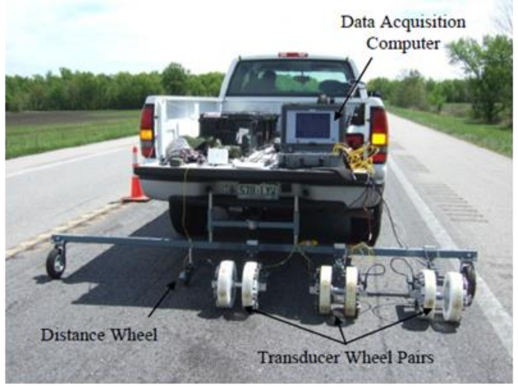




MnDOT Road Doctor Program:
Implementing Advanced Innovative Materials, Testing Procedures, and Pavement Evaluation Technologies – Minnesota Experience

Eyoab Zegeye, Ph.D., P.E.
eyoab.zegeye@state.mn.us
MnDOT Office of Materials and Road Research (OMRR)

DEPARTMENT OF
TRANSPORTATION

Outline

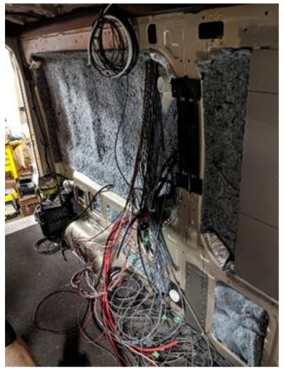
- Incorporating innovative testing technologies in MnDOT pavement evaluation procedures

MnDOT's Road Doctor Survey System

MnDOT Road Doctor Program

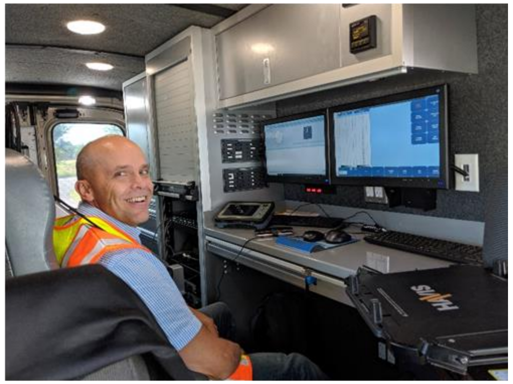
- ❑ Building of MnDOT Road Doctor Survey Van (RDSV)

How it started…..





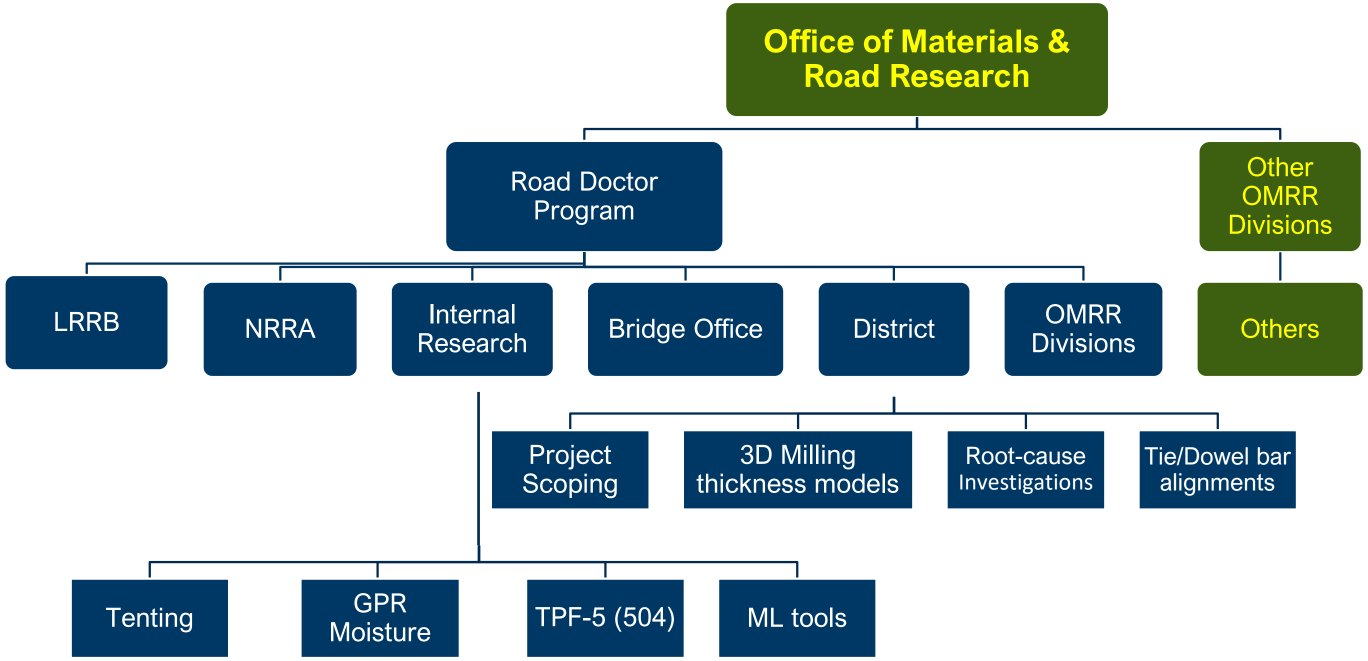

How it's going….

MnDOT RDSV Data Collection, Fusion & Linking

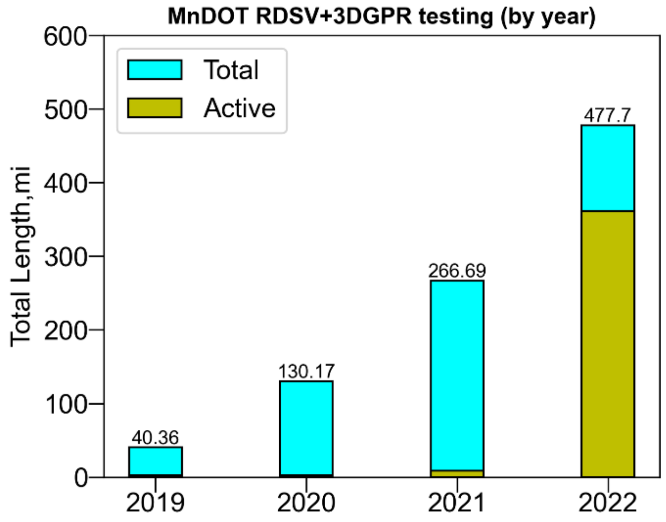
MnDOT Road Doctor Program

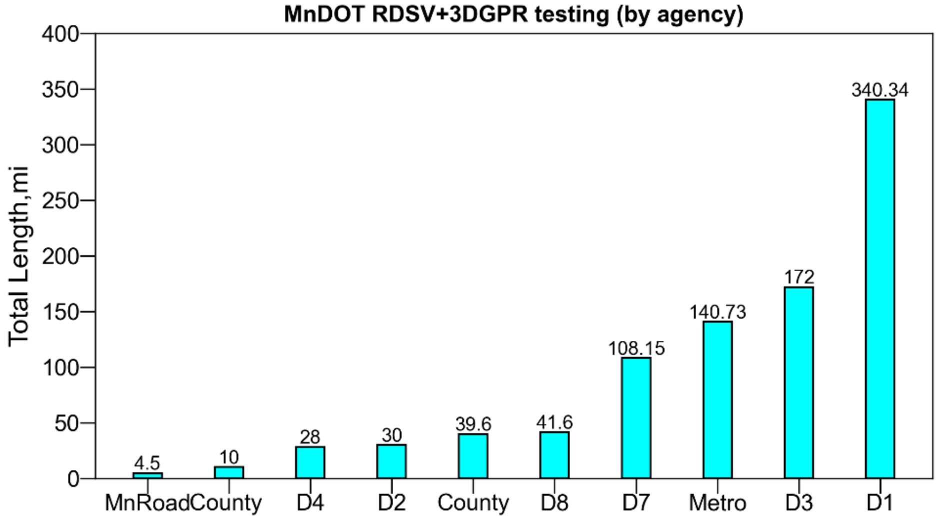
- Technology Implementation Research
  - Identify needs and provide solutions based on the use of RDSV

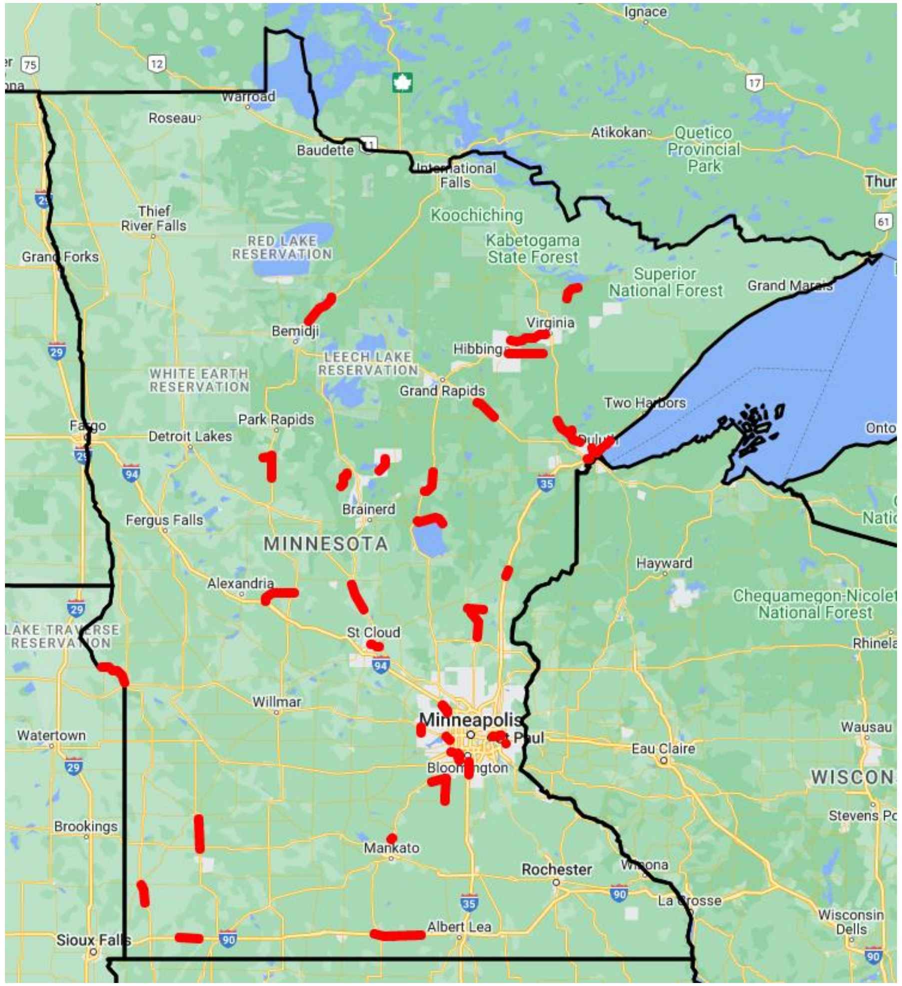


MnDOT Road Doctor Testing Activities Since 2019

- RDSV + 3D GPR Testing
  - Total scanned road: 1600 km
  - Number of projects: 48



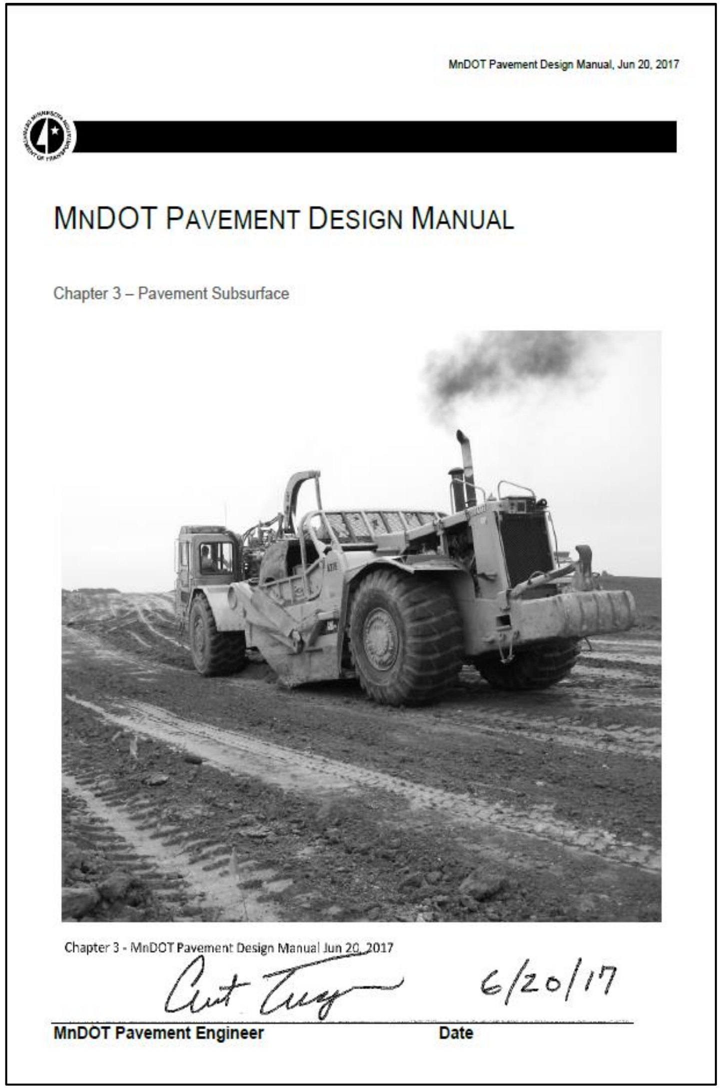




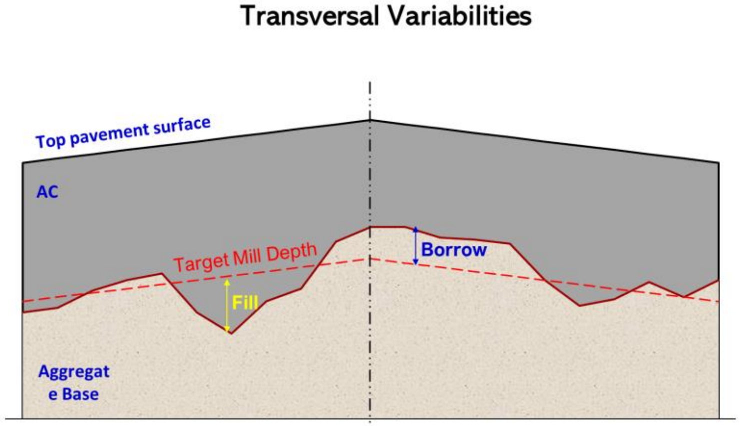
Implementation of 3D-GPR in MnDOT project scoping process

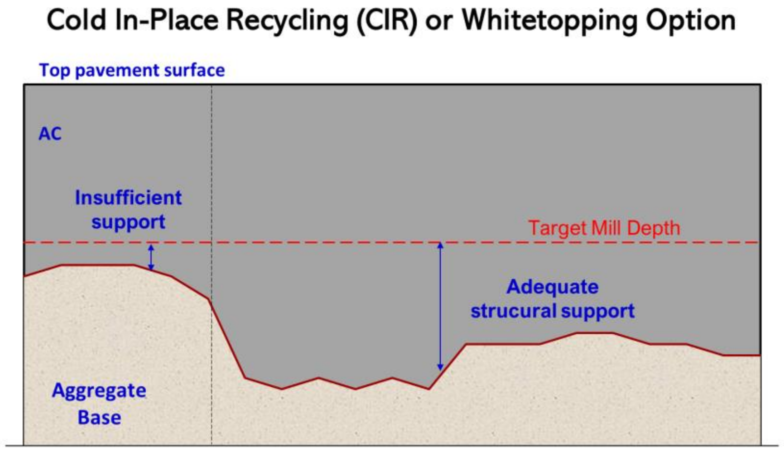
DX-Series Air Launched Antenna Array

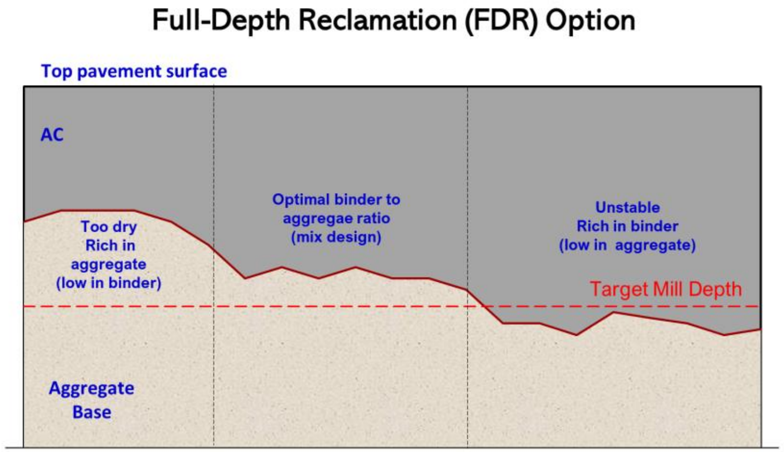
Incorporating 3D-GPR in MnDOT Project Scoping Process



- Selection of proper rehabilitation strategy based on engineering data
  - <u>Thickness variabilities</u>
    - Longitudinal
    - Transversal
  - <u>Structural adequacy</u>
    - Layer quality





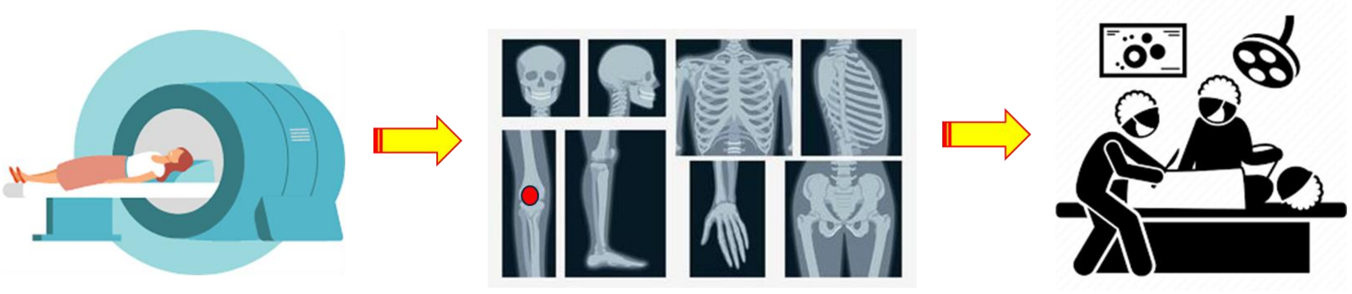


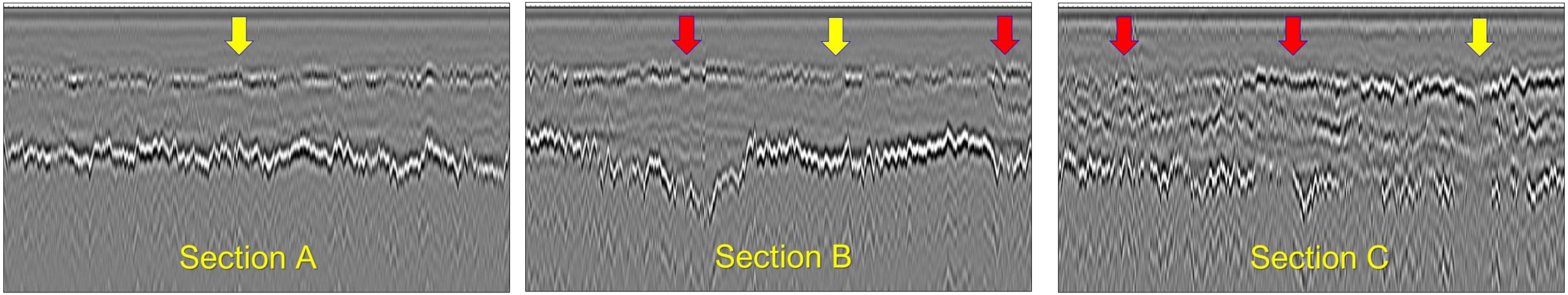
MnDOT Project Scoping Process

- Traditional project scoping tools
  - Coring/boring
  - FWD
  - Skid

- Important limitations
  - Discrete spots taken randomly (blindly)
    - Miss critical deficiencies
    - Over or underestimate the extent issues
  - Impacts negatively traffic flow
  - Safety and cost concerns

- GPR guided coring "Intelligent Coring" – Run GPR before coring your projects

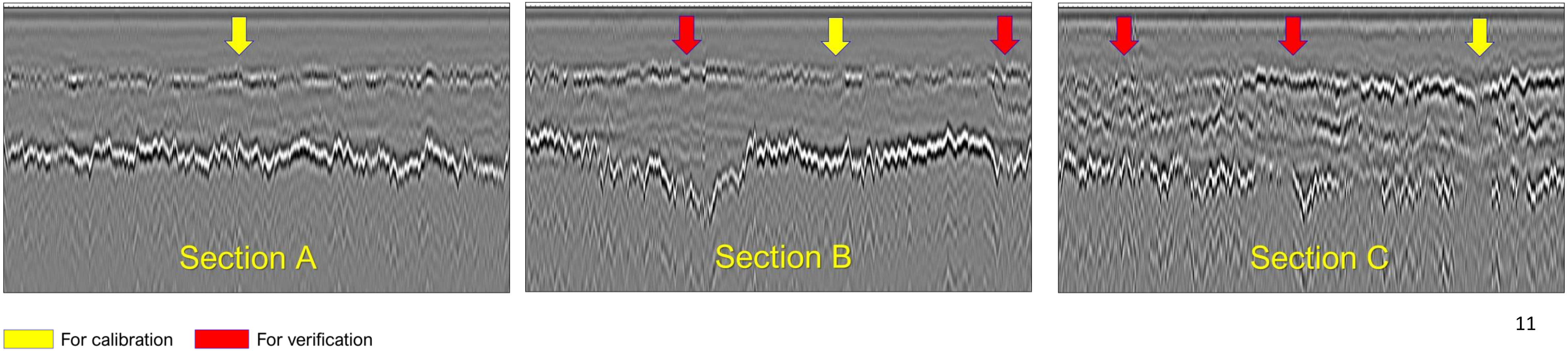




For calibration For verification

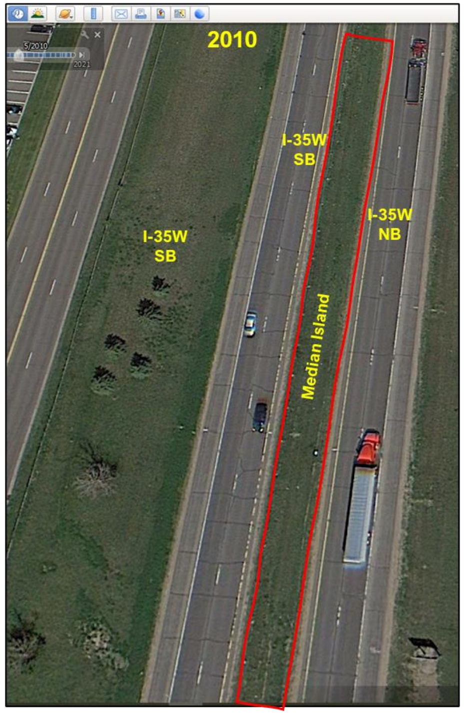
Intelligent Coring

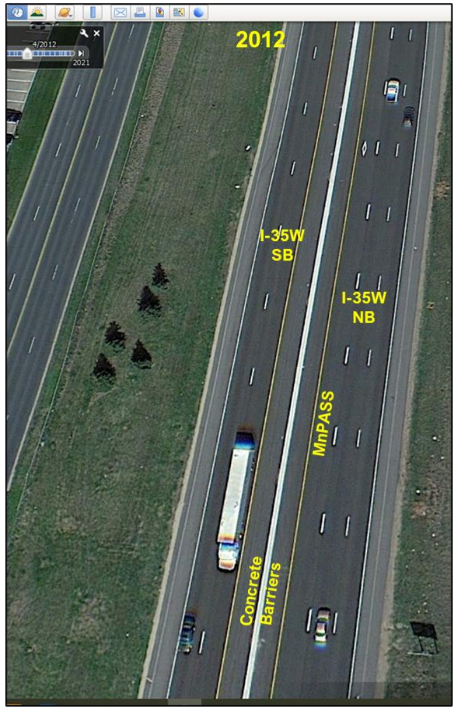
- GPR guided coring “Intelligent Coring” – Run GPR before coring your projects
  - Identify meaningful test section
  - Recommend proper probing depths
  - Reduce number of spot tests
  - Prioritize lanes / Reduce impact to traffic
  - Mitigate safety and cost concerns

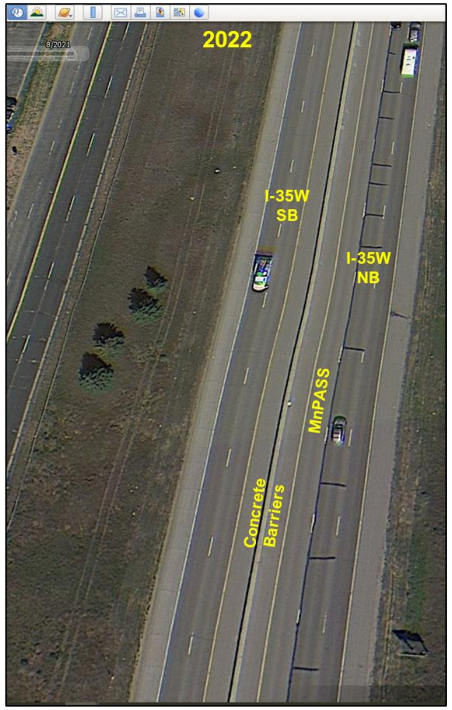


Intelligent Coring

- GPR guided coring "Intelligent Coring"
  - SP1981-140 I35 W (Metro) → Project History
    - First built in 1966 as PCC over aggregate base
    - 12 major interventions
      - Mill & Overlays
      - Replace median island with new inside lanes
      - Add MnPASS lane in the NB
      - Add an auxiliary lane in SB

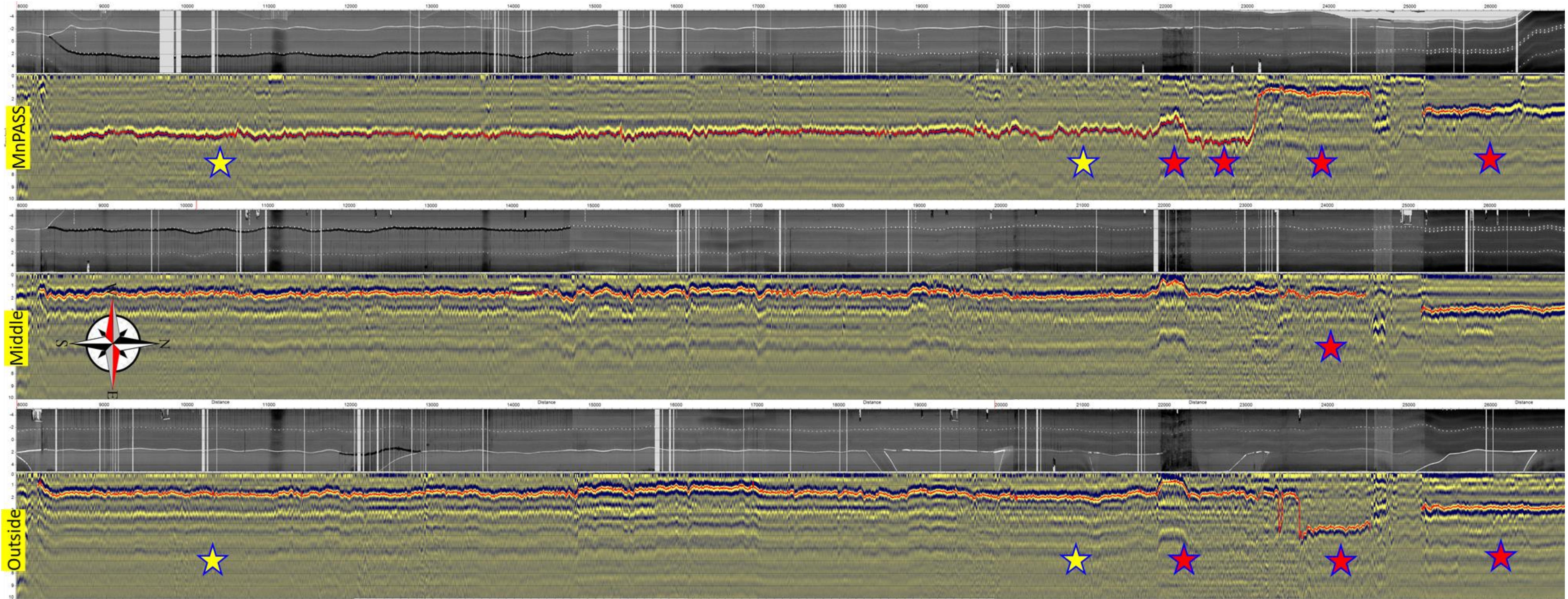






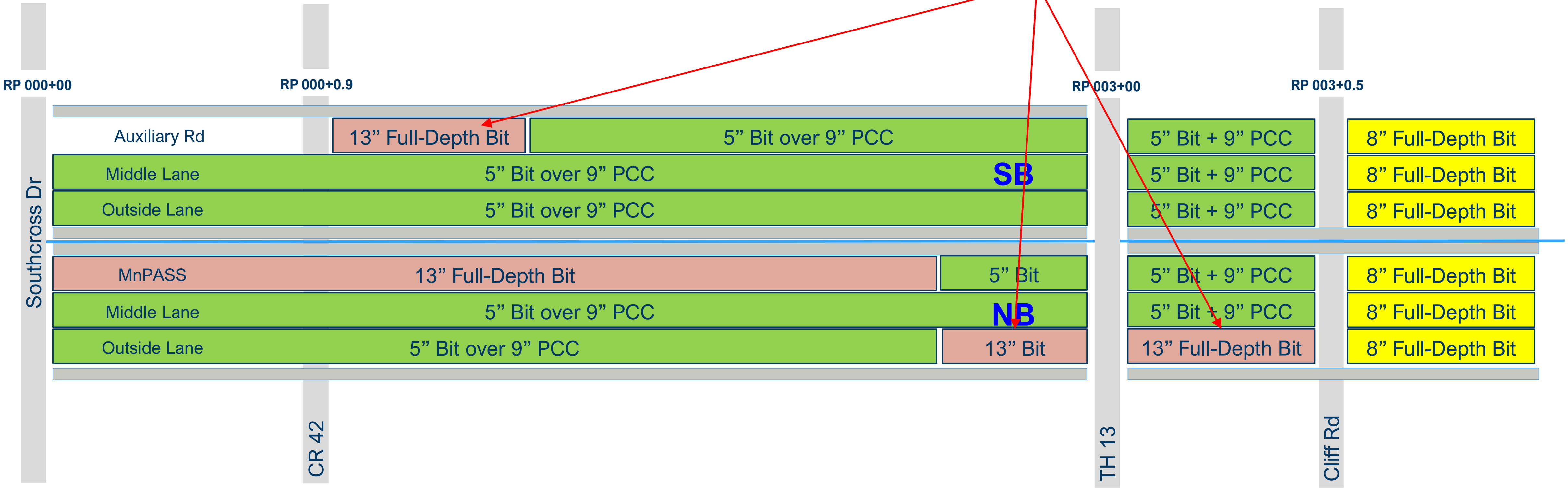
Intelligent Coring

- GPR guided coring “Intelligent Coring”
  - SP1981-140 I35 W (Metro) → Plan



Intelligent Coring

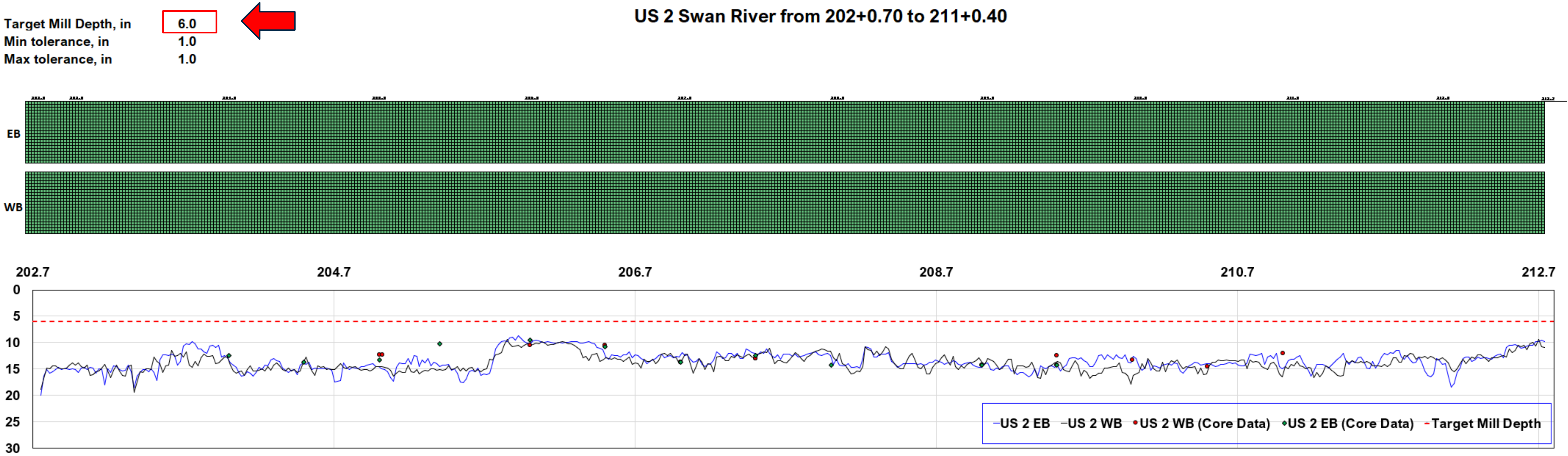
- GPR guided coring “Intelligent Coring”
  - SP1981-140 I35 W (Metro) → Results



3D-GPR Layer Thicknesses (Report Templates)

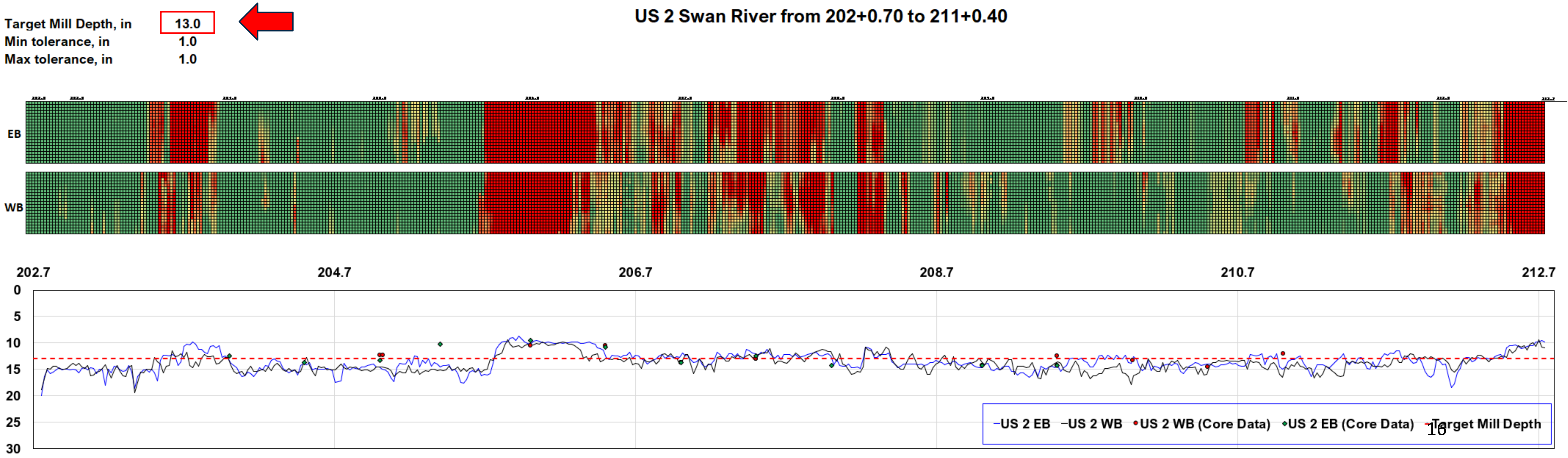
- ❑ Determination of layer thicknesses from 3D-GPR data
  - – SP3104-60 US2 (D1)→ Results
    - o Report in provided in simple excel spreadsheet
    - o Transversal and longitudinal thickness variabilities

Target Mill Depth, in	6.0
Min tolerance, in	1.0
Max tolerance, in	1.0



3D-GPR Layer Thicknesses (Report Templates)

- Determination of layer thicknesses from 3D-GPR data
  - SP3104-60 US2 (D1)→ Results
    - Report in provided in simple excel spreadsheet
    - Transversal and longitudinal thickness variabilities



Automated Detection of Stripping from 3D-GPR Data

DX-Series Air Launched Antenna Array

Stripping in Bituminous Pavements

- **Stripping**: Loss of bond between aggregate particles and binder leading to complete or partial failure of bituminous pavements
  - Water entrapped in the structure (interfaces)
  - Mixes susceptible to moisture damage
  - Freeze-thaw cycles

Stripping at the bottom layer of Full Depth AC pavement

New Asphalt Mixture

Old stripped Asphalt Mixture

Stripping in Bituminous Pavements

- **Stripping consequences:**
  - Surface tearing, potholes, etc.
  - Loss of bearing capacity
  - Increased maintenance costs
  - Premature failure
  - Offsets the effectiveness of repairs

Stripping in Bituminous Pavements

- **Stripping**: Is it still a serious pavement threat ?
  - Superpave & Performance-Based mixture selection tools
  - Antistripping additives
  - Polymer modified binders
  - Proved drainage practices

Toying with Superpave variables to use less binder

New AC placed on top of old moisture susceptible mixes

Use & re-use of high amounts of RAP, RAM, RAS etc.,

Cold recycled mixtures CIR, FDR etc.,

Composite pavements

Traditional Detection Methods

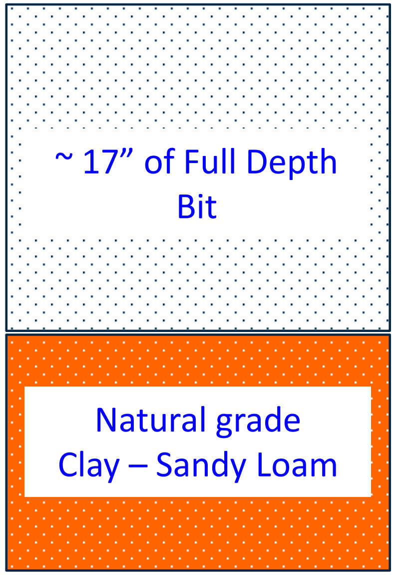
- Major challenges to <u>detecting,</u> <u>locating</u> and <u>quantifying</u> stripping in bituminous pavements
  - Stripping initiates at mid or bottom of pavement layers and propagates upward
  - Difficult to detect, locate, measure and quantify through traditional scoping tools
    - Discrete blind testing
    - Underestimating or missing out stripped sections
    - Overestimation/Generalization

Initiate at mid or bottom layer

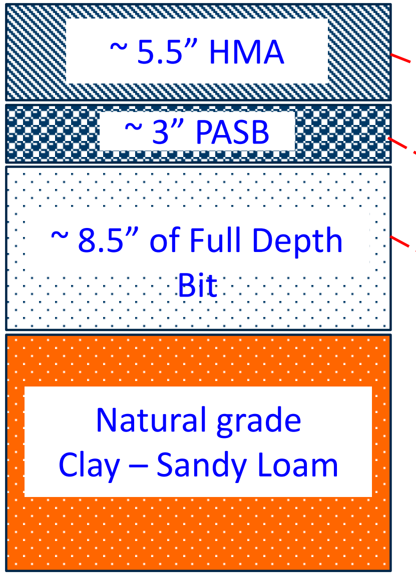
3D-GPR: Stripping and Structural Capacity

- Evaluation of road sections affected by stripping

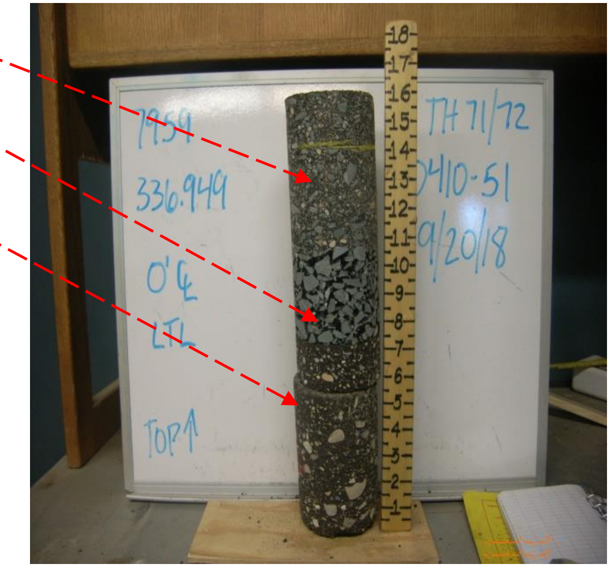
TH71 Bemidji, MN (2020)



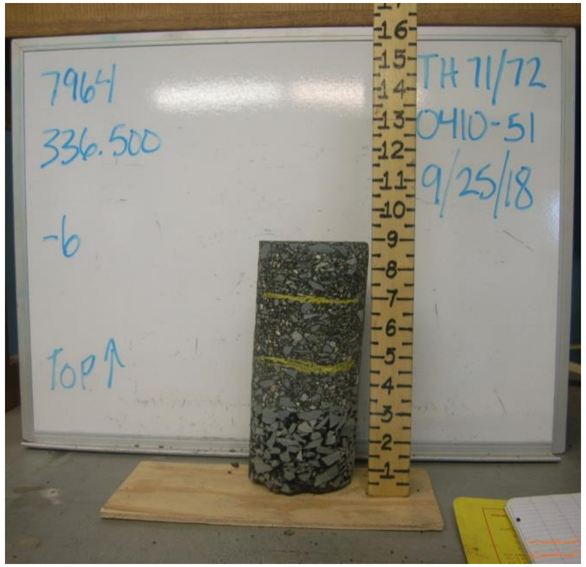
1977
New construction



2002
Mill & Overlay



Cores extracted from Turn Lanes (Corsie di svolta)



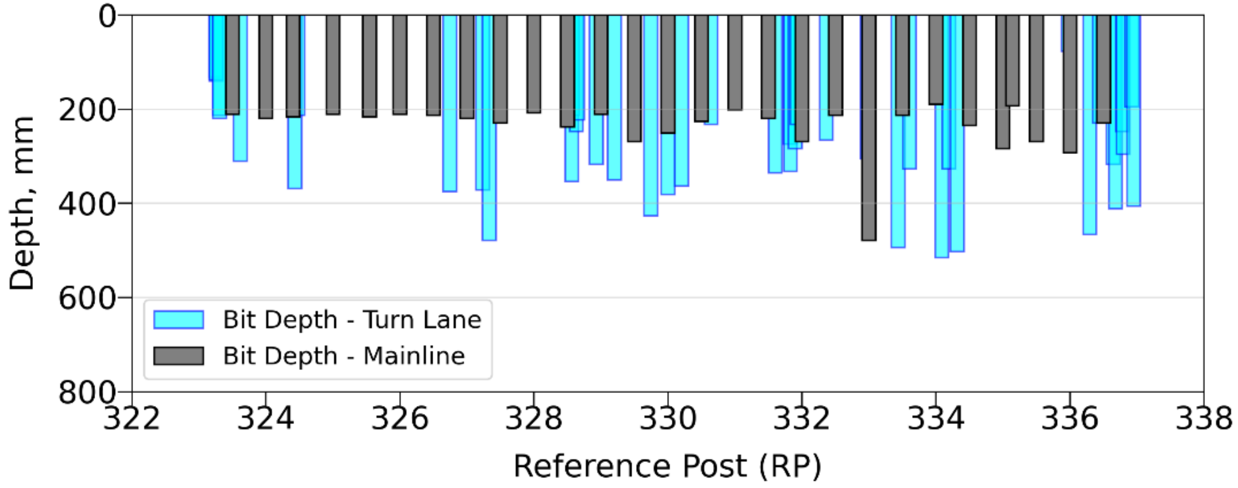
Cores extracted from Main Line (Corsia principale)

3D-GPR: Stripping and Structural Capacity

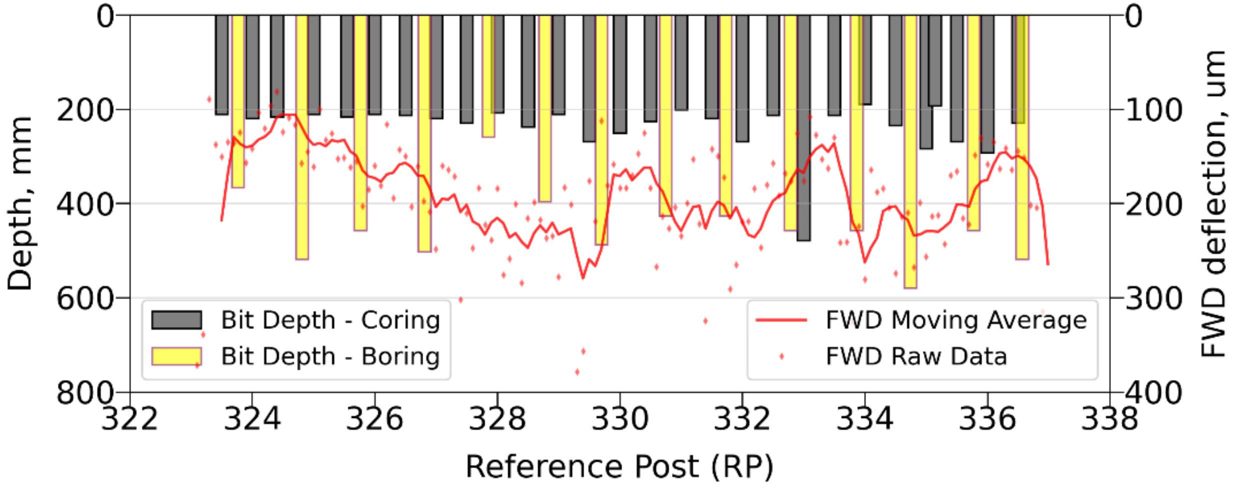
- ❑ Evaluation of road sections affected by stripping

TH71 Bemidji, MN (2020)

Depth of bituminous layer from coring data



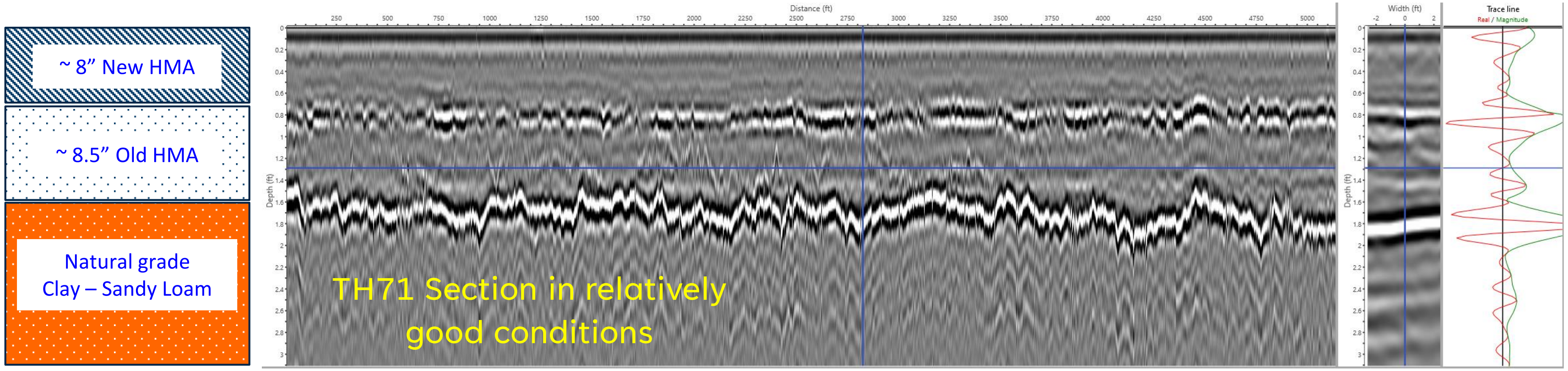
Depth of bituminous layer from coring and geo-probing data



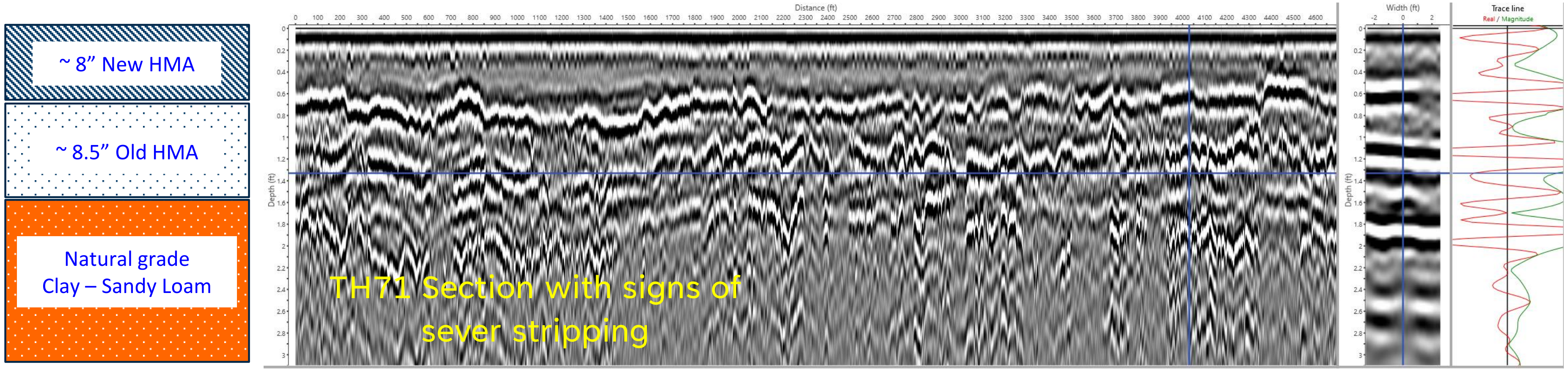
Bottom layer with strong evidence of stripping deterioration

3D-GPR: Stripping and Structural Capacity

- Comparison of sections
  - 1-mile length lots



- Clear image
- Strong & distinguishable layer interfaces
- Homogeneous layers

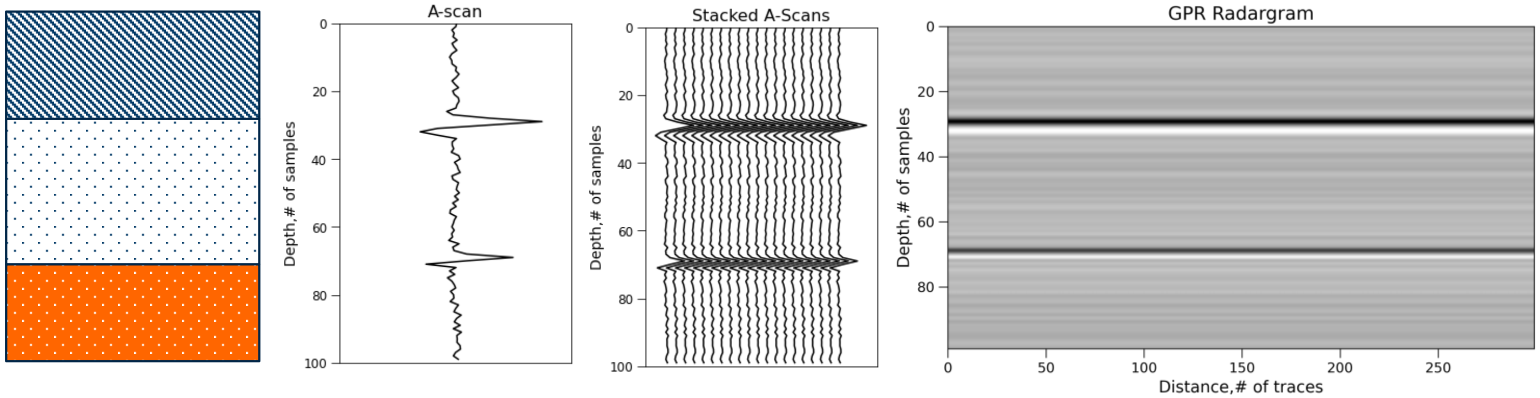


- Blurred image
- Relatively weak layer interface reflections
- Strong noise (non-interface) reflections

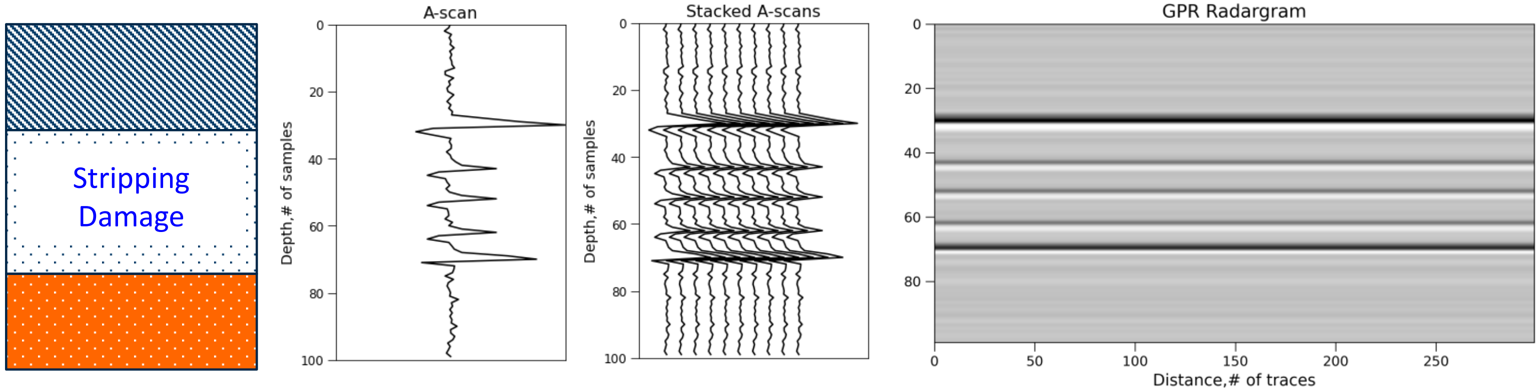
Promising Early Results

- Analysis of 3D-GPR signals in the time domain (MnDOT recent effort)
  - Idealized GPR reflections for a three-layer pavement structure

Homogeneous (good condition) layers

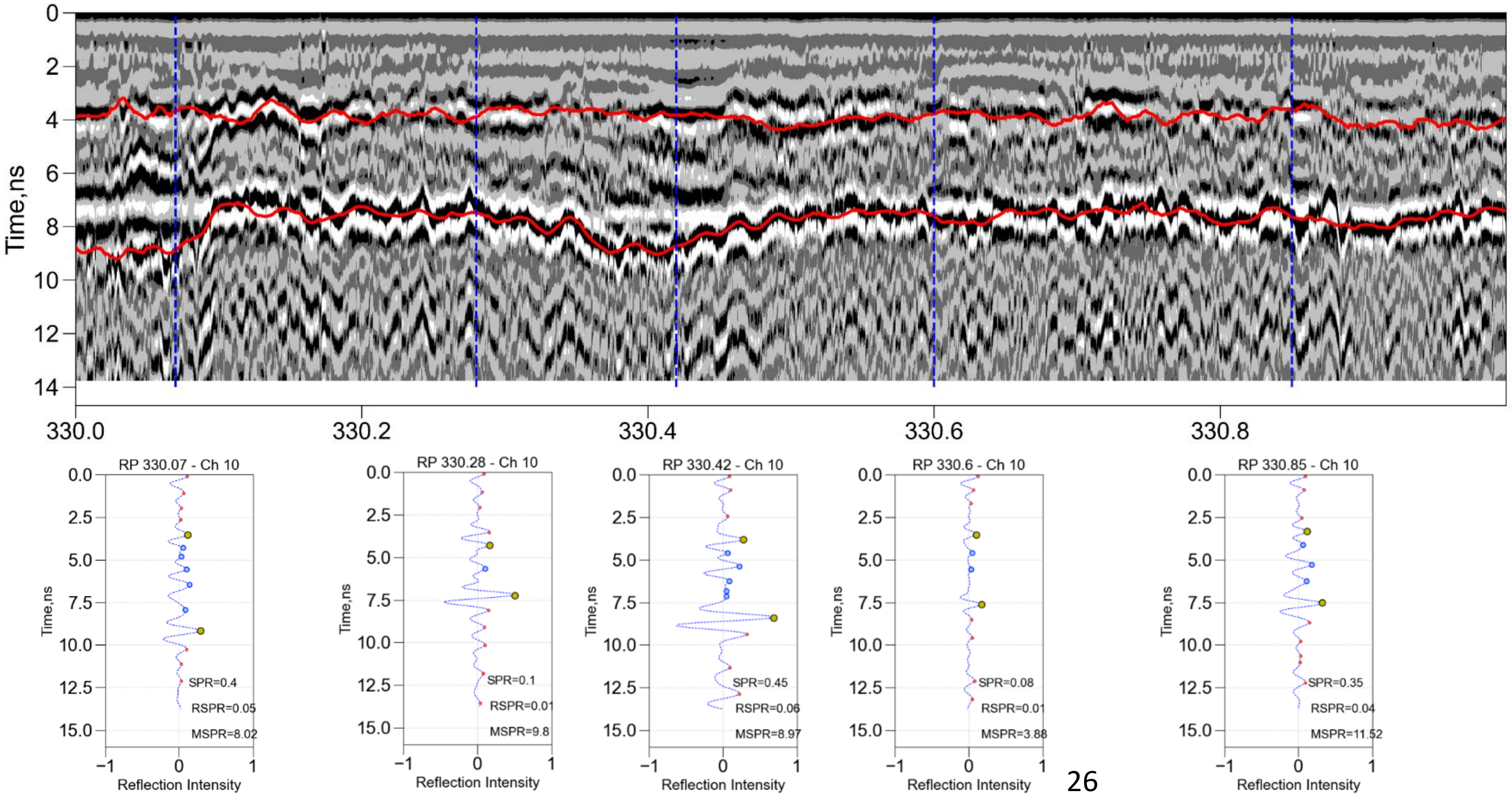


Mid layer showing sign of stripping damage



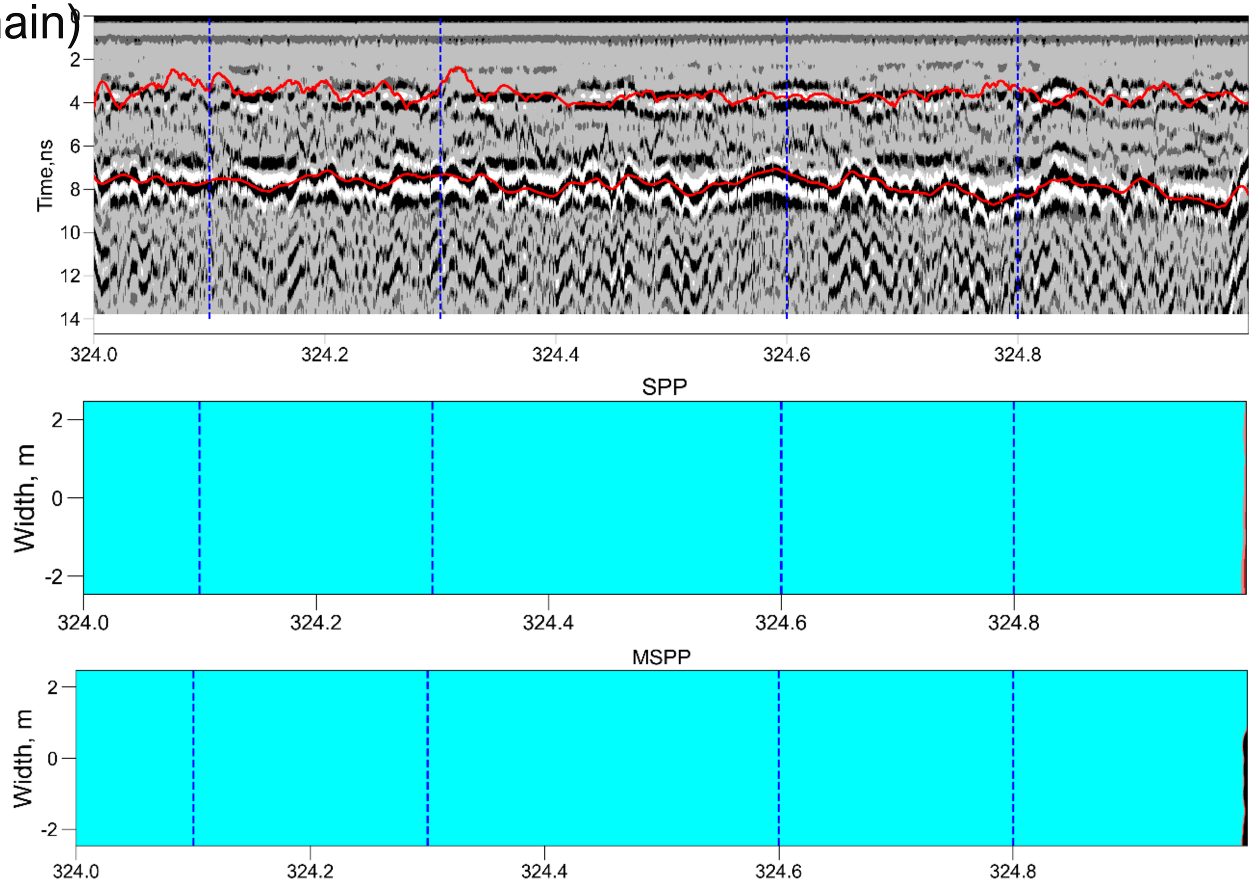
3D-GPR: Stripping and Structural Capacity

- Development an algorithm for automated processing of 3D-GPR data (Python Code)
  - Detect layer interfaces
  - Examine and analyze each A-scan (time-domain)
    - Picks peaks and troughs
    - Computes damage indexes
      - <u>Sum of Positive Reflections (SPR) in specified region</u>
      - Ratio of noise to interface reflections
      - Others



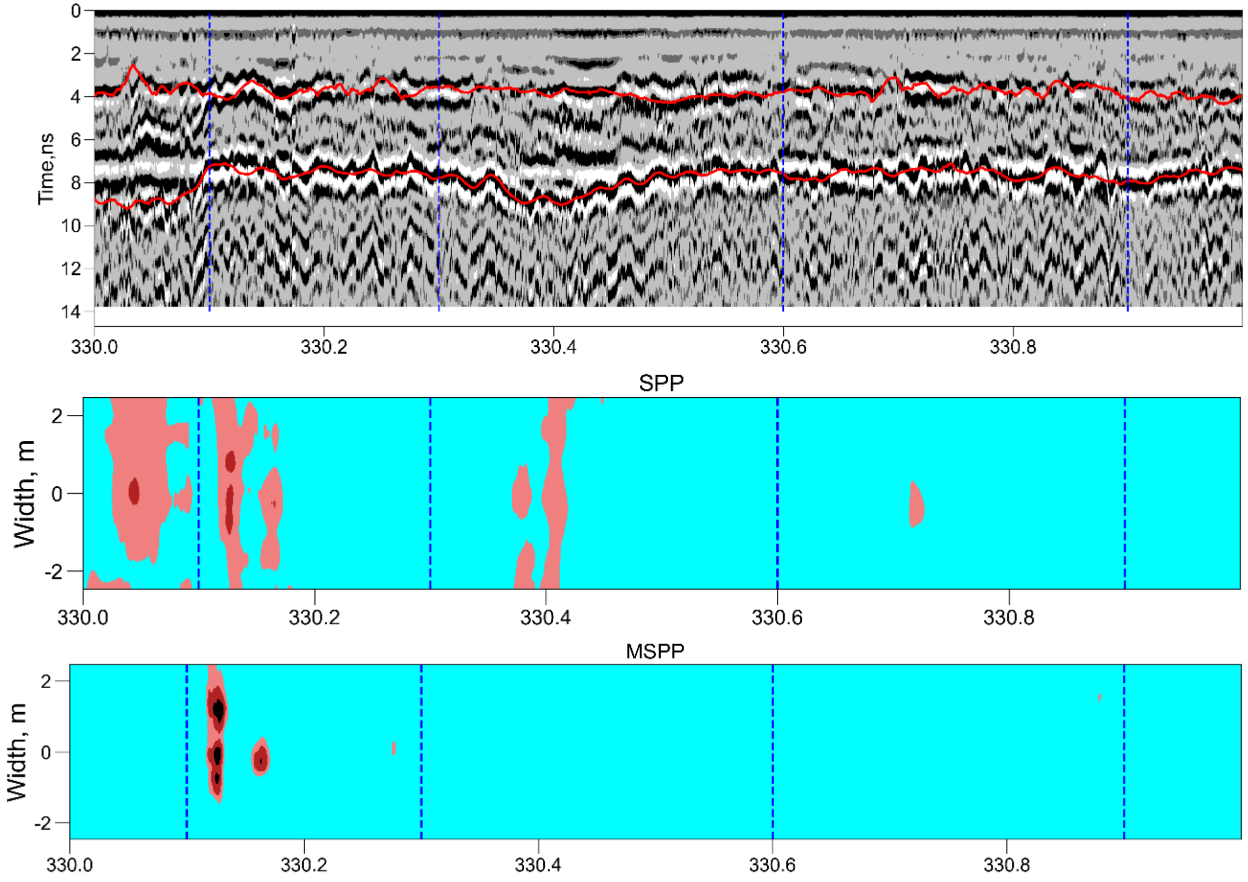
3D-GPR: Stripping and Structural Capacity

- Development an algorithm for automated processing of 3D-GPR data (Python Code)
  - Detect layer interfaces
  - Examine and analyze each A-scan (time-domain)
    - Picks peaks and troughs
    - Computes damage indexes
      - Sum of Positive Reflections (SPR) in specified region
      - Ratio of noise to interface reflections
    - Produces 2D-heatmaps
      - Determine a threshold
    - Computes average stripping index for a lot

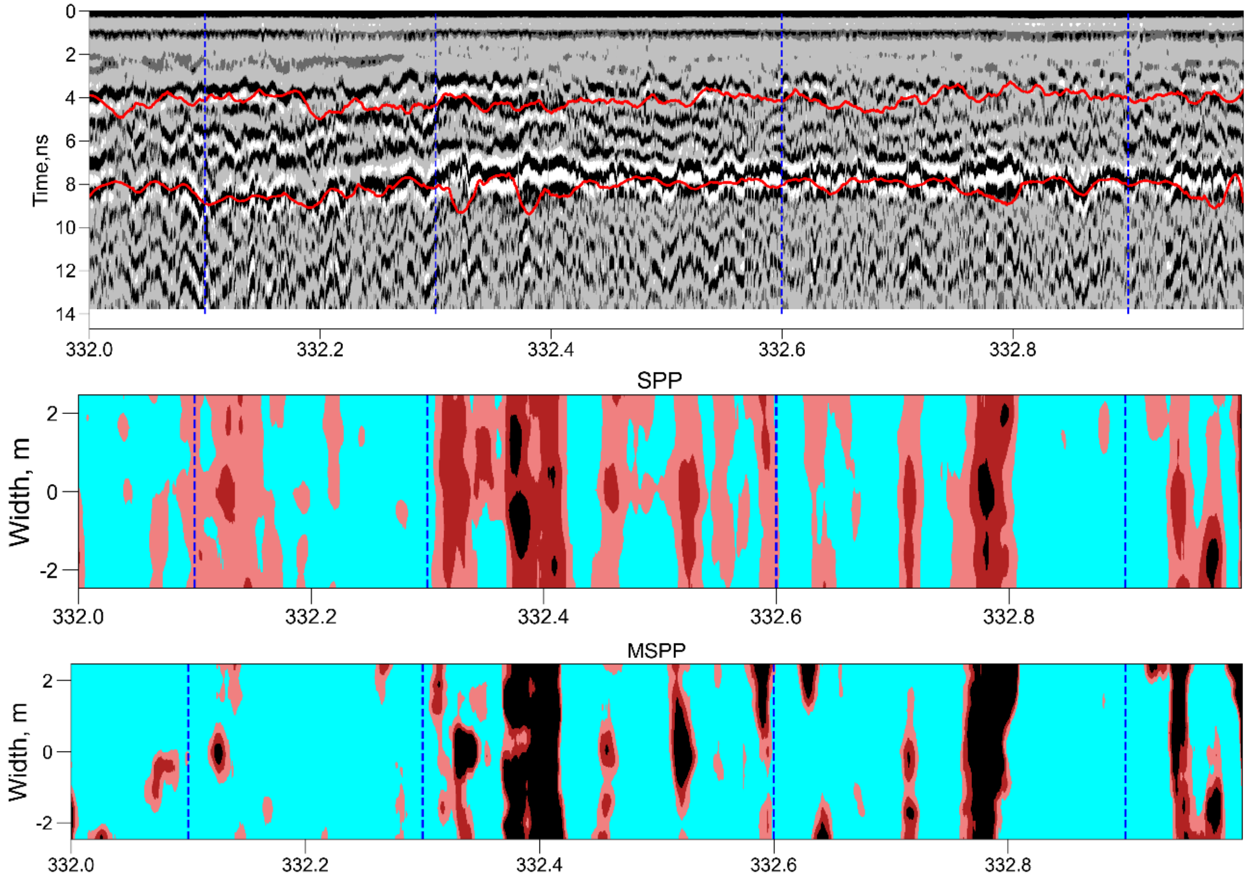


3D-GPR: Stripping and Structural Capacity

TH71 Section in relatively good conditions

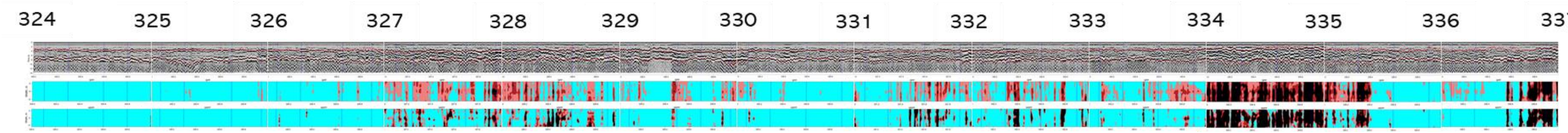


TH71 Section with more signs of stripping



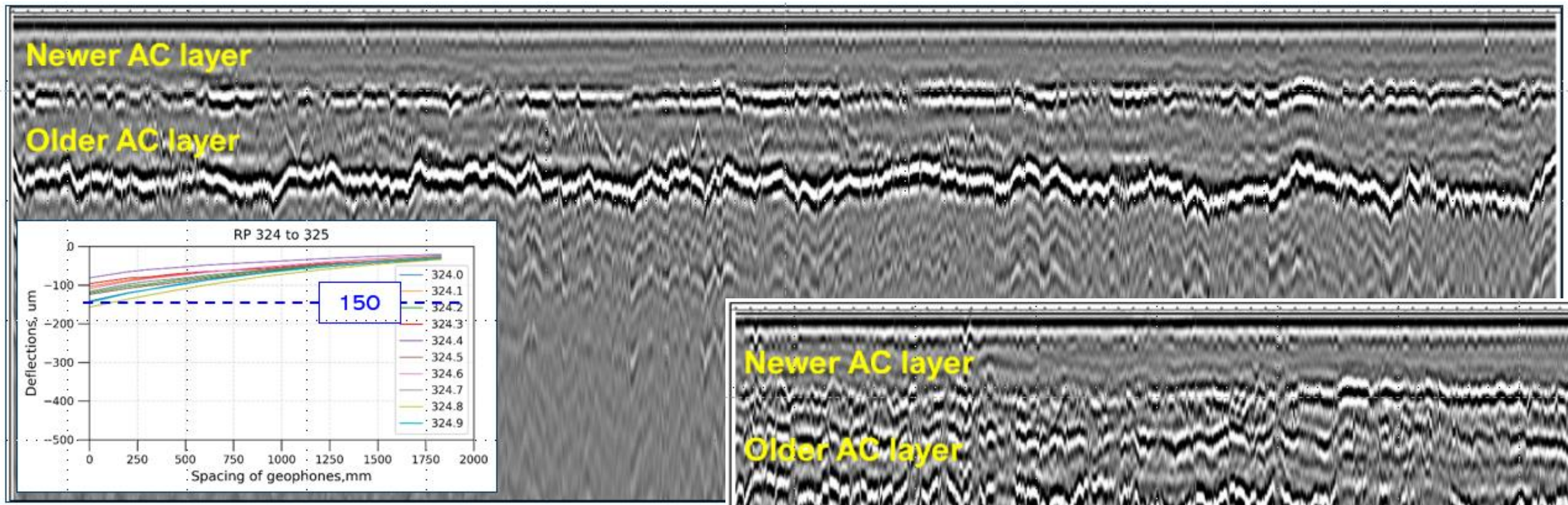
Promising Early Results

- Overall



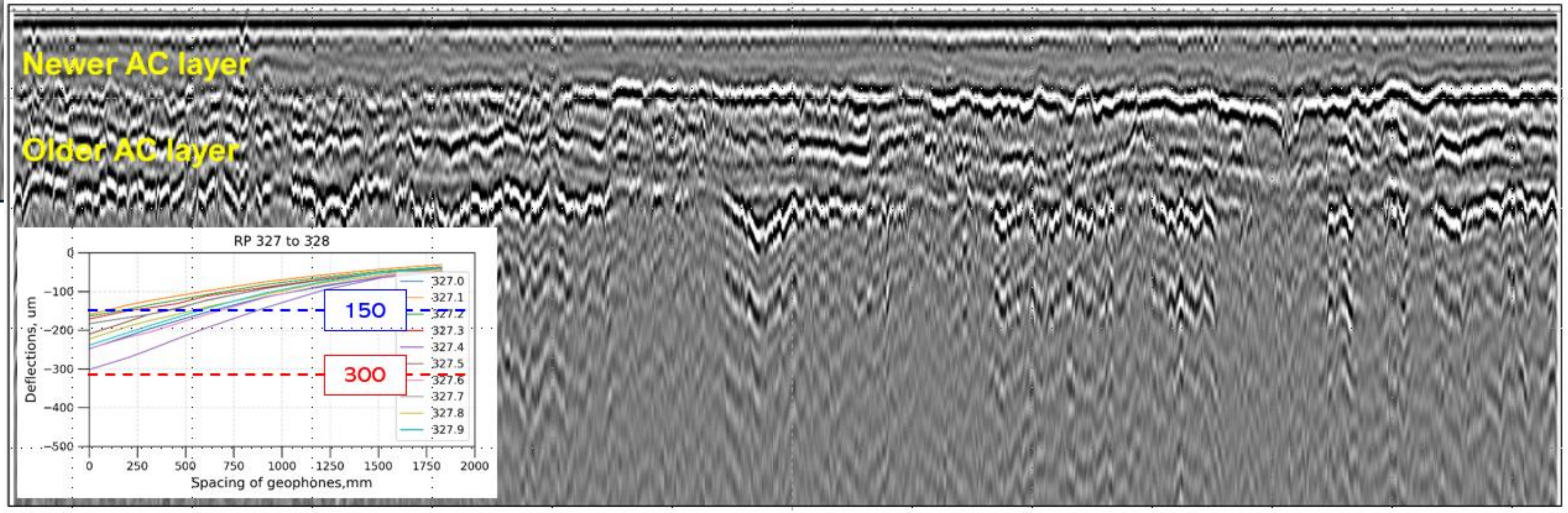
3D-GPR: Stripping and Structural Capacity

- Exploring relationship with Structural Capacity measurements
  - GPR Stripping Damage indexes vs. FWD basin deflections taken every 1/10 of mile



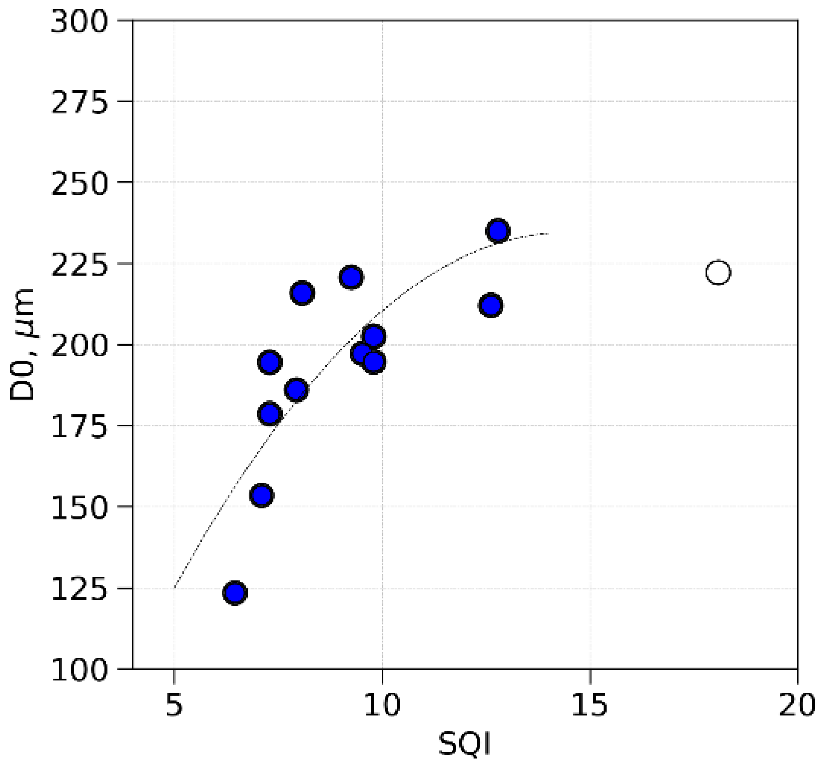
TH71 Section in relatively good conditions

TH71 Section with more signs of stripping



3D-GPR: Stripping and Structural Capacity

- Exploring relationship with Structural Capacity measurements
  - GPR Stripping Damage indexes vs. FWD basin deflections taken every 1/10 of mile
    - Very promising relationship between GPR Damage index (SPR) and FWD center plate deflection (D0)
    - Increasing stripping damage → higher deflection (lower bearing capacity)



TPF-5 (504): Continuous Stripping Assessment Through Non-Destructive Testing

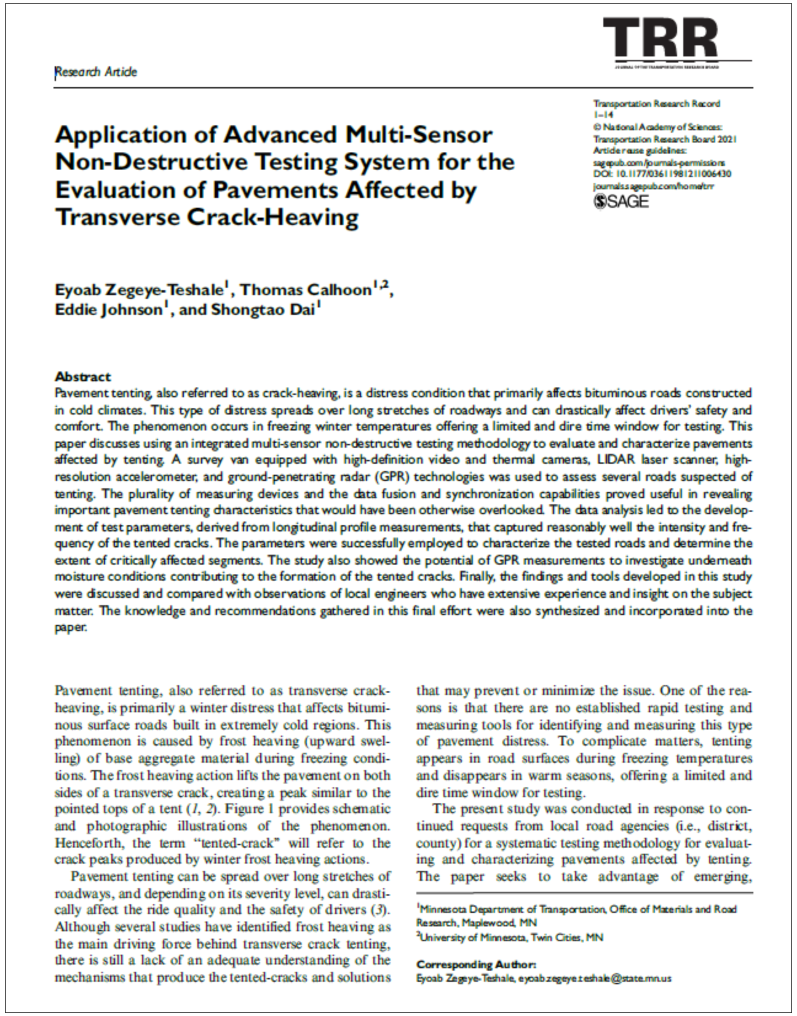
- Active – Starting in January 2023
  - Participating agencies : MN, IL, MO, TN, MS, TX , FHWA
    - Principal Investigator: Eyoab Zegeye (MnDOT)
  - Pending: WI,GE, KS
  - Committed fund $ 800,000

TPF-5 (504) Objectives

- Task 1 - Finalizing the Scope of work
- Task 2 - Survey & Literature Review
- Task 3 – stripping signature database
  - Examination of existing Data
  - Laboratory Experiments
  - Numerical Simulation
- Task 4 – MnROAD Stripped sections
  - Construction plan
  - Construction
  - Testing
- Task 5- Software Development
  - Development of algorithms
  - Verification & validation
  - Software package
- Task 6 – Data collection on state roads
  - Continuous testing
  - NDE Spot test
  - Coring/boring
- Task 7 – Data analysis & report
  - Review task deliverables
  - Analysis of collected data
  - Evaluate effectiveness
  - Improvements need & fix
- Task 8 – AASHTO Draft & testing procedure
  - AASHTO Draft
  - Template Implementation Plan
  - Precision/accuracy guidelines
- Task 9 – Training & Tec. Assistance
- Task 10 – Support & communication

Investigation of Roads Affected by Tenting

Evaluation of Pavement Affected by Transverse Crack-Heaving Using the RDSV system



Research Article

Transportation Research Record
1–14

Article reuse guidelines:
sagepub.com/journals-permissions
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.

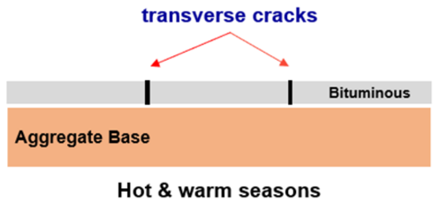
Pavement tenting can be spread over long stretches of roadways, and depending on its severity level, can drastically affect the ride quality and the safety of drivers (*3*). Although several studies have identified frost heaving as the main driving force behind transverse crack tenting, there is still 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.

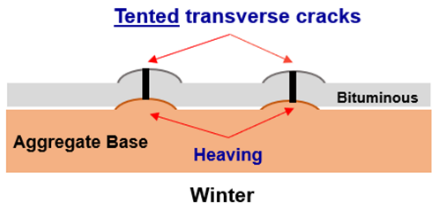
The present study was conducted in response to continued requests from local road agencies (i.e., district, county) for a systematic testing methodology for evaluating and characterizing pavements affected by tenting. The paper seeks to take advantage of emerging,

[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

Investigation of Roads Affected by Tenting





Manual measurement of a tented crack

❑ Causes and contributing factors

- Transverse cracks, moisture, freeze-thaw cycles
- Frost-susceptible aggregates, poor drainage, salt contamination, cement-treated aggregates, rubblizzed concrete

❑ Failure Mechanism

- Frost heaving (upward swelling) in the base aggregate layer

❑ Major Impacts

- Ride, safety and comfort of drivers
- Most visible & complained distress

❑ Key Challenge

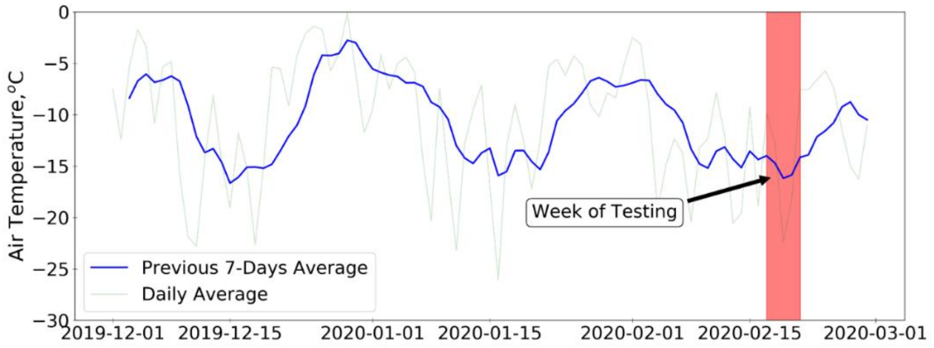
- Manual and visual characterization inadequate
- Lack of a testing methodology for rapid detection, localization and rating

Investigation of Roads Affected by Tenting

- Use of RDSV system for investigating roads affected by crack-heaving

Roadway	Direction	RP (start)	RP (end)	Miles
US-53	I	25+00.8	40+00.0	15
US-2	I	244+00.8	259+00.5	12
MN-194	I	13+60.0	16+00.0	2
US-169	I	346+00.9	362+00.1	16
US-169	D	349+00.5	362+00.1	16
MN-73	Urban	111+00.0	116+00.0	12
MN-37	Urban	1+00.2	20+00.3	20

- Targeted 6 roads with different severity levels
- Total length of survey ~ 100 miles (160 Km)
- Testing on the coldest week of the year ~ - 5 F (- 20 C)

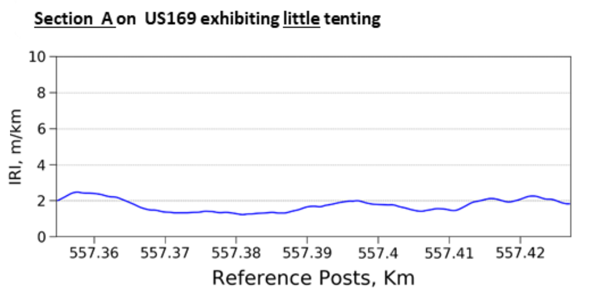


Investigation of Roads Affected by Tenting

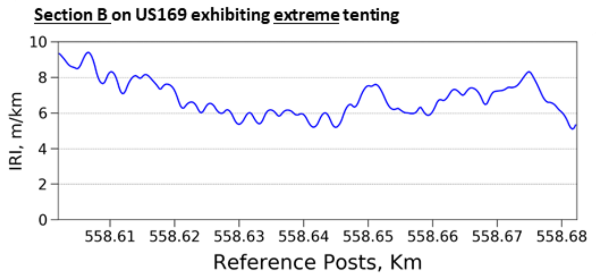
- Key findings

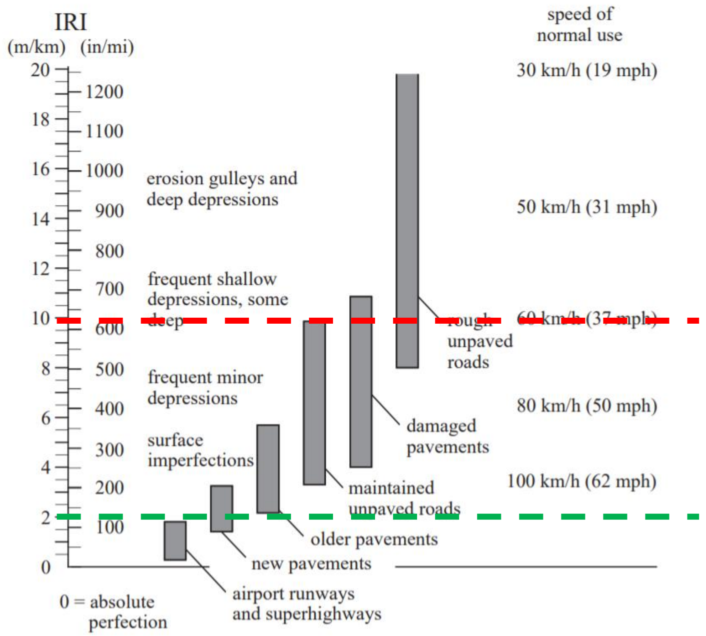
Ride Quality

OK Section



Poor Section





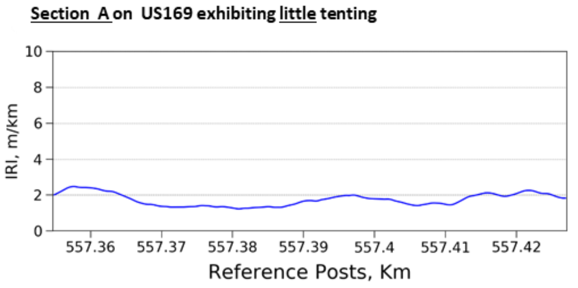
2D- Accelerometer

Investigation of Roads Affected by Tenting

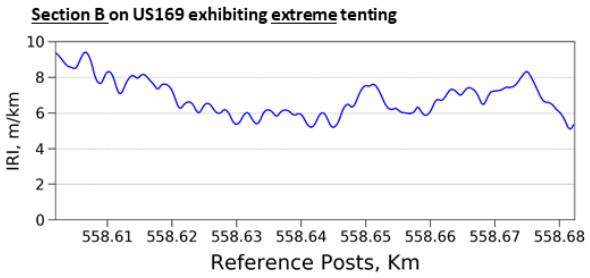
❑ Key findings

Ride Quality

OK Section

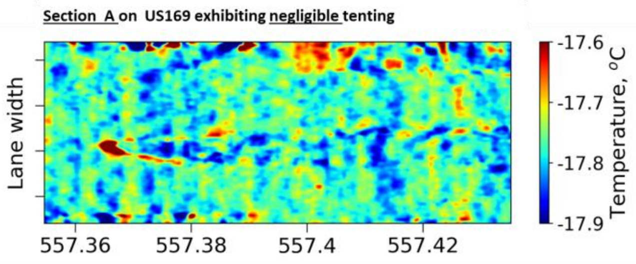


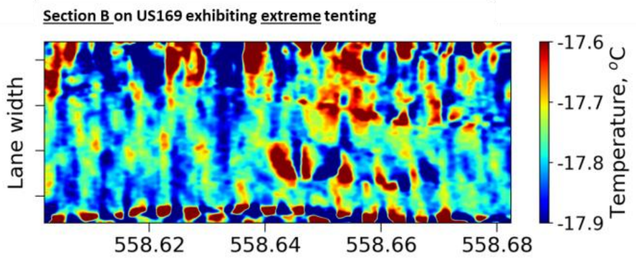
Poor Section



2D- Accelerometer

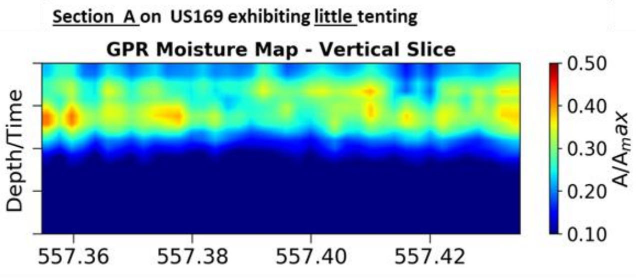
Surface Temperature

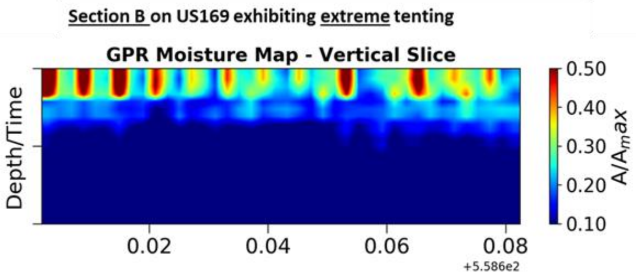




Thermal Camera

GPR- Road Doctor Software Moisture Damage Index



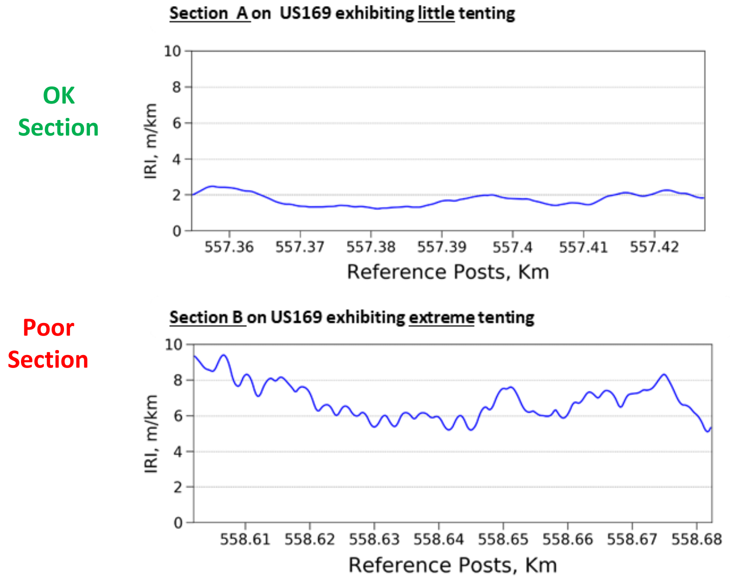


Ground-coupled 400 MHz

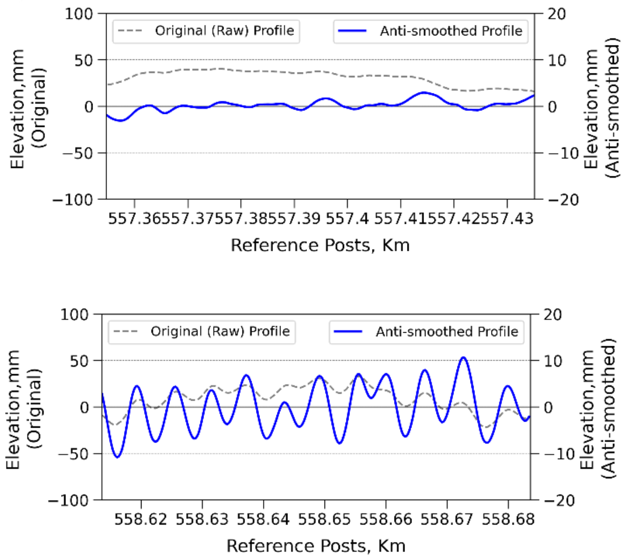
Investigation of Roads Affected by Tenting

- Key findings
  - Further analysis of longitudinal surface profile measurements
    - Long-wavelengths (>10 ft) → Issues in the foundation layers (i.e., differential heaving)
    - Short-wavelength (<10ft) → surface distresses and vehicle vibrations
      - Use anti-smoothing techniques to reveal the short-wavelength fluctuations

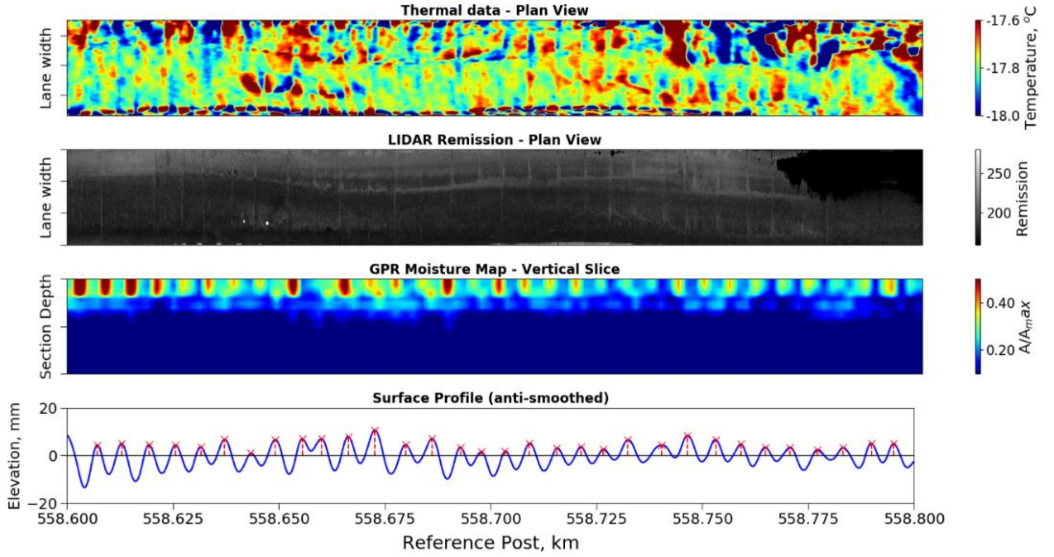
Ride Quality



Profile Elevation

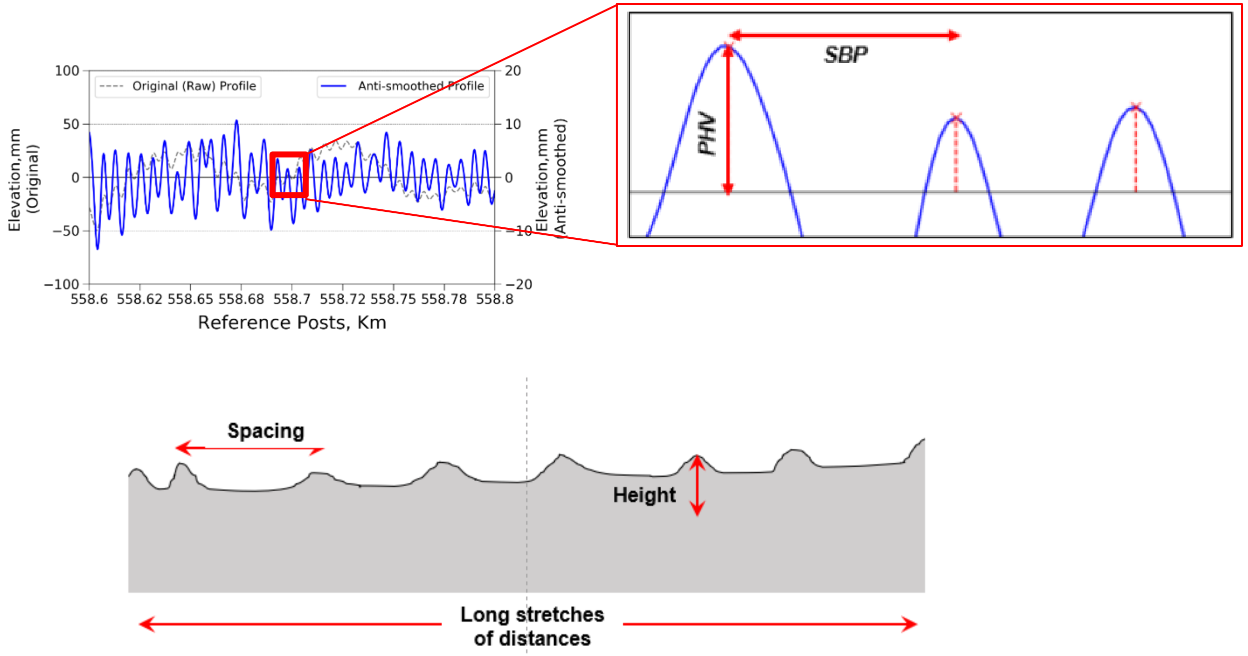


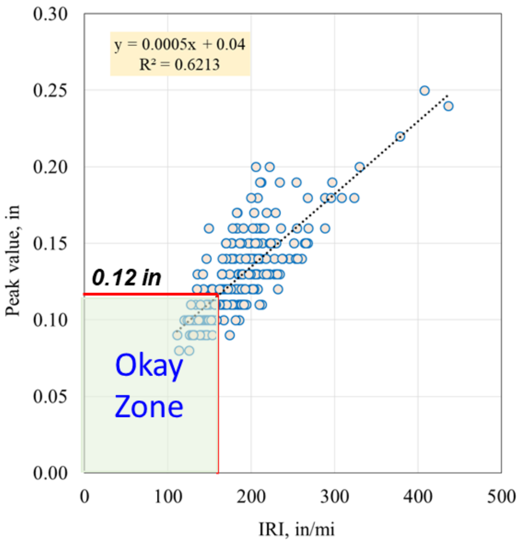
Data Fusion and Linking

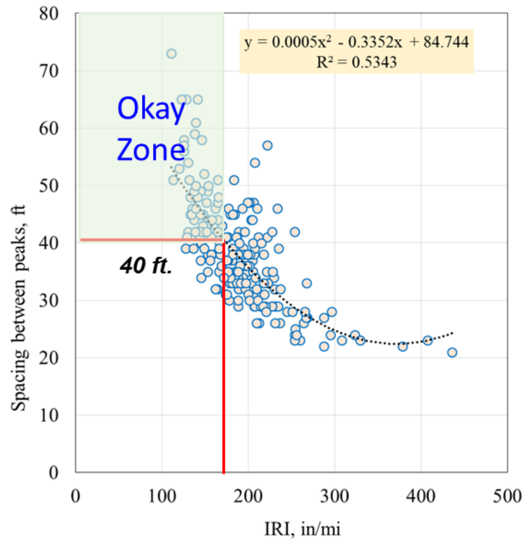


Investigation of Roads Affected by Tenting

- Key findings
  - Automated detection and rating of peaks
    - Peak Height Value (PHV)
    - Spacing Between Peaks (SBP)
  - Establish a rating criteria
    - Exploit PHV, SHB and IRI relationships
    - Based on statistical analyses

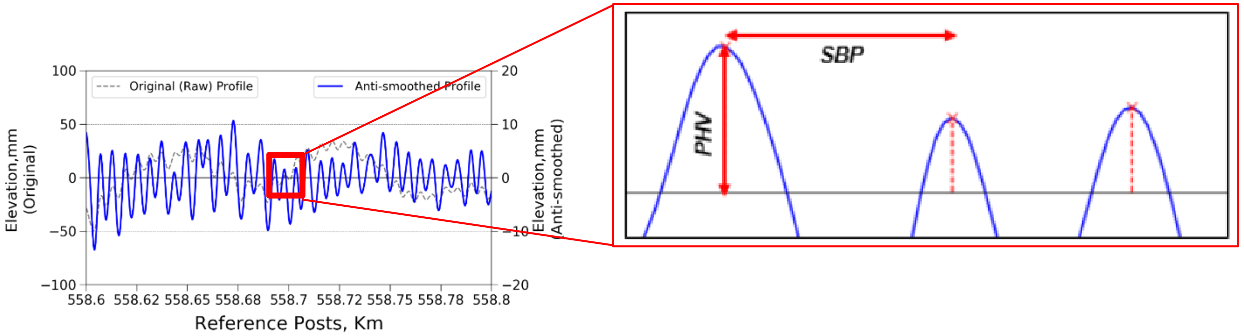


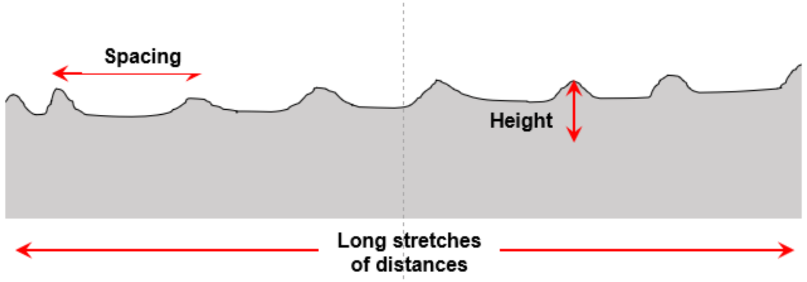


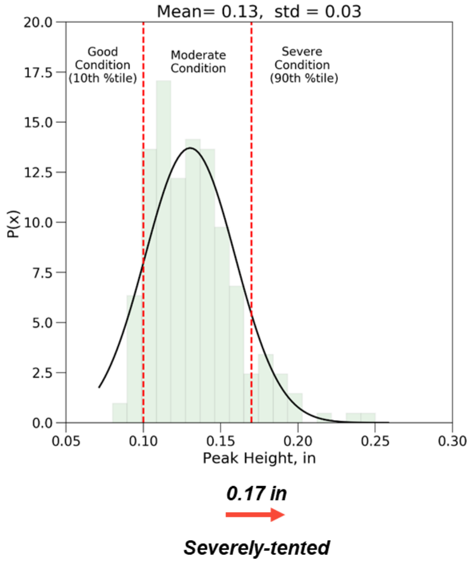


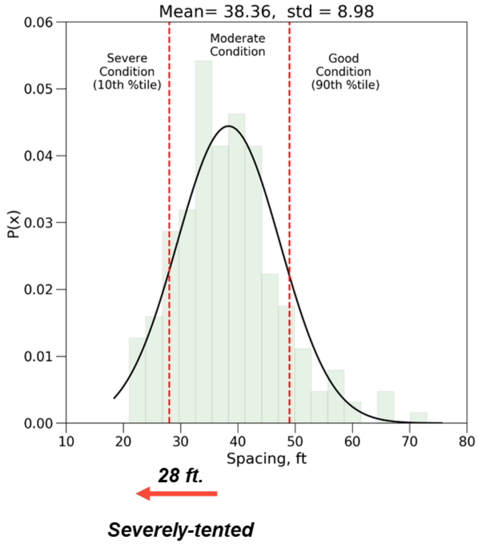
Investigation of Roads Affected by Tenting

- Key findings
  - Automated detection and rating of peaks
    - Peak Height Value (PHV)
    - Spacing Between Peaks (SBP)
  - Establish a rating criteria
    - Exploit PHV, SHB and IRI relationships
    - Based on statistical analyses







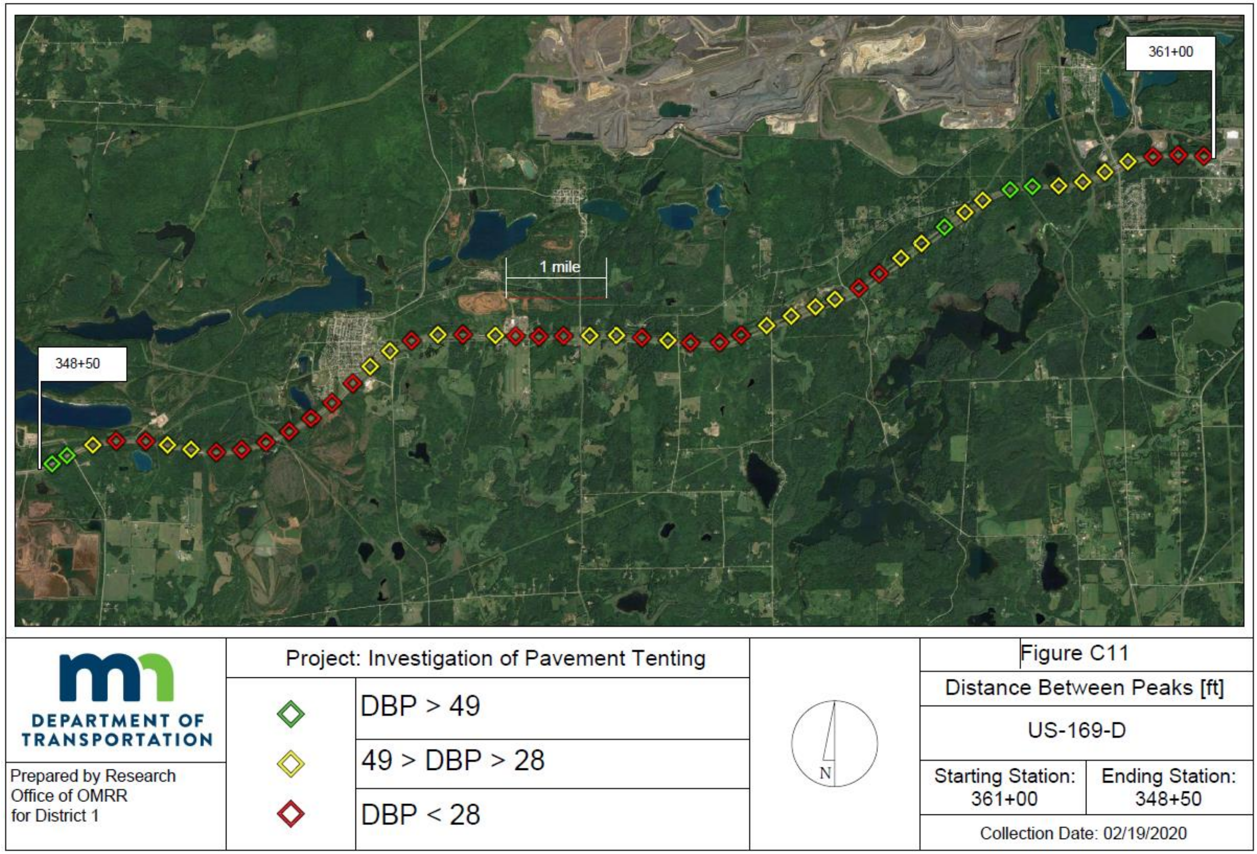


Investigation of Roads Affected by Tenting

- Key findings
  - Prioritizing by severity level
    - Ranking of roads
    - Mapping location & extent of critical sections

Road	Total No. Lots	Peak Height > 90th %tile Height (Percentage)	Peak Spacing > 90th %tile Height (Percentage)
MN37-D	58	2 (3.5%)	1 (1.7%)
MN73-D	24	6 (25%)	0 (0%)
MN73-I	24	4 (16%)	0 (0%)
US169-D	50	7 (14%)	23 (46%)
US169-I	61	4 (6.5%)	2 (3.2%)

Road built on top of an old rubbllized cement concrete pavement

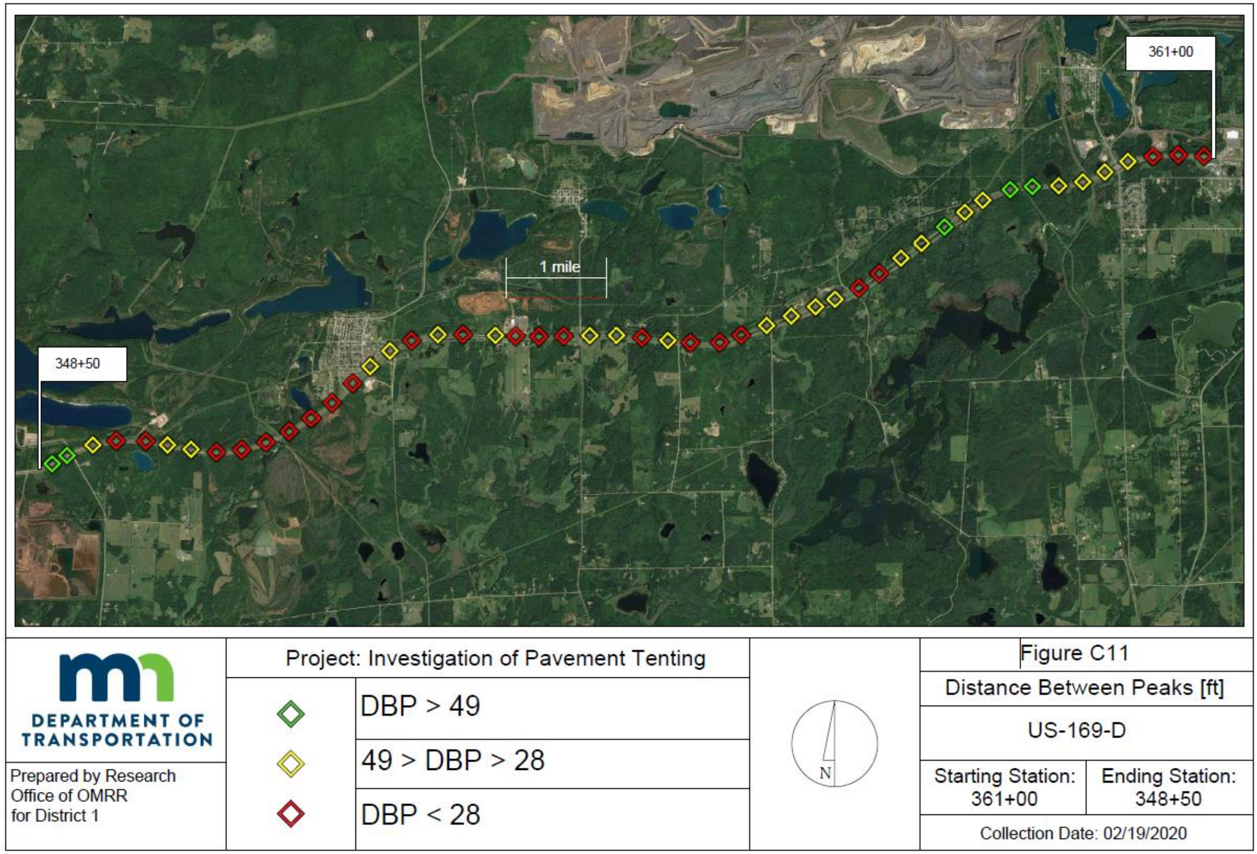


Investigation of Roads Affected by Tenting

- On-going research work
  - Active project: Mitigation of Tenting of Transverse Cracks and Joints in Asphalt Pavement
    - PI: Manick Barman (U of M)
    - Co-PI Mihai Marasteanu (U of M)

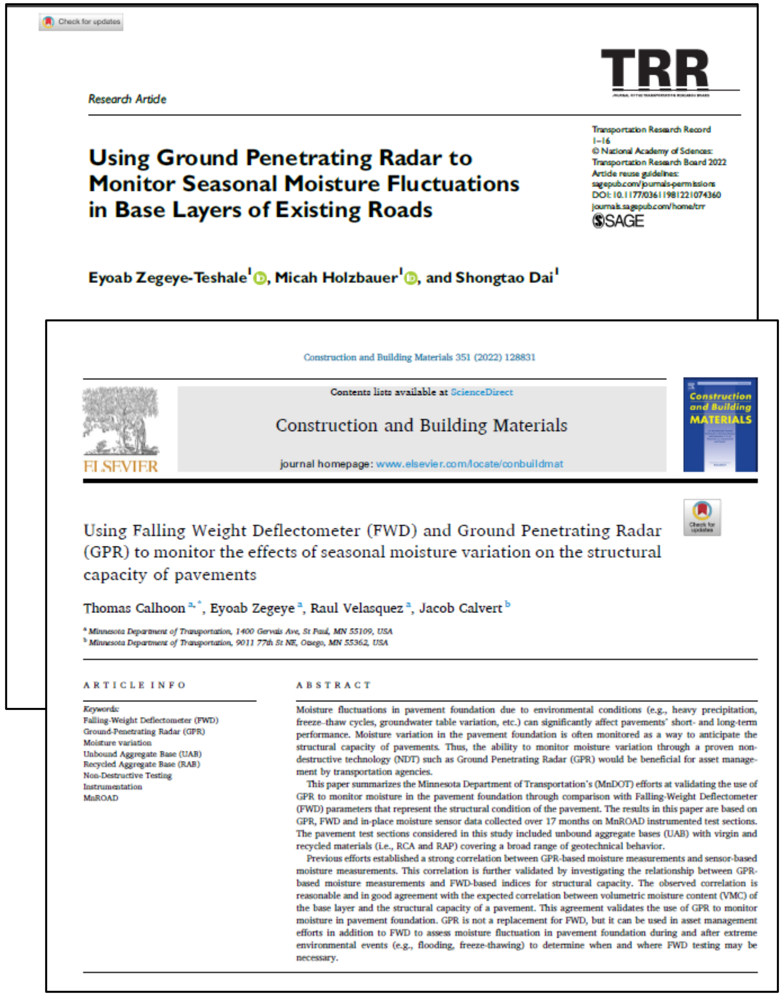
Minnesota Local Road Research Board

University of Minnesota
Driven to Discover®



Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- ❑ Moisture related pavement damages
  - – Effect of heavy traffic loading during the freeze-thaw event
    - o MnDOT Study on the effect of husbandry vehicles (cell 83)
    - o One day of testing (first week of march)



Check for updates

TRR

Research Article

Transportation Research Record
1–16

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]

Construction and Building Materials 351 (2022) 128831

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ELSEVIER

Using Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) to monitor the effects of seasonal moisture variation on the structural capacity of pavements

Thomas Calhoon[a,*], Eyoab Zegeye[a], Raul Velasquez[a], Jacob Calvert[b]

[a] Minnesota Department of Transportation, 1400 Gervais Ave, St Paul, MN 55109, USA
[b] Minnesota Department of Transportation, 9011 77th St NE, Otsego, MN 55362, USA

ARTICLE INFO

Keywords:
Falling-Weight Deflectometer (FWD)
Ground-Penetrating Radar (GPR)
Moisture variation
Unbound Aggregate Base (UAB)
Recycled Aggregate Base (RAB)
Non-Destructive Testing
Instrumentation
MnROAD

ABSTRACT

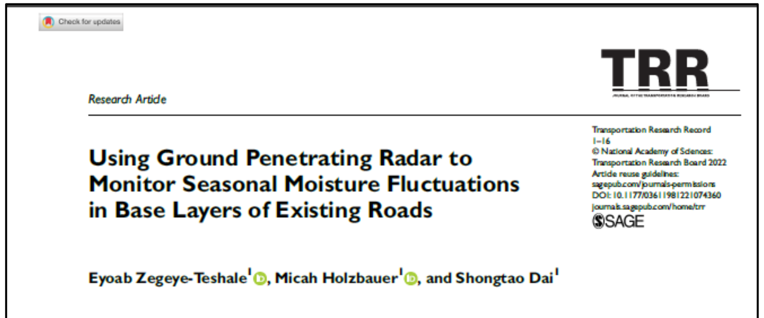
Moisture fluctuations in pavement foundation due to environmental conditions (e.g., heavy precipitation, freeze–thaw cycles, groundwater table variation, etc.) can significantly affect pavements' short- and long-term performance. Moisture variation in the pavement foundation is often monitored as a way to anticipate the structural capacity of pavements. Thus, the ability to monitor moisture variation through a proven non-destructive technology (NDT) such as Ground Penetrating Radar (GPR) would be beneficial for asset management by transportation agencies.

This paper summarizes the Minnesota Department of Transportation's (MnDOT) efforts at validating the use of GPR to monitor moisture in the pavement foundation through comparison with Falling-Weight Deflectometer (FWD) parameters that represent the structural condition of the pavement. The results in this paper are based on GPR, FWD and in-place moisture sensor data collected over 17 months on MnROAD instrumented test sections. The pavement test sections considered in this study included unbound aggregate bases (UAB) with virgin and recycled materials (i.e., RCA and RAP) covering a broad range of geotechnical behavior.

Previous efforts established a strong correlation between GPR-based moisture measurements and sensor-based moisture measurements. This correlation is further validated by investigating the relationship between GPR-based moisture measurements and FWD-based indices for structural capacity. The observed correlation is reasonable and in good agreement with the expected correlation between volumetric moisture content (VMC) of the base layer and the structural capacity of a pavement. This agreement validates the use of GPR to monitor moisture in pavement foundation. GPR is not a replacement for FWD, but it can be used in asset management efforts in addition to FWD to assess moisture fluctuation in pavement foundation during and after extreme environmental events (e.g., flooding, freeze-thawing) to determine when and where FWD testing may be necessary.

Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Moisture related pavement damages
  - Effect of heavy traffic loading during the freeze-thaw event
    - MnDOT Study on the effect of husbandry vehicles (cell 83)
    - One day of testing (first week of march)
  - Effect of “quick rain” or “flash flooding”


Check for updates

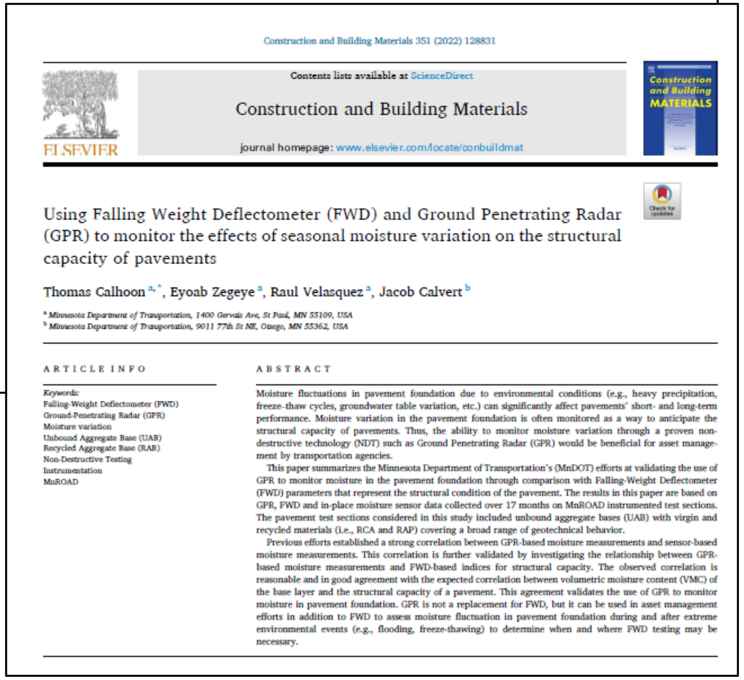
TRR

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]


Construction and Building Materials 351 (2022) 128831

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ELSEVIER

Using Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) to monitor the effects of seasonal moisture variation on the structural capacity of pavements

Thomas Calhoon[a,*], Eyoab Zegeye[a], Raul Velasquez[a], Jacob Calvert[b]

[a] Minnesota Department of Transportation, 1400 Gervais Ave, St Paul, MN 55109, USA
[b] Minnesota Department of Transportation, 9011 77th St NE, Otsego, MN 55362, USA

ARTICLE INFO

Keywords:
Falling-Weight Deflectometer (FWD)
Ground-Penetrating Radar (GPR)
Moisture variation
Unbound Aggregate Base (UAB)
Recycled Aggregate Base (RAB)
Non-Destructive Testing
Instrumentation
MnROAD

ABSTRACT

Moisture fluctuations in pavement foundation due to environmental conditions (e.g., heavy precipitation, freeze–thaw cycles, groundwater table variation, etc.) can significantly affect pavements' short- and long-term performance. Moisture variation in the pavement foundation is often monitored as a way to anticipate the structural capacity of pavements. Thus, the ability to monitor moisture variation through a proven non-destructive technology (NDT) such as Ground Penetrating Radar (GPR) would be beneficial for asset management by transportation agencies.

This paper summarizes the Minnesota Department of Transportation's (MnDOT) efforts at validating the use of GPR to monitor moisture in the pavement foundation through comparison with Falling-Weight Deflectometer (FWD) parameters that represent the structural condition of the pavement. The results in this paper are based on GPR, FWD and in-place moisture sensor data collected over 17 months on MnROAD instrumented test sections. The pavement test sections considered in this study included unbound aggregate bases (UAB) with virgin and recycled materials (i.e., RCA and RAP) covering a broad range of geotechnical behavior.

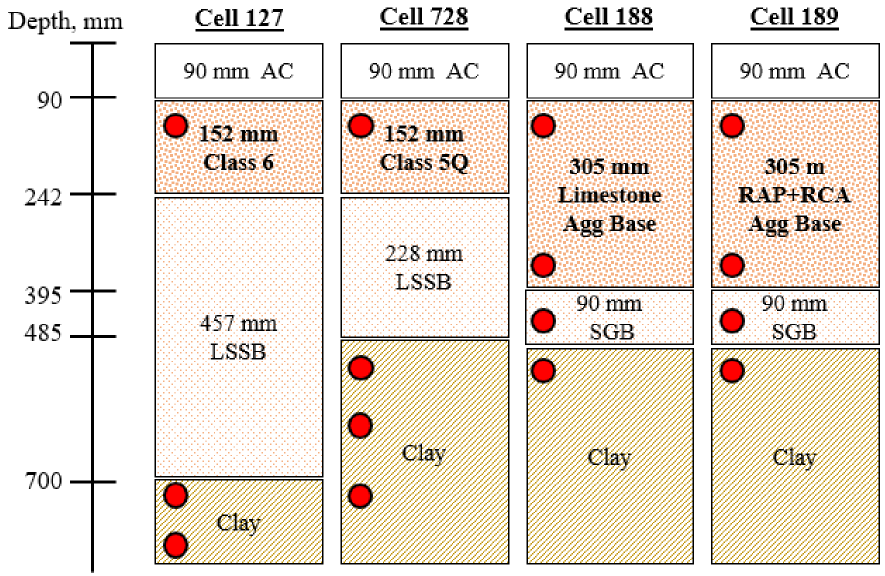
Previous efforts established a strong correlation between GPR-based moisture measurements and sensor-based moisture measurements. This correlation is further validated by investigating the relationship between GPR-based moisture measurements and FWD-based indices for structural capacity. The observed correlation is reasonable and in good agreement with the expected correlation between volumetric moisture content (VMC) of the base layer and the structural capacity of a pavement. This agreement validates the use of GPR to monitor moisture in pavement foundation. GPR is not a replacement for FWD, but it can be used in asset management efforts in addition to FWD to assess moisture fluctuation in pavement foundation during and after extreme environmental events (e.g., flooding, freeze-thawing) to determine when and where FWD testing may be necessary.

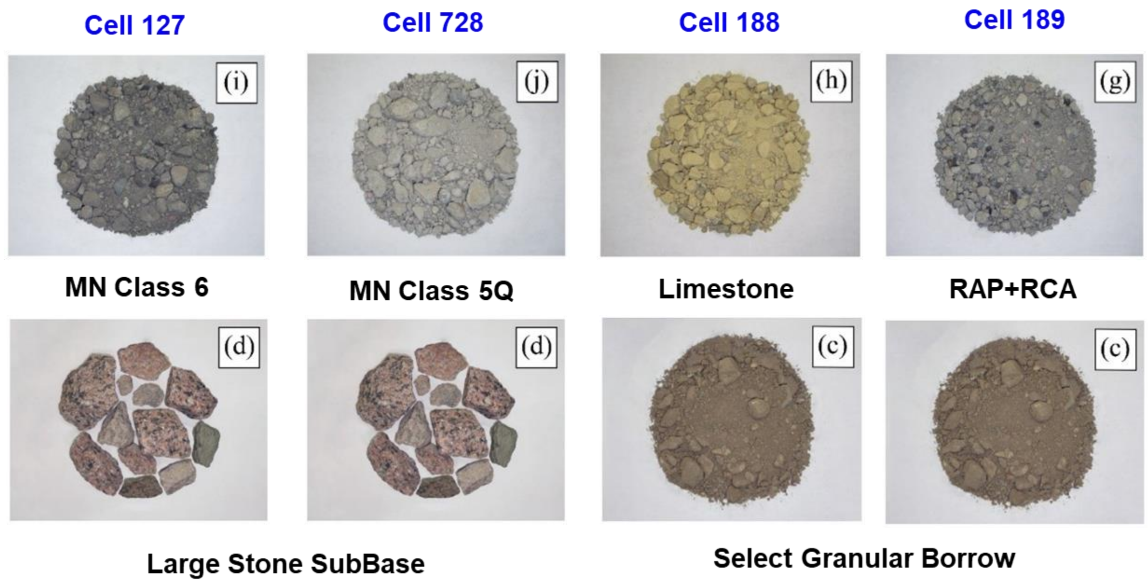
Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Proper traffic load management techniques used to mitigate the effect of high moisture fluctuation
  - Spring Load Restriction (SLR)
  - Winter Load Increase (WLI)
  - Traffic restrictions due to heavy road

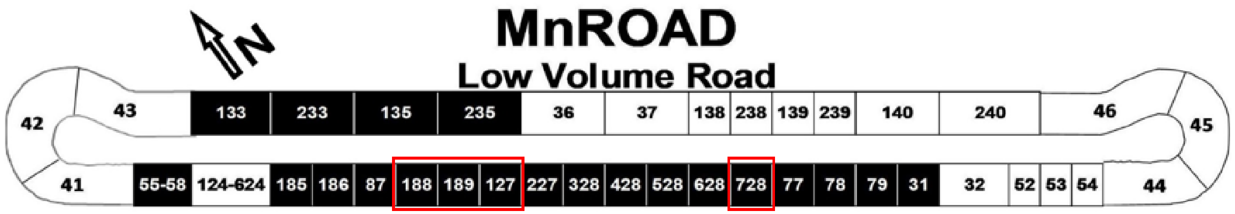
Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Can we use the GPR to monitor moisture in the base aggregate layers of in-service roads?



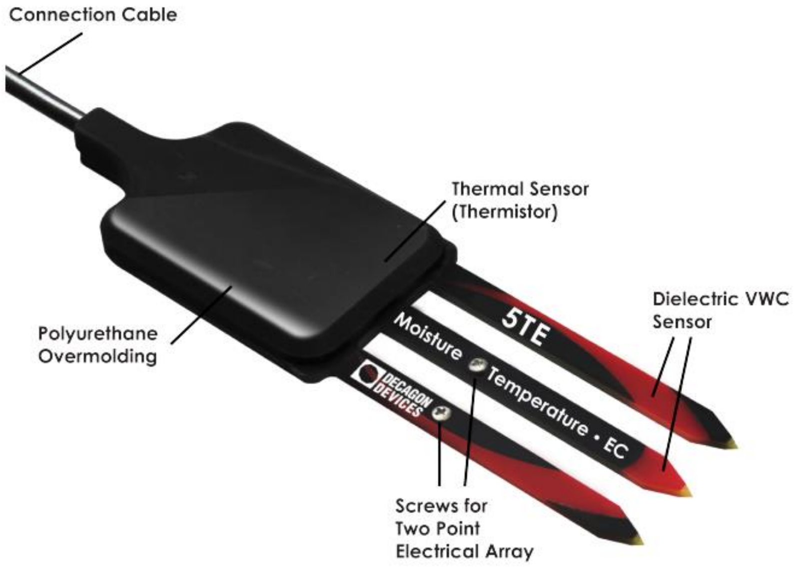


Source NRRA study: Determining Pavement Design Criteria for Recycled Aggregate Base and Large Stone Subbase **- Bora et. al., 2020**



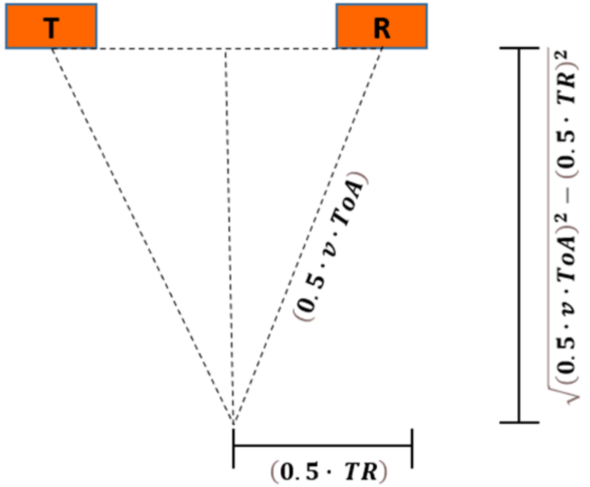
Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- 18 months of periodic testing and monitoring



Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Algorithm for extracting dielectric and moisture content from GPR data
  - Based on solving a trigonometric problem and assumption of plane layer interface
  - Uses Topp's equation to convert dielectric to moisture content



$$D_{des} - \sqrt{(0.5 \cdot v \cdot ToA)^2 - (0.5 \cdot TR)^2} = 0$$

$$v = \sqrt{\frac{D_{des}^2 + 0.25\, TR^2}{0.25\, ToA^2}}$$

Layer velocity

$$\varepsilon_r = \left(\frac{c}{v}\right)^2$$

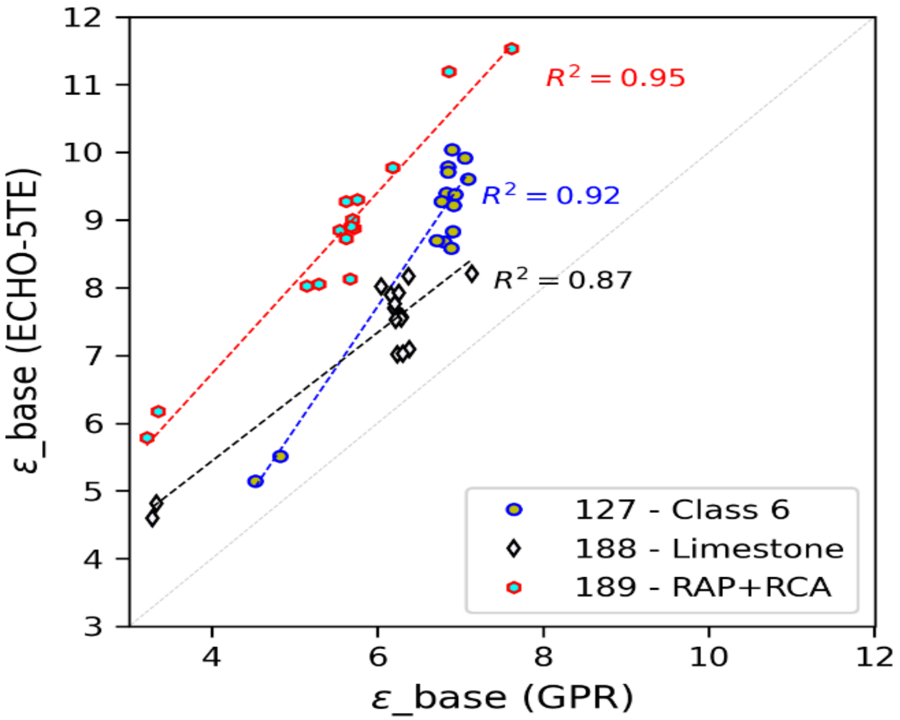
Layer dielectric constant

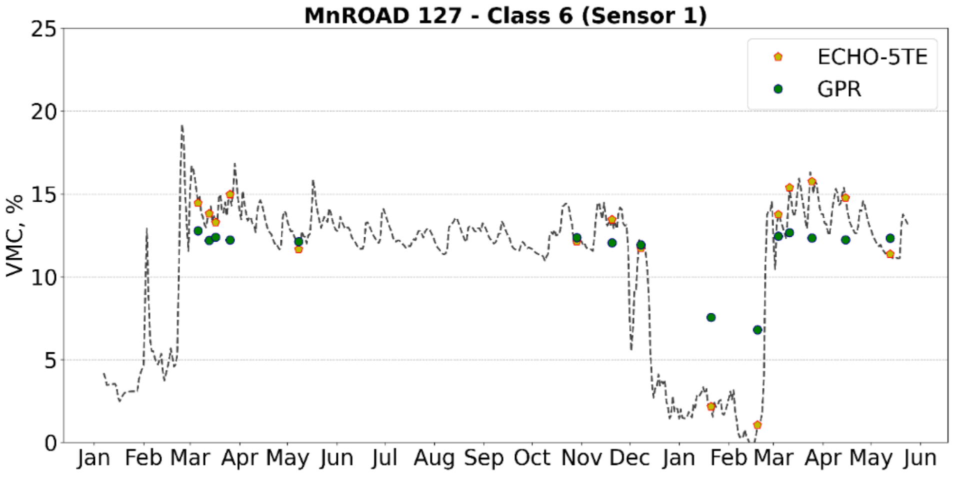
Topp's equation to estimate volumetric moisture content

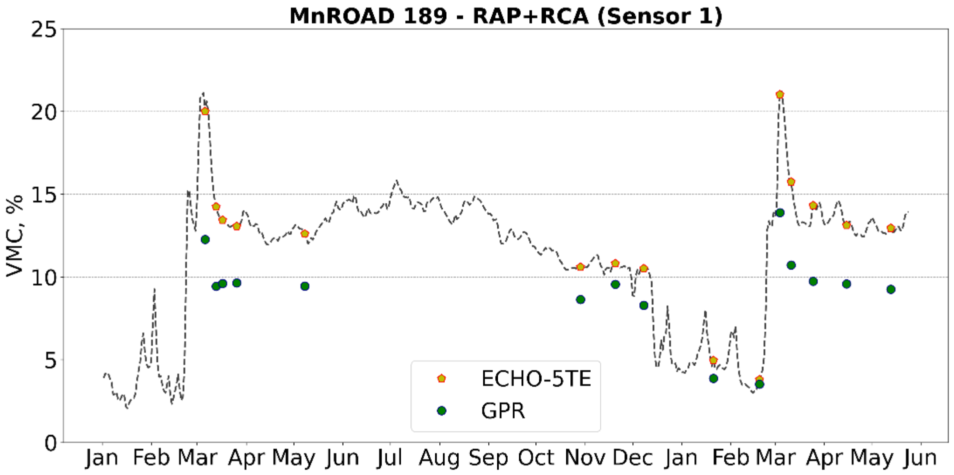
$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} \varepsilon_{base} - 5.5 \times 10^{-4} {\varepsilon_{base}}^2 + 4.3 \times 10^{-6} {\varepsilon_{base}}^3$$

Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Promising Results

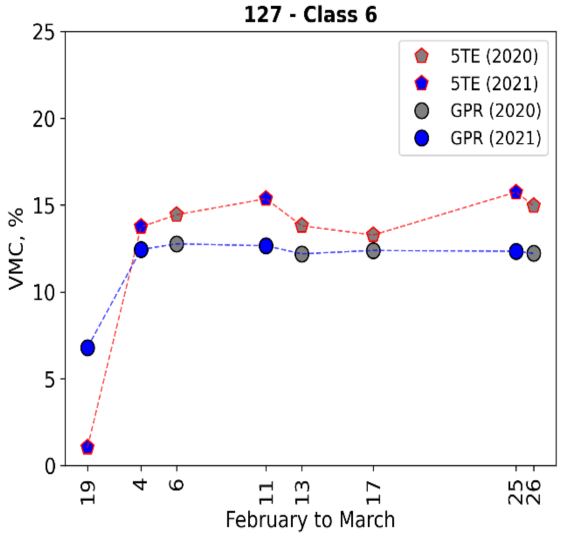




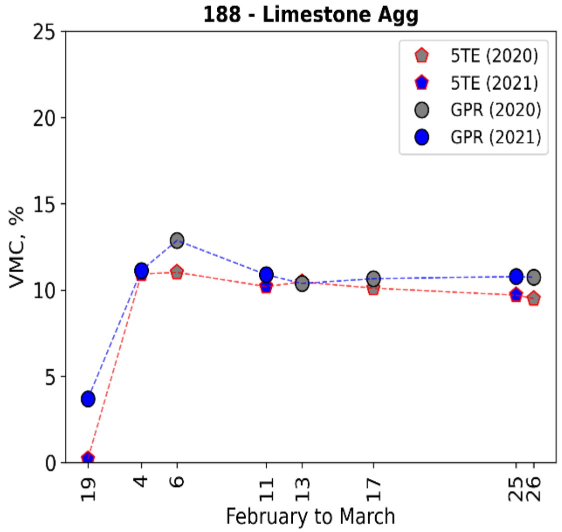


Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

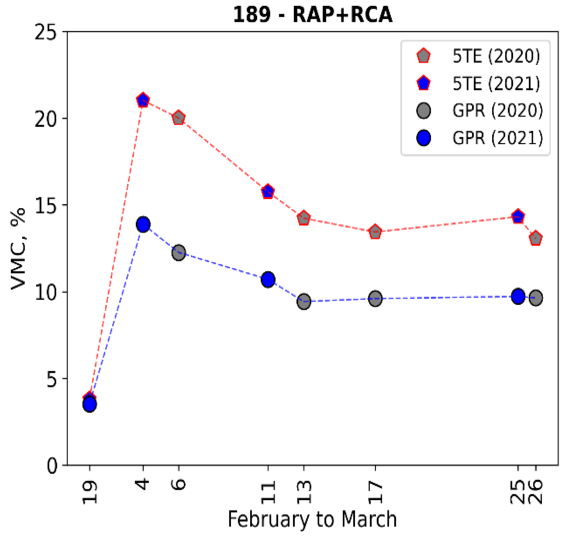
- Promising Results
  - Effect of material quality in early spring thaw period (end of February start of March)



Cell 127 – MN Class 6
Mortar content 25.6%



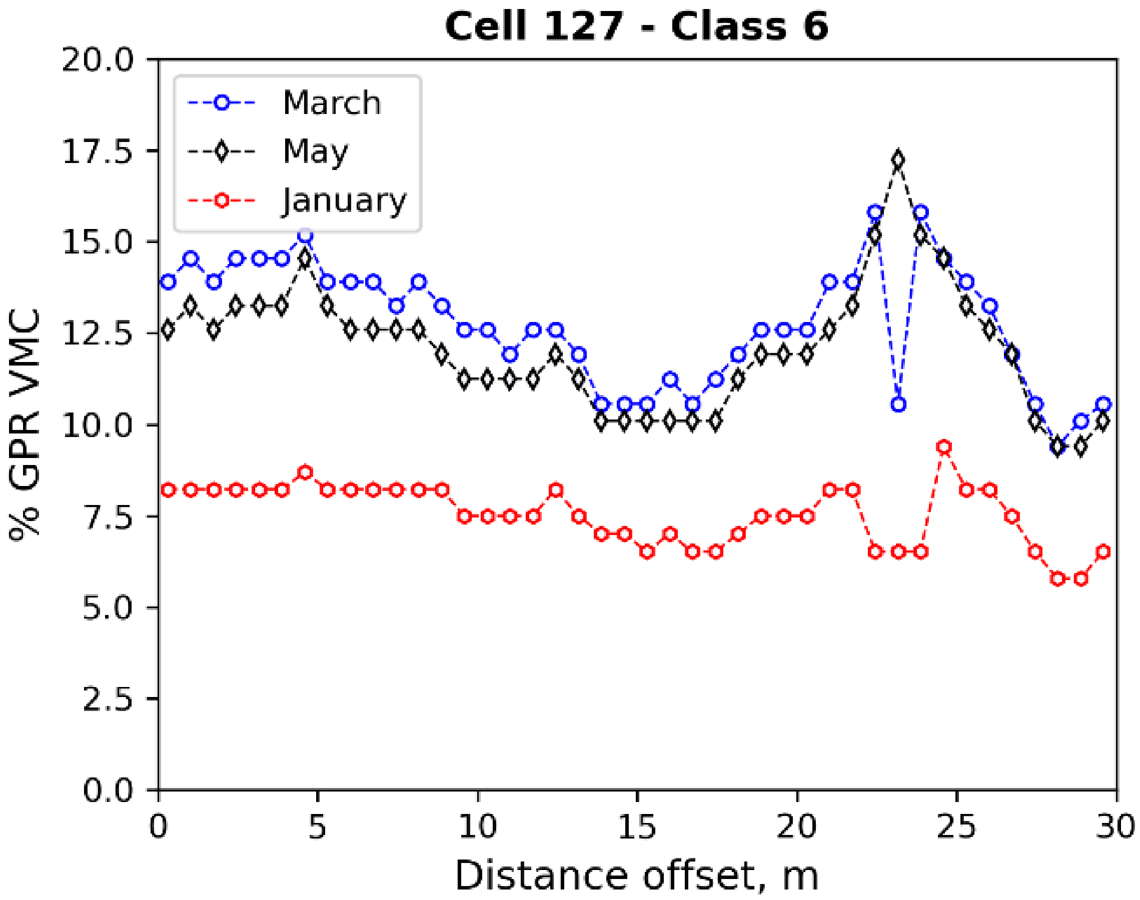
Cell 188 – MN Limestone
Mortar content 1.3%



Cell 189 – MN RAP+RCA
Mortar content 20.1%

Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- ❑ Promising Results
  - – Continuous measurement



Use GPR for Continuous Measurement of Moisture in the Foundation Layers of In-Service Roads

- Future works
  - Working with Kontur to move from 2D to 3D-GPR

MnDOT's Road Doctor Survey System

Thank you

Any Questions or Comments?