Frost Monitoring at MnROAD

2022 BCRRA Workshop

"Managing Impact of Frost on Pavement Systems"

Benjamin Worel, P.E.(MN)

June 27, 2022

DEPARTMENT OF TRANSPORTATION

Outline

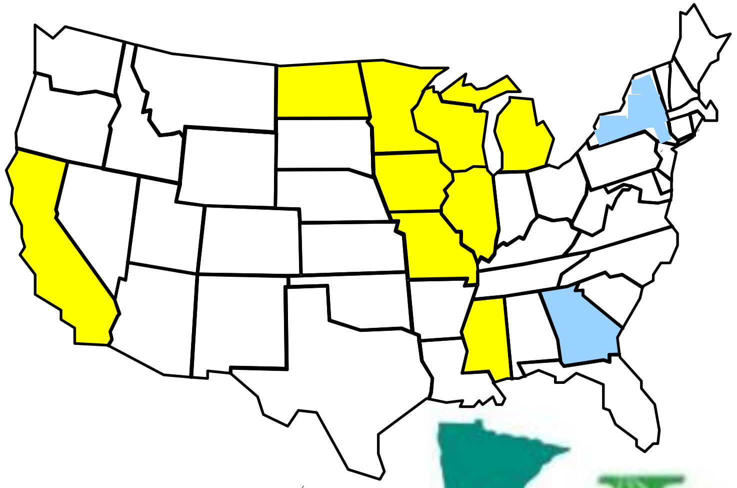
MnROAD Background

- **MnROAD Owned and Operated by Minnesota DOT**
- **HMA and PCC Research**
- **30 Years of Long-Term Customer Service**
  - Minnesota Department of Transportation
  - Minnesota Local Road Research Board
  - SHRP II / NCHRP / FHWA / Partnerships
  - Pooled Funds Efforts (States) / Industry
- **Major Experiments**
  - Phase I (1994-2006)
  - Phase II (2007-2016)
  - Phase III (2017-2022) – NRRA/NCAT
  - Phase IV (2022) – NRRA/NCAT

NRRA
National Road Research Alliance
LRRB
National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY
mn DEPARTMENT OF TRANSPORTATION

National Road Research Alliance and MnROAD Partnerships

- NRRA Phase-I (Feb 2016 – Feb 2021)
  - 13 Government Agencies
  - 60+ Associate Members
  - 40 Projects & Research @ ~$4,700,000
    - 21 Different Contractors
- Organizational Structure
  - Executive Committee (2 representatives)
  - 5 Technical Teams (HMA, PCC, ICT, PM, Geotechnical)
  - Monthly Research Pays off Seminars
- NRRA Phase-II (Jan 2021 – Dec 2025)
  - Pooled Fund Approved - TPF-5(466)
  - NRRA and Veta being combined (2 States for Veta only)
  - ~5 million dollars towards NRRA directed research
  - MnDOT utilize 5 million for 2022 MnROAD construction
- NCAT Partnership



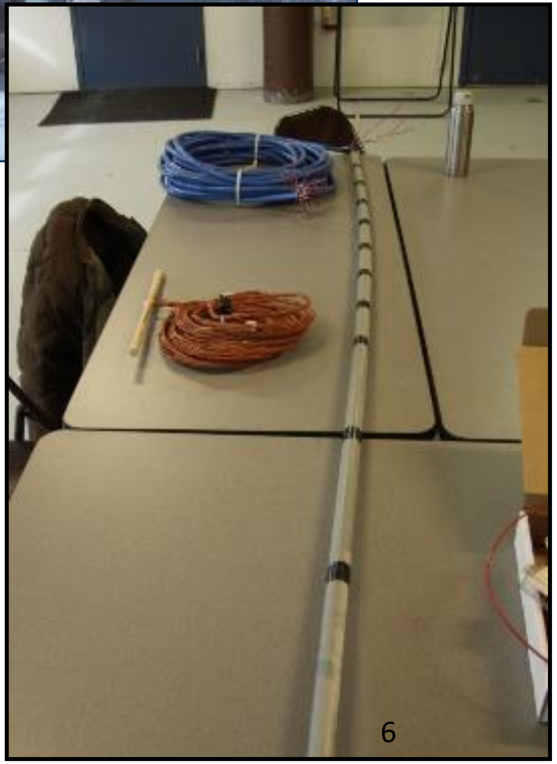
MnROAD- Minnesota Road Research Facility

MnROAD Research Resources

- **Experienced Technical Staff**
  - 19 Road Research
  - 7 MnROAD Operations
- **Safe/Accessible Work Zone**
- **Pavement Database**

  (Long Term Data ~ 30 years data)
  - Lab Testing
  - Performance Monitoring
  - Sensors
    - Data Collection Network
    - 8,500+ Sensors Installed
    - Static and Dynamic Data
    - Weather Data
    - Traffic Data



Typical Frost Data / Sensors / Seasonal Monitoring

- Weather Stations (2)
- Thermal Couples
  - 12 mm to 2400 mm depth (1/2 inch to 8 feet)
  - Many layers and materials
- Moisture Gauges
- Ground Water
- Frost Pins Surveys
- Seasonal Ride Data

(Limitations to our current measurements for both research and our MnDOT pavement management data collection)

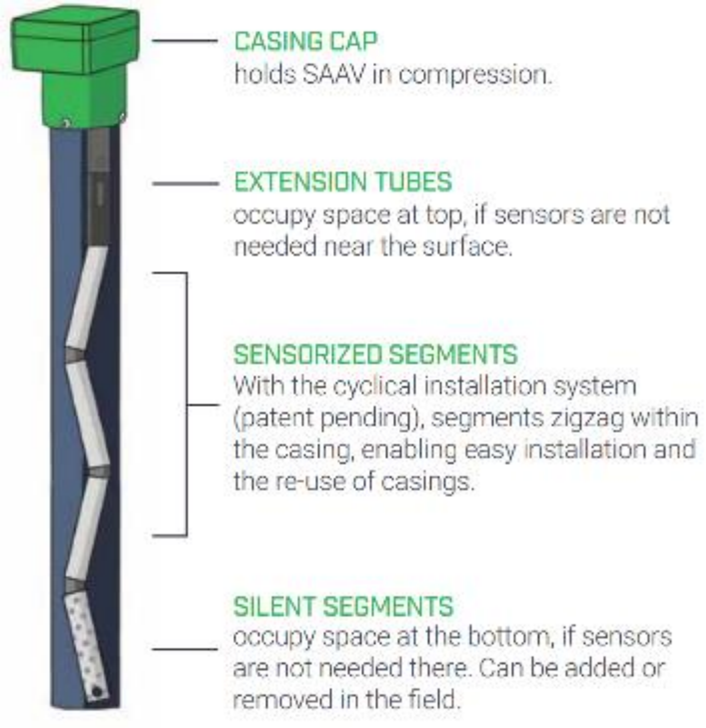
Shape Array Accelerometer(SAA) Sensors

✓ ShapeArray is an integrated measuring tool that measures **deformation in soil and structures** in real time. The instrument can be used horizontally- to monitor **settlement or heave**, vertically to monitor **lateral deformation**, and in an arc to monitor changes in **convergence** (for example, in tunnels, Sewers).

Different applications

- In-situ monitoring of unstable slopes
- Monitoring of civil engineering structures

  (Tunnels, retaining walls, dams, and buildings)
- Monitoring of mines and excavations
- Measuring drill-hole shape
- Laboratory research



Bora Cetin Ph.D.
Associate Professor
Michigan State University
cetinbor@msu.edu

Raul Velasquez P.E. Ph.D.
MnDOT Geomechanics
Research Engineer
Raul.Velasquez@state.mn.us

Practical Application-Asphalt Pavement
(2022 MnROAD Wicking Geotextile Application)

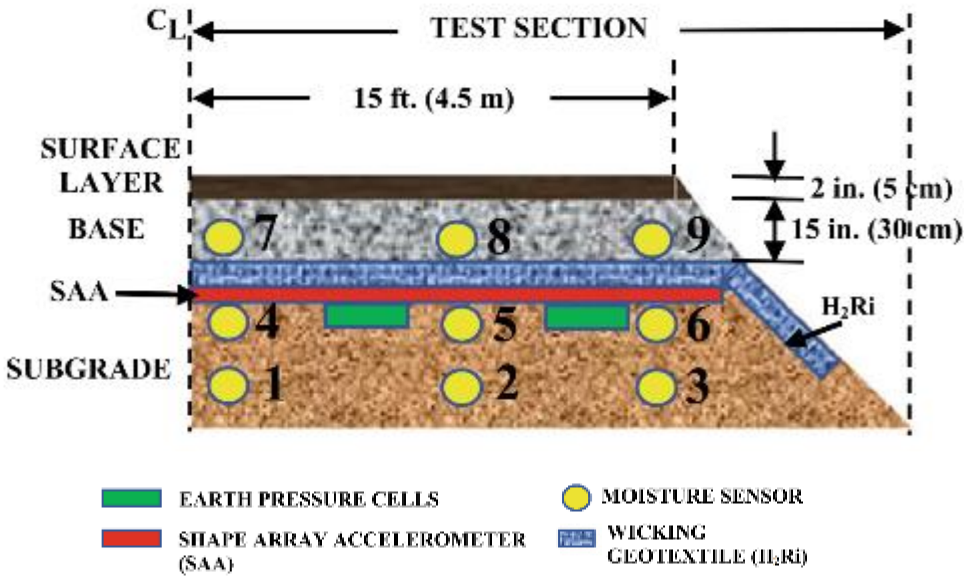


Figure. Section details and instrumentation (Biswas et. al. 2022)

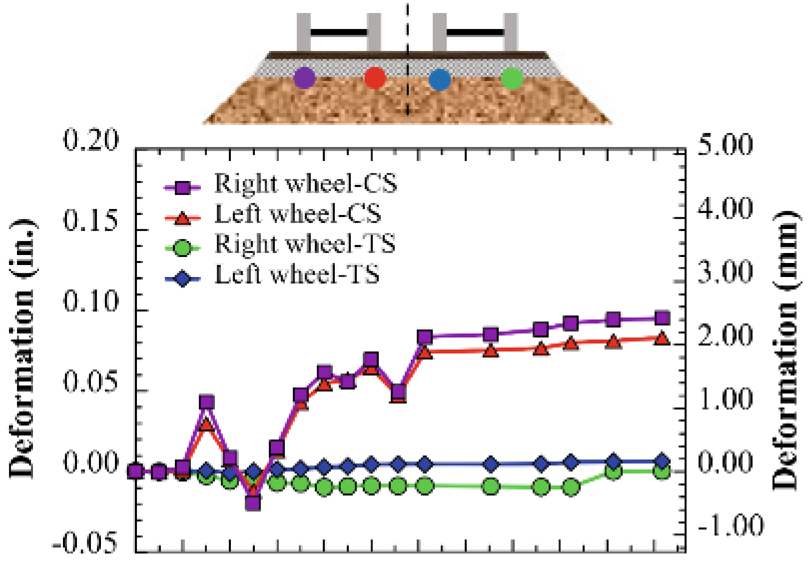
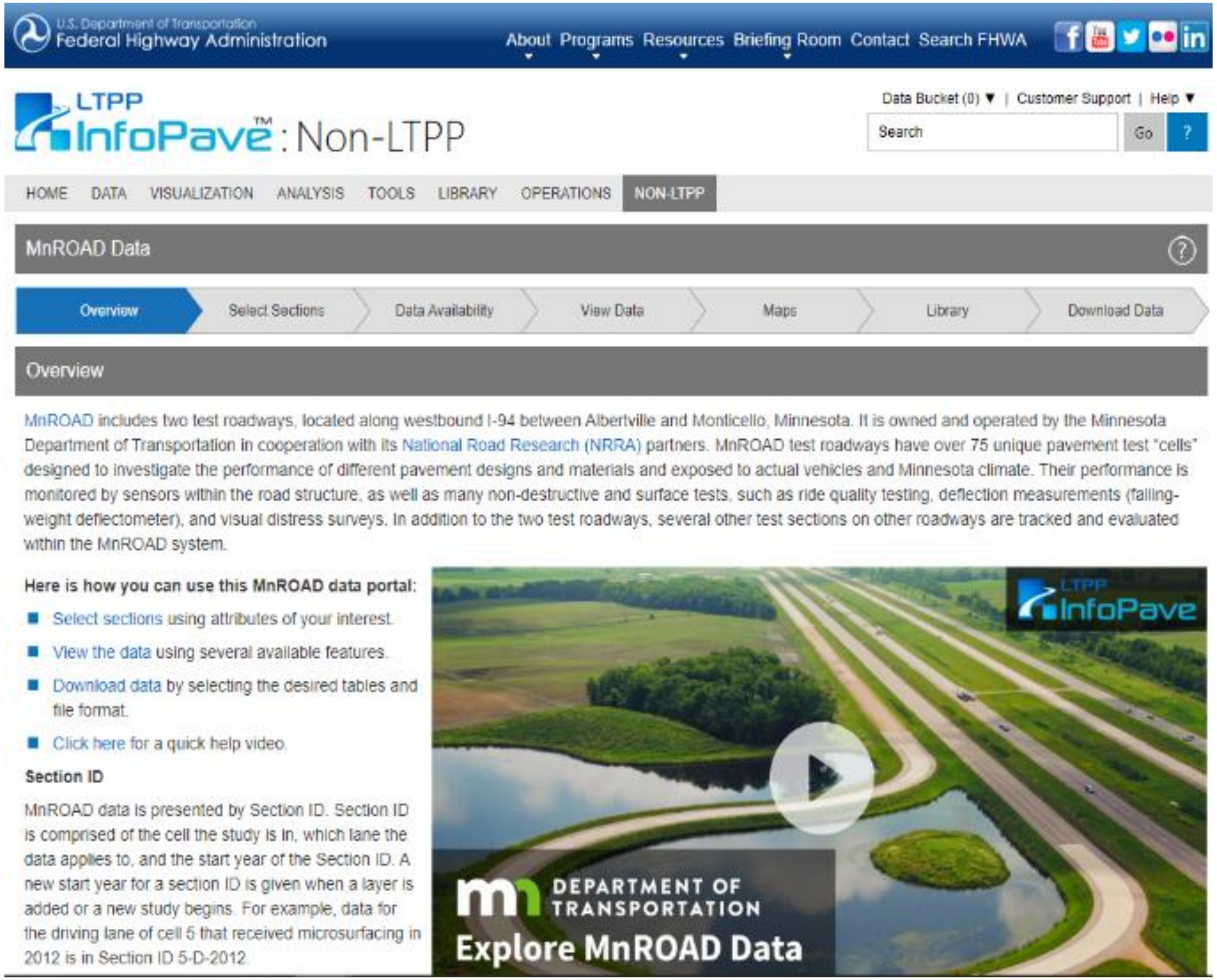


Figure. Deflection of subgrade in test and control Section obtained from SAA (Biswas et. al. 2022)

MnROAD Data Availability

MnROAD is a publicly funded facility all our data is available to the public

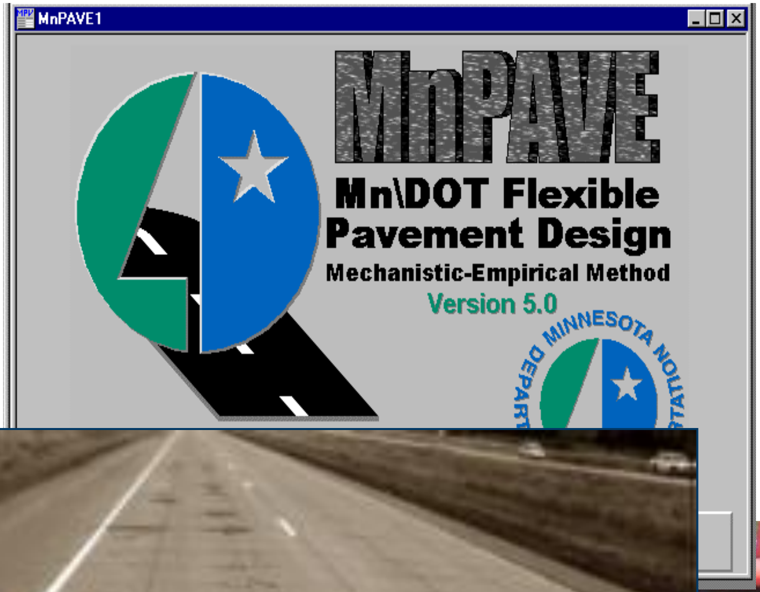
- **MnROAD Website**
  - http://www.dot.state.mn.us/mnroad/
  - Descriptions of data collected
  - Some sensor data at this time
- **InfoPave MnROAD Website**
  - LTPP tied online system
  - https://infopave.fhwa.dot.gov/Mnroad/index
  - Locate sections, data types, view data, downloads
  - Sensors to be added in 2022 and other improvements
- **Email MnDOT Staff**
  - Custom data requests



MnROAD ME Designs Impacts

- **Flexible – MnPAVE**

  (Major Inputs into PavementME)
- **Rigid – MnPAVE Rigid**
- **Concrete Overlay of Asphalt**



AASHTOWare Pavement
AASHTO

BCOA ME
University of Pittsburgh

MnROAD Data and PMS Objekt Comparison

Twenty Years of MnROAD Frost Depth Observations Compared with Predicted Frost Depths Using Sweden's PMS Objekt Design Software

2015 TRB Presentation (P15-5099) -- January 12, 2015

Benjamin Worel
Minnesota Department of Transportation

Tomas Winnerholt
TRAFIKVERKET

Objective

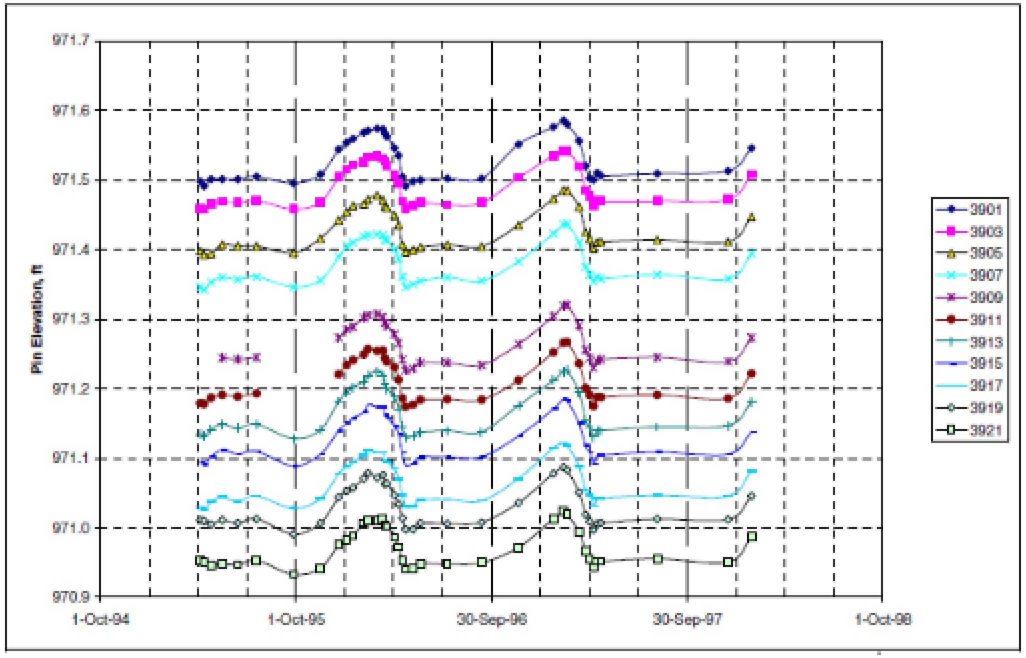
- Use MnROAD Data
- Verify PMS Objekt
- Future use in MnDOT design software
- Move beyond 30" and 36" frost free design criteria MnDOT uses

Past MnROAD Frost Heave Efforts

- **Measured using rod and level measurements**
- **MnROAD Environmental Factors that Affect Ride** - http://www.mrr.dot.state.mn.us/research/pdf/2006MRRDOC014.pdf
  - 2006 ASCE Cold Regions Paper
- **Effects of Pavement Design on Frost Heave at MnROAD**
  - University of Minnesota / MnDOT
  - HMA and PCC Inpacts
  - 2009 TRB Paper #: 09-318

4 years data (two shown)
Variable every year
Very little heave

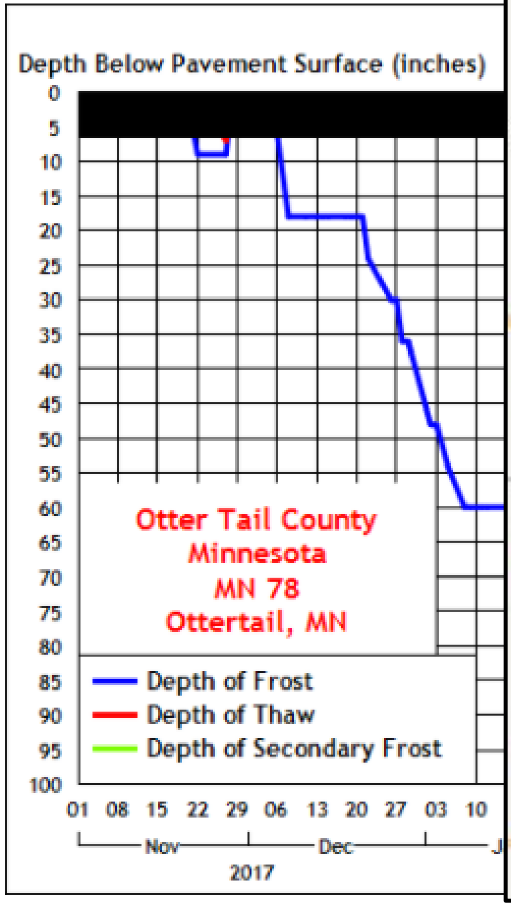
- Clay 1.1” (3 cm)
- Sand .3 to .5” (1 cm)

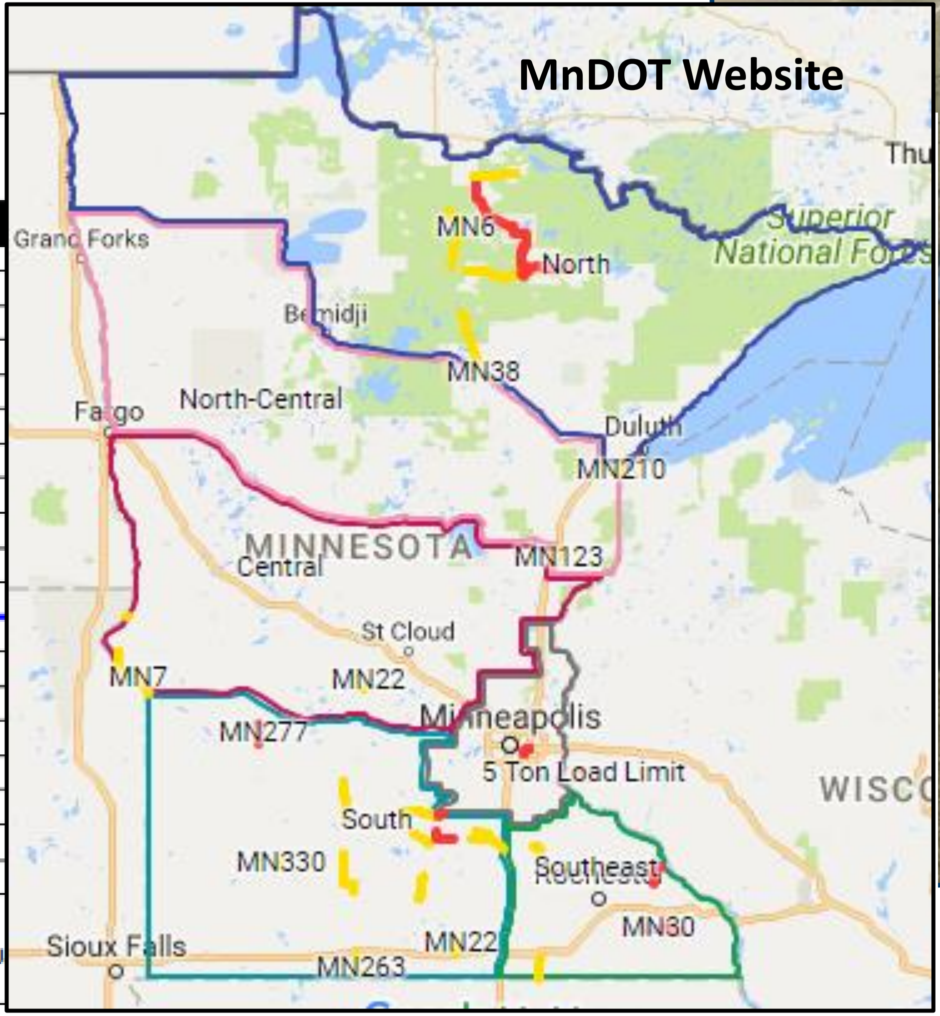


Seasonal Load Limits

Spring Restrictions / Winter Overloads

MnROAD Models
Thawing Index





NRRA Project - Recycled Bases at MnROAD

- This project is funded by National Road Research Alliance (NRRA). Grant # 1003320-2, Report # NRRA202103

Bora Cetin Ph.D.
Associate Professor
Department of Civil & Environmental Engineering
Michigan State University
Email: cetinbor@msu.edu

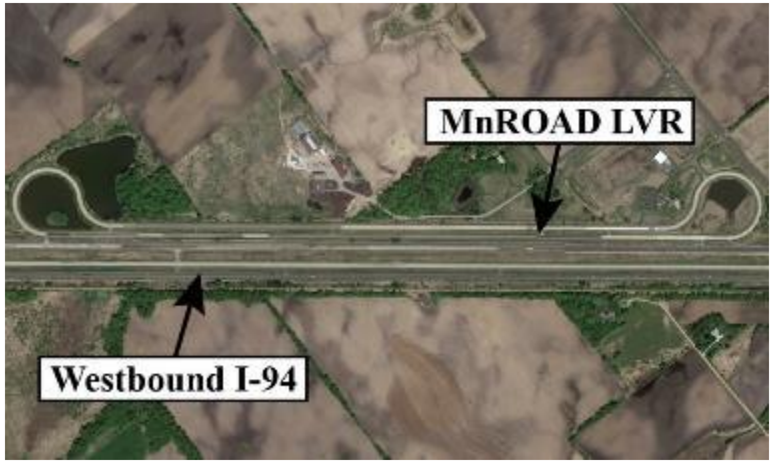
Raul Velasquez P.E. Ph.D.
Geomechanics Research Engineer
MnDOT Office of Materials & Road Research
Email: Raul.Velasquez@state.mn.us

Motivation

- Recycled concrete aggregate (RCA)
  - Old & failed rigid pavements
  - Demolished structures

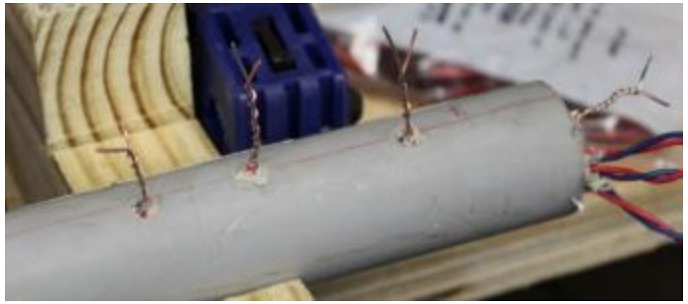
- Recycled asphalt pavement (RAP)
  - Old & failed asphalt pavement surfaces

- Test and Monitor Performance of RAB under unique environmental conditions at MnROAD

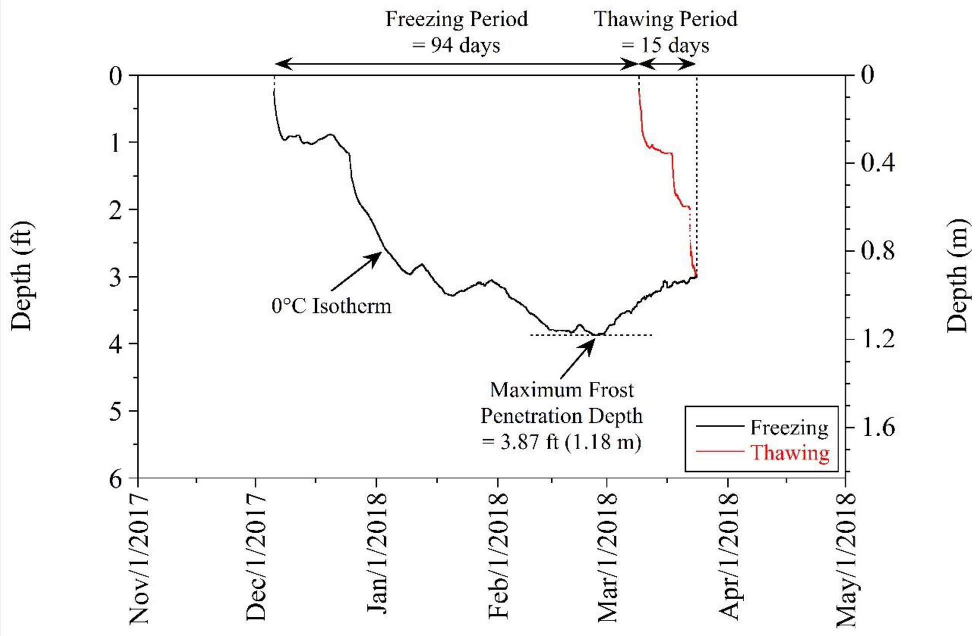


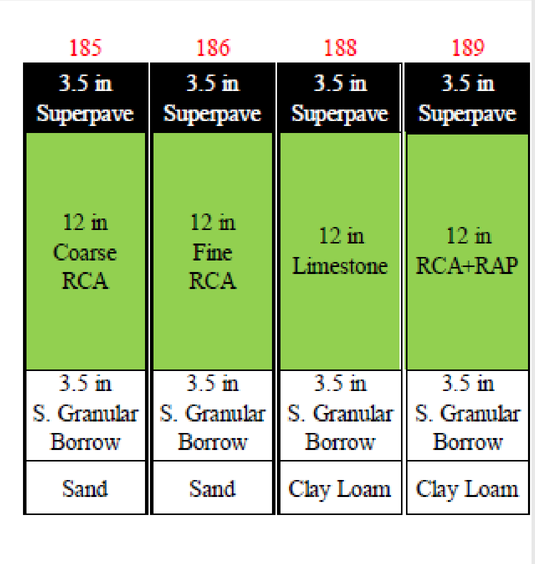
Performance Monitoring of RAB Cells

- Soil temperature and moisture monitoring
  - Temperature profiles
  - VWC profiles
  - Annual frost penetration depths
  - F-T periods
- FWD tests
- Frost heave & thaw settlement
- Rutting
- IRI
- Other pavement distresses



MnROAD RAB Cells
Freeze-Thaw Performance

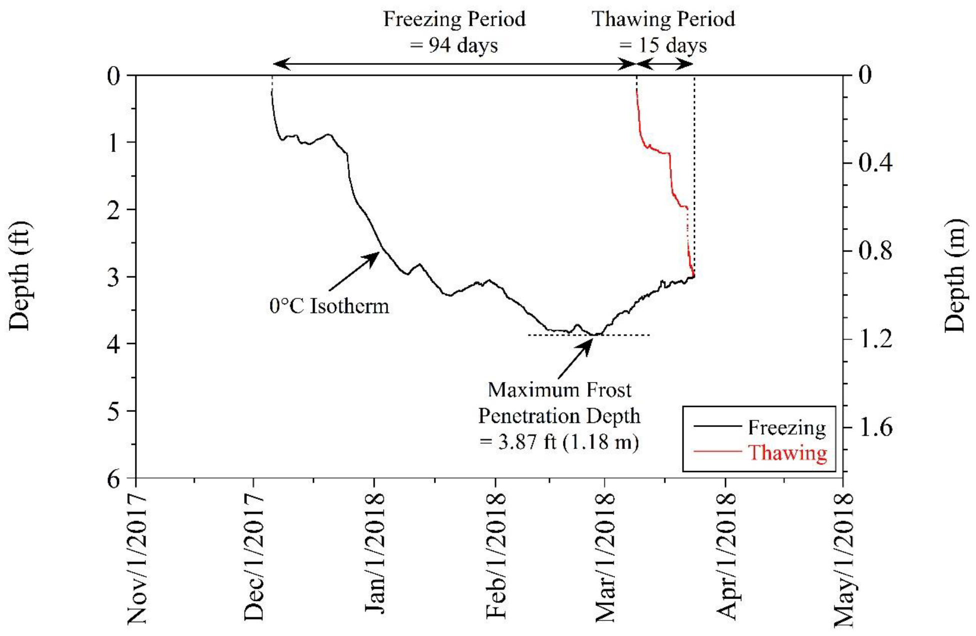


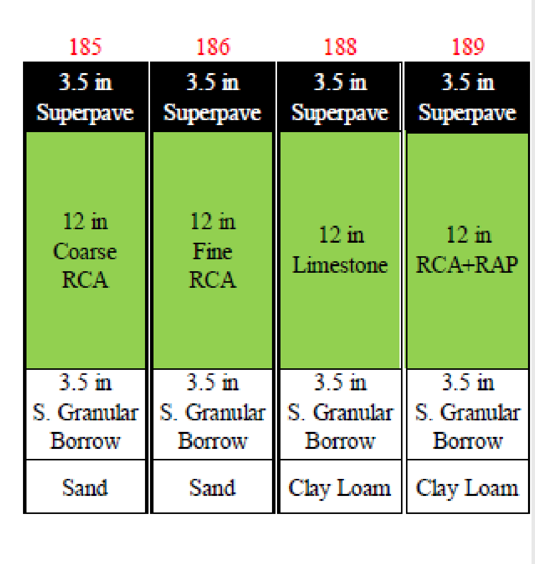


Cell Number	Cell Description	2017-2018		2018-2019	
		Freezing Period (days)	Thawing Period (days)	Freezing Period (days)	Thawing Period (days)
185	12 in Coarse RCA	83	25	116	27
186	12 in Fine RCA	84	28	116	27
188	12 in Limestone	84	18	121	18
189	12 in RCA+RAP	84	16	120	23

Thawing periods were higher for ***RCAs***

MnROAD RAB Cells
Freeze-Thaw Performance

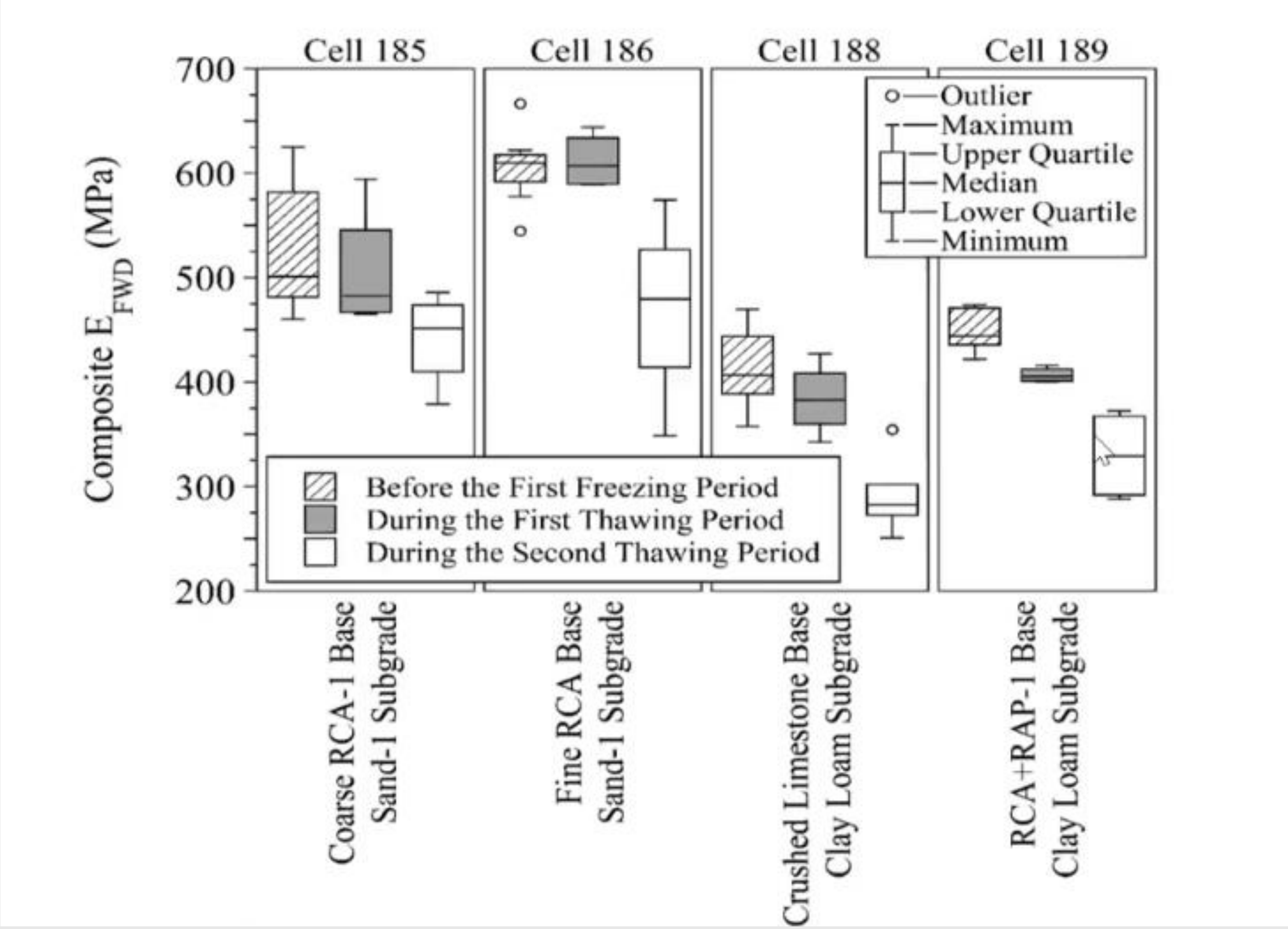




Cell Number	Cell Description	2017-2018 Maximum Frost Penetration Depth		2018-2019 Maximum Frost Penetration Depth	
		(ft)	(m)	(ft)	(m)
185	12 in Coarse RCA	4.44	1.35	4.75	1.45
186	12 in Fine RCA	4.24	1.29	4.39	1.34
188	12 in Limestone	4.9	1.49	5.52	1.68
189	12 in RCA+RAP	4.47	1.36	5.09	1.55

Higher frost penetration depths for ***Limestone***

MnROAD RAB Cells
Freeze-Thaw Performance Strength



Environmental Impacts on the Performance of Pavement Foundation Layers-Phase I

Principal Investigator:

Bora Cetin, Ph.D.

Co-Principal Investigator:

Kristen Cetin, Ph.D.

Tuncer Edil, Ph.D.

Research Team:

Debrudra Mitra

Department of Civil and Environmental Engineering

Michigan State University

PROBLEM STATEMENT

Freezing

Thaw Weakening

Ice Lensing → Frost Boil | Rutting | Potholes

https://myferndalenews.com/frost-boils-reason-emergency-road-restrictions_55759/

https://porthawkesburyreporter.com/spring-weight-restrictions-partially-lifted/

Objective of this Study:

(1) Clean and pre-process the soil & weather data

(2) Develop a data-driven model that uses weather data as input to:

- Predict the soil temperature and certain depths
- Predict the number of freeze thaw cycles at certain depths and start/end time, and duration of cycles over time

(3) Create a tool to provide soil temperature and number/duration of freeze-thaw cycles that implements the model

Tool Development: 2021 *Summary*

The tool has been developed in Excel to predict for a user-specified depth:

1. *Soil temperature*
2. *Number of freeze-thaw cycles*
3. *Starting time of freezing and thawing*
4. *Duration of the cycles*

2021 Final Report - NRRA: Environmental Impacts on the Performance of Pavement Foundation Layers (state.mn.us)

Debugging checks have also been implemented in the tool to provide the user some information about the input data and possible errors.

Using GPR to Monitor Moisture in Base Agg of In-Service Pavements

- Using MnDOT's Road Doctor / GPR to measure & monitor moisture fluctuations in unbound aggregate layers of in-service pavements
  - To establish proper windows for Spring Load Restriction and Winter Load Increase
  - Establish proper traffic opening time for roads affected by flooding
  - Assess the drainage capacities of pavements
  - Identify locations with poor drainage
  - Provide continuous moisture profiles (not spot measurements)

TRR

Research Article

Transportation Research Record
1–16
© National Academy of Sciences: Transportation Research Board 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/03611981221074360
journals.sagepub.com/home/trr
SAGE

Using Ground Penetrating Radar to Monitor Seasonal Moisture Fluctuations in Base Layers of Existing Roads

Eyoab Zegeye-Teshale[1], Micah Holzbauer[1], and Shongtao Dai[1]

Abstract

A high moisture content in the unbound aggregate layers of pavements can lead to severe functional and structural damage, especially in pavement constructed in freeze-thaw environments, such as Minnesota. In these climates, the freezing temperatures can contribute to the formation of severe crack-heaving issues, and the early spring-thaw conditions can significantly reduce a pavement's bearing capacity. A good understanding of subsurface seasonal moisture fluctuation is, therefore, essential for implementing effective maintenance and road load management techniques. Unfortunately, traditional pavement moisture testing approaches are expensive, time-consuming, invasive, limited in spatial coverage, and negatively affect the traffic flow. The present study builds on previous efforts to characterize moisture and frost conditions in pavement base layers using ground penetrating radar (GPR) and moisture sensing instruments. The paper offers a simple methodology for monitoring moisture variations in the base layer and assessing the moisture susceptibility of aggregate base materials from single-offset GPR measurements. The methodology was validated by comparing the GPR data with moisture content readings collected from four different pavement test sections over a period of approximately two years. Overall, the moisture contents obtained from the GPR were comparable with those obtained from sensors installed in the pavement section. However, the GPR approach offered the added advantage of covering long stretches of pavement in short times and with minimal impact on the pavement and traffic.

Keywords

infrastructure, geology and geoenvironmental engineering, geoenvironmental and climatic impacts on geomaterials, moisture and temperature effects, geotechnical instrumentation and modeling, instrumentation design and planning, mechanics and drainage of saturated and unsaturated geomaterials, highway maintenance, maintenance and operations management, structural assessment, road weather, winter maintenance, materials, aggregates, unbound granular material, pavements, pavement condition evaluation, ground penetrating radar, pavement structural testing and evaluation

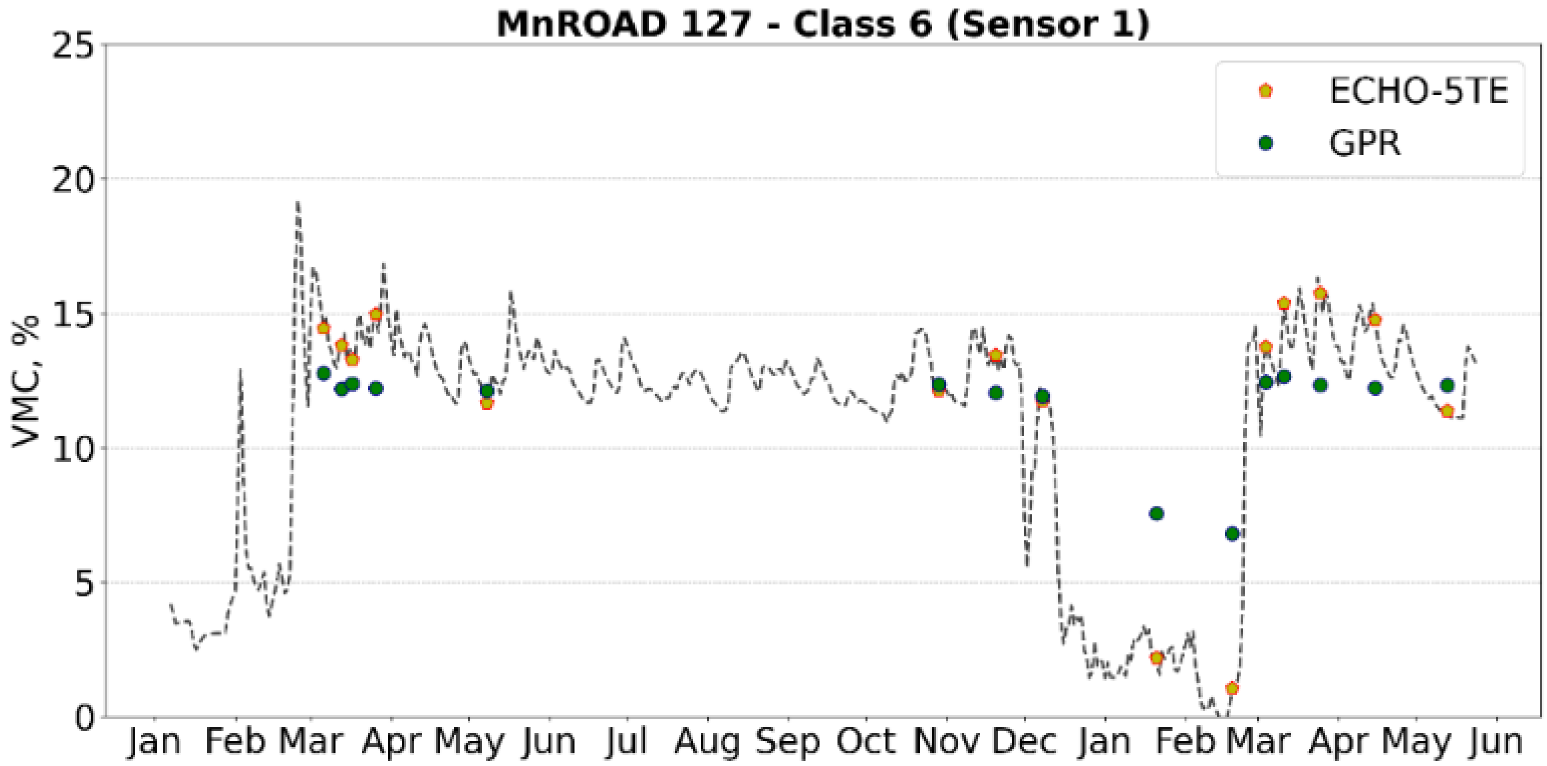
It has been well established that pavements are more vulnerable to damage when the water content in the unbound aggregate layers is high. High moisture content in the unbound aggregate base (UAB) leads to a considerable reduction in the pavement's bearing capacity (strength) and the formation of distresses such as stripping, raveling, crack-heaving, and permanent deformation (*1*). In regions with cold climate, such as Minnesota, where pavements are constructed in freeze-thaw environments, the unbound aggregate layers can be saturated during the first weeks of spring as a result of thaw conditions. Generally, thawing initiates in the upper lifts of a pavement system while the layers farthest away from the pavement surface are still in a frozen condition. As a result of the partial thawing, the water trapped in the upper lift of the pavement system may end up diminishing the bearing capacity of the structure and lead to premature failure (*2*). This undesirable outcome can be prevented or minimized in pavements with unbound aggregate designed to provide adequate drainage and to

[1]Office of Materials & Road Research, Minnesota Department of Transportation, Maplewood, MN

Corresponding Author:
Eyoab Zegeye-Teshale, eyoab.zegeye.teshale@state.mn.us

Using GPR to Monitor Moisture in Base Agg of In-Service Pavements

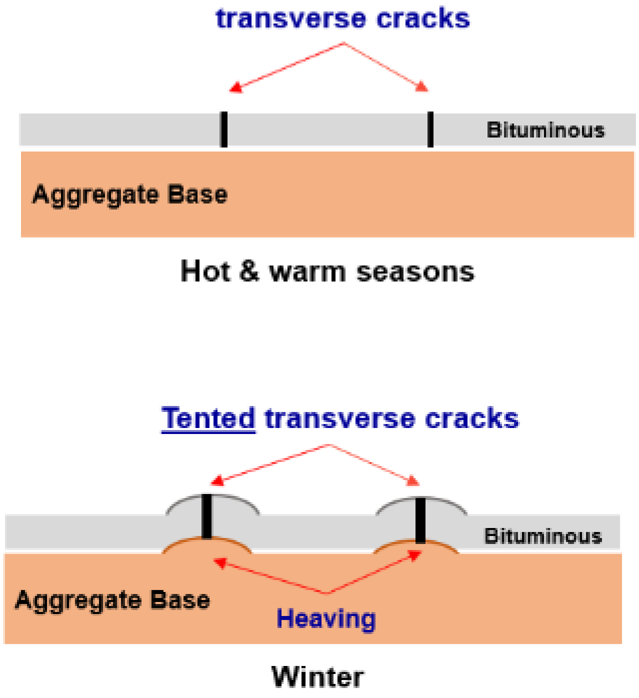
- Performed GPR surveys on several MN Road cells instrumented with moisture gauge
- Extracted moisture indicators from the GPR data
  - Found excellent match between GPR-based and in-place moisture readings
  - Found interesting insights on the effectiveness and limitations of GPR for investigating pavements with different drainage and moisture retaining capabilities

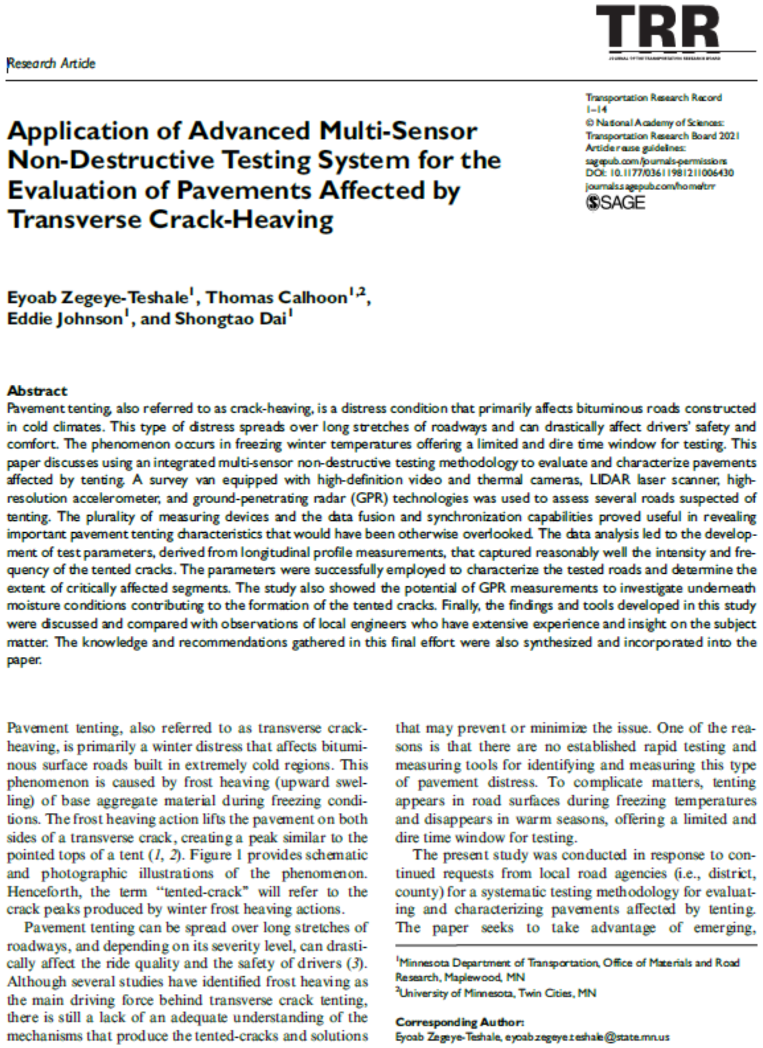


Evaluation of Pavements Affected by Pavement Tenting (Crack-Heaving): Integrated, Multi-Sensor Non-Destructive Testing

- Developed a systematic and rapid testing methodology for evaluating and characterizing pavements affected by tenting

Manual measurement of a tented crack





Research Article

Transportation Research Record
1–14

DOI: 10.1177/03611981211006430
journals.sagepub.com/home/trr
SAGE

Application of Advanced Multi-Sensor Non-Destructive Testing System for the Evaluation of Pavements Affected by Transverse Crack-Heaving

Eyoab Zegeye-Teshale[1], Thomas Calhoon[1,2], Eddie Johnson[1], and Shongtao Dai[1]

Abstract

Pavement tenting, also referred to as crack-heaving, is a distress condition that primarily affects bituminous roads constructed in cold climates. This type of distress spreads over long stretches of roadways and can drastically affect drivers' safety and comfort. The phenomenon occurs in freezing winter temperatures offering a limited and dire time window for testing. This paper discusses using an integrated multi-sensor non-destructive testing methodology to evaluate and characterize pavements affected by tenting. A survey van equipped with high-definition video and thermal cameras, LIDAR laser scanner, high-resolution accelerometer, and ground-penetrating radar (GPR) technologies was used to assess several roads suspected of tenting. The plurality of measuring devices and the data fusion and synchronization capabilities proved useful in revealing important pavement tenting characteristics that would have been otherwise overlooked. The data analysis led to the development of test parameters, derived from longitudinal profile measurements, that captured reasonably well the intensity and frequency of the tented cracks. The parameters were successfully employed to characterize the tested roads and determine the extent of critically affected segments. The study also showed the potential of GPR measurements to investigate underneath moisture conditions contributing to the formation of the tented cracks. Finally, the findings and tools developed in this study were discussed and compared with observations of local engineers who have extensive experience and insight on the subject matter. The knowledge and recommendations gathered in this final effort were also synthesized and incorporated into the paper.

Pavement tenting, also referred to as transverse crack-heaving, is primarily a winter distress that affects bituminous surface roads built in extremely cold regions. This phenomenon is caused by frost heaving (upward swelling) of base aggregate material during freezing conditions. The frost heaving action lifts the pavement on both sides of a transverse crack, creating a peak similar to the pointed tops of a tent (*1*, *2*). Figure 1 provides schematic and photographic illustrations of the phenomenon. Henceforth, the term "tented-crack" will refer to the crack peaks produced by winter frost heaving actions.

Pavement tenting can be spread over long stretches of roadways, and depending on its severity level, can drastically affect the ride quality and the safety of drivers (*3*). Although several studies have identified frost heaving as the main driving force behind transverse crack tenting, there is still a lack of an adequate understanding of the mechanisms that produce the tented-cracks and solutions that may prevent or minimize the issue. One of the reasons is that there are no established rapid testing and measuring tools for identifying and measuring this type of pavement distress. To complicate matters, tenting appears in road surfaces during freezing temperatures and disappears in warm seasons, offering a limited and dire time window for testing.

The present study was conducted in response to continued requests from local road agencies (i.e., district, county) for a systematic testing methodology for evaluating and characterizing pavements affected by tenting. The paper seeks to take advantage of emerging,

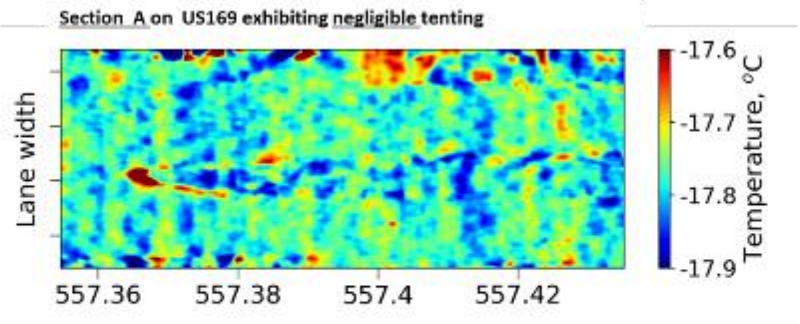
[1]Minnesota Department of Transportation, Office of Materials and Road Research, Maplewood, MN
[2]University of Minnesota, Twin Cities, MN

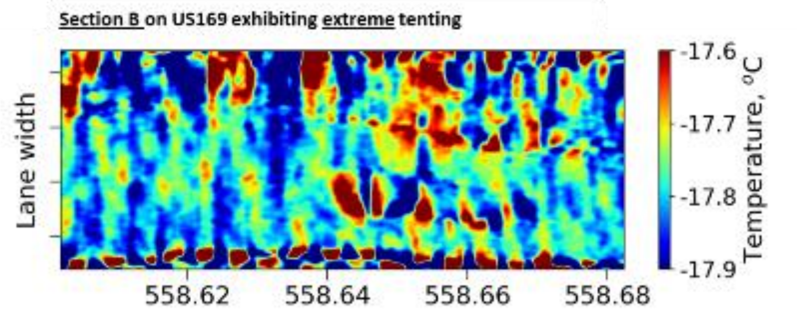
Corresponding Author:
Eyoab Zegeye-Teshale, eyoab.zegeye.teshale@state.mn.us

Evaluation of Pavements Affected by Pavement Tenting (Crack-Heaving): Integrated, Multi-Sensor Non-Destructive Testing

- Comparison of sections affected by tenting

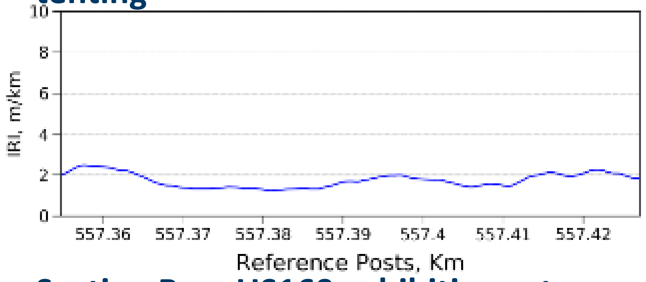
Infrared thermal camera



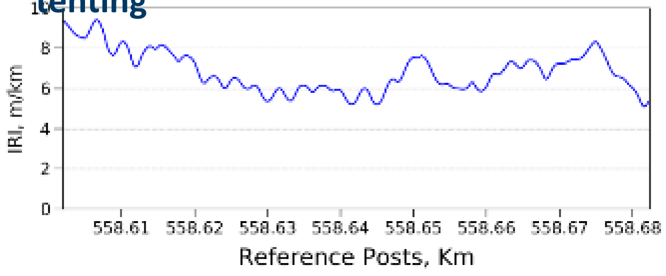


IRI smoothness

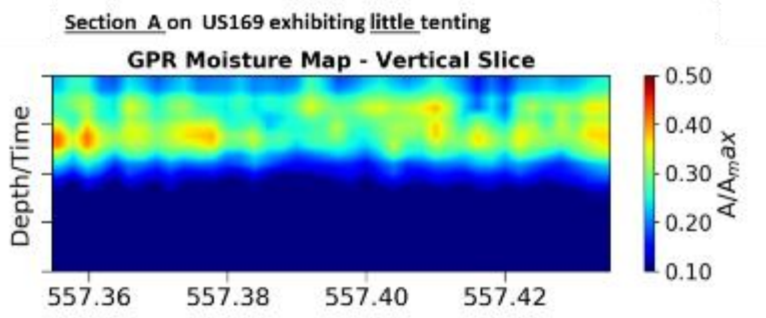
Section A on US169 exhibiting little tenting

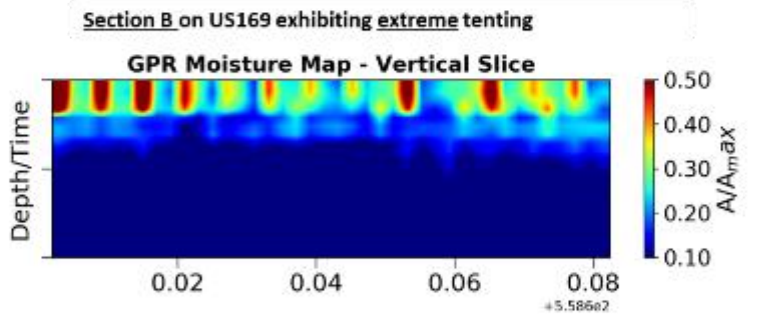


Section B on US169 exhibiting extreme tenting



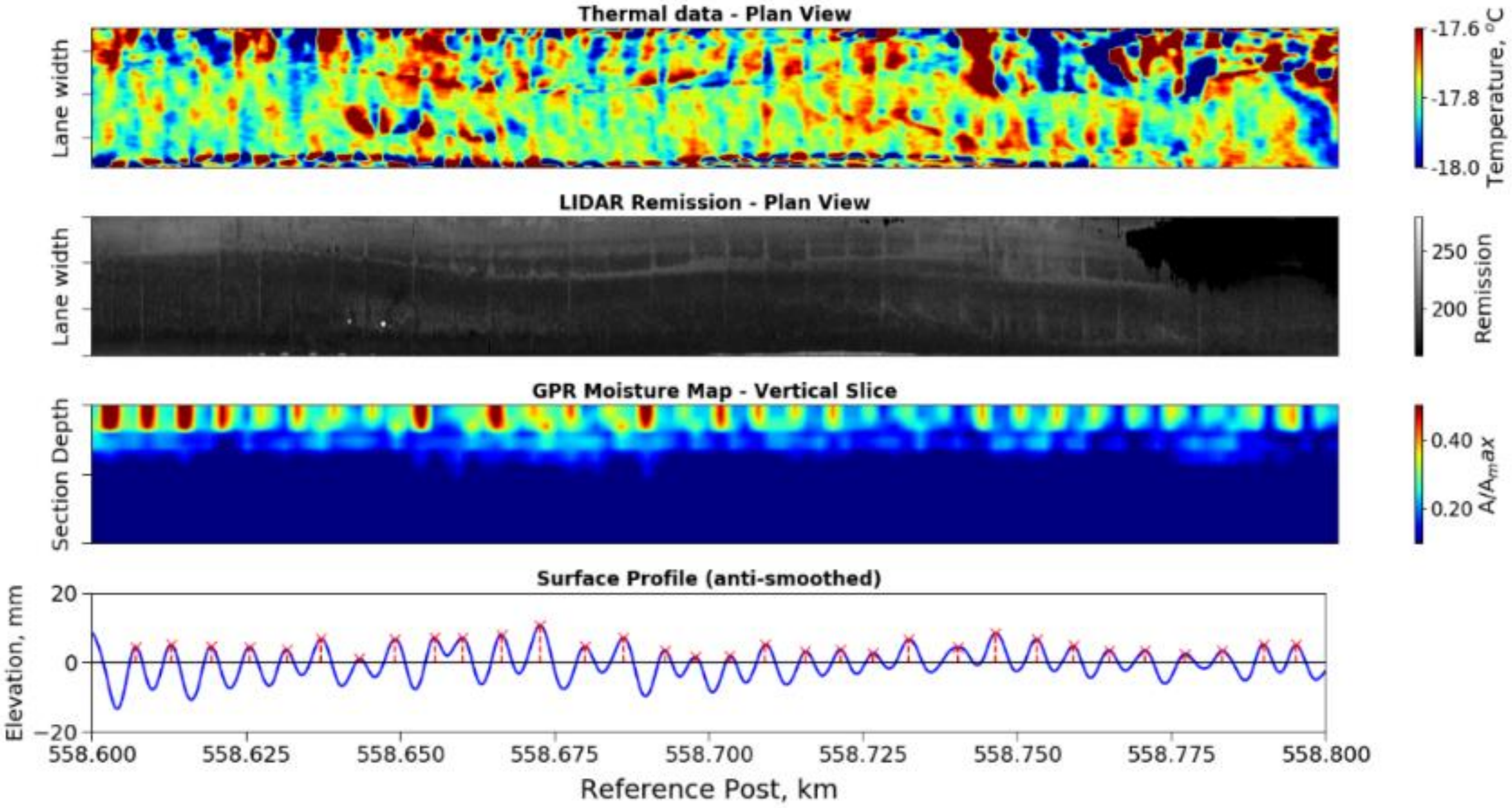
GPR – Moisture Damage Index (Roadscanner)





Evaluation of Pavements Affected by Pavement Tenting (Crack-Heaving): Integrated, Multi-Sensor Non-Destructive Testing

- Linked together surface and subsurface measurements provided a wider picture of the factors contributing to the formation of tented cracks



Discussion

- New sensor ideas?
- New monitoring ideas?