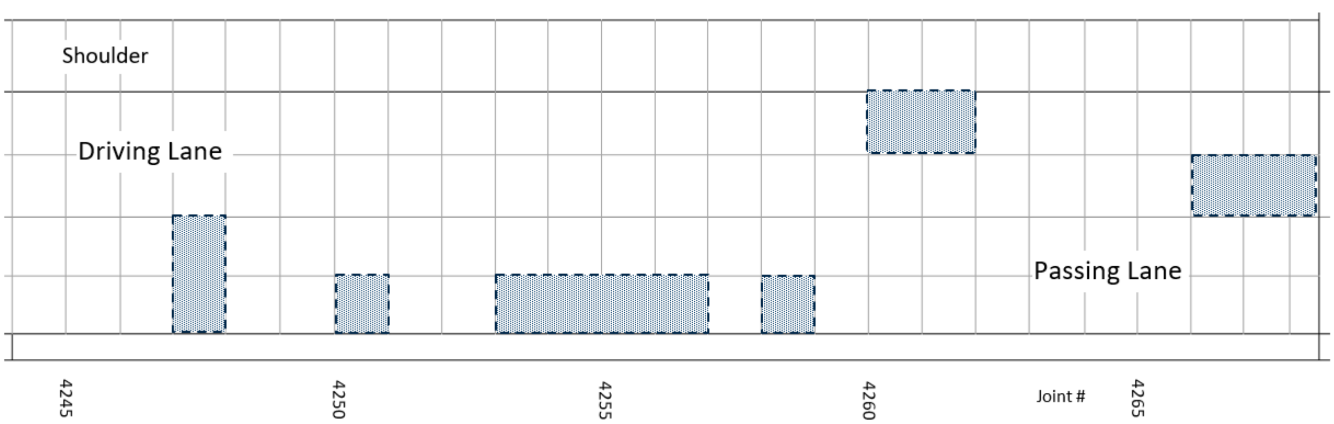
Test Section 162



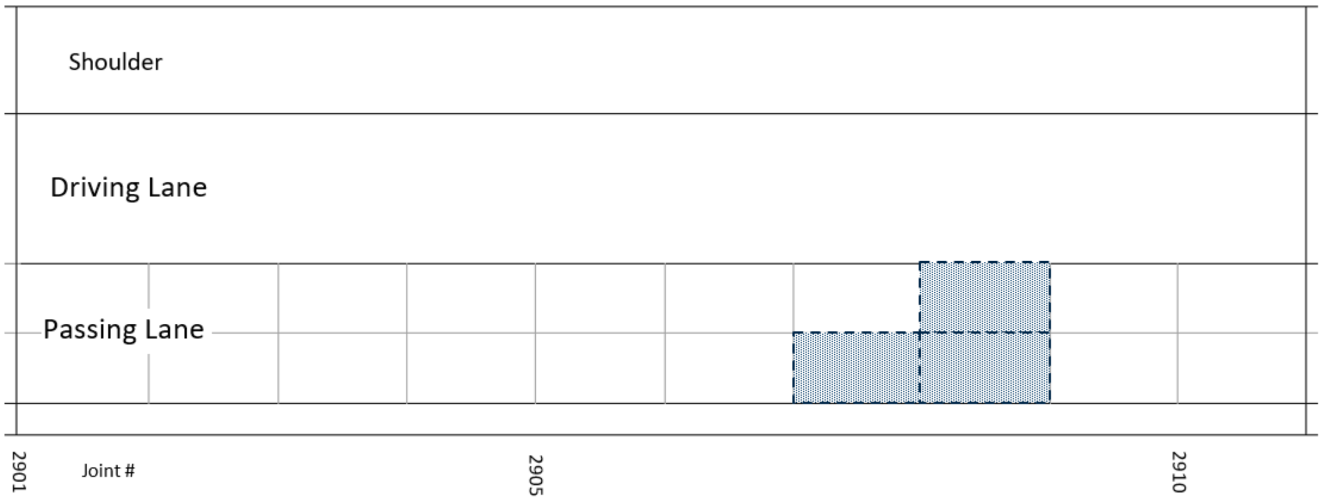
Test Section 505



Test Section 605



Test Section 705



Test Section 805

Appendix D
Project Specific Paving Mix Designs (JMF)

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Ultra High Materials	UHMSCM		2.70
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	FSIVI1000	F	4-12
Admx#3	Retarder	Proprietary	*	0.01%
Admx#4				
Admx#5				
Fiber				
Color				

Use for:

Paving Projects 3,500 CY or greater

Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CIA#1	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-206**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													54		16	22	8				
3A21-RGH1	7.0	152	0			660			100		660	0.23	1662		500	693	250	27.0	145.1	23.5	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst	Digitally signed by Matthew Herbst Date: 2022.08.08 16:04:26 -05'00'

Comments: Ultra High Materials for MNRoad
*Reatrder blended with SCM on the belt

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

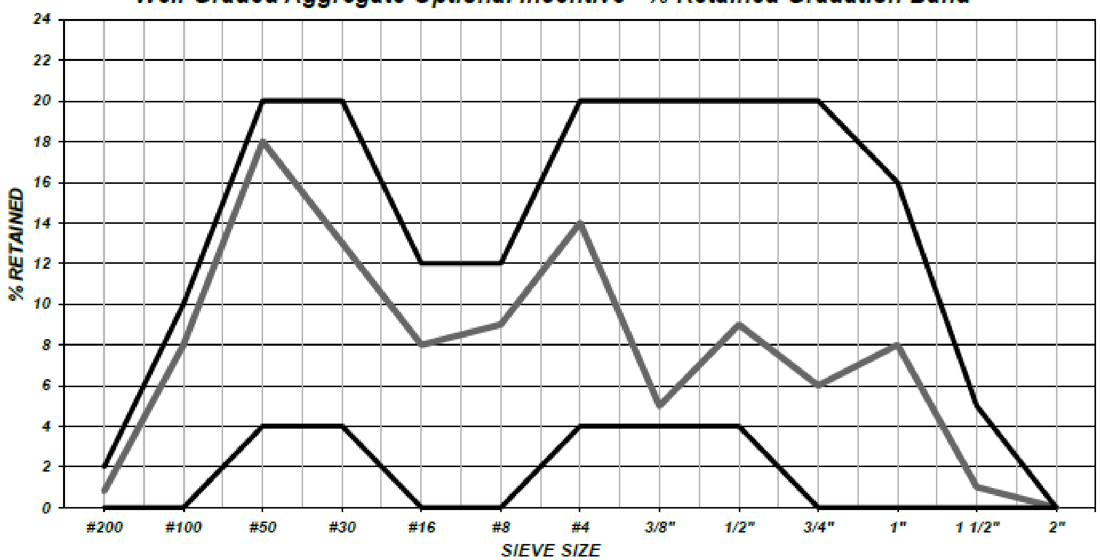
JMF **22-206**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING 100%	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	54		16	22	8					
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	91	± 5	86	96	8
3/4"	100.0		8.5	99.0	100.0	85	± 5	80	90	6
1/2"	100.0		0.4	64.4	100.0	76	± 5	71	81	9
3/8"	100.0		0.2	40.4	98.2	71	± 5	66	76	5
#4	99.0		0.0	4.1	32.9	57	± 5	52	62	14
#8	88.2		0.0	0.0	0.8	48	± 4	44	52	9
#16	74.4		0.0	0.0	0.1	40	± 4	36	44	8
#30	50.7		0.0	0.0	0.0	27	± 4	23	31	13
#50	17.0		0.0	0.0	0.0	9	± 3	6	12	18
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	8
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGH1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
30
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
40
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Contin./Davenport	CONDAIL	IL(10)	3.10
Fly Ash	EM/Coal Creek	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	MBS	MAIR90	AEA	0.1-10
Admx#2	MBS	AMPOL1020	A	0-12
Admx#3	MBS	SMMAT358	S	0-6
Admx#4	MBS	BMSTDELVO	B	0-5
Admx#5	MBS	SMSREZ60	S	0-12
Other	Carbon Cure	SCCCO2	S	6
Color				

Use for:

Paving Projects 3,500 CY or greater

Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71002	SAND		2.66	0.008
FA#2					
CA#1	71002	#67	C	2.70	0.014
CA#2	71002	3/4"+	C	2.65	0.016
CA#3					

SP Number	8680-191
Contract ID	220071
Requested By	Kevin Heindel
Company	Cemstone Products Company
Phone	651-686-4233
Email	kheindel@cemstone.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Cemstone - Dayton (#16)
Plant/Unit #	RM229
Contractor	PCI Roads
JMF Number	**22-178**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume								
													45		42	13					
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGCC	7.0	228	399	171			30				570	0.40	1367		1295	393		27.0	142.7	25.2	1/2 - 3
3A21-RGC1	7.0	228	387	166			30				553	0.41	1374		1301	395		27.0	142.6	24.9	1/2 - 3
3A21-RGC2	7.0	228	399	171			30				570	0.40	1367		1295	393		27.0	142.7	25.2	1/2 - 3
3A21-RGC3	7.0	228	387	166			30				553	0.41	1374		1301	395		27.0	142.6	24.9	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten Digitally signed by Maria Masten Date: 2022.07.26 07:09:36 -05'00'

Comments: Mixes 3A21-RGC1 and 3A21-RGC2 will have 6 oz/yd of CarbonCure.

Submit to: conc1off.dot@state.mn.us

Contractor Mix Design - Job Mix Formula (JMF)

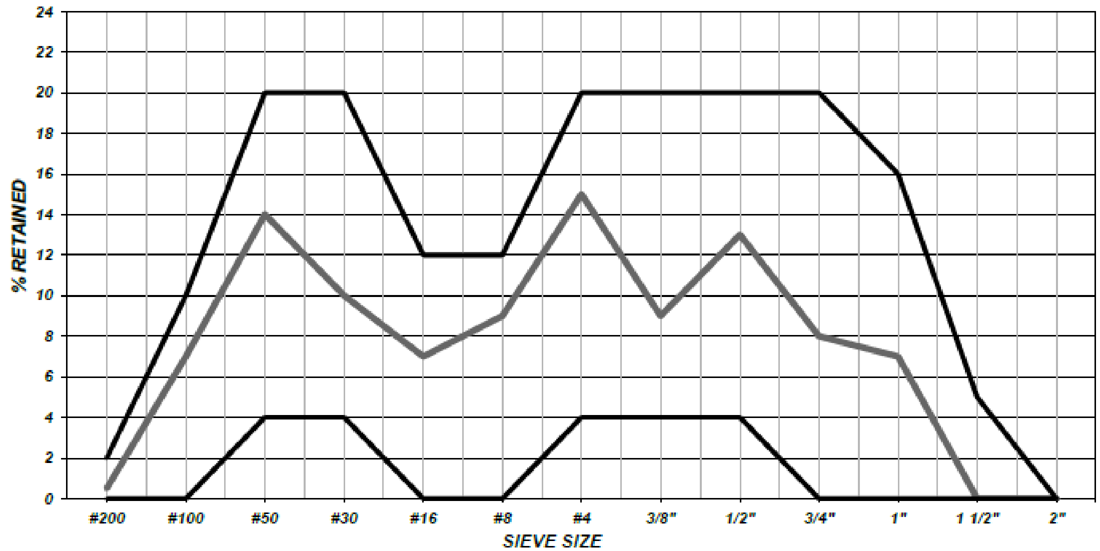
JMF 22-178

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		#67	3/4"+						
Prop. %	45		42	13		100%	LIMITS			
2"	100.0		100.0	100.0		100	± 5	95	100	0
1 1/2"	100.0		100.0	100.0		100	± 5	95	100	0
1"	100.0		100.0	49.0		93	± 5	88	98	7
3/4"	100.0		95.0	3.0		85	± 5	80	90	8
1/2"	100.0		63.0	1.0		72	± 5	67	77	13
3/8"	100.0		43.0	0.0		63	± 5	58	68	9
#4	99.0		8.0	0.0		48	± 5	43	53	15
#8	87.0		0.0	0.0		39	± 4	35	43	9
#16	71.0		0.0	0.0		32	± 4	28	36	7
#30	48.0		0.0	0.0		22	± 4	18	26	10
#50	17.0		0.0	0.0		8	± 3	5	11	14
#100	3.0		0.0	0.0		1	± 2	0	3	7
#200	1.0		0.0	0.0		0.5	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGCC
3A21-RGC1
3A21-RGC2
3A21-RGC3

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
26
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
32
Between 24-34%, generally enhances workability of the mix.

mn DOT

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Contin./Davenport	CONDAIL	IL(10)	3.10
Fly Ash	EM/Coal Creek	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	MBS	MAIR90	AEA	0.1-10
Admx#2	MBS	AMPOL1020	A	0-12
Admx#3	MBS	SMMAT358	S	0-6
Admx#4	MBS	BMSTDELVO	B	0-5
Admx#5	MBS	SMSREZ60	S	0-12
Other	Carbon Cure	SCCCO2	S	6
Color				

Use for:

Paving Projects 3,500 CY or greater

Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71002	SAND		2.66	0.008
FA#2					
CA#1	71002	#67	C	2.70	0.014
CA#2	71002	3/4"+	C	2.65	0.016
CA#3					

SP Number	8680-191
Contract ID	220071
Requested By	Kevin Heindel
Company	Cemstone Products Company
Phone	651-686-4233
Email	kheindel@cemstone.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Cemstone - Dayton (#16)
Plant/Unit #	RM229
Contractor	PCI Roads
JMF Number	**22-178**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													45		42	13					
3A21-RGCC	7.0	228	399	171			30				570	0.40	1367		1295	393		27.0	142.7	25.2	1/2 - 3
3A21-RGC1	7.0	228	387	166			30				553	0.41	1374		1301	395		27.0	142.6	24.9	1/2 - 3
3A21-RGC2	7.0	228	399	171			30				570	0.40	1367		1295	393		27.0	142.7	25.2	1/2 - 3
3A21-RGC3	7.0	228	387	166			30				553	0.41	1374		1301	395		27.0	142.6	24.9	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten — Digitally signed by Maria Masten Date: 2022.07.26 07:09:36 -05'00'

Comments: Mixes 3A21-RGC1 and 3A21-RGC2 will have 6 oz/yd of CarbonCure.

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Carbon Upcycling	CUCAAL		2.55
Admx#1	Sika Air 260	SIAIR260	AEA	As needed
Admx#2	Sika Visocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5				
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	Sand		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-181**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume								
													41		14	37	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGU1	7.0	200	350			150			30		500	0.40	1289		447	1190	255	27.0	143.7	22.1	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten — Digitally signed by Maria Masten Date: 2022.07.26 07:24:21 -05'00'

Comments: Carbon Upcycling 30% ASCM

Submit to: conc1off.dot@state.mn.us

Contractor Mix Design - Job Mix Formula (JMF)

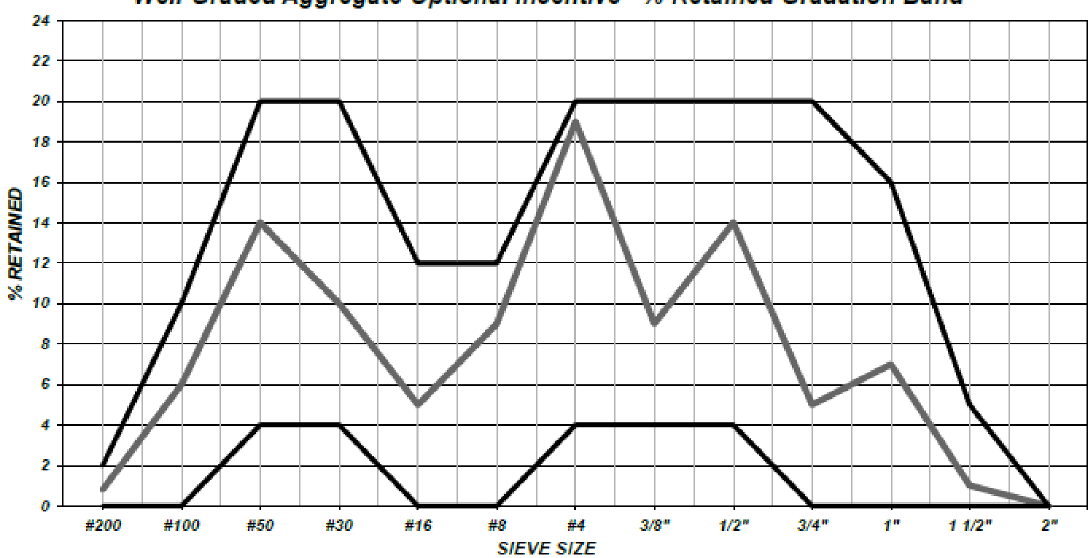
JMF **22-181**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	Sand		3/4"+	#67	CIA					
Prop. %	41		14	37	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	87	± 5	82	92	5
1/2"	100.0		0.4	64.4	100.0	73	± 5	68	78	14
3/8"	100.0		0.2	40.4	98.2	64	± 5	59	69	9
#4	99.0		0.0	4.1	32.9	45	± 5	40	50	19
#8	88.2		0.0	0.0	0.8	36	± 4	32	40	9
#16	74.4		0.0	0.0	0.1	31	± 4	27	35	5
#30	50.7		0.0	0.0	0.0	21	± 4	17	25	10
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	14
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGU1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
24
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
31
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Ash Grove LC3	ASGLC3		2.90
Fly Ash				
Slag				
Other CM				
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5				
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-180**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													39		15	39	7				
3A21-RGA1	7.0	239	570								570	0.42	1160		453	1187	211	27.0	141.5	25.9	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten — Digitally signed by Maria Masten Date: 2022.07.26 07:21:29 -05'00'

Comments: Ash Grove LC3 Cement

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation

CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

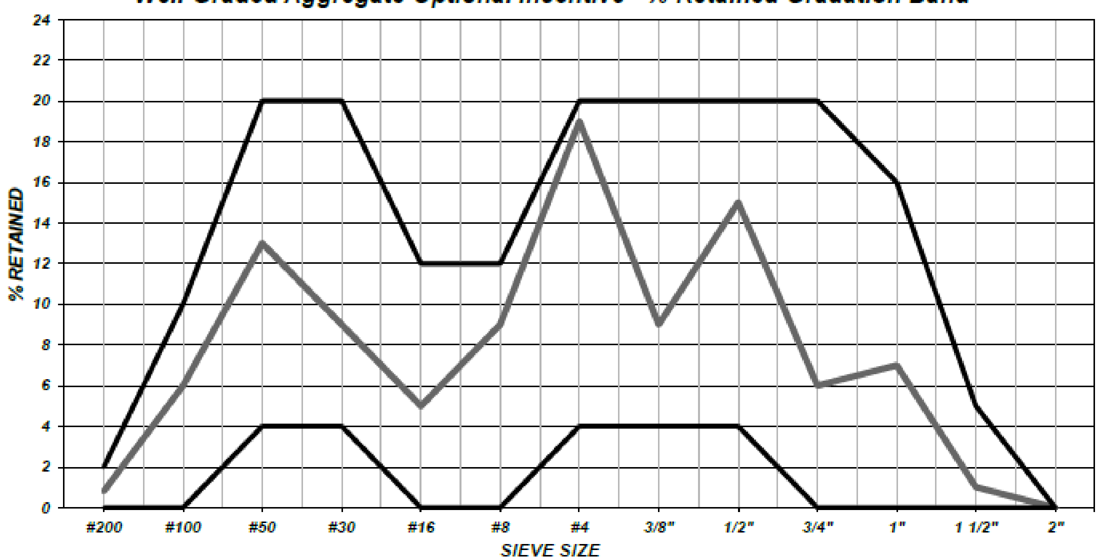
JMF **22-180**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	39	7	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	71	± 5	66	76	15
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	9
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGA1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Pozzotive	UMPOZZ		2.51
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5				
Fiber				
Color				

Use for:

Paving Projects 3,500 CY or greater

Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-179**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													39		15	38	8				
3A21-RGM1	7.0	217	400			170			30		570	0.38	1183		462	1179	246	27.0	142.8	24.6	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten — Digitally signed by Maria Masten Date: 2022.07.26 07:16:04 -05'00'

Comments: Urban Mining Pozzotive ASCM

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

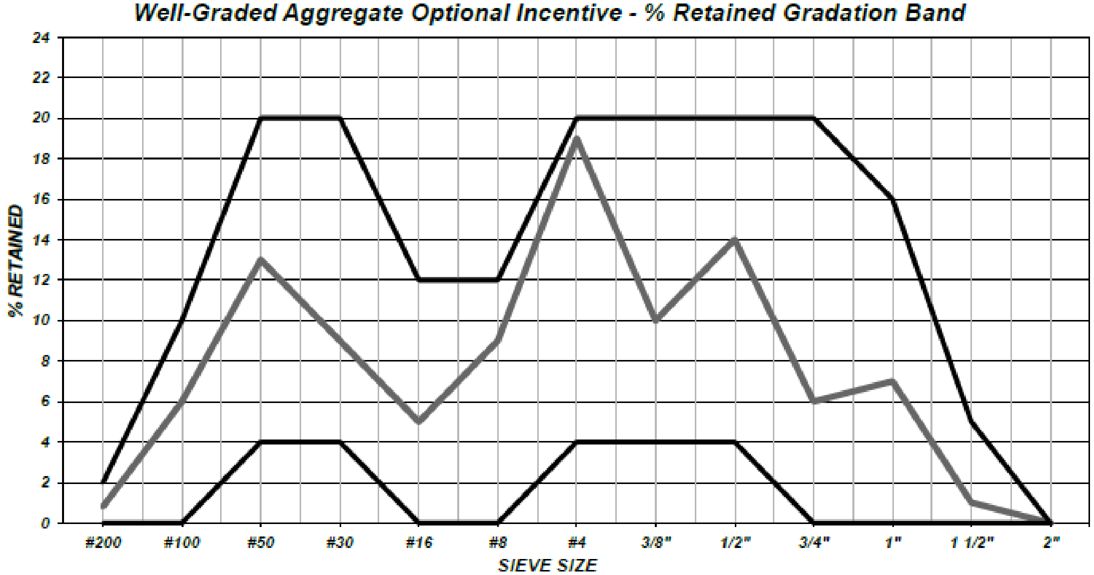
JMF **22-179**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGM1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Opus Terra CO2	TEOPUS		2.58
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5				
Fiber				
Color				

Use for:

Paving Projects 3,500 CY or greater

Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-182**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume								
													39		15	38	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGT1	7.0	217	370			200			35		570	0.38	1183		462	1179	246	27.0	142.8	24.6	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten Digitally signed by Maria Masten Date: 2022.07.26 07:41:39 -05'00'

Comments: MNRoad Paving with Terra CO2 Opus SCM

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation

CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

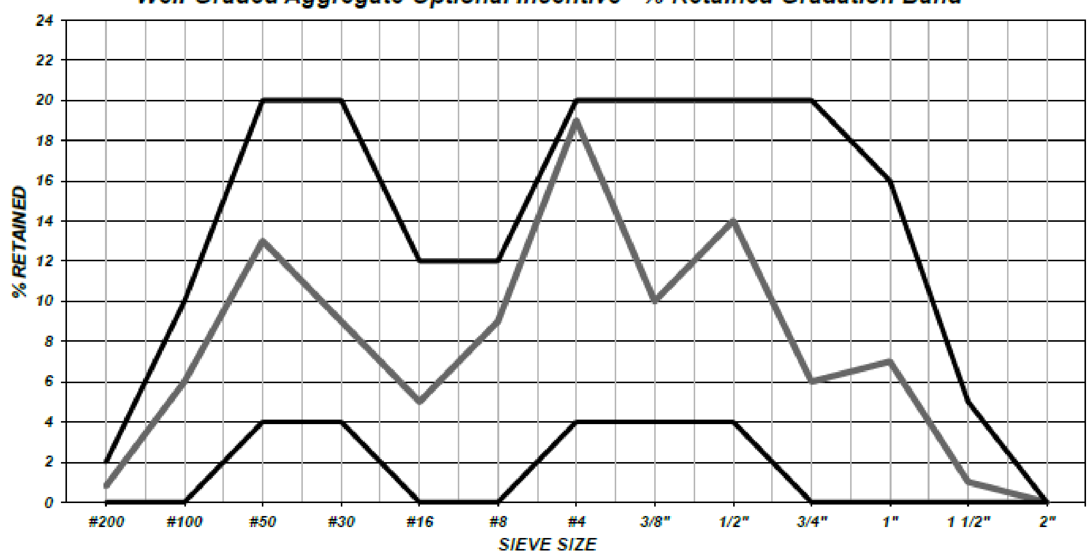
JMF **22-182**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGT1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation (4/28/21)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash	Boral Coal Creek	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Viscocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-184**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

% Aggregate Proportion by Volume: FA#1 39, FA#2 —, CA#1 15, CA#2 38, CA#3 8

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
												% Aggregate Proportion by Volume	39		15	38	8				
3A21-RGSC	7.0	228	400	170			30				570	0.40	1171		457	1167	244	27.0	142.1	25.2	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst — Digitally signed by Matthew Herbst Date: 2022.08.02 14:10:27 -05'00'

Comments: MNRoad Control Mix Design
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation (4/28/21)

Contractor Mix Design - Job Mix Formula (JMF)

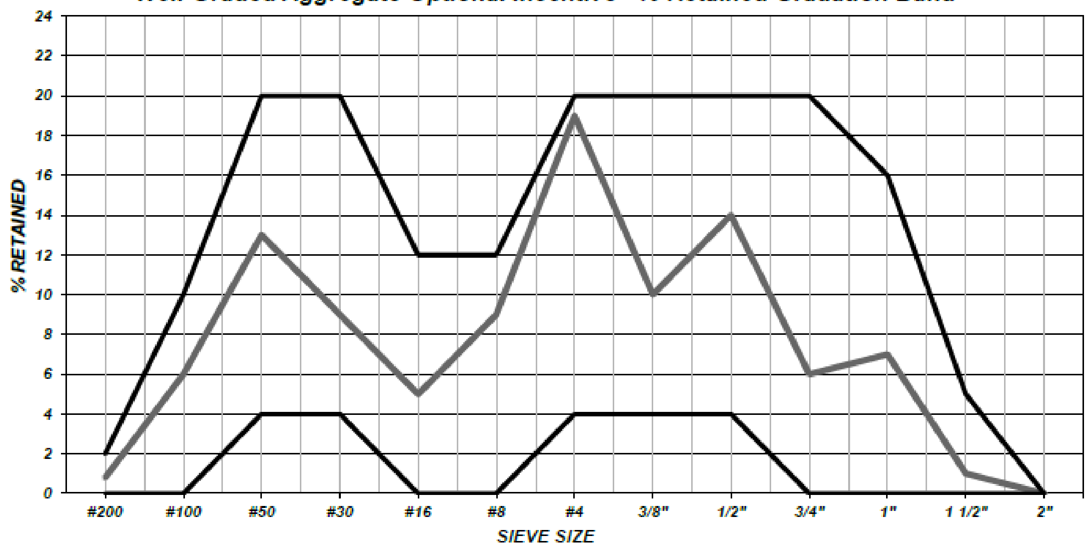
JMF **22-184**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8	100%				
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGSC

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash	EM Resources	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	0-7
Admx#5	Sika Viscocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

<u>Use for:</u>
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	841 - Rogers
Plant/Unit #	81/RM051
Contractor	PCI Roads
JMF Number	**22-183**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume									
													41		21	30	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGI1	7.0	200	351	150			30				501	0.40	1318		669	963	255	27.2	143.7	22.0	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst Digitally signed by Matthew Herbst Date: 2022.08.02 14:01:04 -05'00'

Comments: Optimized 3A21-RG paving mix
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Contractor Mix Design - Job Mix Formula (JMF)

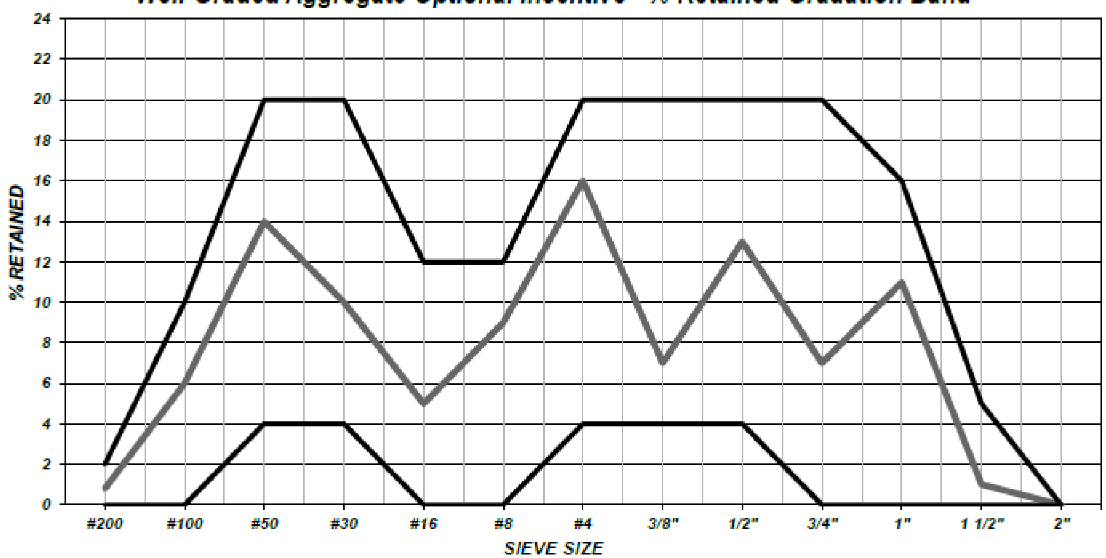
JMF **22-183**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	41		21	30	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	88	± 5	83	93	11
3/4"	100.0		8.5	99.8	100.0	81	± 5	76	86	7
1/2"	100.0		0.4	64.4	100.0	68	± 5	63	73	13
3/8"	100.0		0.2	40.4	98.2	61	± 5	56	66	7
#4	99.8		0.0	4.1	32.9	45	± 5	40	50	16
#8	88.2		0.0	0.0	0.8	36	± 4	32	40	9
#16	74.4		0.0	0.0	0.1	31	± 4	27	35	5
#30	50.7		0.0	0.0	0.0	21	± 4	17	25	10
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	14
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGI1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
24
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
31
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation
CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Burgess Optipozz	BPOPTPOZZ		2.51
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Viscocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-189**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume								
													39		15	38	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGB1	7.0	217	400			170			30		570	0.38	1183		462	1179	246	27.0	142.8	24.6	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst Digitally signed by Matthew Herbst Date: 2022.08.02 14:11:08 -05'00'

Comments: Burgess Pigments "Optipozz"
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

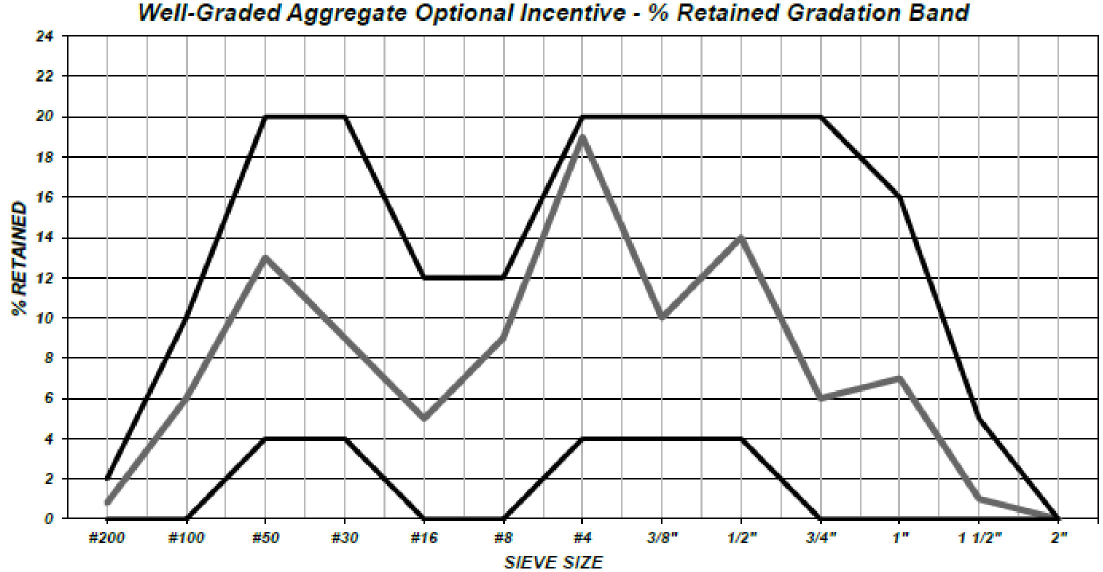
JMF 22-189

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGB1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation

CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	3M + Prarie State	3MNPPSGS		2.50
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Viscocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-188**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													39		15	38	8				
3A21-RG31	7.0	239	400			170			30		570	0.42	1160		453	1156	242	27.0	141.5	25.9	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst — Digitally signed by Matthew Herbst Date: 2022.08.02 14:10:49 -05'00'

Comments: 3M Natural Pozzolan and 15% Prairie State Fly Ash blended ASCM
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Contractor Mix Design - Job Mix Formula (JMF)

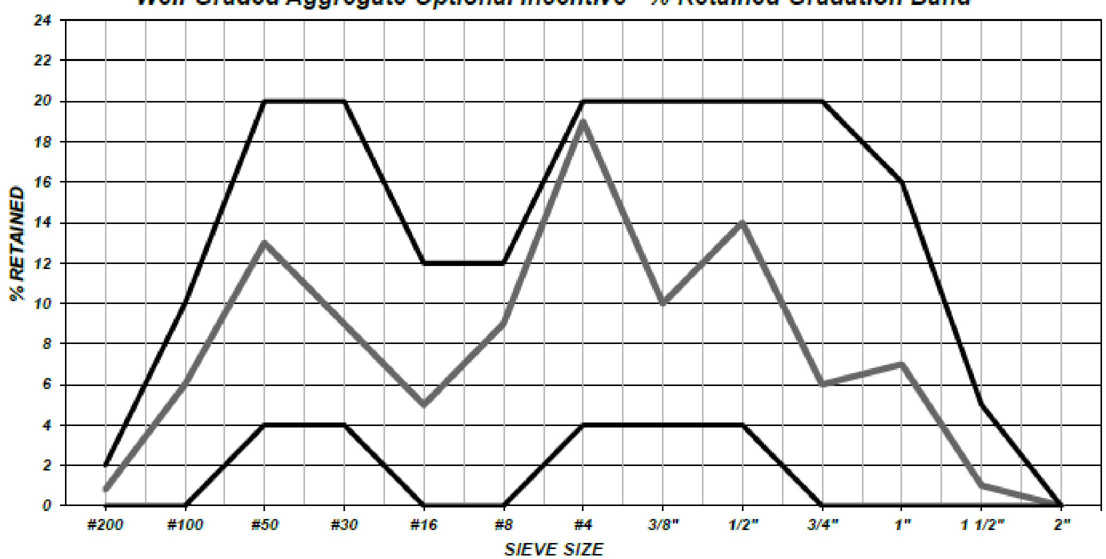
JMF **22-188**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING	WORKING RANGE	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8	100%	LIMITS			
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RG31

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Hess Pumice Standard	HPPOZZ		2.30
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Viscocrete 1000	FSIVI1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-185**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume									
													39		15	38	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGP1	7.0	239	400	85		170	13		26	39	655	0.36	1154		451	1150	240	27.0	144.0	26.2	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst Digitally signed by Matthew Herbst Date: 2022.08.02 14:01:46 -05'00'

Comments: Hess Pumice ASCM
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

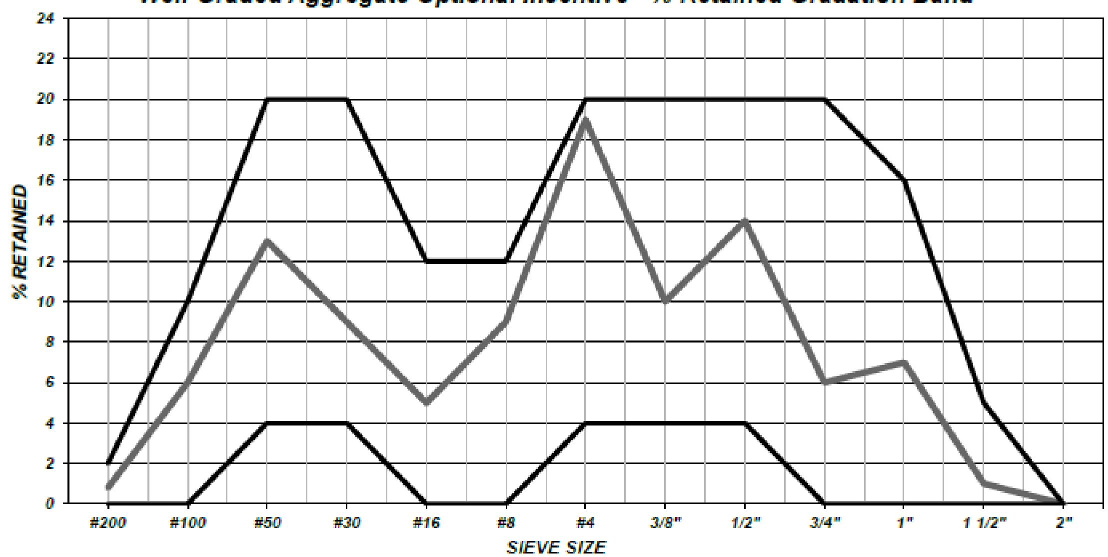
JMF **22-185**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL %	WORKING	JMF		TOTAL %
Agg. Size	SAND		3/4"+	#67	CIA	PASSING	RANGE	WORKING		RETAINED
Prop. %	39		15	38	8	100%	LIMITS	RANGE		
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGP1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Page 2

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Continental IL(20)	CONDAIL20		3.15
Fly Ash	EM Resources	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Viscocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-186**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
												% Aggregate Proportion by Volume	39		15	38	8				
3A21-RGO1	7.0	228	400	170			30				570	0.40	1173		458	1169	244	27.0	142.3	25.1	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst — Digitally signed by Matthew Herbst Date: 2022.08.02 14:01:26 -05'00'

Comments: Continental Davenport IL(20)
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation

CONC-203 (4/

Contractor Mix Design - Job Mix Formula (JMF)

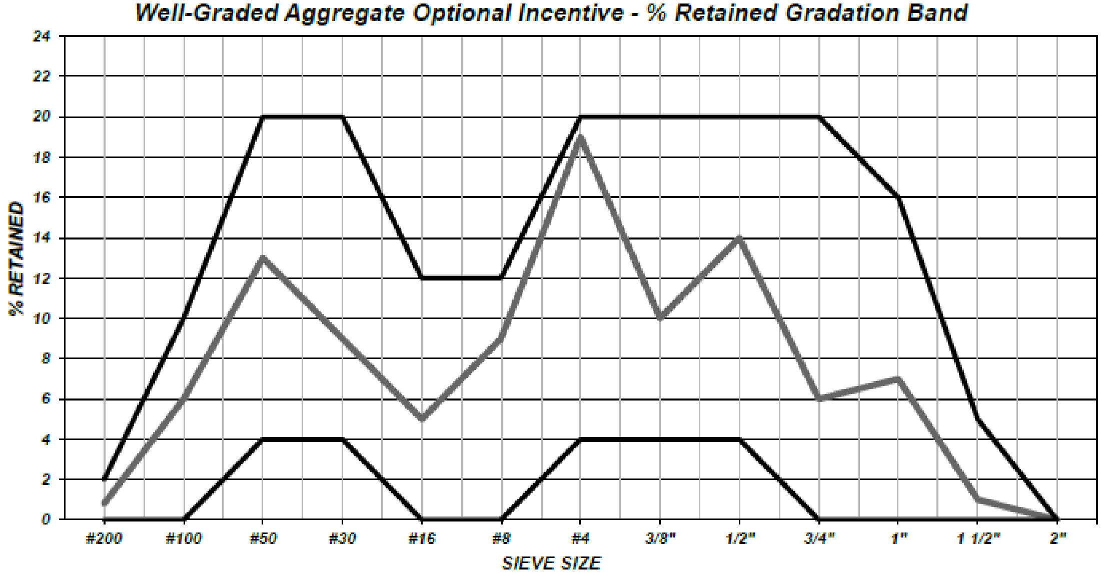
JMF **22-186**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING 100%	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	SAND		3/4"+	#67	CIA					
Prop. %	39		15	38	8					
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGO1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.

Page 2

Minnesota Department of Transportation CONC-203 (4/19/22)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash				
Slag				
Other CM	Carbon Limit	CLMLTDZ		2.06
Admx#1	Sika Air 260	SIAIR260	AEA	As needed
Admx#2	Sika Visocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5	Sika Visocrete 1000	FSIV1000	F	3-12
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	Sand		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-187**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
% Aggregate Proportion by Volume													40		15	37	8				
3A21-RGL1	7.0	228	400			170			30		570	0.40	1186		451	1122	241	27.0	140.7	26.1	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Matthew Herbst — Digitally signed by Matthew Herbst Date: 2022.08.02 14:11:25 -05'00'

Comments: Carbon Limit Natural Pozzolan and Catalyst
*High range water reducer, Sika Viscocrete 1000, dosage allows 2 to 3 times the control dosage per trial batch report.

Submit to: conc1off.dot@state.mn.us Page 1

Contractor Mix Design - Job Mix Formula (JMF)

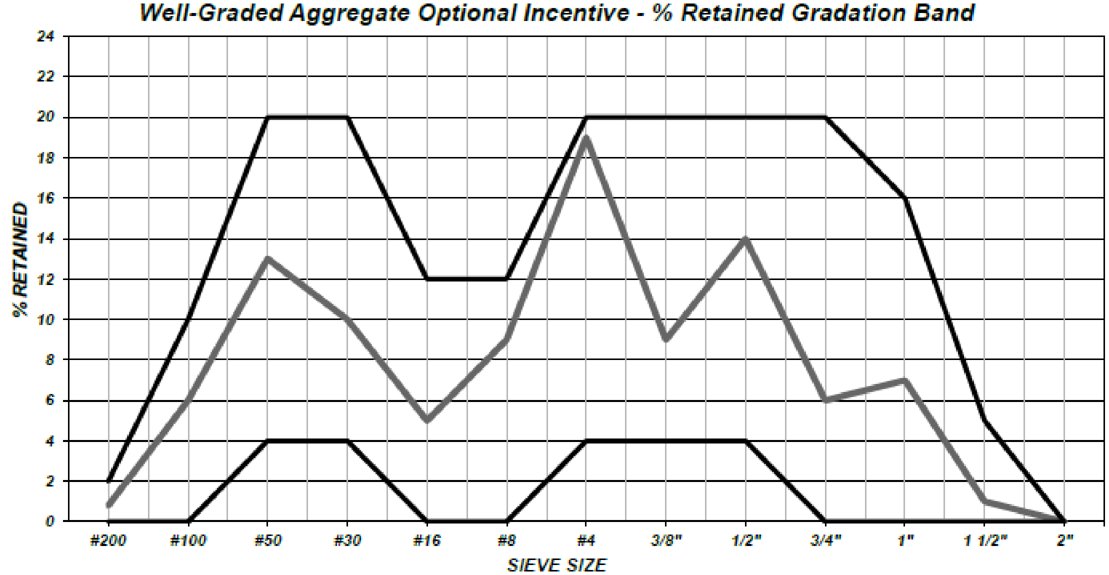
JMF **22-187**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL % PASSING 100%	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
Agg. Size	Sand		3/4"+	#67	CIA					
Prop. %	40		15	37	8					
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	63	± 5	58	68	9
#4	99.0		0.0	4.1	32.9	44	± 5	39	49	19
#8	88.2		0.0	0.0	0.8	35	± 4	31	39	9
#16	74.4		0.0	0.0	0.1	30	± 4	26	34	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	10
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGL1

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
24
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
30
Between 24-34%, generally enhances workability of the mix.

Minnesota Department of Transportation (4/28/21)

Project Specific Paving Mix Design (JMF)

	Name/Mill/Plant	MnDOT Abbreviation	Type/Class	SP.G / Dosage
Cement	Holcim St. Genevieve	STGBLIL	IL(10)	3.10
Fly Ash	Boral Coal Creek	COCUNND	F	2.50
Slag				
Other CM				
Admx#1	Sika Air 260	SIAIR260	AEA	As Needed
Admx#2	Sika Viscocrete 1000	ASIV1000	A	1-3
Admx#3	Sikatard 440	BSITA440	B	2-8
Admx#4	Stabilizer 4R	SSISA4R	S	1-7
Admx#5				
Fiber				
Color				

Use for:
Paving Projects 3,500 CY or greater
Job Specific Concrete using a JMF

	Pit #	Size	Class	SP.G.	ABS.
FA#1	71041	SAND		2.63	0.009
FA#2					
CA#1	19129	3/4"+	C	2.67	0.012
CA#2	71041	#67	C	2.69	0.013
CA#3	71041	CIA	C	2.67	0.015

SP Number	8680-191
Contract ID	220071
Requested By	Dustin Forester
Company	Aggregate Industries
Phone	612-961-2218
Email	dustin.forester@holcim.com
Agency Contact	Ben Worel
Agency Phone	651-358-1328
Agency Email	ben.worel@state.mn.us
Plant Name	Rogers
Plant/Unit #	841/RM051
Contractor	PCI Roads
JMF Number	**22-184**

All weights are in lb/cy. Aggregates are considered to be Oven Dry.

													% Aggregate Proportion by Volume									
													39		15	38	8				
Mix #	% Air	Water	Cement	Fly Ash	Slag	Other CM	% Fly Ash	% Slag	% Other CM	% Ternary	Total CM	W/C Ratio	FA#1	FA#2	CA#1	CA#2	CA#3	Volume	Unit Wt.	% Paste Volume	Slump Range, in
3A21-RGSC	7.0	228	400	170			30				570	0.40	1171		457	1167	244	27.0	142.1	25.2	1/2 - 3

The Concrete Engineer reviews the Contractor's concrete mix design submittal and approves the materials and mix design based on compliance with the contract. Final approval for payment is based on satisfactory field placement and performance.

MnDOT Approval	Maria Masten Digitally signed by Maria Masten Date: 2022.07.26 07:34:59 -05'00'

Comments: MNRoad Control Mix Design

Submit to: conc1off.dot@state.mn.us

Minnesota Department of Transportation (4/28/21)

Contractor Mix Design - Job Mix Formula (JMF)

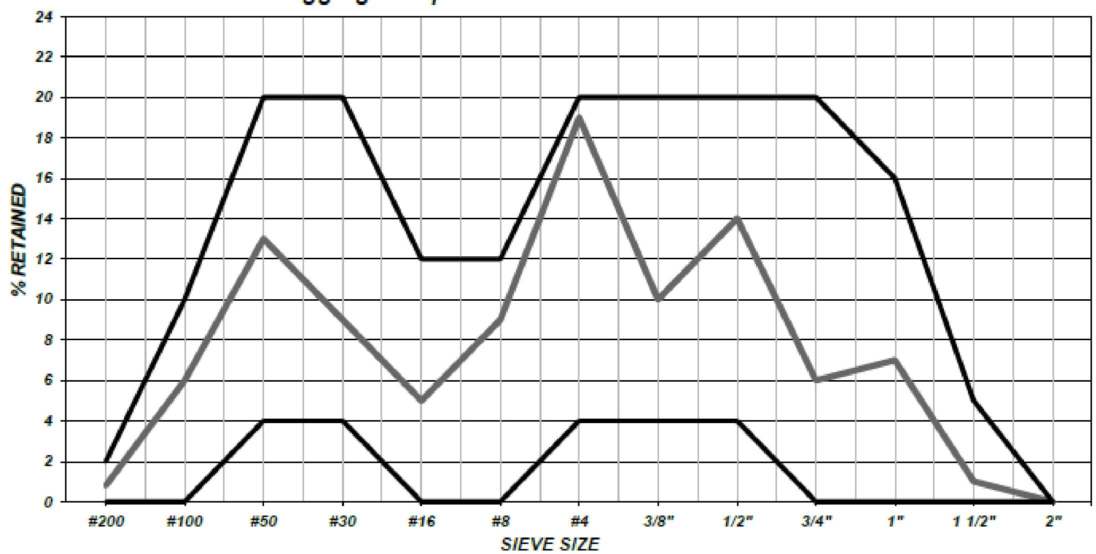
JMF **22-184**

SP 8680-191

	FA #1	FA #2	CA #1	CA #2	CA #3	TOTAL %	WORKING	JMF		TOTAL %
Agg. Size	SAND		3/4"+	#67	CIA	PASSING	RANGE	WORKING		RETAINED
Prop. %	39		15	38	8	100%	LIMITS	RANGE		
2"	100.0		100.0	100.0	100.0	100	± 5	95	100	0
1 1/2"	100.0		96.1	100.0	100.0	99	± 5	94	100	1
1"	100.0		45.2	100.0	100.0	92	± 5	87	97	7
3/4"	100.0		8.5	99.0	100.0	86	± 5	81	91	6
1/2"	100.0		0.4	64.4	100.0	72	± 5	67	77	14
3/8"	100.0		0.2	40.4	98.2	62	± 5	57	67	10
#4	99.0		0.0	4.1	32.9	43	± 5	38	48	19
#8	88.2		0.0	0.0	0.8	34	± 4	30	38	9
#16	74.4		0.0	0.0	0.1	29	± 4	25	33	5
#30	50.7		0.0	0.0	0.0	20	± 4	16	24	9
#50	17.0		0.0	0.0	0.0	7	± 3	4	10	13
#100	2.7		0.0	0.0	0.0	1	± 2	0	3	6
#200	0.4		0.0	0.0	0.0	0.2	≤ 1.6	0.0	1.6	1

Mix #
3A21-RGSC

Well-Graded Aggregate Optional Incentive - % Retained Gradation Band



Coarse Sand % Retained (#8 through #30)
23
Greater than 15%, generally enhances cohesion of the mix.

Fine Sand % Retained (#30 through #200)
29
Between 24-34%, generally enhances workability of the mix.