Current Geotechnical Research Activities to Support Project Delivery & Asset Management

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MN DEPARTMENT OF TRANSPORTATION

Current Geotech Research

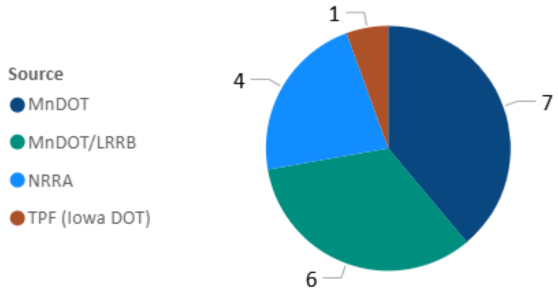
Title

- Vulnerability Assessments of Critical Slope Areas Using Advanced Monitoring Techniques
- TPF-5(546) Transportation Material Resource Center
- Quantify the Benefits of Using Geotextiles and Geogrids to Improve the Performance of Unbound Pavement Layers
- Performance Evaluation of Wicking Geotextiles for Improving Drainage and Stiffness of Road
- Pavement Design: Performance of Base versus Subbase
- Novel Durability Screening Method for Stabilized Geomaterials
- MnROAD In-Situ Investigation Environmental Effects of RCA in Pavement Bases
- Instrumentation and Data Management/Analyses for Measurement While Drilling (MWD) Technology
- Improving Moisture Resistance/Control of Pavement Foundation Systems via Engineered Water Repellency
- Improving and Developing Pavement Design Inputs and Performance Functions for Cold Recycled Pavement Layers in Minnesota
- Holistic Design and Selection Criteria for Unbound Geomaterials Used in Pavement Systems

Number of Active Projects:

18

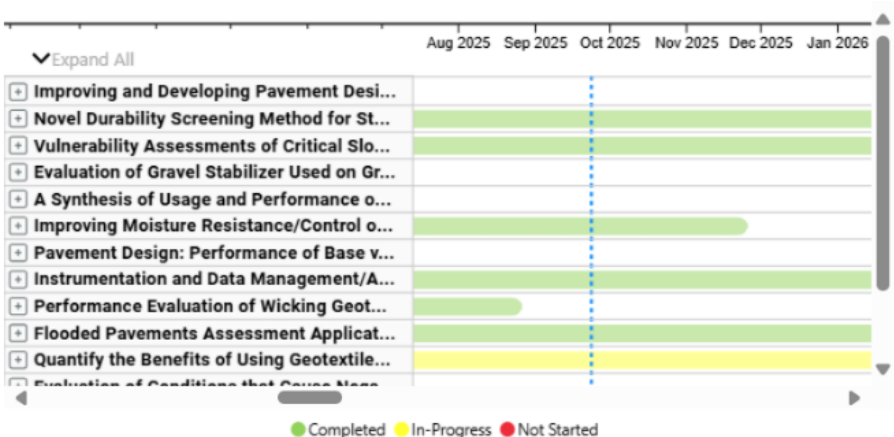
Project Sources



Project Roles

TL

Project Timelines

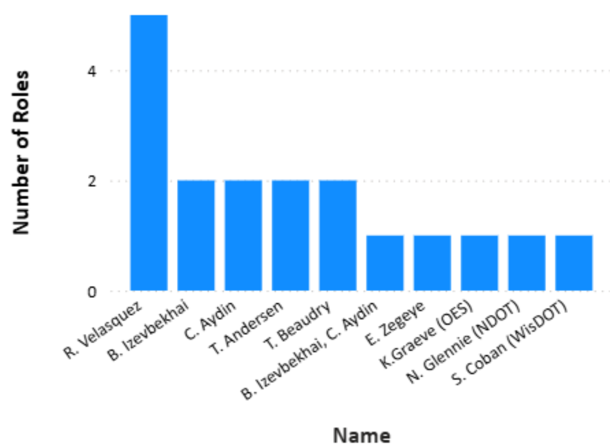


Created by L. Siebert

Current Action Items

- Action item 1:
- Action item 2:
- Action item 3:

Roles Per Researcher



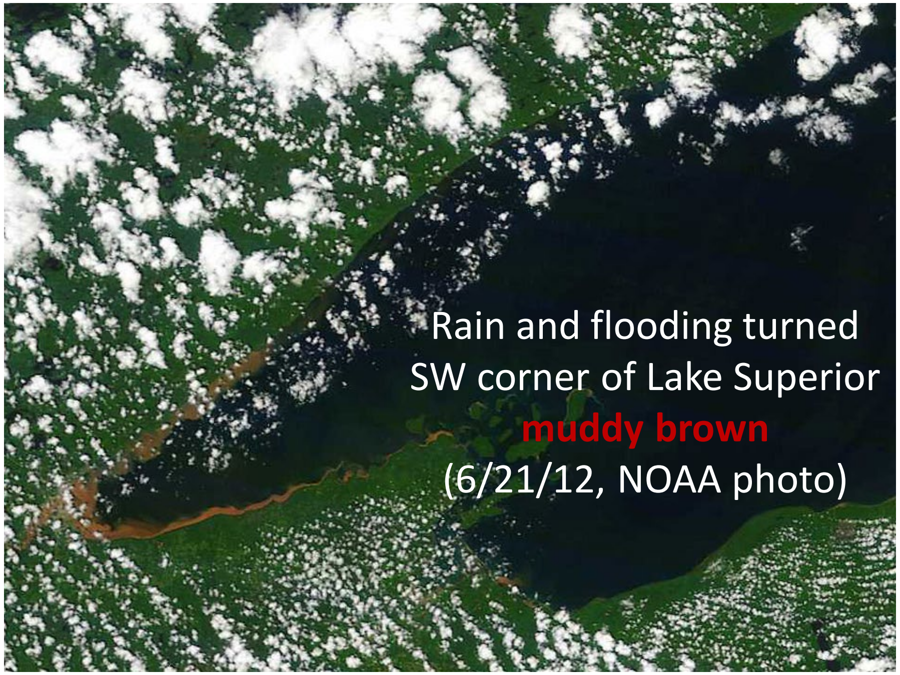
Selected Geotech Research Projects

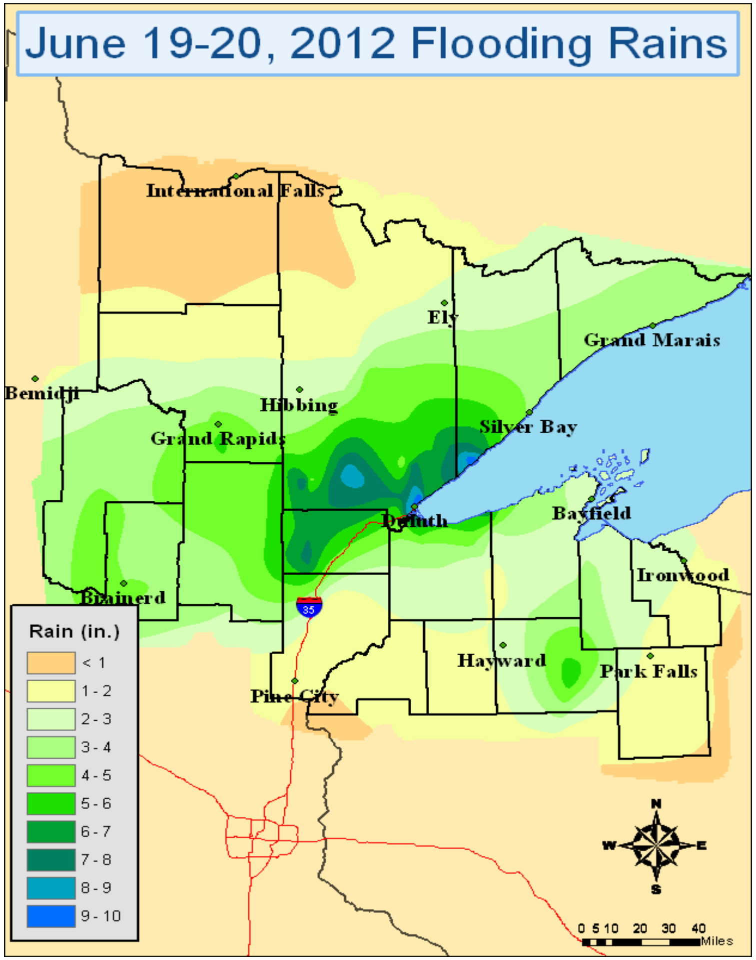
1. Vulnerability Assessment of Slopes
   - Geomorphology-based (WSB)
   - Geotech-based (MSU)
2. InSAR for Geotech Asset Management (AUB and TAMU)
3. Quantifying Benefits of Geosynthetics for Pavement Foundations (UIUC and ISU)
4. RCA (MTU, MSU, Internally)
5. Optimization of CSE (Internally)
6. Pavement Foundation Uniformity (Internally, Ingios, UTEP)
7. Temperature as Surrogate of Pavement Performance (Internally)

*GAM + Project Delivery *GAM *Project Delivery *Other

Why Slope Vulnerability Assessment?

- Rainy season in June 2012 in Minnesota caused slope failures and major damage in MN Trunk Highway (~ $50 million dollars in damage)





Why Slope Vulnerability Assessment?

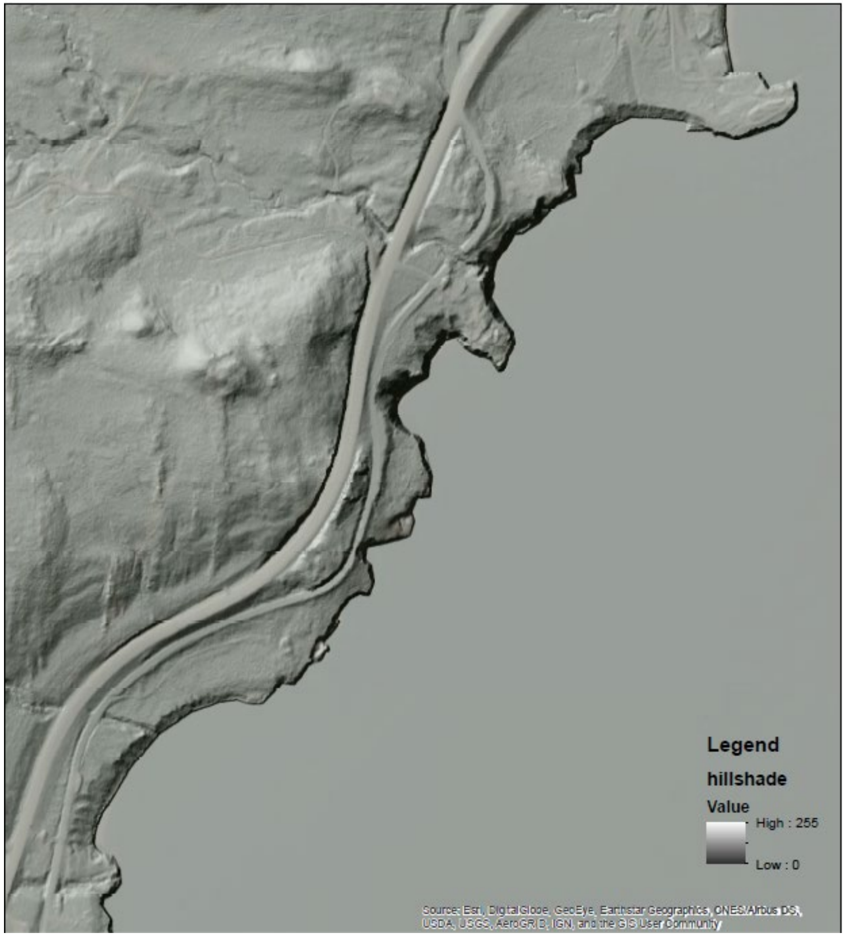
- **26** Road Closures on Trunk Highway System
- Major team effort to bring system back:
  - MnDOT, DNR, DPS, Local Law Enforcement, FHWA, Consultants, Contractors.
- MnDOT Main Damage Areas:
  - TH-210 in Jay Cooke
  - TH-210 in Thomson
  - TH-23 in Fond du Lac
  - TH-2 from Proctor to I-35

Goals of Slope Vulnerability Model (Geomorphology-Based)

- *Assist engineers to proactively identify and mitigate slope risk along interstate highways*
  - Help during **project scoping** to **long range planning**
  - Enhance risk-based **asset management** decision making

Model assist in proactive identification of slope failures like deep-seated slide in TH-67

Slope Vulnerability Model



Geographic Information Systems (GIS) model that uses:

- **Geomorphology** of site among other key parameters to provide a *vulnerability rating score*
- **Geographic Weighted Regression (GWR)** to account for local variation of key parameters and minimized bias and subjectivity

Slope Vulnerability Model

Vulnerability Rating Score is computed with:

$$p = \frac{e^z}{1 + e^z}$$

$$z = \beta_o + \beta_1 X_1 + \cdots + \beta_n X_n$$

p= probability of slope failure ($0 < p < 1$)

X_n=input parameters (independent variables)

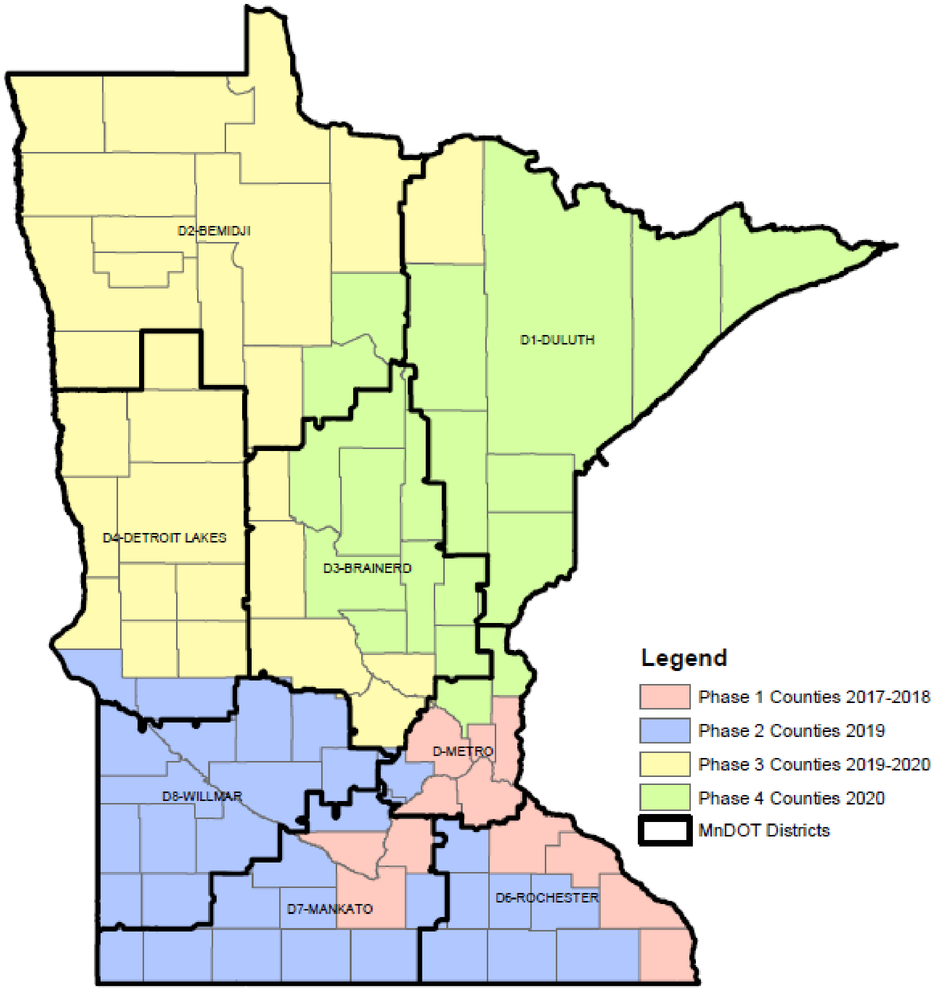
β_n=regression coefficients from GWR

Model Development

1. Selection of preliminary input parameters (vulnerability factors) and interaction terms based on geomorphology and geology of region
2. Checking vulnerability rating using preliminary input parameters and historical slope failures (sensitivity analysis)
3. Selecting final input parameters (statistically significant)
4. Field verification of model
5. Further adjustment (if required)

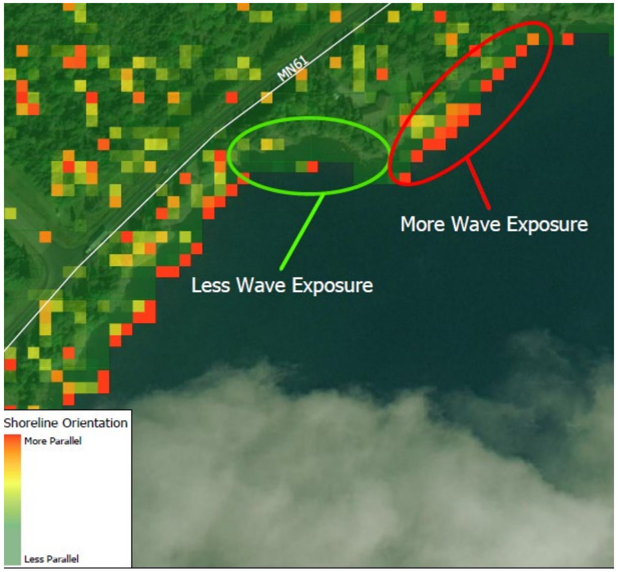
Model Development

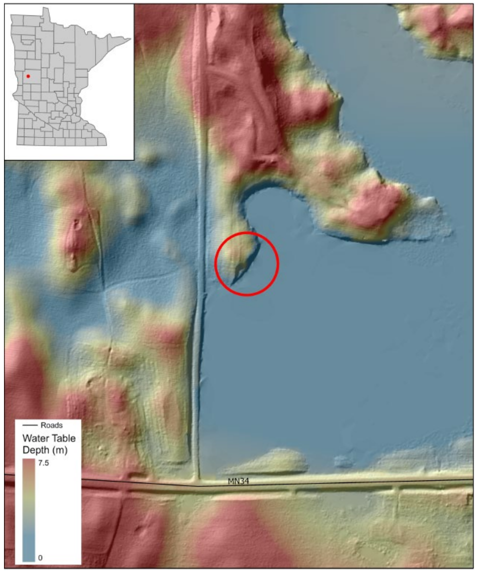
- **Phase 1** - includes steep terrain and bedrock exposures
- **Phase 2** - contains steep slopes along river tributaries formed by catastrophic drainage of Glacial Lake Minnesota
- **Phase 3** - low relief and gradual slopes formed in bed of Glacial Lake Agassiz and glacially eroded and deposited landforms
- **Phase 4** - small mountain ranges with steep slopes and exposed bedrock and glacial till deposits that form gently rolling terrain



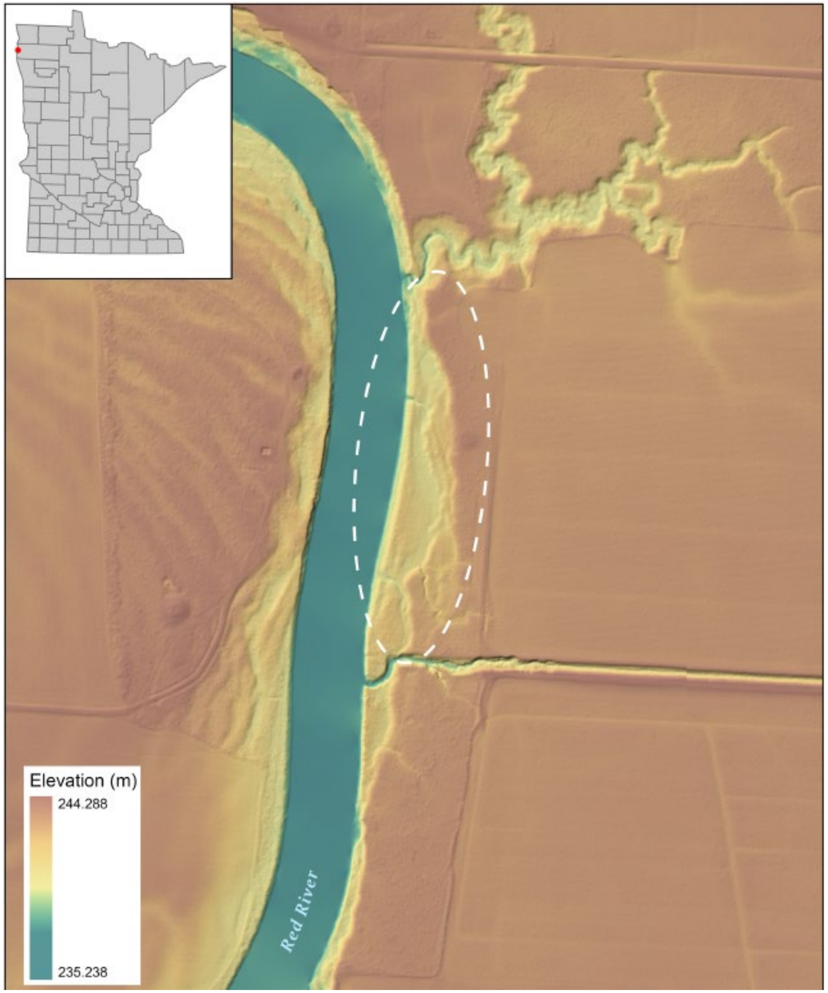
Model Development- Final Input Parameters

- **Phase 1**
  - Slope angle
  - Terrain curvature
  - Distance to streams
  - Distance to bedrock outcrops
- **Phase 2**
  - Slope angle
  - Terrain curvature
  - Incision potential
  - Local relief
- **Phase 3**
  - Slope angle
  - Terrain curvature
  - Water table depth
- **Phase 4**
  - Slope angle
  - Slope orientation
  - Local relief
  - Bedrock proximity
  - Elevation

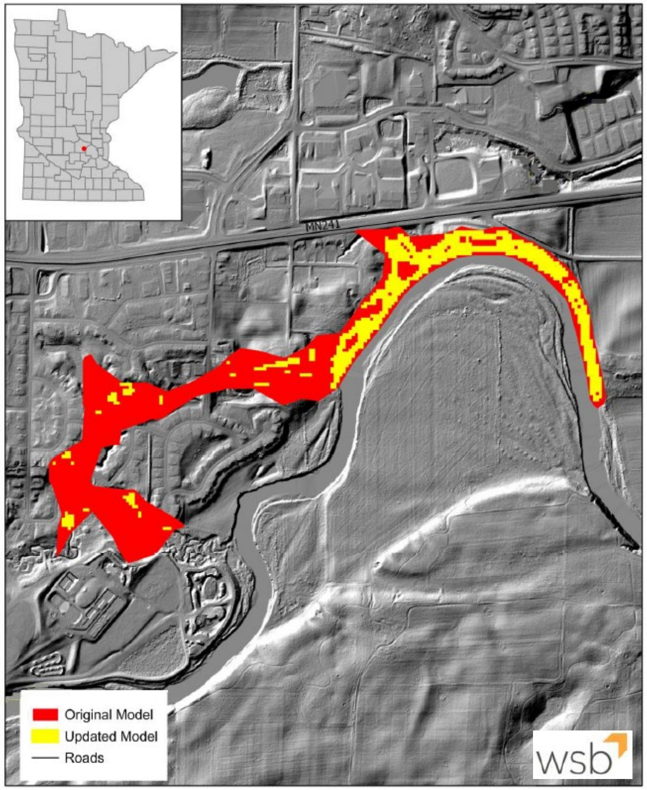




Deep-Seated Slide

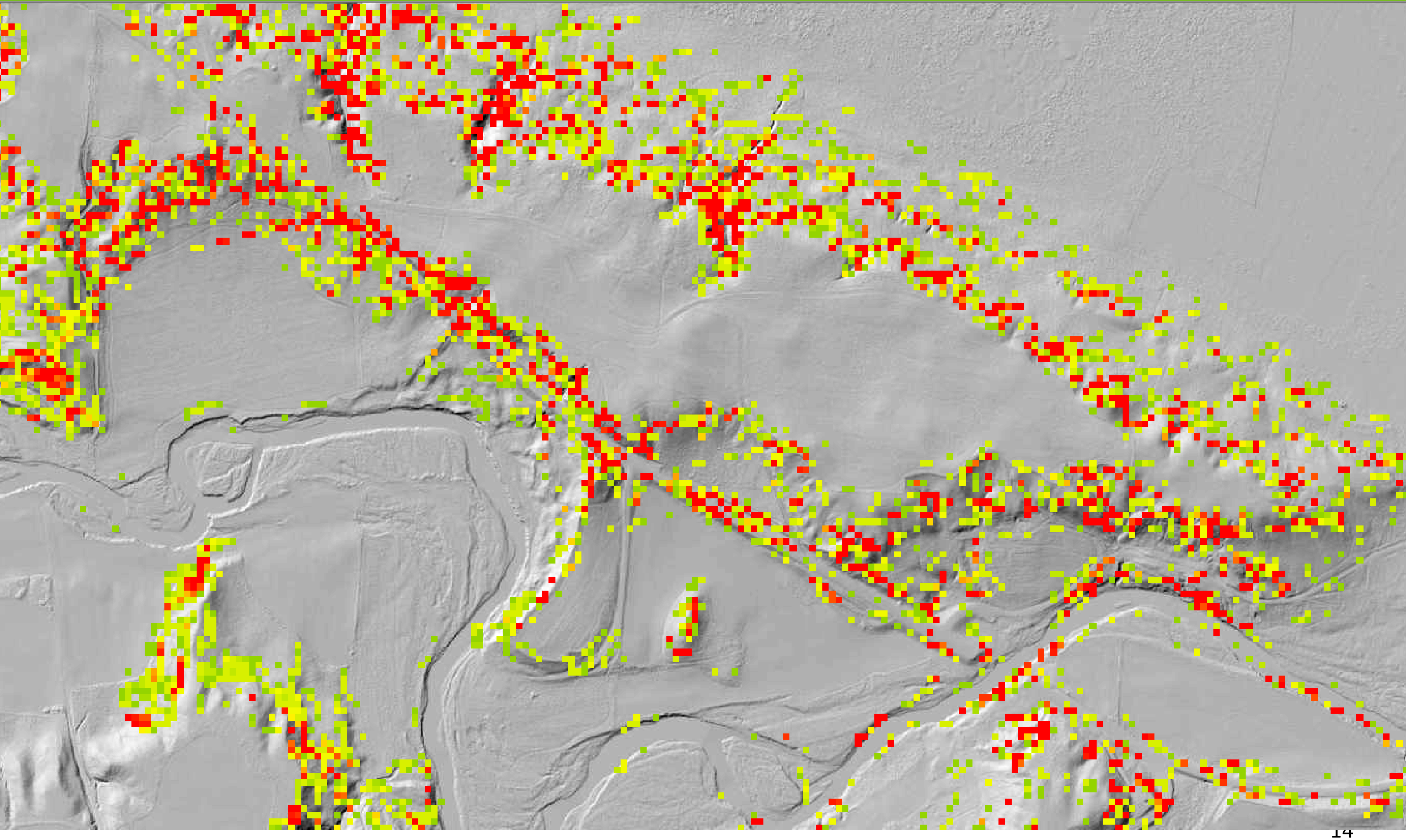


Field Verification



- Validation of final input parameters and vulnerability rating score
- Selection of sites with different geomorphology, geology, and hydrology

Example

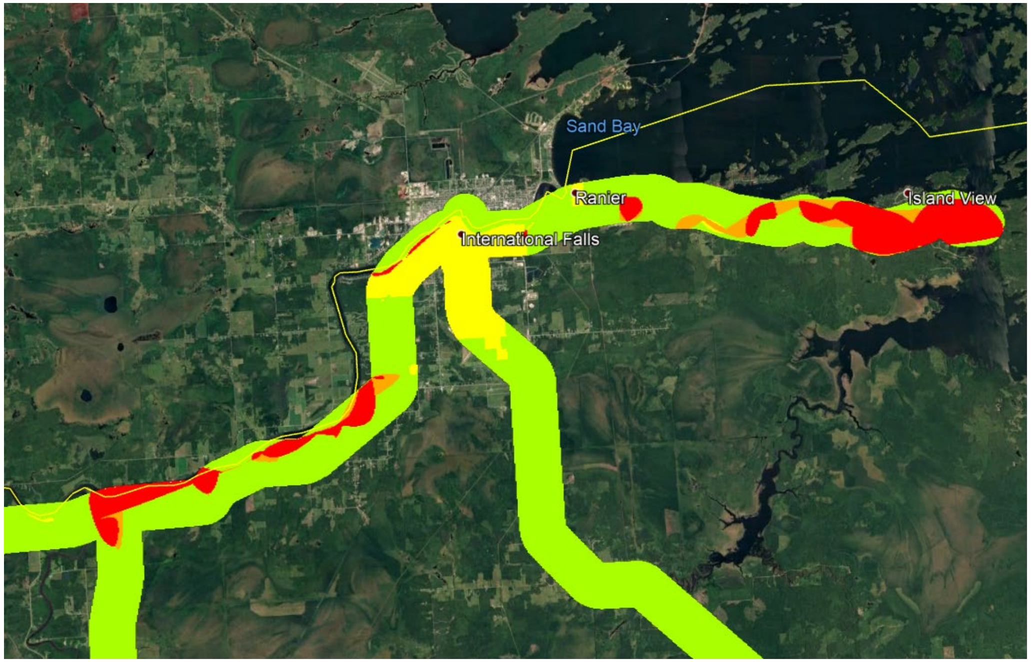


Preliminary Risk Ranking

				Consequence		
				Intersects Trunk Highways	Within 500 feet of Trunk Highways	More than 500 feet of Trunk Highways
				Within Metro or Incorporated Town	Rural	
	Slope Stability	Rational		Critical (5)	Serious (3)	Marginal (2)
LIKELIHOOD	Low	Slope is likely already experiencing mass failure or has the highest risk of failure.	Likely (4)	20 Site Visit / Action Recommended	12 Further Evaluation	8 Monitoring
	Medium	Surface erosion and other pre-cursors for catastrophic failure.	Possible (3)	15 Further Evaluation	9 Monitoring	6 No Action Recommended
	High	Slope has been repaired, recovered, or shows no signs of imminent future.	Unlikely (2)	10 Monitoring	6 No Action Recommended	4 No Action Recommended

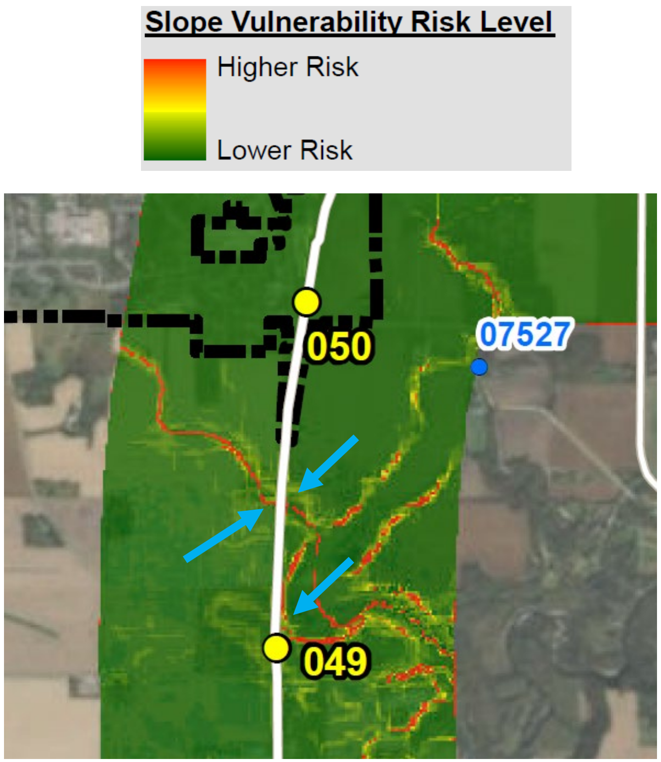
Risk = Likelihood (model output) × Consequence (effect on infrastructure)

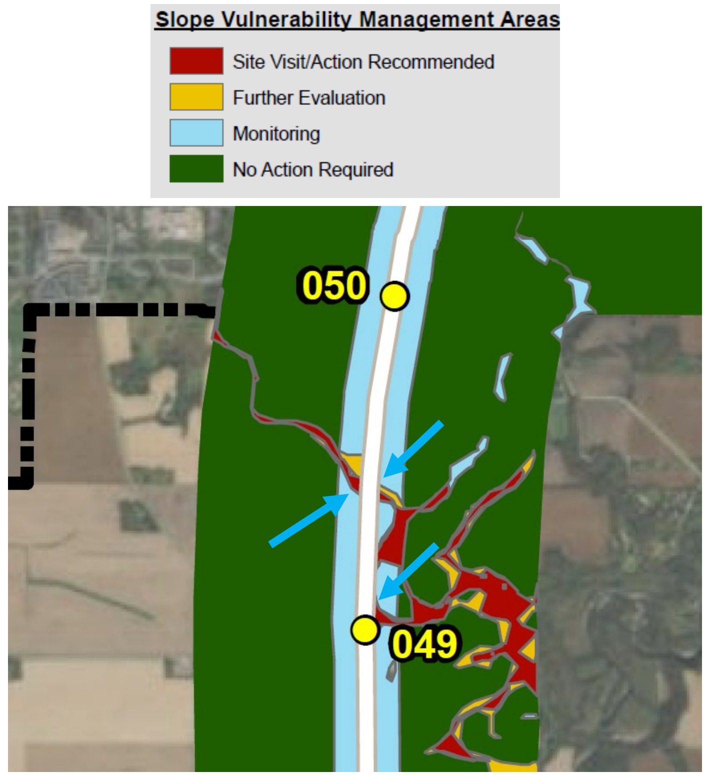
Preliminary Risk Ranking



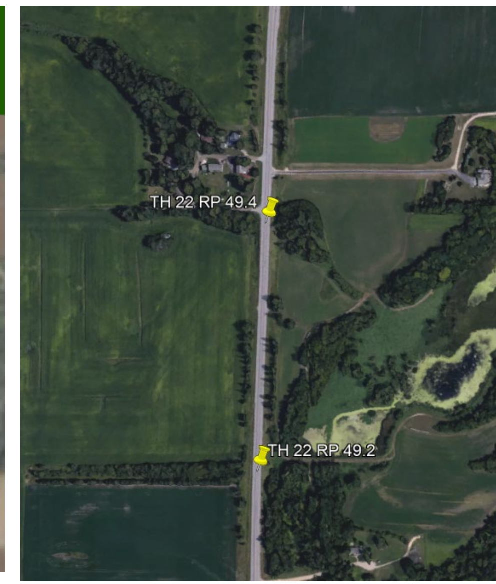
- Risk matrix used to create **Preliminary Management Areas**
- Preliminary Management Areas => <u>*delineated areas in GIS with similar risk ranking*</u>

Verification of Model





Location of TH-22 Slides, July 2020

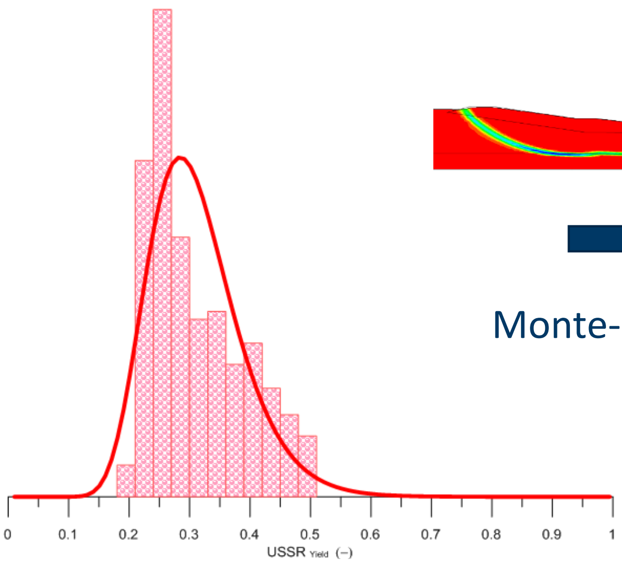


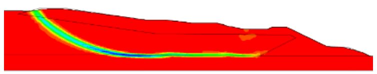
Vulnerability Assessment of Slopes (Geotech-Based)

1. Address recommendations and gaps from previous studies:
    - *MnDOT Slope Vulnerability Phase I-IV*
2. Help with implementation of advanced geotechnical tools such as 2D and 3D modeling software for slope stability (e.g., PLAXIS 3D)
3. Assess value of advanced remote sensing technologies such as UAVs for geotechnical applications
4. Improve quantification of risk via powerful numerical methods (commonly available)
5. Help with Geotechnical Asset Management (GAM) efforts
6. Internal Staff Development

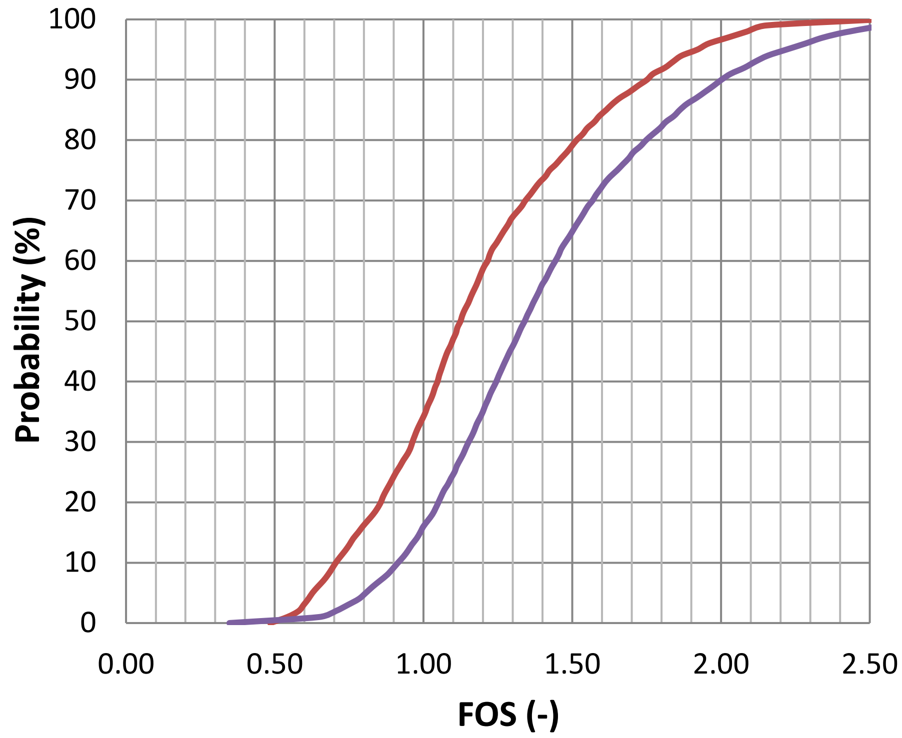
Geotechnical Approach for Slope Assessment

<u>Risk Assessment</u> can be added via powerful numerical methods commonly available:





Monte-Carlo

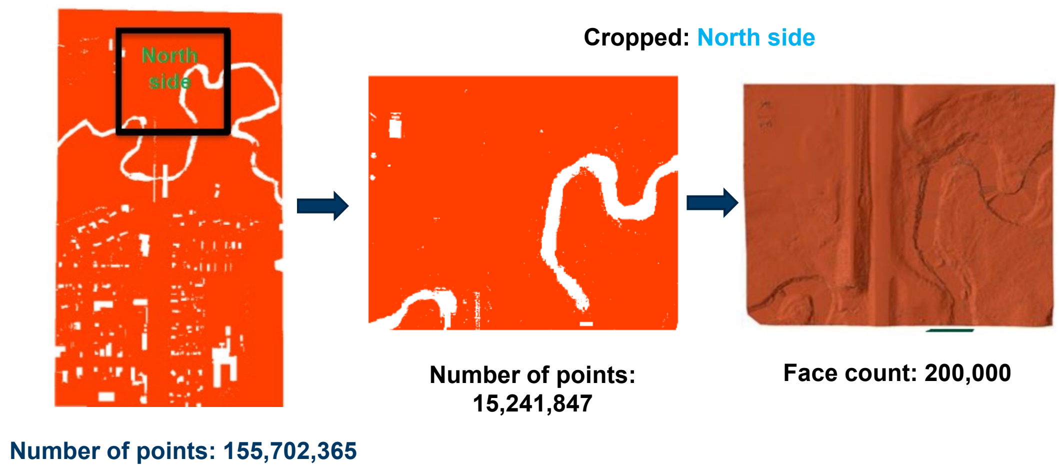


Vulnerability Assessment of Slopes (Geotech-Based)

Property or In Situ test results	Coefficient of Variation (CoV) (%)	Source
Unit weight (γ)	3–7%	Harr (1984), Kulhawy (1992)
Buoyant unit weight (γ_b)	0–10%	Lacasse and Nadim (1997), Duncan (2000)
Effective stress friction angle (φ')	2–13%	Harr (1984), Kulhawy (1992)
Undrained shear strength (S_u)	13–40%	Harr (1984), Kulhawy (1992), Lacasse and Nadim (1997), Duncan (2000)
Undrained strength ratio (S_u/σ'_v)	5–15%	Lacasse and Nadim (1997), Duncan (2000)
Compression index (C_c)	10–37%	Harr (1984), Kulhawy (1992), Duncan (2000)
Preconsolidation pressure (P_p)	10–35%	Harr (1984), Lacasse and Nadim (1997), Duncan (2000)
Coefficient of permeability of saturated clay (k)	68–90%	Harr (1984), Duncan (2000)
Coefficient of permeability of partly saturated clay (k)	130–240%	Harr (1984), Benson et al. (1999)
Coefficient of consolidation (c_v)	33–68%	Duncan (2000)
Standard penetration test blow count (N)	15–45%	Harr (1984), Kulhawy (1992)
Electric cone tip resistance (q_c)	5–15%	Kulhawy (1992)
Mechanical cone tip resistance (q_c)	15–37%	Harr (1984), Kulhawy (1992)
Dilatometer test tip resistance (q_{DMT})	5–15%	Kulhawy (1992)
Vane shear test undrained strength (S_u)	10–20%	Kulhawy (1992)
Shear modulus	30 to 90%	Phoon et al. (1995)
Soil modulus	30 to 90%	Phoon et al. (1995)

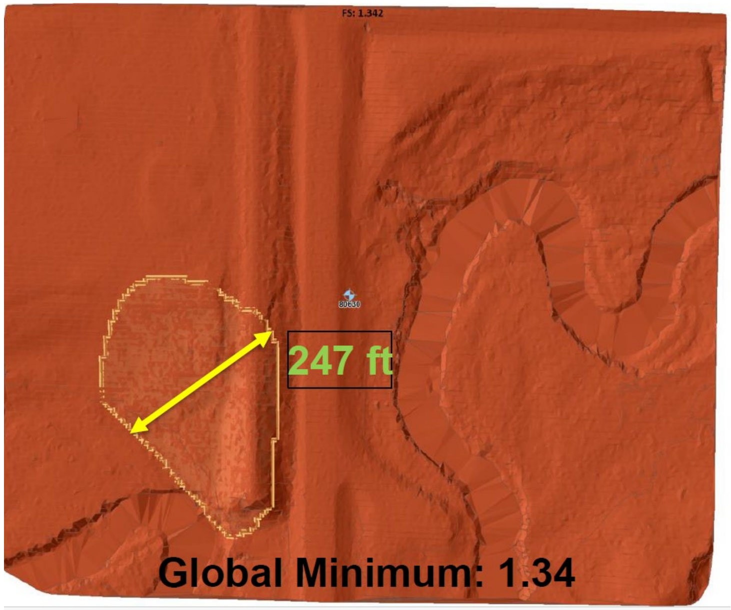
Vulnerability Assessment of Slopes (Geotech-Based)

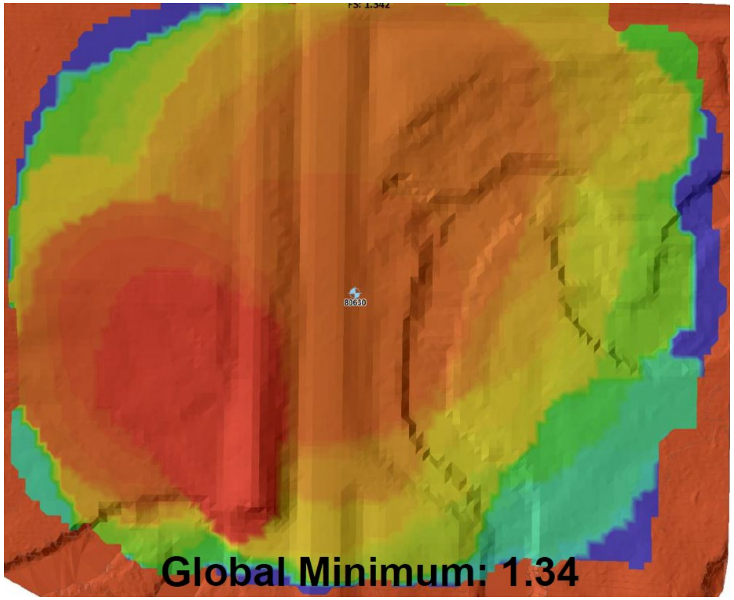
Climax, MN

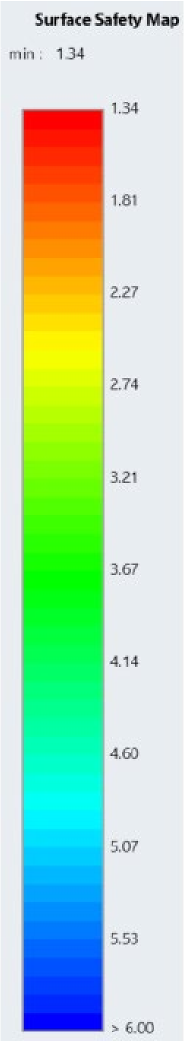


Vulnerability Assessment of Slopes (Geotech-Based)

Climax, MN

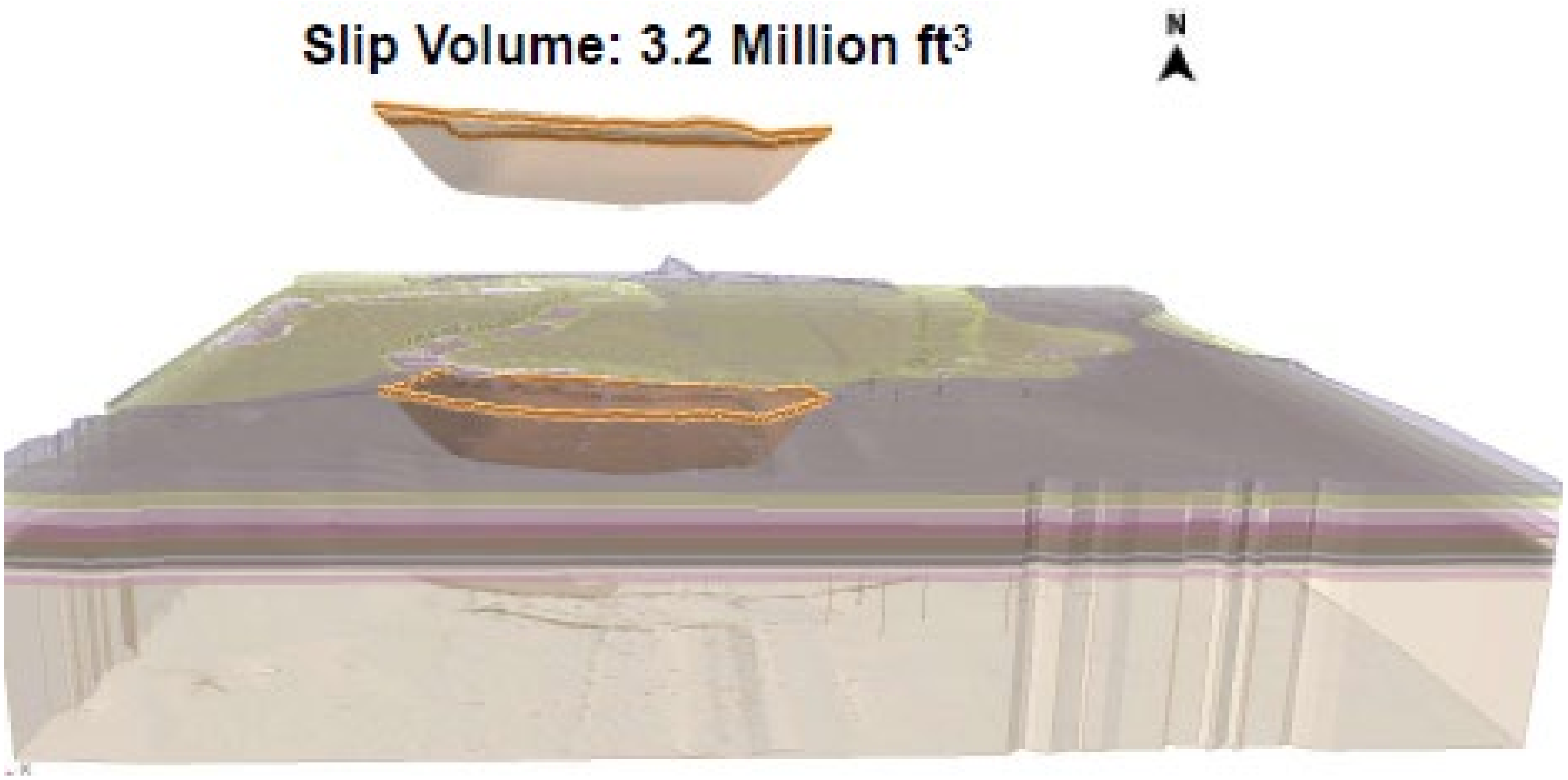




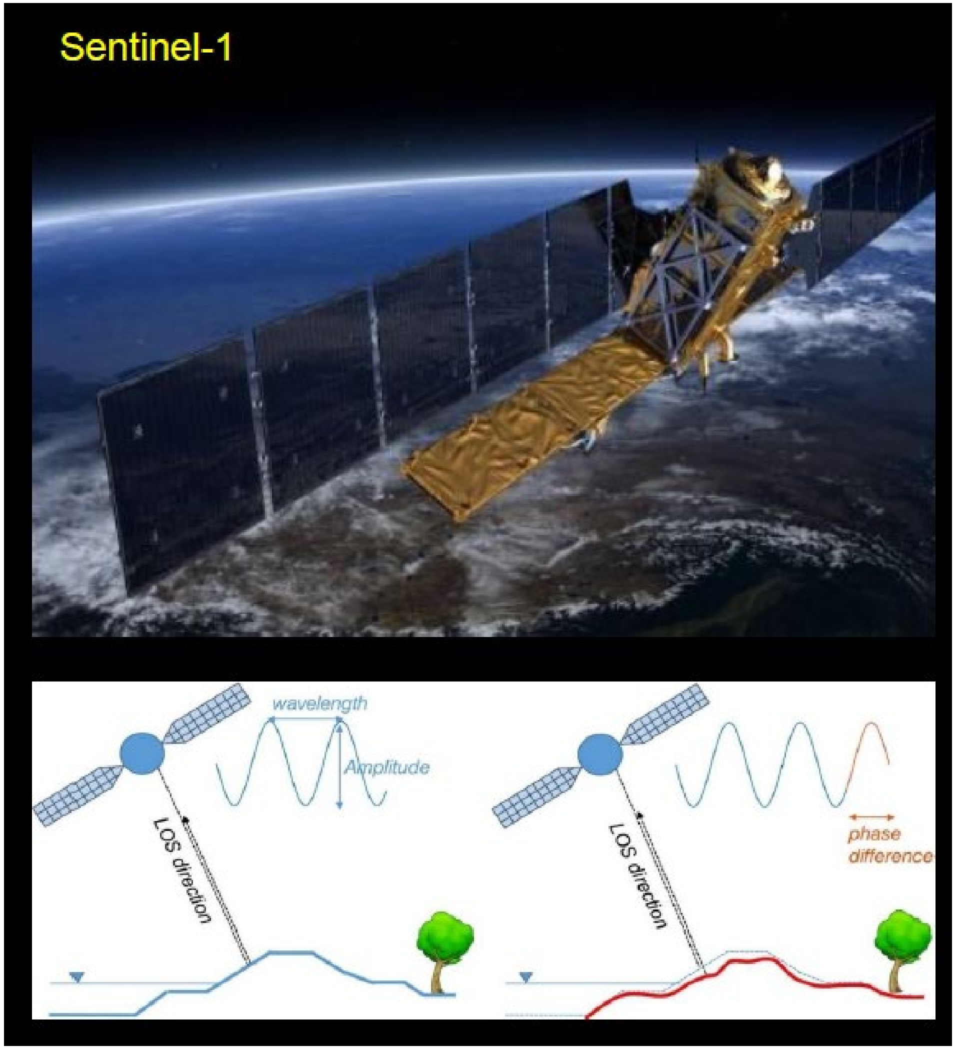


Vulnerability Assessment of Slopes (Geotech-Based)

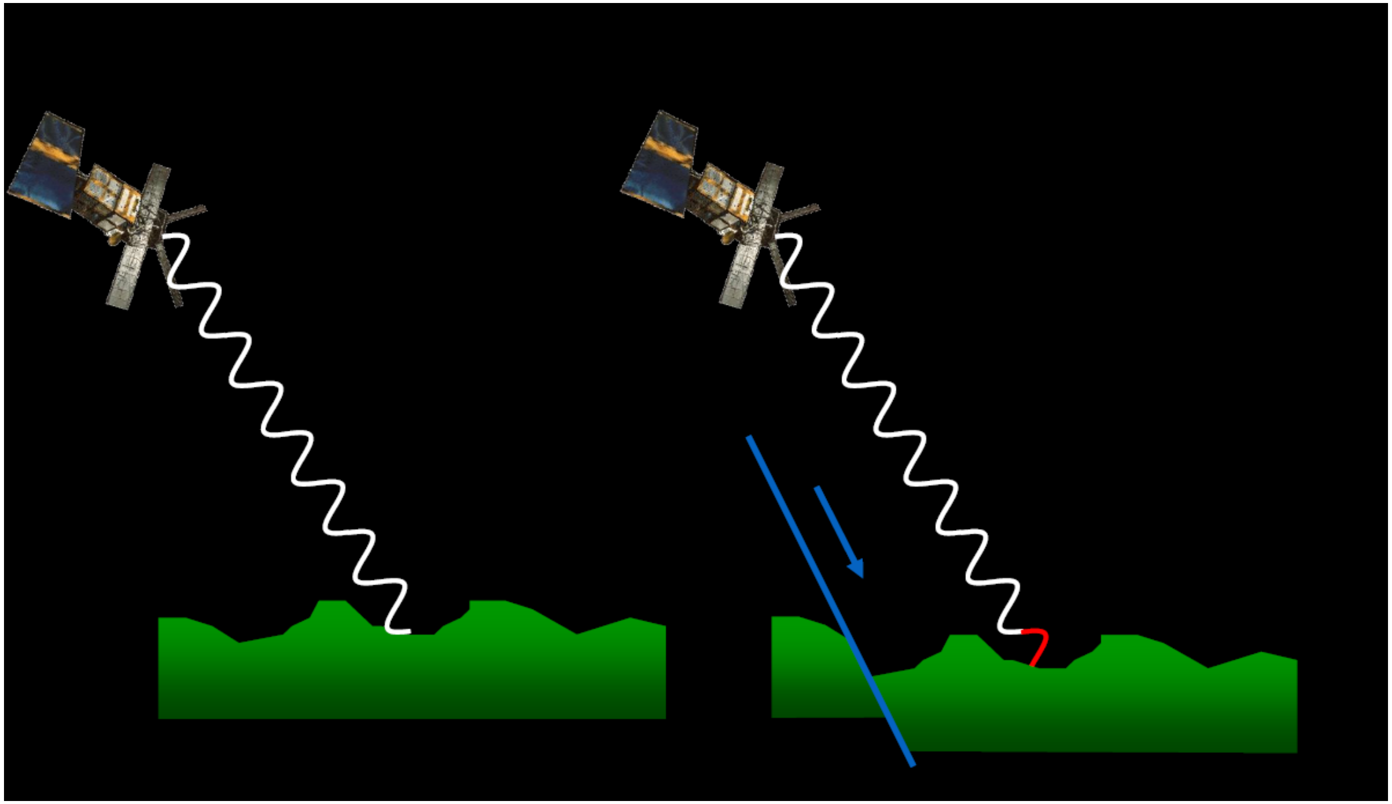
Climax, MN



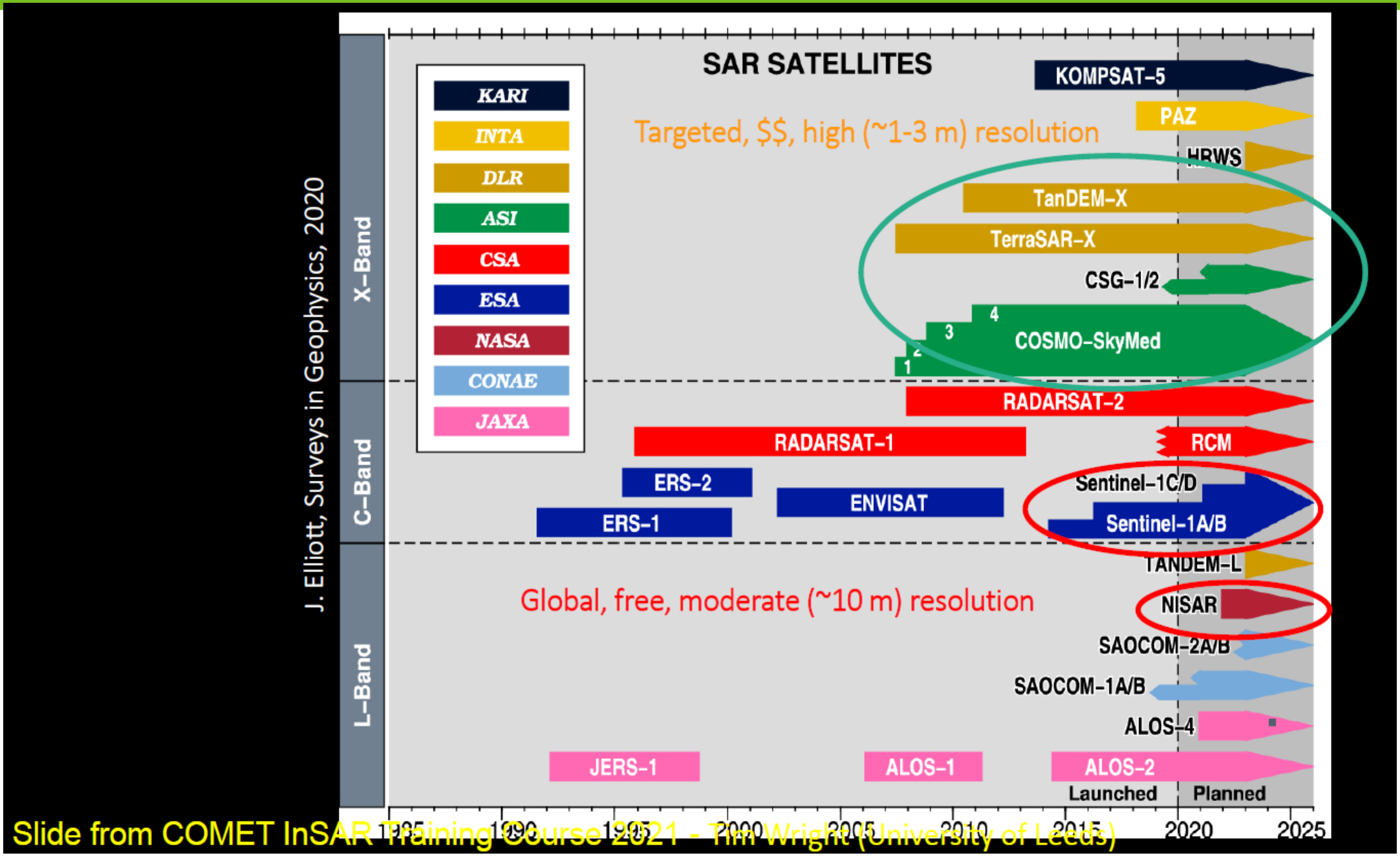
InSAR for Geotech Asset Management



InSAR for Geotech Asset Management

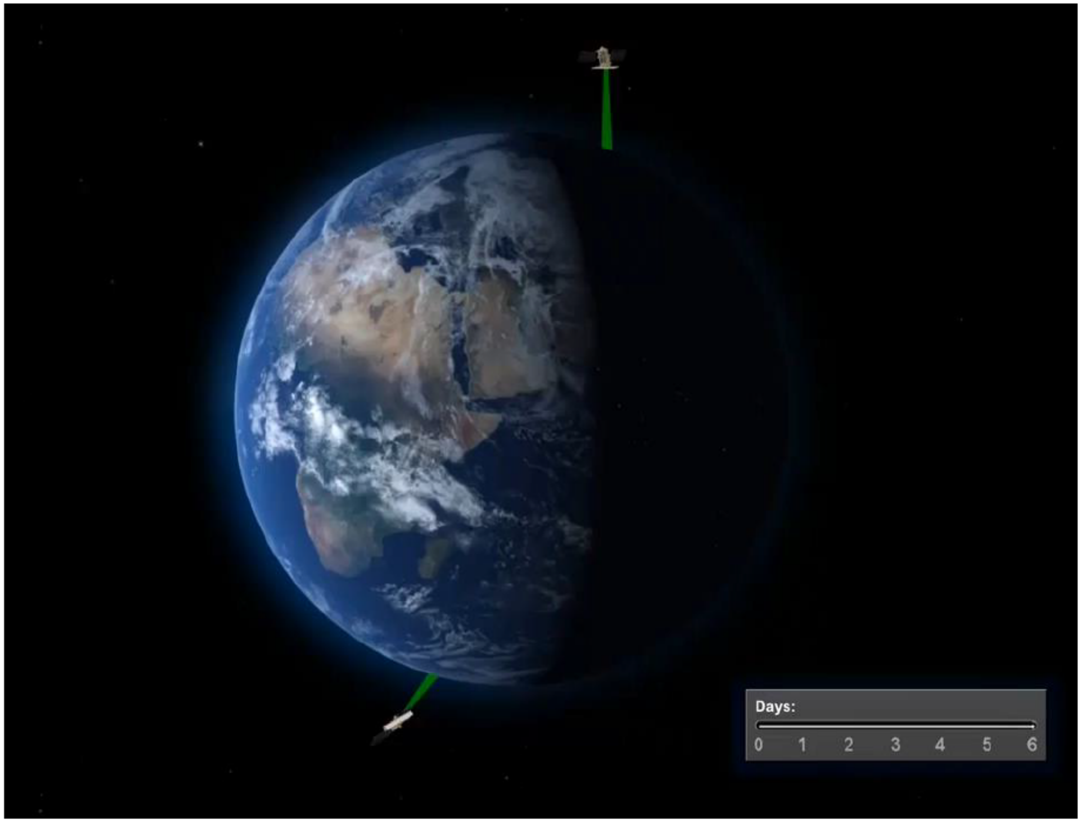


InSAR for Geotech Asset Management



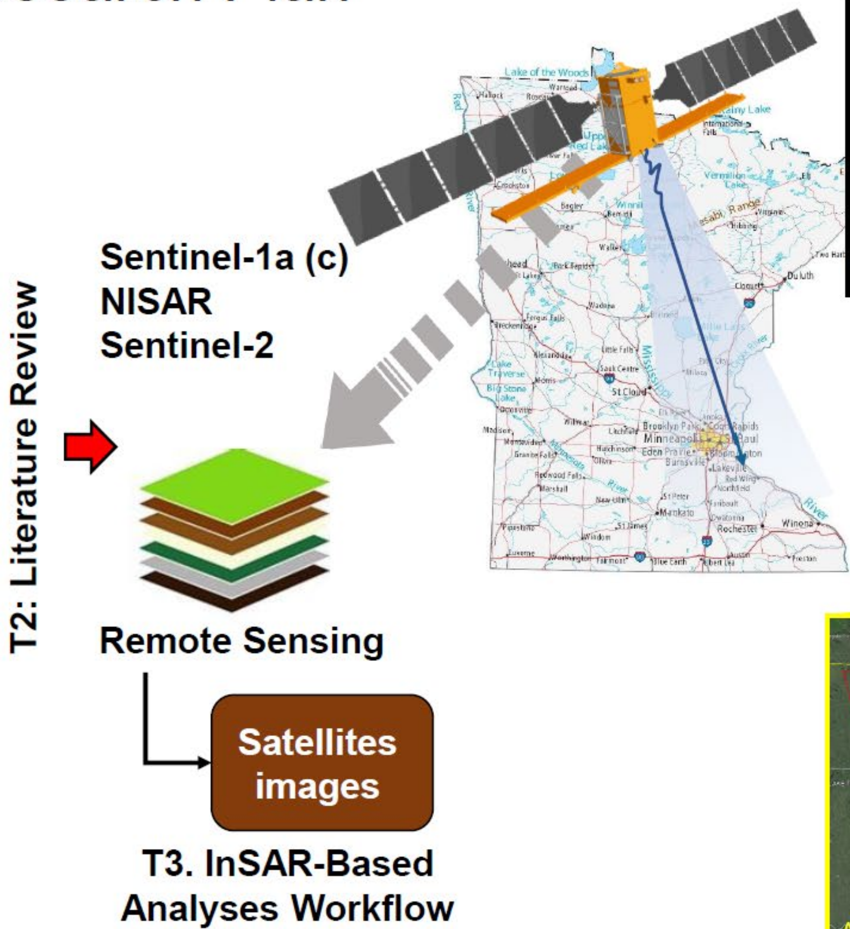
InSAR for Geotech Asset Management

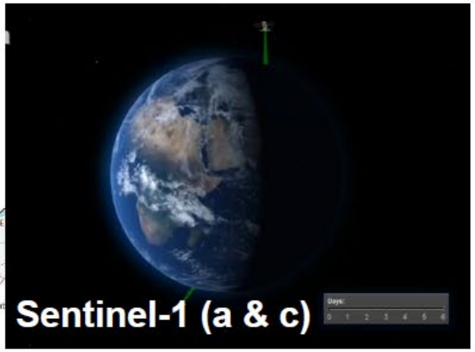
- Develop a fully automated, near real-time monitoring system to detect and extract abnormal ground deformation along highways using:
  - Interferometric Synthetic Aperture Radar (InSAR)
  - SAR
  - Optic data
  - Combined with in-situ data (GNSS and corner reflectors)

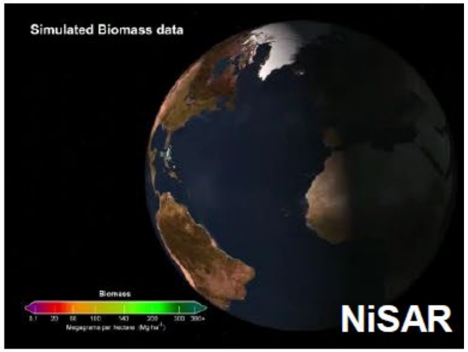


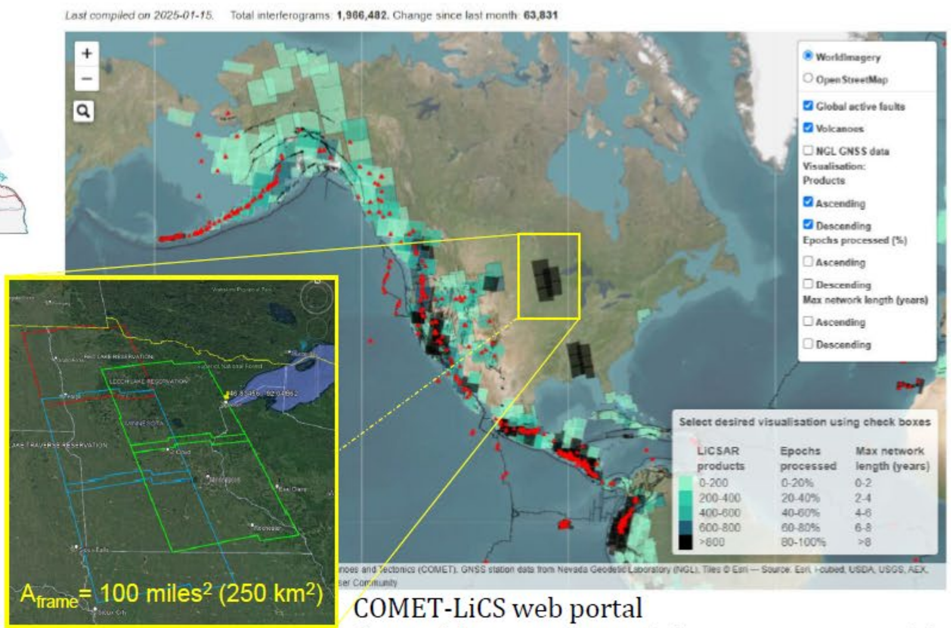
InSAR for Geotech Asset Management

Research Plan





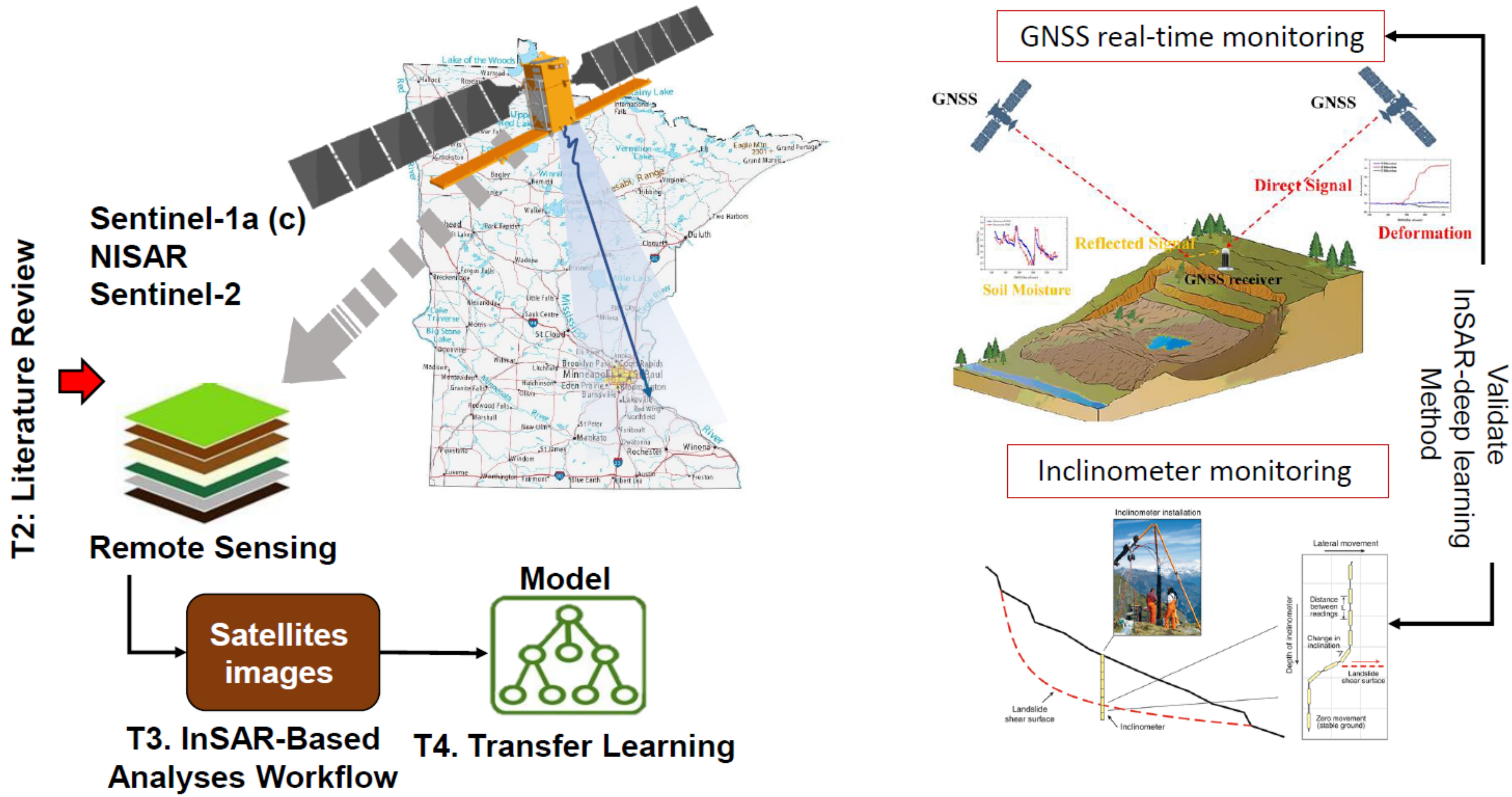




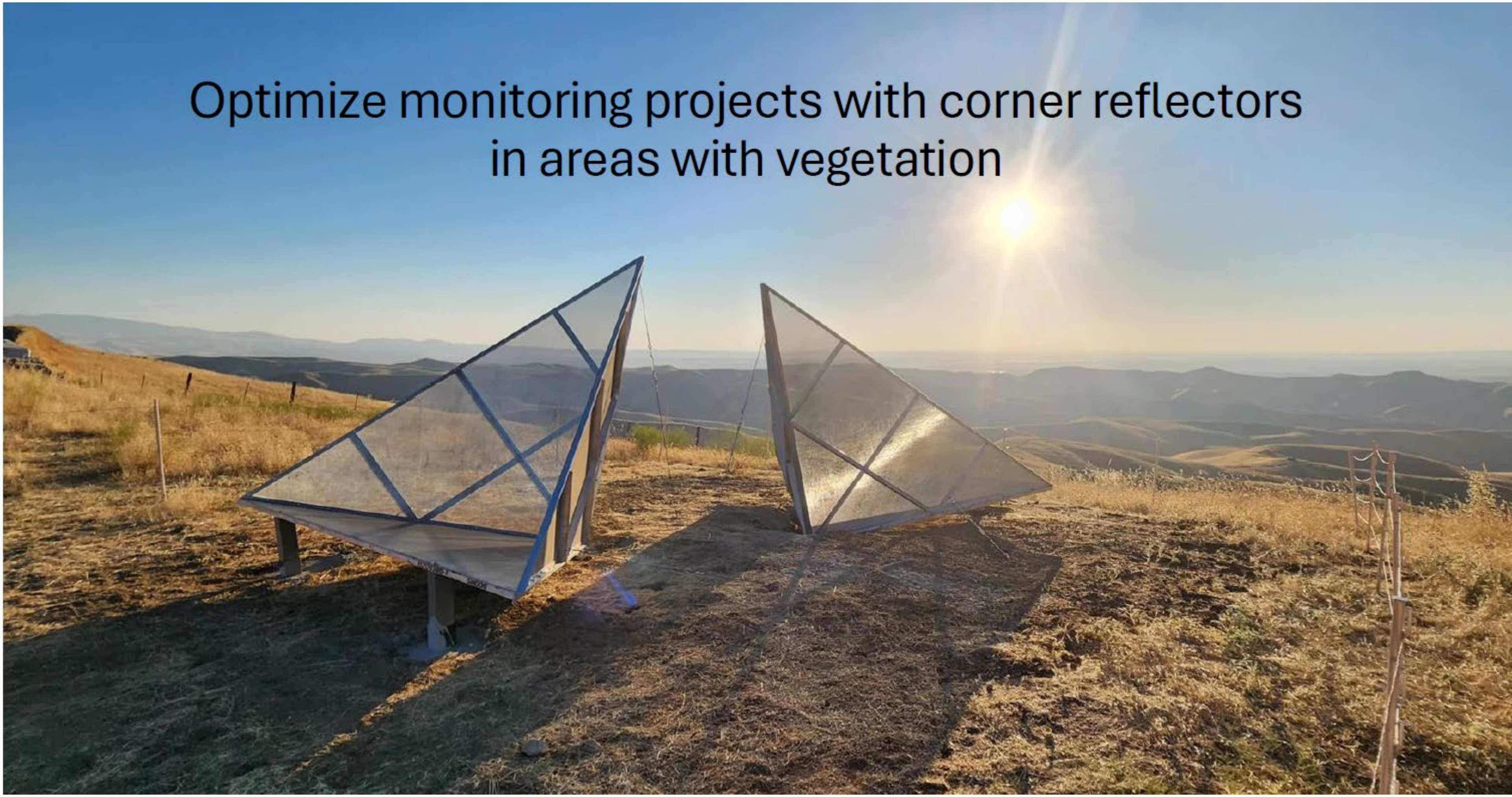
COMET-LiCS web portal
(https://comet.nerc.ac.uk/COMET-LiCS-portal/)

InSAR for Geotech Asset Management

Research Plan



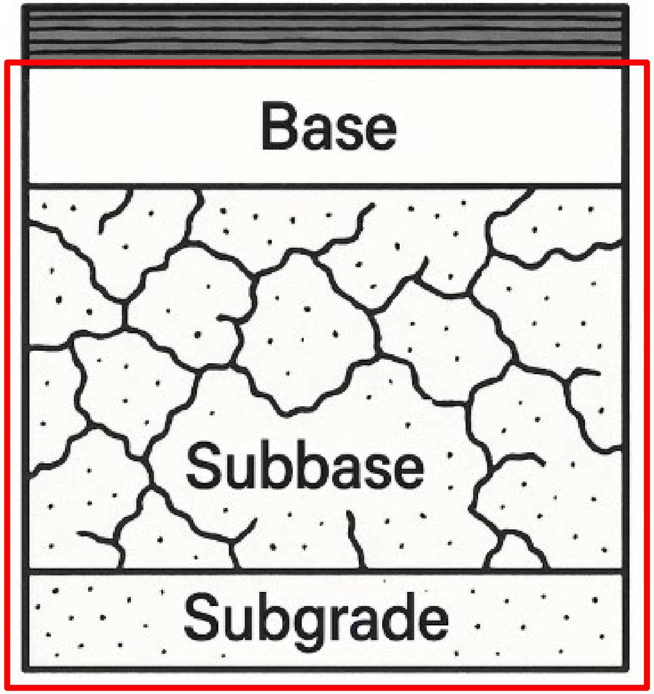
InSAR for Geotech Asset Management



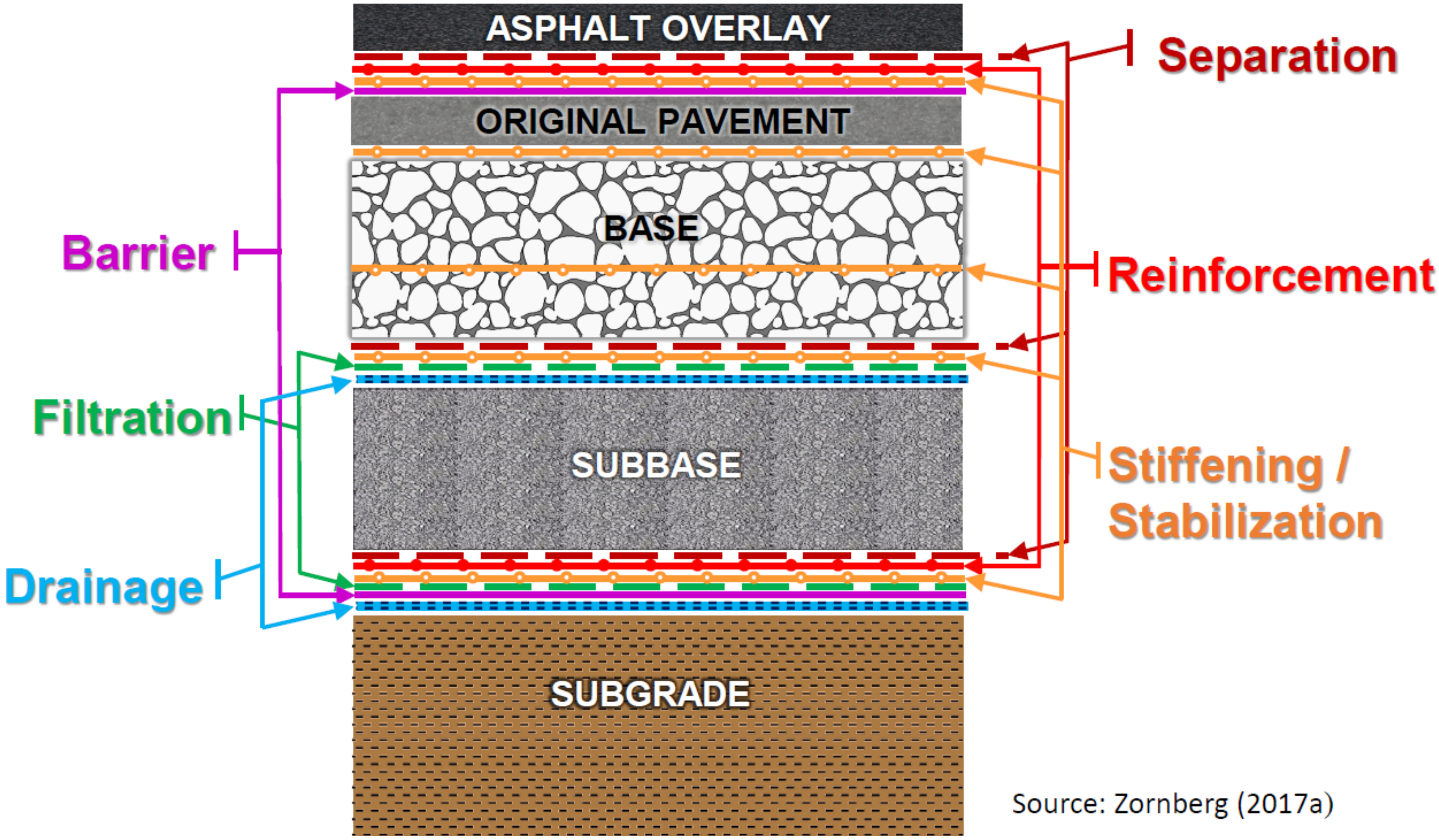
Quantifying Benefits of Geosynthetics for Pavement Foundations

In the context of Geosynthetics in *Pavement Foundations:*

- Improve/update general guidelines and specs
- Framework to add benefits of geosynthetics in:
  - Pavement design (MnPAVE)
  - LCCA



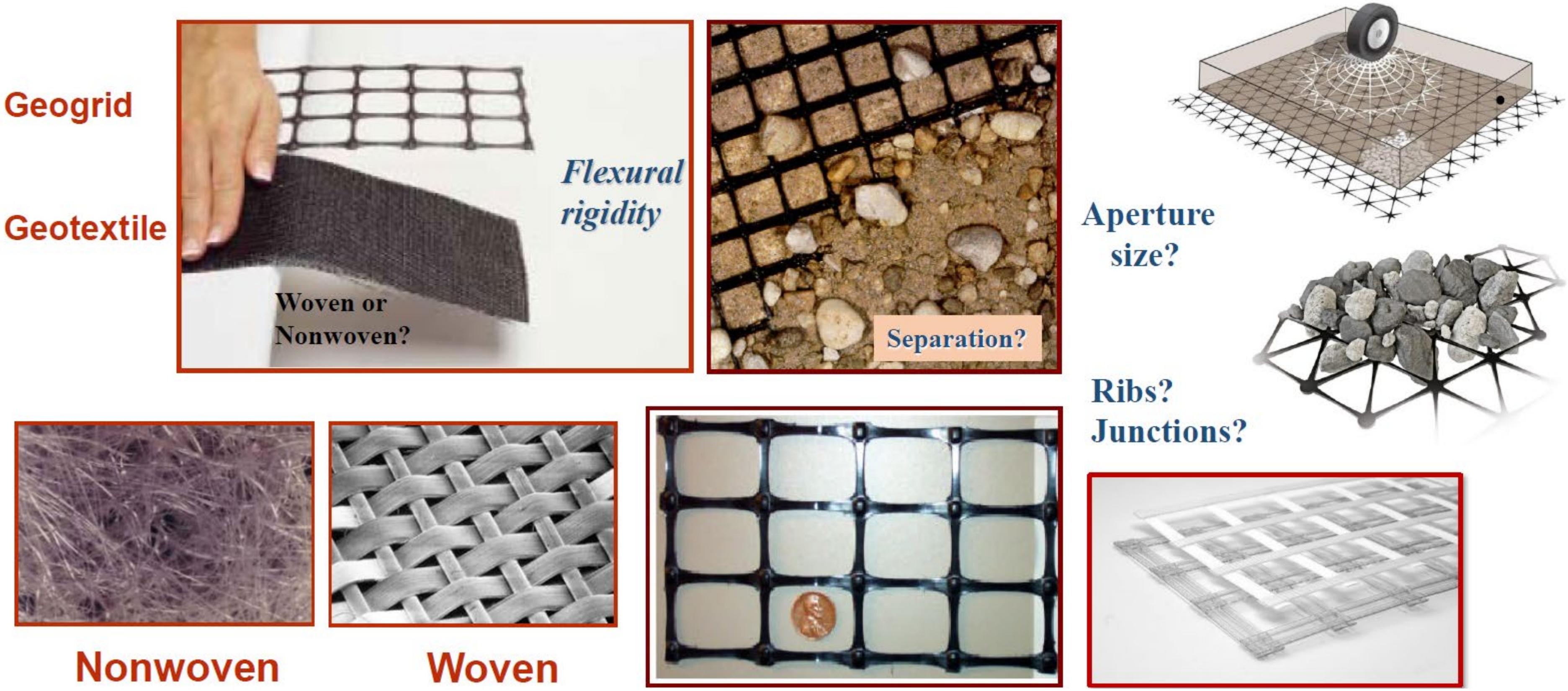
Quantifying Benefits of Geosynthetics for Pavement Foundations



Source: Zornberg (2017a)

Quantifying Benefits of Geosynthetics for Pavement Foundations

Geogrids vs Geotextiles for Stabilization

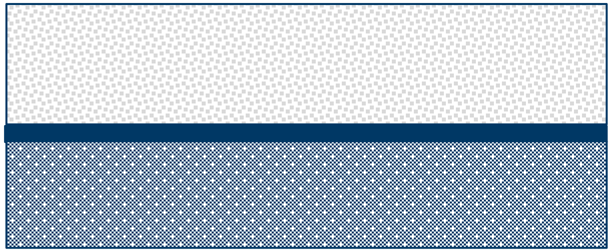


When to Use Geosynthetics?

- Deal with poor/soft subgrade
- Improve structural support of traffic loads
- Extend service life of pavement
- Reduce thickness of pavement foundation layers
- Increase reliability of design (e.g., reduce subgrade variability)
- To account for *actual* subgrade stiffness/strength lower than assumed stiffness/strength in design
- Improve water management in pavement system

Quantifying Benefits of Geosynthetics for Pavement Foundations

Mechanisms

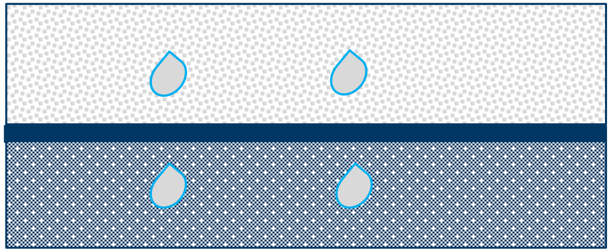


Separation

Properties for Consideration:

- Soil/Aggregate:
  - Relatively high contrast in gradations for layers in contact (e.g., coarse subbase on fine subgrade)
- Geotextile:
  - Permittivity

Mechanisms



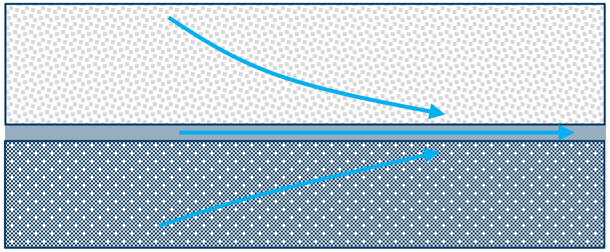
Filtration

Properties for Consideration:

- Soil/Aggregate:
  - N/A
- Geotextile:
  - Permittivity and Apparent Opening Size (AOS)

Quantifying Benefits of Geosynthetics for Pavement Foundations

Mechanisms



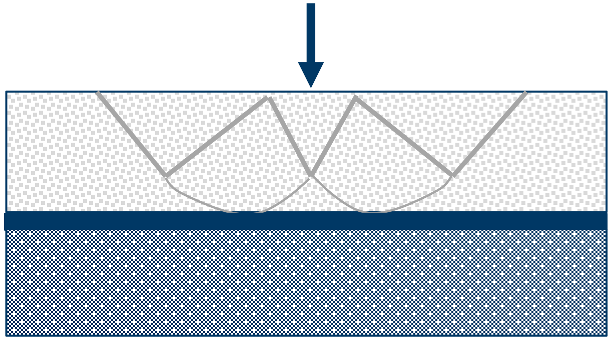
Drainage

Properties for Consideration*:*

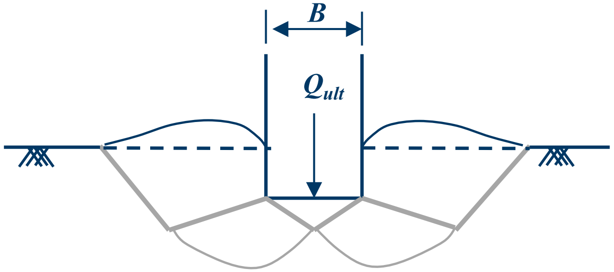
- Soil/Aggregate:
  - N/A
- Geotextile:
  - Permittivity and Apparent Opening Size (AOS)
- Pavement Geometry:
  - x-slope

Quantifying Benefits of Geosynthetics for Pavement Foundations

Mechanisms



Reinforcement

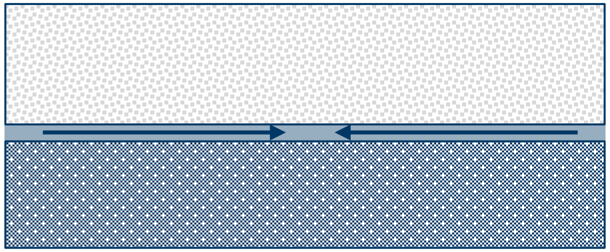


Properties for Consideration:

- Soil/Aggregate:
  - Gradation and Particle Shape
- Geotextile:
  - Apparent Opening Size (AOS) and Tensile Strength
- Geogrid:
  - Grid Aperture Size and Tensile Strength

Quantifying Benefits of Geosynthetics for Pavement Foundations

Mechanisms



Confinement (lateral restraint)

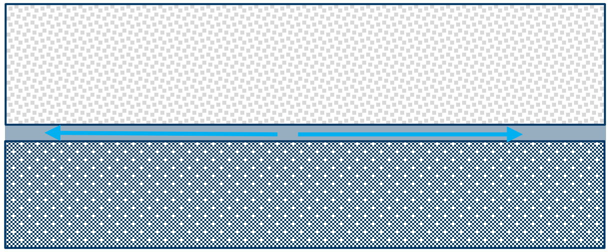
Properties for Consideration:

- Soil/Aggregate:
  - Gradation and Particle Shape
- Geotextile:
  - Apparent Opening Size (AOS)
- Geogrid:
  - Grid Aperture Size
  - Size geogrid according to

$$D_{50} \leq \underline{\text{Geogrid Aperture Size}} \leq 2*D_{85}$$

Note: Use the smaller grid aperture dimension

Mechanisms


Wicking

Properties for Consideration:

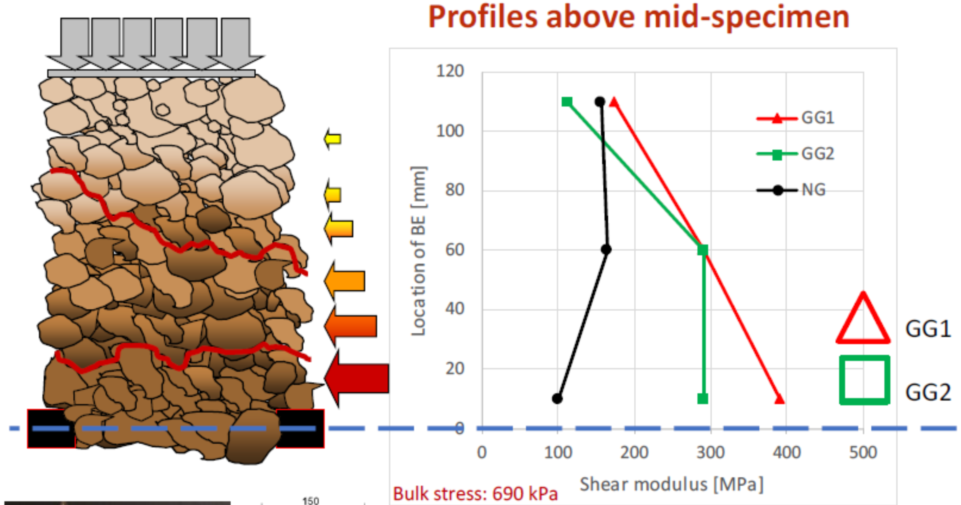
- Soil/Aggregate:
  - Classification
- Geotextile:
  - Permittivity, AOS, Flow Rate, Wet Front Movement
- Pavement Features:
  - Proper Drainage System(e.g., ditch, edge drains, etc)

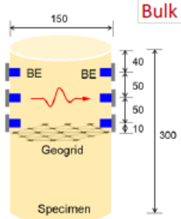
MnDOT Geotextile Guideline

Soil Type/Rvalue/DCP/CBR	R_{value}	DCP	CBR	MnDOT Type	Separation	Filtration	Drainage	Reinforcement	Confinement	Moisture Management	Approx. Cost
Good to marginal dry soils	>25	<20	>6	4	Yes	Yes	Yes	Yes	No	No	$
Good to marginal dry soils	>25	<20	>6	7	Yes	Yes	Yes	Yes	No	No	$
Weak Dry/Damp Soils	15-25	20-60	3-6	New 5	Yes	Yes	Yes	Yes	Yes	No	$
Weak Dry/Damp Soils	15-25	20-60	3-6	9	Yes	Yes	Yes	Yes	Yes	No	1.5 x $
Weaker Damp Soils	<15	>60	<3	10	Yes	Yes	Yes	Yes	Yes	No	1.5 x $
Very weak and/or wet soils	<15	>60	<3	11	Yes	Yes	Yes	Yes	Yes	Some Manufactures	2 x $
Very weak and/or wet soils	<15	>60	<3	12	Yes	Yes	Yes	Yes	Yes	Some Manufactures	2 x $
Very weak and/or wet soils	<15	>60	<3	13	Yes	Yes	Yes	Yes	Yes	Yes	2 x $

Quantifying Benefits of Geosynthetics for Pavement Foundations

Shear Modulus (Mechanically Stabilized Layer)
Profiles above mid-specimen

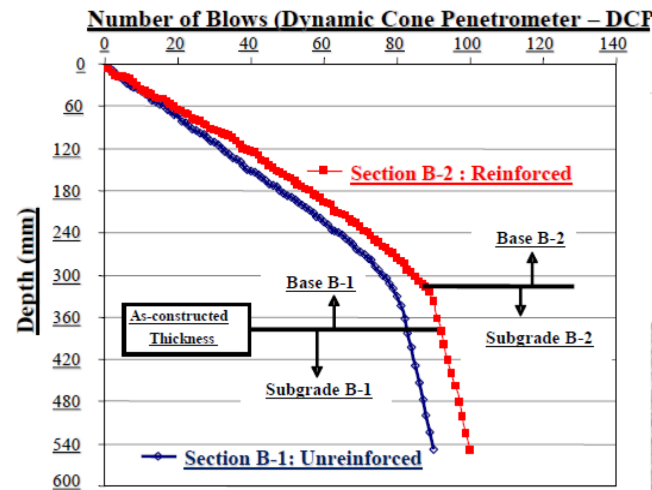


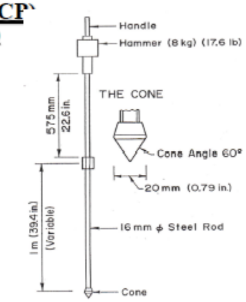


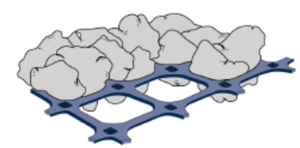
AASHTO T307
Resilient Modulus Testing

Kang et al. (TRR 2020)

Univ. of Illinois Full-scale Tests







Kwon and Tutumluer (TRR 2009)

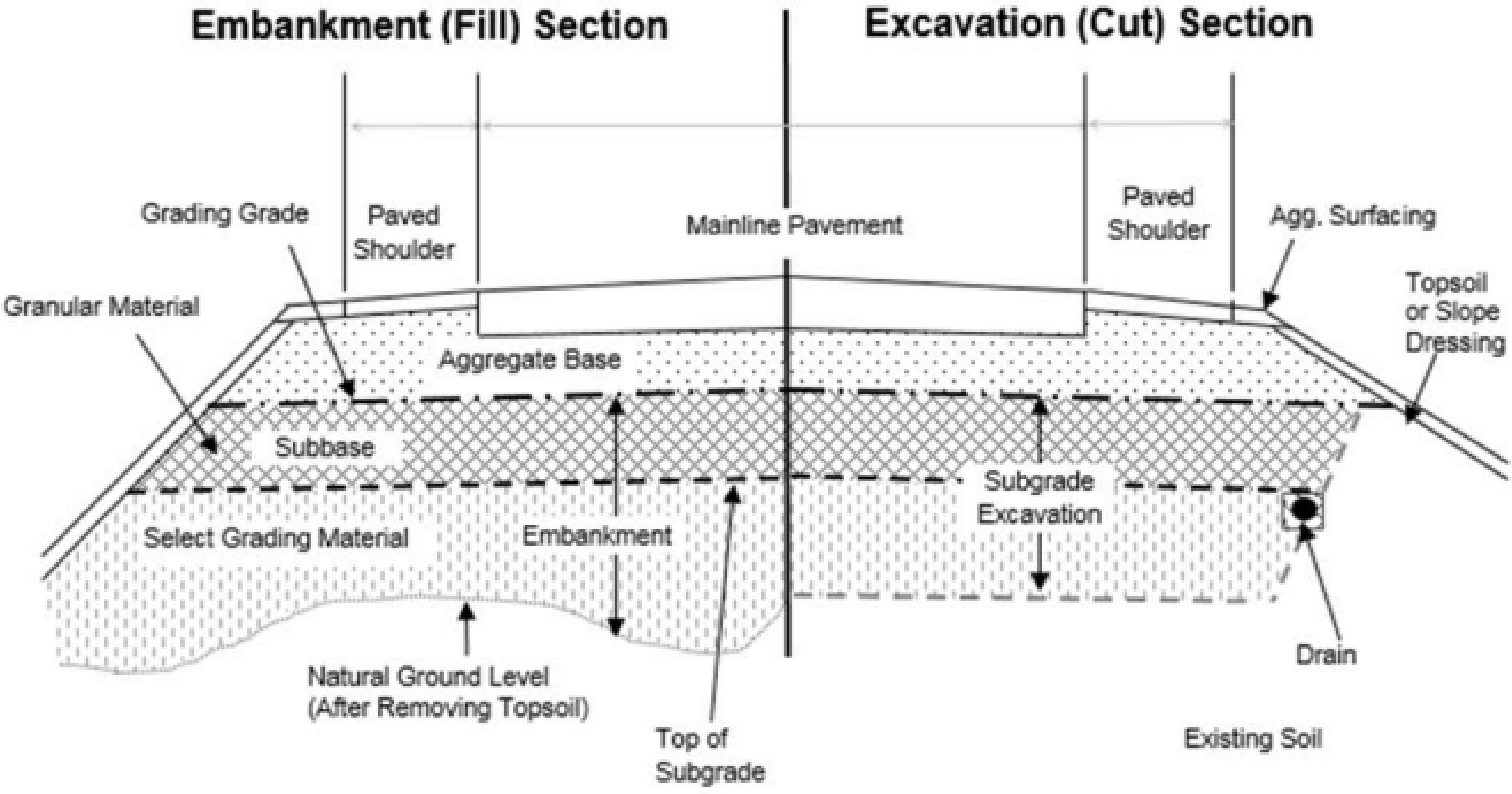
Field & Laboratory Validation of Geogrid Stiffening due to Aggregate Interlock

RCA Main Environmental and Performance Issues

- Environmental:
  - High pH
  - Leaching of heavy metals
- Performance (drainage):
  - Tufa formation (calcium carbonate)

Photos: PennDOT

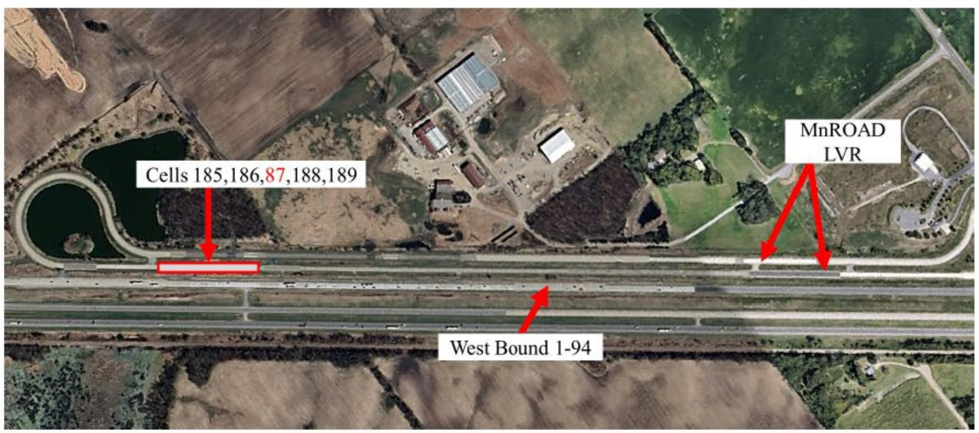
Where to use RCA?



RCA in Pavement Foundations

LOCATION OF TEST CELLS

- 4 x Test Cells
  - Cell 185 – Coarse RCA
  - Cell 186 – Fine RCA
  - Cell 188 – Limestone (Virgin Aggregate)
  - Cell 189 – RCA+RAP



CELL 185	CELL 186	CELL 188	CELL 189
3.5in Asphalt	3.5in Asphalt	3.5in Asphalt	3.5in Asphalt
12in Coarse RCA	12in Fine RCA	12in Limestone (VA)	12in RCA + RAP
3.5in Sand Subbase	3.5in Sand Subbase	3.5in Sand Subbase	3.5in Sand Subbase
Sand	Sand	Clay Loam	Clay Loam

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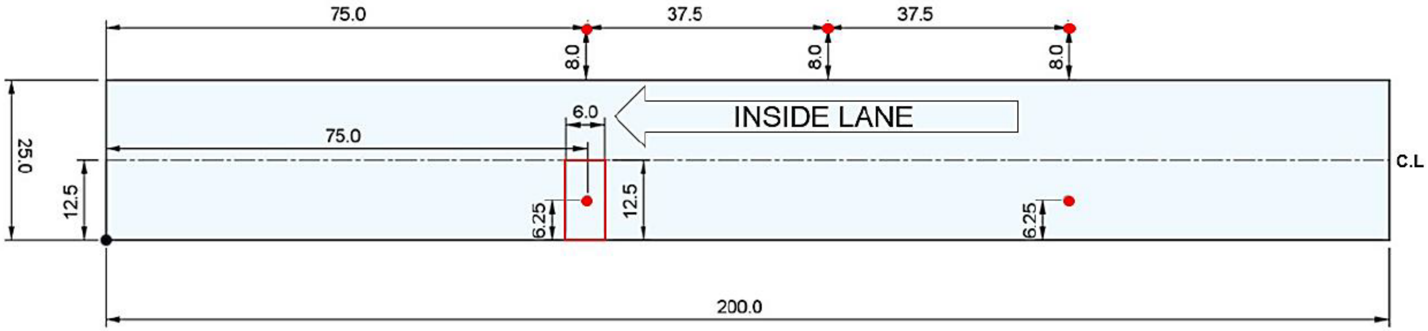
Sample Collection



*All measurements are in feet.
*The sketch applies to all cells (Cell185, 186, 188 and 189) as they share identical dimensions.

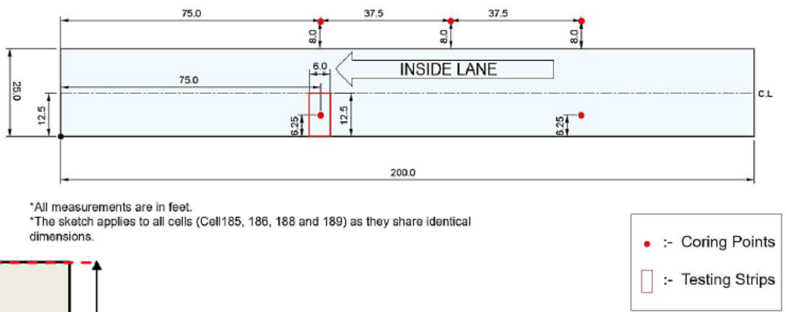
● :- Coring Points
▯ :- Testing Strips

2 x Sampling points on the section (with 3 on shoulders)
1 x Test Strip

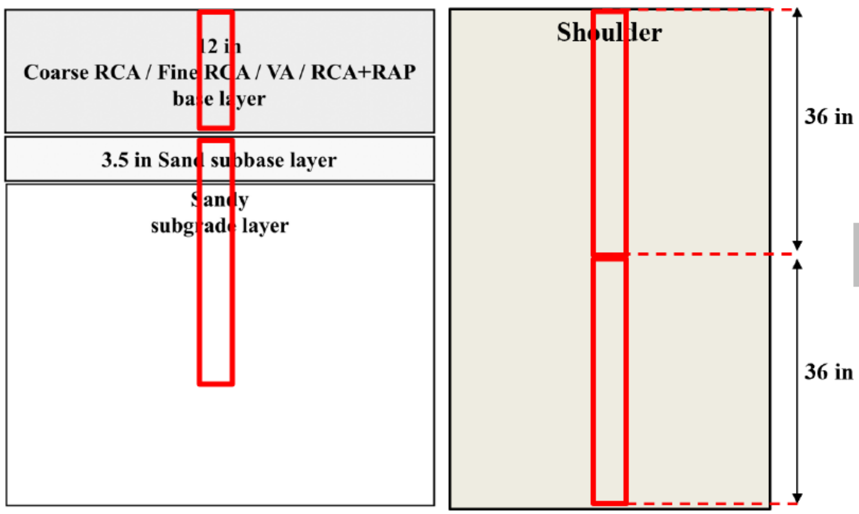
ORDER OF WORK PRIORITY
FINE RCA (Cell 186) > LIMESTONE (Cell 188) > COARSE RCA (Cell 185) > RCA+RAP (Cell 189)

MICHIGAN STATE UNIVERSITY

Sample Collection (cont)



*All measurements are in feet.
*The sketch applies to all cells (Cell185, 186, 188 and 189) as they share identical dimensions.



Shelby Tubes Cutting
Extraction of samples for every 6 in depth

MICHIGAN STATE UNIVERSITY

Field Work

:- Testing Strips

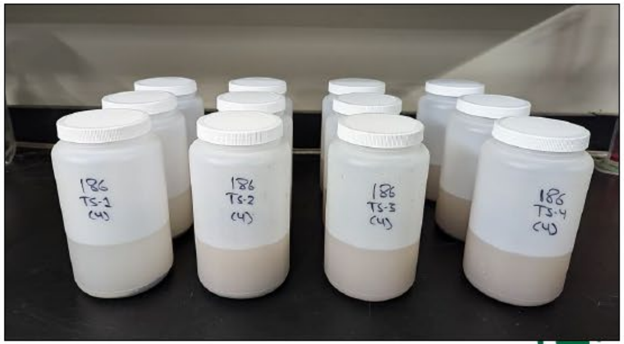
MICHIGAN STATE
UNIVERSITY

Leaching Tests

Parameters	Details
Particle Size (85% wt less than)	No 4 sieve
Minimum Dry Mass (g-dry)	80 ± 0.02
Contact Time (hours)	72 ± 2
Effluent (DI Water) Concentration	1000 ml
Vessel Size	2000 ml
Revolutions (rpm) for EPA 1316	28 ± 2

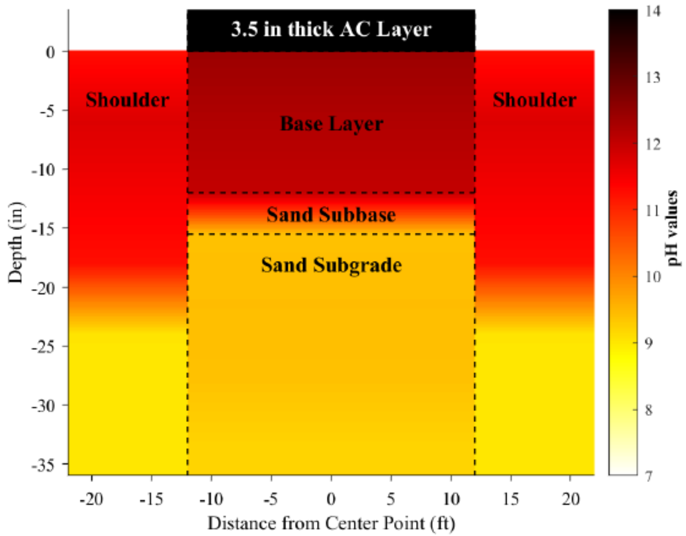
AIR DRYING OF SAMPLES

LEACHING TEST (EPA 1316)



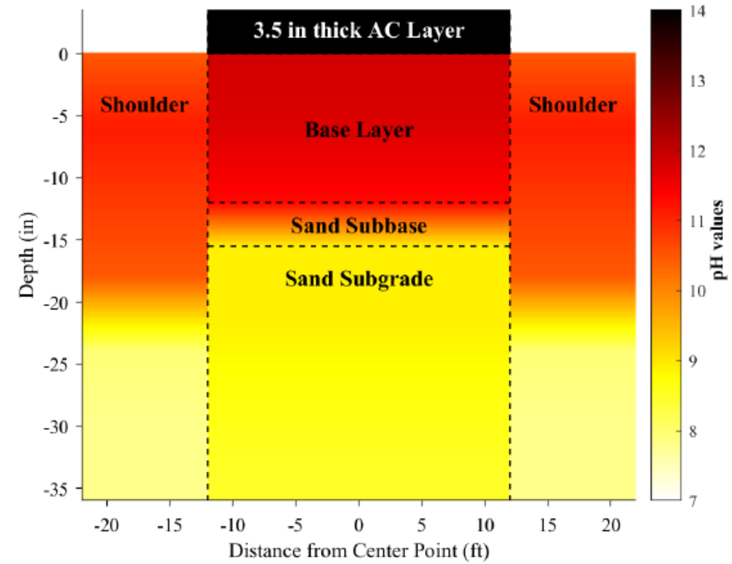
LEACHING TEST (STAGNANT PROCEDURE)

Test Results (Cell 185 Coarse RCA)



pH Measurements

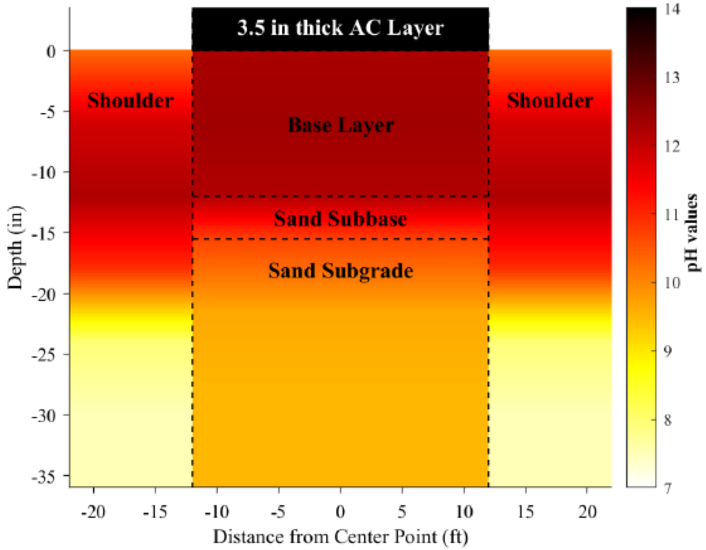
EPA 1316



pH Measurements

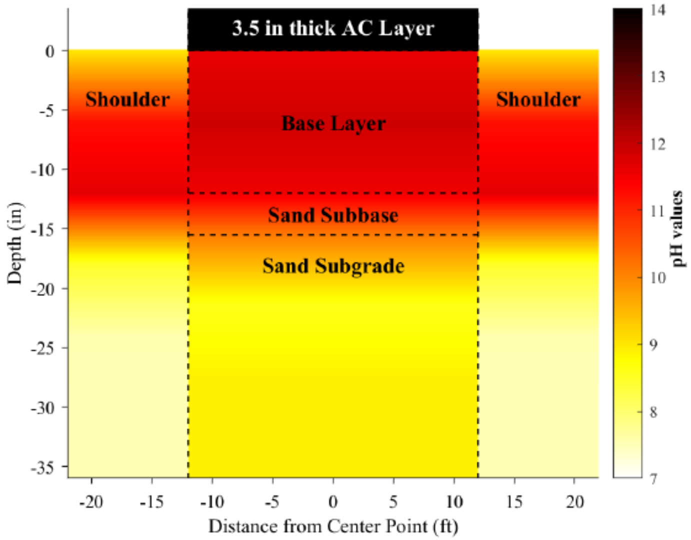
STAGNANT TESTS

Test Results (Cell 186 Fine RCA)



pH Measurements

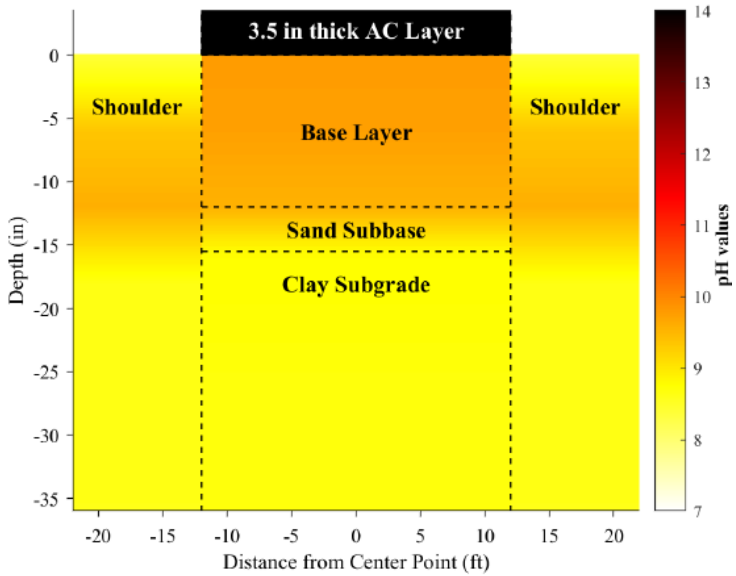
EPA 1316



pH Measurements

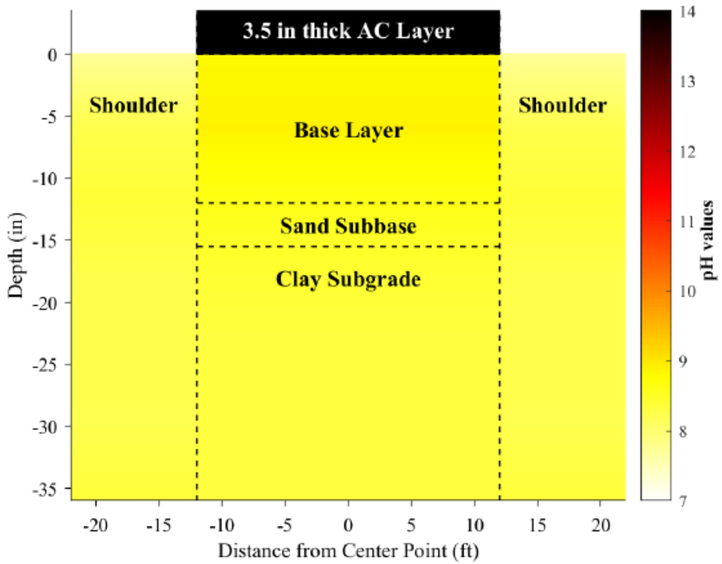
STAGNANT TESTS

Test Results (Cell 188 Limestone)



pH Measurements

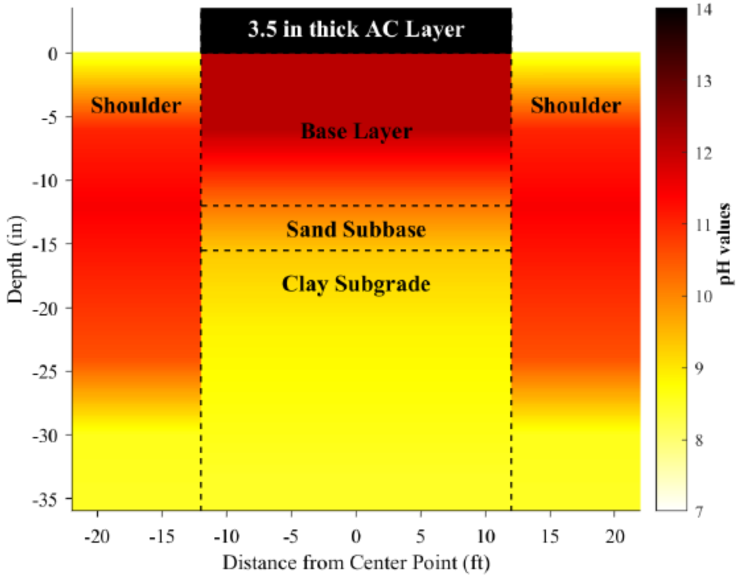
EPA 1316



pH Measurements

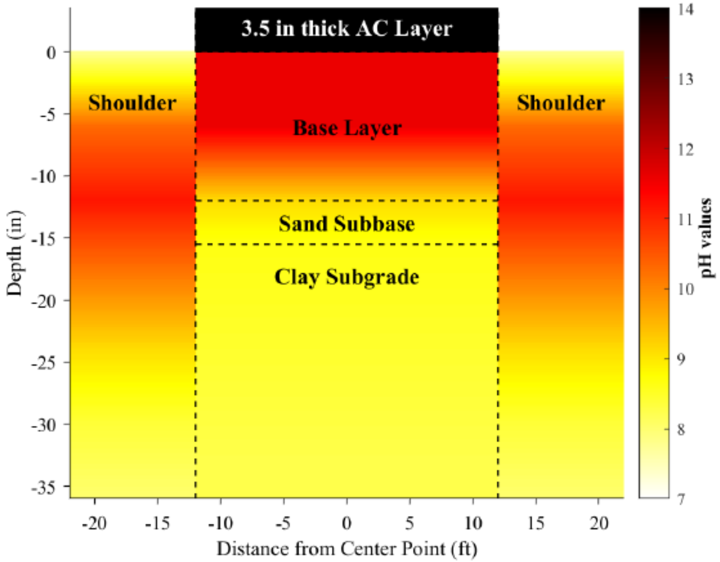
STAGNANT TESTS

Test Results (Cell 189 RCA+RAP)



pH Measurements

EPA 1316

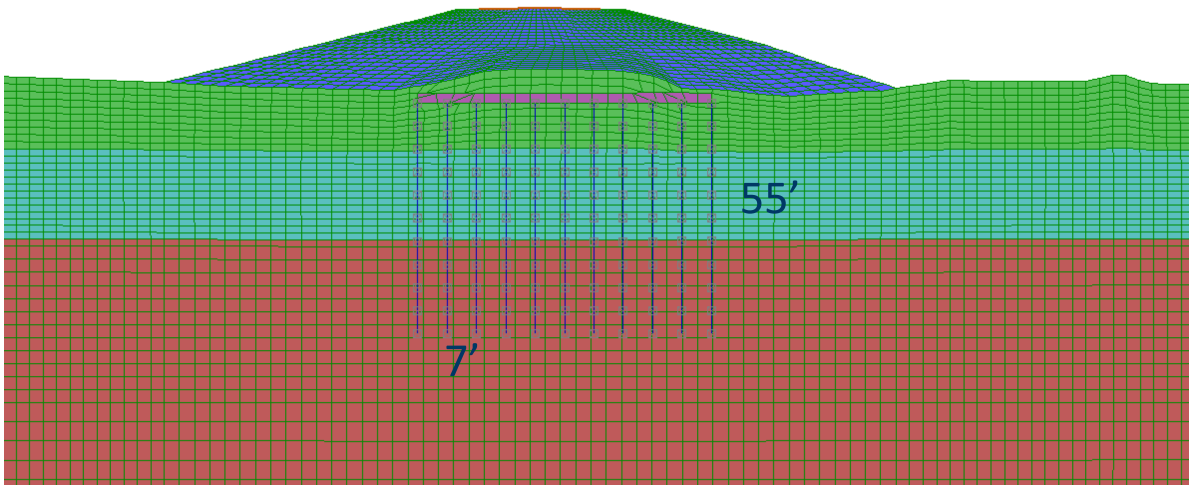


pH Measurements

STAGNANT TESTS

Optimization of CSE

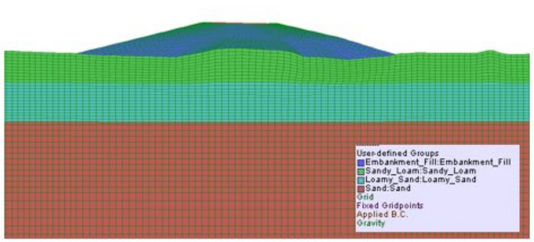
- Implementation of Advanced Geotech Modeling Software for Complex Projects



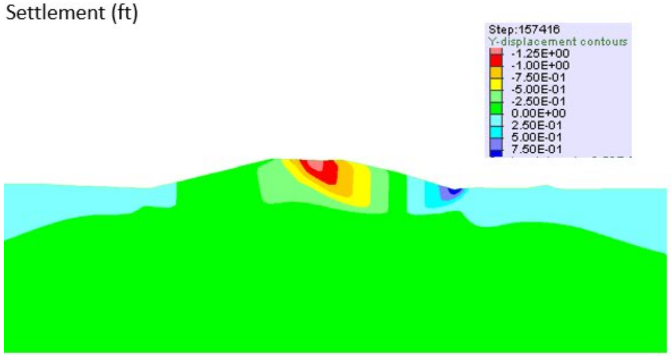
TH-93 – Column Supported Embankment (CSE)

Embankment without support

Mesh/Geometry

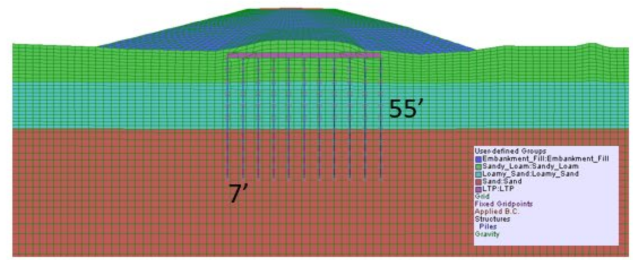


Settlement (ft)

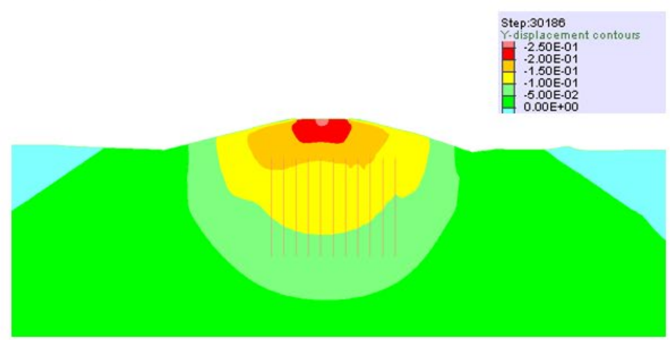


Column Supported Embankment (CSE)

Mesh/Geometry



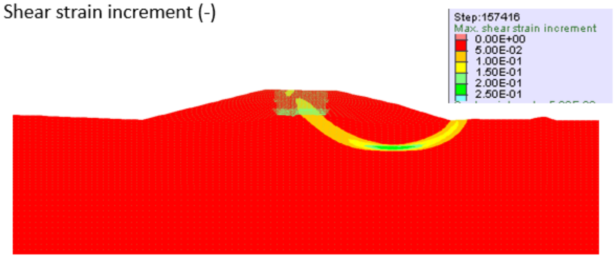
Settlement (ft)



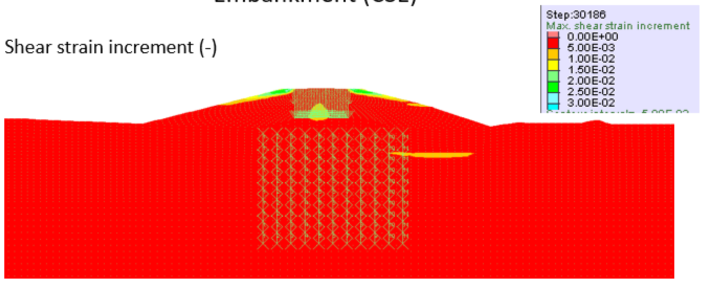
TH-93 – Column Supported Embankment (CSE)

Embankment without support	Column Supported Embankment (CSE)

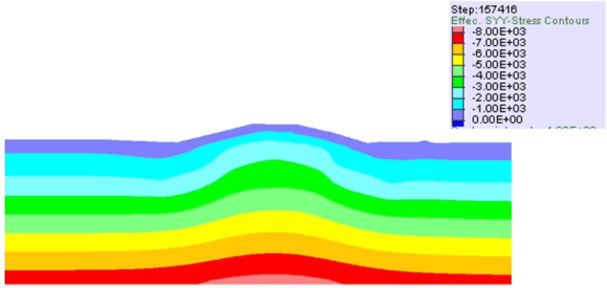
Shear strain increment (-)



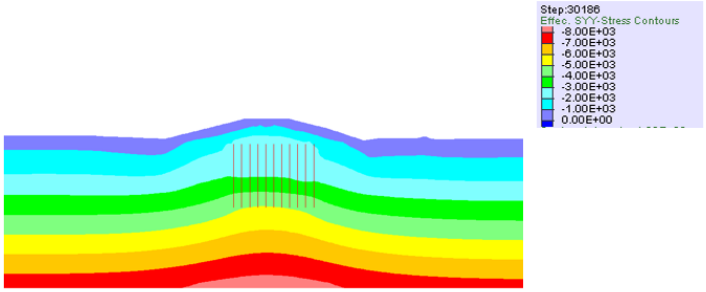
Shear strain increment (-)



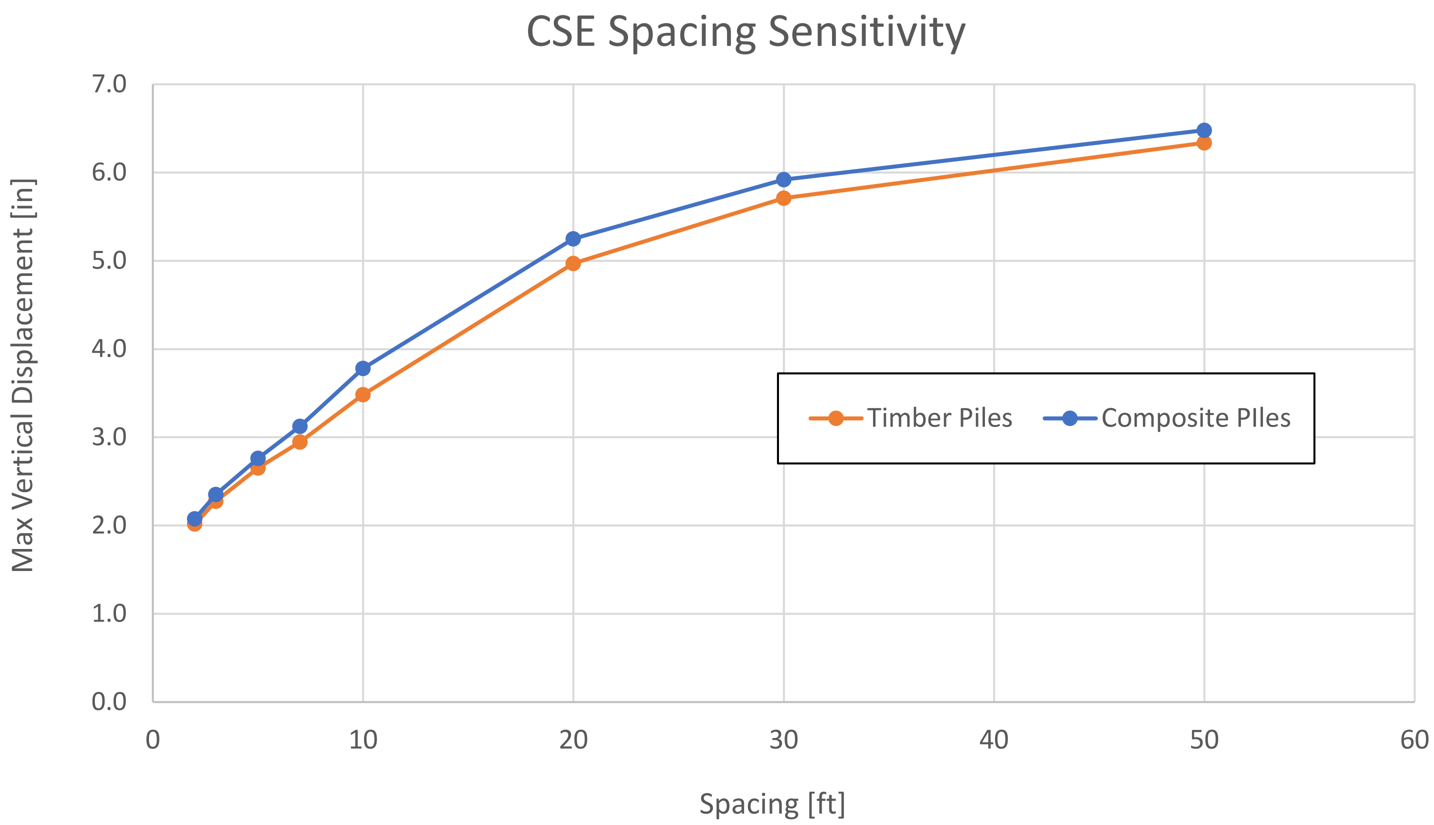
Vertical effective stress (psf)



Vertical effective stress (psf)

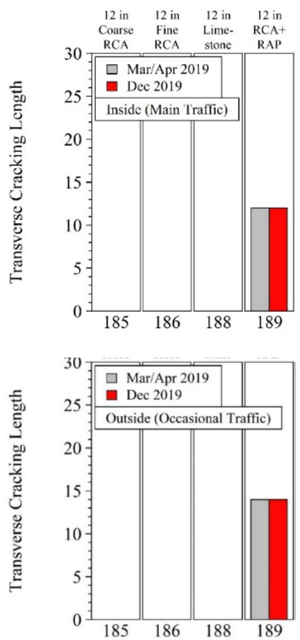


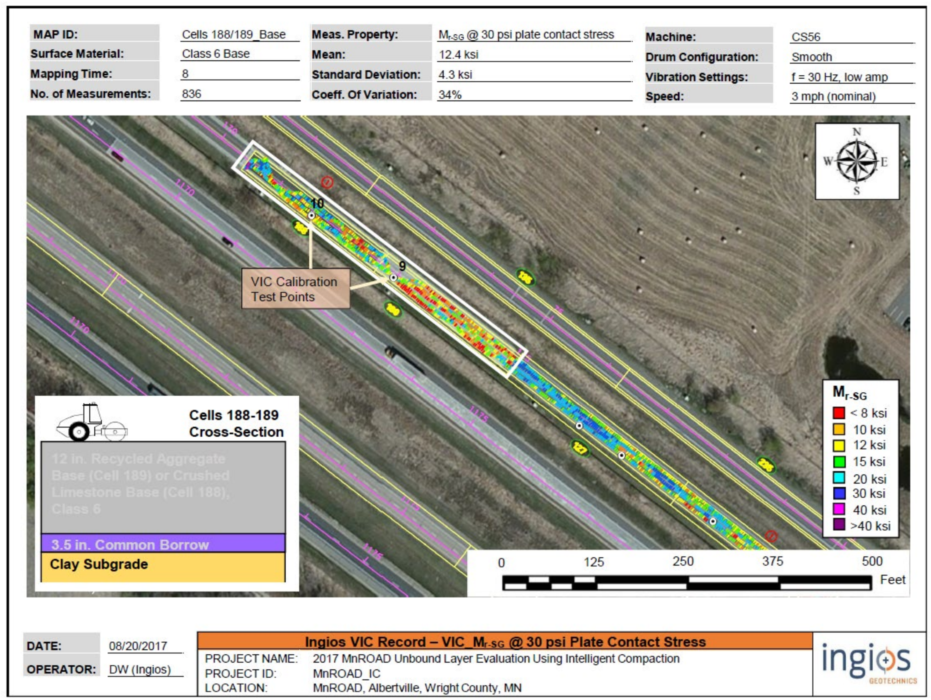
TH-93 – Column Supported Embankment (CSE)



Pavement Foundation Uniformity (aka IC)

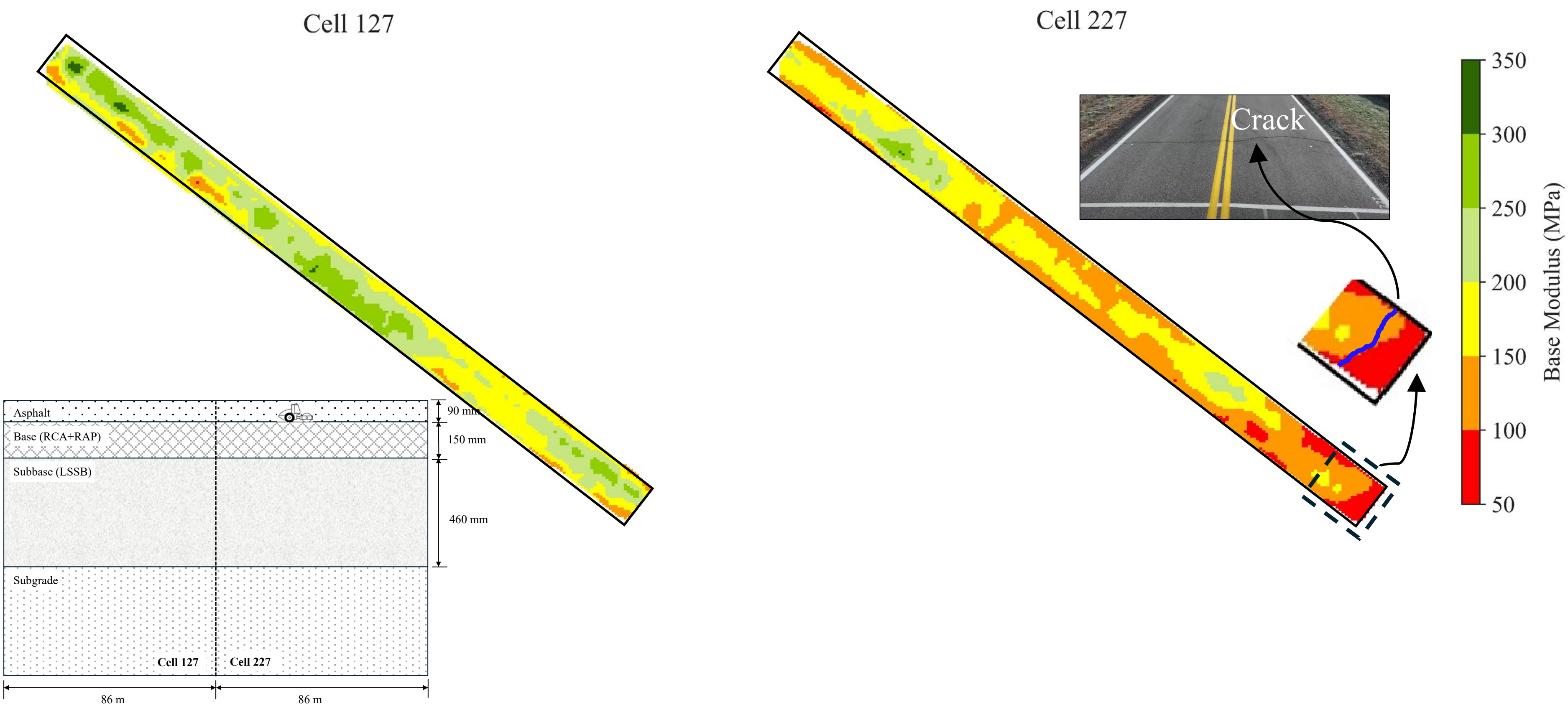
Pavement Foundation Uniformity





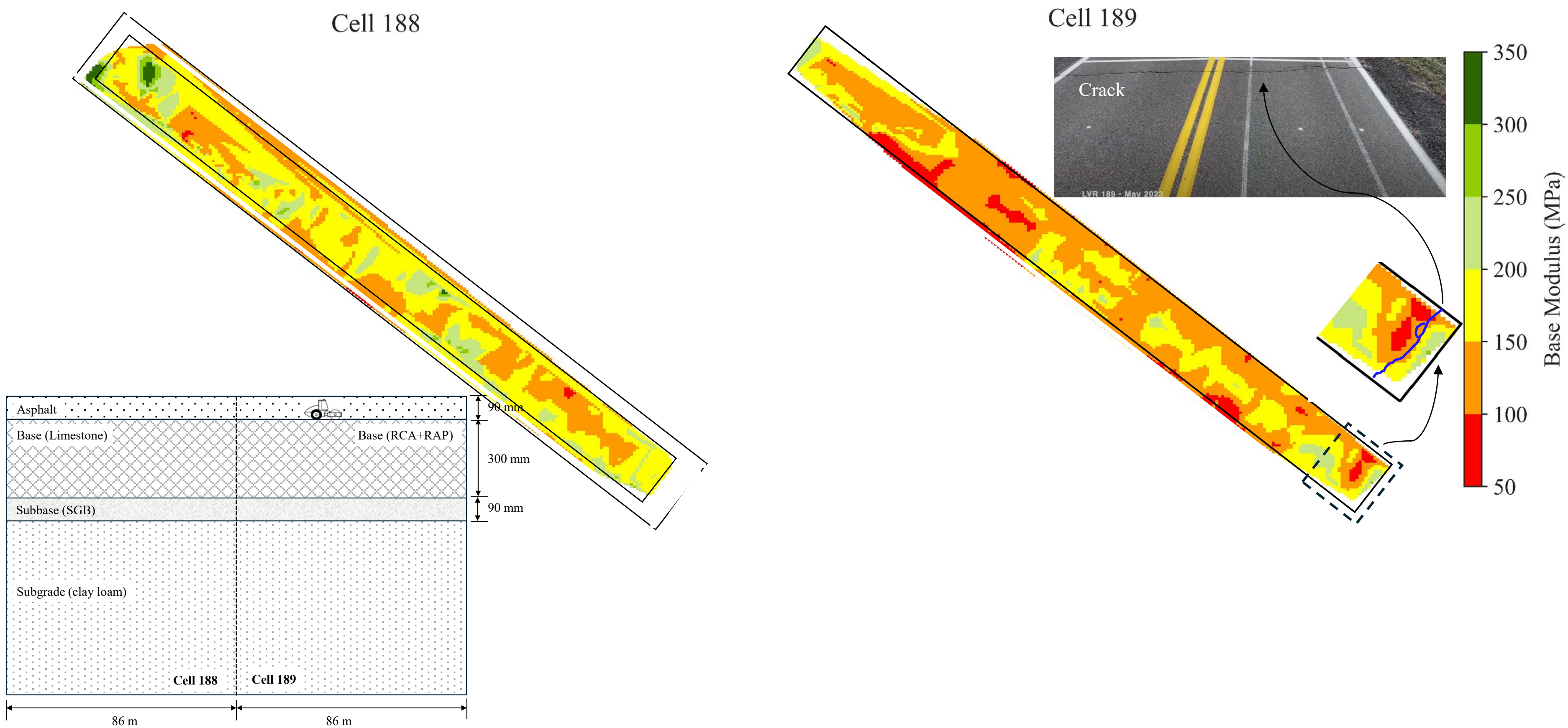
White and Vennapusa (2017)

Pavement Foundation Uniformity



*Sadiq, M., Velasquez, R., Aydin, C., Cetin, B., Izevbekhai, B. (2025), Influence of Initial Stiffness and Foundation Uniformity on Pavement Performance, IJPE

Pavement Foundation Uniformity



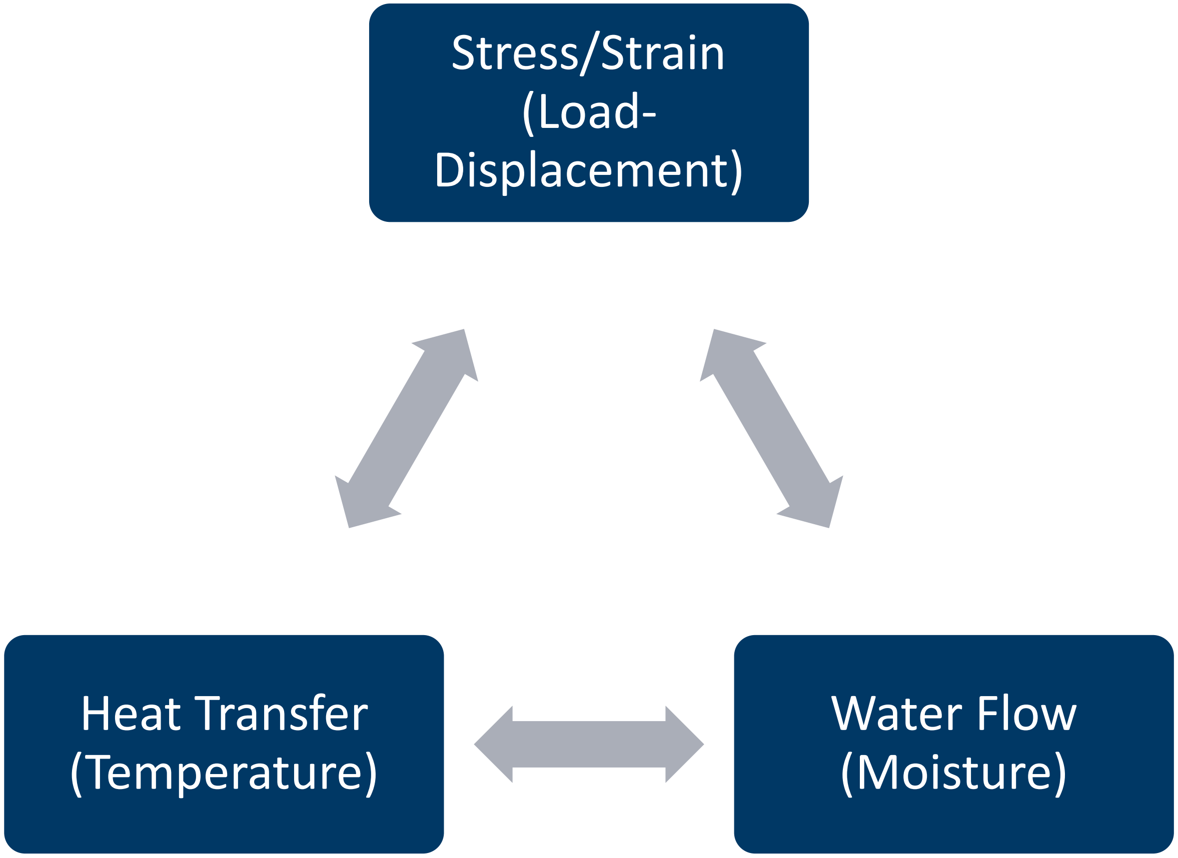
*Sadiq, M., Velasquez, R., Aydin, C., Cetin, B., Izevbekhai, B. (2025), Influence of Initial Stiffness and Foundation Uniformity on Pavement Performance, IJPE

Pavement temperature as a surrogate of performance

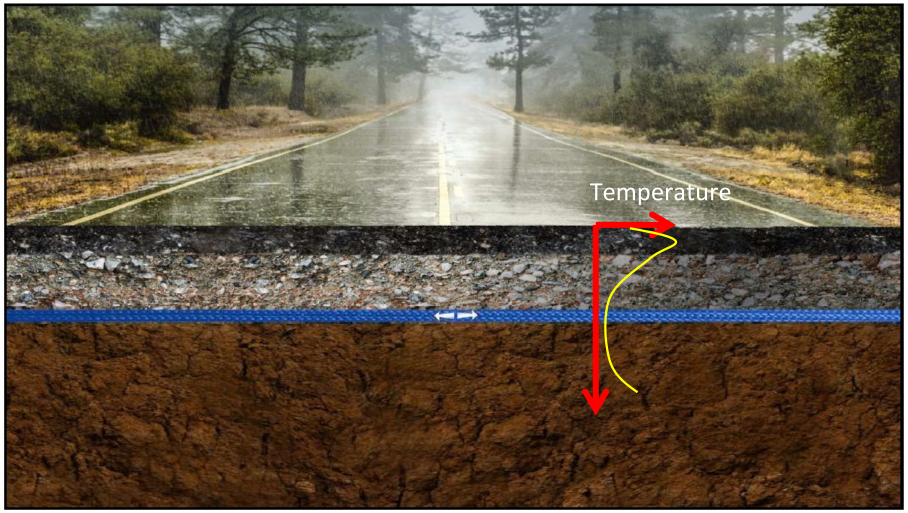
~15,000+
Sensors
Installed

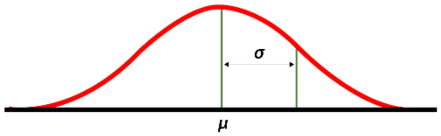
Temperature
~ 1 billion total values

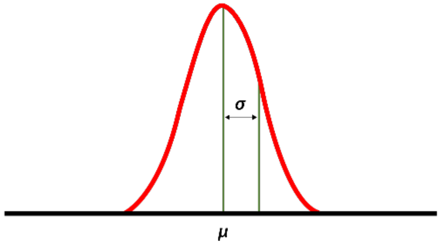
Pavement temperature as a surrogate of performance



Pavement temperature as a surrogate of performance





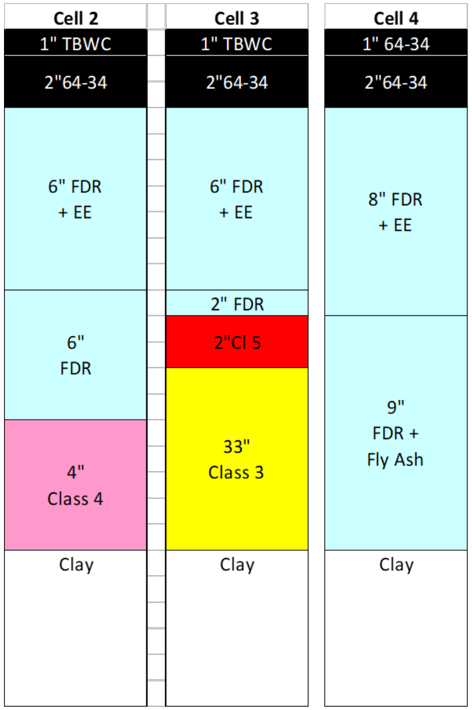


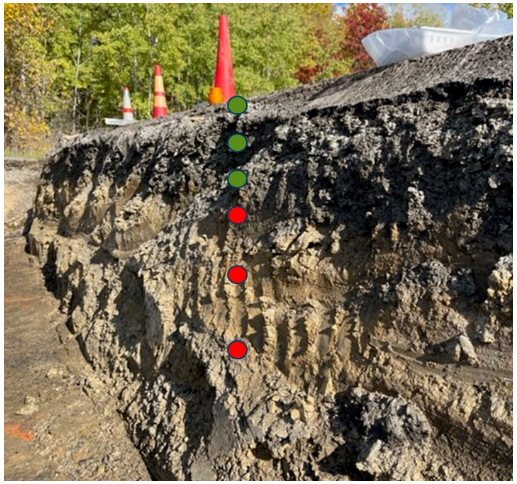
Processing Data with Descriptive Statistics:

Mean
Max
Min
Median
Variance
Standard Deviation
Kurtosis
Skewness
Range

Pavement temperature as a surrogate of performance

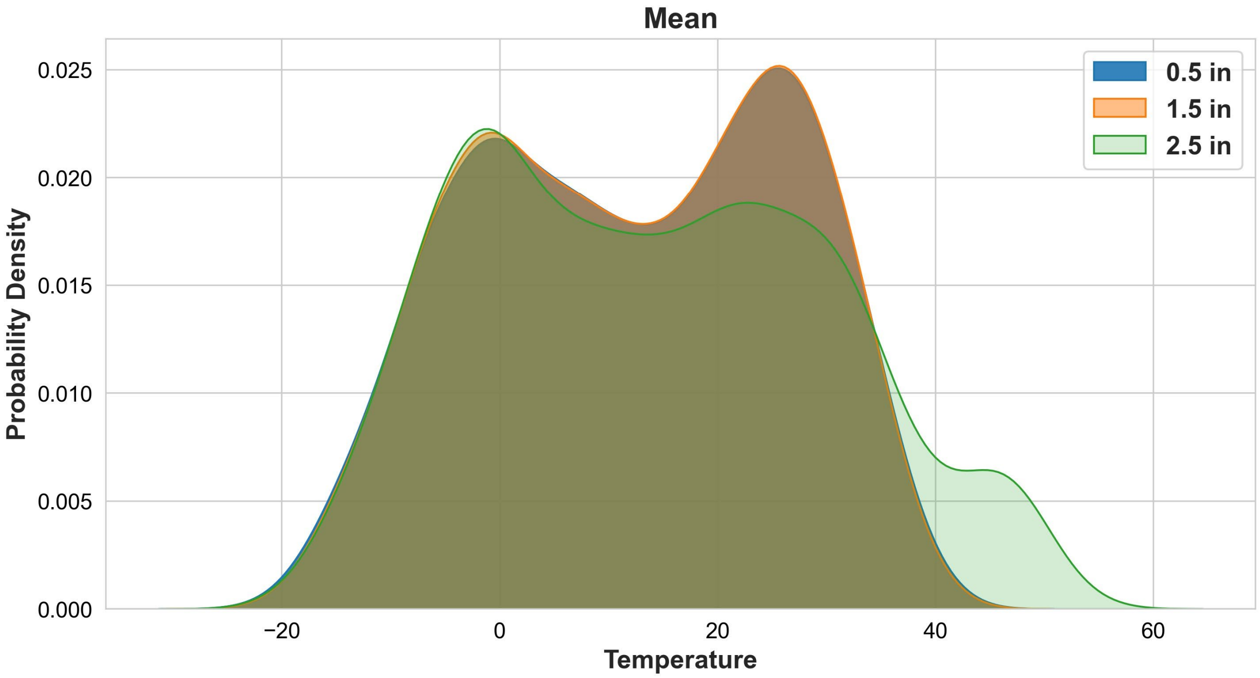
- Collected data from 3 flexible pavement test sections
  - Built on different foundations such as aggregate, Full Depth Reclamation (FDR) and Stabilized Full Depth Reclamation (SFDR)
  - Test section 2 and 3 have proper drainage vs Test section 4 that is directly on top of clay layer

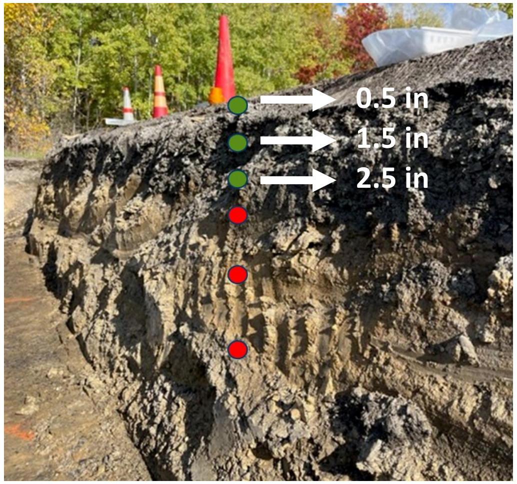




Pavement temperature as a surrogate of performance

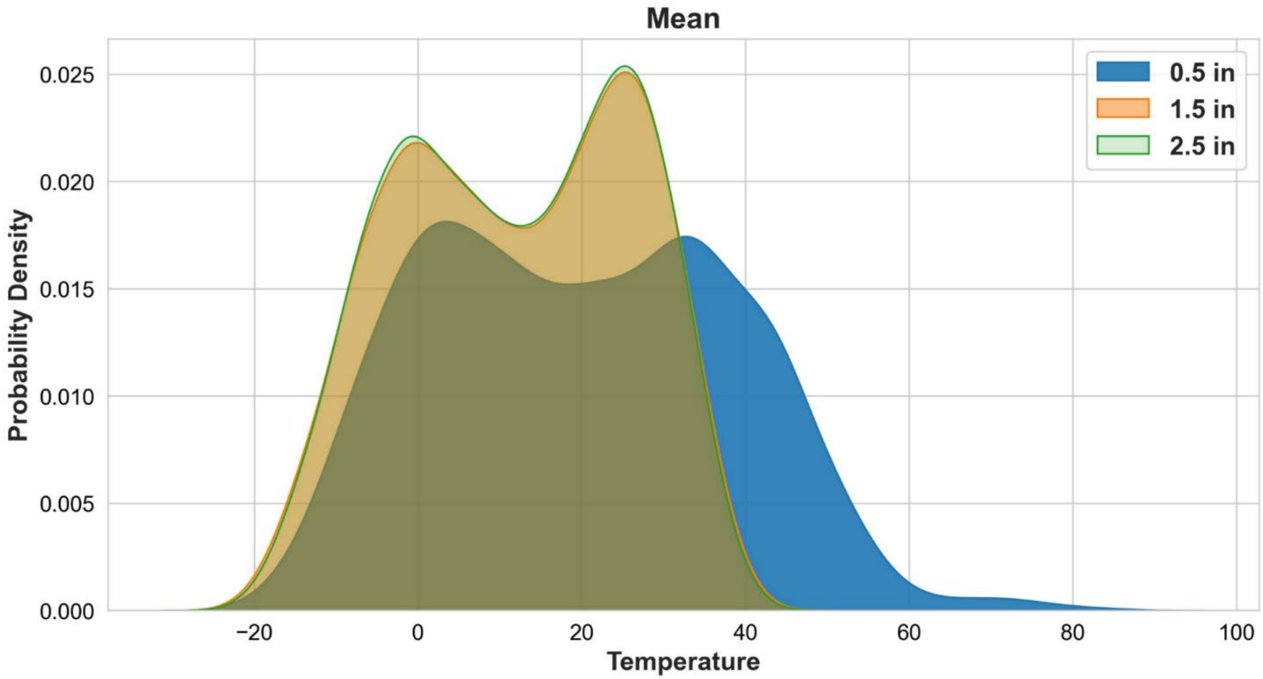
Cell 4

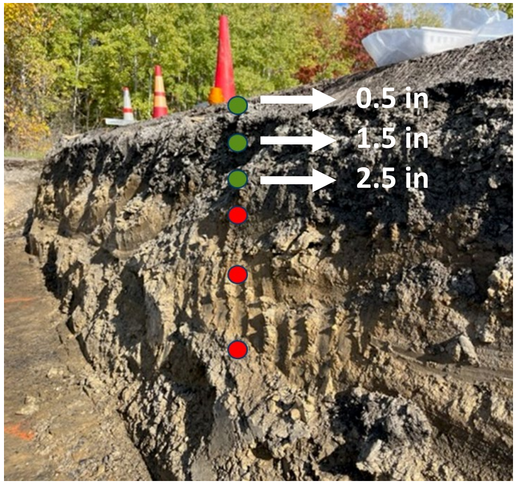




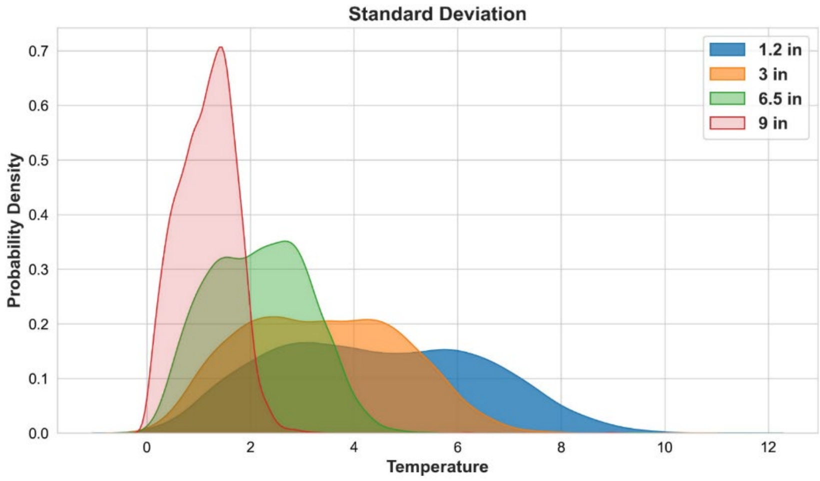
Pavement temperature as a surrogate of performance

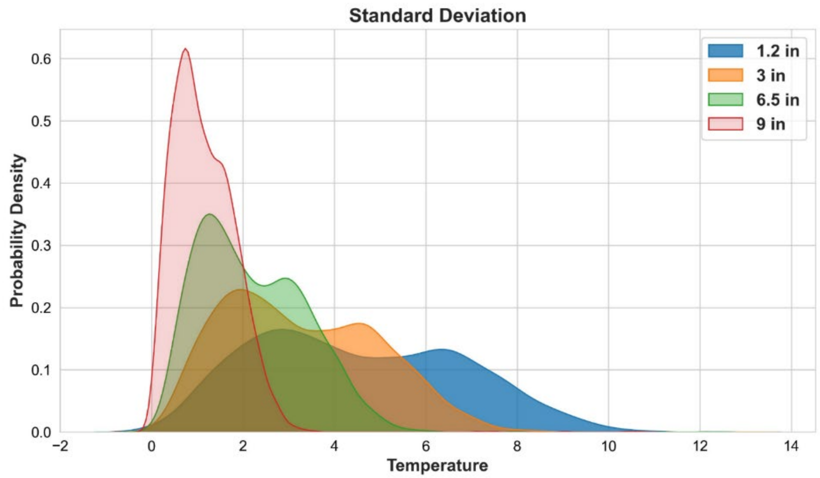
Cell 3



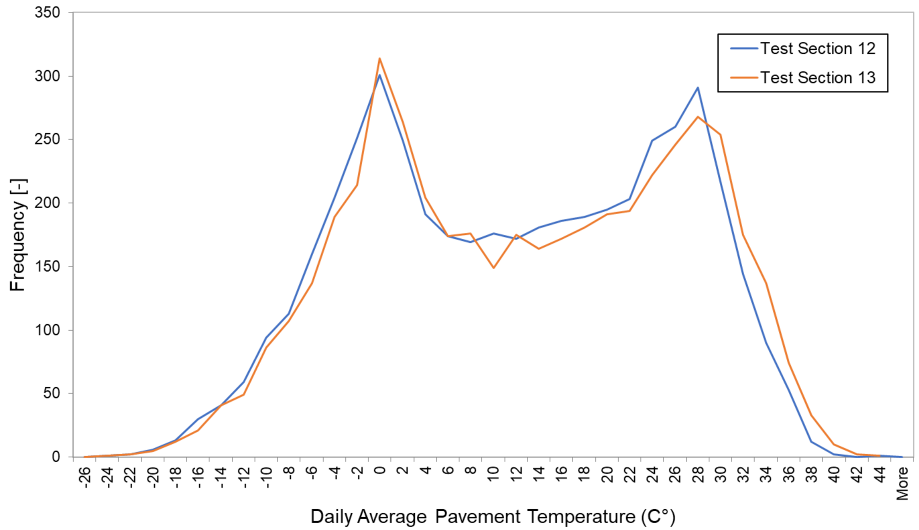


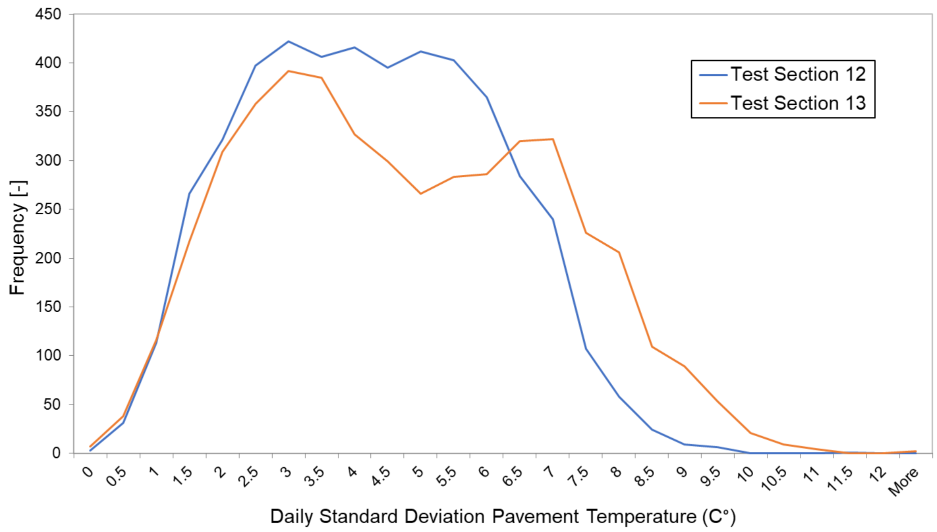
Pavement temperature as a surrogate of performance





Pavement temperature as a surrogate of performance

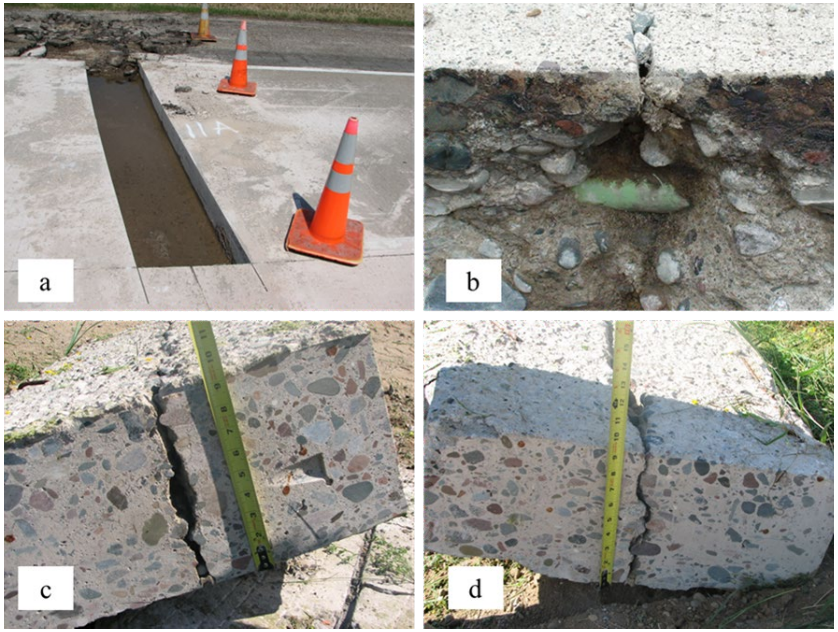




Pavement temperature as a surrogate of performance

Good Pavement – Test Section 12

Distressed Pavement – Test Section 13



THANK YOU!

2025 Midwest Geotechnical Conference

September 23-25, 2025

Sheraton City Centre Hotel, Indianapolis, Indiana

DEPARTMENT OF TRANSPORTATION