

# Cold Central Plant Recycling

NRRA FLEXIBLE TEAM

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# **COLD CENTRAL PLANT RECYCLING (CCPR) – NATIONAL ROAD RESEARCH ALLIANCE (NRRA)**

## **FINAL REPORT**

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## LIST OF ABBREVIATIONS

AC	Asphalt Concrete
CCPR	Cold Central Plant Recycling
CIR	Cold In-place Recycling (or Cold In-Place Reclamation)
CR	Cold-recycled (or Cold-reclaimed)
CSAH	County State Aid Highway
DCT	Disc-shaped Compact Tension
DIV	Digital inspection vehicle
EE	Engineered Emulsion
ESAL	Equivalent Single-Axle Load
FDR	Full-depth Reclamation
FWD	Falling-weight Deflectometer
GE	Granular Equivalency
HMA	Hot-Mix Asphalt
IDT	Indirect Tensile Strength
IRI	International Roughness Index
LVR	Low-Volume Road
M-E	Mechanistic-Empirical
MnDOT	Minnesota Department of Transportation
MnROAD	Minnesota Road Research Facility
NRRA	National Road Research Alliance
RAP	Recycled Asphalt Pavement
RQI	Ride Quality Index
SCB	Semi-Circular Bend
SFDR	Stabilized Full-depth Reclamation
SPT	Simple Performance Tester
SR	Surface Rating

## EXECUTIVE SUMMARY

Reclamation techniques such as cold-recycling and full-depth reclamation are sometimes treated as foundation (i.e., base or subgrade) concerns, and as a result, the materials and structures that result from these materials are not well understood by pavement engineers. This impression is reinforced by responses to a National Road Research Alliance (NRRRA) member survey completed in the early stages of this project; while many NRRRA members are accustomed to using recycled asphalt pavement (RAP) as a secondary material in pavement layers or in hot-mix asphalt (HMA) mixtures, the survey indicates that most members are new and/or unfamiliar with the use of RAP in cold-recycled (CR) layers such as those resulting from cold in-place recycling (CIR) or cold-central plant recycling (CCPR).

This NRRRA study was initiated with the construction of MnROAD CCPR test sections to investigate various options for CCPR in low-volume road applications, where local engineers or contractors may rely on a stockpiled, single-source RAP as a quality cold-recycled layer for a paving project. Both the laboratory and field testing strove to characterize the CR layers as they performed *in-situ*. The field sections at MnROAD were intended to simulate low-volume road applications, therefore the project endeavored to limit the preparation demands and characterization needs of the RAP stockpile. Furthermore, the field sections adequately represented the performance of CR mixtures in wet-freeze climates such as those found in the Upper Midwest region of the United States.

Major conclusions from this study are as follows.

- The laboratory tests determined that the MnROAD CCPR mixtures performed comparably to cold-recycled mixtures that were tested in other studies (Zegeye et al., 2017; Schwartz et al., 2017). The project team encountered difficulty with low-temperature semi-circular bending (SCB) tests.
- Field surveys and field tests determined that the CCPR test section performance was more of a study of the structural properties of two surface types adopted (1.5-inch HMA overlay and double chip-seal treatment) over the CCPR lifts than it was an investigation of the recycling agents and binders. The field performance of the test sections suggested that chip-sealed CCPR lifts risk early significant rutting. However, the sections with 1.5 inches of HMA did not develop significant rutting and are possible designs for future projects.
- The study demonstrated for NRRRA members that CCPR with a sufficient structural overlay (roughly equivalent to a 1.5-inch HMA overlay in MnROAD's experience) provides a promising pavement for low-volume applications. Future studies may refine this result by determining what structure can best meet traffic and environmental demands (i.e., for the MnROAD application, the double chip seal was insufficient while the "thinlift" HMA performed well).

In addition to the original scope of this project, this study was able to use project resources to assist NRRRA in the development of stabilized full-depth reclamation (SFDR) mix designs for the construction of new test cells at MnROAD. These reclamation efforts add another point of emphasis on the importance of reclamation techniques for roads at all levels of management.

## CHAPTER 1: INTRODUCTION

Local and state agencies are increasingly using recycled asphalt pavement (RAP) materials to construct structural layers of asphalt pavements. These layers are typically constructed using cold in-place recycling (CIR) methods, which involve cold-milling 3 to 4 inches of the existing pavement, mixing it with added asphalt emulsion or foamed asphalt and placing and compacting the material in one continuous operation. An alternative method using stockpiled RAP can be used to construct a reclaimed structural pavement layer. This method is known as cold central plant recycling (CCPR).

In 2017, the National Road Research Alliance (NRRRA) supported the construction of full-scale pavement test sections at the Minnesota Road Research (MnROAD) facility that featured the use of CCPR for low-volume applications. These test sections were constructed using different asphalt recycling agents (both foamed asphalt and engineered emulsion) for the CCPR layer and different surface courses (thin hot-mix asphalt or double chip seal). After the construction of these sections, NRRRA initiated a study to characterize the CCPR layers and CCPR test section performance. This report details that project.

### 1.1 PROJECT OBJECTIVES

The research objectives were to explore the performance of the MnROAD CCPR test sections through laboratory and field tests to characterize properties of the CCPR layer and general performance of the pavements. In addition, the study included a literature review and survey of NRRRA members to assess NRRRA awareness of, and interest in, CCPR.

### 1.2 REPORT STRUCTURE

The remainder of the report documents the project work in the chapters listed below.

- Chapter 2: Focused literature review of CCPR and a summary of the NRRRA member survey
- Chapter 3: MnROAD construction information for the CCPR test sections
- Chapter 4: Laboratory tests of CCPR mixtures and analysis of collected laboratory data
- Chapter 5: Field tests and analysis of collected field data
- Chapter 6: Summary of the Stabilized Full Depth Reclamation (SFDR) mix design that was provided for MnROAD Cells 1 and 2 using resources from this project
- Chapter 7: Discussion and conclusion

The chapters may refer to supplementary information and data in the appendices summarized below.

- Appendix A: Full results of the NRRRA member survey
- Appendix B: Field test data and results of analysis
- Appendix C: Laboratory test data and results of analysis
- Appendix D: SFDR mix design reports for MnROAD Cells 1 and 2.

## CHAPTER 2: LITERATURE REVIEW AND NRRRA MEMBER SURVEY

### 2.1 LITERATURE REVIEW

#### 2.1.1 Cold-Recycling Asphalt for Road Rehabilitation

In response to an increased need to reuse materials in new and rehabilitated pavements, local and state agencies rely on recycling techniques using RAP to create environmentally friendly and cost-effective solutions. Recycling not only promotes the conservation of non-renewable natural resources (reduction of use of virgin materials), but it also reduces the volume of stockpile materials. Recycling methods that use RAP to create a renewed/rehabilitated pavement include hot in-place recycling (HIR), CIR, and CCPR.

- Due to hot-mixing of RAP, HIR can differ considerably from cold recycling methods. HIR is not as common among NRRRA member states as a rehabilitation method as is CIR.
- CIR is an entire recycling process that occurs directly in situ. It consists of an equipped train that can range in size from a single unit to multi-unit train. (ARRA, 2015) During the CIR process, the existing pavement is cold milled to a desired particle size distribution. The generated RAP is then processed and mixed with a recycled agent. Once the mixing process is complete, the product is placed back, typically through a bituminous paver, and compacted directly on the same roadway.
- Unlike HIR and CIR, the reclamation portion of CCPR is not performed directly on site (i.e., “in-place”). Instead, material from one or more pavements are recycled – typically through milling operations – and the resulting RAP is then stockpiled at a location for later use in other applications, including CCPR. When used for CCPR, the stockpiled RAP is sized, cold-mixed, hauled to the paving site, and dumped into pavers which then place the CCPR layer. The cold-mixing process denotes the “central plant” in CCPR, and mixing can take place at a stationary batch plant near the paving site or a stationary CIR pugmill mixer at or near the paving site. After placement, the CCPR layer is compacted as a CIR layer would be, using vibrating steel drum rollers or other methods.

For the purposes of this study, the literature review provides a brief history of CCPR and recent research that investigated CCPR. In addition, figures illustrating cold recycling and CCPR concepts are well documented in the literature (ARRA, 2015) and are provided exclusively in the Chapter 3 of this report as they pertained to the MnROAD CCPR test cell construction.

#### 2.1.2 Recent Literature

Much of the older literature describing cold recycling methods, such as a Minnesota Department of Transportation (MnDOT) sponsored overview of CIR/CCPR literature (Salomon and Newcomb, 2000) allude to CCPR but do not describe its methods and field applications in detail. For this reason, a precise history of CCPR projects in North America is difficult to track. The CIR practices of agencies and contractors were reported on in Wood et al (1988), which notes that 24 of 50 states contacted had CIR experience as of 1988. Of those 24 states, half had a CIR paving specification. Wood et al (1988) does

not comment on the use of CCPR. Wood et al (1988) notes that most states using CIR did not have a mix design procedure or criteria; Scholtz et al (1990, 1991) and Salomon and Newcomb (2000) detail the development of CIR mix designs – which may have been applied to CCPR. In short, literature that discusses cold asphalt recycling focuses on CIR, and discussion of CCPR largely alludes to the fact that CCPR can be used in the rare instances when CIR is not practical or possible due to site constraints.

There are a handful of recent unpublished resources, such as conference presentations, that describe CCPR case studies (i.e., local/state experience). These case studies often describe location and illustrate construction, but exclude details on the decision-making process, design, material characterization, long-term performance, and/or costs. However, some presentations by Pavement Recycling Systems, Inc. (PRS), of Jurupa Valley, CA, details this contractor's decades long experience with recycling methods – including CCPR. An example of one such presentation by Valentine (2016) is included in the references. Experienced contractors should be included in the NRRRA CCPR survey to harvest more specific details on CCPR projects.

Most published work in CCPR-related research can be attributed to the ongoing effort of the Virginia Department of Transportation (DOT), which has directly investigated and/or supported cold recycling options, including CCPR, in the past five years. The project most relevant to this project is the study of three full-scale pavement test sections at the National Center for Asphalt Technology (NCAT) that were constructed using CCPR layers (Diefenderfer et al, 2017). The full-scale sections were built in 2012 – including instrumentation – and regularly monitored and tested (e.g. FWD) for two years. The initial intent of the project was to use cold in-place recycling (CIR) to construct the base layer. However, due to concerns over the ability to maintain a consistent recycled material through milling and processing on-site, the project instead used a stockpiled, processed RAP. The processing of stockpiled RAP is a critical, and often overlooked, component of CCPR. Fractionated RAP was used to improve consistency in the Virginia DOT/NCAT sections.

The Virginia DOT/NCAT study included useful testing data and analysis characterizing the CCPR layers used in a pavement structure designed for interstate-type, heavy truck traffic. Material characterization of these layers is in keeping with research and discussion to be found in Schwartz et al (2017). An interesting result from the Virginia DOT/NCAT data was the response of pavements using these CCPR layers under loading: the strain response of CCPR layers under load resembled those of conventional asphalt layers. This points to the ability of recycled material layers to do more than benefit a given pavement economically – CCPR methods allow for recycled layers to be engineered in such a way as to benefit the pavement structurally.

The reader is referred to the Diefenderfer et al (2017) and Schultz et al (2017) studies for further discussion of CCPR-related literature.

### **2.1.3 CCPR Mix Design Process and Specifications**

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The literature review did not uncover many state agency paving specifications for mix design and construction specific to CCPR. Nevada DOT maintains a specification for cold processing of centrally located RAP stockpiles. Other guidance for CCPR mix design and construction were industry guidelines,

most notably the guidelines developed by the Asphalt Recycling and Reclaiming Association (ARRA) in its *Basic Asphalt Recycling Manual* (2015). ARRA's resources detail specifications, material selection, mix design, construction, and quality control for cold-mixed methods in a manner that assists NRRRA state members in determining important factors.

Because the reader may not be familiar with cold-recycled mix design procedures for CIR/CCPR, the general mix design method is summarized below.

- Field sampling should provide RAP materials that represent, as completely as possible, the length, width, and depth of the pavement to be reclaimed/rehabilitated. For CCPR operations, the sampling plan would account for RAP stockpiles intended for use on the project.
- Cores should be processed to determine binder content and other characteristics. Processing should ultimately produce RAP at a gradation that resembles the target gradation for field reclaiming. For CCPR operations, given that materials are stockpiled, it is possible to control the field gradation tightly to reduce the variability of the mix and improve performance. For example, the Virginia DOT/NCAT collaboration demonstrated the use of fractionated RAP to produce a consistent mix and well-performing cold-recycled layer.
- The mix at the target gradation is combined with the recycling agent to batch and cure specimens for physical testing for Marshall stability (ASTM D6927), indirect tensile strength (ITS) (ASTM D4867 or AASHTO T 283), and/or low-temperature creep/strength (AASHTO T 322). Marshall stability and/or ITS testing will normally include saturated specimens to develop retained strength relationships. Methods of saturation will vary, but normally these methods target a minimum of 50 to 60 percent saturation in samples.
- NOTE: A key distinction between cold-recycled and HMA mix designs is the compactive effort required to produce a laboratory specimen that resembles the placed field mix in density. ARRA and AASHTO recommend 30 gyrations using a Superpave gyratory compactor (or 75 Marshall blows) to produce samples for a cold-recycled mix design (ARRA 2015; AASHTO 2017; AASHTO 2018). This requirement ensures that laboratory specimens for mix designs resemble as-compacted field CR layers.
- The pavement engineer consults test results and relevant performance specifications to determine an optimum addition rate for the recycling agent. AASHTO MP 38-18, the preliminary specification for the mix design of CR mixtures with foamed asphalt, indicates a minimum cured strength in indirect tensile testing (AASHTO T 283) of 45 psi and a retained strength of 70%. Retained strength may also be referred to as the tensile strength ratio (TSR), which in this instance would be 0.70. Other specifications may use additional tests for performance requirements (e.g. Marshall stability) or for information only (e.g. AASHTO T 322 for low-temperature performance).

The above summary is by no means comprehensive. Important steps that are not included are accounting for optimum moisture of the mix (including water added at the milling head) and the selection of the asphalt recycling agent. The reader is referred to ARRA and AASHTO for more details on accounting for moisture. Regarding the recycling agent, the most common recycling agents for cold-

mixed RAP are emulsified asphalts, which include engineered emulsion (EE), foamed asphalt, and, in older designs, cutback asphalts. The MnROAD CCPR test sections used EE and foamed asphalt.

- Engineered emulsion (EE) agents are modified emulsions that outperform unmodified emulsions in important ways, such as curing time, moisture resistance, or binder stiffness. Methods of adjustment for a given EE include but are not limited to pH modification, polymer modification, and the use of fluxing agents.
- Foamed asphalt agents are a mixture of air, cold water, and hot asphalt. The introduction of cold water into the hot asphalt creates a rapidly emulsified mixture that includes a large amount of regularly sized and regularly dispersed bubbles. These bubbles reduce the viscosity of the agent and increase its volume and effective surface area, thereby allowing it to better coat reclaimed materials.

In addition to an asphalt recycling agent, some CCPR mix designs may include the use of lime or cement to increase the stiffness of the completed layer at early ages and improve moisture resistance. When used, cement or lime content is typically between 1 and 2 percent of the mixture by weight. While many CR mix designs use added cement or lime when moisture or early strength is a concern, cement/lime use is not a necessity. In some cases, lime/cement use can lead to brittle mixtures that can degrade prematurely (ARRA, 2015).

#### **2.1.4 Incorporating CCPR Layers in Structural Pavement Designs**

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Many conventional pavement design procedures used by state agencies can accommodate CR layers without any issue. For AASHTO 1993 and other empirical low-volume procedures that rely on structural coefficients or equivalent concepts, designers can refer to agency experience or published research that includes the following resources.

- As a product of the NCAT study of its CCPR sections, Diaz-Sanchez et al (2017) estimated from FWD data and data from instrumented CCPR layers that the AASHTO structural number of the CCPR lift was approximately 0.36-0.39 in-1.
- The MnDOT State Aid Office, which Minnesota city and county engineers consult on low-volume pavement designs, assigns a granular equivalency (GE) value of 1.5 to CR layers. That is, MnDOT estimates that 1 inch of a CR base has the structural equivalency (in terms of stiffness) as 1.5 inches of a prepared MnDOT Class 5 granular base.

Mechanistic-empirical (M-E) designs typically prioritize the use of the elastic/resilient modulus to characterize layer behavior. Test methods (e.g. AASHTO T 307) used to estimate resilient modulus for other base materials are appropriate for CR materials. The reader is again referred to Diefenderfer et al (2017) and Schwartz et al (2017) for more information on material properties of CR layers and the use of these properties in M-E design procedures.



## 2.2 NRRRA MEMBER SURVEY QUESTIONS AND RESPONSES

On April 2019, an online survey was distributed to NRRRA members to learn more about member experiences with CCPR/CIR and their interests in the project work. The survey was created through online survey services. A total of 19 NRRRA members responded to the survey. The questions were as follows.

- 1) Please provide your name and organizational affiliation.
- 2) Is your organization aware of CCPR technology?
- 3) On what type of projects would you consider using CCPR?
- 4) Does your agency have a CCPR mix design and/or construction specification?
- 5) Does your state have field QC/QA procedures established for CCPR?
- 6) The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to [dave.vandeusen@state.mn.us](mailto:dave.vandeusen@state.mn.us)
- 7) What do you believe to be the challenges to acceptance of CCPR in your state/region?
- 8) Any additional comments?
- 9) If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please contact the Technical Liaison.

NRRRA State and Industry Members responses are attached in Appendix A. The survey uncovered that only a few state members had recent experience with CCPR, and that state representatives had generally little to no exposure to cold-recycling techniques. This observation was supported by NRRRA Flexible team meetings during the lifespan of the CCPR project, which did not include extensive discussion of CCPR beyond repairs to MnROAD Cell 133 (Section 3.5.1).

During the summer of 2020, just prior to the conclusion of the CCPR project, the NRRRA organizers created a series of workshops in to meet directly with state agency members and discuss their interest in ongoing NRRRA research. Despite the previous survey results, three agencies identified the CCPR project as one of a few key interests to discuss at those meetings. An example of the three-slide presentation for each agency is shown in Figure 1. The NRRRA-led, single agency-focused workshops confirmed survey results that many state agency engineers were not familiar with cold-recycling techniques, however those workshops also revealed an interest in the basics of cold-recycling construction and mix design development.

## Cold Central Plant Recycling (CCPR)

**Project Introduction**

- PI: David Rettner
- American Engineering

**What is CCPR?**

- C
- A

**CCPR vs CIR**

- C
- C
- C

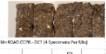
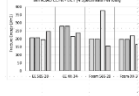
**NRRA CCPR Project Goals**

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- C
- C
- C
- C
- C

**Cold Central Plant Recycling (CCPR)**

**MnROAD Field Section**

- 3.5" CCPR
- 1
- Clay/loam subgrade
- Fall 2017 construction

**Lab Tests @ AET**

**Cold Central Plant Recycling (CCPR)**

**Project Status**

- Lab tests complete, results discussed at NRRA 2019 workshop
- Current field condition monitoring on-going by MnROAD engineers
- Other activities ongoing, TAP meeting early May
- NOTE:** Project resources used to develop last-minute MnROAD SFDR mix designs in Aug 2019

**Findings and Implementation**

- General DOT interest in CCPR low (not a lot of stockpiled RAP waiting to be used)
- Implementation through briefs (to be produced) and discussion with interested DOTs

*Thank you for your interest! Let's Discuss with MDOT*

Figure 1 Three-slide project summary delivered at NRRA-led workshops for member agencies

## CHAPTER 3: MNROAD TEST SECTION CONSTRUCTION AND PLANNING

The study focused on the performance of CCPR test sections at MnROAD that were constructed in 2017. Those test sections are designated as MnROAD Cells 133, 233, 135, and 235. The CCPR sections are each 425 ft long and occupy a total length of 1,700 ft.

### 3.1 STRUCTURAL DESIGN

The MnROAD CCPR sections replaced the low-volume road (LVR) Cells 33 and 35, which were constructed in 2007. Cells 33 and 35 were 4-inch HMA pavements over a MnDOT Class 6 base layer and clay loam subgrade. In a process that was intended to mimic LVR circumstances for many cities and counties, the 4-inch HMA layer on Cells 33 and 35 was replaced with a CCPR (i.e., structural or asphalt base) layer and a surface layer. The Class 6 base and prepared subgrade from Cells 33 and 35 were left undisturbed – that is, they were adopted in the designs for 133, 233, 135, and 235, which are shown in Figure 2.

The CCPR lift thickness was 4 inches, and the wearing course was either a double chip seal surfacing or a 1.5-inch HMA layer. MnROAD construction records do not indicate an intent to follow a design procedure or meet a structural thickness requirement. While there are field pavements featuring cold-recycled or SFDR layers that are surfaced with thin HMA or chip seals, in general a conventional pavement using a CCPR layer would be finished 3-inches of HMA. In the MnROAD case, the pavement cross-sections were designed to investigate less robust pavement structures with CCPR layers for rural/local applications and to accelerate damage so that distress could be observed within the lifespan of the test sections.

133	233	135	235
2X Chjp	2X Chjp	1.5" HMA	1.5" HMA
4" CCPR Emulsion	4" CCPR Foam	4" CCPR Foam	4" CCPR Emulsion
12" Class 6	12" Class 6	12" Class 6	12" Class 6
Clay	Clay	Clay	Clay
2017 425	2017 425	2017 425	2017 437

Figure 2 Cross-section design for MnROAD Cells 133, 233, 135, 235

### 3.2 MATERIALS AND COLD-RECYCLING MIX DESIGN

Prior to construction, the contractor for the MnROAD CCPR construction (or “paving contractor”) obtained samples of stockpiled RAP intended for use in the CCPR sections at MnROAD. These materials were used to develop four CCPR mix designs using combinations of (1) foamed asphalt and engineered emulsion and (2) PG 58S-28 or PG XX-34 binders. The mix design reports provided to the paving contractor prior to construction are reproduced in Appendix B. The general procedure followed to develop the mix designs is outlined in Section 2.1.3. For the MnROAD CCPR mix designs, the laboratory procedure included tests for raveling (ASTM D7196) and low-temperature creep compliance (AASHTO T 322). Results from mix design tests for the recommended optimum recycling agent contents are provided in Table 1.

As indicated in Table 1, the MnROAD CCPR mixtures contain no added cement. When it is used, lime or cement can improve moisture susceptibility and/or strength performance immediately after curing. The mix designs performed for these CR materials determined that, due to the strength and raveling performance, added cement or lime was not necessary. More discussion of cement and lime use in CR mixtures is provided in Section 2.1.3.

**Table 1 As-reported laboratory test results for recommended additive rates from MnROAD CCPR mix designs**

	<b>Cell 133 (2.0% Emulsion PG 58S-28)</b>	<b>Cell 233 (1.5% Foam PG 58S-28)</b>	<b>Cell 135 (1.5% Foam PG XX-34)</b>	<b>Cell 235 (2.0% Emulsion PG XX-34)</b>
<b>Voids @ Opt, %</b>	11.5	11.7	12.2	10.8
<b>Max Dens @ Opt, pcf</b>	133.1	132.8	133.7	131.8
<b>Marshall @ Opt, lbs</b>	1272	1365	1311	1272
<b>Ret. Stability @ Opt, %</b>	72.1	71.0	70.4	73.2
<b>Raveling, %</b>	1.60	1.70	3.30	2.50
<b>Est Crit Crack Temp, °C</b>	-35	-36	-34	-34
<b>IDT @ CC Temp, psi</b>	155	158	128	132
<b>Added Cement, %</b>	0.0	0.0	0.0	0.0

### 3.3 CONSTRUCTION

The following section outlines the steps for general CCPR construction while describing the construction activities on the MnROAD Cells 133, 135, 233, and 235, which took place in September 2017. For more information on the MnROAD construction experience or general CCPR construction practices, the reader is encouraged to refer to *Report on 2017 MnROAD Construction Report* or *Basic Asphalt Recycling Manual*, respectively (MnDOT 2018; ARRA 2015).

Milling and Stockpiling. The existing asphalt on Cells 33 and 35 was removed using cold-milling, and the milled RAP was hauled to the MnROAD facility and stockpiled for future processing. Note that the milled RAP from Cells 33 and 35 was not used in the placed CCPR layers on Cells 133, 233, 135, and 235. After evaluating the milled RAP from Cells 33 and 35, MnDOT engineers felt it was not representative of stockpiled RAP for CCPR because the original binder was acid-modified. Instead, the paving contractor was required to provide RAP from an external stockpile from a single source?.

RAP Processing. The extent of RAP processing was not documented during the MnROAD construction. As the stockpiled RAP used for construction was also provided for the laboratory mix designs, the project team understands that the field and lab gradations were similar if not effectively identical (Appendix B). Historically, CCPR uses of stockpiled RAP include various stages of processing to achieve desired particle sizes and composition (Diefenderfer, 2017). Some CCPR designs may introduce new aggregate into the blend to improve performance. As for particle size, most RAP blends for CCPR target a maximum size no larger than one-third of the compacted CCPR layer thickness. For the MnROAD CCPR sections, the maximum RAP size was screened at 1 inch but no additional processing (screening, cleaning, or adding to the gradation) was done. The stockpiled RAP used for the MnROAD CCPR construction is shown in Figure 3.



**Figure 3 Contractor processing RAP used in the MnROAD CCPR test sections**

Laboratory Mix Designing. Using field-sampled RAP or processed stockpiled RAP, mix designs should be prepared in advance of laydown. The mix designs for the MnROAD CCPR sections are summarized in Section 3.2.



**Figure 4 Laydown of CCPR mixture for MnROAD Cells 133, 233, 135, and 235**

Laydown. For more conventional CCPR projects, prior to laydown of the CCPR lift, the existing surface (whether a milled asphalt surface or an aggregate base) should be inspected and cleaned of debris. After removing the asphalt surface, MnDOT engineers surveyed the in place MnDOT Class 6 aggregate base (visible in Figure 4) and found it to be in very good condition. Trucks with cleaned beds should be used for hauling the CCPR mixture to the construction site, and the CCPR mixture is placed with the same equipment as used for conventional HMA. The placement of the CCPR lift at MnROAD is illustrated in Figure 4. The construction of a typical CIR project is shown in Figure 5 to contrast the differences in these processes. CCPR requires less on-site equipment than CIR, making it easier to implement in high traffic, low clearance projects such as those found in many urban locations.



Figure 5 CIR process from project along County State Aid Highway (CSAH) 11 in Chisago Co., MN

Compaction and curing. Because the CCPR mixture is characterized by high internal friction between the particles, high viscosity, and colder compaction temperature, a higher compactive effort is required relative to HMA. Test strips should be used to determine rolling patterns to achieve 95-105% of the target density. The start of the compaction depends on the type of recycled agent, additives, and climate conditions. For emulsified asphalt, compaction generally begins within an hour (after the emulsion breaks). For foamed asphalt, the compaction process can start immediately. Compaction on MnROAD CCPR sections is shown in Figure 6. All rollers should have working water spray systems to prevent pickup. Density should be monitored throughout the compaction process – during the MnROAD construction, nuclear gauge readings were taken at regular intervals on all four test sections to monitor density after passes of a vibratory roller.

The finished CCPR layer will have a high void content (10-13%) relative to conventional HMA. After compaction, the finished surface is cured for a few days. Additional compaction may be performed after curing. In general, overcompaction of CR layers is rarely an issue given the air void content of these mixes. A cured cold-recycled layer typical of the CCPR lift at MnROAD is shown in **Error! Reference source not found.** The gray color and open, coarser-appearing texture is unlike that of a much darker, denser-appearing HMA layer, such as the HMA lift placed on Cells 135 and 235 (Figure 7). Table 2 summarizes the compaction effort on the MnROAD test cell construction in 2017 and indicates that all cells were at or below target air void contents.

**Table 2. Results of roller compaction from MnROAD CCPR test cell construction records**

Date	Cell	Station	Initial Pass Count			Final Pass Count		
			Average Air Void Content (%)	Vibratory Roller	Rubbertyre Roller	Average Air Void Content	Vibratory Roller	Rubbertyre Roller
8/18/2017	133	64+24.0	17.4	1	0	11.6	4	2
8/18/2017	133	64+79.0	16.4	1	0	11.2	4	4
8/16/2017	135	74+75.0	14.7	1	0	11.0	4	2
8/16/2017	135	75+39.0	15.3	1	0	10.0	4	2
8/16/2017	233	68+23.0	16.0	1	0	9.2	5	4
8/18/2017	235	79+00.0	14.9	1	0	10.6	4	3
8/18/2017	235	79+21.0	13.9	1	0	9.2	4	3



**Figure 6 Compaction of placed CCPR on MnROAD Cells 133, 233, 135, and 235**

Surfacing. Given the air void content of CCPR, a surfaces course is required to avoid moisture intrusion. After the application of a tack coat, the MnROAD CCPR lifts were surfaced with double chip seal or 1.5-inch HMA layer (Figure 7), which were intended as low-volume road designs. For higher-volume designs, thicker HMA surfacing lifts would be adopted. The Virginia DOT/NCAT experience also describes more uses of CCPR structural lifts in pavement designs for heavy, interstate traffic applications. (Diefenderfer et al 2017).





Figure 7 Compacting the paved HMA surface on MnROAD Cell 135

### 3.4 INSTRUMENTATION

Thermocouple temperature arrays, pressure cells, and strain gauges sensors were installed during the construction of Cells 133 and 235. While the project effort did not include a review of the sensor data from Cells 133 and 235, a description of the sensors is provided for the sake of reporting. The sensors are summarized first by location and then by sensor type/function.

- Thermocouple temperature arrays, pressure cells, and longitudinal and transverse asphalt strain gauges were installed in Cell 235 (Figure 8)
- Thermocouple temperature arrays were installed in Cell 133.

Thermocouples were placed within the asphalt, CCPR, base and Subgrade layer of Cells 133 and 235. The thermocouples used are built at MnROAD using a Type T thermocouple extension cable that ensures a precision of 1 degree Celsius. The thermocouple is then inserted into a PVC pipe that provides protection. Temperatures are recorded every 15 minutes.

Pressure cells were placed within the base layer of Cell 235. Soil pressure gauges are used to measure the vertical pressure in the base and subgrade layer. Pressure gauge is made of two 6-inch diameter plates that are welded together and filled with a fluid. A sensor measures the change in pressure of the fluid.

Strain gauges were placed at the bottom of the CCPR layer in Cell 235. Dynamic strain gauges are used to measure the strain response under the traffic loading at the bottom of the asphalt layer. Strain response data are collected on four occasions each year as the test cell is being loaded by the MnROAD low-volume road traffic vehicle.

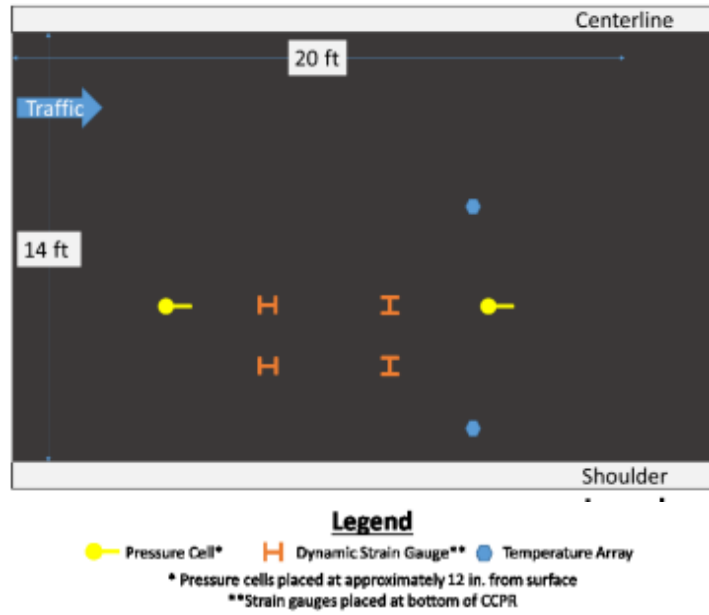


Figure 8 Sensor location map for MnROAD Cell 235

## CHAPTER 4: LABORATORY TESTING

Because MnROAD engineers were aware of possible future research efforts involving the CCPR sections at MnROAD, the construction process for the CCPR test cells included reserving mix materials for future studies (Figure 9). Reserved CCPR materials from MnROAD were used by the project team to batch cold-recycled mix and create test specimens in the laboratory to further characterize cold-recycled mix behavior, including but not limited to its low-temperature response. Laboratory fabrication of test specimens from unused mixture materials or field cores is commonly required when performing mix design activities – more information on recomposing samples in the laboratory and the differences in CR and HMA samples can be found in the literature (ARRA, 2015).



Figure 9 (a) MnDOT engineers reserving CCPR field mix materials at MnROAD and (b) reserved MnROAD CCPR materials in the laboratory for test specimen preparation

### 4.1 TEST PLAN

The project team collaborated with MnROAD engineers to develop a test plan for the MnROAD CCPR mixes that investigated both the foamed asphalt and asphalt emulsion mixes. Two important factors in determining the test plan were a desire to perform low-temperature cracking (i.e., fracture energy) tests and the need to limit the test plan to agree with the amount of reserved CCPR materials from MnROAD. The following items describe those factors and other issues related to the development of the project test plan.

- Material limitations were four (4) one-gallon cans of each binder, twelve (12) five-gallon buckets of stockpiled RAP, and two (2) five-gallon buckets of emulsion.
- Prioritized tests were low-temperature experiments for disk-shaped compact tension (DCT) testing and semi-circular bending (SCB). The project technical liaison and laboratory team selected  $-18^{\circ}\text{C}$  as the conditioning and test temperature for DCT and SCB samples.
- In addition, MnROAD engineers were interested in the performance of cold-recycled mixtures in dynamic modulus (commonly known as “E-star” or  $E^*$ ) tests using the Asphalt Mixture Performance Tester (AMPT), which is also known as the Simple Performance Tester (SPT).

- The test plan also included more routine tests such as low-temperature creep and strength in indirect tensile (IDT) testing (AASHTO T 322) and Hamburg wheel tracking (HWT) testing (AASHTO T 324). The project technical liaison and laboratory team selected -20°C, -30°C, and -40°C, as the conditioning and test temperatures for IDT samples.
- The rationale and draft testing plan were later discussed with and approved by the NRRRA Flexible Team.
- The final test plan and total specimen/material requirements are summarized in Table 3.
- For certain specimens that can be difficult to create with cold-recycled mixtures, the test plan included the creation of an additional specimen so that issues in sawing or notching did not prevent a given procedure from having a full complement of test samples. Wherever possible, all successfully created specimens (Figure 10) were tested – i.e., if four specimens were made, four specimens were tested.

**Table 3 Laboratory test plan for Cells 133, 233, 135, 235**

	<b>Cell 133 (2.0% Emulsion PG 58S-28)</b>	<b>Cell 233 (1.5% Foam PG 58S-28)</b>	<b>Cell 135 (1.5% Foam PG XX-34)</b>	<b>Cell 235 (2.0% Emulsion PG XX-34)</b>
<b>IDT creep/strength</b>	6 specimens (Test 6)	6 specimens (Test 6)	6 specimens (Test 6)	6 specimens (Test 6)
<b>Semi-circular bending (SCB)</b>	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)
<b>Disk-shaped compact tension (MnDOT modified)</b>	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)
<b>Simple performance tester (SPT) for E*</b>	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)	4 specimens (Test 3)
<b>Hamburg wheel rutting</b>	2 specimens (Test 2)	2 specimens (Test 2)	2 specimens (Test 2)	2 specimens (Test 2)

Other common tests of cold-recycled mixtures, such as Marshall stability tests (ASTM D6927) or conditioned indirect tensile strength (ITS) tests (AASHTO T 283), were not included due to limitations on available CCPR mix materials. Another reason to exclude these tests was that they had been performed as a part of the mix design process prior to construction. The test results from the mix designs are provided in Appendix XX????

Information on the laboratory tests performed, test results, analysis, and relevant discussion are provided in the remaining sections of this chapter. The reader is referred to the cited test standards for more information on each procedure.



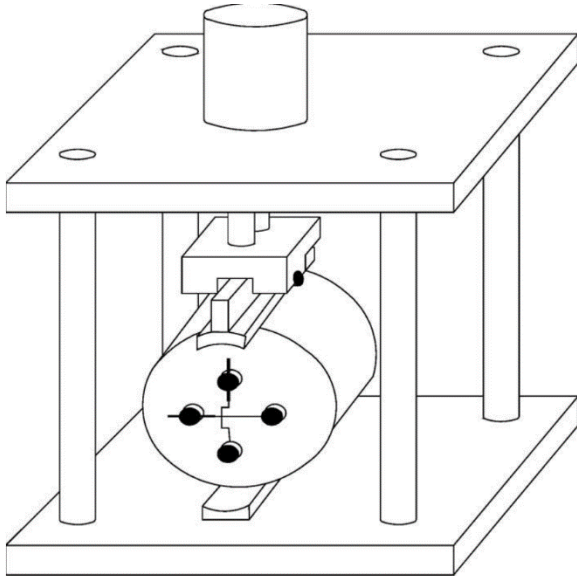
Figure 10. Laboratory batched, compacted CCPR mixtures for project tests

## 4.2 TEST METHODS AND RESULTS

### 4.2.1 IDT Test

The IDT creep and strength test (AASHTO T 322) was developed to understand the performance of asphalt concrete mixtures at low temperatures. Low-temperature behavior of asphalt pavements may involve a special kind of distress known as thermal or low-temperature cracking, which can occur due to extreme changes in temperatures below freezing. Using creep testing (and associated analysis and modeling) and tensile strength testing, the IDT procedure results in an understanding of tensile strength at low-temperatures and a predicted critical temperature for the tested mixture. This critical temperature is the threshold below which low-temperature cracking is expected to occur.

Six specimens were prepared for each of the cold recycled mixes associated with the four MnROAD test cells. AASHTO T 322 specifies that specimens are approximately 44 mm in height and 150 mm in diameter (within specified tolerances). Samples were tested in creep and tensile strength at -20 C, -30 C, and -40 C (two samples tested per temperature) in the splitting tensile-type arrangement in the load frame, illustrated in Figure 11



**Figure 11. AASHTO T 322 configuration to load specimen along diametral axis for tensile creep and strength [AASHTO]**

For creep testing, a static load that produces horizontal deformation of approximately 0.01 mm is applied to each specimen for 100 seconds. Specimen deformation is recorded using four displacement transducers at 10 Hz for the first 10 second and 1 Hz for the final 90 seconds. After the creep test is completed at each temperature, the tensile strength for a given combination of specimen and temperature is determined using a displacement-controlled load (at a rate of 12.5 mm/min) until failure is achieved.

Upon completing tests, low-temperature tensile creep and thermal stress analysis was performed according to methods described in the AASHTO T 322 standard, Buttlar and Roque (1994), and Christensen and Bonaquist (2004).

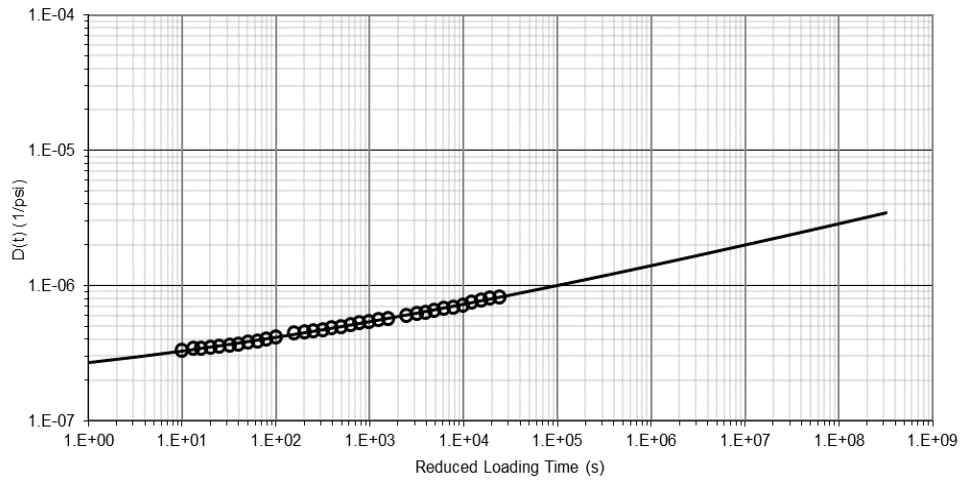
- Table 4 summarizes the critical low-temperature values associated with the specimens from creep compliance and low-temperature strength analysis and modeling described in AASHTO T 322. The results in Table 3 highlight the difference in low temperature properties from the two binder sources used and are not influenced heavily by the foam or emulsion process.
- The modeled creep compliance of a cold-recycled mix is illustrated in Figure 12 using the results of analysis and modeling for the PG 58S-28 EE mix; similar results for other mixes are provided in Appendix C. The creep compliance model has the form shown in Equation 1, where  $D(t)$  is the creep compliance at time  $t$ ,  $D_0$  is the glassy compliance,  $D_1$  is the location parameter,  $C_2$  is the shift constant,  $T_{ref}$  is reference temperature of the mixture,  $T$  is the test temperature, and  $m$  is the limiting log-log slope of the compliance function (Christensen and Bonaquist 2004).

$$D(t) = D_0 + D_1 \left( \frac{t}{10^{C_2(T_{ref}-T)}} \right)^m \quad (1)$$

- The thermal stress analysis for the PG 58S-28 EE mix is illustrated in Figure 13. The results of thermal stress modeling for each cold-recycled mix is provided in Appendix C. As above, information on the thermal stress modeling can be found in Christensen and Bonaquist (2004).

**Table 4. Estimated critical low temperatures for each of the MnROAD CCPR mixtures from AASHTO T 322 testing**

	Cell 133 (2.0% Emulsion PG 58S-28)	Cell 233 (1.5% Foam PG 58S-28)	Cell 135 (1.5% Foam PG XX-34)	Cell 235 (2.0% Emulsion PG XX-34)
Critical Low Temperature	-8 F	-7 F	-24 F	-25 F



**Figure 12 Creep compliance of the PG 58S-28 EE cold-recycled mix, where the line indicates the modeled creep behavior and each circle represents measured creep compliance**

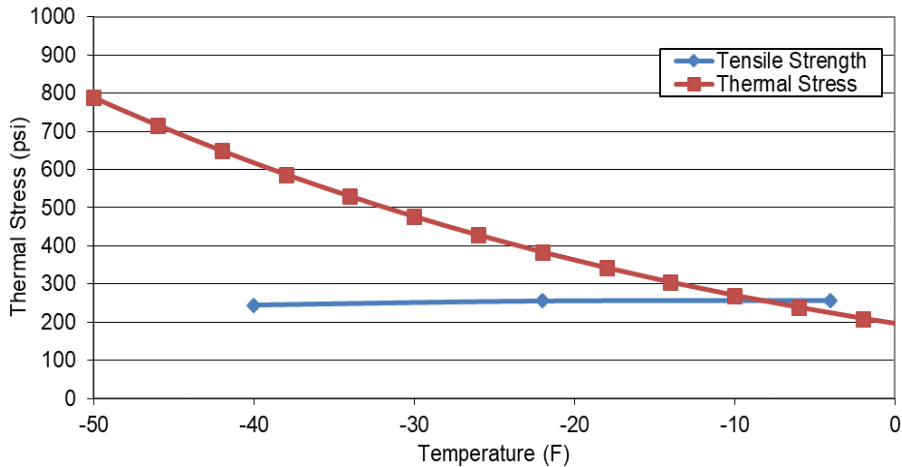


Figure 13 IDT Modeled thermal stress and measured specimen tensile strength for the PG 58S-28 EE mix

#### 4.2.2 DCT Test

Disk Shaped Compact Tension (DCT) testing is performed on asphalt concrete (AC) samples to assess fracture behavior. Unlike SCB, DCT is performed at freezing temperatures on HMA mixtures. In performing their adaptation of low-temperature SCB to CR mixtures, Zegeye et al (2017) performed companion DCT tests and found that DCT required no modification to accommodate CR mixtures. For these reasons, and due to NRR Flexible Team interest, the study included DCT testing according to the MnDOT-modified ASTM D7313 procedure.

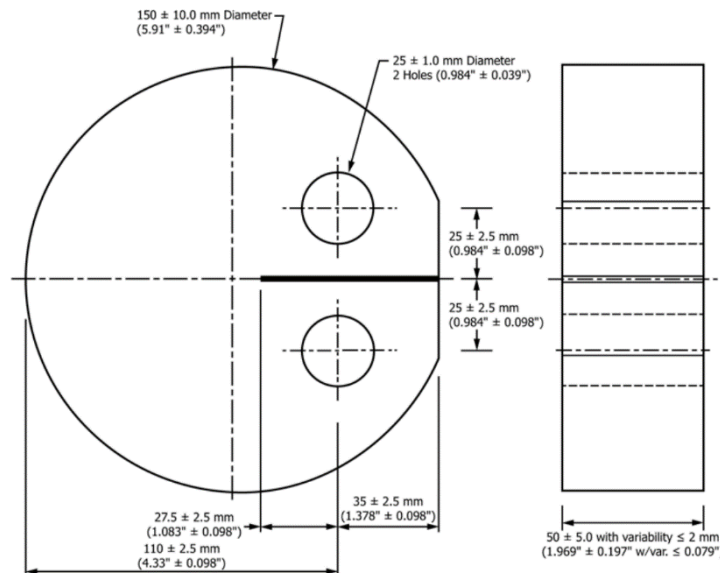


Figure 14. Geometry and dimensions of DCT specimen for fracture testing [ASTM]

The DCT test was performed on specimens 150 mm in diameter and 50 mm thick, with other dimensions shown in Figure 14. Specimens are notched to a length of 62.5 mm. All DCT tests were performed at a



temperature of -18°C. A tensile load was distributed between fixtures within the specimen holes to create at a constant CMOD rate of 0.017 mm/sec. As with SCB and other fracture tests, the fracture energy was calculated given estimates of the work (from the load-displacement relationship) and fracture surface.

- Load-displacement curves for DCT tests of the four EE PG 58S-28 samples are shown in Figure 15.
- Table 5 summarizes statistics for DCT-estimated fracture energies by MnROAD CCPR mixture type, and Figure 16 reports the fracture energies by specimen for each mixture. Comparing these items with the Figure 19 summary confirms the finding in Zegeye et al (2017) that the DCT procedure did not require alteration to accommodate specimens composed of CR mixtures.
- The fracture energies obtained from the MnROAD CCPR mixtures compared favorably with fracture energies determined using DCT for CIR mixtures in Zegeye et al (2017). While the MnROAD CCPR mixtures had roughly double the fracture energy of the CIR mixtures tested in Zegeye et al (2017), the MnROAD CCPR DCT tests were performed at a temperature that was 10°C warmer than DCT tests in Zegeye et al (2017). This temperature difference was procedural, and future studies may replicate the tests at an identical temperature to avoid convolution.
- Full test report sheets for all DCT tests performed on MnROAD CCPR mixtures are provided in Appendix C.

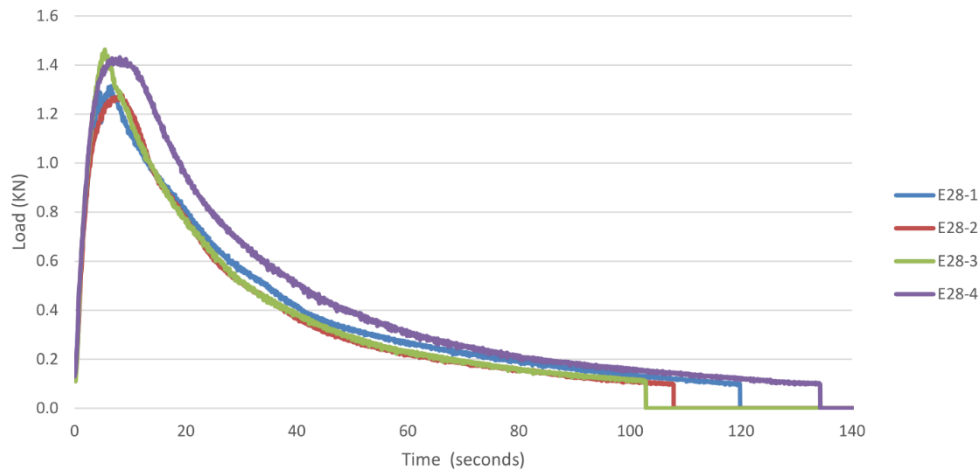
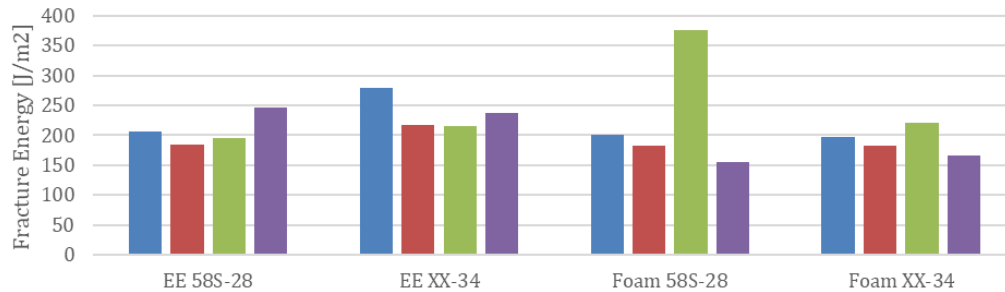


Figure 15. Load-displacement curve for low-temperature DCT test of CR mixtures using EE 58S-28

**Table 5. Average and standard deviation values of DCT-estimated fracture energy for MnROAD CCPR mixtures**

MnROAD CCPR Mixture	Fracture Energy [J/m <sup>2</sup> ]	
	Average	Standard Deviation
EE 58S-28	208.0	27.7
EE XX-34	237.1	29.8
Foam 58S-28	228.5	100.0
Foam XX-34	191.2	23.1

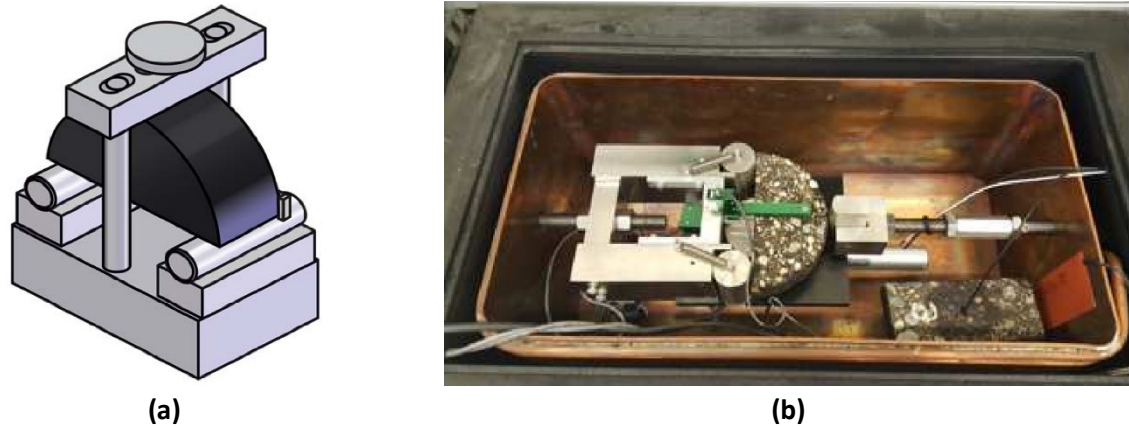


**Figure 16. Individual calculated fracture energy for DCT specimens for each MnROAD CCPR mixture**

#### 4.2.3 SCB Test

The semi-circular bending (SCB) test is used to determine a load displacement curve for asphalt specimens that can be used to calculate fracture energy. SCB test specimens are cut from gyratory-compacted cylinders, notched, and loaded in a configuration resembling a three-point flexural beam test (Figure 17). Load and displacement are measured from initial loading until failure.

The SCB test according to AASHTO TP 105-13 was selected for tests of CCPR mixtures given the project team experience with low-temperature tests of CR mixtures using SCB, discussed in part in Zegeye Teshale et al (2017). This procedure orients the SCB specimen on its side, as shown in Figure 17. Despite the challenges of low-temperature tests of CR mixtures, as discussed above, the NRRRA Flexible Team determined that low-temperature SCB tests were of interest to the study.



**Figure 17. SCB specimen for fracture behavior using (a) ASTM D8044 orientation and (b) modified horizontal orientation for AASHTO TP 105-13 using Testquip DCT tester**

Four semi-circular specimens 30 mm thick and 150 mm in diameter were notched to a depth of 15 mm at mid-span and tested in the configuration shown in Figure 17b. This notch depth is shallower than values recommended in other SCB test standards. The notch was 2 mm wide. The effective crosshead or load line displacement (LLD) used in the fracture energy computation was measured using an extensometer fixed opposing ends of the testing frame; the LLD measurement apparatus had a measurement range of 0.25 mm. An extensometer was used to measure the crack mouth opening displacement (CMOD) rate during loading. A CMOD rate of 0.0005 mm/sec was used for the test duration, and specimens were loaded until either the CMOD gauge limit of 1 mm was reached or the load force was less than 0.5 kN. All tests were performed at a temperature of  $-18^{\circ}\text{C}$ . More information on the low-temperature SCB procedure for CR mixes is provided in Zegeye et al (2017).

Low-temperature SCB results are a load-displacement curve, which illustrates the peak load and post-peak behavior (i.e., resilience), and the calculated fracture energy (i.e., the ratio of the area under the load-displacement curve to the fracture surface).

- An example of a load-displacement curve for a low-temperature SCB sample is shown in Figure 18, where post-peak behavior beyond the measurement limits is modeled using a power law proposed in Zegeye et al (2017).
- A summary of the recorded fracture energies for SCB tests is shown in Figure 19. The Figure 19 summary illustrates that many samples did not survive the notching or test setup process due to their fragility at  $-18^{\circ}\text{C}$ . (Failed samples correspond with missing bars in Figure 19.) Because a limited number of samples survived, statistics summarizing mixture performance in fracture were not calculated.
- The success rate of tests did not compare favorably internally with DCT tests performed on MnROAD CCPR mixture nor externally with low-temperature SCB tests performed in Zegeye et al (2018). As the tests were performed at a commercial lab by the same experienced technicians who performed the tests for Zegeye et al (2017), the disposition of the project team is to attribute the difficulties to material issues more than the possibility of lab error.

- Appendix C documents the load-displacement curves and associated fracture energies for the low-temperature SCB samples.

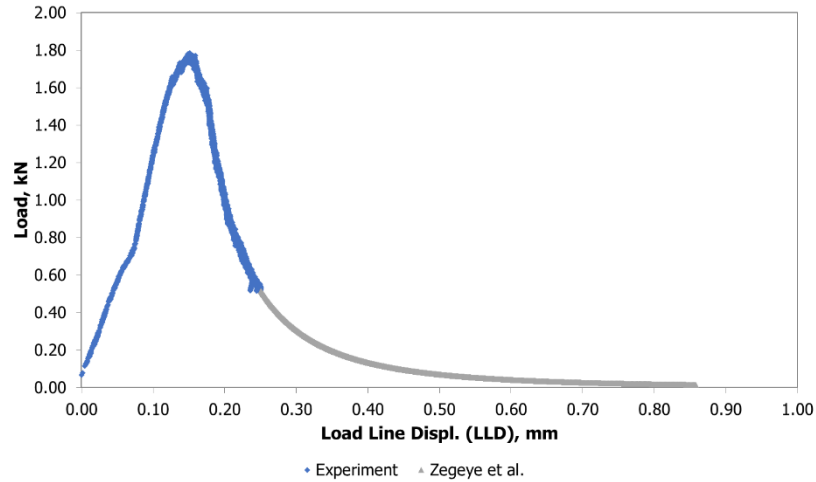


Figure 18. Load-displacement curve for low-temperature SCB test of a CR mix using PG 58S-28 EE

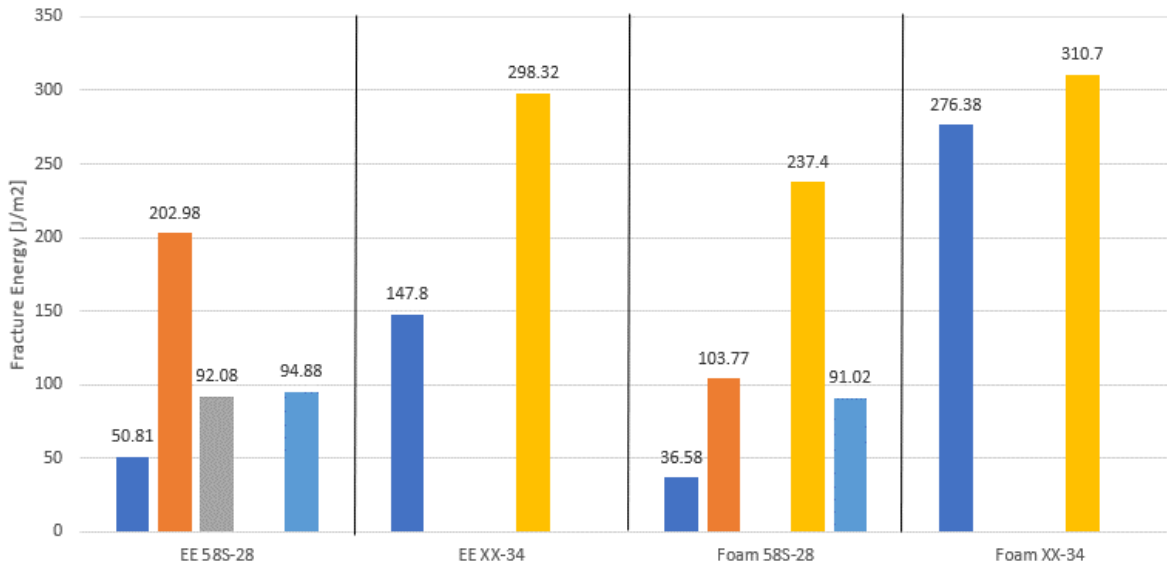


Figure 19 Summary of fracture energy  $G_f$  (J/m<sup>2</sup>) for successfully tested low-temperature SCB samples

#### 4.2.4 SPT (Dynamic Modulus) Test

The Simple Performance Tester (SPT), or Asphalt Mixture Performance Tester (AMPT), is a computer-controlled test machine used to determine the dynamic modulus and flow number of asphalt mixtures according to the AASHTO TP 79 test standard. The test is often applied to characterize mixtures for the

benefit of the AASHTO mechanistic-empirical pavement design procedure, which uses SPT-determined parameters as project design inputs. The application of SPT to CR mixtures is uncommon.

Four cylindrical specimens 100 mm in diameter and 150 mm in height were created per CR mixture for SPT testing for unconfined dynamic modulus. Flow time and flow number tests were not performed. The reader is referred to TP 79 for more information on the dynamic modulus test procedure. In short, the procedure consists of compressive sinusoidal (i.e., dynamic) loading applied at varied frequencies (0.01 Hz, 0.1 Hz, 1 Hz, and 10 Hz) and temperatures (4.0°C, 19.8°C, and 38.0°C). Three specimens were selected per CR mixture for testing.

When applied to conventional HMA mixtures, SPT is typically used to characterize the dynamic modulus (usually expressed through a master curve) and phase angle for mechanistic-empirical pavement design procedures. A more basic use of dynamic modulus, which is adopted here, is to summarize specimen performance in terms of the maximum calculated dynamic modulus.

- Average dynamic modulus values for MnROAD CCPR mixtures at 10 Hz and 19.8°C are shown in Figure 20. (Note: Each point represents the average of three test specimens.)
- An example of a completed master curve for the EE 58S-28 mixture is shown in Figure 21. Test temperatures (in degrees centigrade) corresponding to measured dynamic modulus (ksi) are indicated in the figure legend.
- The literature review only uncovered one resource that included dynamic tests of CR mixes, which was Schwartz et al (2017). The values shown in Figure 20 are comparable to CR mixes tested under Schwartz et al (2017), which performed a significant number of dynamic modulus tests on varied CIR, CCPR, and SFDR mixtures in general accordance with AASHTO TP 79.
- An important distinction between the MnROAD CCPR dynamic modulus tests and those of Schwartz et al (2017) is that the Schwartz study adopted so-called small-scale cylindrical specimens that were created from field cores. The specimens also differ in terms of orientation – the small-scale specimens are extracted by coring in a plane that is parallel to the surface. Therefore, the asphalt matrix in the small-scale cylindrical specimens involves consolidation forces (through compaction and gravity) that do not resemble consolidation forces in lab-prepared specimens. Therefore, comparisons in results are not made beyond similarity in value.
- The SPT dynamic modulus test reports for each of the tested CR mixtures are reported in Appendix C.

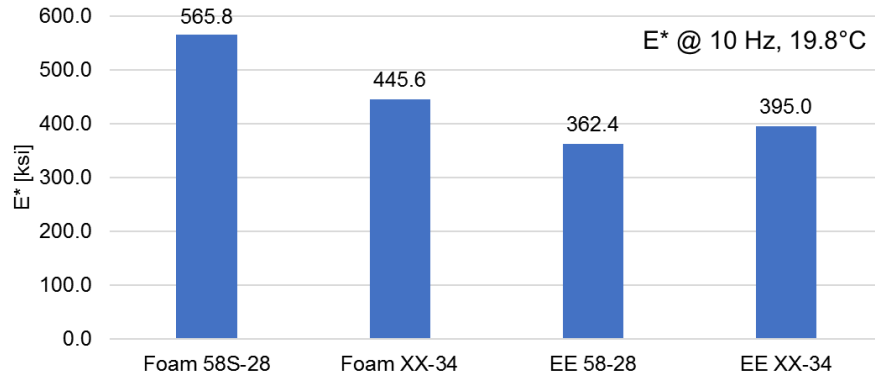


Figure 20. Average dynamic modulus at 10 Hz and 19.8°C for MnROAD CCPR mixture

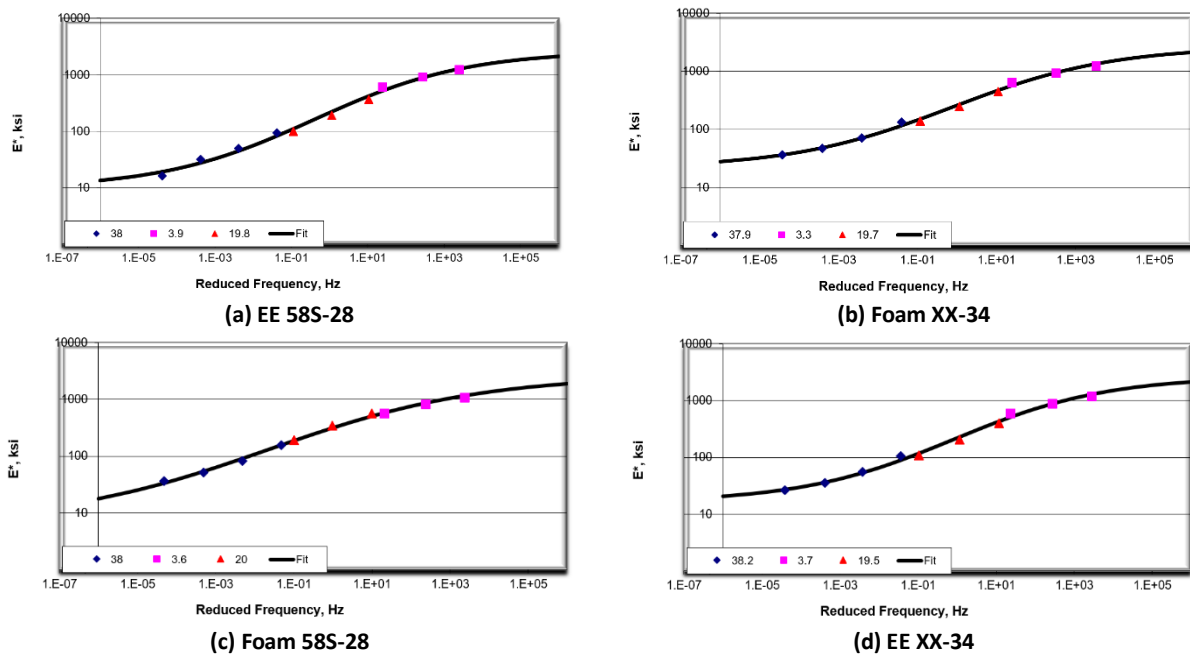
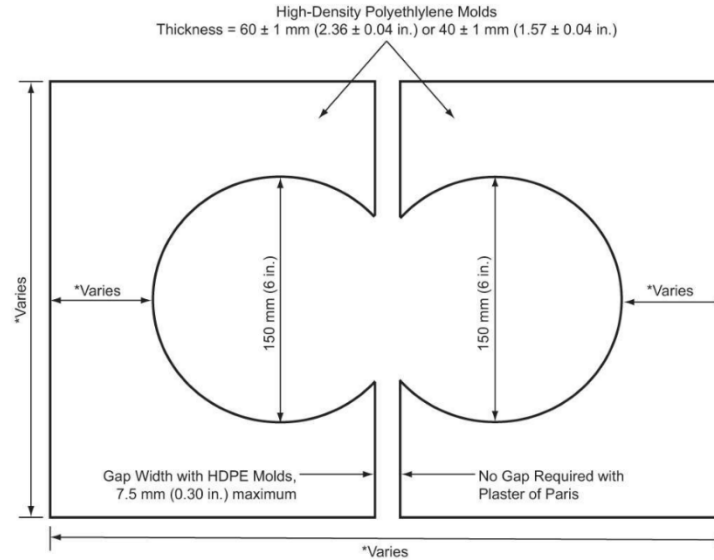


Figure 21 Master curves for CCPR mixtures, with temperatures shown in the legend

#### 4.2.5 Hamburg Test

The Hamburg Wheel Tracking (HWT) Test is commonly used to assess the rutting resistance and moisture susceptibility of asphalt concrete mixtures. HWT tests of CCPR mixtures for this study were in accordance with AASHTO T 324. During the test, specimens are worn with a stainless-steel wheel for either a pre-determined number of wheel passes or until the specimens reach a predetermined value for vertical deformation (i.e., rut depth). These values will vary by performance specification or material. For example, for the CR mixtures tested in this study, a maximum rut depth of 0.49 inches (12.5 mm) was adopted.



**Figure 22 Geometry of an HWT test specimen [AASHTO]**

HWT specimens, illustrated in Figure 22, are composed of two conjoined, trimmed cylindrical specimens that are inserted into a high-density polyethylene mold for testing. Each specimen, while within the mold, was submerged in a 40°C bath and kneaded under repeated loading of the test wheel until failure or the designated number of wheel passes is reached. A bath temperature of 40°C was selected as – at the time of testing in 2018 – this temperature was commonly requested by agencies and contractors for HWT tests. There is still ongoing debate regarding HWT bath temperature as some prefer higher temperatures (50-60°C) for the HWT bath.

Two HWT specimens were tested for each of the MnROAD CCPR mixtures. The air void content of the tested CR mixtures was roughly 15 percent to conservatively resemble the air void content of field mixtures (“conservative” in the sense that this target is roughly 3 percent higher than the MnROAD field mixtures). This practice deviates from AASHTO T 324, which requires 7.0 percent air void content for conventional HMA mixtures.

- The average number of passes to failure and average creep slope (i.e., the vertical deformation per wheel pass) are summarized in Table 6.
- Due to the nature of failure in all specimens, a stripping inflection point was not recognizable. That is, the nature of rutting remained in a single mode (referred to in T 324 as a “portion” of steady-state behavior) throughout the HWT test. For this reason, a strip slope is also not reported. HWT data for the MnROAD CCPR specimens is provided
- As noted above, the air void content of the tested CR mixtures was much higher than air void contents of conventional HMA mixtures, which is to be expected. A result of this practice, however, is that the CR mixtures will deform under loading rapidly. These CR mixtures in the field would be protected from direct contact with wheel loads that create rutting by a surface layer (in the MnROAD test cell cases, a thin HMA overlay or double chip seal surfacing). Therefore, the rapid degradation of these layers is comparable with other CR mixtures, not

conventional asphalt mixtures. In this sense, the results suggest that the engineered emulsion mixtures do not deform in rutting as rapidly as the foamed asphalt mixtures.

- The HWT test reports for each of the tested CR mixtures are reported in Appendix C.

**Table 6. Average rutting information from HWT tests of MnROAD CCPR mixtures**

	<b>Cell 133 (2.0% Emulsion PG 58S-28)</b>	<b>Cell 233 (1.5% Foam PG 58S-28)</b>	<b>Cell 135 (1.5% Foam PG XX-34)</b>	<b>Cell 235 (2.0% Emulsion PG XX-34)</b>
Number of Passes at Failure	7120	3520	2880	5400
Creep Slope (mm/pass)	-1.28E-03	-2.97E-03	-3.83E-03	-1.66E-03



## CHAPTER 5: FIELD TESTING

For this study, pavement field performance was measured and quantified by performing rutting tests, ride quality tests, surface distress evaluations, and falling weight deflectometer (FWD) tests. The tests were initiated after the construction of the test cells at MnROAD in 2017 and completed on the removal of the CCPR sections in 2020. Detailed documentation of the field performance monitoring equipment used at MnROAD is available on MnROAD’s website.

### 5.1 MNROAD MONITORING

#### 5.1.1 Rutting

The rutting in the MnROAD CCPR sections was measured by MnDOT engineers using the Automated Laser Profile System (ALPS), shown in Figure 23. ALPS measurements were performed in both wheel paths of both lanes at 50-ft longitudinal intervals – measurements in the transverse direction were recorded for every 0.25 inches to create a transverse profile. More information on the use of ALPS at MnROAD is provided in MnDOT resources available online.

ALPS profiling of MnROAD Cells 133, 135, 233, and 235 was performed on six occasions: June 2017, June 2018, October 2018, May 2019, October 2019, and May 2020. Data from these rutting surveys were consulted in this study and are discussed in later sections (and in Appendix B).



Figure 23. ALPS device mounted to a vehicle to provide rutting profiles for MnROAD test sections

#### 5.1.2 Ride and Pavement Condition Surveys

Ride quality and pavement condition were regularly assessed by MnDOT engineers during the lifespan of the CCPR test cells at MnROAD. These assessments were performed according to MnDOT’s procedure for condition monitoring, as established by its Pavement Management office (2015). This procedure relies upon the MnDOT Digital Inspection Vehicle (DIV) and the lightweight internal surface analyzer (LISA), which are shown in Figure 24. The overall the International Roughness Index (IRI), which is

converted to MnDOT's Ride Quality Index (RQI) and combined with a condition survey rating (surface rating, or SR) to result in MnDOT's Pavement Quality Index (PQI).

Ride quality and pavement condition surveys of the MnROAD CCPR test cells were performed using the DIV on eleven occasions: October 2017; March, April, May, August, and October of 2018, March, May, August, and October of 2019; and March 2020. For the purposes of this study, IRI data and distress survey information were consulted and documented in later sections and Appendix B.

Cracking data was collected every spring and fall following FHWA Long-term Pavement Performance (LTPP) Manual Distress Survey Guidelines. Thus, cracking performance is characterized by crack type and severity.



**Figure 24. (a) Digital Inspection Vehicle and (b) vehicle-mounted LISA device to assess pavement condition and ride**

### 5.1.3 Falling Weight Deflectometer

MnROAD sections were regularly tested using a falling-weight deflectometer (FWD) device (shown in Figure 25) to assess the structural properties of the pavement system and changes to the pavement structure over time. FWD testing is common to all state agencies, and the reader is left to consult other resources on the nature of the test.

At each FWD test location within the MnROAD CCPR sections, three increasing loads were dropped, and the respective deflection basins for each drop were recorded. The first FWD test of the CCPR sections was performed on November 7, 2017. The final test was performed on June 17, 2020.

Of importance to this particular project is the analysis of FWD, which is complicated by the presence of a thin surfacing in the CCPR test sections. This analysis will be discussed in more detail in later sections and in Appendix B.



Figure 25. One of the trailer-mounted FWD test devices used at MnROAD

#### 5.1.4 Traffic Information

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As noted in Chapter 3, the low-volume road test sections at MnROAD are subjected to controlled traffic in one lane only. The controlled traffic is a 5-axle, 80-kip truck/trailer that is applied whenever possible, averaging 80 trucks laps per day. MnROAD intends for traffic to be applied five days per week, however due to testing, construction, and/or repairs, traffic loading has been irregular at times.

Traffic information provided to the project indicated that a total of 60,416 Bituminous ESALs were applied to MnROAD Cells 133, 135, 233, and 235 between the first truck load after construction (September 9, 2017) and September 18, 2020 (date of last data collection prior to report cutoff date). Figure 26 illustrates the accumulation of traffic on the MnROAD load-volume loop during this time period. Traffic information was consulted to better understand the development of rutting and deterioration of ride, if applicable.

The AASHTO Guide for the Design of Pavement Structures (1993) defines low-volume roads are those that will experience between 50,000 and 1,000,000 18-kip ESALs over their service life, which can be between 15 and 40 years depending on location and traffic. The traffic applied on the MnROAD low-volume loop is within these bounds in terms of total ESALs (more than 50,000) and the maximum annual ESALs: at most the MnROAD sections experienced approximately 25,000 ESALs in one year, which is much less than the upper bound for ESALs per year suggested by AASHTO (1993).

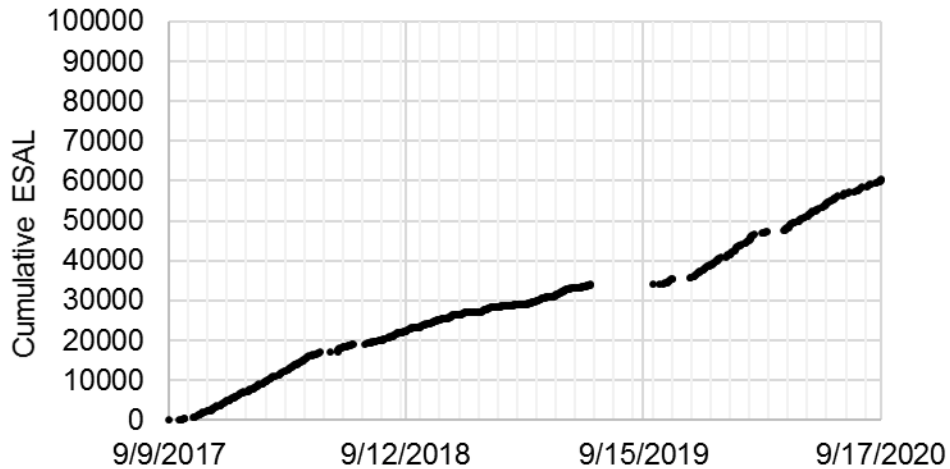


Figure 26. Cumulative ESALs applied to the CCPR sections within the MnROAD low-volume loop

### 5.1.5 Embedded Sensor Monitoring Data

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Finally, as noted in Chapter 3, thermocouples, pressure cells, and strain gauges were installed in Cells 133 and 235 (Figure 8) to continuously monitor the response of the sections to traffic and environmental loads. MnROAD engineers indicated that all dynamic sensors in Cell 235 (strain gauges and pressure cells) survived construction and were functional throughout the life of the test section. While these data were not consulted in this study, they are available to researchers for further study.

### 5.1.6 Pavement Coring

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In June 2020, prior to the completion of the CCPR project, MnDOT engineers and the project team surveyed the final condition of the pavement. During this survey, the project team identified locations in the transition panels between test sections (i.e., not in the actual sections themselves) for pavement coring. MnROAD staff collected cores of the surface and CCPR layer from 32 locations and provided these to the project team for laboratory tests. An example of a recovered core is shown in Figure 27.



Figure 27. (a) Top and (b) side view of a pavement core from the outer lane of MnROAD Cell 133 (double chip seal, EE PG 58S-28)

## 5.2 FIELD RESULTS

### 5.2.1 Damage and Repairs to MnROAD Cell 233

In early May 2018, MnROAD engineers performed local repairs to MnROAD Cell 233, as the extent of the damage in the chip seal and CCPR layers had created unsafe driving conditions for the MnROAD truck. As MnROAD engineers determined that the underlying cause for the pavement failure was not due to the CCPR design or construction, the failure and repair operations are briefly summarized in this section for the sake of reporting.

- During the early spring months of 2018, MnROAD noticed quickly progressing surface damage in the trafficked lane of MnROAD Cell 233.
- Fatigue cracking in the wheelpath and alligator cracking was observed in March 2018. By April 2018, the distress had fully raveled into the surface shown in Figure 28.
- MnROAD initiated and completed repair operations by May 18th. Photographs of the repair are shown in Figure 29.

MnROAD engineers observed that the failure occurred in a region immediately above a subgrade culvert. It is possible that the combination of spring conditions (i.e., saturated sublayers), truck traffic, and a less densified subgrade resulted in unusual vertical deformation in the base, CCPR, and chip seal layers of the structure. In general, the rapidity of the damage after approximately 10,000 passes of the 5-axle, 80-kip truck/trailer points to seasonal support issues rather than critical failure in an engineered, asphalt bound layer.



Figure 28 Failed pavement in MnROAD Cell 233 due to potential subgrade/culvert issues



(a)



(b)

Figure 29 (a) Removal of pavement and CCPR to base and (b) HMA paving to repair damage over culvert in MnROAD Cell 233

### 5.2.2 Rutting

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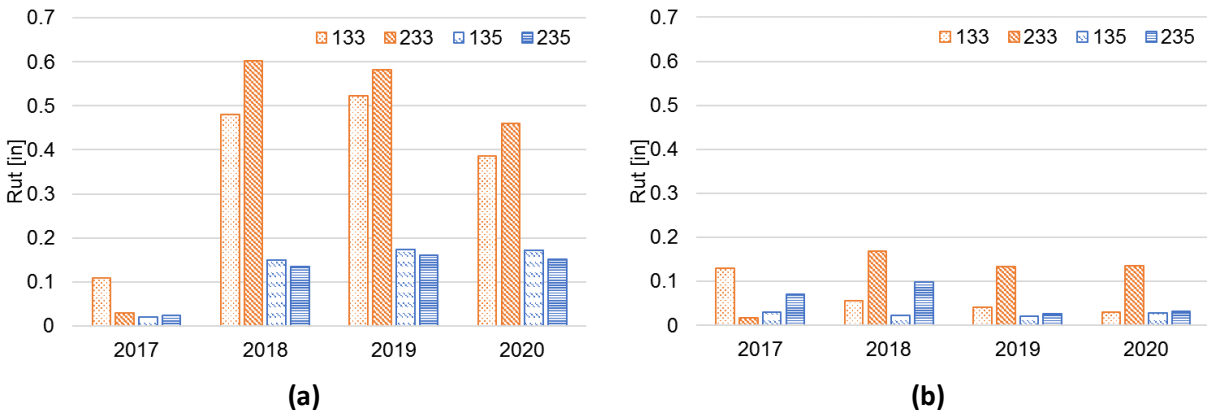
Prior to analyses of rutting data, outliers were identified and removed from the data set using an interquartile rule. The data were filtered by removing the outliers and represented graphically by year, lanes and wheel path section as reported in Appendix B. The average rut depths are summarized in Figure 30. The following items briefly summarize observations of trends in the rutting data.

- The trafficked lane (the inner lane) shows higher values of rut depths compared to the outer lane, which does not bear traffic. MnROAD engineers believe that the small amount of rutting measured in the outside lane is due to the MnROAD truck maneuvering around the patched area discussed previously. Average rutting in traffic lanes exceeded values of 0.5 inches for some test sections (Figure 30).

- Lower levels of rutting are observed in Cells 135/235 (the HMA-surfaced sections) than in Cells 133/233 (the double chip seal surfaced sections). Rutting in Cells 133/233 after one year of traffic is shown in Figure 31. While this result confirms expectations of these surfaces, it does confound attempt to distinguish CCPR performance in rutting by CR mixture properties (i.e., emulsion vs. foamed asphalt or PG high temperature grade).
- A comparison of rutting depths in outer lanes does not distinguish the test section behavior meaningfully in terms of CR mixture properties.

Overall, while repairs to Cell 133 obscure a larger statement on the potential of rutting for chip-sealed CCPR under traffic, the chip seal may not contribute to rutting resistance in a measurable, structural sense. The HMA-surfaced CCPR sections performed well over the 3-year period in which 60,000 ESALs were applied, particularly in the sense that almost 45 percent of the ESALs applied were between September 2019 and September 2020 – in that span, average rutting in Cells 135/235 did not increase.

More comprehensive detail on rutting in the MnROAD CCPR test sections is provided in Appendix B.



**Figure 30. Left wheel path rutting by calendar year for (a) inside lane (truck lane) and (b) outer lane, where 133/233 are chip sealed and 135/235 are surfaced with HMA**



**Figure 31. Condition photo showing rutting in double chip sealed CCPR sections at MnROAD**

### **5.2.3 Ride and Pavement Condition**

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The final recorded distresses, as of 2020, are reported in Table 7 and Table 8. These distresses were classified in terms of surface distress types: longitudinal crack, transverse crack, patch, raveling, and cracking at the longitudinal construction (cold) joint. Similar modes and amounts of surface distress were reported for the HMA-surfaced sections (135/235).

For sections 135 and 235, condition surveys recorded substantially more cracking in the outer (untrafficked) lane than in the inner (trafficked) lane. This observation raises a number of discussion points for more involved studies of this phenomenon, and the possibility that regular traffic is somehow kneading and mending cracks in the underlying CR layer, thereby preventing their propagation through the interface of the CR layer and HMA overlay and thereafter through the overlay to the surface.

While the later cracking of Cells 135/235 above is noted, the predominant mode of distress reported for Cells 135/235 was construction joint distress, which does not contribute substantially to a loss of ride quality. The lowest number of distresses was recorded by Cell 133, however this is not indicative of chip-sealed sections in general given the issues with Cell 233 (described in more detail in Section 3.5). A more comprehensive review of pavement condition surveys is provided in Appendix B.



**Table 7 Total pavement condition distresses recorded along MnROAD Cells 133 and 233 (double-chip surfacing) through July 2020( or whatever date)**

Distress	133	133	233	233
	Inner	Outer	Inner	Outer
Longitudinal cracking, non-wheel path, length, low severity (ft)	0	0	31	1
Longitudinal cracking in wheel path, length, low severity (ft)	5	0	8	46
Transverse cracks, count, low severity	4	2	1	0
Transverse cracks, length, low severity (ft)	29	16	2	0
Patches, count, low severity	0	0	2	2
Patches, area, low severity (ft <sup>2</sup> )	0	0	612	128
Raveling, area, low severity(ft <sup>2</sup> )	0	3	0	0
Centerline joint, length of distress, low severity (ft)	0	0	0	24

**Table 8 Total pavement condition distresses recorded along MnROAD Cells 135 and 235 (HMA surfacing)**

Distress	135	135	235	235
	Inner	Outer	Inner	Outer
Longitudinal cracking, non-wheel path, length, low severity (ft)	0	0	0	0
Longitudinal cracking in wheel path, length, low severity (ft)	0	0	9	1
Transverse cracks, count, low severity	0	74	12	25
Transverse cracks, length, low severity (ft)	0	136	59	100
Patches, count, low severity	0	0	0	0
Patches, area, low severity (ft <sup>2</sup> )	0	0	0	0
Raveling, area, low severity(ft <sup>2</sup> )	0	0	0	0
Centerline joint, length of distress, low severity (ft)	350	0	350	0

Figure 32 summarizes IRI (averaged between wheelpaths) for each lane and CCPR test cell at MnROAD over their 3-year lifespans. More comprehensive information on IRI is provided in in Appendix B. The effects of rutting, cracking, and surface deterioration in Cell 133/233 due to traffic is evident. In addition, the difference in ride quality due to surfacing is also evident – that is, the HMA surfaced CCPR test cells were substantially less rough than the chip-sealed sections. Appendix B contains additional figures illustrating the evolution of roughness in the MnROAD CCPR test sections.

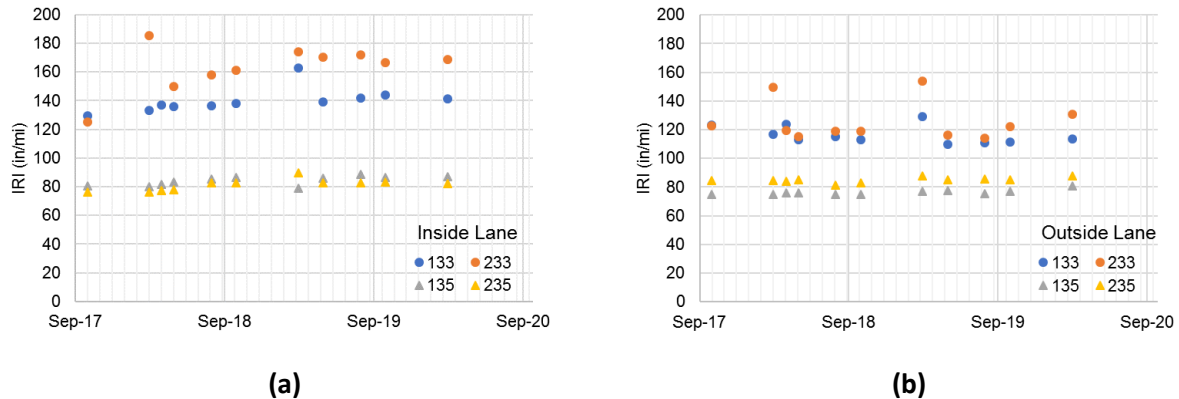


Figure 32. IRI over time for MnROAD CCPR test sections for (a) inside lane (truck lane) and (b) outer lane

### 5.2.4 Falling Weight Deflectometer

Analysis of FWD data was performed using various backcalculation procedures (e.g. TONN2010, ELMOD, and MODULUS 7.0). As discussed above, one of the challenges of FWD data analysis was related to the thicknesses of the top layer of the pavement structure. For reasons that are discussed in the literature, backcalculation algorithms generally do not return reasonable estimates of layer stiffness (i.e., elastic modulus) when layers are particularly thin. When the thinnest layer is also potentially its stiffest layer, additional complications are introduced into the analysis. For this reason, the analysis for Cells 133/233 assumes a composite layer that combines the double chip-seal surfacing and the analysis for Cells 135/235 treats the HMA surfacing and CCPR lift as a composite layer.

The results obtained with TONN2010, reported in Table 9, show agreement between the four cells on calculated base and subgrade stiffness, which is reasonable as the foundation design and construction (summarized in Section 3.1) is similar for all four cells. These results indicate that the composite layer (“L1,” i.e., the surfacing and CCPR layer) is stiffer in the HMA-surfaced sections (Cells 135/235). These results from TONN2010 resemble those obtained using MODULUS 7.0 or ELMOD.

A larger concern in the analysis – regardless of the procedure – is that the deflections under FWD loading were unusually high for backcalculation analysis procedures. This is reasonable, as the structures do not feature layers that are thick nor are they composed of stiff materials. However, the higher deflection and the nature of the structure makes convergence difficult in the calculations using all three procedures. More detail on convergence issues as experienced using different backcalculation analysis procedures are reported in Appendix B.

These issues confirm that thin surface layers within a generally “soft” composite layer (that includes a CCPR lift), where interfacial effects and layer Poisson’s ratios are uncertain, complicate FWD analysis. More to the point, these circumstances suggest that (A) the assumption of elastic behavior for this layered system may not be valid and/or (B) additional analyses could be performed to validate layered elastic analysis (LEA) assumptions, but more details about the base and subgrade would be necessary to address the backcalculation issues raised here.

Finally, Appendix B also documents some FWD analysis attempts to explore seasonal effects in the data. Due to convergence issues, these attempts were not pursued beyond the early stages of analysis.

**Table 9. Layer stiffness (average and standard deviation) from TONN2010 for Cells 133, 135, 233, and 235.**

Cell	Number of Tests	L1 Avg [ksi]	L1 St.Dev [ksi]	Base Avg [ksi]	Base St.Dev [ksi]	SG Avg [ksi]	SG St.Dev [ksi]
133	191	117.7	59.3	6.0	1.5	5.6	1.2
233	189	103.0	55.4	5.3	1.1	5.1	1.0
135	176	152.3	55.1	9.1	2.1	6.7	1.1
235	176	158.3	44.3	9.7	2.3	7.7	1.1

### 5.2.5 Laboratory Analysis of Field Cores

After discussions with MnDOT engineers on-site, the project team determined that the remaining project resources allowed for laboratory testing to indirectly assess air-void content of the CCPR lift through water displacement testing (using vacuum sealed cores). To perform these tests, laboratory staff proceeded as follows.

- Each as-received core was cataloged and photographed. These cores are documented in Appendix E.
- The lab manager inspected and marked each core to indicate a plane just above the interface between the wearing course (0.5-inch double chip seal or 1.5-inch HMA) and the CCPR layer. This mark was used as a guide for sawing.
- Note: The location of the sawcut was placed above the interface (i.e., slightly within the wearing course) for the benefit of a clean sawcut and to avoid damaging the CCPR layer.
- The cores were sawed to create a representative sample of the CCPR lift from the core. Figure 33 illustrates a processed core separating the chip-seal from the CCPR. As can be seen, the exposed surface of the CCPR portion is darker than the rest of the portion due to the additional binder from the chip seal.
- Cores were then sealed in bags and the water displacement test to assess bulk specific gravity was conducted according to ASTM D6572.

Appendix B documents the bulk specific gravity results for each CCPR sample. Analysis of these results was performed to assess air void content using the lab-determined bulk specific gravity and the theoretical maximum specific gravity from the mix design analysis. The results of that analysis for air void content are summarized in Table 10 below.

These results are difficult to interpret for many reasons, most notably because the air-void contents substantially exceed the values obtained in the laboratory mix design and the values confirmed from construction nuclear gauge density testing during roller compaction (Table 2). These results defies expectations, which is that air-void content may be lower than the mix design due to a combination of densification (due to construction compaction effort and traffic) and the marginal presence of the wearing course (which is denser than the CCPR layer).

The results in Table 10 satisfy a basic inspection. For instance, the air void content of samples from the outer lane, which was not trafficked, was consistently higher than the air void content of samples from the inner lane. Otherwise, it is difficult attribute significance to air-void content results. Overall, they may point to inadequate compaction in the construction stages, however the increase in apparent air voids may also be due to stripping at the bottom of the CCPR layer.

**Table 10. Indirect air void analysis of CCPR samples from MnROAD Cells 133, 135, 233, and 235.**

Cell	Lane	Average Air Void Content (%)	Lane	Average Air Void Content (%)
133	Inside	16.7	Outside	17.8
233	Inside	16.2	Outside	16.8
135	Inside	12.9	Outside	17.8
235	Inside	14.1	Outside	17.8



**Figure 33. Processed core from MnROAD Cell 133 (double chip seal, EE PG 58S-28)**

## CHAPTER 6: MNROAD STABILIZED FULL-DEPTH RECLAMATION MIX DESIGN

As a part of constructing low-volume full-scale test sections near MnROAD, MnDOT, and NRRA elected to use this study of CCPR as a resource for the development of two stabilized full-depth reclamation (SFDR) mix designs. The project team was able to perform these SFDR mix designs given its experience with reclaimed materials on local and state road rehabilitation projects. MnDOT modified its contract with the project team so that the SFDR mix designs could be produced in time for construction. These SFDR mix designs are not related to the CCPR portion of the project work, however they are documented here for completeness.

Unlike cold-recycling methods, SFDR mix design and construction processes must account for a wide variety of on-site materials and stabilizing agents. For more information on these methods, the reader is encouraged to consult the MnDOT *Grading and Base Manual* (2018), the ARRA *Basic Asphalt Recycling Manual* (2015), and the Portland Cement Association *Guide to Full-depth Reclamation with Cement* (Gross and Adaska, 2020) for more information.

### 6.1 BACKGROUND

MnDOT and NRRA developed test sections to be implemented as a part of the reconstruction of a low-volume road (70<sup>th</sup> Street) leading to MnROAD. While the 70<sup>th</sup> Street sections would not be within the mainline or low-volume loop of MnROAD itself, they would be along the only route into MnROAD and therefore subject to regular monitoring. Two test sections – Cells 1 and 2 – along 70<sup>th</sup> Street were proposed to be rehabilitated using SFDR with either foamed asphalt or engineered emulsion and a 1-inch HMA layer (“thinlay”). These sections were to be constructed in late August 2019.

### 6.2 WORK PERFORMED AND RESULTS

MnDOT obtained adequate samples of field RAP and base materials and provided these to the project team in early August for the laboratory testing and analysis required for SFDR mix designs. MnDOT sampled projects to meet their intended reclaiming depth to construct a 7-inch SFDR layer. Therefore, provided FDR materials for the mix design laboratory study were roughly 60 percent RAP and 40 percent gravel/soil (i.e., the reclaimer would process a 4-inch HMA pavement and 3 inches into the existing base/subgrade).

In addition to materials, MnDOT engineers also provided information on a target field gradation and intended use (i.e., target additive rate) for each recycling agent. (Given time restraints, the SFDR mix design assumed the addition of 1 percent cement by weight, rather than iterate on cement use as would normally be performed.)

The SFDR mix design using foamed asphalt involved testing at 2.0, 2.5, and 3.0 percent additive rates with 1.0 percent cement. The mix design procedure, results, and evaluation fulfilled requirements that are outlined in the 2018 MnDOT Grading and Base Manual. The final SFDR foamed asphalt mix design

report recommended an optimum foamed asphalt content of 2.0 percent. That report is included in Appendix D of this report.

Likewise, MnDOT and NRRA also solicited an SFDR mix design using an engineered emulsion (EE) at 3.0, 3.5, and 4.0 percent additive rates with 1.0 percent cement. The SFDR EE mix design also followed the procedures of the 2018 MnDOT Grading and Base Manual. The final SFDR EE mix design report (provided in Appendix D) recommended an optimum EE content of 3.0 percent.

## CHAPTER 7: DISCUSSION AND CONCLUSIONS

Reclamation techniques such as cold-recycling and full-depth reclamation sometimes are treated as foundation (i.e., base or subgrade) concerns, and as a result, the materials and structures that result from these materials are not well understood by pavement engineers. This impression is reinforced by responses to a NRRRA member survey in the early stages of this project; while many NRRRA members are accustomed to using recycled asphalt pavement (RAP) as a secondary material in pavement layers or in hot-mix asphalt (HMA) mixtures, the survey indicates that most members are new and/or unfamiliar with the use of RAP in cold-recycled (CR) layers such as those resulting from cold in-place recycling (CIR) or cold-central plant recycling (CCPR).

This NRRRA study was initiated with the construction of MnROAD CCPR test sections to investigate various options for CCPR in low-volume road applications, where local engineers or contractors may rely on a stockpiled, single-source RAP as a quality cold-recycled layer for a paving project. Both the laboratory and field testing strove to characterize the CR layers as they performed *in-situ*. The field sections at MnROAD were intended to simulate low-volume road applications, therefore the project endeavored to limit the preparation demands and characterization needs of the RAP stockpile. Furthermore, the field sections adequately represented the performance of CR mixtures in wet-freeze climates such as those found in the Upper Midwest region of the United States.

Major conclusions from this study are as follows.

- The laboratory tests determined that the MnROAD CCPR mixtures performed comparably to cold-recycled mixtures that were tested in other studies (Zegeye et al., 2017; Schwartz et al., 2017). The project team encountered difficulty with low-temperature SCB tests.
- Field surveys and field tests determined that the CCPR test section performance was more of a study of the structural properties of two surface types adopted (1.5-inch HMA overlay and double chip-seal treatment) over the CCPR lifts than it was an investigation of the recycling agents and binders. The field performance of the test sections suggested that chip-sealed CCPR lifts risk early significant rutting (i.e., 0.5-inch rut depth prior to 40,000 ESALs). However, the sections with 1.5 inches of HMA did not develop significant rutting and are possible designs for future projects.
- The study demonstrated for NRRRA members that CCPR with a sufficient structural overlay (roughly equivalent to a 1.5-inch HMA overlay in MnROAD's experience) provides a promising pavement for low-volume applications. Future studies may refine this result by determining what structure can best meet traffic and environmental demands (i.e., for the MnROAD application, the double chip seal was insufficient while the "thinlift" HMA performed well).

In addition to the original scope of this work, this study was able to use project resources to assist NRRRA in the development of SFDR mix designs for the construction of new test cells at MnROAD. These reclamation efforts add another point of emphasis on the importance of reclamation techniques for roads at all levels of management.

Finally, as noted in the literature review, near the later stages of this study, four NRRRA state members identified this project as a specific focus for research and implementation. As a result, it is hoped that as more NRRRA members become interested in cold-recycling, this report could guide them toward more specific resources on cold-recycling and other reclamation techniques.



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**APPENDIX A**  
**NRRA MEMBER SURVEY**

#1

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Friday, April 19, 2019 6:03:27 AM  
**Last Modified:** Friday, April 19, 2019 6:06:53 AM  
**Time Spent:** 00:03:26  
**IP Address:** 206.169.244.48

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Tompkins</b>
Organization	<b>AET</b>
Job Title	<b>Survey Test</b>
Email	<b>dtompkins@amengtest.com</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it **NRRA**

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program. **NRRA**

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs\*. **NRRA**

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes\*, please provide details. **NRAA**

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us **Respondent skipped this question**

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Dave, would it be possible to create a rule in your outlook to auto-forward emails from this survey to me?

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

# #2

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Monday, April 22, 2019 4:22:48 PM  
**Last Modified:** Monday, April 22, 2019 4:23:30 PM  
**Time Spent:** 00:00:41  
**IP Address:** 74.95.140.5

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation. **Respondent skipped this question**

---

**Q2** Is your organization aware of CCPR technology?

No and we aren't planning on using it (if so, you can exit the survey here)

**We do not use this material**

---

**Q3** On what type of projects would you consider using CCPR? **Respondent skipped this question**

---

**Q4** Does your agency have a CCPR mix design and/or construction specification? **Respondent skipped this question**

---

**Q5** Does your state have field QC/QA procedures established for CCPR? **Respondent skipped this question**

---

**Q6** The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to [dave.vandeusen@state.mn.us](mailto:dave.vandeusen@state.mn.us) **Respondent skipped this question**

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region? **Respondent skipped this question**

---

**Q8** Any additional comments? **Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to: [dave.vandeusen@state.mn.us](mailto:dave.vandeusen@state.mn.us) **Respondent skipped this question**

---

#3

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Monday, April 22, 2019 4:20:13 PM  
**Last Modified:** Monday, April 22, 2019 4:24:55 PM  
**Time Spent:** 00:04:41  
**IP Address:** 73.88.14.109

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Dan Wegman</b>
Organization	<b>Braun Intertec</b>
Job Title	<b>Principal</b>
Email	<b>Dwegman@braunintertec.com</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>Wright County Project- consultants</b>
--	---

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Any project with excess RAP availability</b>
--	---

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls*.	<b>No</b>
---	-----------

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>No</b>
----------------------------------	-----------

---

<b>Q6</b> The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us	<b>Respondent skipped this question</b>
---	---

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Lack of projects

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

No

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**



#4

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Monday, April 22, 2019 6:33:56 PM  
**Last Modified:** Monday, April 22, 2019 6:41:28 PM  
**Time Spent:** 00:07:32  
**IP Address:** 75.168.74.110

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Terry Beaudry</b>
Organization	<b>MnDOT</b>
Job Title	<b>Reclamation Engineer</b>
Email	<b>terry.beaudry@state.mn.us</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>MnROAD</b>
--	---------------

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>To repair a full depth asphalt pavement grade. Mill to within 4" of bottom, stabilized grade, bring back at least 4" of cold mix.</b>
--	--

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>Yes, on line spec 2390, mix design in Grading and Base Manual</b>
---	--

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>Yes, see schedule of materials control</b>
----------------------------------	---

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us

**Respondent skipped this question**

---

Cold Central Plant Recycling--CCPR

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

none

---

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

#5

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 23, 2019 5:58:37 AM  
**Last Modified:** Tuesday, April 23, 2019 6:03:02 AM  
**Time Spent:** 00:04:24  
**IP Address:** 136.181.195.23

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Kevin Kennedy</b>
Organization	<b>Michigan Department of Transportation</b>
Job Title	<b>HMA Operations Engineer</b>
Email	<b>kennedyk@michigan.gov</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>We have seen presentations from vendors</b>
--	--

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>low volume roadways</b>
--	----------------------------

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls*.	<b>no</b>
---	-----------

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>no</b>
----------------------------------	-----------

---

<b>Q6</b> The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us	<b>Respondent skipped this question</b>
--	---

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Lack of familiaraty with technology and whether it is appropriate for state trunklines

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

n/a

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

#6

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 23, 2019 7:04:26 AM  
**Last Modified:** Tuesday, April 23, 2019 7:14:10 AM  
**Time Spent:** 00:09:43  
**IP Address:** 151.111.143.17

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Jerry Geib</b>
Organization	<b>MnDOT</b>
Job Title	<b>Research Operations Engineer</b>
Email	<b>jerry.geib@state.mn.us</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction

**The only one I am aware of is a test section at MnROAD, built for the NRRA**

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.

**I am not aware of any projects**

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls\*.

**Not sure**

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes\*, please provide details.

**not sure**

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us

**Respondent skipped this question**

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

staff for implementation

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

#7

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 23, 2019 7:20:14 AM  
**Last Modified:** Tuesday, April 23, 2019 7:22:47 AM  
**Time Spent:** 00:02:32  
**IP Address:** 204.98.245.34

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	thomas j wood
Organization	WSB & Ass.
Job Title	Pavement Specialist
Email	twood@wsbeng.com

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction	Yes
--	-----

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	shoulders on interstate, up grading gravel surfaced roads
--	---

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls*.	no
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---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	na
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**Q6** The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us

Respondent skipped this question

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Respondent skipped this question

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**



#8

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 23, 2019 8:57:56 AM  
**Last Modified:** Tuesday, April 23, 2019 9:02:42 AM  
**Time Spent:** 00:04:46  
**IP Address:** 151.111.143.17

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Dave Van Deusen</b>
Organization	<b>MnDOT OMRR</b>
Job Title	<b>Research Operations Engineer</b>
Email	<b>dave.vandeusen@state.mn.us</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>Four test sections constructed at MnROAD in 2017</b>
Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>I am aware of a local job in Otter Tail County constructed 2018</b>

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Surfacing projects where there is no available RAP on the project but significant stockpiled RAP available from potential bidders.</b>
--	---

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>MnROAD adapted our CIR spec for the research sections</b>
---	--

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>We attempted to implement the Virginia DOT model but were unsuccessful</b>
----------------------------------	---

---

**Q6** The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us

**Respondent skipped this question**

---

## Cold Central Plant Recycling--CCPR

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

General awareness will lead to usage

---

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

---

**Respondent skipped this question**

#9

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 23, 2019 12:44:19 PM  
**Last Modified:** Tuesday, April 23, 2019 12:58:38 PM  
**Time Spent:** 00:14:19  
**IP Address:** 132.177.238.74

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Eshan V. Dave</b>
Organization	<b>University of New Hampshire</b>
Job Title	<b>Associate Professor</b>
Email	<b>eshan.dave@unh.edu</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>Responding for NHDOT: CCPR is being extensively used by NHDOT for major rehabilitation and reconstruction.</b>
-------------------------------------	---

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Everything from low volume to high volume.</b>
--	---

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls*.	<b><a href="https://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBookWeb.pdf">https://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2016NHDOTSpecBookWeb.pdf</a></b>
---	--

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>Not well developed, but mostly driven by density and moisture content measurements.</b>
----------------------------------	--

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us

**Respondent skipped this question**

---

Cold Central Plant Recycling--CCPR

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Faster QA process and results.

---

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

---

**Respondent skipped this question**

#10

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Wednesday, April 24, 2019 9:32:17 AM  
**Last Modified:** Wednesday, April 24, 2019 9:35:00 AM  
**Time Spent:** 00:02:42  
**IP Address:** 162.40.44.67

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Daniel Staebell</b>
Organization	<b>Asphalt Pavement Alliance</b>
Email	<b>dstaebell@asphaltroads.org</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>Yes, we currently train and mention during presentations</b>
Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>IA</b>

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Commercial Work, Base Construction prior to paving.</b>
--	--

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>NA</b>
---	-----------

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>NA</b>
----------------------------------	-----------

---

<b>Q6</b> The NRRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us	<b>Respondent skipped this question</b>
--	---

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

QC/QA requirements and methods

---

## Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

Thanks for taking this on, looking forward to results.

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

#11

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Wednesday, April 24, 2019 12:06:11 PM  
**Last Modified:** Wednesday, April 24, 2019 12:09:48 PM  
**Time Spent:** 00:03:36  
**IP Address:** 151.111.143.16

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	Tim Clyne
Organization	MnDOT
Job Title	Metro Materials Engineer
Email	tim.clyne@state.mn.us

---

**Q2** Is your organization aware of CCPR technology?

No, but we are considering using CCPR in an upcoming project

**Yes, we're aware of CCPR, but haven't found the "right" project yet. We will possibly use on shoulder M&O.**

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.

**M&O of bit shoulders next to concrete mainline. Multi-lift M&O over concrete pavement. We would look on lower volume roads first.**

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs\*.

**Yes, MnDOT Spec 2390.**

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes\*, please provide details.

**Yes, MnDOT Spec 2390 and Schedule of Materials Control.**

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us

**Respondent skipped this question**

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

**Respondent skipped this question**

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**



#12

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Wednesday, April 24, 2019 1:27:53 PM  
**Last Modified:** Wednesday, April 24, 2019 1:29:15 PM  
**Time Spent:** 00:01:22  
**IP Address:** 168.166.80.221

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Phil Ruffus</b>
Organization	<b>MoDOT</b>
Job Title	<b>Pavement Engineer</b>
Email	<b>phillip.ruffus@modot.mo.gov</b>

---

**Q2** Is your organization aware of CCPR technology?

No and we aren't planning on using it (if so, you can exit the survey here)

**We are using cold in place but not central****Q3** On what type of projects would you consider using CCPR?**Respondent skipped this question****Q4** Does your agency have a CCPR mix design and/or construction specification?**Respondent skipped this question****Q5** Does your state have field QC/QA procedures established for CCPR?**Respondent skipped this question****Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us**Respondent skipped this question****Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?**Respondent skipped this question****Q8** Any additional comments?**Respondent skipped this question**

Cold Central Plant Recycling--CCPR

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

**Respondent skipped this question**

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#13

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Wednesday, April 24, 2019 1:33:07 PM  
**Last Modified:** Wednesday, April 24, 2019 1:35:26 PM  
**Time Spent:** 00:02:19  
**IP Address:** 168.166.80.221

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Mike Shea &amp; Jason Blomberg</b>
Organization	<b>MoDOT</b>
Email	<b>michael.shea@modot.mo.gov</b>

---

**Q2** Is your organization aware of CCPR technology?

No and we aren't planning on using it (if so, you can exit the survey here)	<b>x</b>
---	----------

---

<b>Q3</b> On what type of projects would you consider using CCPR?	<b>Respondent skipped this question</b>
---	---

---

<b>Q4</b> Does your agency have a CCPR mix design and/or construction specification?	<b>Respondent skipped this question</b>
--	---

---

<b>Q5</b> Does your state have field QC/QA procedures established for CCPR?	<b>Respondent skipped this question</b>
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---

<b>Q6</b> The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeußen@state.mn.us	<b>Respondent skipped this question</b>
---	---

---

<b>Q7</b> What do you believe to be the challenges to acceptance of CCPR in your state/region?	<b>Respondent skipped this question</b>
--	---

---

<b>Q8</b> Any additional comments?	<b>Respondent skipped this question</b>
------------------------------------	---

---

Cold Central Plant Recycling--CCPR

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

**Respondent skipped this question**

---

#14

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Thursday, April 25, 2019 10:23:54 AM  
**Last Modified:** Thursday, April 25, 2019 10:46:22 AM  
**Time Spent:** 00:22:28  
**IP Address:** 149.136.17.252

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Raghubar Shrestha</b>
Organization	<b>Caltrans</b>
Job Title	<b>Sr. Transportation Engineer</b>
Email	<b>raghubar.shrestha@dot.ca.gov</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>yes, but have not used it.</b>
-------------------------------------	-----------------------------------

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>N/A</b>
--	------------

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>n/A</b>
---	------------

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>N/A</b>
----------------------------------	------------

---

<b>Q6</b> The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandusen@state.mn.us	<b>Respondent skipped this question</b>
--	---

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

n/A

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

# #15

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Friday, April 26, 2019 2:18:35 PM  
**Last Modified:** Friday, April 26, 2019 2:25:20 PM  
**Time Spent:** 00:06:45  
**IP Address:** 165.189.255.34

---

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Peter Kemp</b>
Organization	<b>Wisconsin Department of Transportation</b>
Job Title	<b>Pavement Supervisor</b>
Email	<b>peter.kemp@dot.wi.gov</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>None to date</b>
--	---------------------

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Where a traditional Cold in Place because of staging, base repairs or utility work would require the removal of millings off the roadway. May also consider use where large stockpiles exist adjacent to a reconstruction or pavement replacement where the rise in profile would be allowable or mitigated through the construction process.</b>
--	--

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>This currently would be the same as a traditional Cold in Place as there is a common specification that would be used for a CCPR project.</b>
---	--

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>This currently would be the same as a traditional Cold in Place as there is a common specification that would be used for a CCPR project</b>
----------------------------------	---

---

## Cold Central Plant Recycling--CCPR

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to [dave.vandeusen@state.mn.us](mailto:dave.vandeusen@state.mn.us)

---

**Respondent skipped this question**

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

The need to show the better performance of CCPR/CIR products vs just using crushed RAP. The historical use of crushed RAP as a lower layer is more popular than using CIR. This mentality may exist with CCPR also. Also hindering the use of the process is related to the rise in profile while maintaining allowable shoulder and cross section geometrics without the expansion of the roadways original footprint

---

**Q8** Any additional comments?

**Respondent skipped this question**

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
[dave.vandeusen@state.mn.us](mailto:dave.vandeusen@state.mn.us)

---

**Respondent skipped this question**



# #16

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Monday, April 29, 2019 8:57:29 AM  
**Last Modified:** Monday, April 29, 2019 10:54:15 AM  
**Time Spent:** 01:56:46  
**IP Address:** 216.17.49.53

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Dan Schellhammer</b>
Organization	<b>Midstate Reclamation and Trucking</b>
Job Title	<b>President</b>
Email	<b>dans@midstatecompanies.com</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>Contractor producing and placing CCPR cold mix</b>
Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>MN, SD, CA, NM, NV, UT</b>

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Any project that is currently slated to utilize HMA</b>
--	--

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project Pls*.	<b>We are not an agency, but could provide CCPR mix design/specs if necessary. We've found that it is also important to include a spec for stockpile management with the CCPR spec.</b>
---	---

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>We're a contractor.</b>
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<b>Q6</b> The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandusen@state.mn.us	<b>Respondent skipped this question</b>
--	---

---

## Cold Central Plant Recycling--CCPR

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Proper project selection, lack of performance data, hot mix industry competition, engineers that compare cold mix to hot mix

---

**Q8** Any additional comments?

None

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

**Respondent skipped this question**

---

#17

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Monday, April 29, 2019 11:40:33 AM  
**Last Modified:** Monday, April 29, 2019 12:01:36 PM  
**Time Spent:** 00:21:02  
**IP Address:** 163.191.13.70

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	Tom Zehr
Organization	IDOT Central Bureau of Materials
Job Title	HMA Implementation Engineer
Email	thomas.zehr@illinois.gov

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	Yes, but IDOT has done few if any projects using CCPR.
-------------------------------------	--

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	Mostly low ESAL, rural
--	------------------------

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	No
---	----

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	No
----------------------------------	----

---

<b>Q6</b> The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandusen@state.mn.us	Respondent skipped this question
--	----------------------------------

---

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Industry acceptance. Availability of any speccial equipment.

---

Cold Central Plant Recycling--CCPR

**Q8** Any additional comments?

**Respondent skipped this question**

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

#18

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Tuesday, April 30, 2019 12:30:49 PM  
**Last Modified:** Tuesday, April 30, 2019 12:34:53 PM  
**Time Spent:** 00:04:04  
**IP Address:** 208.103.61.163

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Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Jason Wielinski</b>
Organization	<b>Heritage Research Group</b>
Job Title	<b>Reseach Engineer</b>
Email	<b>jason.wielinski@hrglab.com</b>

---

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>One state job constructed, multiple local agency projects</b>
Yes and these are the state or local projects involving CCPR within our jurisdiction	<b>INDOT SR 101, Monroe CO MI, various others</b>

---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>In combination with FDR, on top of repaired PCC pavements, upgrade gravel roadways</b>
--	---

---

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>Yes</b>
---	------------

---

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>Yes, they are described in the specification</b>
----------------------------------	---

---

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandeusen@state.mn.us

---

**Respondent skipped this question**

## Cold Central Plant Recycling--CCPR

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

Push back from HMA industry, lack of agency experience

---

**Q8** Any additional comments?

Seems like a great cost effective tool

---

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

**Respondent skipped this question**

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#19

**COMPLETE**

**Collector:** Web Link 1 (Web Link)  
**Started:** Friday, May 03, 2019 10:30:28 AM  
**Last Modified:** Friday, May 03, 2019 10:36:46 AM  
**Time Spent:** 00:06:18  
**IP Address:** 163.191.13.70

Page 1: CCPR

**Q1** Please provide your name and organizational affiliation.

Name	<b>Charles Wienrank</b>
Organization	<b>Illinois Department of Transportation</b>
Job Title	<b>Pavement Design Engineer</b>
Email	<b>Charles.Wienrank@illinois.gov</b>

**Q2** Is your organization aware of CCPR technology?

Yes, and here's how we are using it	<b>Yes, but it has not been used on a project yet</b>
-------------------------------------	---

**Q3** On what type of projects would you consider using CCPR?

Please provide details relative to your network pavement rehabilitation program.	<b>Primarily on the local road network</b>
--	--

**Q4** Does your agency have a CCPR mix design and/or construction specification?

If so, please provide a copy to the project PIs*.	<b>No, but a committee has been formed to develop a spec</b>
---	--

**Q5** Does your state have field QC/QA procedures established for CCPR?

If yes*, please provide details.	<b>Will be included in development of spec</b>
----------------------------------	--

**Q6** The NRRA is interested in obtaining construction cost information for CCPR projects. Are you aware of costs associated with CCPR? If so, please send cost information to dave.vandusen@state.mn.us

**Respondent skipped this question**

**Q7** What do you believe to be the challenges to acceptance of CCPR in your state/region?

**Respondent skipped this question****Q8** Any additional comments?**Respondent skipped this question**

## Cold Central Plant Recycling--CCPR

**Q9** \* If you have plans, special provisions, mix designs, construction specifications, QA/QC procedures and cost information, please send them to:  
dave.vandusen@state.mn.us

**Respondent skipped this question**



**APPENDIX B**  
**MNROAD TEST SECTIONS AND FIELD DATA**

## 1.1 RUTTING

### 1.1.1 Inside-Inside

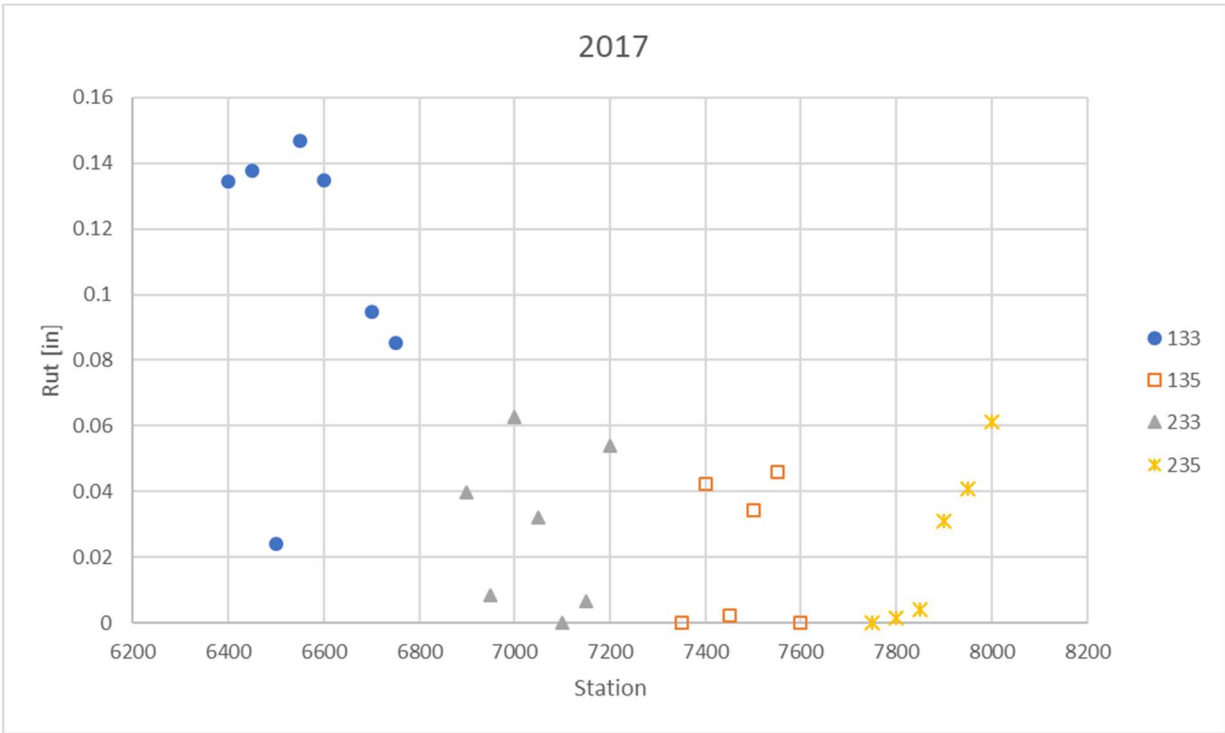


Figure 1 Rutting Results: Inside lane – Inside wheel path

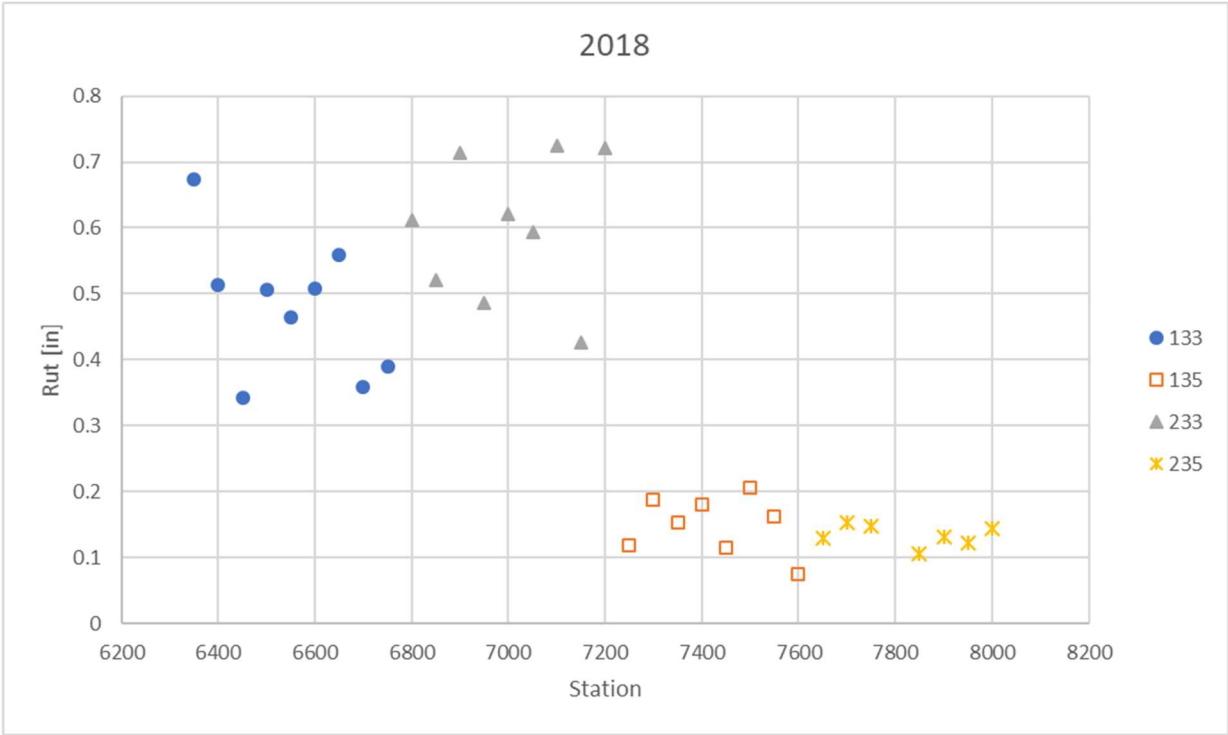


Figure 2 Rutting Results: Inside lane – Inside wheel path

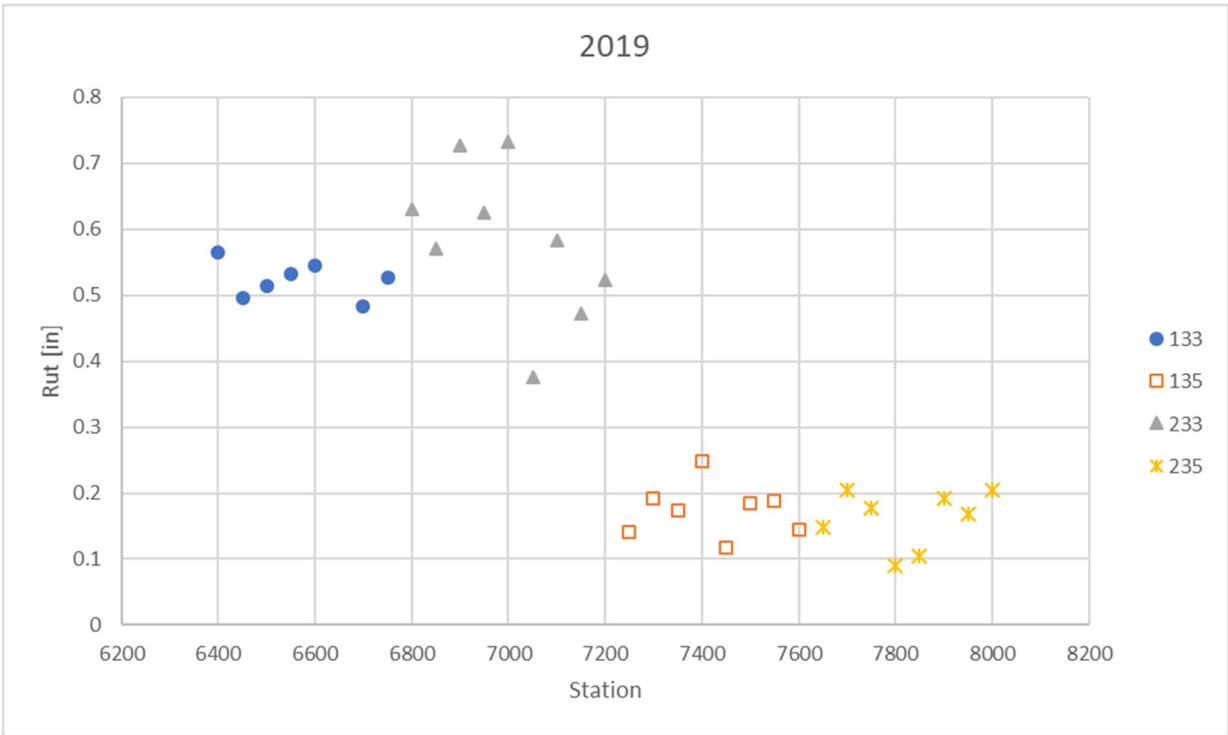


Figure 3 Rutting Results: Inside lane – Inside wheel path

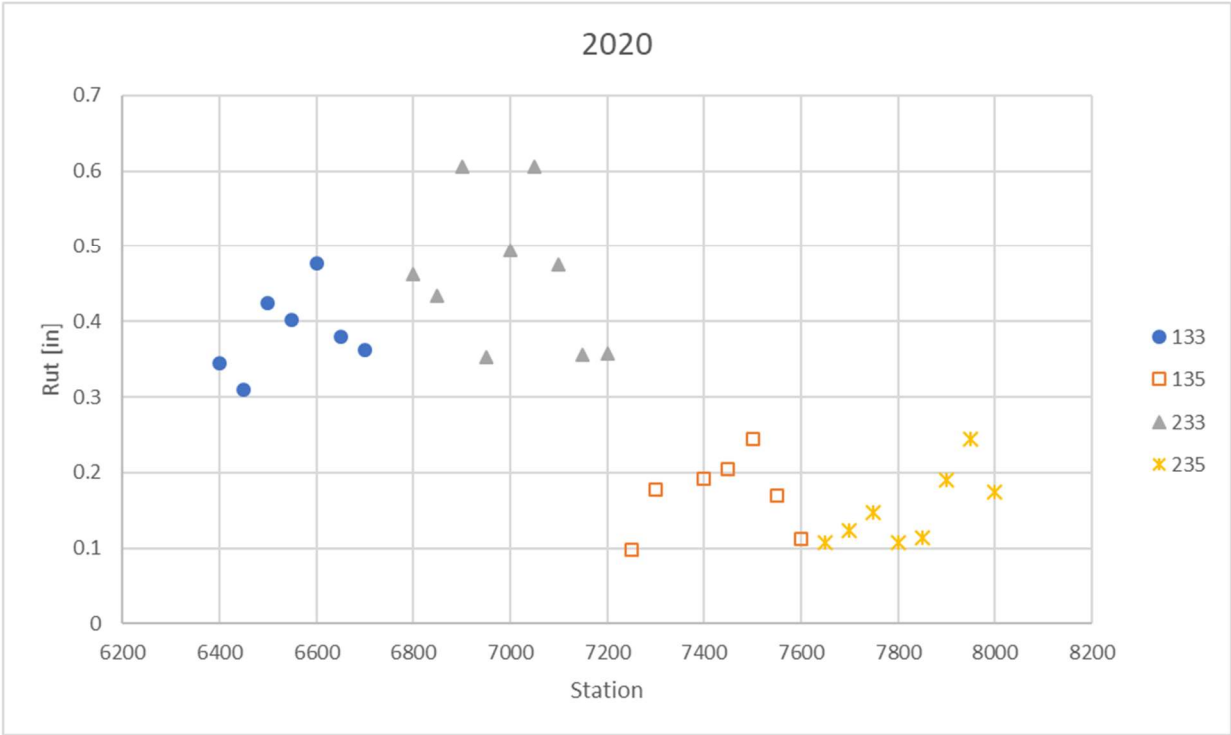


Figure 4 Rutting Results: Inside lane – Inside wheel path

### 1.1.2 Inside Outside

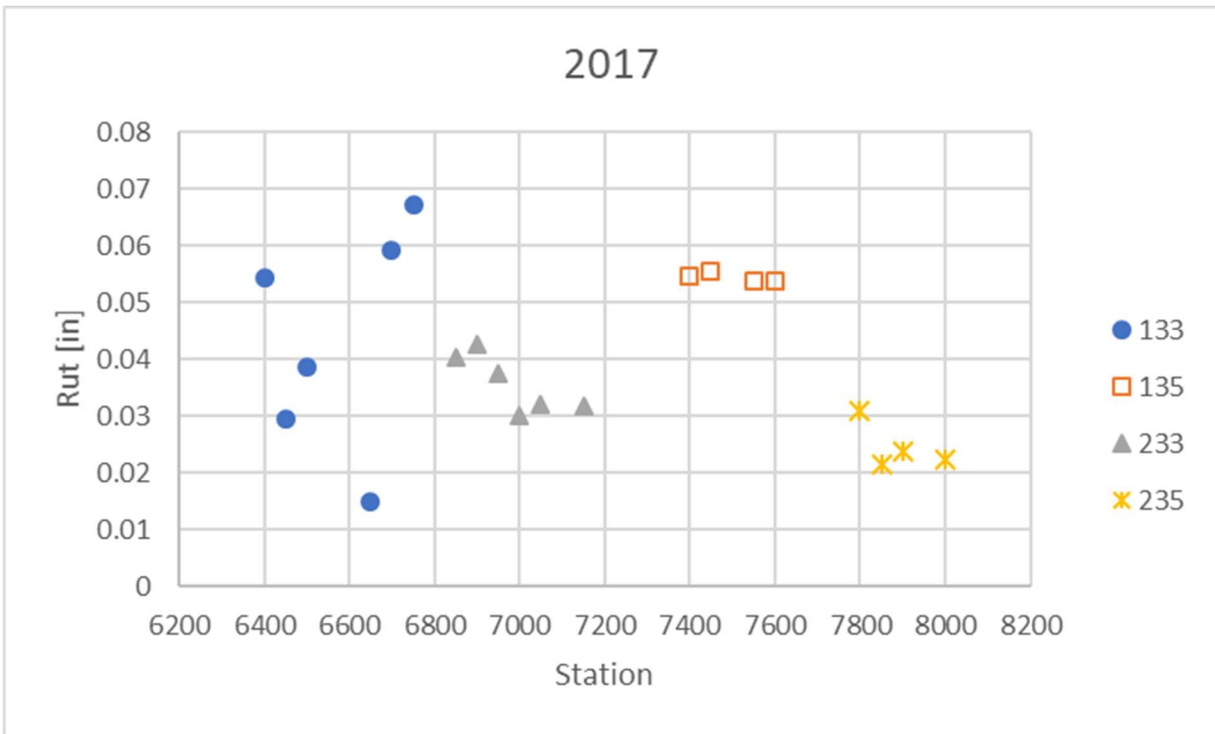


Figure 5 Rutting Results: Inside lane – Outside wheel path

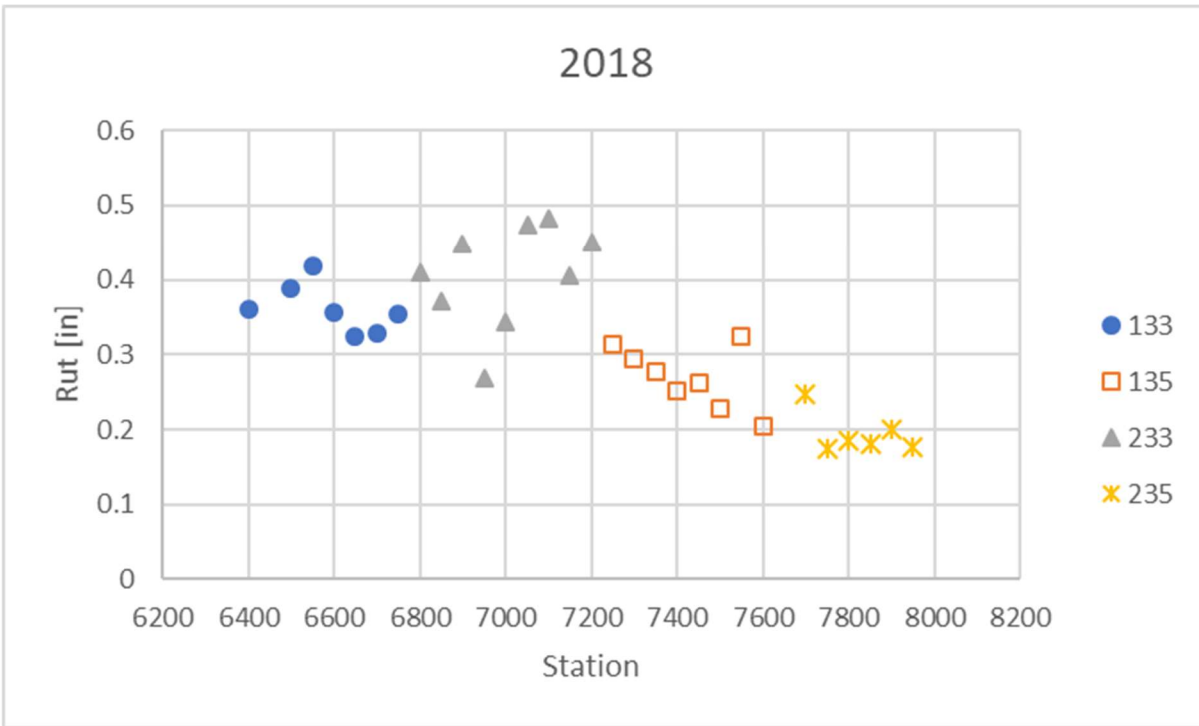


Figure 6 Rutting Results: Inside lane- Outside wheel path

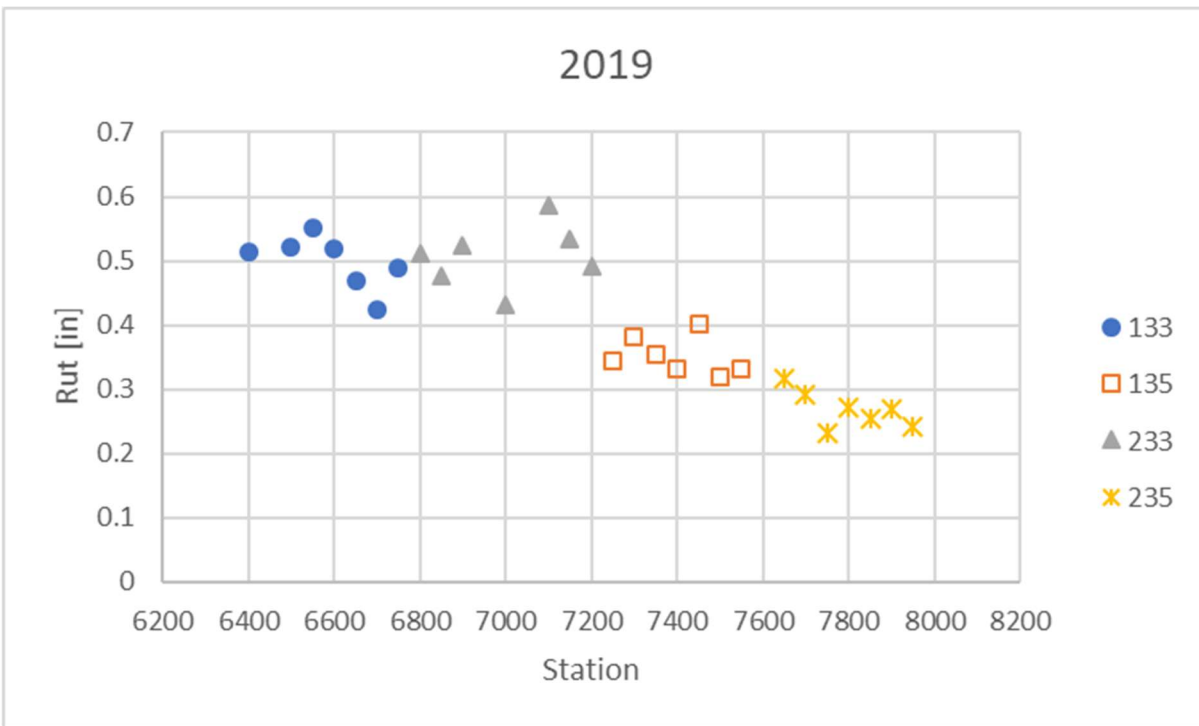


Figure 7 Rutting Results: Inside lane- Outside wheel path

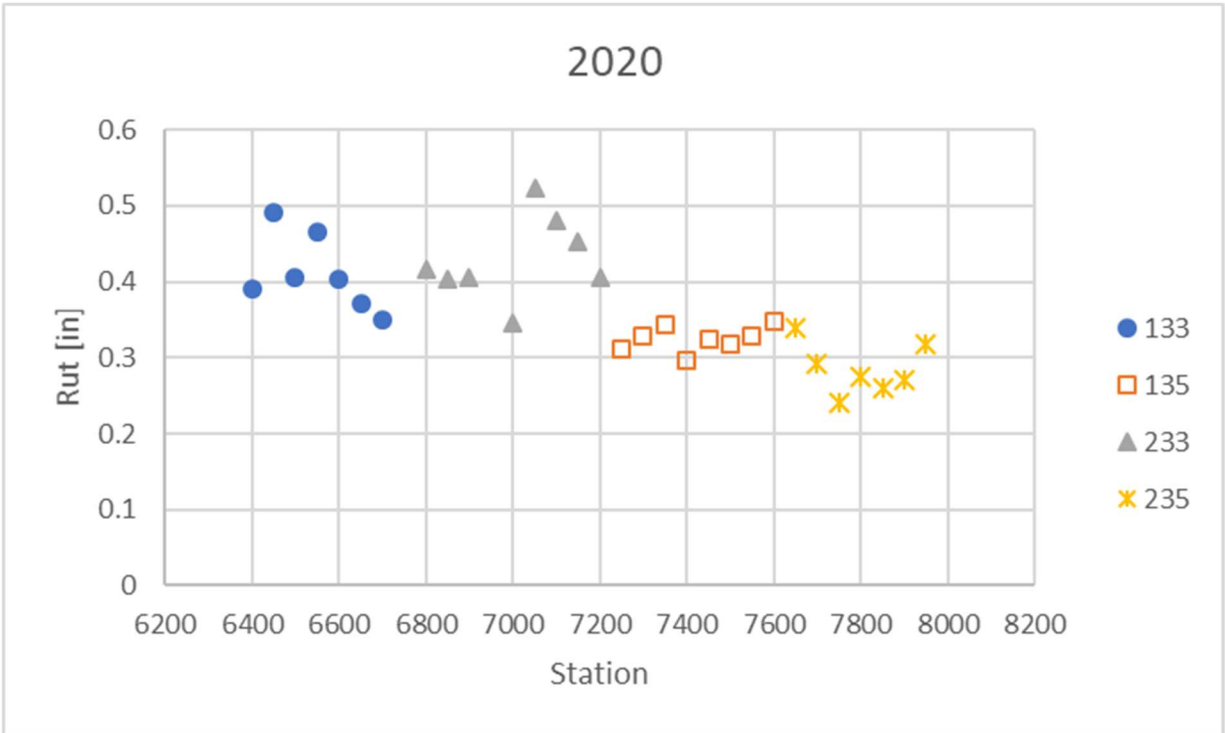


Figure 8 Rutting Results: Inside lane- Outside wheel path

### 1.1.3 Outside – Inside

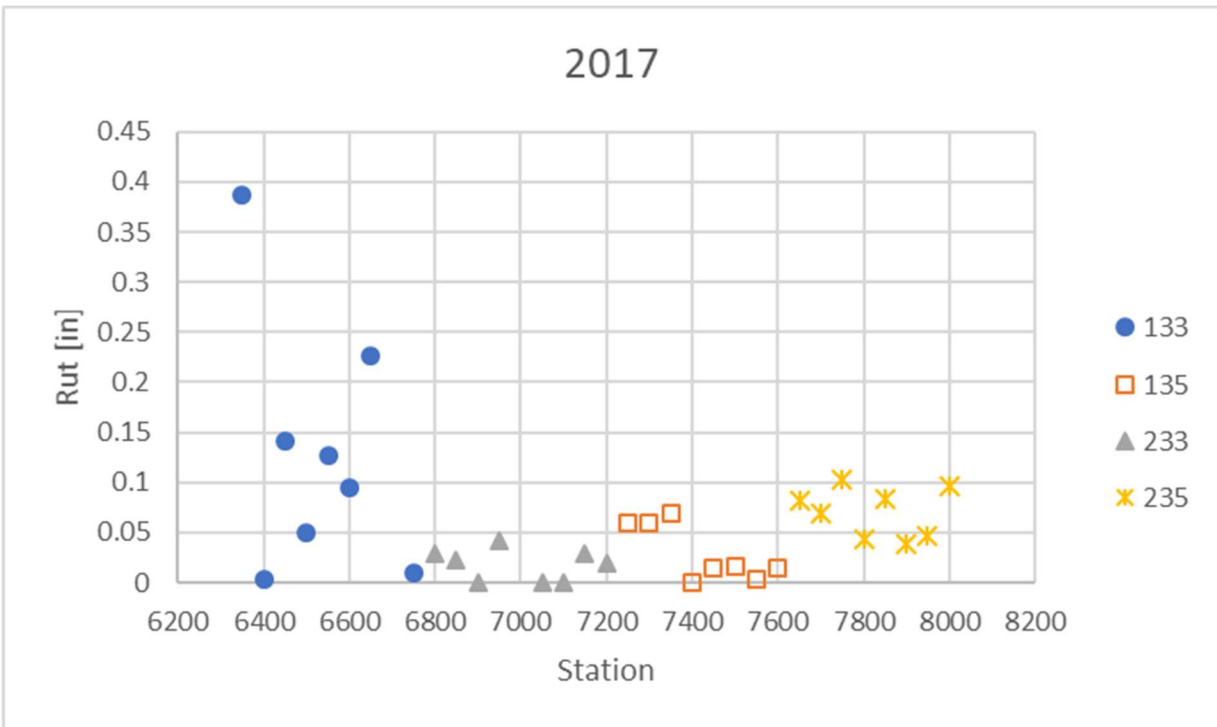


Figure 9 Rutting Results: Outside lane – Inside wheel path



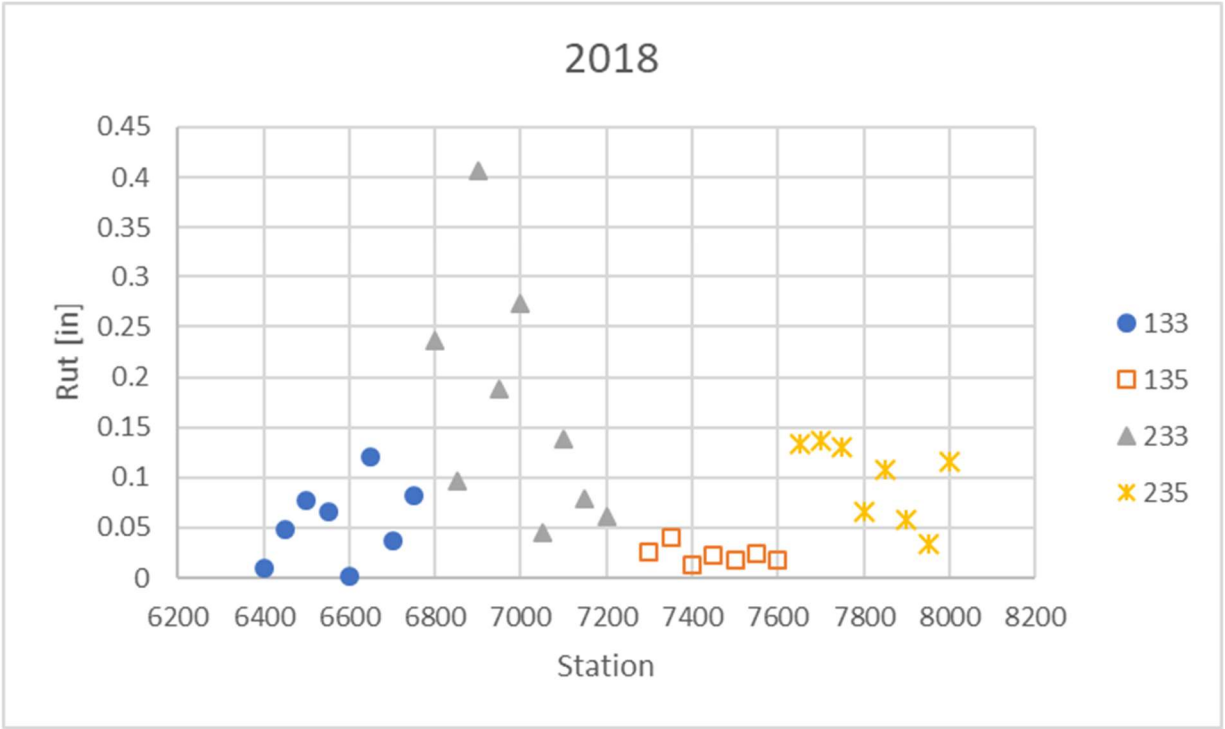


Figure 10 Rutting Results: Outside lane – Inside wheel path

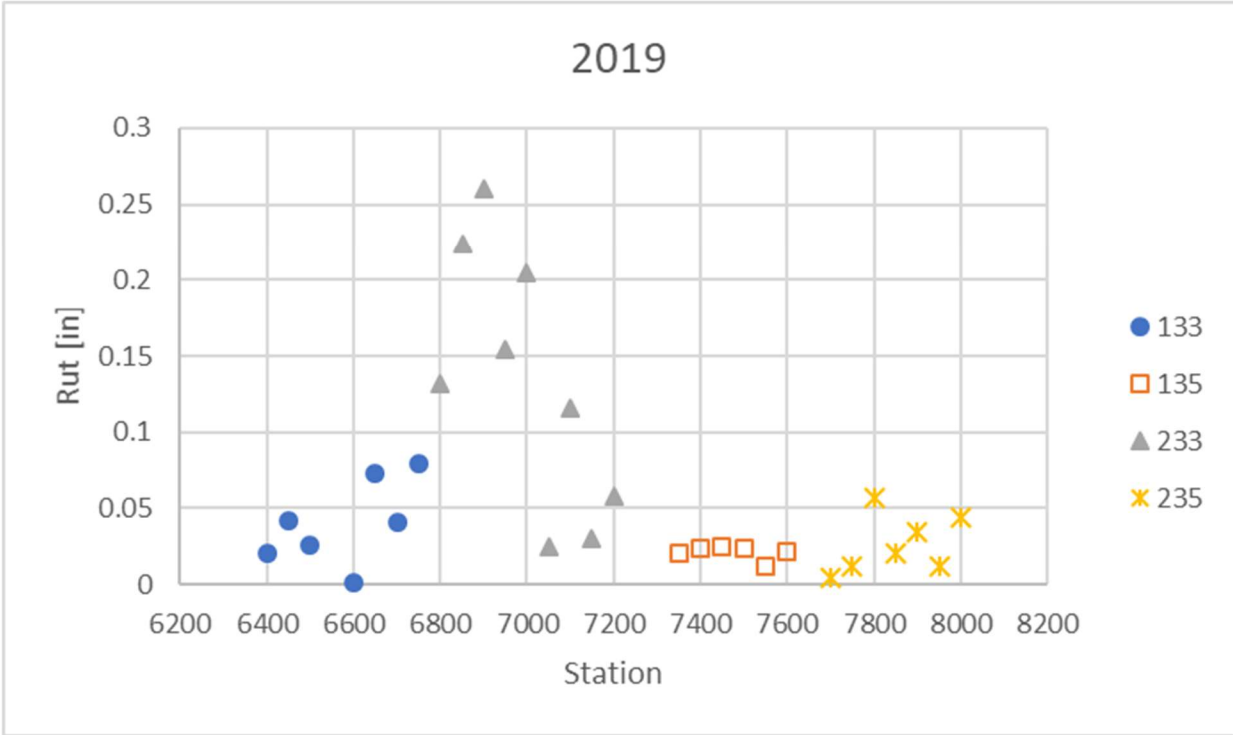


Figure 11 Rutting Results: Outside lane – Inside wheel path

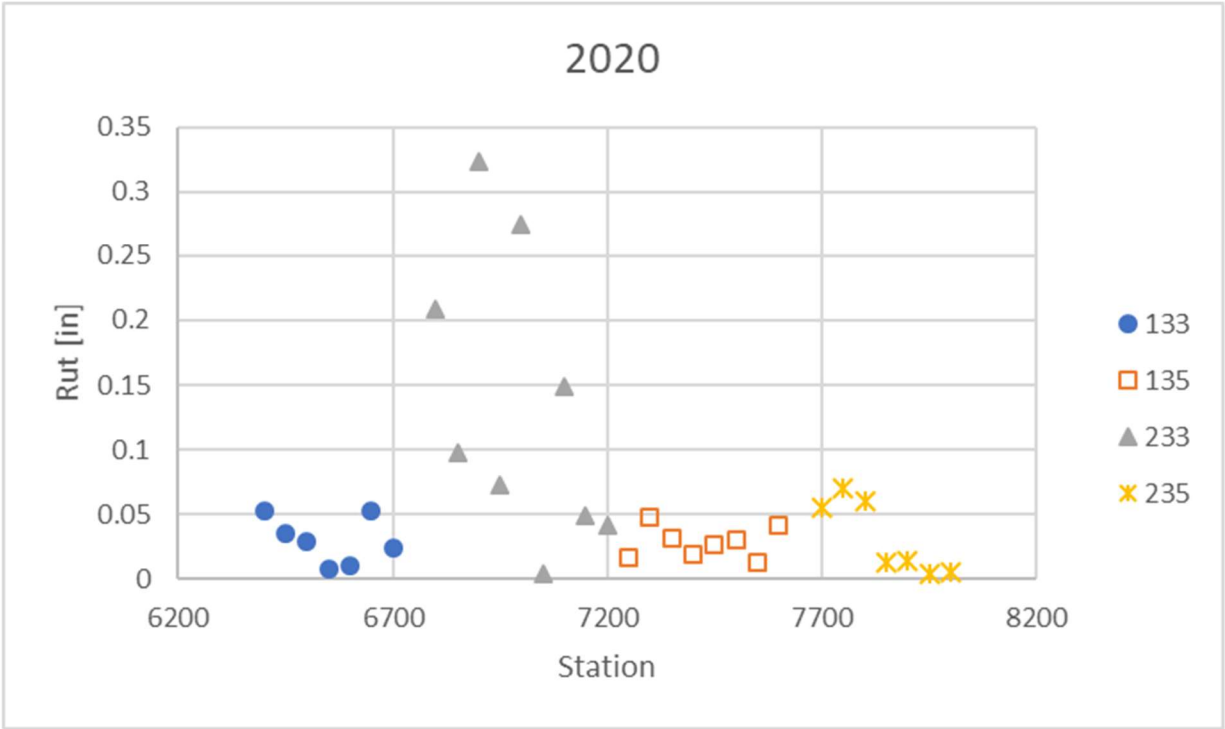


Figure 12 Rutting Results: Outside lane – Inside wheel path

### 1.1.4 Outside – Outside

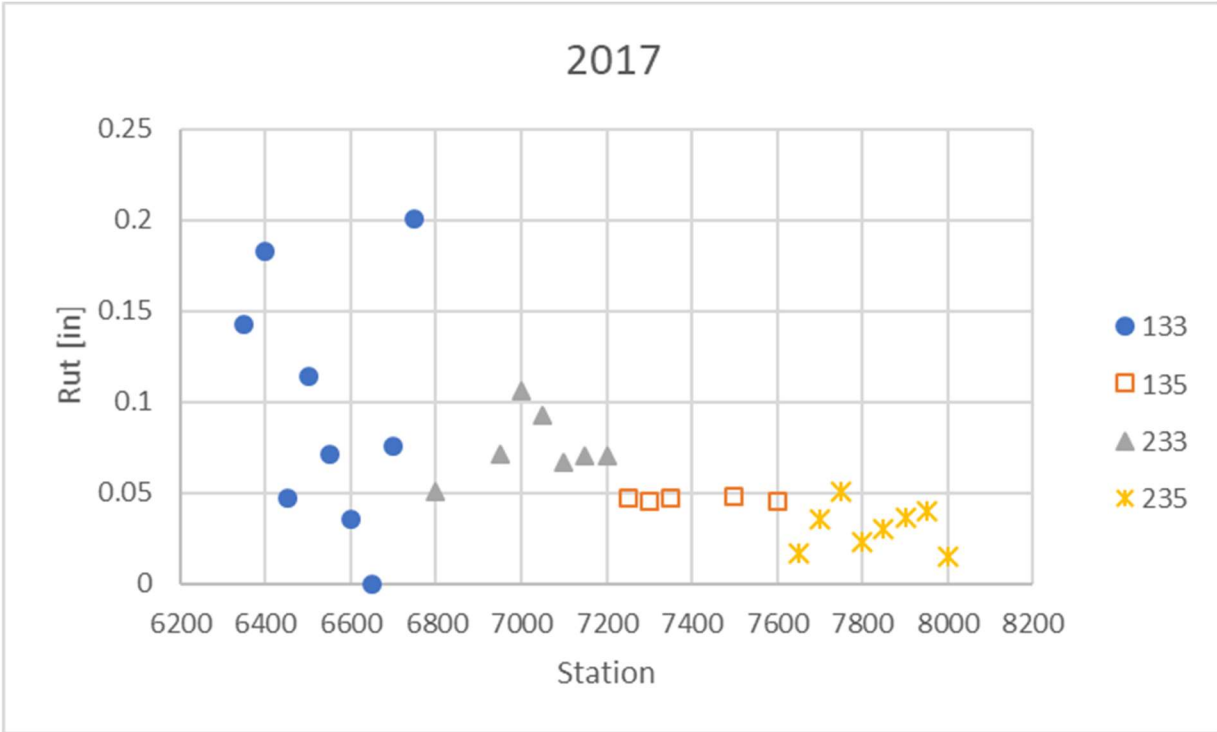


Figure 13 Rutting Results: Outside lane – Outside wheel path

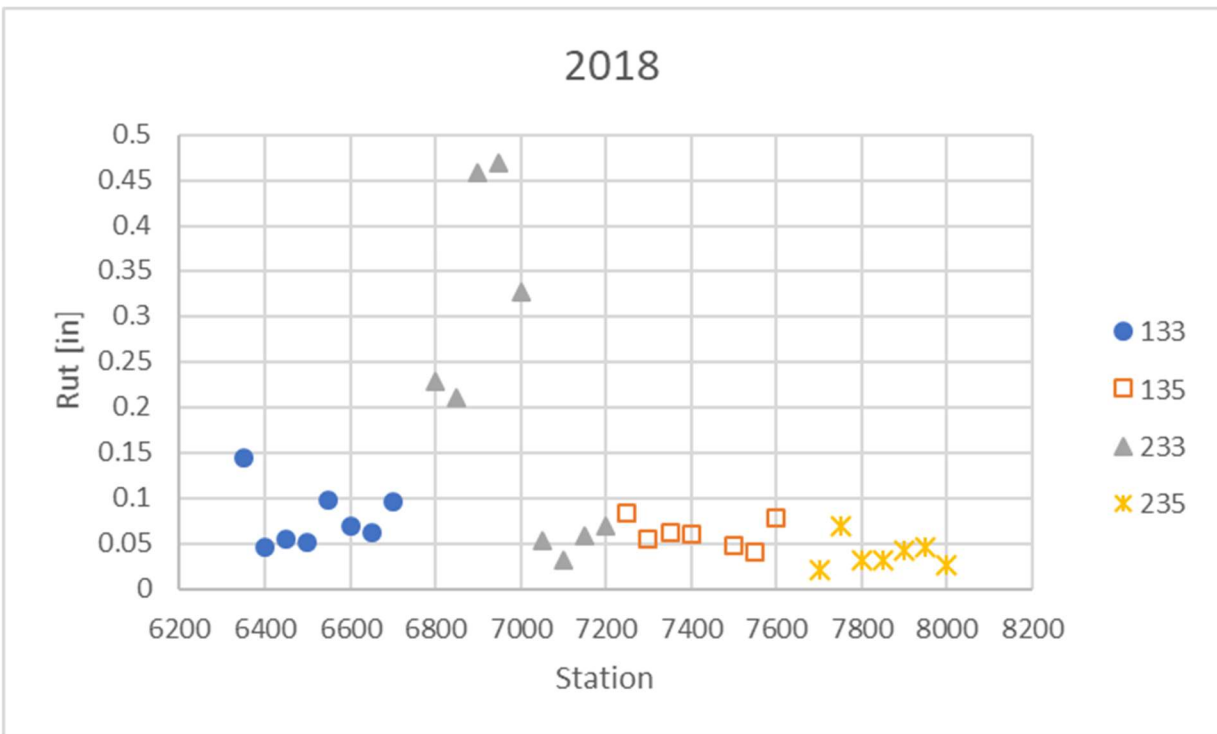


Figure 14 Rutting Results: Outside lane – Outside wheel path

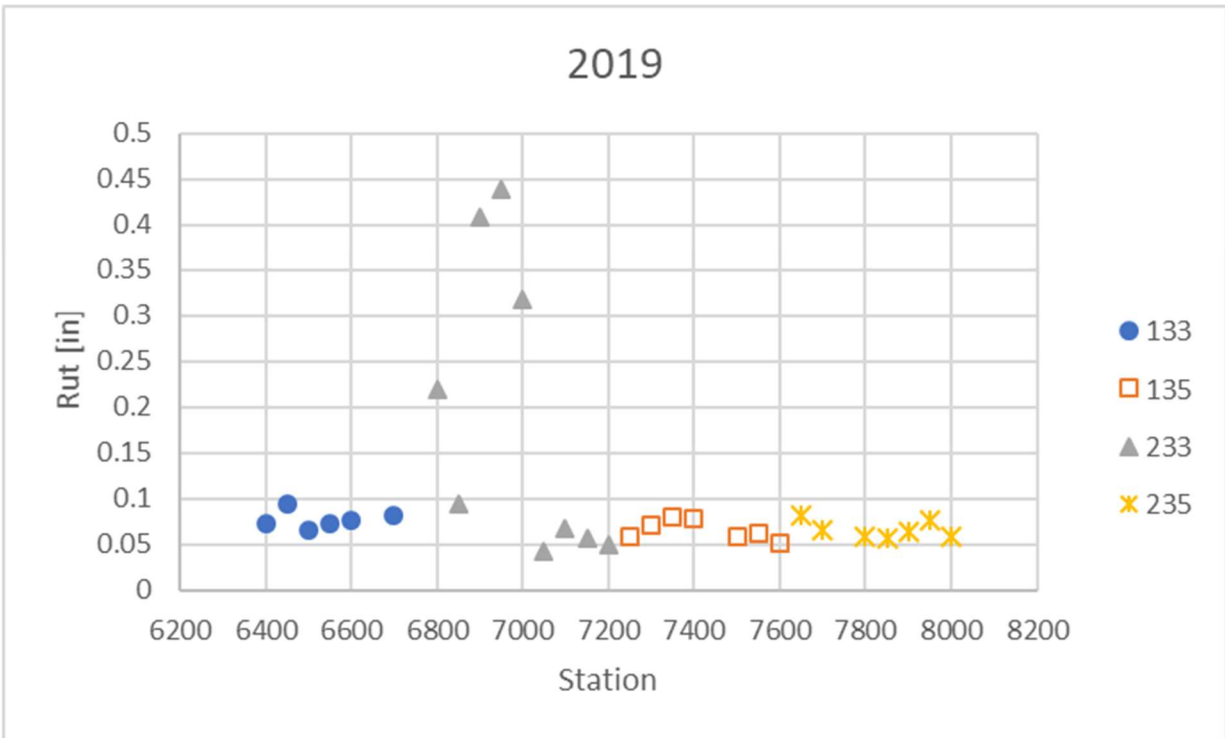


Figure 15 Rutting Results: Outside lane – Outside wheel path

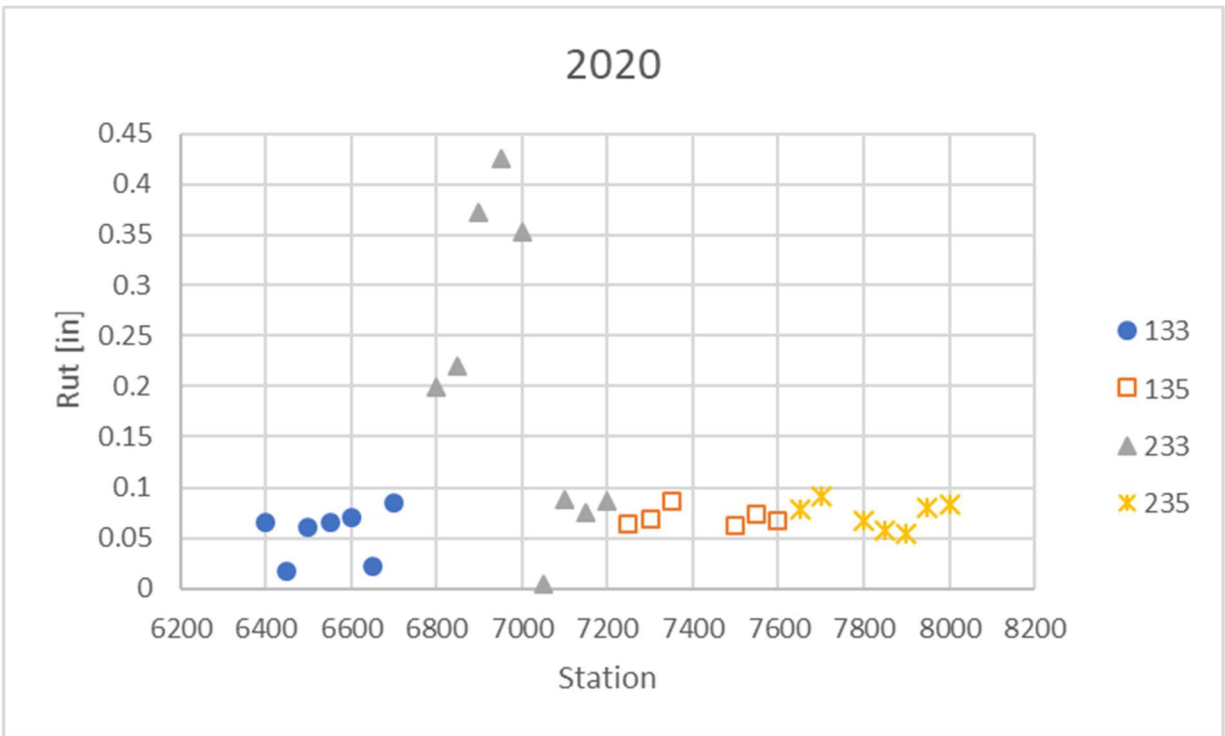


Figure 16 Rutting Results: Outside lane – Outside wheel path

1.2 RIDE

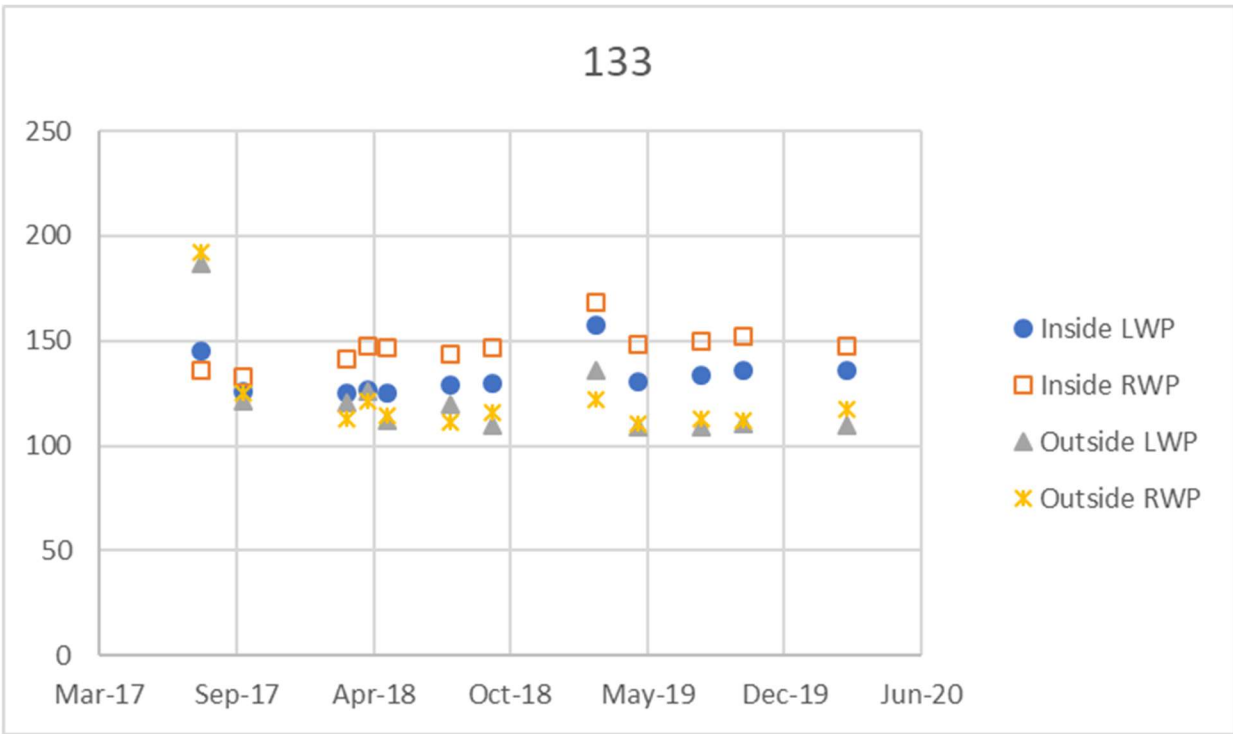


Figure 17 Ride quality results: Inside – Outside left wheel path (LWP) and right wheel path (RWP)

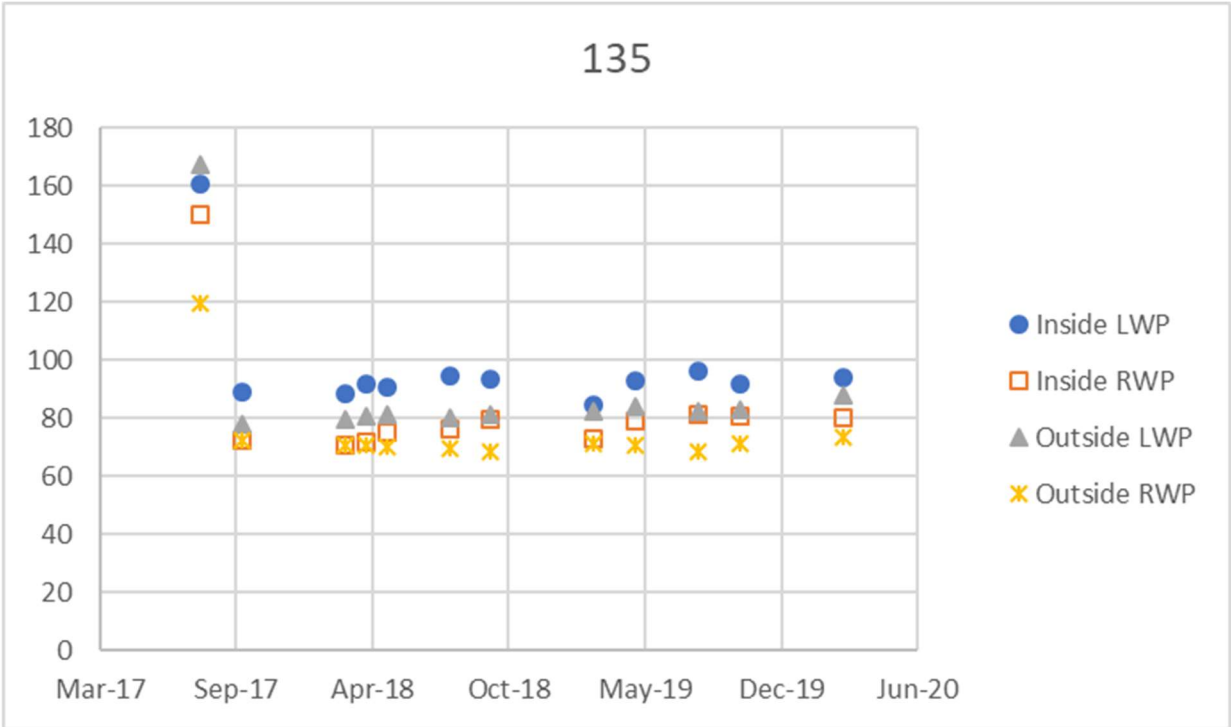


Figure 18 Ride quality results: Inside – Outside left wheel path (LWP) and right wheel path (RWP)

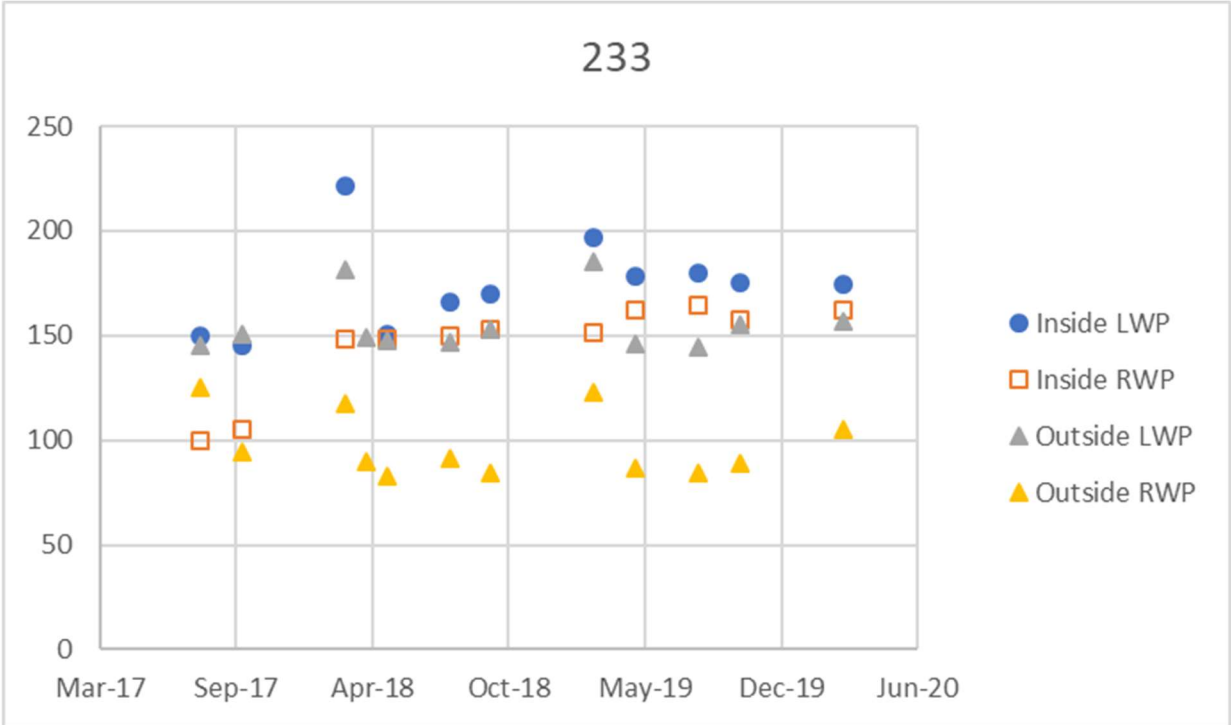


Figure 19 Ride quality results: Inside – Outside left wheel path (LWP) and right wheel path (RWP)

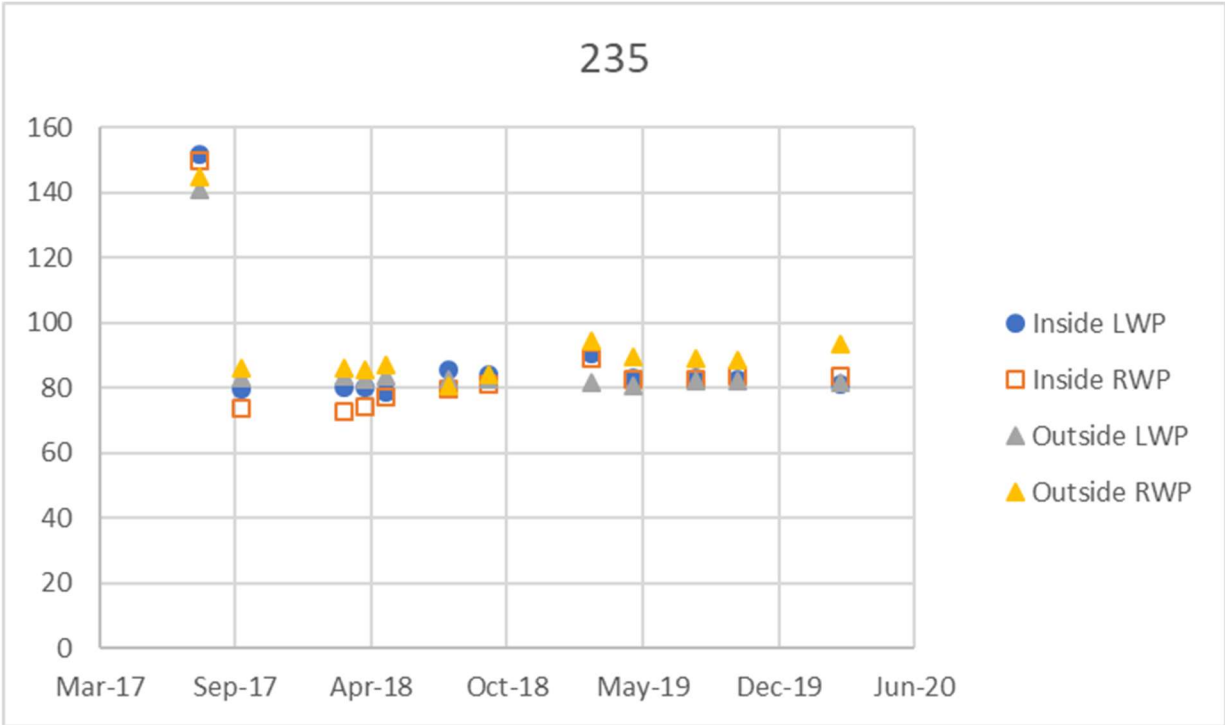
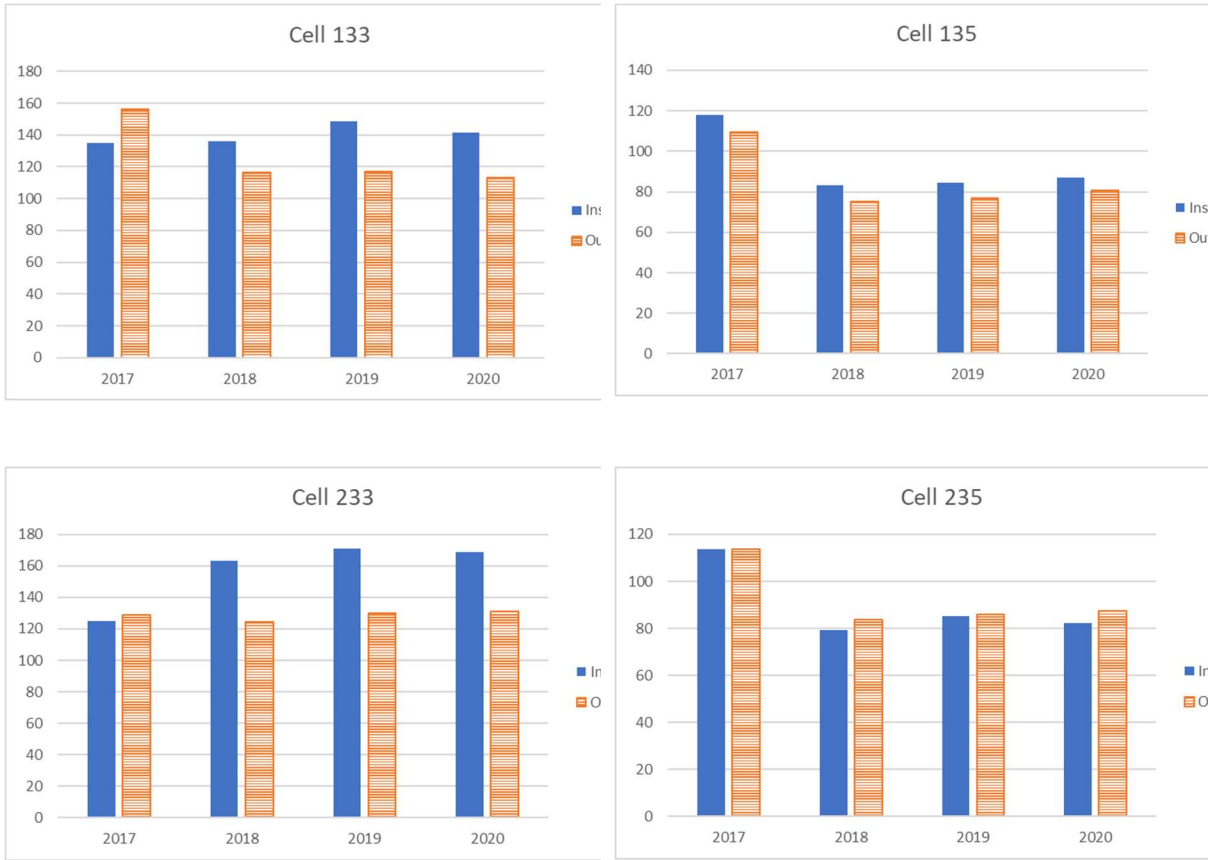


Figure 20 Ride quality results: Inside – Outside left wheel path (LWP) and right wheel path (RWP)

**Table 1 Average values of IRI for Cells 133, 135, 233, 235 for the Inside and Outside lane**



### 1.3 PCI

**Table 2 Distresses Summary**

CELL	133	133	135	135	233	233	235	235
LANE	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
LONG_NWP_L_L					2018	2019		
LONG_WP_L_L					2020	2020	2019	2019
TRANSVERSE_NO_L	2018	2018		2019	2019		2019	2019
TRANSVERSE_L_L	2018	2018		2019	2019		2019	2019
PATCH_NO_L					2018	2018		
PATCH_A_L					2018	2018		
RAVELING_A_L		2019						



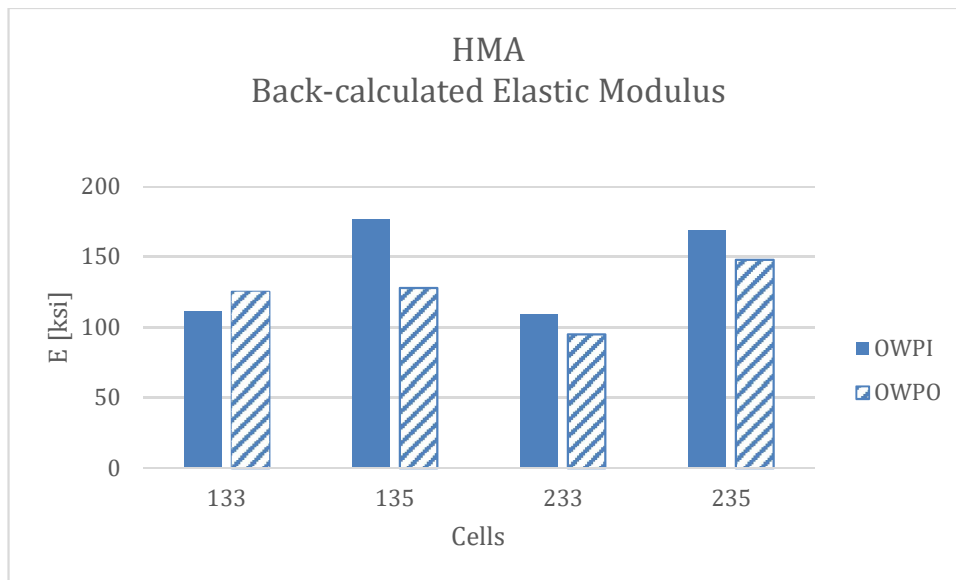
**Table 3 Distresses Description\***

<b>Distresses</b>	<b>Description</b>	<b>Units</b>
LONG_WP_L_L	longitudinal wheel path cracking length - low severity	FEET
LONG_NWP_L_L	longitudinal non-wheel path cracking length - low severity	FEET
TRANSVERSE_NO_L	number of transverse cracks - low severity	
TRANSVERSE_L_L	length of transverse cracks - low severity	FEET
PATCH_NO_L	number of patches - low severity	
PATCH_A_L	area of low severity patches	SQUARE FEET
RAVELING_A_L	area of raveling - low severity	SQUARE FEET
CONST_CL_JNT_L	length of distress along centerline joint - low severity	FEET

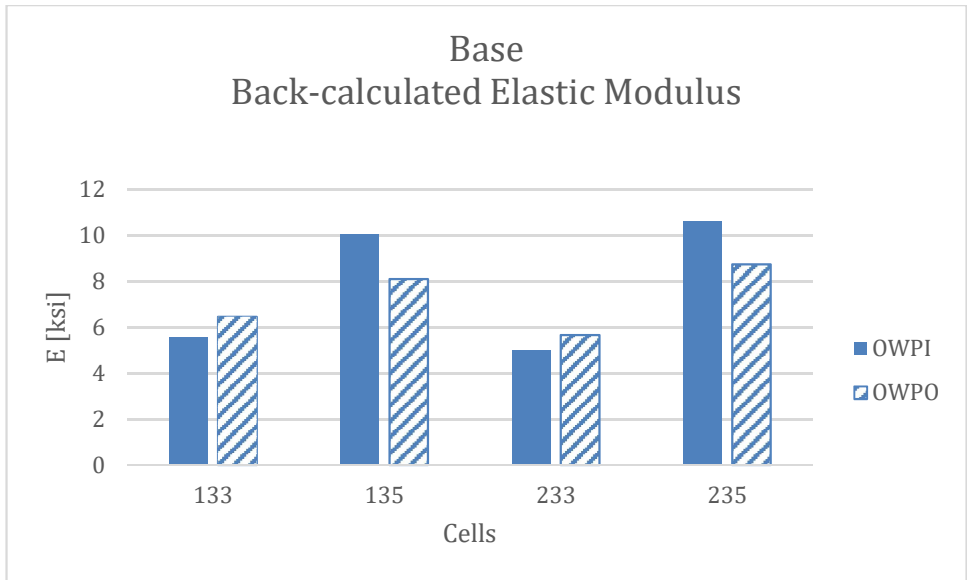
\*The description of the distresses are published on MnRoad website.

## 1.4 FALLING WEIGHT DEFLECTOMETER

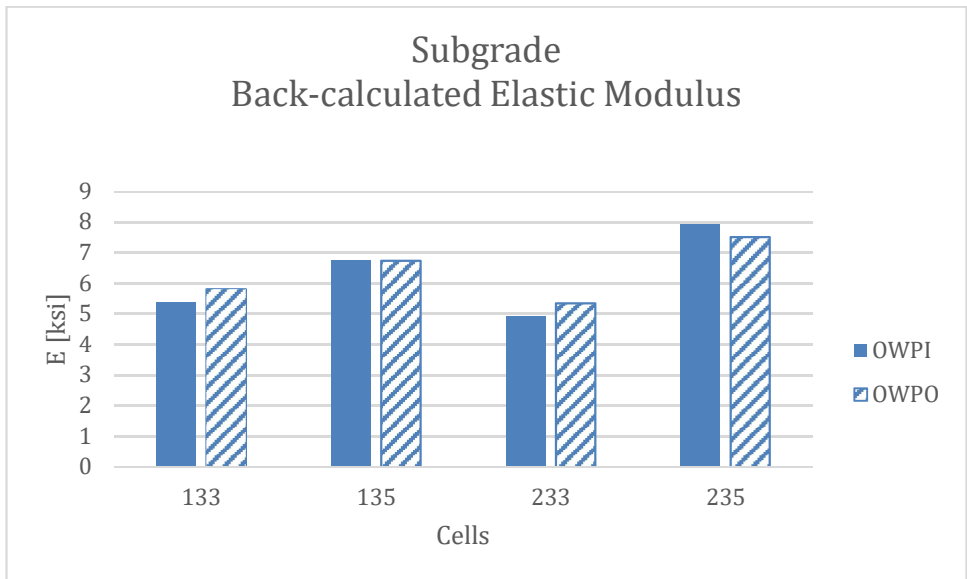
### 1.4.1 FWD Results: Lane Comparison



**Figure 21 FWD Results: HMA**



**Figure 22 FWD Results: Base**



**Figure 23 FWD Results: Subgrade**

### 1.4.2 Case study

Table 4 FWD Results: Summary of back-calculated elastic moduli

Back-calculation	Cell	Lane	Date	HMA Poisson	HMA Thickness [in]	Base Thickness [in]	HMA [ksi]	Baae [ksi]	Subgrade [ksi]
TONN2010	235	OWPO	5/24/2018	*	5.5	12	150.2	8.8	8.8
TONN2010	235	OWPO	6/26/2018	*	5.5	12	166.3	9.3	8.8
Modulus 7	235	OWPO	5/24/2018	0.35	5.5	12	123.5	6.5	12.1
Modulus 7	235	OWPO	6/26/2018	0.35	5.5	12	157.2	6.9	14.3
Elmod	235	OWPO	5/24/2018	*	5.5	12	388.1	7.6	14.3
Elmod	235	OWPO	6/26/2018	*	5.5	12	388.5	7.8	15.2

\*The software doesn't allow to define Poisson's ratio

### 1.4.3 TONN 2010 (Excel) vs TONN2010 (Fortran)

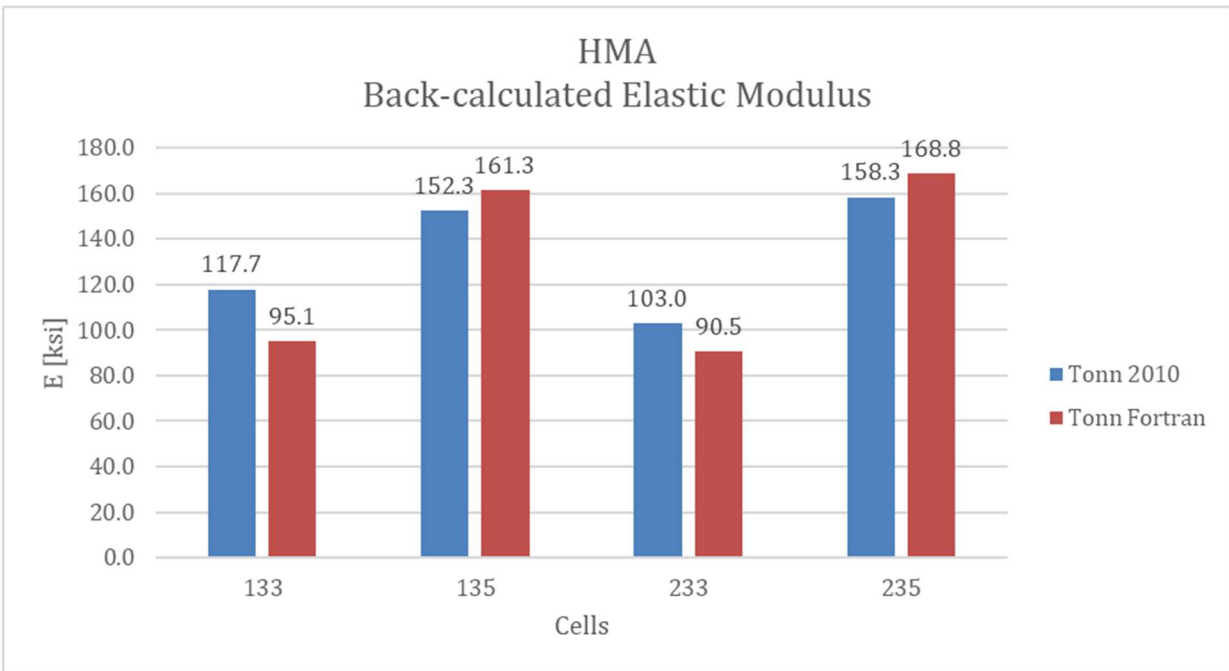
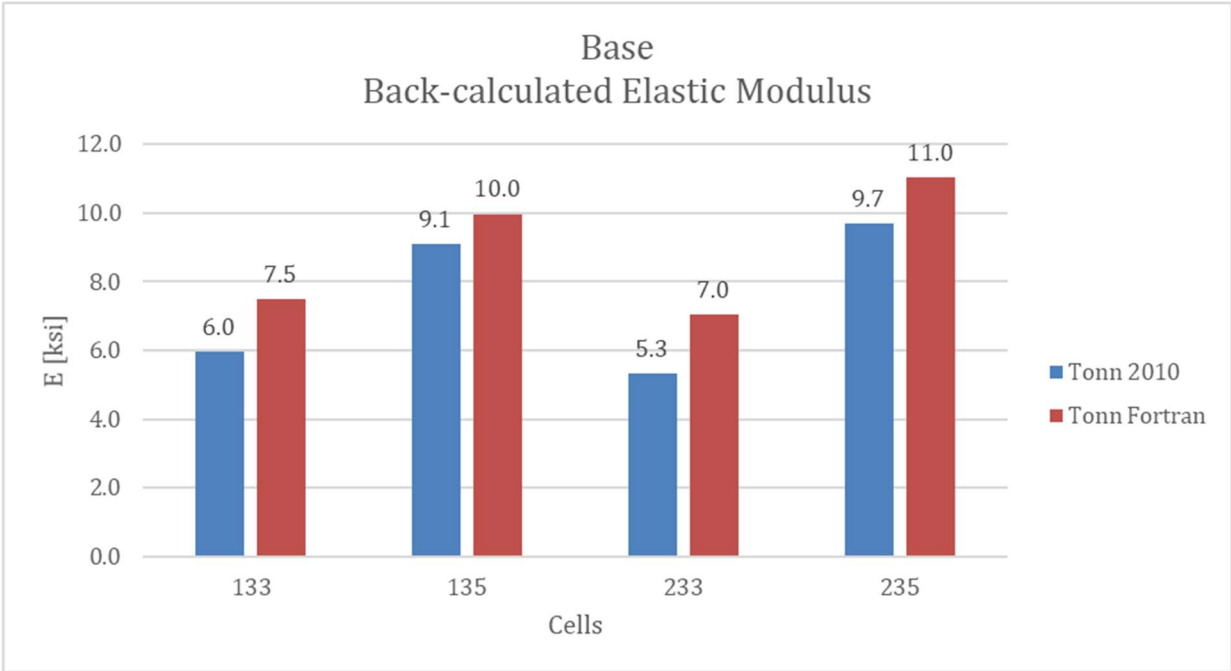
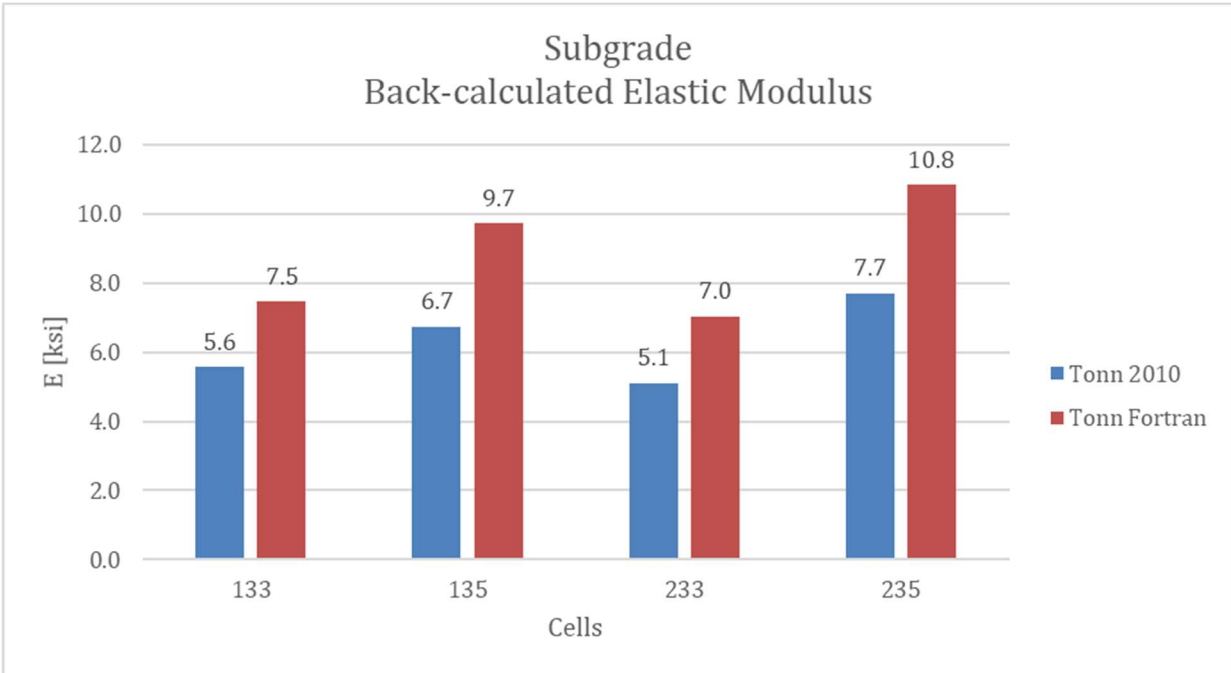


Figure 24 Backcalculated HMA - Comparison between Tonn2010 and Fortan version of Tonn2010



**Figure 25 Backcalculated base - Comparison between Tonn2010 and Fortan version of Tonn2010**



**Figure 26 Backcalculated Subgrade - Comparison between Tonn2010 and Fortan version of Tonn2010**

**APPENDIX C**  
**LABORATORY TEST REPORTS AND DATA ANALYSIS**

# SPT TEST

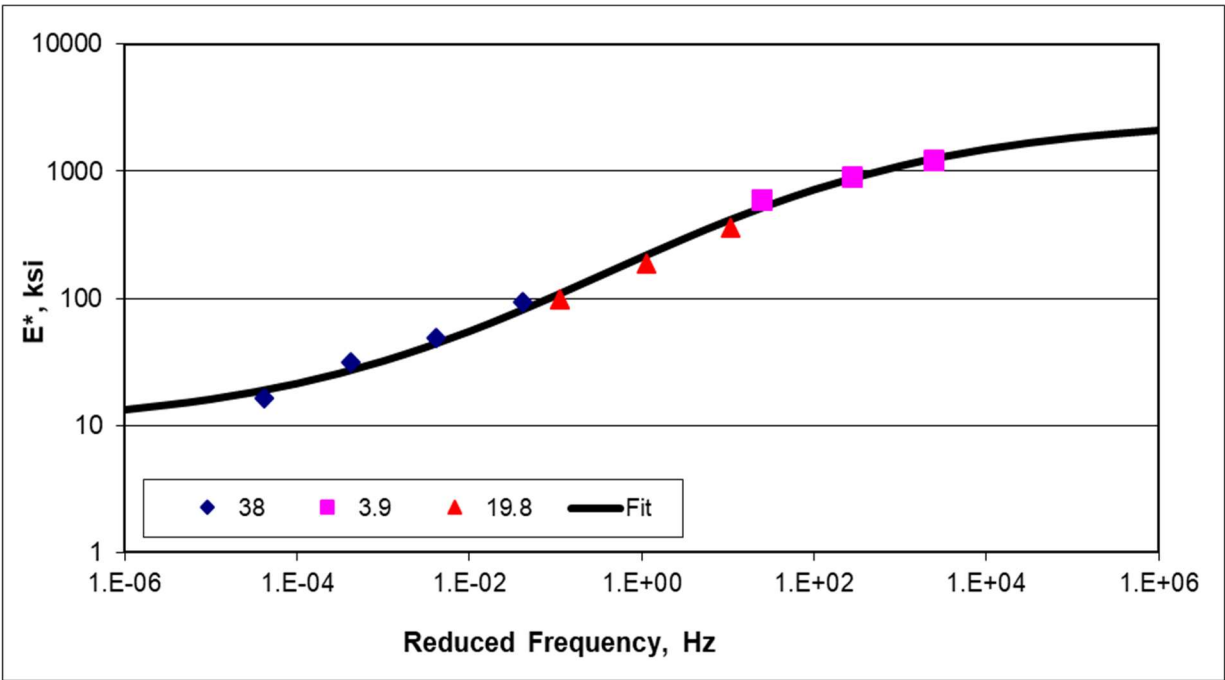


Figure 1 SPT Results: Reduced frequency-E\* curve for EE 58S-28

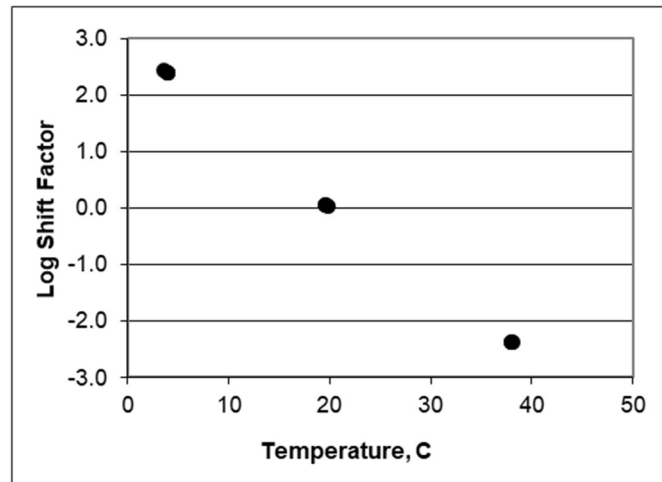


Figure 2 SPT Results: Shift factor - EE 58S-28

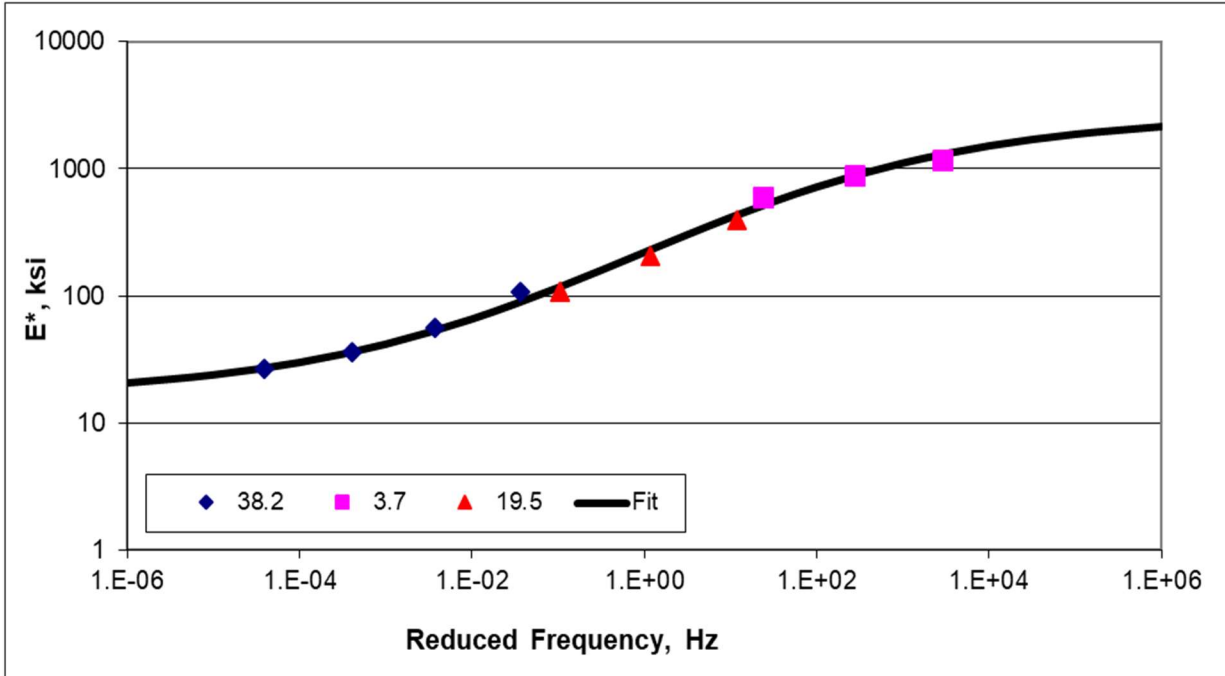


Figure 3 SPT Results: Reduced frequency-E\* curve for EE XX-34

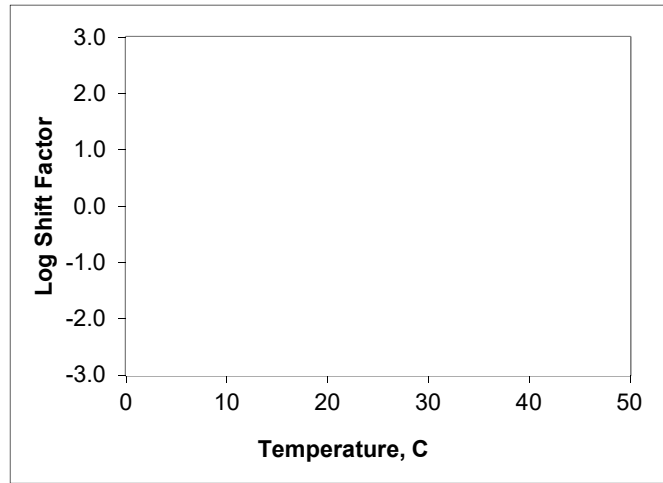


Figure 4 SPT Results: Shift factor - EE XX-34

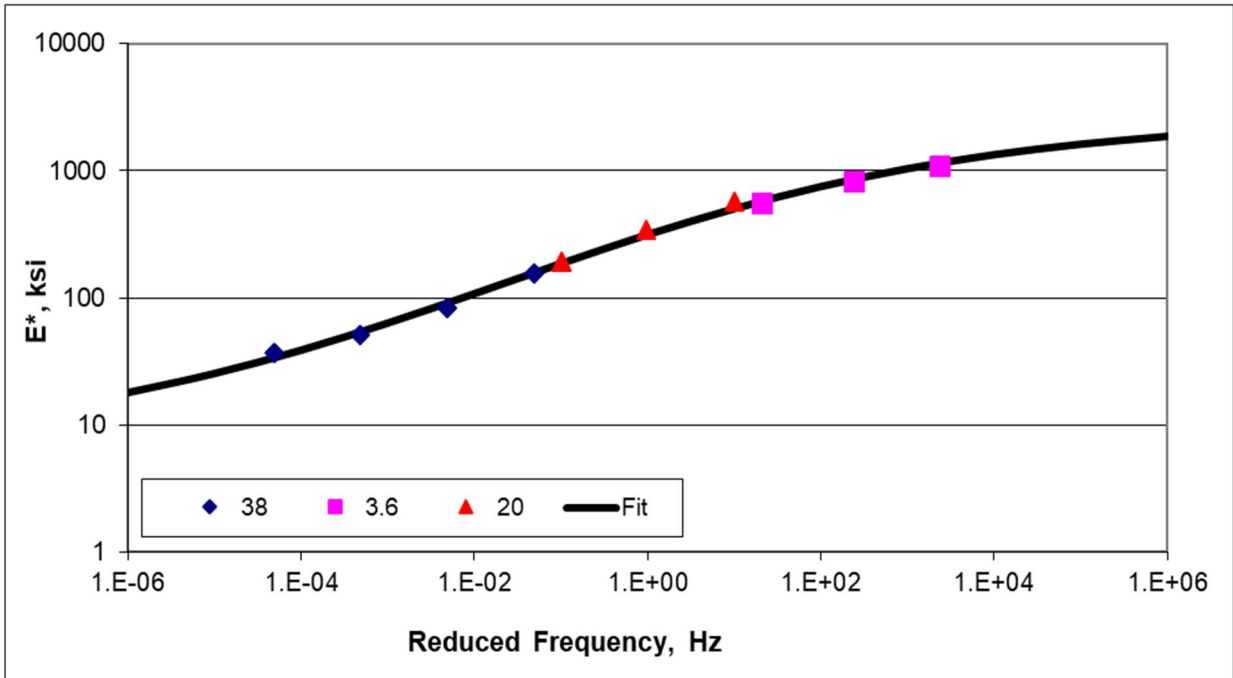


Figure 5 SPT Results: Reduced frequency-E\* curve for Foam 58S-28

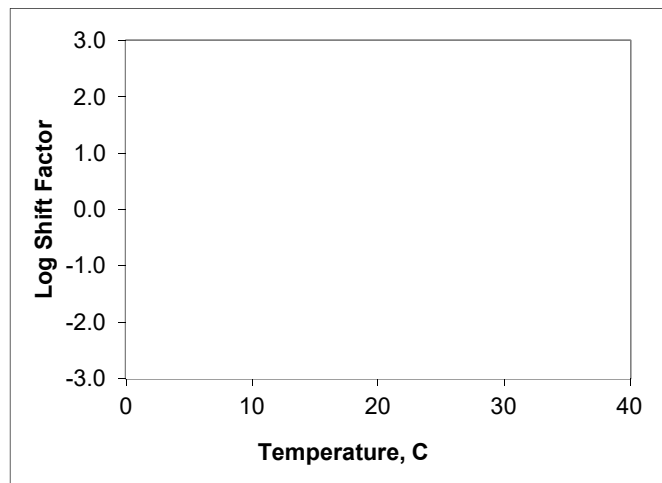


Figure 6 SPT Results: Shift factor - Foam 58S-28



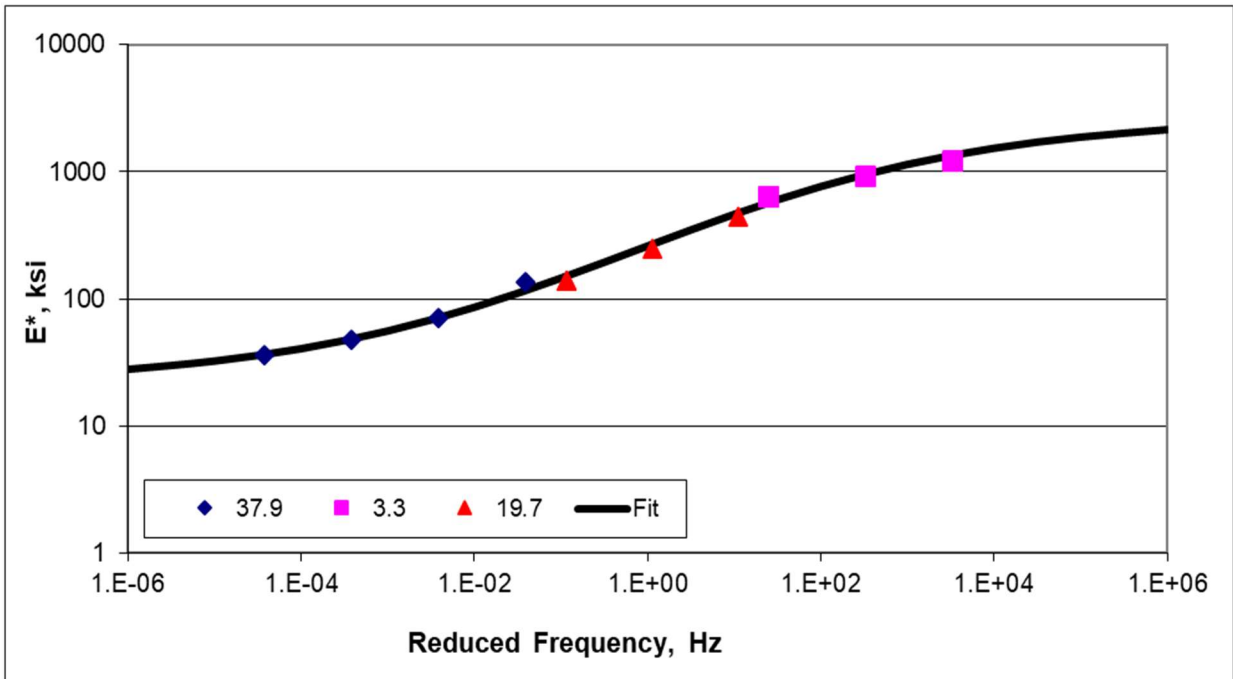


Figure 7 SPT Results: Reduced frequency-E\* curve for Foam XX-34

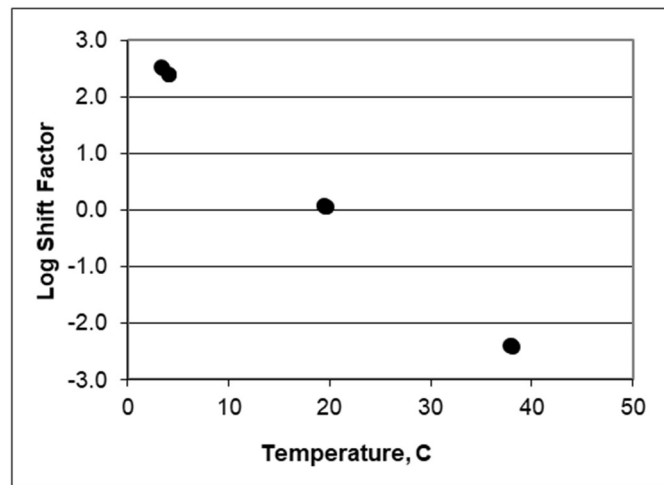


Figure 8 SPT Results: Shift factor - Foam XX-34





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 Saint Paul  
 550 Cleveland Ave N  
 St. Paul, MN 55114  
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## Hamburg Wheel-Tracker Test Report

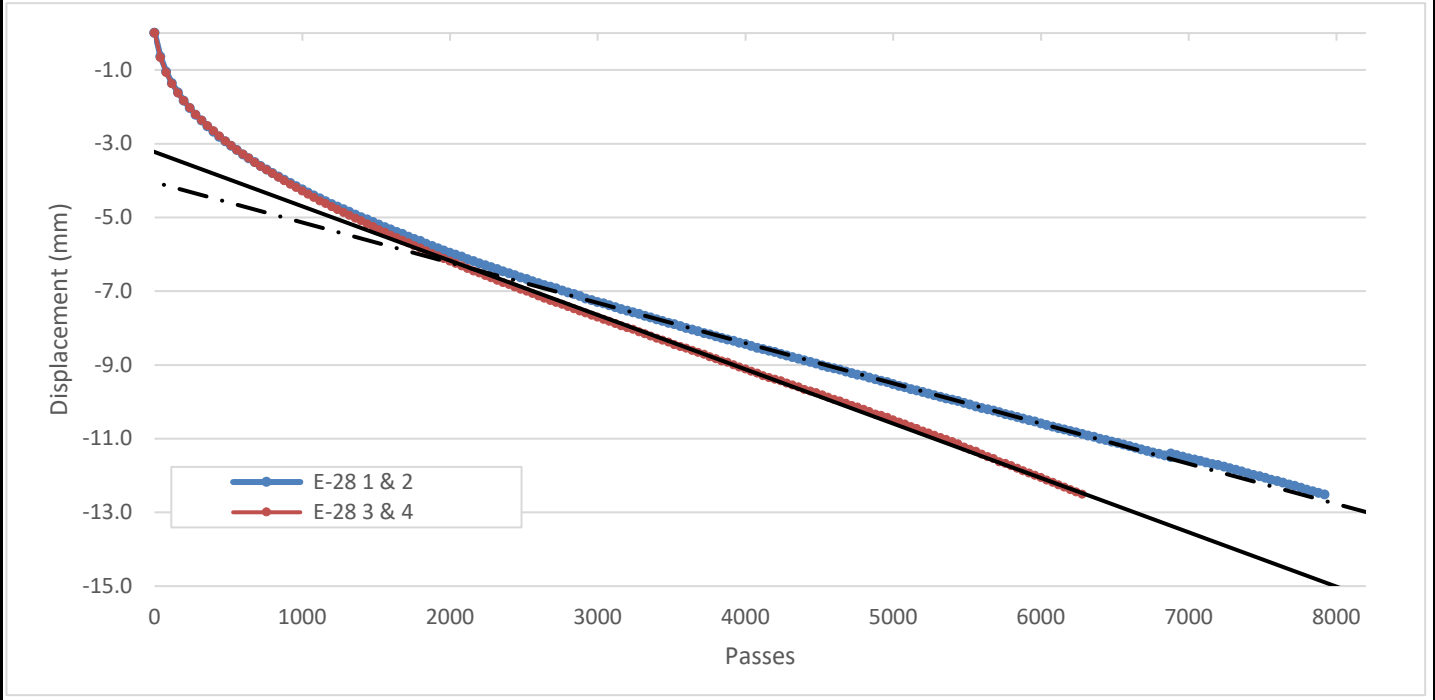


<b>Client:</b> MNDOT	<b>CC:</b>	<small>This document shall not be reproduced except in full, without written approval from American Engineering Testing, Inc.</small> Date of Issue: 3/6/2019 Reviewed By: Daniel Kriesel
<b>Project:</b> 27-00077 CCPR Research		

### Sample Information

Asphalt Mixture Type: CCPR Emulsion XX-28	Testing Temperature: 40.0 C
---	-----------------------------

### Passes vs. Displacement



### Specimen Information

ID	Compaction Method	Compaction Type	% Voids	Max Passes	Max Impression mm	Creep Slope	Strip Slope	Stripping Inflection Point Passes
E-28 1 & 2	Lab	SGC	15.2	7920	-12.52	-0.00109	N/A	N/A
E-28 3 & 4	Lab	SGC	15.2	6320	-12.51	-0.00147	N/A	N/A
Average Passes to Failure:					7120			

Tested By	Remarks
Charlie Wirth	AASHTO T324-17 No Anti-Stripping Agent Identified



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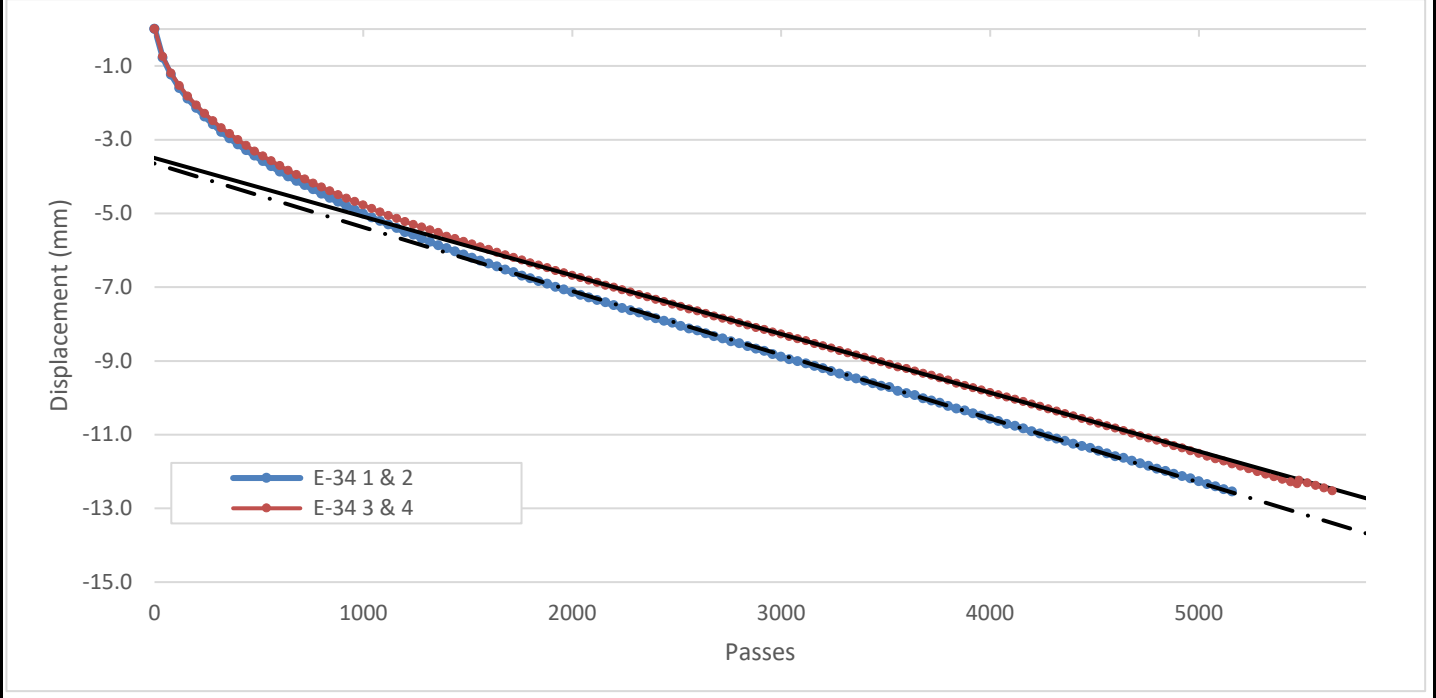
## Hamburg Wheel-Tracker Test Report

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<b>Project:</b> 27-00077 CCPR Research		

### Sample Information

Asphalt Mixture Type: CCPR Emulsion XX-34	Testing Temperature: 40.0 C
---	-----------------------------

### Passes vs. Displacement



### Specimen Information

ID	Compaction Method	Compaction Type	% Voids	Max Passes	Max Impression (mm)	Creep Slope	Strip Slope	Stripping Inflection Point (Passes)
E-34 1 & 2	Lab	SGC	14.2	5160	-12.55	-0.00173	N/A	N/A
E-34 3 & 4	Lab	SGC	13.5	5640	-12.53	-0.00159	N/A	N/A
Average Passes to Failure:					5400			

Tested By	Remarks
Charlie Wirth	AASHTO T324-17 No Anti-Stripping Agent Identified



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## Hamburg Wheel-Tracker Test Report

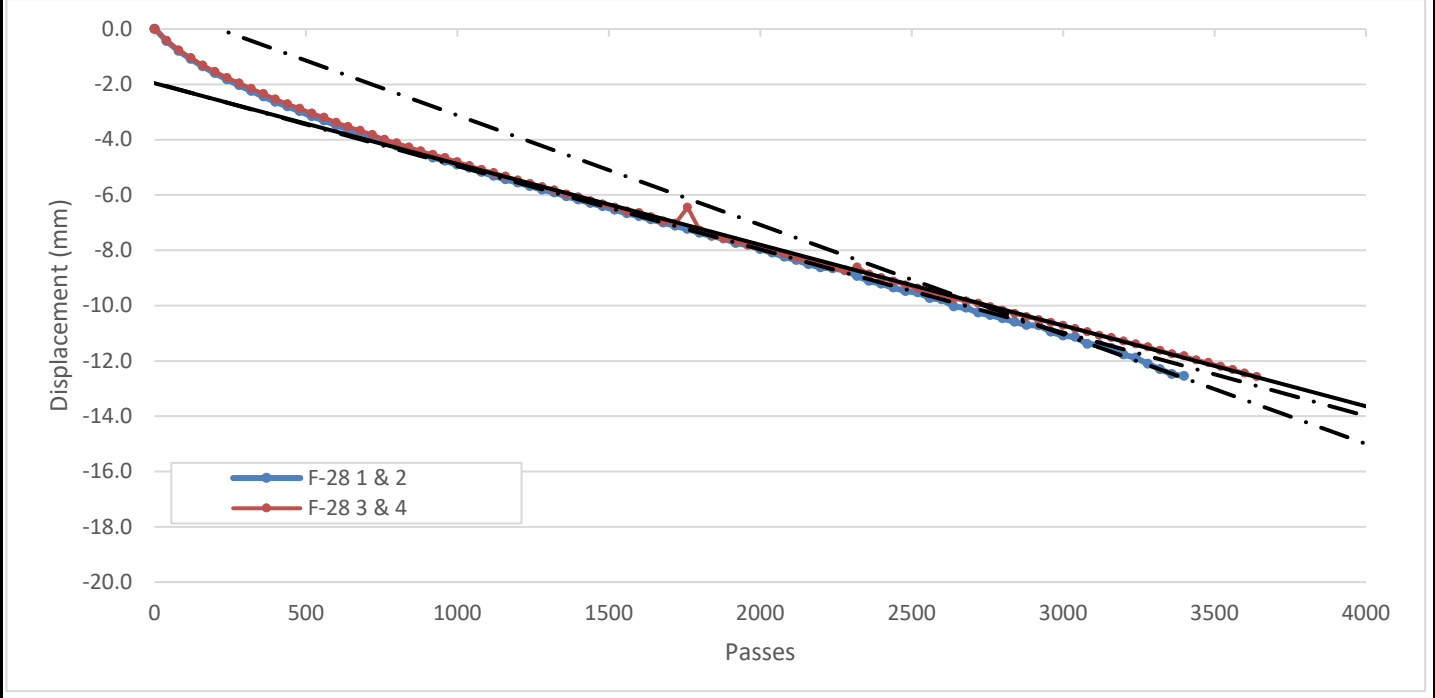


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		Date of Issue: 3/6/2019
		Reviewed By: Daniel Kriesel

### Sample Information

Asphalt Mixture Type: CCPR Emulsion XX-28	Testing Temperature: 40.0 C
---	-----------------------------

### Passes vs. Displacement



### Specimen Information

ID	Compaction Method	Compaction Type	% Voids	Max Passes	Max Impression mm	Creep Slope	Strip Slope	Stripping Inflection Point Passes
F-28 1 & 2	Lab	SGC	14.4	3400	-12.55	-0.00301	-0.00396	2935
F-28 3 & 4	Lab	SGC	14.7	3640	-12.57	-0.00292	N/A	N/A
Average Passes to Failure:					3520			

Tested By	Remarks
Charlie Wirth	AASHTO T324-17 No Anti-Stripping Agent Identified



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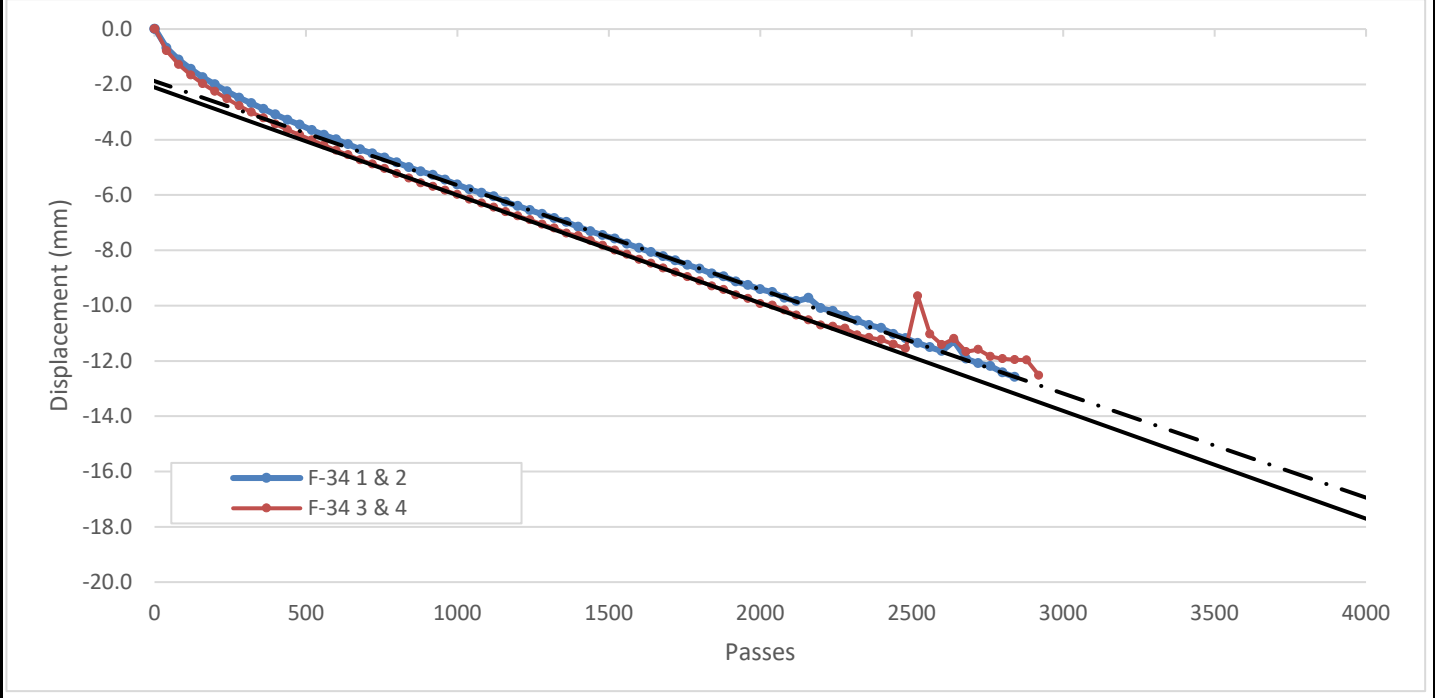
## Hamburg Wheel-Tracker Test Report

<b>Client:</b> MNDOT	<b>CC:</b>	This document shall not be reproduced except in full, without written approval from American Engineering Testing, Inc.
<b>Project:</b> 27-00077 CCPR Research		
		Date of Issue: 3/6/2019
		Reviewed By: Daniel Kriesel

### Sample Information

Asphalt Mixture Type: CCPR Foamed XX-34	Testing Temperature: 40.0 C
---	-----------------------------

### Passes vs. Displacement



### Specimen Information

ID	Compaction Method	Compaction Type	% Voids	Max Passes	Max Impression mm	Creep Slope	Strip Slope	Stripping Inflection Point Passes
F-34 1 & 2	Lab	SGC	15.3	2840	-12.59	-0.00377	N/A	N/A
F-34 3 & 4	Lab	SGC	15.1	2920	-12.52	-0.00390	N/A	N/A
Average Passes to Failure:					2880			

Tested By	Remarks
Charlie Wirth	AASHTO T324-17 No Anti-Stripping Agent Identified

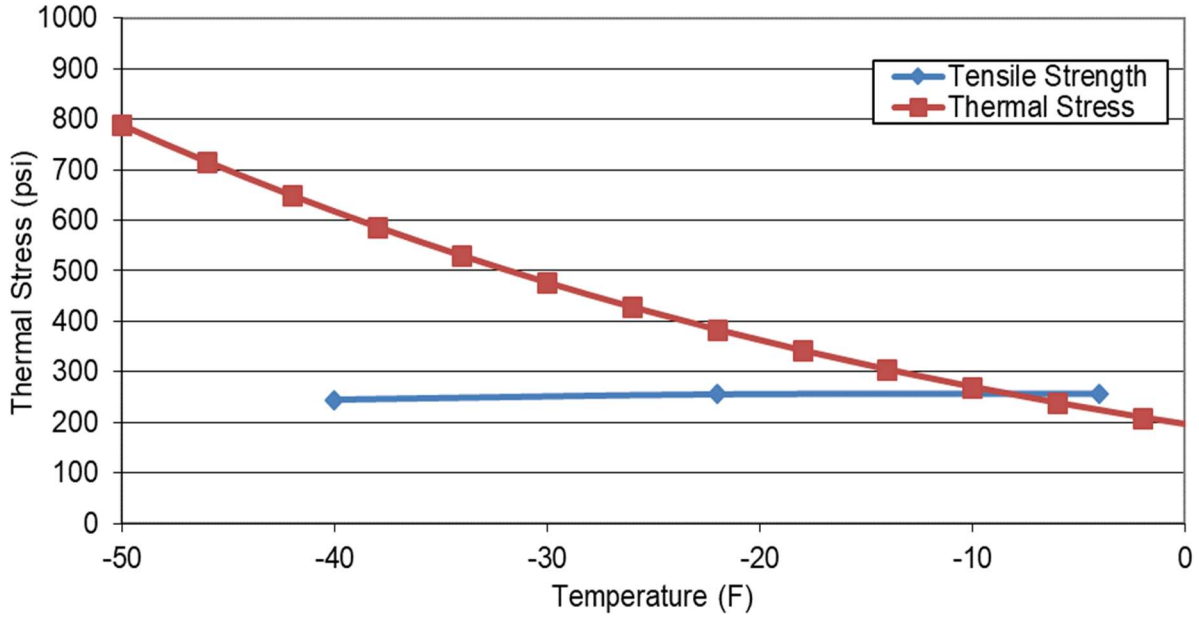


Figure 9 IDT Results: Tensile Strength and Thermal Stress representation for EE 58S-28

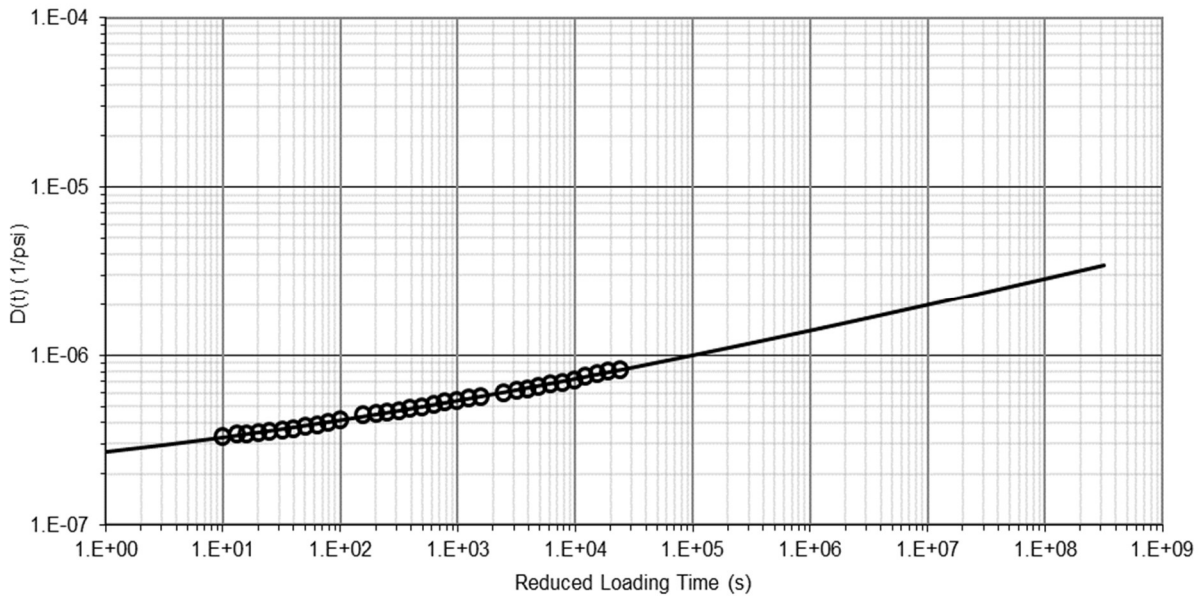


Figure 10 IDT Results: Creep compliance for EE 58S-28

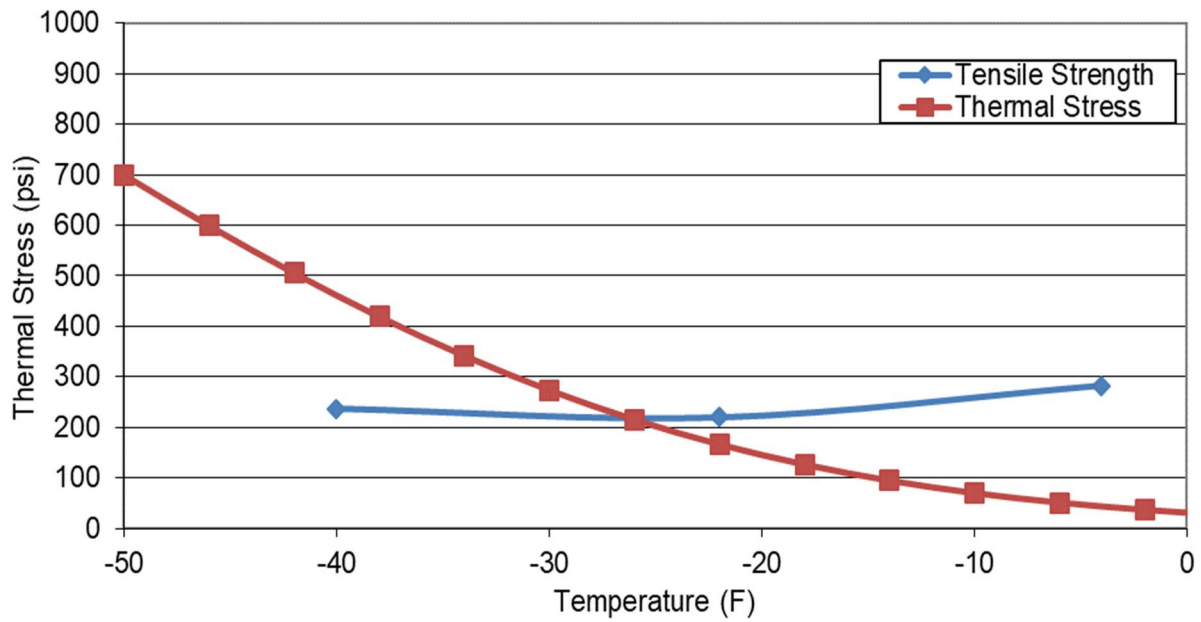


Figure 11 IDT Results: Tensile Strength and Thermal Stress representation for EE XX-34

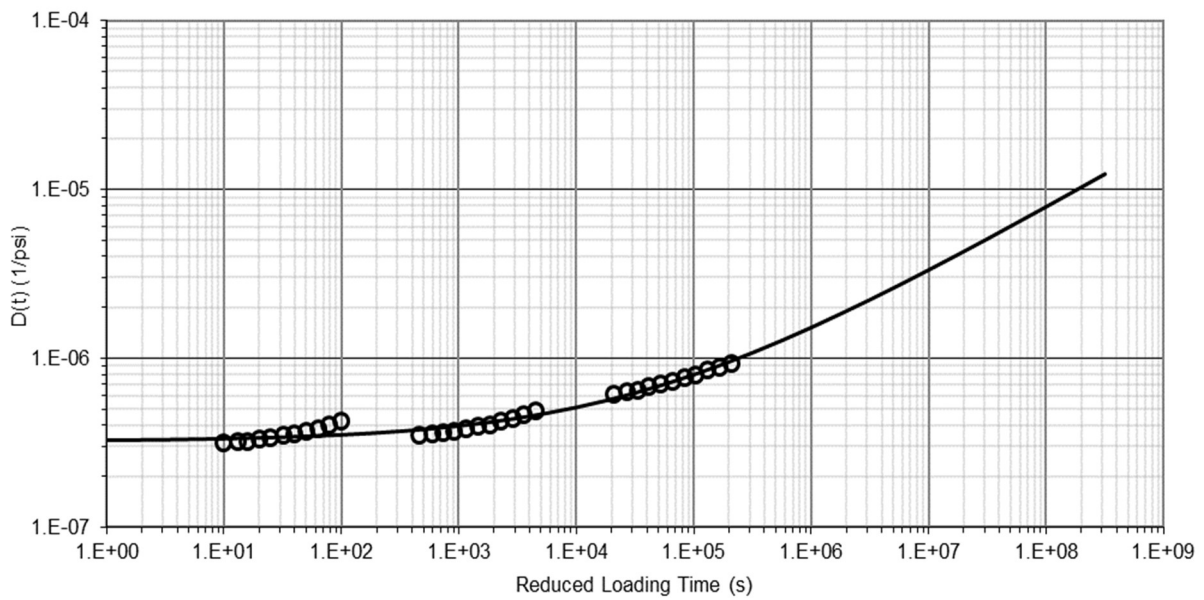


Figure 12 IDT Results: Creep compliance for EE XX-34



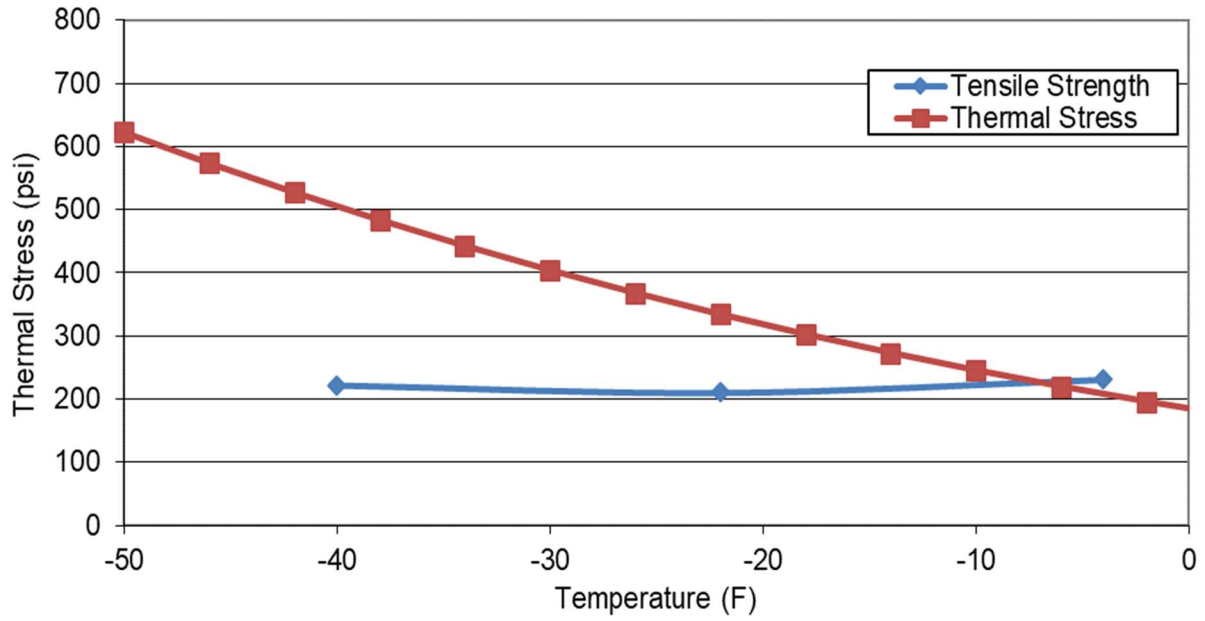


Figure 13 IDT Results: Tensile Strength and Thermal Stress representation for Foam 58S-28

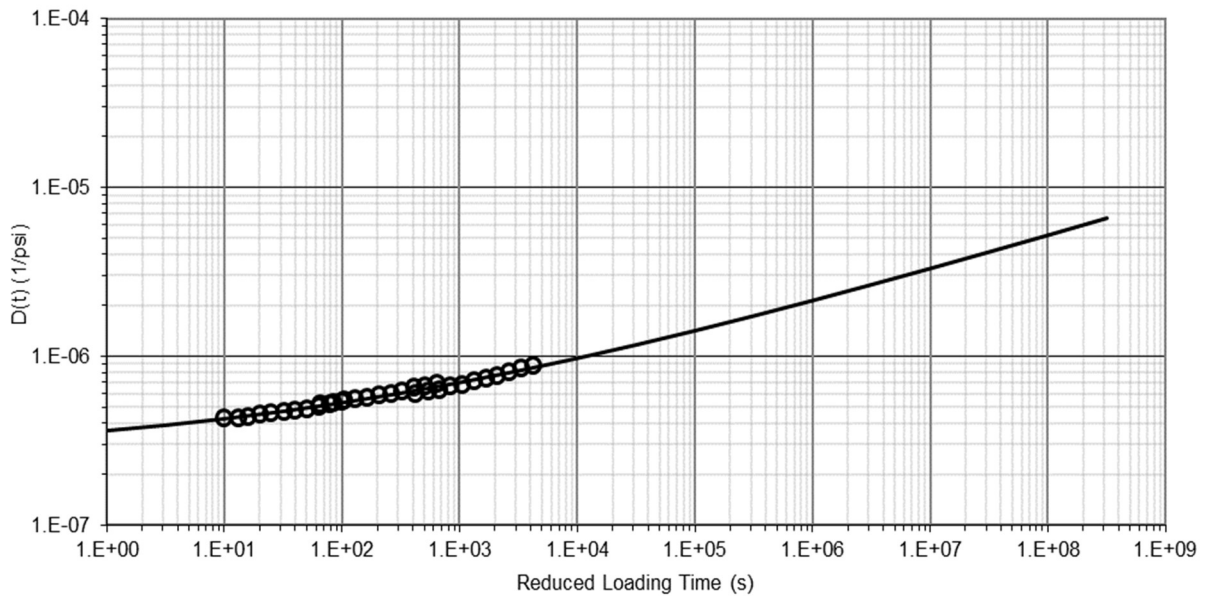


Figure 14 IDT Results: Creep compliance for Foam 58S-28

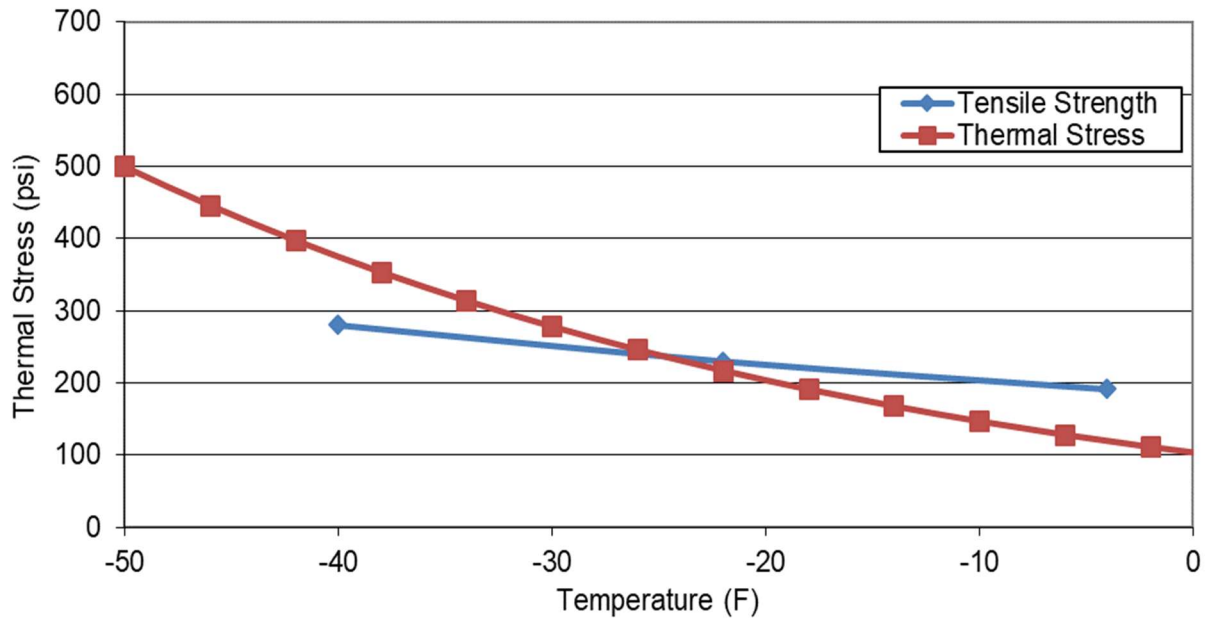


Figure 15 IDT Results: Tensile Strength and Thermal Stress representation for Foam XX-34

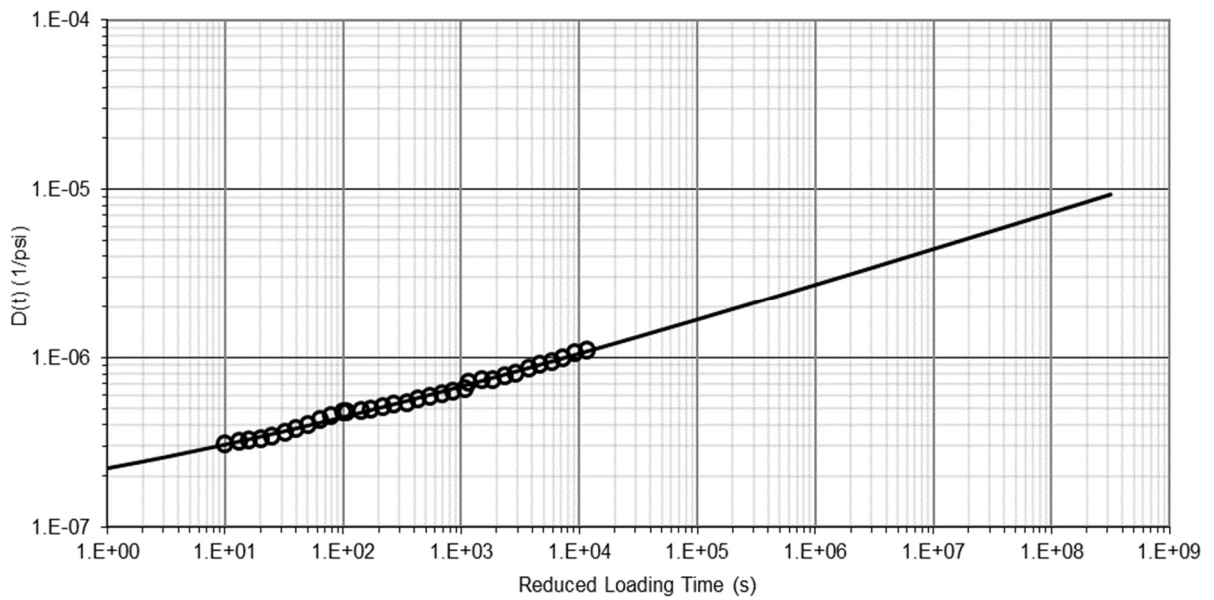


Figure 16 IDT Results: Creep compliance for Foam XX-34

**APPENDIX D**  
**MNROAD SFDR MIX DESIGNS**



CONSULTANTS  
• ENVIRONMENTAL  
• GEOTECHNICAL  
• MATERIALS  
• FORENSICS

August 15, 2019

Office of Materials and Road Research  
Minnesota Department of Transportation  
1400 Gervais Ave  
Maplewood, MN 55109

Attn: Gerald Geib, Research Operations Engineer  
RE: AET 27-00077, MnDOT Contract 1030151, CCPR NRRRA  
Foamed SFDR Mix Designs for MnROAD

Dear Mr. Geib,

American Engineering Testing, Inc. (AET) is pleased to present the foamed asphalt-stabilized full-depth reclamation (SFDR) mix design for your paving project near the MnROAD facility in Albertville, MN. We performed the mix design according to the MnDOT procedure for SFDR mix design using foamed asphalt. This letter report summarizes the mix design procedure, results, and evaluation in fulfillment of mix design requirements outlined in the 2018 MnDOT Grading and Base Manual.

Our testing using our Wirtgen Foamed Asphalt Laboratory determined the foamed asphalt binder properties as follows:

1. The asphalt we used in the mix designs is a PG 58-28 that was provided by Hardrives. The foaming results are attached to this report.
2. The recommended asphalt temperature for foaming was determined to be 150°C.
3. The optimum water addition rate for foaming was determined to be 1.2 percent.

The mix design properties were as follows:

1. The material was a roughly 60/40 blend of RAP and base material provided to AET by MnDOT. The gradation of each material is shown on the attached sieve analysis report.
2. Portland cement (referred to in the Filler field of test reports as "Cement") was added to the RAP at an addition rate of 1.0 percent.
3. The optimum moisture content of unstabilized reclaimed materials was 7.2 percent at a maximum dry density of 127.8 pcf (modified Proctor according to Method C of ASTM D1557).
4. We performed mix testing at 2.0, 2.5, and 3.0 percent foamed asphalt contents (FAC).
5. The best average dry ITS result was 78 psi at 2.0 and 2.5 percent FAC. The best average conditioned ITS result was 30 psi at 2.0 percent FAC.
6. The cured Marshall stability was 2851, 2973, and 2843 lb at 2.0, 2.5, and 3.0 percent FAC, respectively. All three levels exceed the suggested minimum of 1250 lb for foamed asphalt SFDR (see Table 19 of the 2018 MnDOT Grading and Base Manual).
7. The conditioned Marshall stability was 1722, 1768, and 1722 at 2.0, 2.5, and 3.0 percent FAC, respectively. These result in retained stabilities of 60, 59, and 61 percent, respectively. All values are under the MnDOT-suggested minimum of 70% for foamed asphalt SFDR (see Table 19 of the 2018 MnDOT Grading and Base Manual).
8. The bulk density results were 134.3, 134.6, and 134.2 pcf at 2.0, 2.5, and 3.0 percent FAC, respectively.

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As noted above, the three-point design did not result in a mix that meets the MnDOT suggestions for retained stability. (Table 19 requires values to be reported but does not establish a performance specification). You may wish to overlook results for retained stability – relative to suggested performance levels of 70 percent – given the following characteristics of the mixes tested.

- The dry Marshall stability for all mixes tested was more than double the required cured stability from the specification.
- The conditioned Marshall stability for all mixes tested exceeds the performance requirement for dry Marshall stability.
- The retained stabilities were roughly 60 percent for all mixes tested – considering the magnitude of the dry Marshall results, these results are relatively close to 70 percent retained stability.

If you accept the above rationale, then test results indicate an optimum foamed asphalt content of 2.0 percent. If you have questions or need additional information, please do not hesitate to contact us. Thank you for the opportunity to provide MnDOT with these important engineering services.

Sincerely,

**American Engineering Testing, Inc.**



Derek Tompkins, PhD, PE (MN)  
Principal Civil Engineer  
612-297-3058  
dtompkins@amengtest.com



David L. Rettner, PE (MN)  
President and Principal Engineer  
612-297-3058  
drettner@amengtest.com

Attachments:

- a. Foamed Bitumen Mix Design Report, Sieve Analysis, and Foaming Result

Sample Number *MnROAD Cell 1 SFDR*

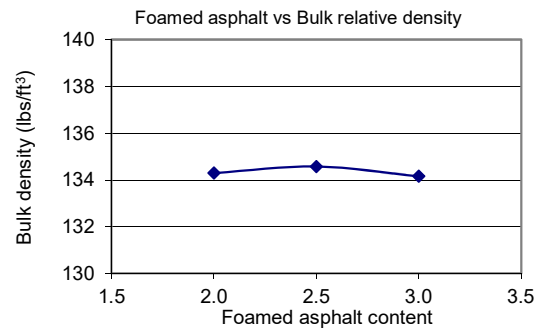
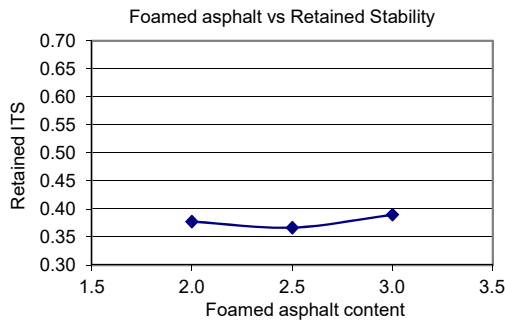
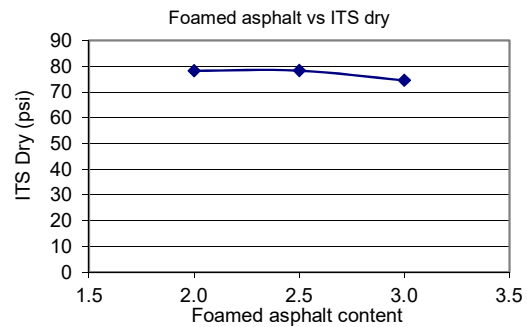
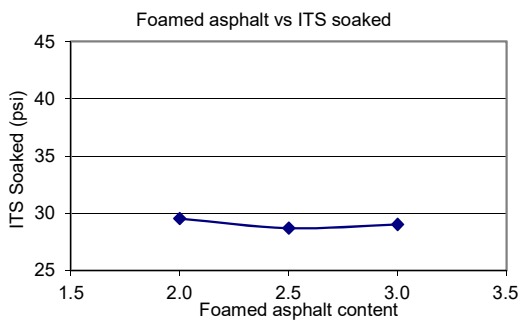
Date *8/15/2019*

Material to be foamed	RAP	Bitumen	Filler
Location / Source	Cores from Roadway	Hardives	Cement
Description	MnROAD Cell 1 SFDR	58-28	1.0%
Optimum moisture content (%)	7.2		
Maximum dry density (pcf)	127.8		

Foamed bitumen requirements	
Percentage "foaming" water	1.2
Temperature of bitumen	150

RAP Coating Test (T 59)
Good

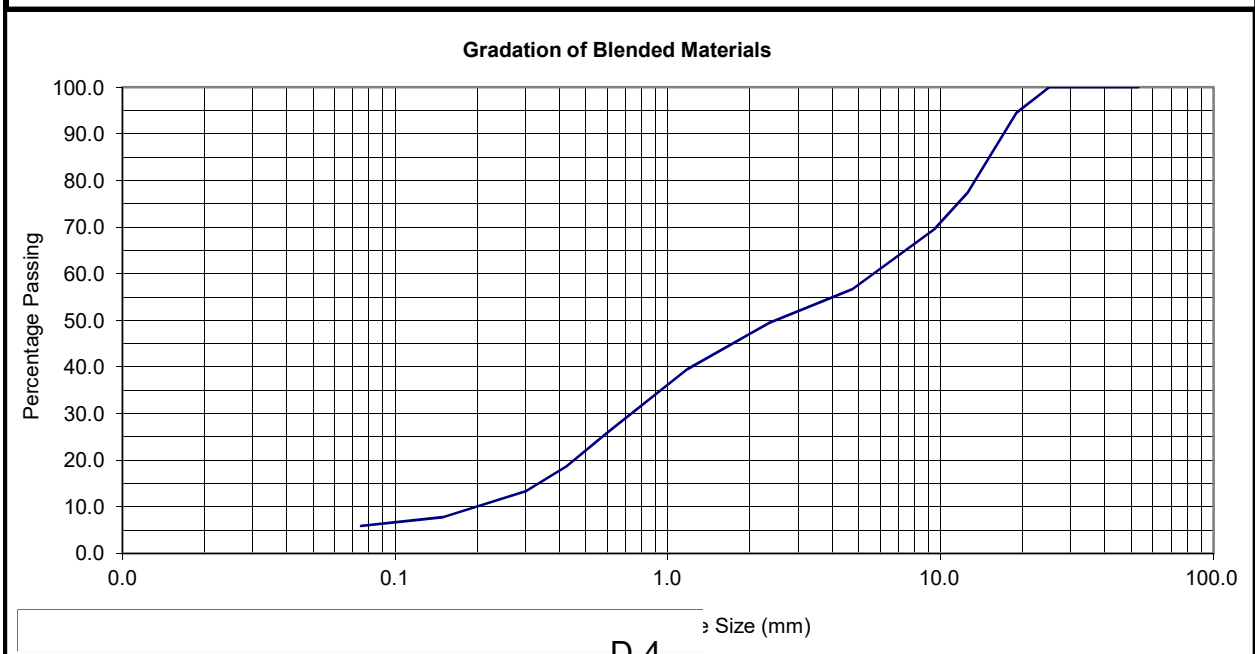
Foamed asphalt treated material characteristics				
Foamed bitumen added (%)	2.0	2.5	3.0	
Filler added	1.0%	1.0%	1.0%	Cement
Diameter of specimen (mm)	100.0	100.0	100.0	
Height of specimen (mm)	63.9	63.3	63.9	
Mass of specimen (g)	1059	1057	1065	
Bulk density (lbs/ft <sup>3</sup> )	134.3	134.6	134.2	
Gmb	2.156	2.2	2.2	
Gmm	2.420	2.406	2.385	
Air voids (%)	10.9	10.2	9.7	
ITS, Soaked (psi)	29.5	28.7	29.0	
ITS, Dry (psi)	78.2	78.3	74.5	
Retained ITS (TSR)	0.38	0.37	0.39	
Marshall Stability, Dry (lb)	2851	2973	2843	Report (Min 1250)
Marshall Stability, Wet (lb)	1722	1768	1722	
Retained Stability	0.60	0.59	0.61	Report (Min 0.70)
Resilient Modulus (psi)	NT	NT	NT	
Critical Low Temperature (°C)	NT	NT	NT	



<b>AET</b>	<b>27-00077</b>	<b>FOAMED BITUMEN SIEVE ANALYSIS</b>	<b>ASTM D 422</b>
------------	-----------------	--	-----------------------

Client	MnDOT Research
Project	MnROAD Cell 1 SFDR

		1		2		3		
Location:		Cores from Roadway						Total percentage in Blend
Description:		Crushed Bituminous		base agg				
Sample No.:		1		2				
Date sampled:								
Percentage in Blend		57.4		41.6		1		<b>100</b>
Mass of sample (g)								
Sieve size		Weight	%	Weight	%	Weight	%	Combined Grading
mm	inch	Retained	Pass.	Retained	Pass.	Retained	Pass.	
53.0	2		100.0		100.0		100.0	100.0
37.5	1½		100.0		100.0		100.0	100.0
25.0	1		100.0		100.0		100.0	100.0
19.0	¾		93.0		96.6		100.0	94.6
12.5	½		70.0		86.7		100.0	77.3
9.5	⅜		60.0		82.1		100.0	69.6
4.75	# 4		45.0		71.8		100.0	56.7
2.36	# 8		36.7		66.0		100.0	49.5
2	#10		33.8		64.3		100.0	47.1
1.18	#16		25.5		57.4		100.0	39.5
0.6	# 30		13.1		42.0		100.0	26.0
0.425	# 40		7.7		32.0		100.0	18.7
0.30	# 50		4.3		23.6		100.0	13.3
0.150	# 100		1.7		14.0		100.0	7.8
0.075	# 200		0.9		10.6		100.0	5.9



# BITUMEN CALIBRATION

## BITUMEN

Source :	Hardrives
Type :	58-28
Test temperature:	150

## MACHINE SETTINGS

### Bitumen pump

#### Calibration

	1	2	3	4
Timer setting (sec)	1	3	5	7
Pump output (g/sec)				

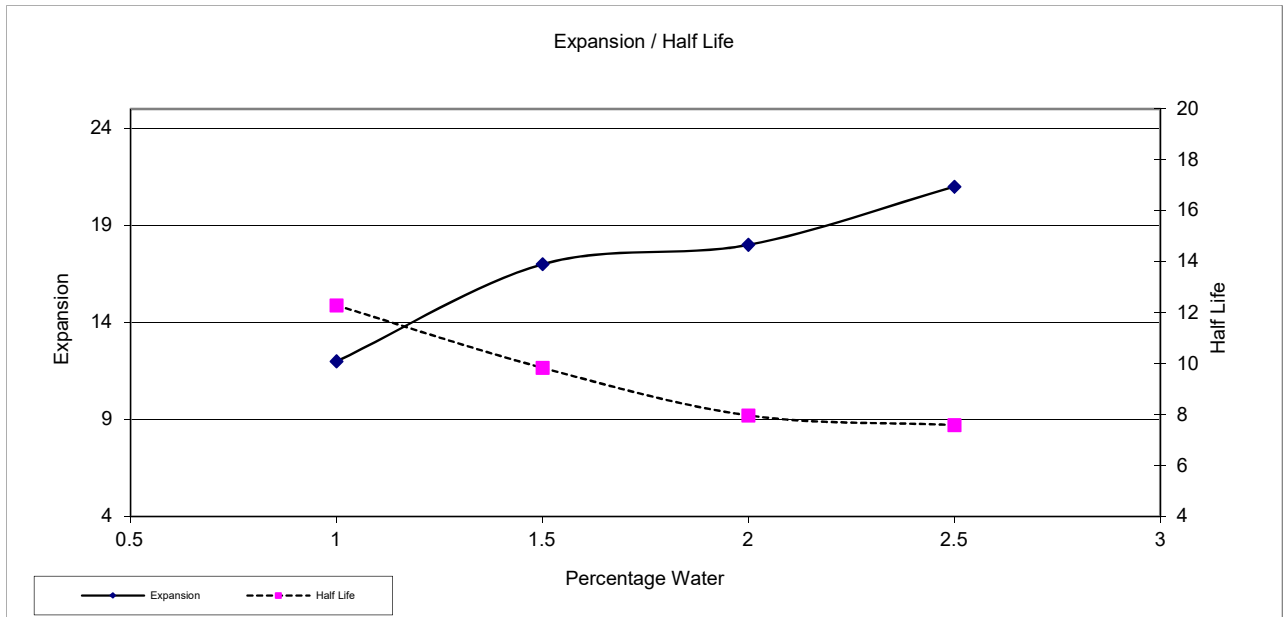
### Setting

Quantity required (g):	100	300	500	
Pump output (g/sec):	100	300	500	
Timer setting (sec)	1.00	1.00	1.00	

### Water

Quantity required (%):	1	1.5	2	2.5
Flow meter setting (l/h):	3.6	5.4	7.2	9

% Water	Expansion	Half Life
1	12	12.29
1.5	17	9.84
2	18	7.97
2.5	21	7.59



## OPTIMUM FOAM MOISTURE CONTENT

<b>1.2</b>
------------





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• GEOTECHNICAL  
• MATERIALS  
• FORENSICS

August 16, 2019

Office of Materials and Road Research  
Minnesota Department of Transportation  
1400 Gervais Ave  
Maplewood, MN 55109

Attn: Gerald Geib, Research Operations Engineer  
RE: AET 27-00077, MnDOT Contract 1030151, CCPR NRRRA  
Emulsion SFDR Mix Design for MnROAD

Dear Mr. Geib,

American Engineering Testing, Inc. (AET) is pleased to present the results of our asphalt emulsion stabilized full-depth reclamation (SFDR) mix design for your paving project in near the MnROAD facility in Albertville, MN. We performed the mix design according to the MnDOT procedure for SFDR mix design using emulsified asphalt. This letter report summarizes the mix design procedure, results, and evaluation in fulfillment of mix design requirements outlined in the 2018 MnDOT Grading and Base Manual.

The mix design properties were as follows:

1. The material was a roughly 60/40 blend of RAP and base material provided to AET by MnDOT. The gradation of each material is shown on the attached sieve analysis report.
2. The engineered emulsion (EE) was graded as PG XX-28 and provided to AET by MnDOT.
3. Portland cement (referred to in the Filler field of test reports as "Cement") was added to the RAP at an addition rate of 1.0 percent.
4. The optimum moisture content of unstabilized reclaimed materials was 6.0 percent at a maximum dry density of 127.3 pcf (modified Proctor according to Method C of ASTM D1557). Prior to mixing reclaimed materials with the emulsion, 2.7 percent water was added to the blend.
5. We performed mix testing at 3.0, 3.5, and 4.0 percent EE content.
6. The best average dry ITS result was 76 psi at 3.0 percent AC. The best average conditioned ITS result was 65 psi at 3.0 percent EE content. ITS values of at all tested asphalt contents exceeded performance specifications outlined in Table 18 of the 2018 MnDOT Grading and Base Manual (dry ITS over 40 psi, wet ITS over 25 psi)
7. The cured Marshall stability was 3825, 3883, and 3755 lb at 3.0, 3.5, and 4.0 percent AC, respectively. All three levels exceed the MnDOT-suggested minimum of 1250 lb for SFDR (see Table 18 of the 2018 MnDOT Grading and Base Manual).
8. The conditioned Marshall stability was 2382, 2463, and 1543 lb at 3.0, 3.5, and 4.0 percent, respectively. These result in retained stabilities of 62, 63, and 41 percent, respectively. The values do not meet the suggested minimum of 70% (see Table 18 of the 2018 MnDOT Grading and Base Manual).
9. The SFDR mixes met MnDOT performance specifications for short-term strength in cohesionmeter testing (ASTM D 1560-92).
10. The resilient modulus (ASTM D 7369) for each mix was 438, 362, and 192 ksi at 3.0, 3.5, and 4.0 percent EE content, respectively. These values meet MnDOT performance specifications.

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11. The creep compliance and tensile strength performance of the mixes were evaluated at low temperatures according to AASHTO T 322. This test estimates a critical threshold for low-temperature performance. The estimated critical temperatures from these tests were -42°C, -35°C, and -27°C at 3.0, 3.5, and 4.0 percent EE content, respectively.
12. The bulk density results were 135.1, 135.2, and 135.3 pcf at 3.0, 3.5, and 4.0 percent FAC, respectively.

As noted above, the three-point design did not result in a mix that meets the MnDOT suggestions for retained stability. (Table 19 requires values to be reported but does not establish a performance specification). You may wish to overlook results for retained stability – relative to suggested performance levels of 70 percent – given the following characteristics of the mixes tested.

- The dry Marshall stability for all mixes tested was more than triple the required cured stability from the specification. As a result, the retained stabilities at 3.0 and 3.5 percent, which were roughly 62 percent, are relatively close to 70 percent retained stability.
- ITS results of all mixes greatly exceeded minimum values specified in Table 18 of the 2018 MnDOT Grading and Base Manual.

If you accept the above rationale, then test results indicate an optimum EE content of 3.0 percent. While an increase to 3.5 percent results in marginal improvement to Marshall stability results, in every other respect there is no benefit to additional binder.

If you have questions or need additional information, please do not hesitate to contact us. Thank you for the opportunity to provide MnDOT with these important engineering services.

Sincerely,

**American Engineering Testing, Inc.**



Derek Tompkins, PhD, PE (MN)  
Principal Civil Engineer  
612-297-3058  
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President and Principal Engineer  
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Attachments:

- a. SFDR Engineering Emulsion Mix Design Report



**AMERICAN ENGINEERING TESTING, INC. (AET)**

550 Cleveland Avenue North  
 St. Paul, MN 55114  
 Phone: (651) 659-9001

**MIX DESIGN FOR STABILIZED FULL DEPTH RECLAMATION (SFDR)**

<b>Date:</b>	8/16/19	<b>Engineer:</b>	Derek Tompkins
<b>Customer:</b>	MnDOT	<b>Phone:</b>	651-999-1789
<b>Mix Type:</b>	SFDR		
<b>AET Project No.:</b>	27-00077	<b>Review:</b>	David Rettner
<b>Project:</b>	MnROAD Cell 2		

**Sampling & Compaction Details**

<b>Sample Type:</b>	RAP and Base	<b>Compaction:</b>	Superpave Gyratory Compactor
<b>Sampling Date:</b>	n/a (Provided by MnDOT)		Compactor Internal Angle 1.16°
<b>Sampling Interval:</b>	n/a		600 kPa RAM Pressure, 30 Gyration

**Recommendation (See Conclusions Below)**

<b>Target Emulsion Content % (based on dry wt.):</b>	3.0
<b>Gal/SY (Based on 7 in. depth)</b>	2.5
<b>Opt. Moisture Content of Unstabilized FDR (from Proctor)</b>	6.0%
<b>Maximum Dry Density of Unstabilized FDR (from proctor), lbs./ft<sup>3</sup></b>	127.3

**Mixture Data & Volumetric**

Gradation Level	Laboratory Test results						Specification Requirement
	XX-28	XX-28	XX-28				
Emulsion Type	XX-28	XX-28	XX-28				
Emulsion (%)	3.0	3.5	4.0				
Prewet Water (%)	2.7	2.7	2.7				
Cement (%)	1.0	1.0	1.0				
Max. Specific Gravity (G <sub>mm</sub> )	2.465	2.447	2.430				
Density, lbs./ft <sup>3</sup>	135.1	135.2	135.3				Measured on ITS samples
Air Voids (%)	12.2	11.5	10.8				Measured on ITS samples
ITS at 25°C, psi	75.5	70.8	67.8				40 psi (min)
Conditioned ITS at 25°C, psi	65.0	60.4	55.9				25 psi (min)
Cured Marshall Stability, lb.	3824.5	3883.0	3755.0				1250 lb. (Report Only)
Retained Marshall Stability, %	62.3	63.4	41.1				Report Only
Cohesimeter, g/25 mm	293.2	256.4	252.0				175 min
Resilient Modulus, ksi	483.4	363.2	191.6				150 ksi (min)
Critical Low Temp., °C	-42	-35	-27				Report Only

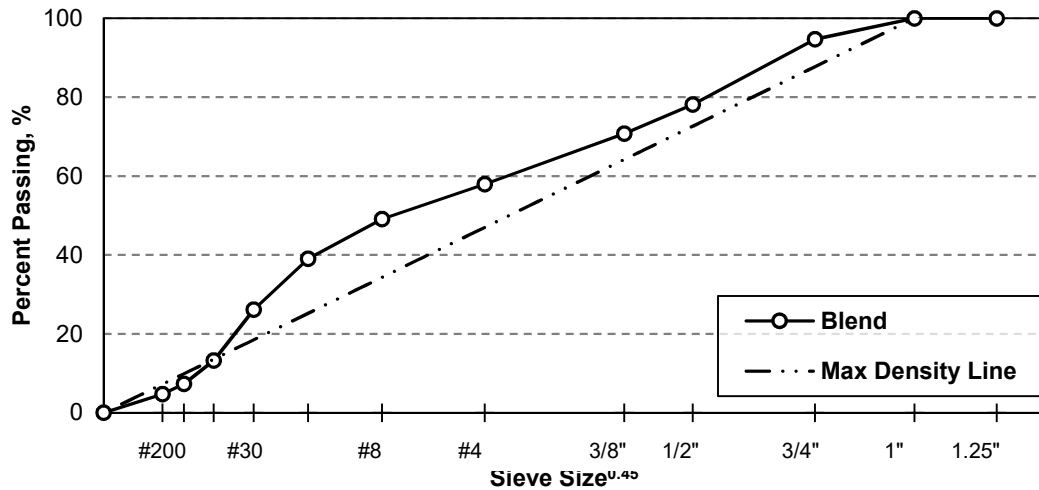


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 St. Paul, MN 55114  
 Phone: (651) 659-9001

**Project:** AET Job: 27-00077 MnROAD Cell 2

**Aggregate Gradation on 0.45 Power Chart**

Sieve Size (US / mm)	RAP	Agg#1	Agg#2	Blend	
	57.6	41.4	1	% Pass	C.P.
1 1/4" (31.5 mm)	100	100	100	100	
1" (25.4 mm)	100	100	100	100	
3/4" (19 mm)	93	97	100	95	
1/2" (12.5 mm)	70	89	100	78	
3/8" (9.5 mm)	60	85	100	71	
#4 (4.75 mm)	45	75	100	58	
#8 (2.36 mm)	34	69	100	49	
#16 (1.2 mm)	23	60	100	39	
#30 (0.6 mm)	12	44	100	26	
#50 (0.3 mm)	4	24	100	13	
#100 (0.15 mm)	1	14	100	7	
#200 (0.075 mm)	0.7	10.2	10	4.7	

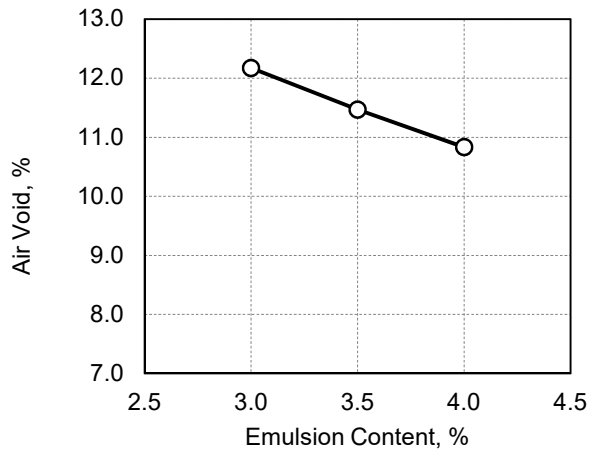
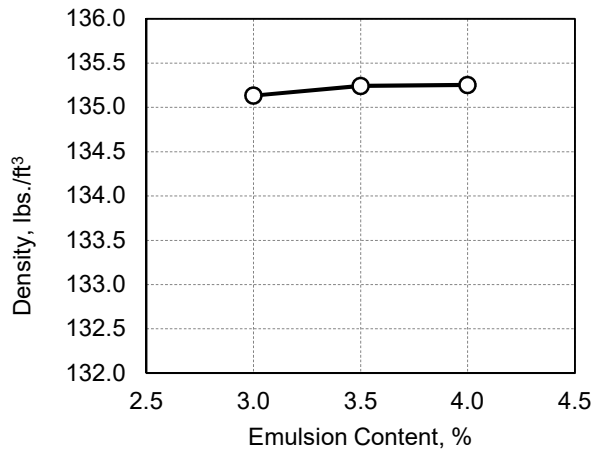




Project:

AET Job: 27-00077 MnROAD Cell 2

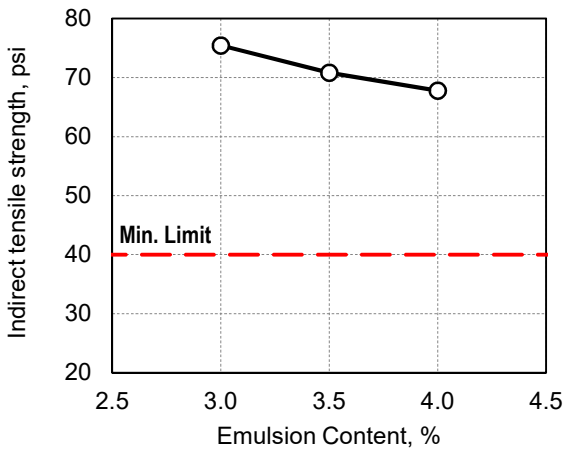
Mixture & Volumetric Graphs



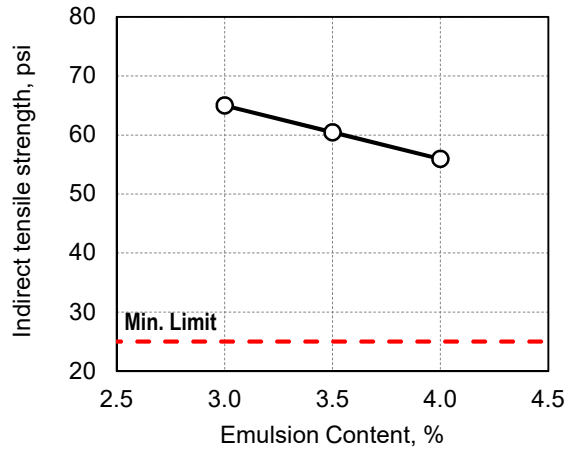
Density and Void Content Results

Indirect Strength Tests (ITS) at 25°C - ASTM D 4867

Dry Specimens



Moisture-Conditioned Specimens



Dry and Retained Marshall Stability Test Results



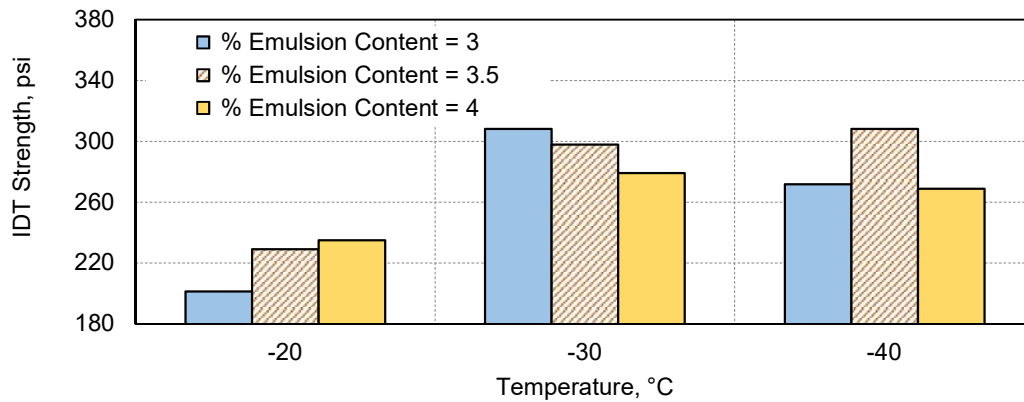
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 St. Paul, MN 55114  
 Phone: (651) 659-9001

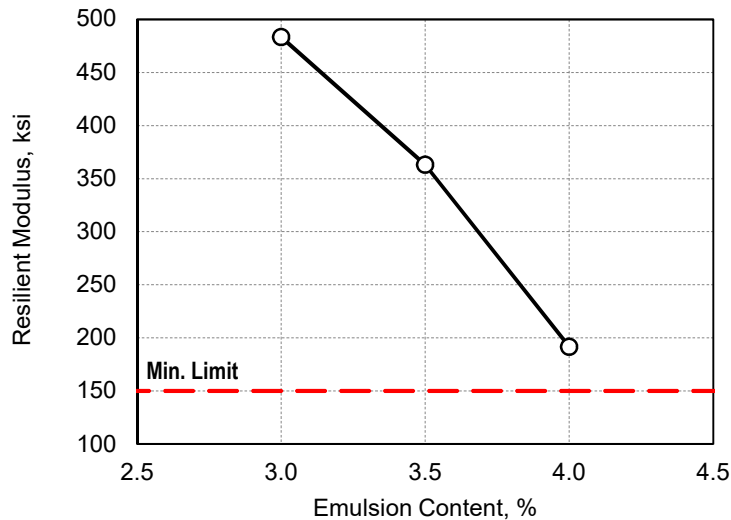
**Project:** AET Job: 27-00077 MnROAD Cell 2

**Indirect Tensile Test (IDT) Strength Test Results - AASHTO T322**

	% Emulsion Content = 3			% Emulsion Content = 3.5			% Emulsion Content = 4		
Temperature, °C	-20	-30	-40	-20	-30	-40	-20	-30	-40
Strength, psi	201.4	308.1	271.9	229.1	297.9	308.3	235.0	279.2	268.9



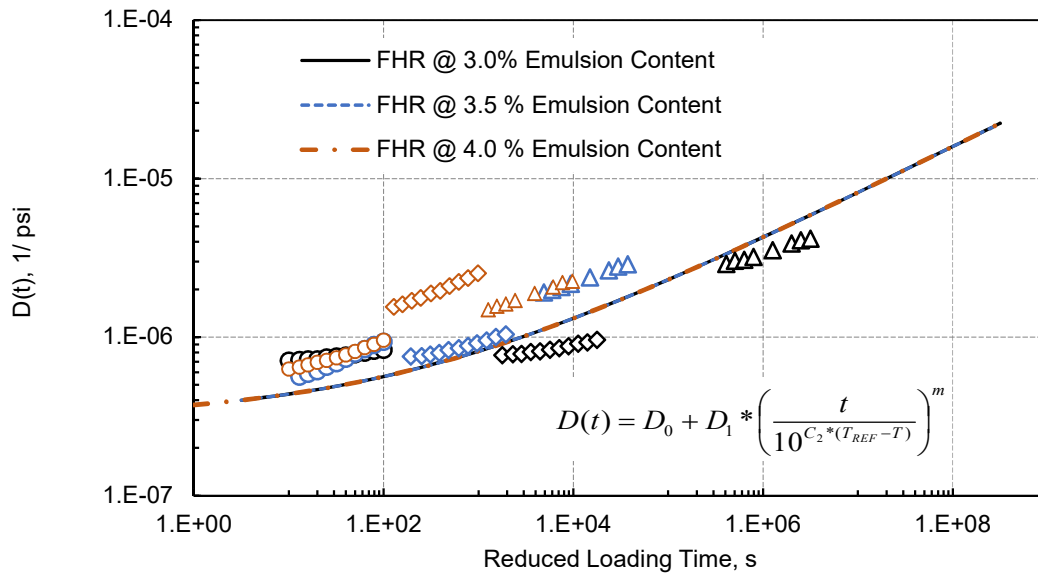
**Resilient Modulus Test Results - ASTM D 7369**



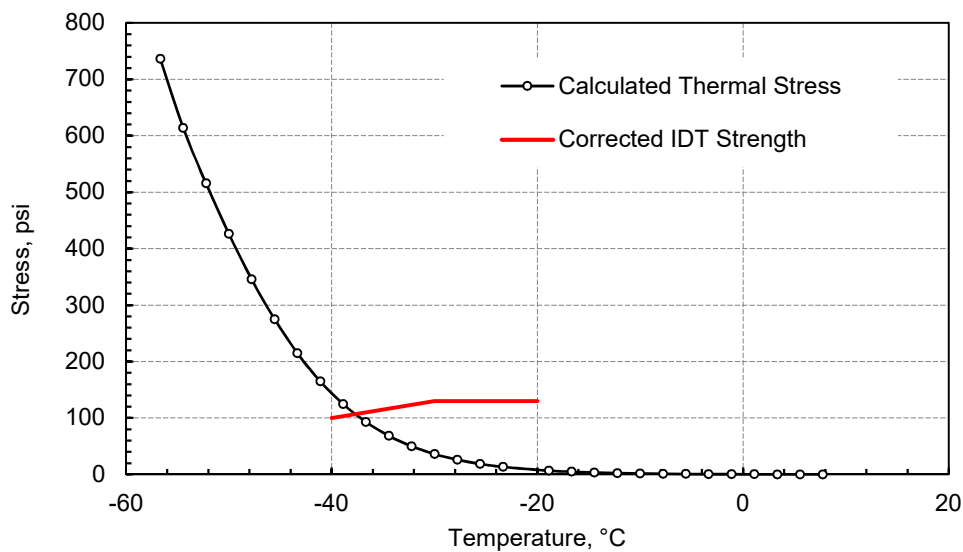


Project: AET Job: 27-00077 MnROAD Cell 2

### Indirect Tensile Test (IDT) Strength Test Results - AASHTO T322



### Critical Low Pavement Temperature at % Emulsion Content = 3

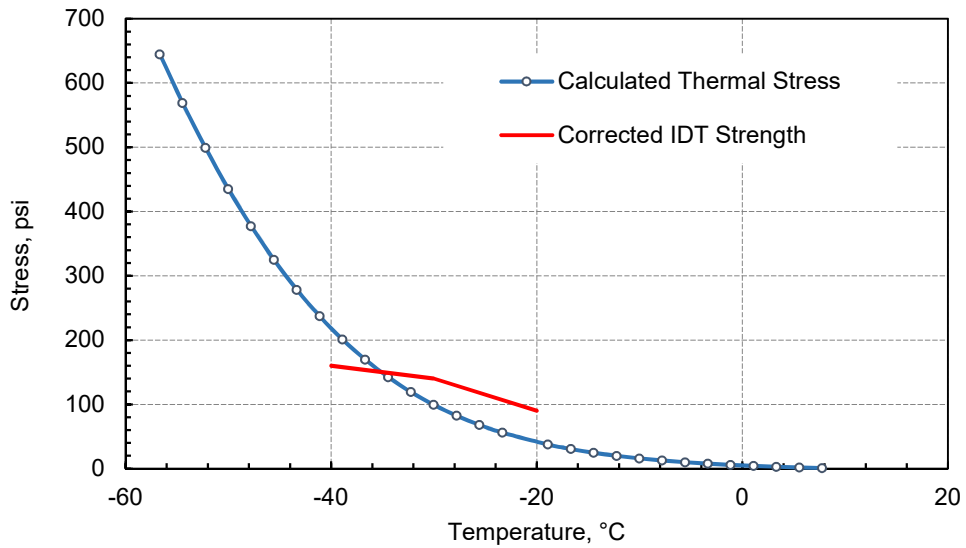




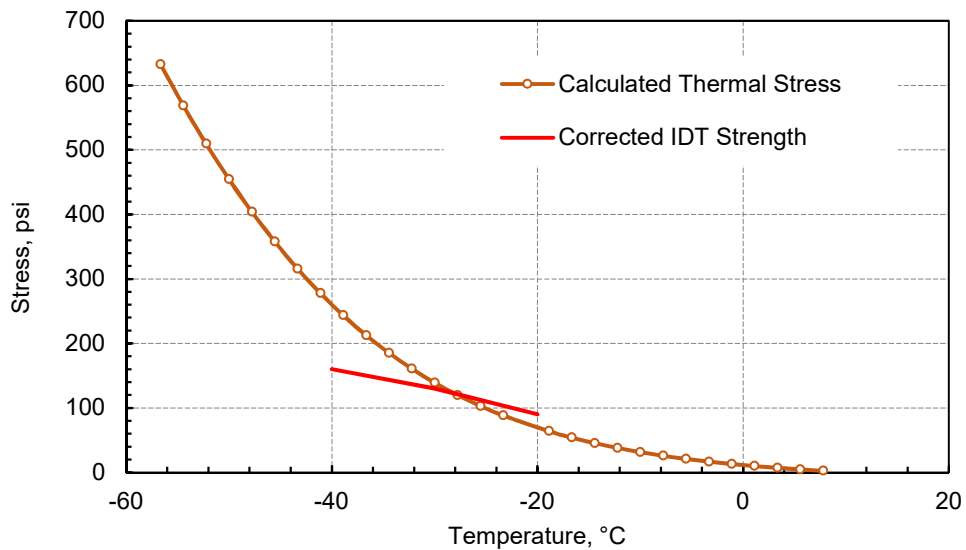
Project:

AET Job: 27-00077 MnROAD Cell 2

**Critical Low Pavement Temperature at % Emulsion Content = 3.5**



**Critical Low Pavement Temperature at % Emulsion Content = 4**



Note: The IDT tensile strengths have been corrected to account for the slight increase in load that occur during the IDT test, as well as to account for the difference between the laboratory and field strengths of pavements



**APPENDIX E**  
**MNROAD CCPR TEST SECTION CORES**



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 235 inside In  
2350BC007



AET No. 27-00077

*Side*

Mn Rd LVR 235 inside In

2350BC007





**A** AET No. 27-00077  
TOP  
Mn Rd LVR 235 inside In  
2350BC007



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 235 inside In  
2350BC008

**A**

AET No. 27-00077

*Side*  
Mn Rd LVR 235 inside In  
2350BC008





**A** AET No. 27-00077  
TOP  
Mn Rd LVR 235 inside In  
2350BC008





**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 133 outside In  
13320BC001





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 133 outside ln  
13320BC001



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 133 outside In  
13320BC002



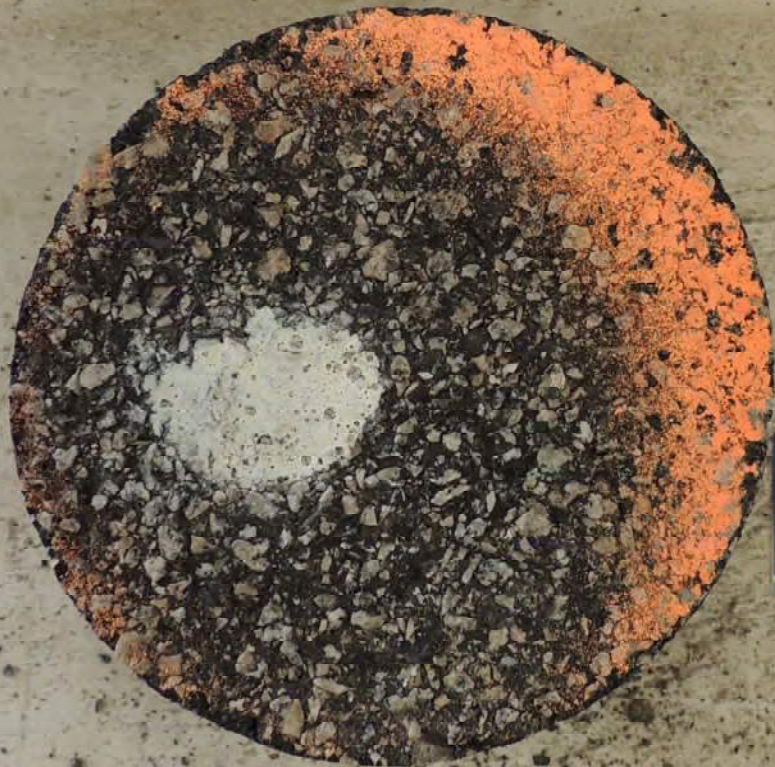
AET No. 27-00077

*Side*

Mn Rd LVR 133 outside In

13320BC002





**A** AET No. 27-00077  
Top  
Mn Rd LVR 133 outside In  
13320BC002



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 133 outside In  
13320BC003

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 133 outside In  
13320BC003





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 133 outside In  
13320BC003





**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 133 outside In  
13320BC004

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 133 outside In  
13320BC004





**A** AET No. 27-00077  
Top  
Mn Rd LVR 133 outside ln  
13320BC004



**A** AET No. 27-00077  
*Bottom*  
Mu Rd LVR 133 inside In  
13320BC005



AET No. 27-00077

*Side*

Mn Rd LVR 133 inside In  
13320BC005





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 133 inside In  
13320BC005



**A** AET No. 27-00077  
Borran  
Mn Rd LVR 133 inside ln  
13320BC006



AET No. 27-00077

*Side*

Mn Rd LVR 133 inside In  
13320BC006







**A** AET No. 27-00077  
Top  
Mn Rd LVR 133 inside In  
13320BC006



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 133 inside ln  
13320BC007

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 133 inside ln  
13320BC007





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 133 inside ln  
13320BC007



**A** AET No. 27-00077  
*Boston*  
Mn Rd LVR 133 inside ln  
13320BC008

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 133 inside In  
13320BC008





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 133 inside In  
13320BC008



**A** AET No. 27-00077  
*Boston*  
Mn Rd LVR 135 outside In  
13520BC001







**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 135 outside In  
13520BC001



**A** AET No. 27-00077  
*Berman*  
Mn Rd LVR 135 outside In  
13520BC002

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 135 outside ln  
13520BC002





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 135 outside ln  
13520BC002



**A** AET No. 27-00077  
*Born*  
Mn Rd LVR 135 outside In  
13520BC003

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 135 outside In  
13520BC003





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 135 outside In  
13520BC003





**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 135 outside In  
13520BC004

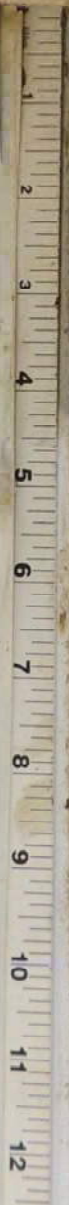


AET No. 27-00077

*Side*

Mn Rd LVR 135 outside ln

13520BC004





**A** AET No. 27-00077  
Top  
Mn Rd LVR 135 outside ln  
13520BC004



**A** AET No. 27-00077  
Bottom  
Mn Rd LVR 135 inside In  
13520BC005



AET No. 27-00077

*Side*

Mn Rd LVR 135 inside In

13520BC005





**A** AET No. 27-00077  
Top  
Mn Rd LVR 135 inside ln  
13520BC005



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 135 inside In  
13520BC006

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 135 inside In  
13520BC006







**A** AET No. 27-00077  
Top  
Mn Rd LVR 135 inside In  
13520BC006



**A** AET No. 27-00077  
*Barton*  
Mn Rd LVR 135 inside ln  
13520BC007

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 135 inside ln  
13520BC007





**A** AET No. 27-00077  
T<sub>10</sub>  
Mn Rd LVR 135 inside In  
13520BC007



**A** AET No. 27-00077  
Bottom  
Mn Rd LVR 135 inside In  
13520BC008



AET No. 27-00077

*Side*

Mn Rd LVR 135 inside In

13520BC008





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 135 inside In  
13520BC008



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 outside In  
23320BC001



**A** AET No. 27-00077  
*side*  
Mn Rd LVR 233 outside ln  
23320BC001





**A** AET No. 27-00077  
TOP  
Mn Rd LVR 233 outside In  
23320BC001



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 outside In  
23320BC002

**A** AET No. 27-00077  
*side*  
Mn Rd LVR 233 outside In  
23320BC002





**A** AET No. 27-00077  
TOP  
Mn Rd LVR 233 outside ln  
23320BC002



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 inside ln  
23320BC003

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 233 inside In  
23320BC003





**A** AET No. 27-00077  
Top  
Mn Rd LVR 233 inside ln  
23320BC003





**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 outside ln  
23320BC003

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 233 outside In  
23320BC003





AET No. 27-00077  
*Top*  
Mn Rd LVR 233 outside In  
23320BC003



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 inside In  
23320BC004



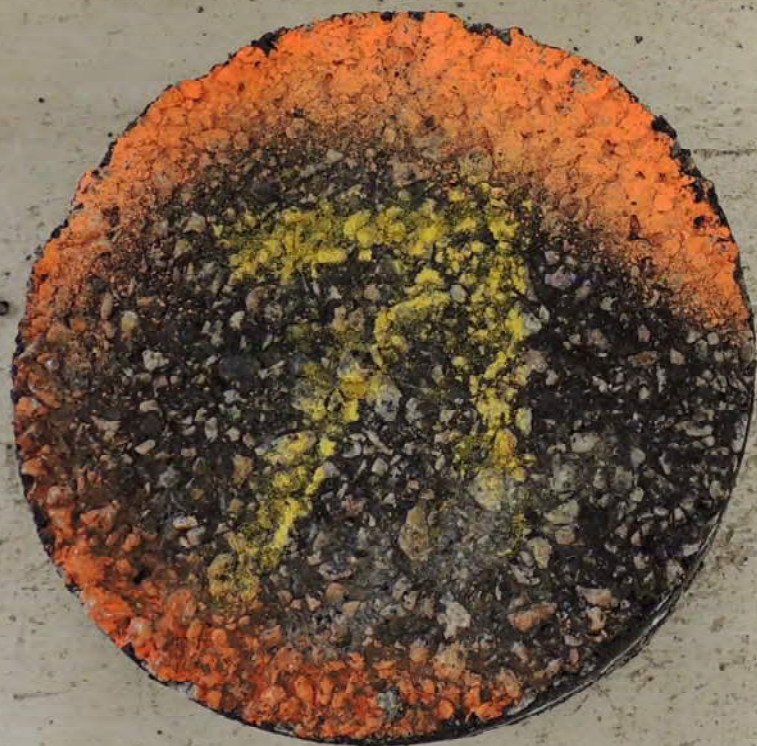
AET No. 27-00077

*Side*

Mn Rd LVR 233 inside In

23320BC004





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 233 inside ln  
23320BC004



**A** AET No. 27-00077  
Bottom  
Mn Rd LVR 233 outside In  
23320BC004



AET No. 27-00077

*Site*


Mn Rd LVR 233 outside In

23320BC004







 AET No. 27-00077  
*Top*  
Mn Rd LVR 233 outside In  
23320BC004



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 inside ln  
**23320BC005**



AET No. 27-00077

*Side*

Mn Rd LVR 233 inside ln

23320BC005





**A** AET No. 27-00077  
*TOP*  
Mn Rd LVR 233 inside ln  
23320BC005



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 233 inside ln  
**23320BC006**

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 233 inside In  
23320BC006





**A** AET No. 27-00077  
*Top* Mn Rd LVR 233 inside ln  
23320BC006

**A** AET No. 27-00077  
*side*  
Mn Rd LVR 235 outside ln  
23520BC001







**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 235 outside In  
23520BC001





AET No. 27-00077

*side*  
Mn Rd LVR 235 outside In

23520BC002





**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 235 outside In  
23520BC002



**A** AET No. 27-00077  
TOP  
Mn Rd LVR 235 outside In  
23520BC002



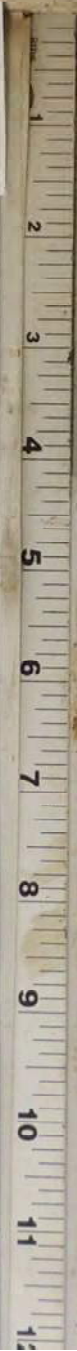


AET No. 27-00077

*Side*

Mn Rd LVR 235 outside In

2350BC003





**A** AET No. 27-00077  
Top  
Mn Rd LVR 235 outside In  
2350BC003





**A** AET No. 27-00077  
Bottom  
Mn Rd LVR 235 outside ln  
2350BC004



AET No. 27-00077

*Side*  
Mn Rd I.VR 235 outside In  
2350BC004





**A** AET No. 27-00077  
Top  
Mn Rd LVR 235 outside In  
2350BC004



**A** AET No. 27-00077  
Bottom  
Mn Rd LVR 235 inside In  
23520BC007

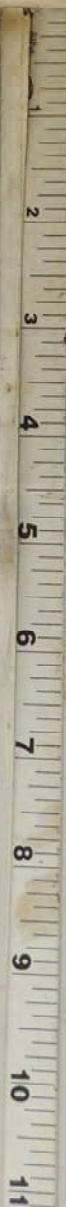


AET No. 27-00077

*Side*

Mn Rd LVR 235 inside ln

23520BC007





**A** AET No. 27-00077  
*Top*  
Mn Rd LVR 235 inside ln  
23520BC007



**A** AET No. 27-00077  
*Bottom*  
Mn Rd LVR 235 inside ln  
23520BC008

**A** AET No. 27-00077  
*Side*  
Mn Rd LVR 235 inside ln  
23520BC008







**A** AET No. 27-00077  
Type  
Mn Rd LVR 235 inside In  
23520BC008