SIMSG ISSMGE



2026 AUSTRIA VIENNA WHERE IT ALL BEGAN 21st ICSMGE

6th Proctor Lecture

Transportation Geotechnical Asset Management: Role of Novel Materials, Robust Designs, Innovative Technologies and Tools

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Presentation at 58th Annual Geotechnical Engineering Conference

KU Memorial Union, Lawrence, Kansas, Nov 12, 2026

TEXAS A&M UNIVERSITY

Austrian Geotechnical Society

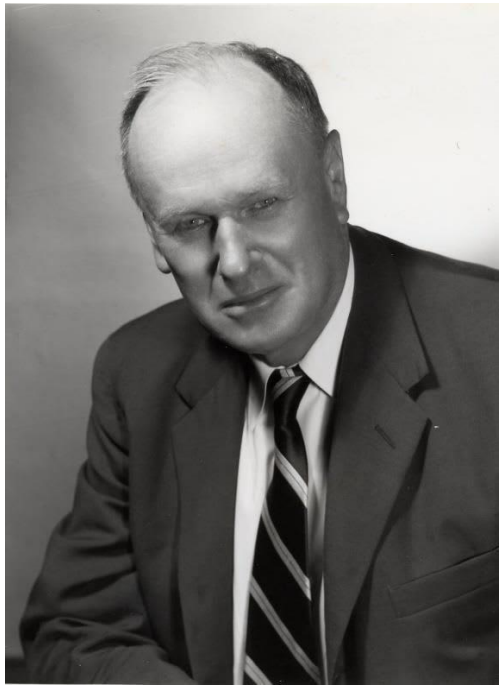
OIAV AUSTRIAN ASSOCIATION OF ENGINEERS AND ARCHITECTS

ÖGG

VÖBU

Father of Modern Soil Compaction Principles

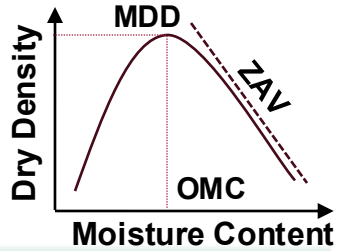
"Pioneer of soil compaction whose work has left a lasting legacy in geotechnical engineering"



Ralph R. Proctor, PE
(1894-1962)

Modern Soil Compaction Principles





- Compaction energy
- Field compaction needs
- Soil behavior patterns
- Expected engineering performance

Civil and Transportation Infrastructure Applications



From Proctor's Test to Transportation Asset Management

"From compaction control to transportation infrastructure resilience and risk-informed planning"





Proctor's Test Objectives

- Transportation infrastructure needs sound and **stable subgrade foundation** support
- What **moisture and dry density** condition gives **best support to infrastructure?**

Transportation Infrastructure Asset Management Objectives

- How can **soils** be improved to develop **robust infrastructure**?
- How can **materials, monitoring**, and **tools** improve **sustainability** and **resilience**?
- Proactive infrastructure asset monitoring and management

From Proctor's Test to Transportation Asset Management

"From **compaction control** to **transportation infrastructure resilience** and **risk-informed planning**"





Proctor's Test Objectives

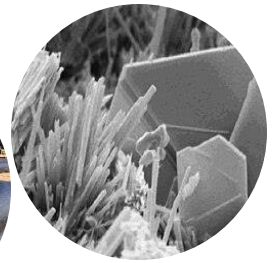
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Transportation Infrastructure Asset Management Objectives

- How can **soils** be improved to develop **robust infrastructure**?
- How can **materials, monitoring**, and **tools** improve **sustainability** and **resilience**?
- Proactive infrastructure asset monitoring and management

"Modern transportation geotechnical asset management extends Proctor's legacy from basic compaction test results to better infrastructure performance"

Transportation Geotechnics (TG) - Core Research Areas


Problematic Soils: Stabilized Geomaterials





Resilience Against Extreme Weather

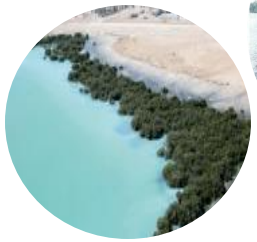
TG Assets





Innovations: Tools and Technologies





Coastal Transportation Infrastructure

Presentation Outline

Thrust in Four Thematic Research Areas

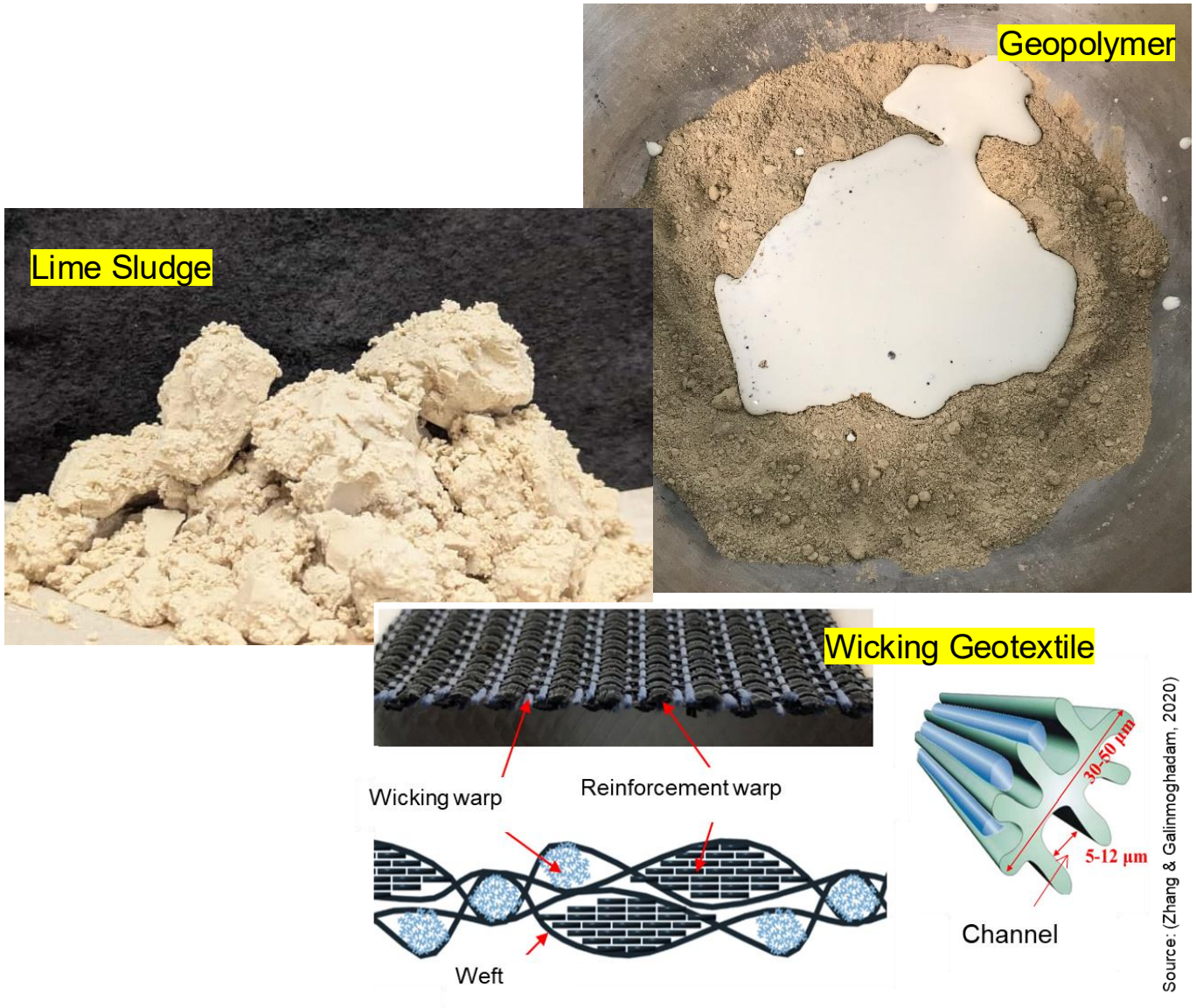
A. **Novel Stabilization Methods**
   I. Calcined-Clay Based Geopolymers (CCBGPs) and Recycled Lime Sludge (LS)
   II. Wicking Geotextiles

B. **Extreme Weather Resiliency Studies**
   I. Novel Durability to Screen Stabilization
   II. Bridge Deicing Using Shallow Geothermal Energy

C. **Coastal Transportation Infrastructure**
   I. Artificial Mangrove Systems – Wave Induced Erosion
   II. Erosion Resistant TRMs for Highways

D. **Tools and Technologies**
   I. Remote Sensing (UAV and SAR) and Unmanned Ground Vehicles
   II. Additive Manufacturing or 3D-Printing for Rehabilitation

Thematic Research Area - A



Novel Stabilization Methods

I. Calcined-Clay Based Geopolymers & Recycled Lime Sludge

II. Wicking geotextiles

Materials and Stabilization Techniques

- Traditional stabilizers → Problematic Soils – Mixed Results
- High Carbon Footprint
- Seek Novel Stabilizers and Geosynthetics



www.britpave.org.uk



https://mintekresources.com/



https://colonial-materials.com/

Need for Novel Stabilization Methods…



Research

Innovative Materials Development

and

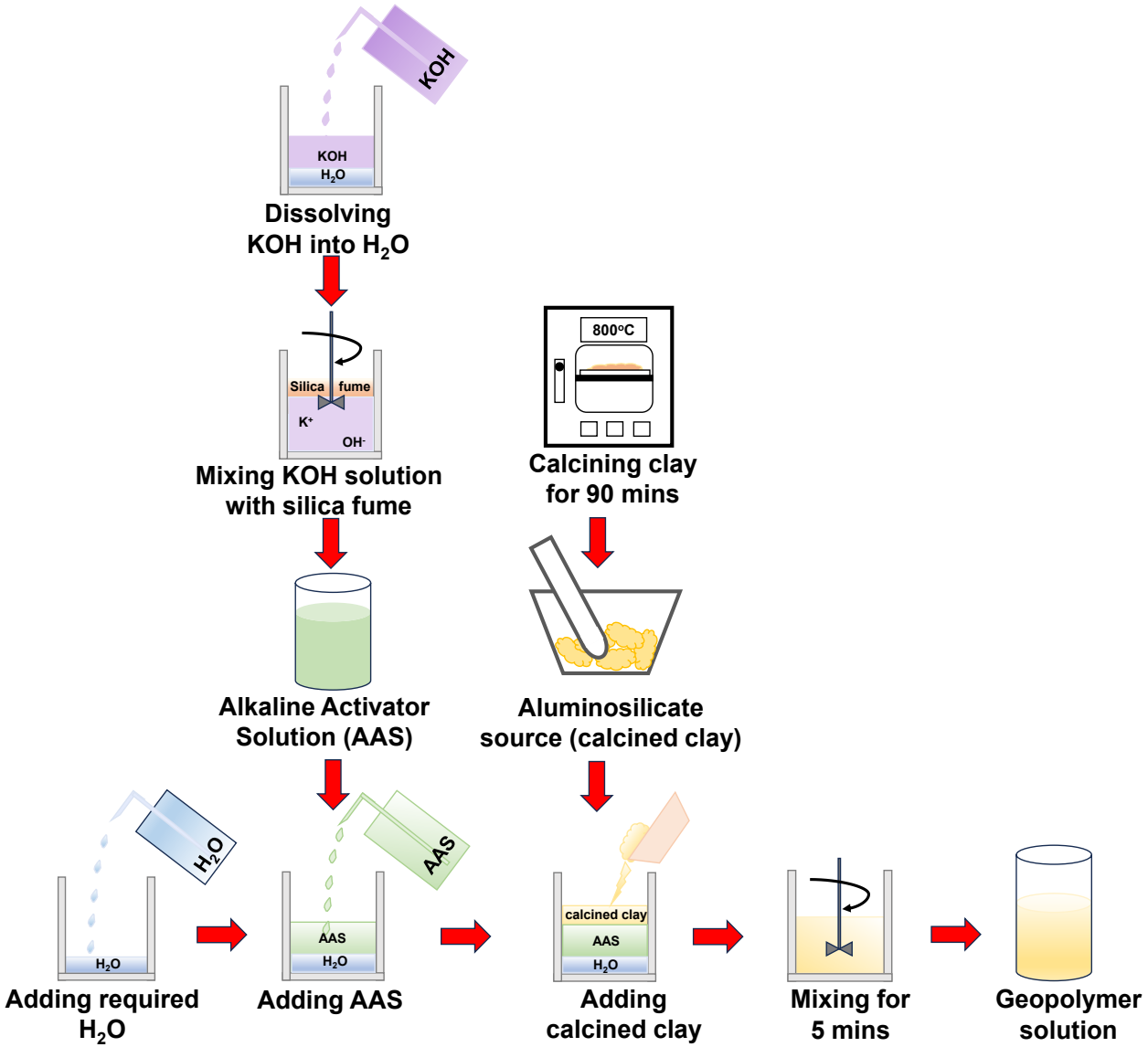
Recycling and Reuse



I. **Calcined Clay Based Geopolymers (CCBGP) & Lime Sludge (LS)**

II. **Wicking Geotextile**

Ia. Calcined-Clay Based Geopolymer (CCBGP) - Synthesis



Aluminosilicate Source

UPF (U)	TNKY (T)
○ Kaolinite: 91%	○ Kaolinite: 75%
○ Quartz: 0%	○ Quartz: 24%
○ Anatase: 2%	○ Anatase: 1%
○ Muscovite: 7%	○ Muscovite: 0%

Activator Cation

H_2O/solids

K331

Cation/Al

SiO_2/Al_2O_3

Ia. CCBGP – Stabilization Process

Geopolymer Gel

Aluminosilicate Sources

Calcined Clay

Alkaline Activator Solution

Alkali metal cation
(**KOH**)
+
Additional Silica Source
(**Silica fume**)
+
Water

at room temperature
(23 ± 1°C)

Mixing

Geopolymer – Soil Mixture

≈ 6 hours – 7 days with
100% relative humidity

Curing

Hardened Geopolymer – Soil Specimen







Ia. CCBGP – Testing Program

Optimize lime dosage with soils (ASTM D6276)



Eades & Grim pH test

Optimization of GP

Select 8% and 20% GP

Select 5% Lime

Note: Lime was studied as a comparison.

Engineering Tests



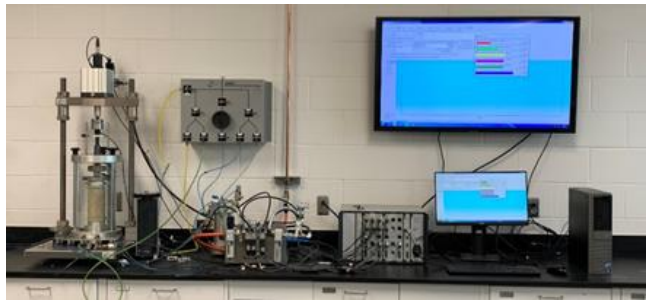
UCS



Free Swell

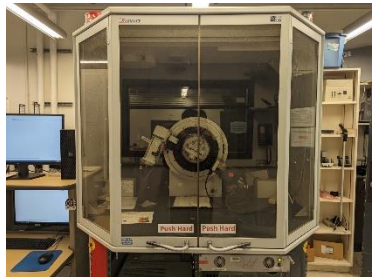


Shrinkage



Repeated Load Triaxial

Micro-studies



XRD



Optical Microscope

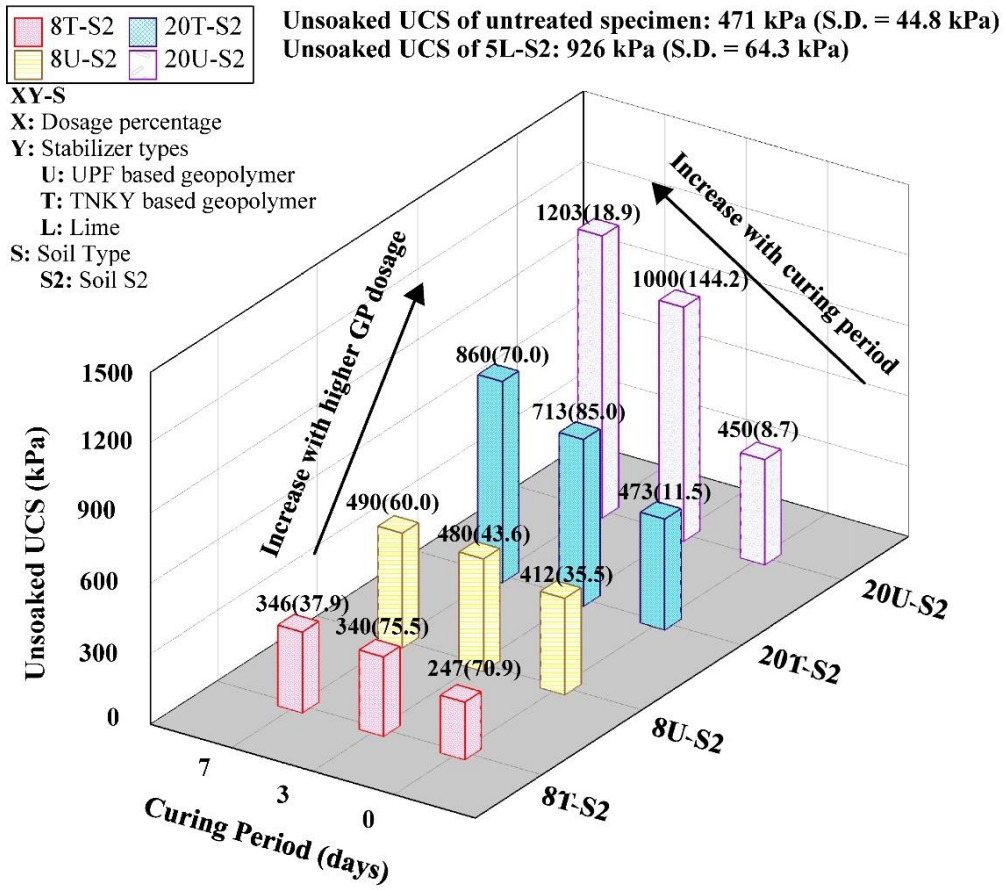


FESEM-EDS

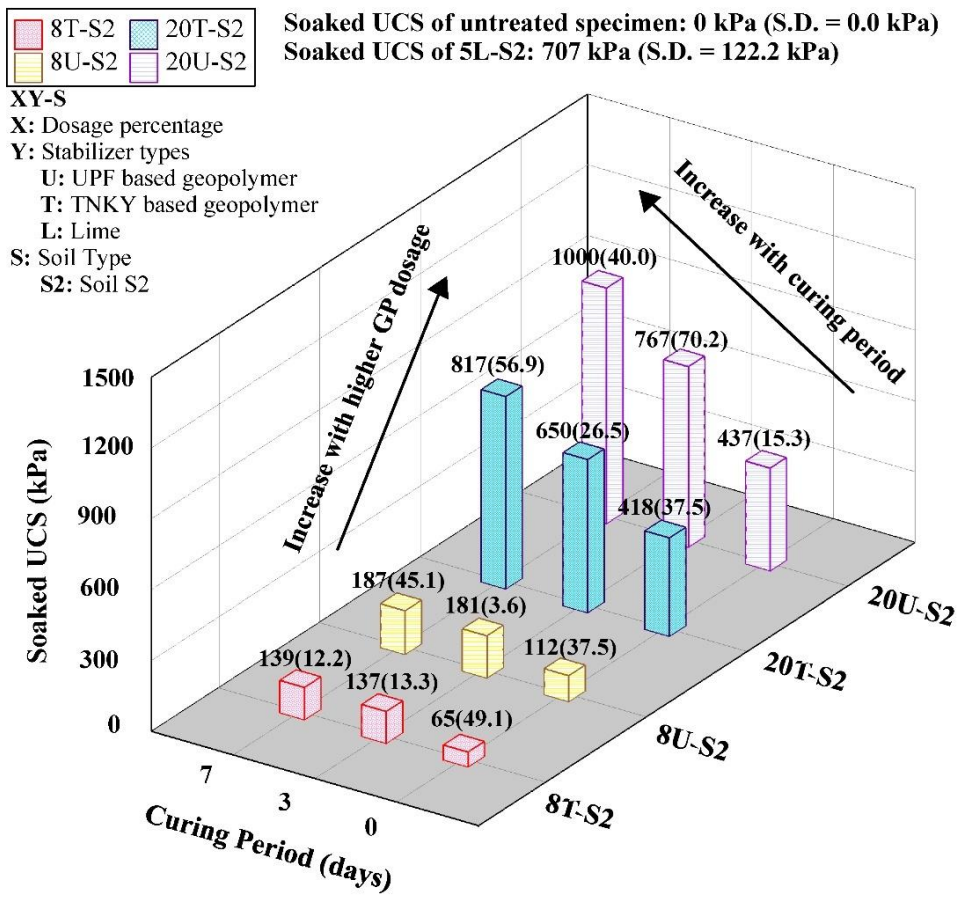
Ia. CCBGP – Results

UNCONFINED COMPRESSIVE STRENGTH (UCS)

Unsoaked UCS



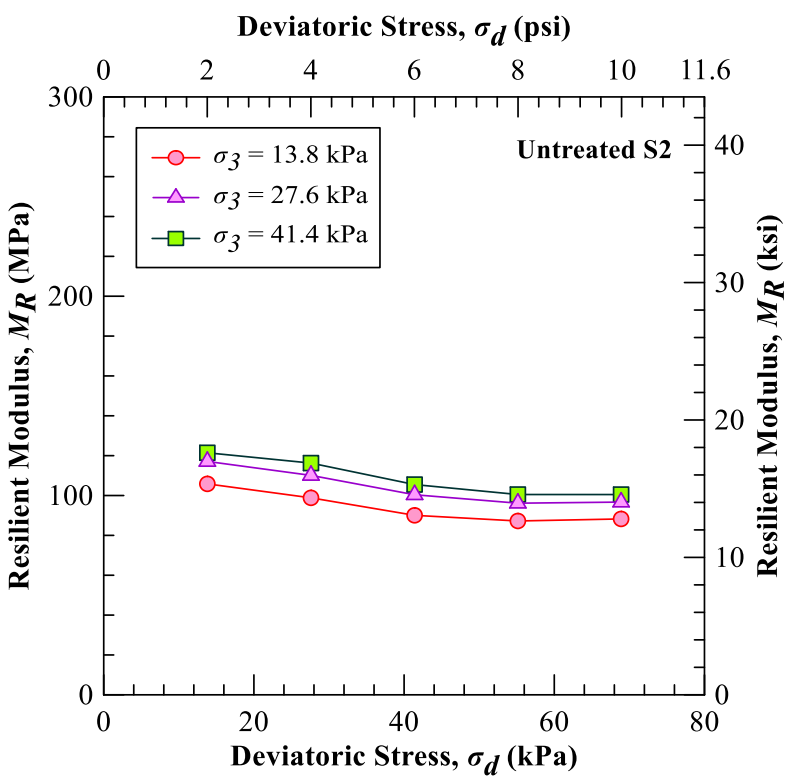
Soaked UCS

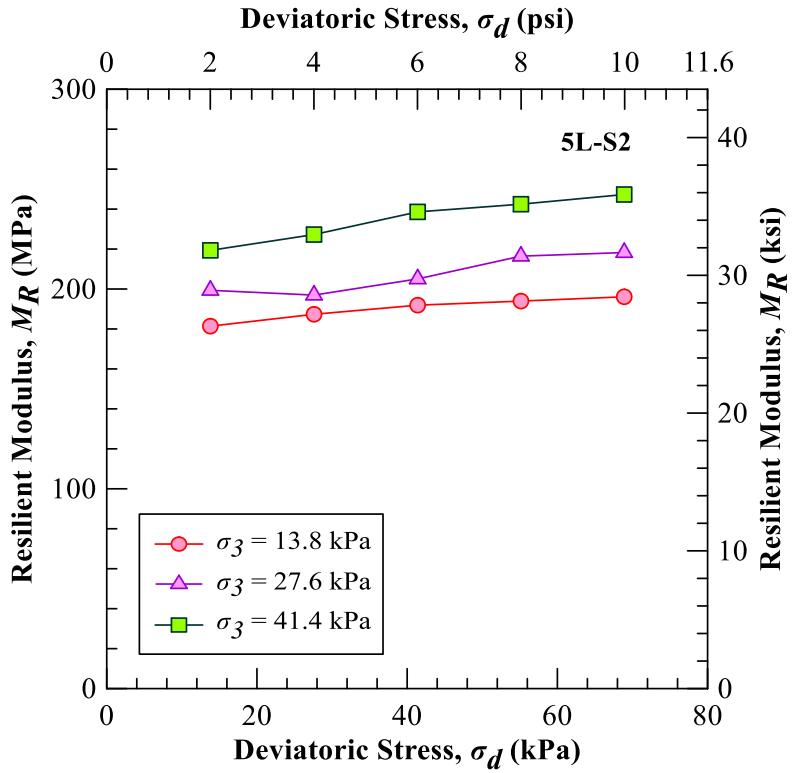


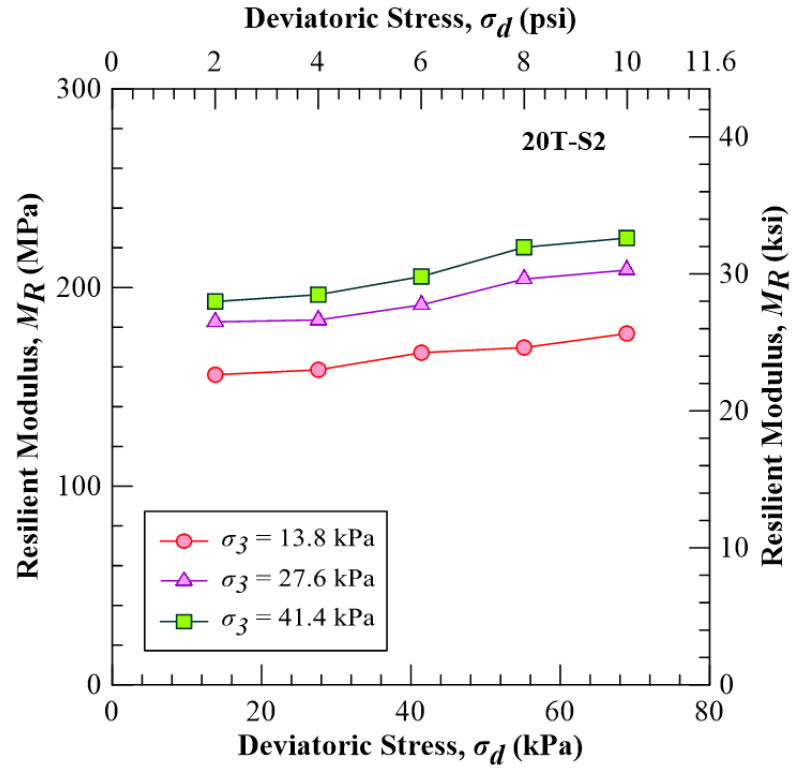
Effect of Strength Enhancement: 20% GP > 5% Lime >> 8% GP

Ia. CCBGP – Results

RESILIENT MODULI (M_R) STUDIES





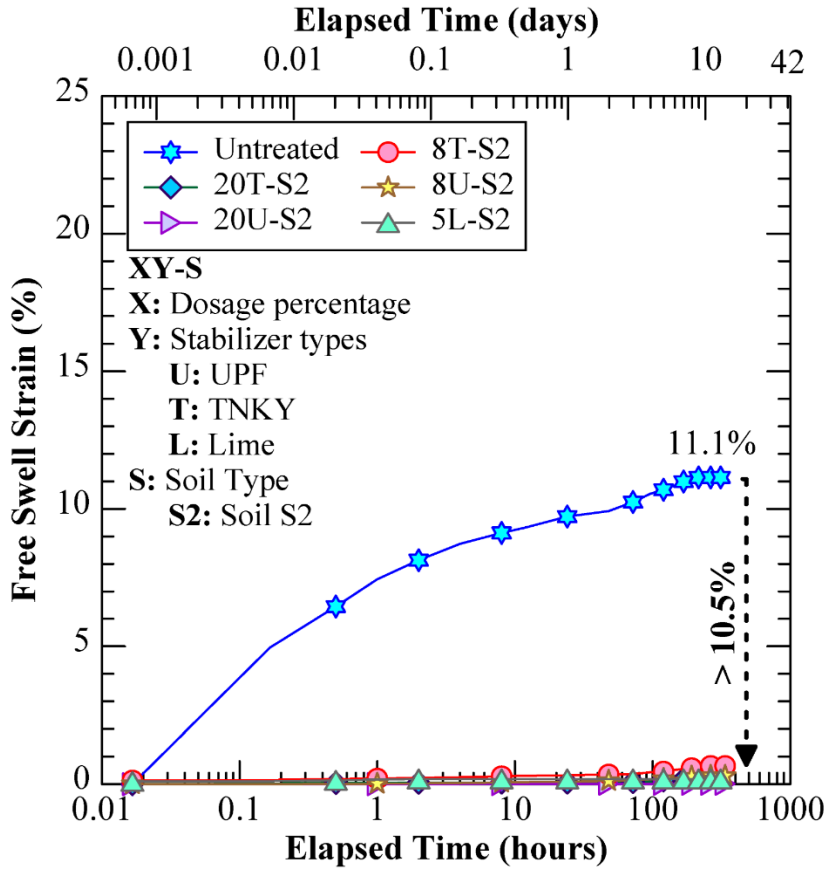


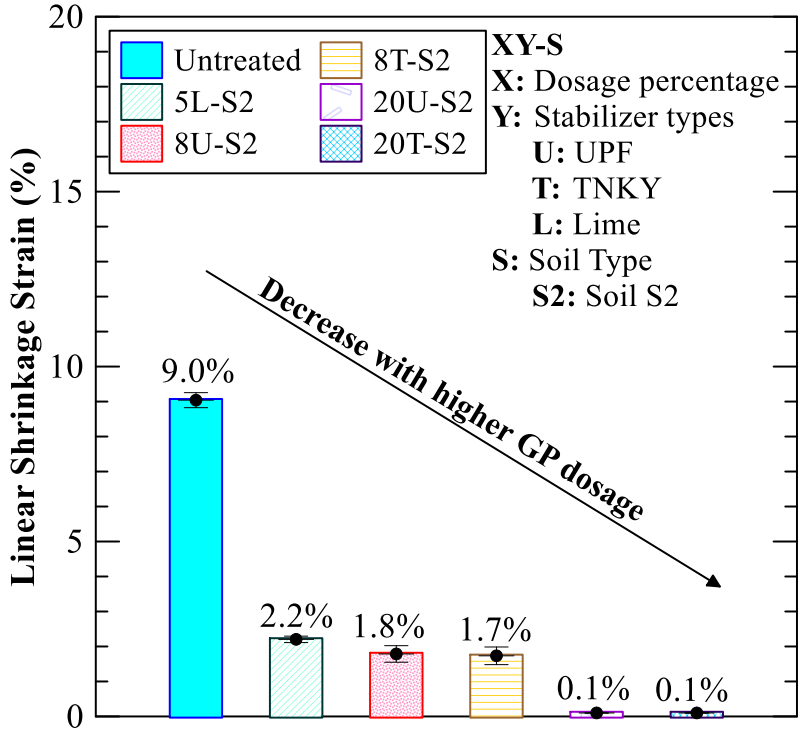
Untreated soil (Softening), Lime treated soil (Hardening, M_R ↑)

20% GP treatment has **a comparable performance** to **lime treatment**

Ia. CCBGP – Results

FREE SWELL & SHRINKAGE STRAIN RESULTS – Volumetric Stability





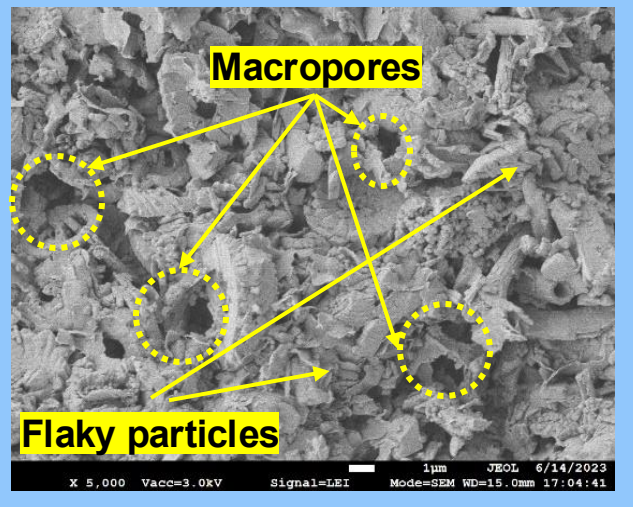
Vertical Free Swell Strain for Problematic Soil:
5% Lime > 20% GP

Linear Shrinkage Strain in Problematic Soil :
5% Lime >> 20% GP

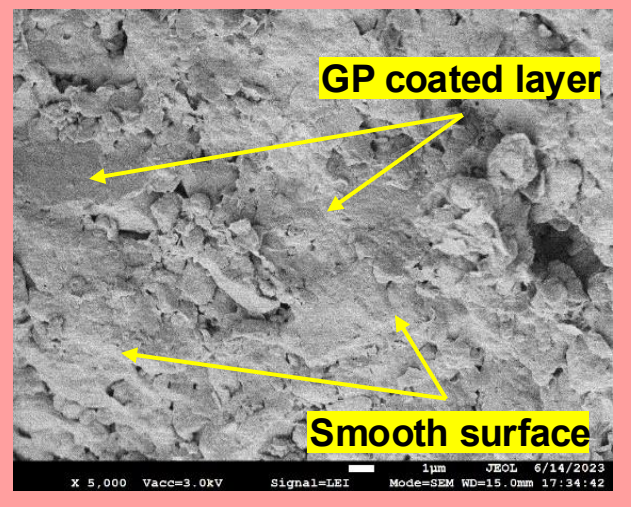
Ia. CCBGP – Results

FIELD EMISSION SCANNING ELECTRON MICROSCOPY (FESEM) IMAGES









Untreated soils showed **open pore structures** with **flaky particles**.
After stabilization, the clay particles were observed to be **coated** with a layer of **geopolymer matrix**, resulting in **reduced macro pores** and a **smoother surface**.

Ib. Lime Sludge (LS)



Lime sludge

- Water utilities generate **million tons** of **lime sludge** per year, with estimated **disposal costs** of **millions of US dollars** annually
- Without recycling, lime sludge poses **serious waste** and **environmental challenges**.



Lime sludge landfill in the city of Mount Vernon, OH

Human health

- **Chemical burns**
- **Respiratory system irritation**

Environment

- **Change in Soil and water pH**
- **Air emission**
- **Contaminants**

Environmental **concerns** and **regulatory** ↑
Research on **recycling LS** for **engineering applications**

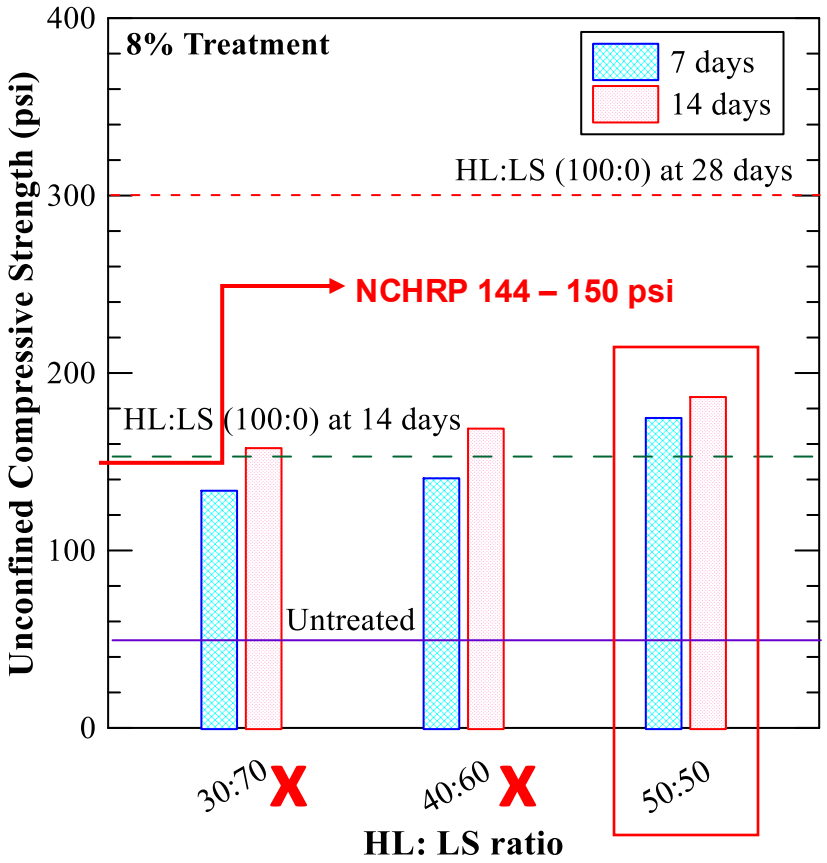
- Potential for **soil stabilization** due to its **abundance** and **calcite-rich content**
- LS → **plasticity ↓, UCS ↑** when mixed with cement, or other additives
- **Careful dosage** and **strategic pairing** with other stabilizers is **essential** for **optimal** results

Can **lime sludge** be **reused** in **soil stabilization**?

Ib. Lime Sludge (LS)

DOSAGE SELECTION AND ENGINEERING STRENGTH PERFORMANCE

- **Insufficient pH** level of LS (**pH < 12.4**) → Needed Hydrated Lime (HL) mixture

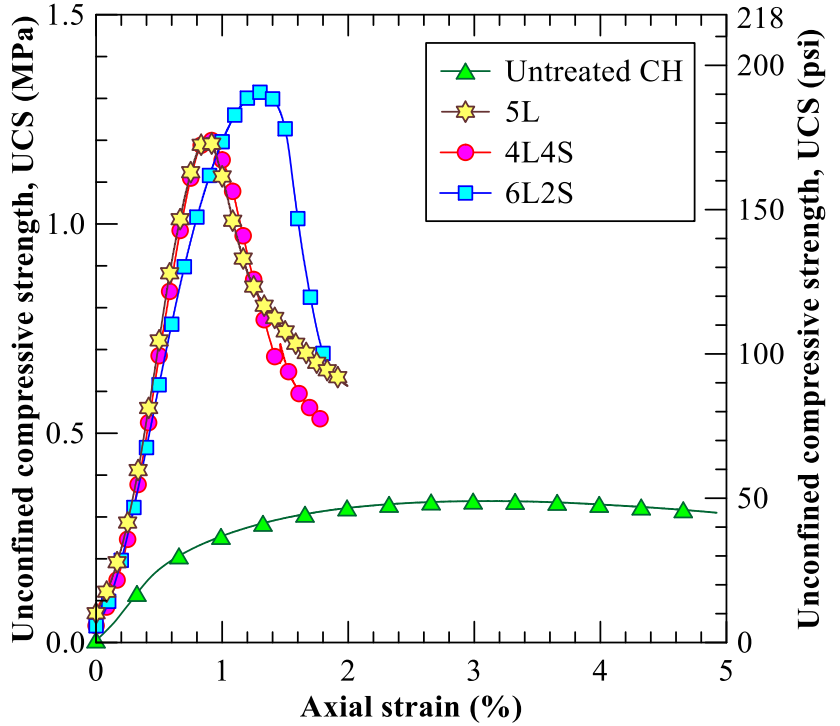


HL:LS < (50:50) did not meet the required UCS

Selected mixes (8% treatment):

50:50 [4L4S], 75:25 [6L2S]

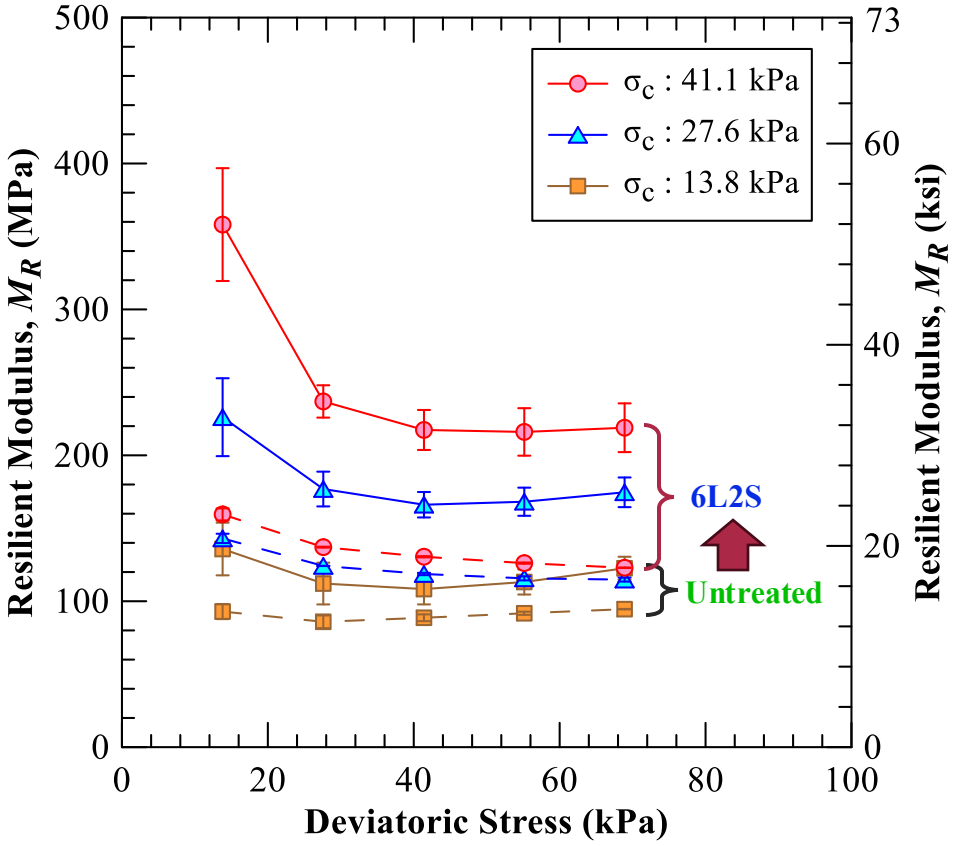
LS (high **calcite** content) → **plasticity ↓**, enhancing lime stabilization

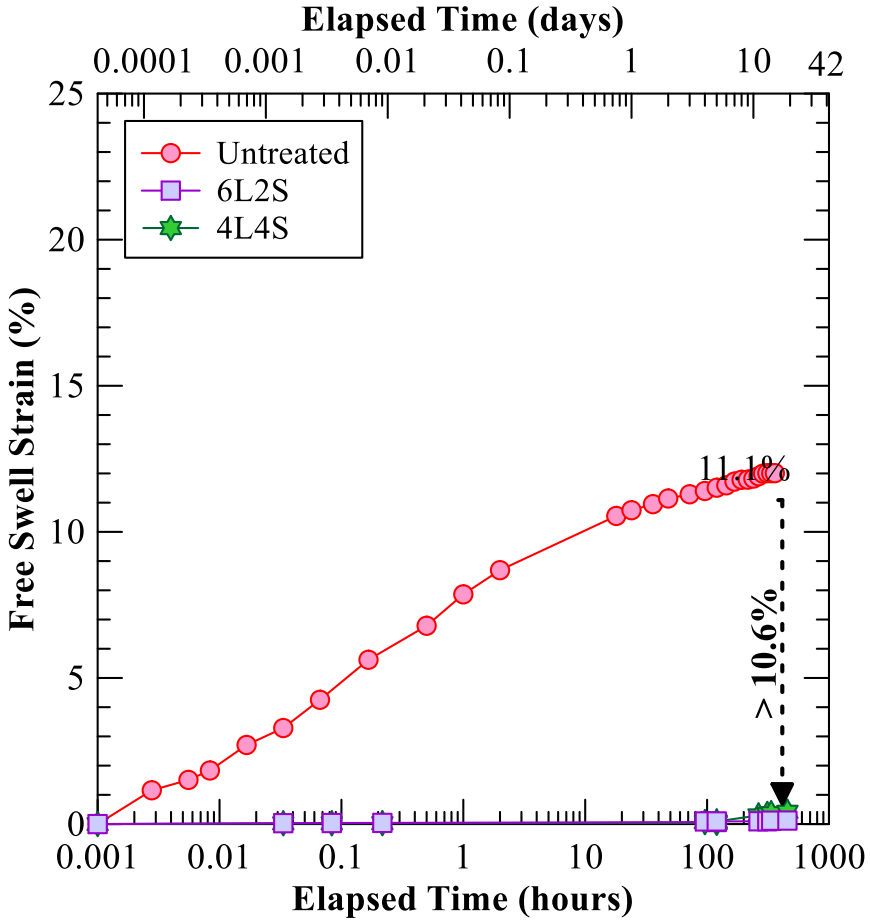


- **$UCS_{4L4S} \approx UCS_{5L}$** after 14-day curing
- **6L2S achieved the highest UCS**

Ib. Lime Sludge (LS) – Co-Additive

RESILIENT MODULUS & FREE SWELL STRAIN



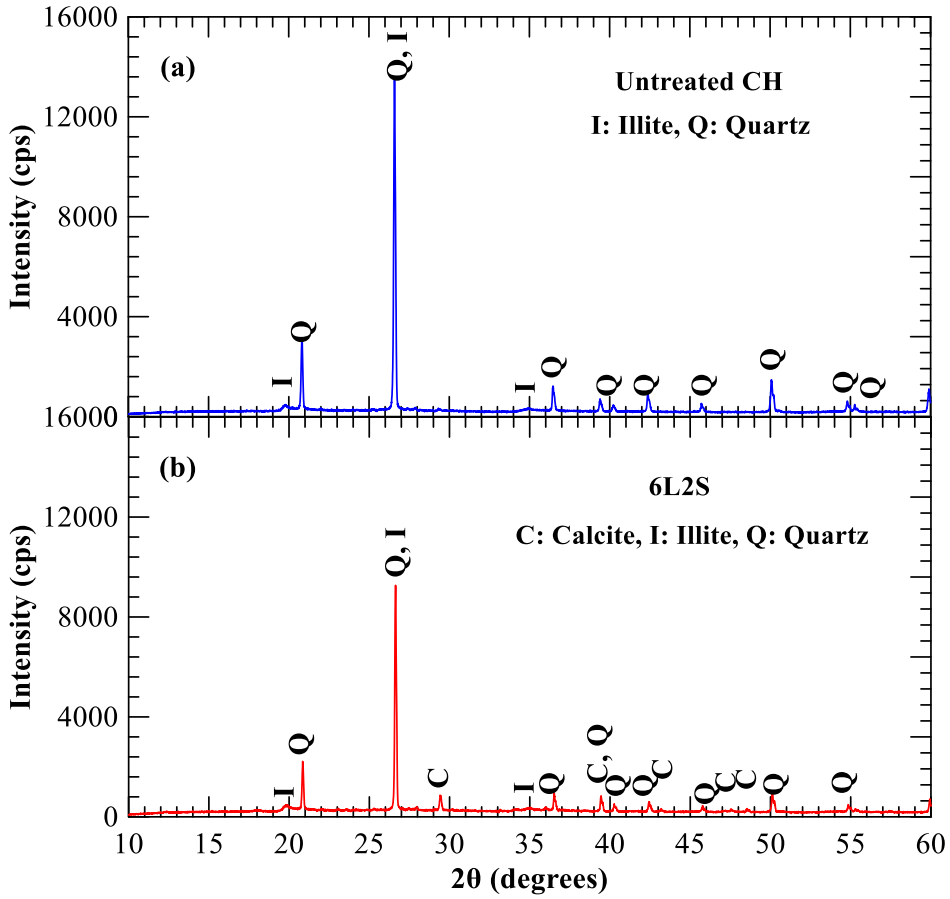


Increase in **resilient modulus**

Reduction in **swelling potential – can be effective as a co-additive**

Ib. Lime Sludge (LS) – Co-Additive

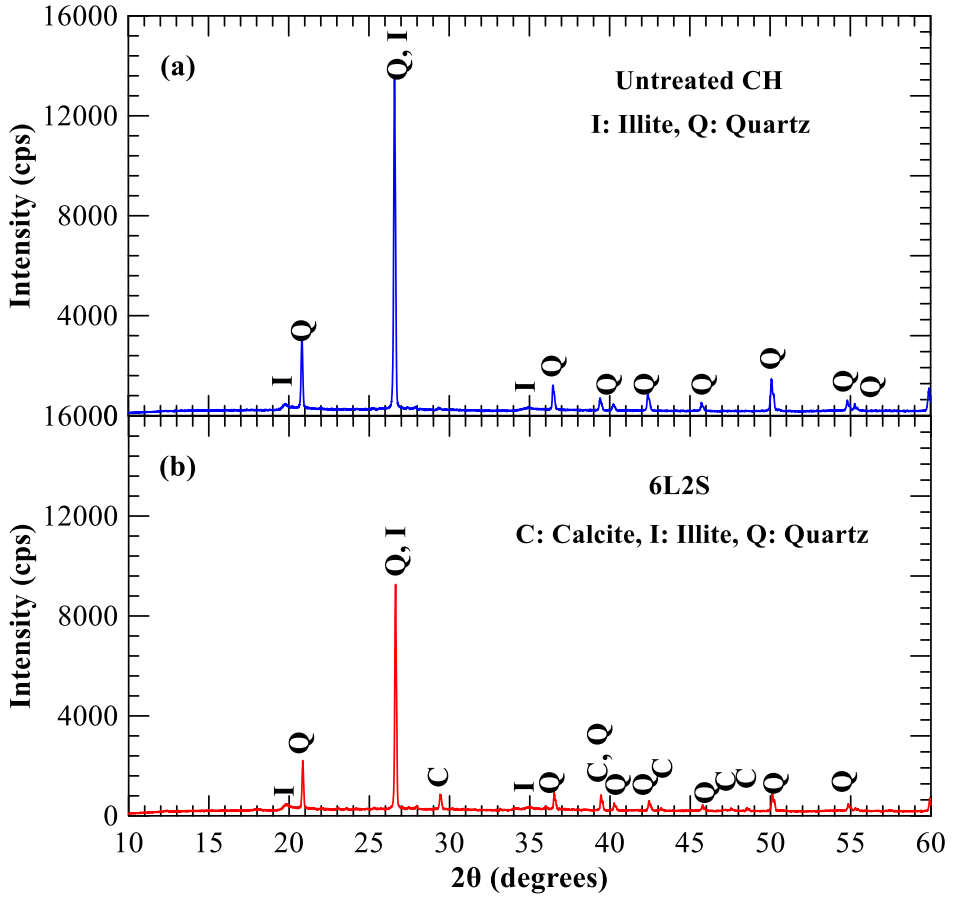
MICROSTRUCTURAL ANALYSIS

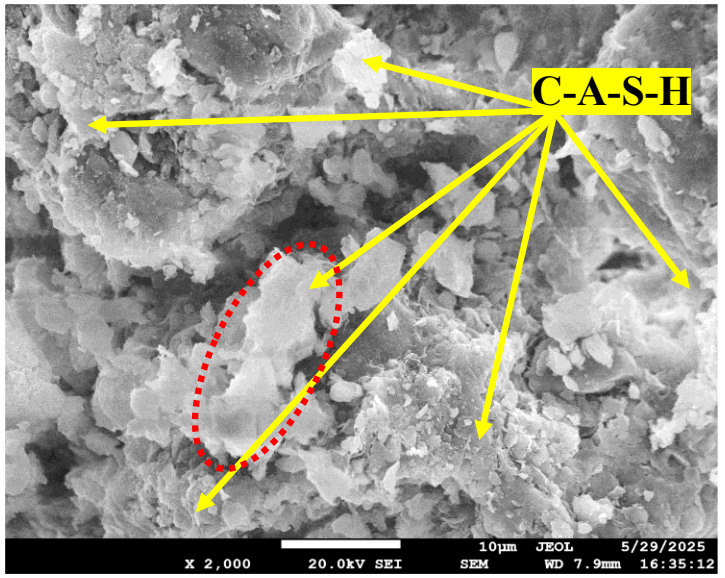


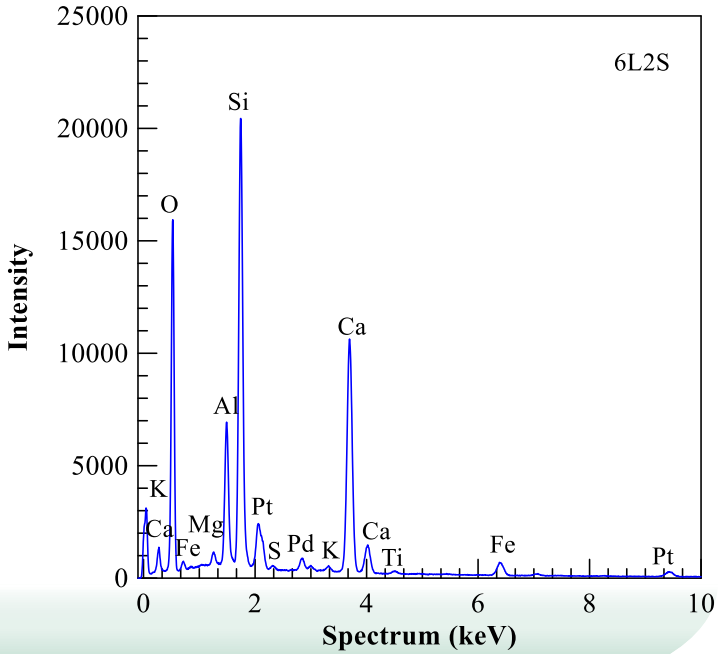
Reduction of Quartz and Illite →
Formation of pozzolanic products

Ib. Lime Sludge (LS) – Co-Additive

MICROSTRUCTURAL ANALYSIS





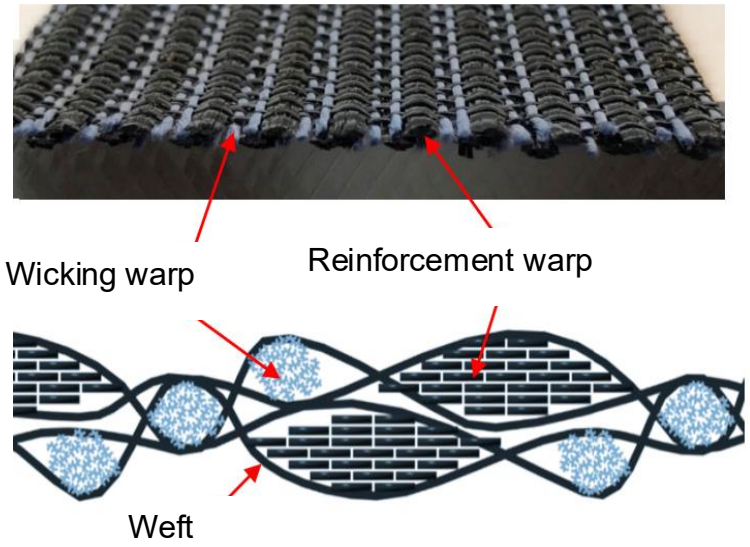


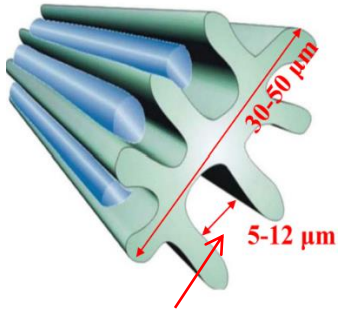
Reduction of Quartz and Illite →
Formation of pozzolanic products

Formation of Cementitious Binding Gels

Improved Engineering Performance

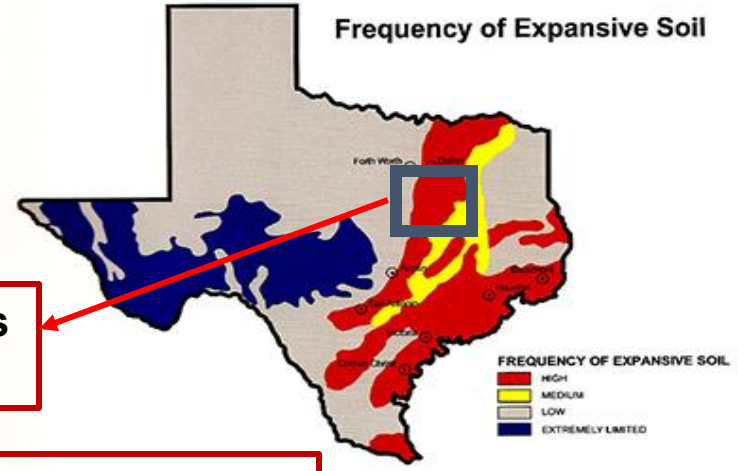
II. Wicking Geotextile Applications





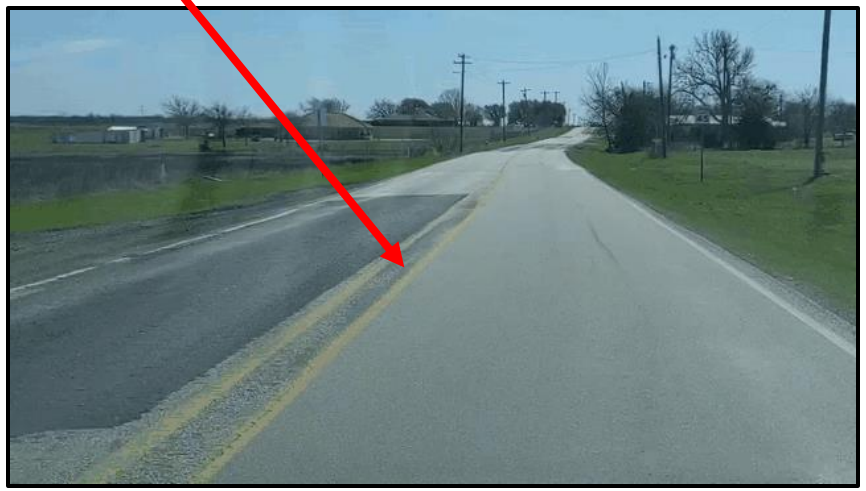
Source: (Zhang & Galinmoghadam, 2020)

SITE DETAILS



FM 1807,Venus Texas

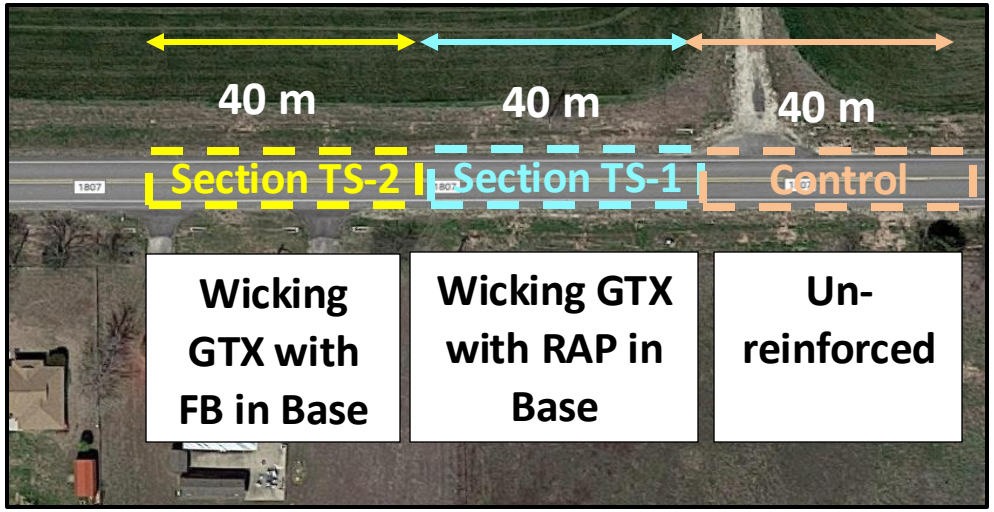
Visible cracking and rutting

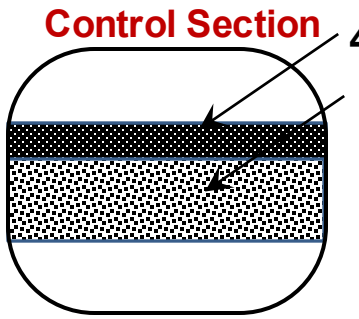


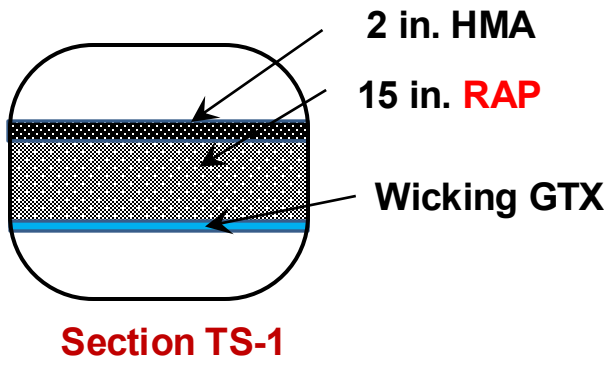
- **Wicking geotextile – Made of Hydrophilic Wicking fibers**
- **Facilitates lateral drainage – Grooves for moisture transportation**
- **Capillary Drainage – Effective for both saturated and unsaturated soils**

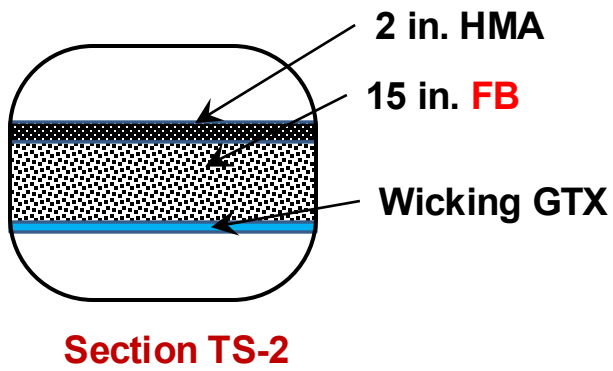
TEST SECTIONS

- Three test sections were constructed
  - Control Section (CS) → Unreinforced
  - Test Section – 1 (TS-1) → Wicking GTX + RAP Aggregate Layer
  - Test Section – 2 (TS-2) → Wicking GTX + Flex Base (FB) Aggregate Layer







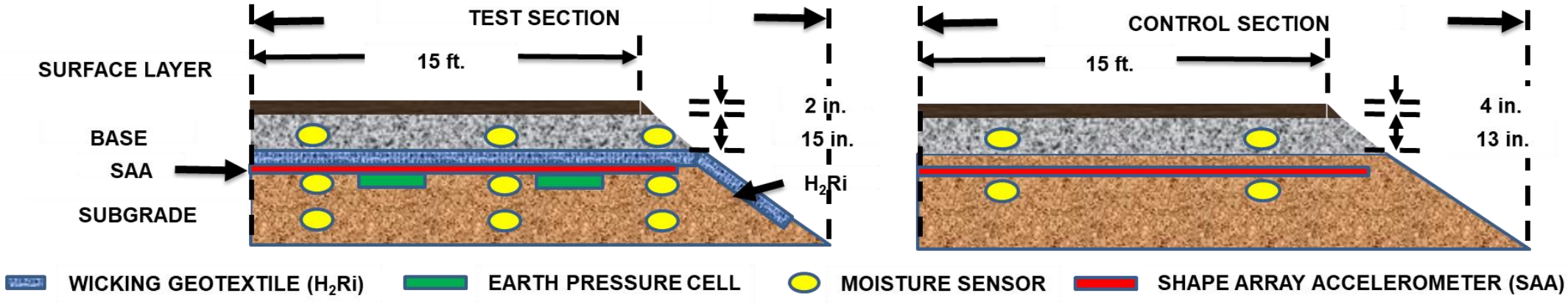




RAP - Reclaimed Asphalt Pavement Aggregates, FB - Flex Base, GTX - Geotextile

II. Wicking Geotextile Applications

INSTRUMENTATION

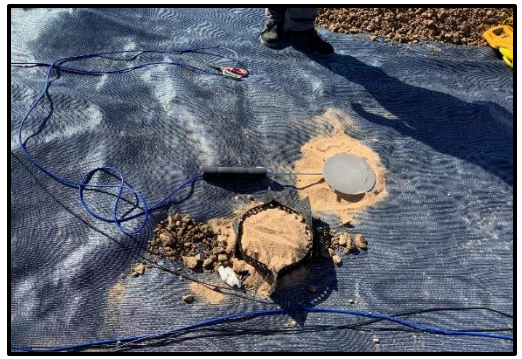




Moisture sensor



SAA installation



Earth pressure cell

II. Wicking Geotextile Applications

CONSTRUCTION



Milling and excavation



Instrumentation trench



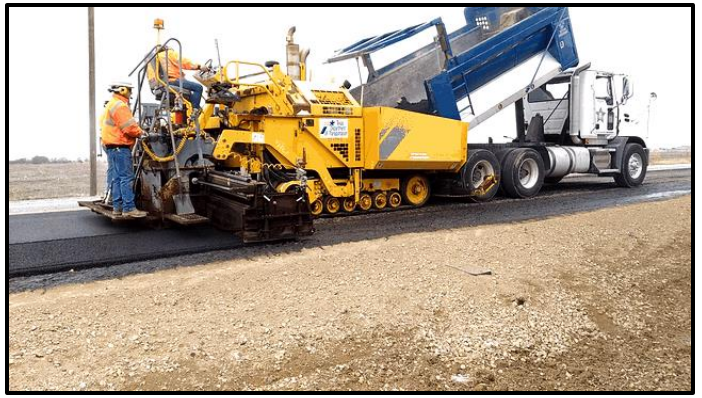
Preparing RAP section



Preparing FB section



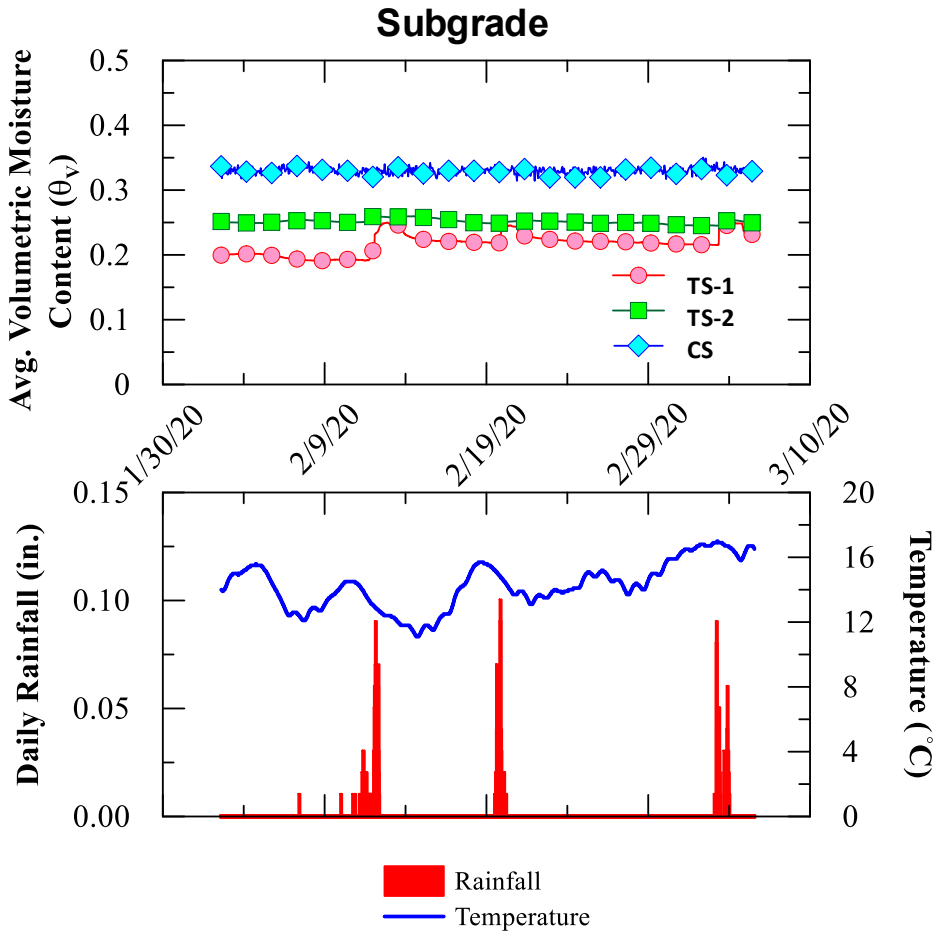
Levelling

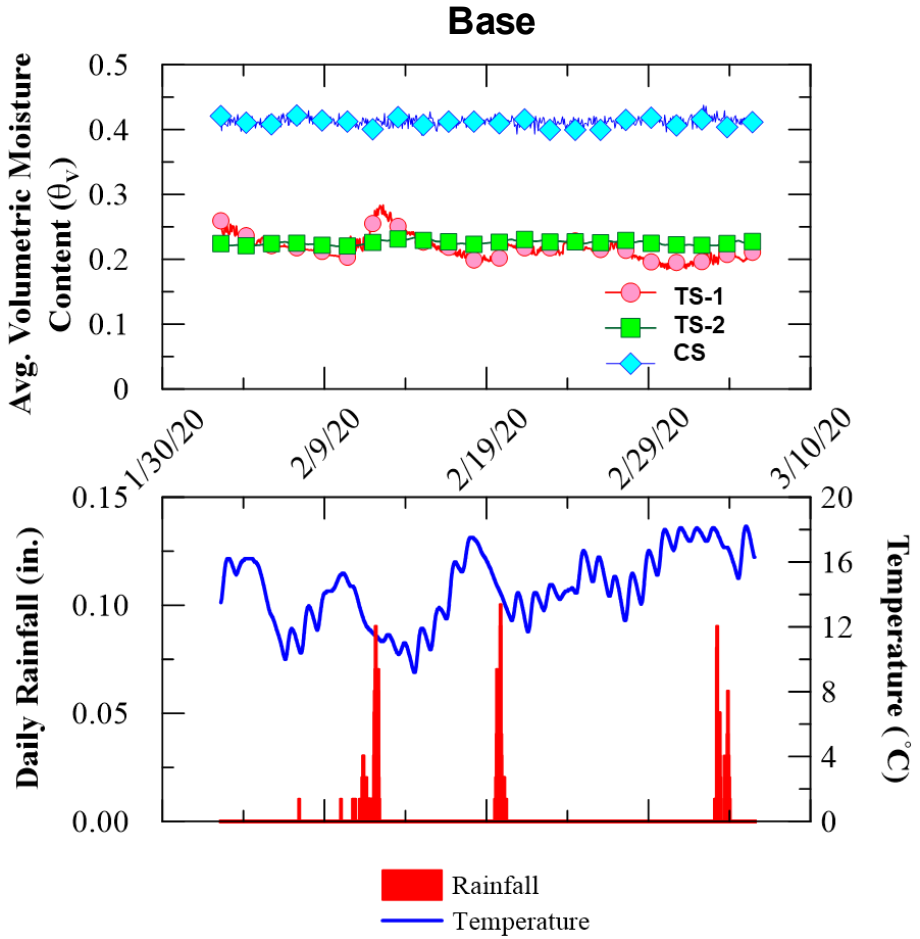


Surface course

II. Wicking Geotextile Applications

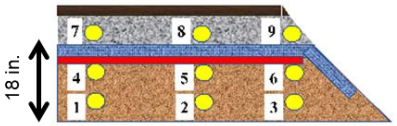
FIELD MOISTURE CONTENT VARIATION

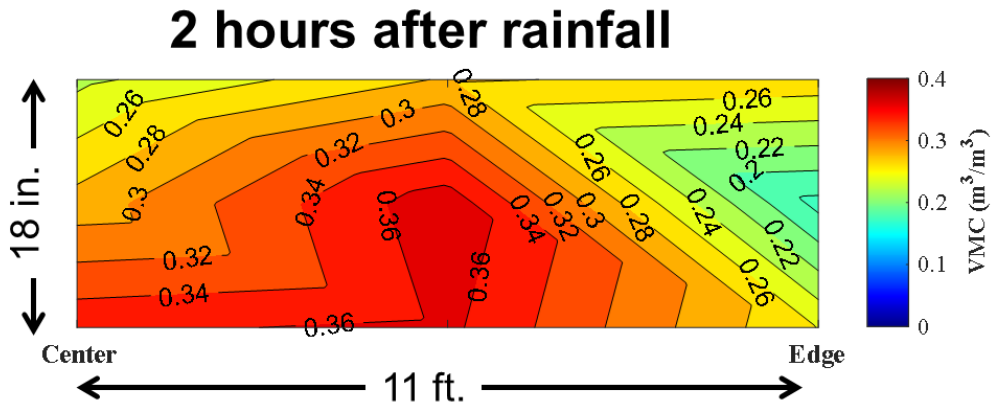


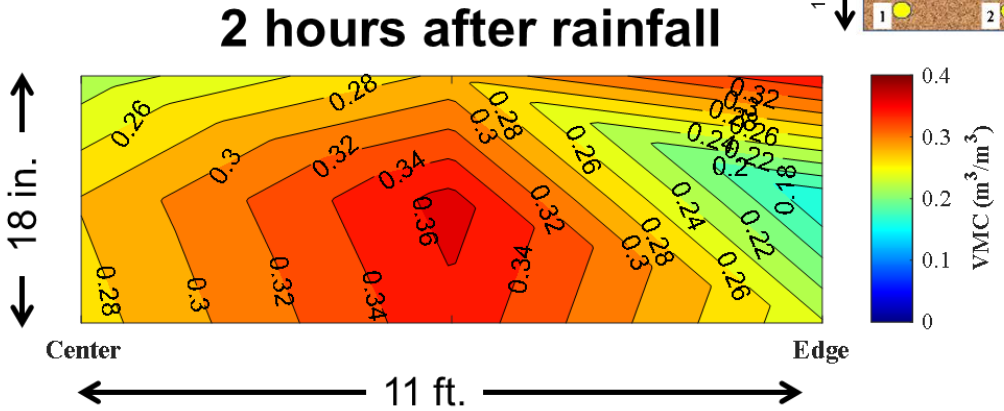


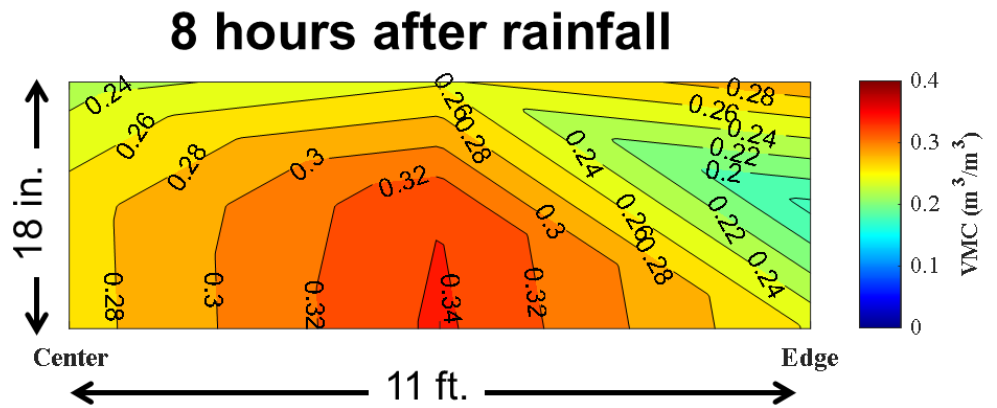
Wicking Geotextile Reinforced Sections Showed Lower Moisture Content in Base and Subgrade Layers

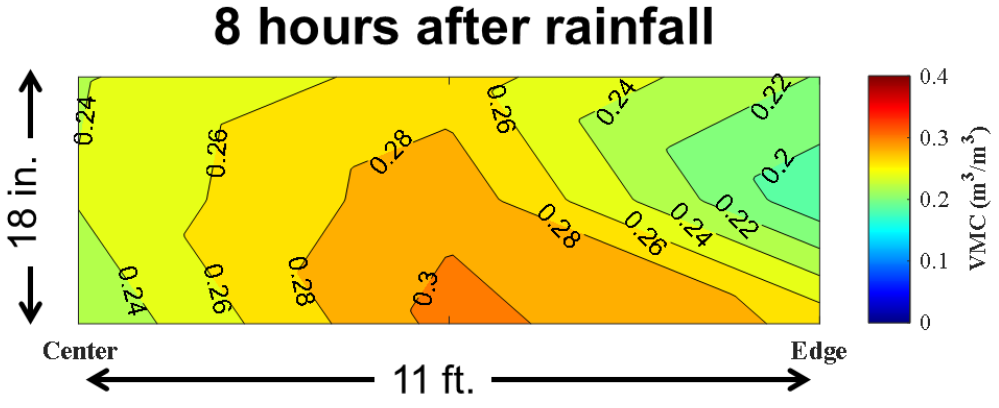
MOISTURE VARIATION AFTER RAINFALL EVENTS











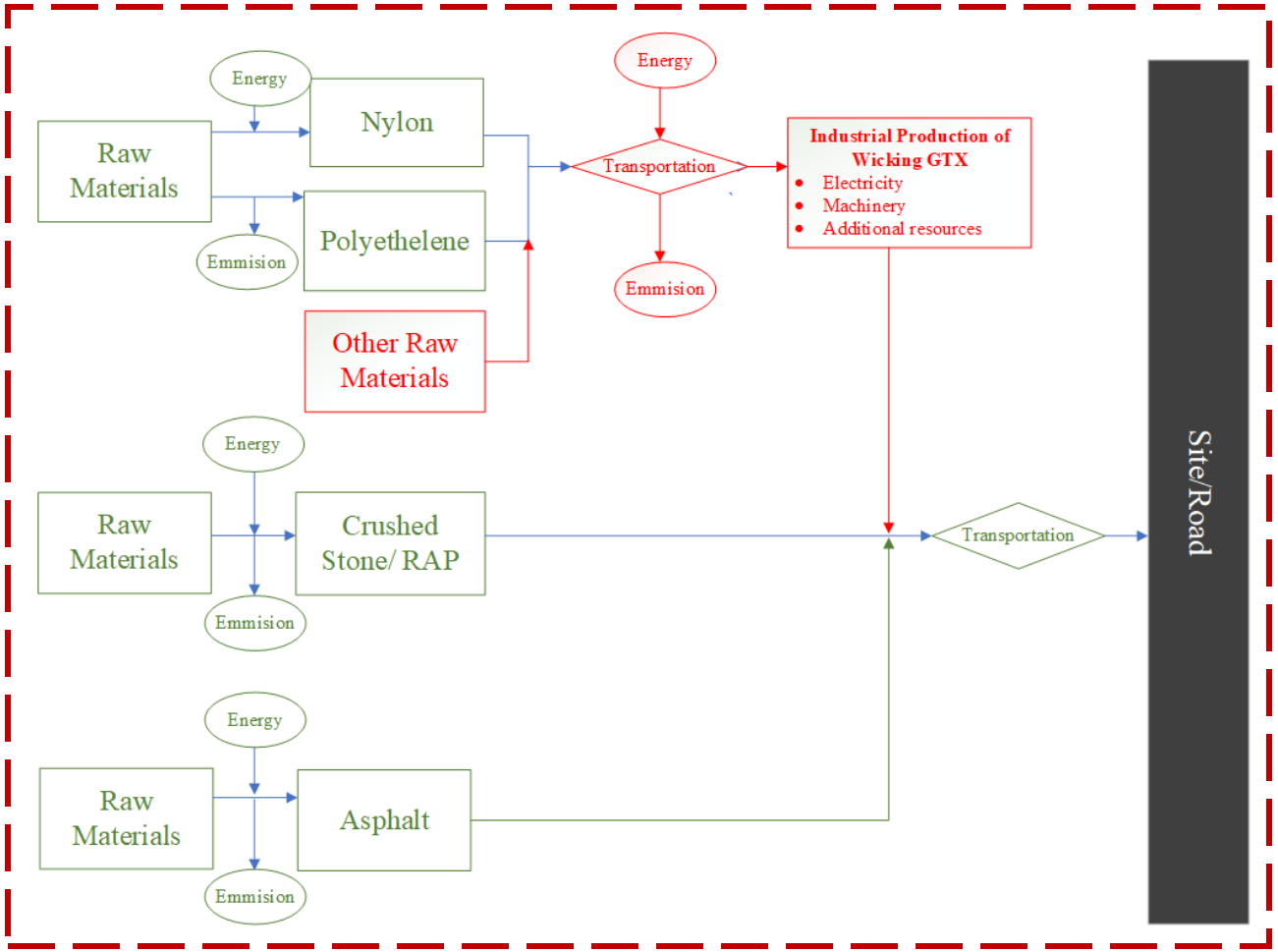
Wicking GTX + RAP

Wicking GTX + FB

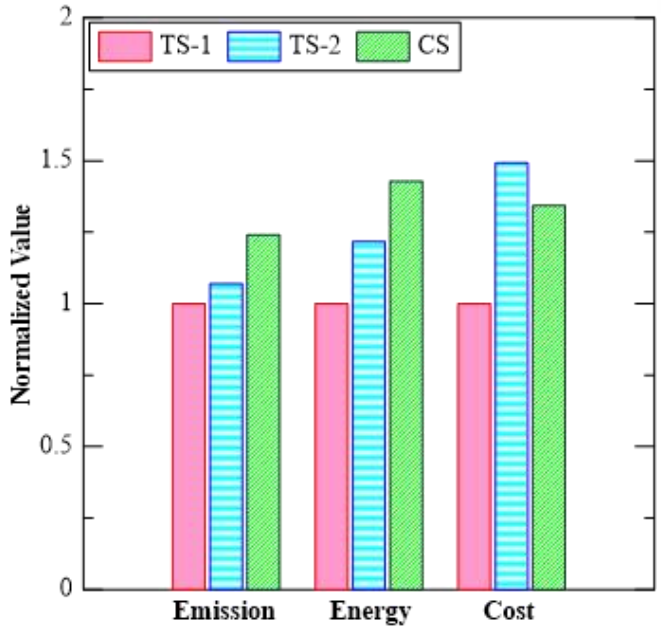
FB section showed faster redistribution when compared to RAP section

II. Wicking Geotextile Applications

LIFE CYCLE ANALYSIS (LCA)



Sustainability analysis using OpenLCA software



- **TS-1 with RAP showed lowest impact across all categories, indicating superior environmental performance**
- **Control Section: Exhibited the highest impact in emissions and energy due to thicker asphalt layer**
- **Cost Comparisons: TS-1 is more economical than TS-2, as TS-2's thicker flex base layer combined with geotextile significantly increases construction costs**

Our Research Outputs on Novel Stabilization Methods


Canadian Geotechnical Journal

Research Article

Role of calcined-clay-based geopolymers for effective stabilization of expansive soils

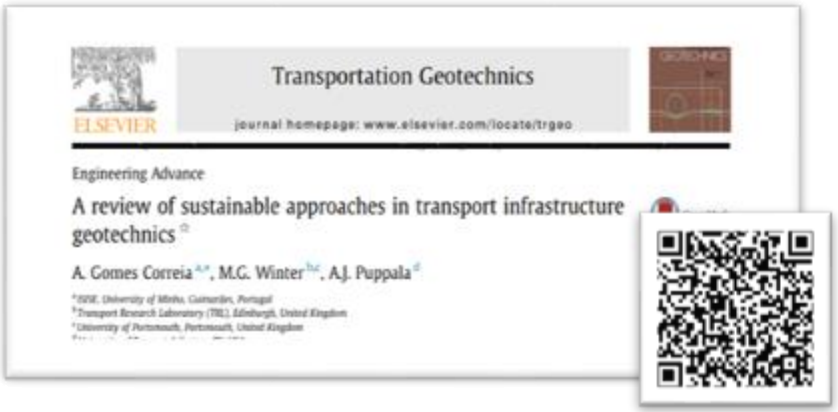
Sopharith Chou, Anand J. Puppala, Nripojyoti Biswas, Oscar Huang, and Miladin Radovic

Corresponding author: Anand J. Puppala


Engineering Geology

Experimental study on engineering and microstructural behavior of lime sludge stabilized expansive soils under cyclic environmental stresses

Sopharith Chou, Jianxin Huang, Balaji Lakkimsetti, Kyle Parr, Anand J. Puppala, Bora Cetin


Transportation Geotechnics

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

Engineering Advance

A review of sustainable approaches in transport infrastructure geotechnics

A. Gomes Correia, M.G. Winter, A.J. Puppala


Role of crystalline silica admixture in mitigating ettringite-induced heave in lime-treated sulfate-rich soils

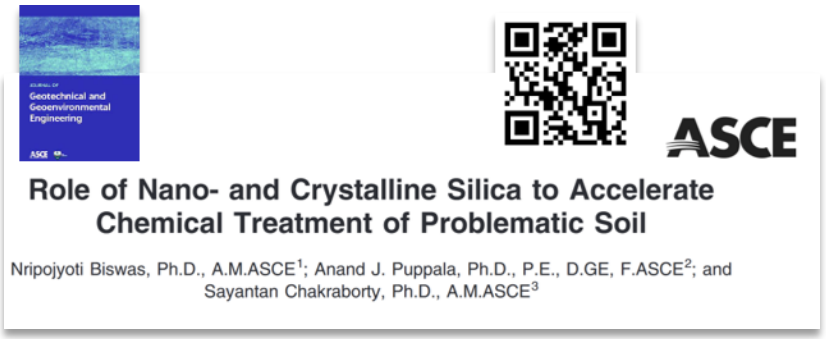
Sayantan Chakraborty; Anand J. Puppala; Nripojyoti Biswas

Author & Article Information

Geotechnique (2022) 72 (5): 438–454.

https://doi.org/10.1680/jgeot.20.P.154 Article history

GÉOTECHNIQUE


Geotechnical and Geoenvironmental Engineering

ASCE

Role of Nano- and Crystalline Silica to Accelerate Chemical Treatment of Problematic Soil

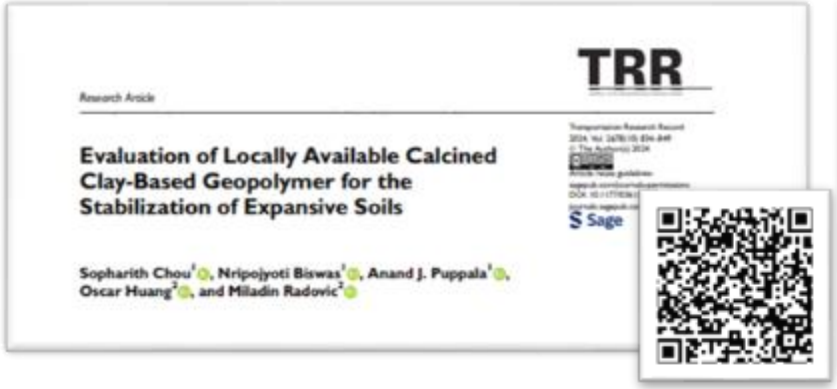
Nripojyoti Biswas, Ph.D., A.M.ASCE[1]; Anand J. Puppala, Ph.D., P.E., D.GE, F.ASCE[2]; and Sayantan Chakraborty, Ph.D., A.M.ASCE[3]


TRR

Research Article

Evaluating the Drainage Performance of Wicking Geotextile Under Freeze–Thaw Conditions below Pavement Infrastructure

Shanmukha Sai Avinash Gonnabathula, Nripojyoti Biswas, Krishneswar Ramineni, Md. Fyaz Sadiq, Bora Cetin, Raul Velasquez, and Anand J. Puppala


TRR

Research Article

Evaluation of Locally Available Calcined Clay-Based Geopolymer for the Stabilization of Expansive Soils

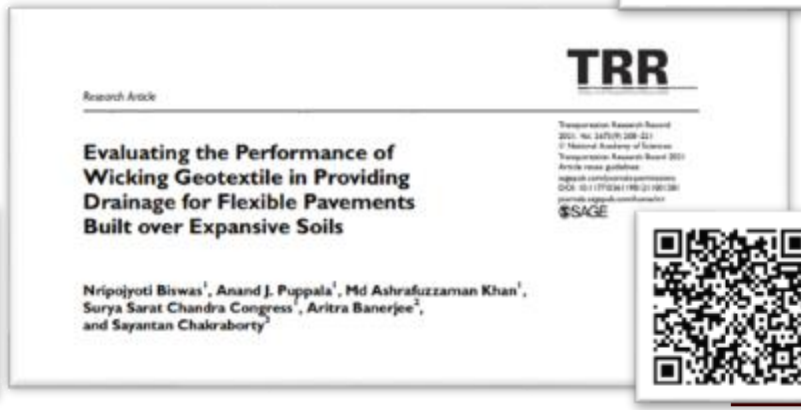
Sopharith Chou, Nripojyoti Biswas, Anand J. Puppala, Oscar Huang, and Miladin Radovic


TRR

Research Article

Insights into the Influence of Environmental Stressors on Expansive Subgrades Stabilized with Different Calcium-Based Stabilizers for Resilient Transportation Infrastructure

Sopharith Chou, Jianxin Huang, Balaji Lakkimsetti, Anand J. Puppala, and Raul Velasquez

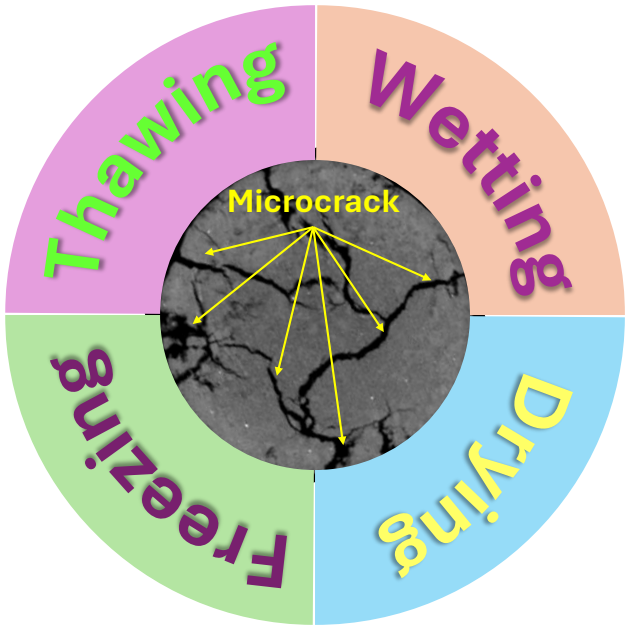

TRR

Research Article

Evaluating the Performance of Wicking Geotextile in Providing Drainage for Flexible Pavements Built over Expansive Soils

Nripojyoti Biswas, Anand J. Puppala, Md Ashrafuzzaman Khan, Surya Sarat Chandra Congress, Aritra Banerjee, and Sayantan Chakraborty

Thematic Research Area - B





Extreme Weather Resiliency Studies

I. Novel Durability to Screen Stabilization

II. Bridge Deicing Using Shallow Geothermal Energy

DEPARTMENT OF TRANSPORTATION

Texas Department of Transportation

US Army Corps of Engineers®

I. Novel Durability to Screen Stabilization

Major Extreme Weather Events in the Last Decade



Flooding After Hurricane Harvey in Houston, TX (2017)[1]



Severe Winter Storm in Houston, TX (2021) [2]



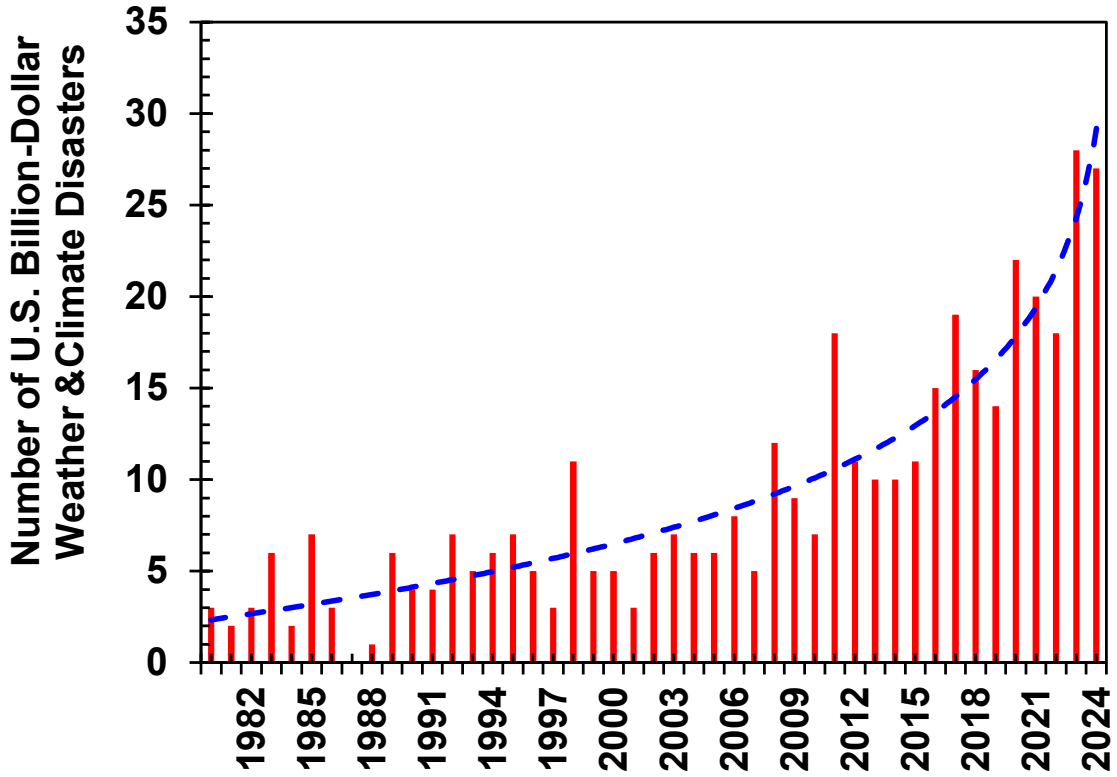
Landslide after heavy rains following a long drought, CA (2017) [3]



First Time in 34 Years Amid Flooding and Mudslides, Yellowstone (2022) [4]

[1] Sprague, K., (2017), [2] Jolles, W., (2021) , [3] Keeling, B., (2017), [4] Reuters (2022), [5] NOAA National Centers for Environnemental Information (2025)

Number of US Billion-Dollar Weather and Climate Disasters [5]



I. Novel Durability to Screen Stabilization

‘Four-Season’ Climatic and Extreme Weather Conditions



Durability Conditioning Protocols

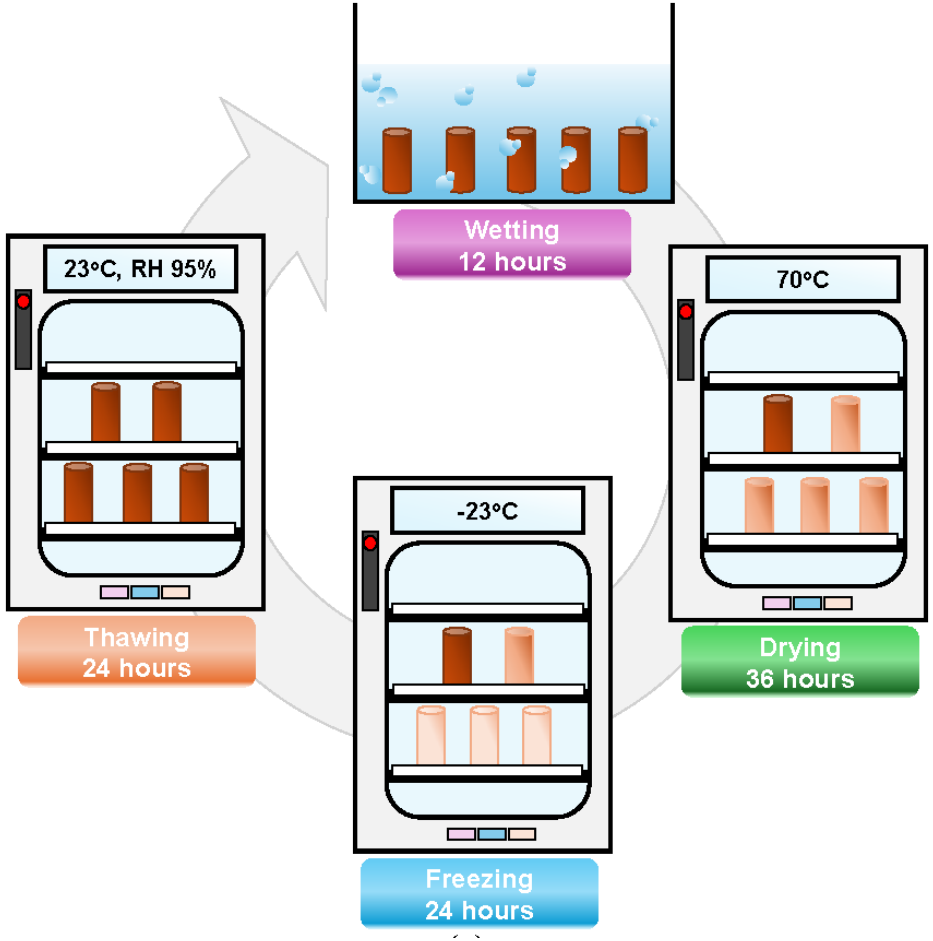
FT ASTM D560	WD ASTM D559	FTWD	WDFT	FTWDe	WDeFT
F: -23°C, 24 hours **T**: 23°C, RH 95%, 23 hours	**W**: 23°C, 5 hours **D**: 70°C, 42 hours	**F**: -23°C, 24 hours **T**: 23°C, RH 95%, 24 hours **W**: 23°C, 12 hours **D**: 70°C, 36 hours	**W**: 23°C, 12 hours **D**: 70°C, 36 hours **F**: -23°C, 24 hours **T**: 23°C, RH 95%, 24 hours	**F**: -23°C, 24 hours **T**: 23°C, RH 95%, 24 hours **W**: 23°C, 12 hours **De**: 20°C, RH 50%, 36 hours	**W**: 23°C, 12 hours **De**: 20°C, RH 50%, 36 hours **F**: -23°C, 24 hours **T**: 23°C, RH 95%, 24 hours

- F : Freezing
- T : Thawing
- W : Wetting
- D : Drying
- De : Desaturating

I. Novel Durability to Screen Stabilization

Durability Screening Plan

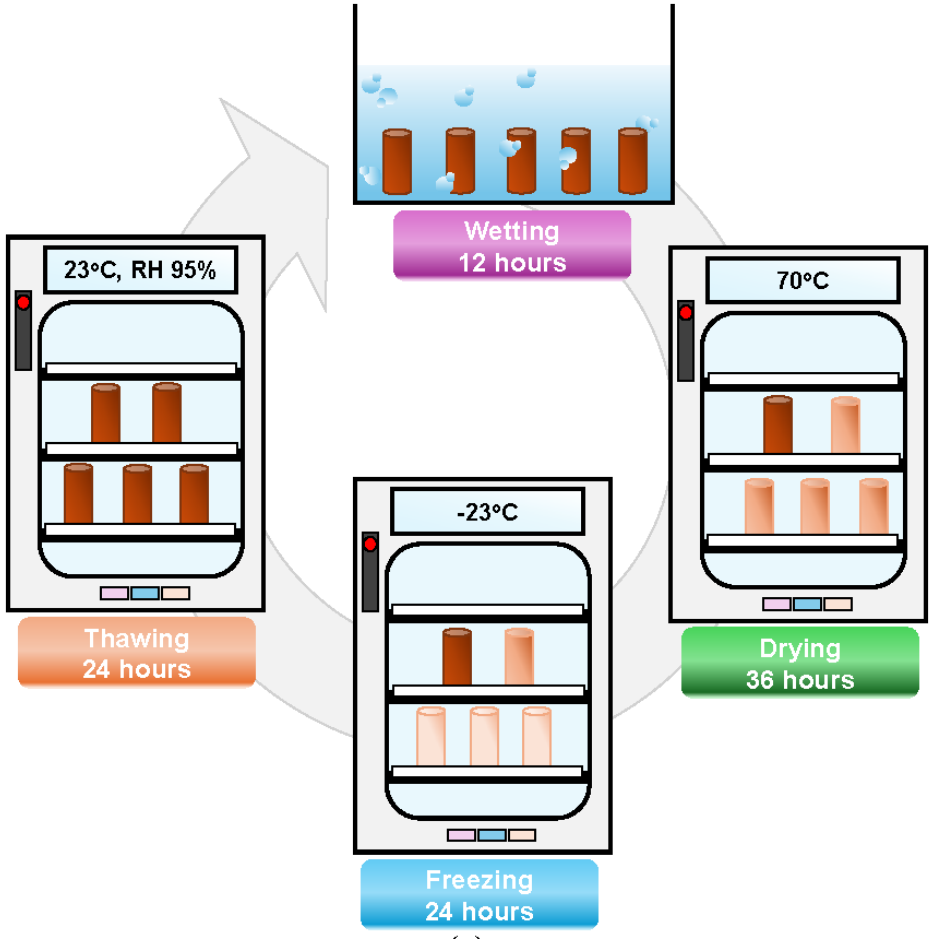
Environmental Conditioning

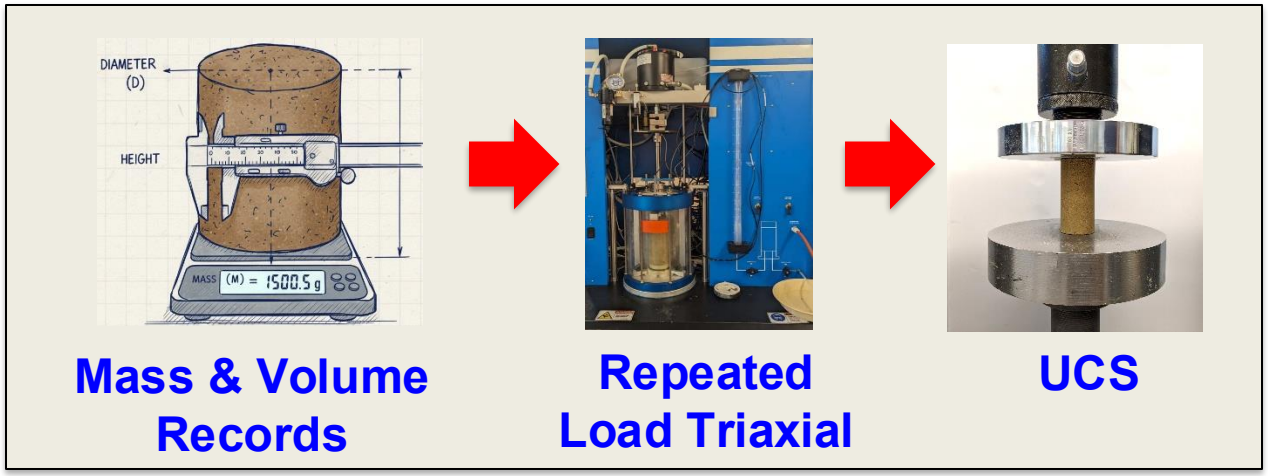


I. Novel Durability to Screen Stabilization

Durability Screening Plan

Environmental Conditioning



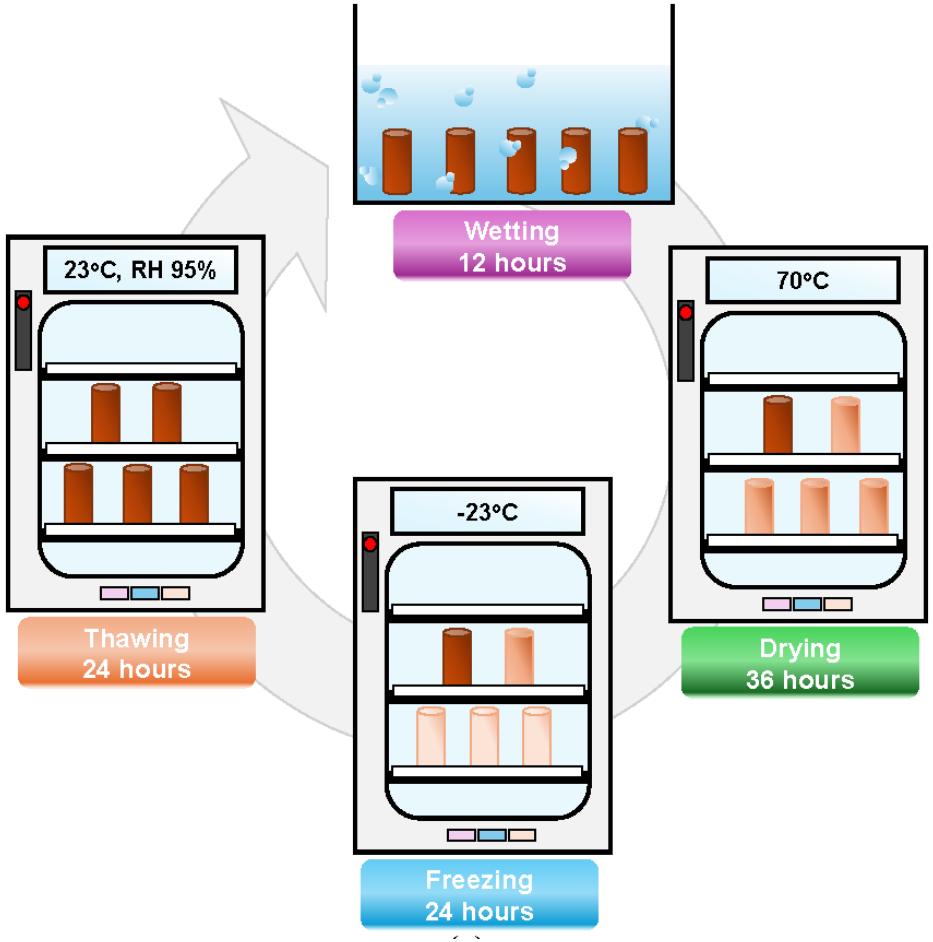


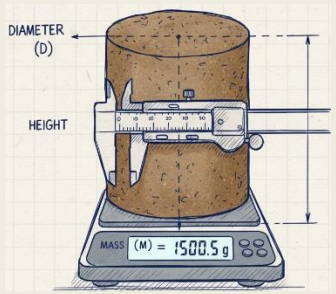
Engineering Tests

I. Novel Durability to Screen Stabilization

Durability Screening Plan

Environmental Conditioning





Mass & Volume Records



Repeated Load Triaxial



UCS

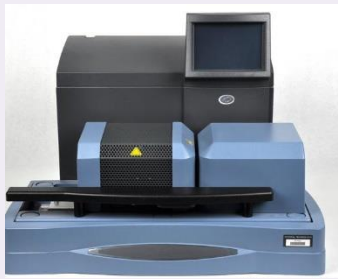
Engineering Tests



XRD



FESEM-EDS

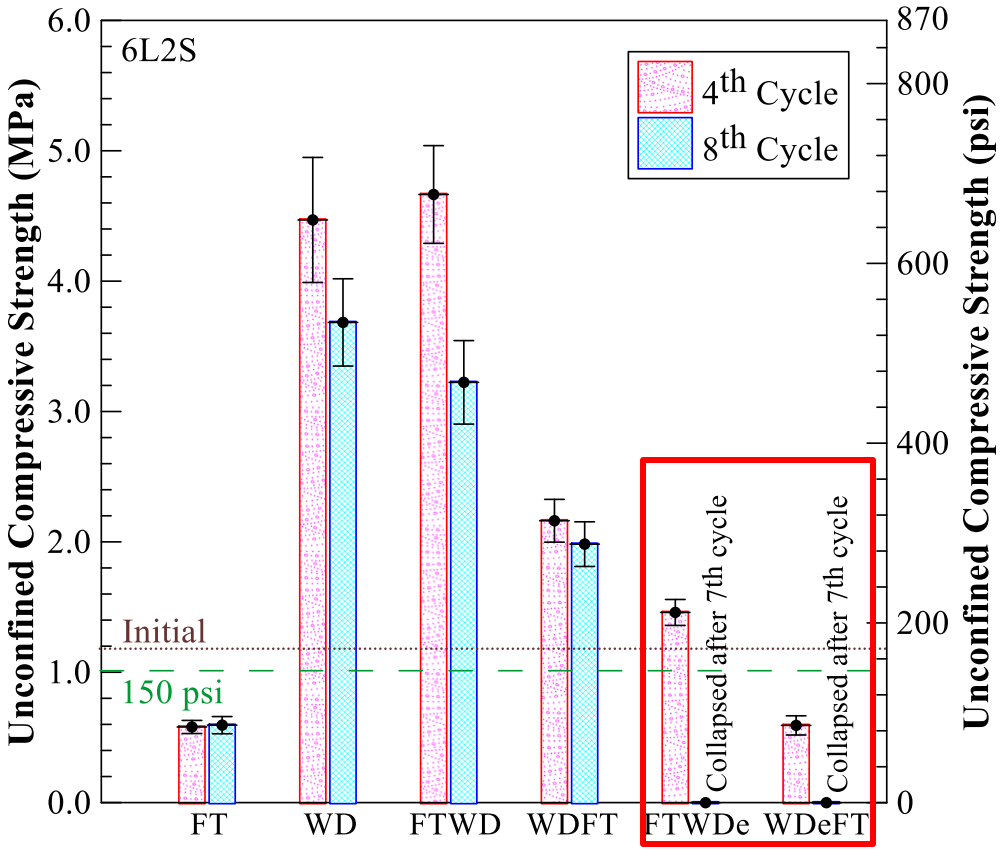


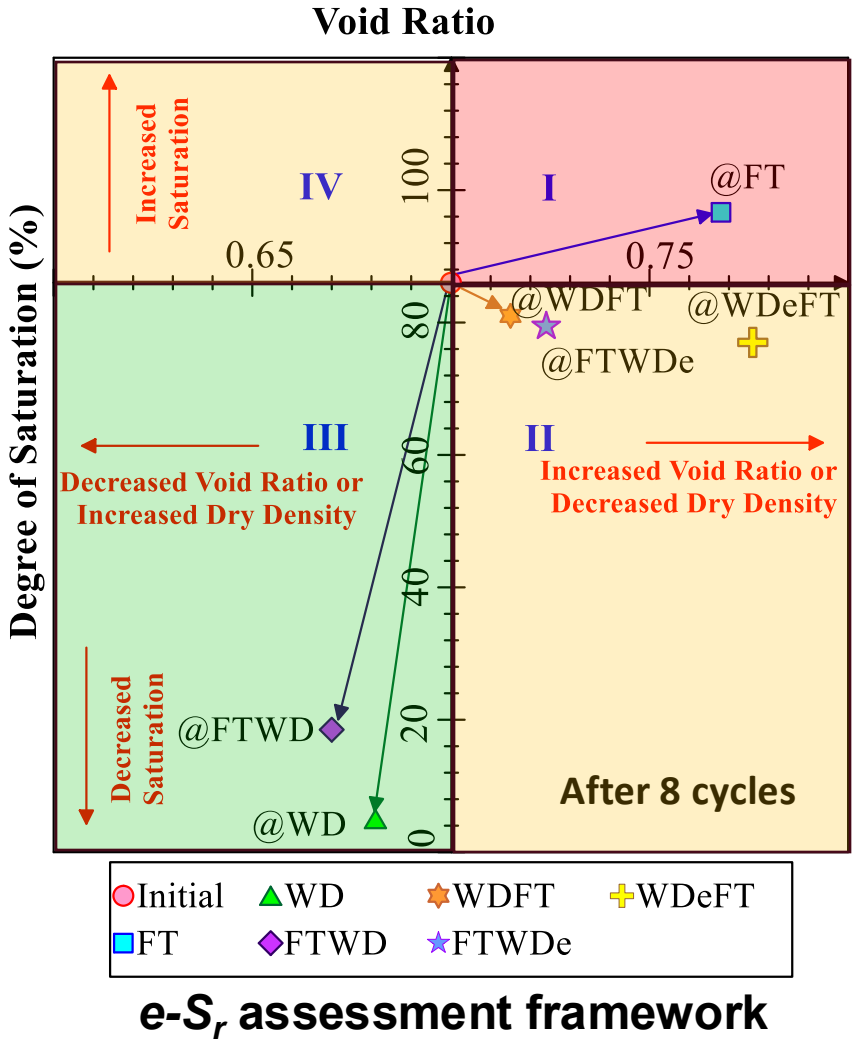
TGA-DSC

Micro-studies

I. Novel Durability to Screen Stabilization

CH Soil – 6% Lime and 2% Lime Sludge

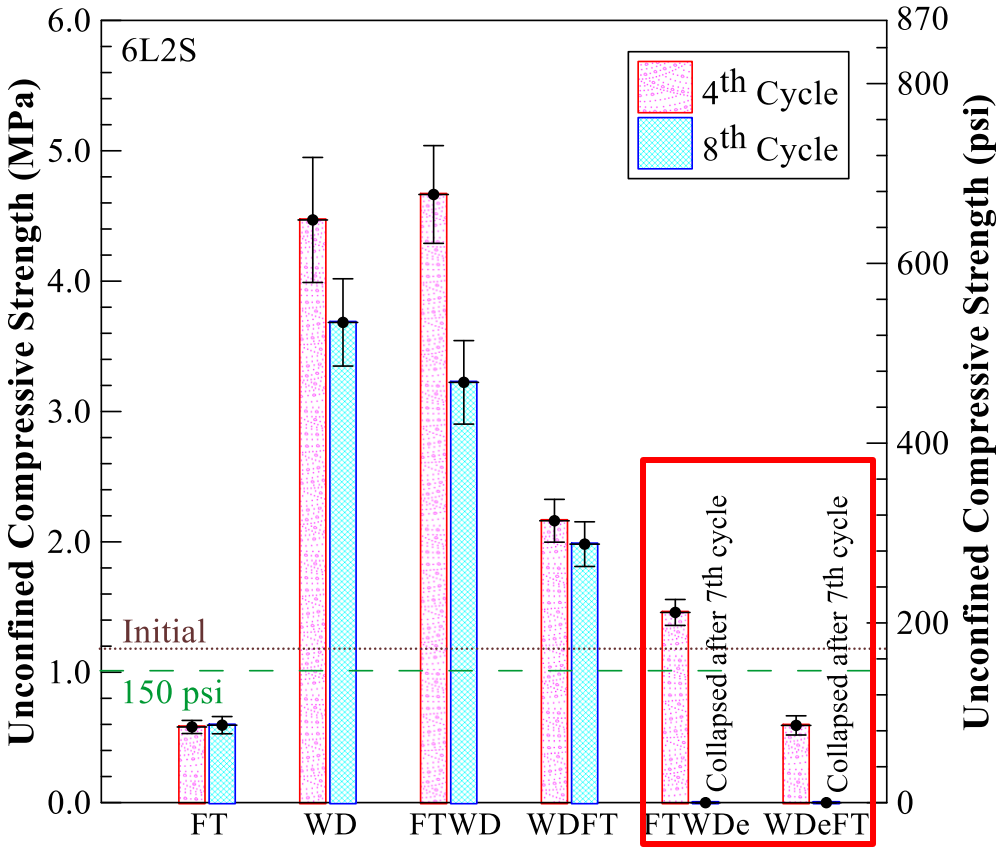


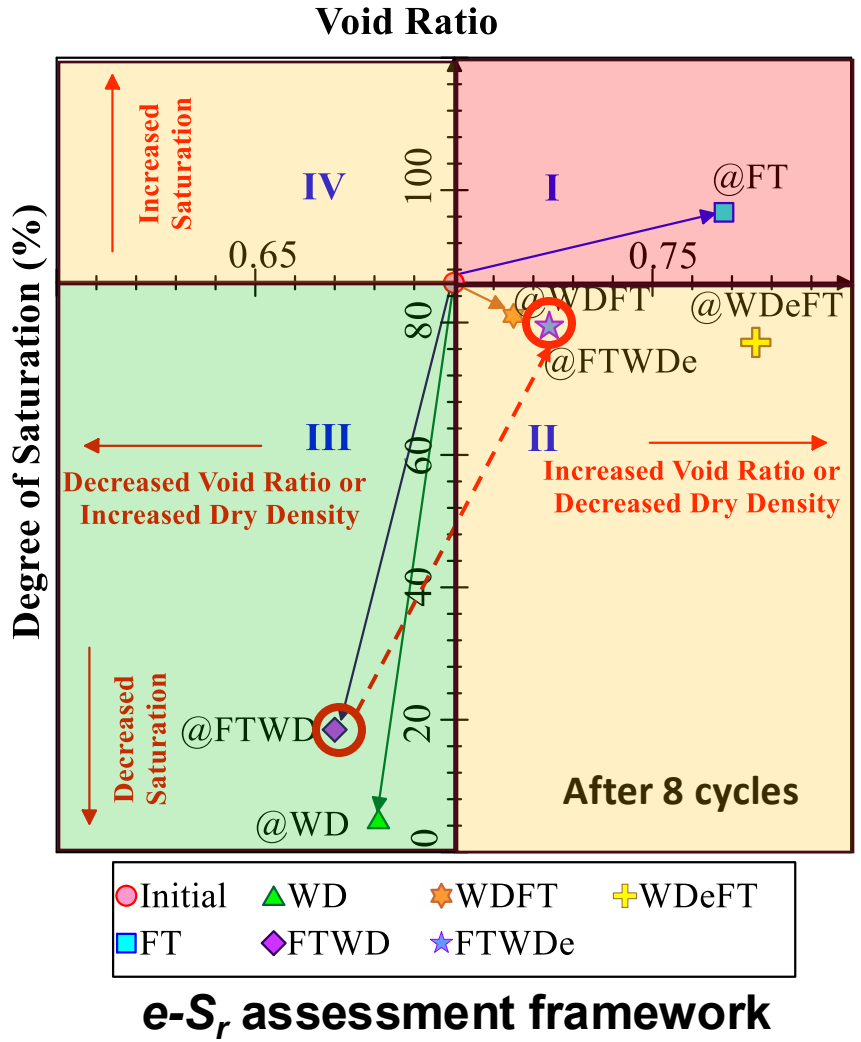


e-S_r assessment framework

I. Novel Durability to Screen Stabilization

CH Soil – 6% Lime and 2% Lime Sludge

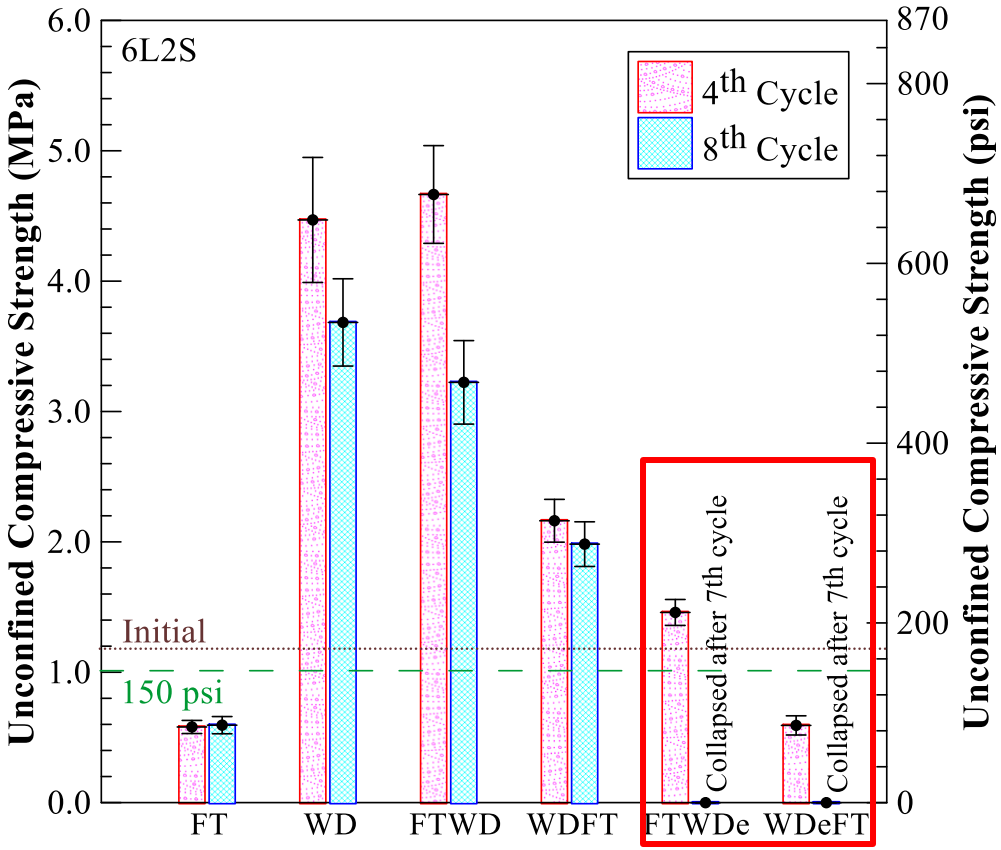


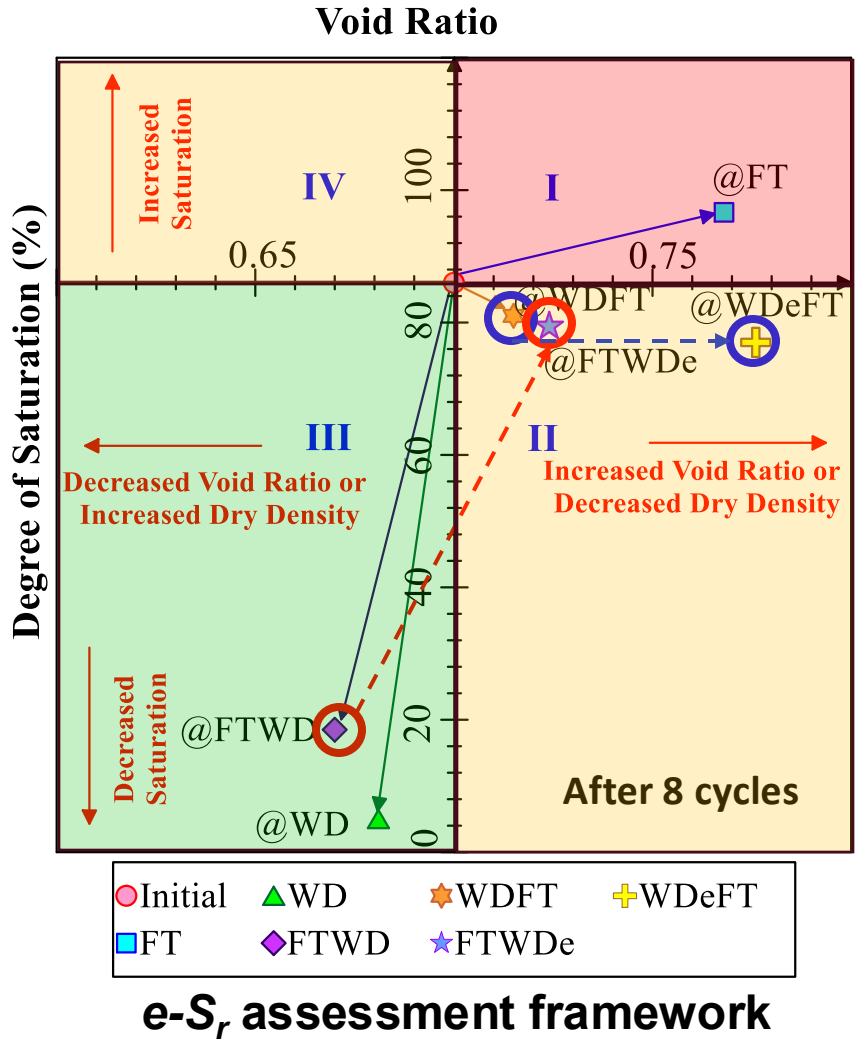


e-S_r assessment framework

I. Novel Durability to Screen Stabilization

CH Soil – 6% Lime and 2% Lime Sludge

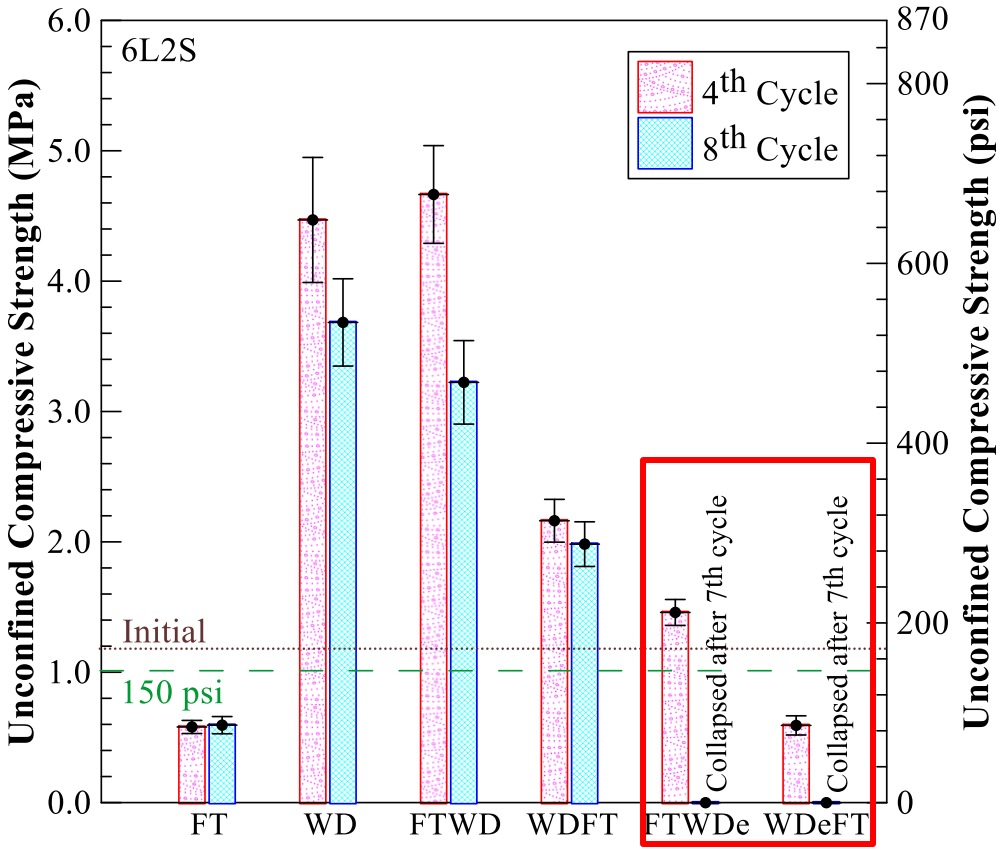


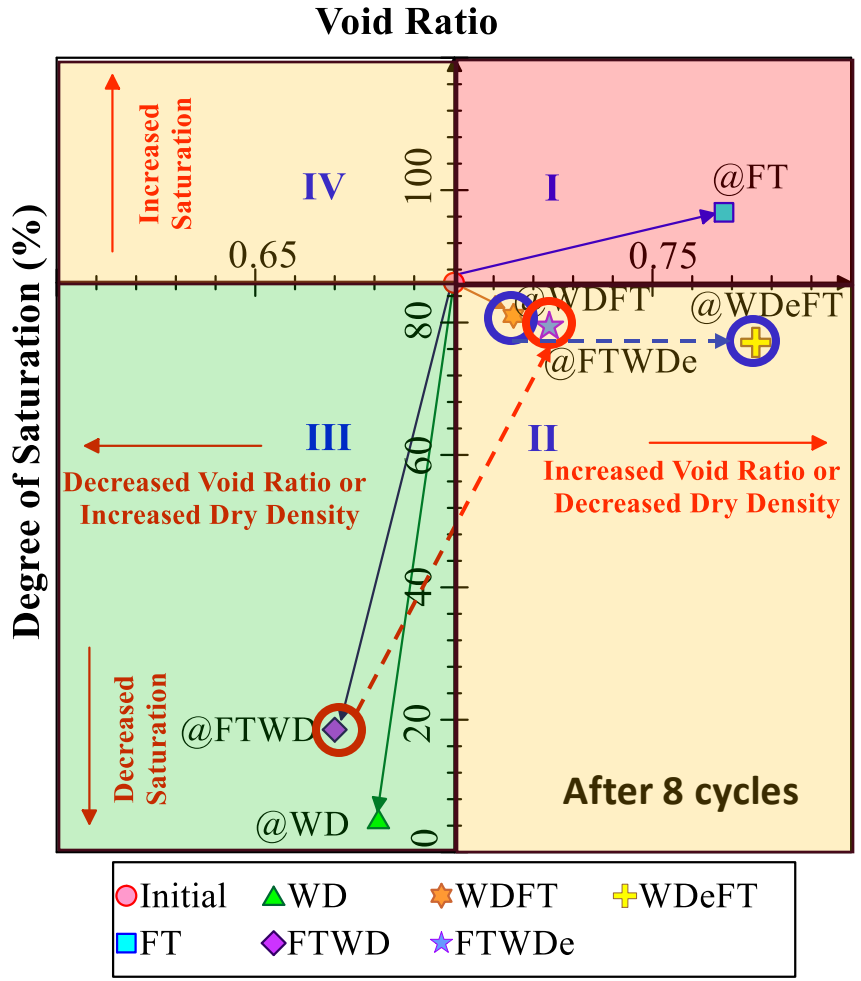


e-S_r assessment framework

I. Novel Durability to Screen Stabilization

CH Soil – 6% Lime and 2% Lime Sludge

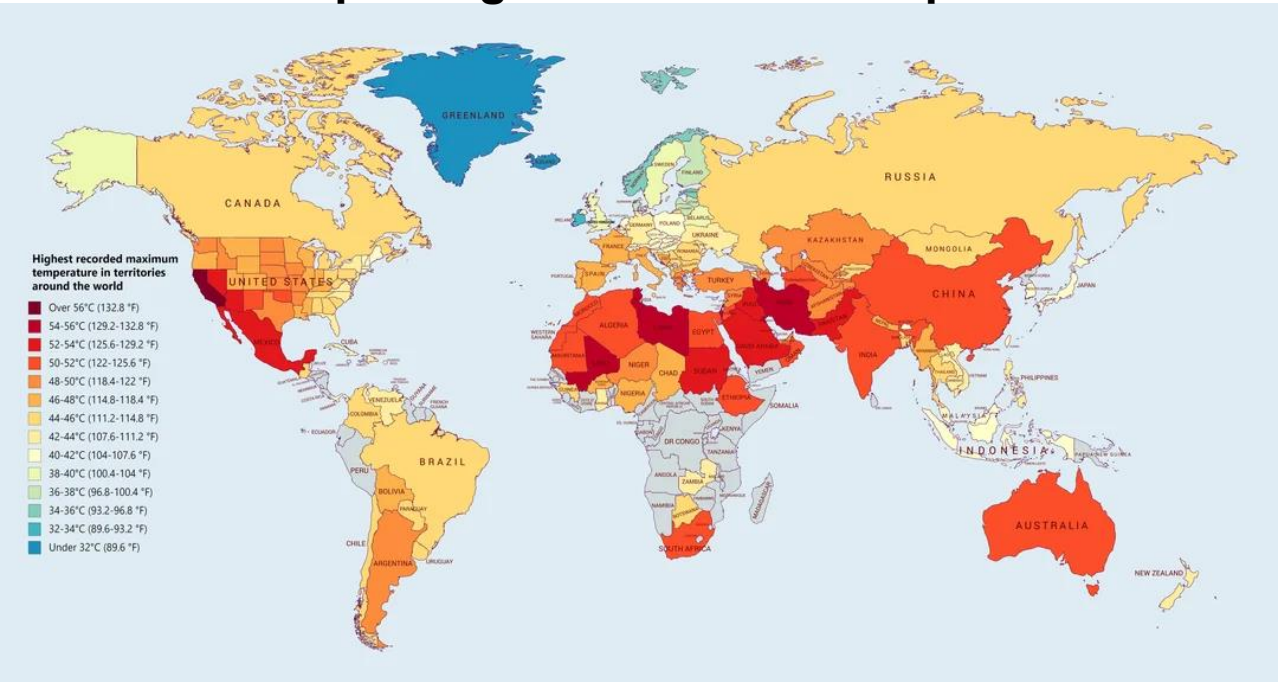




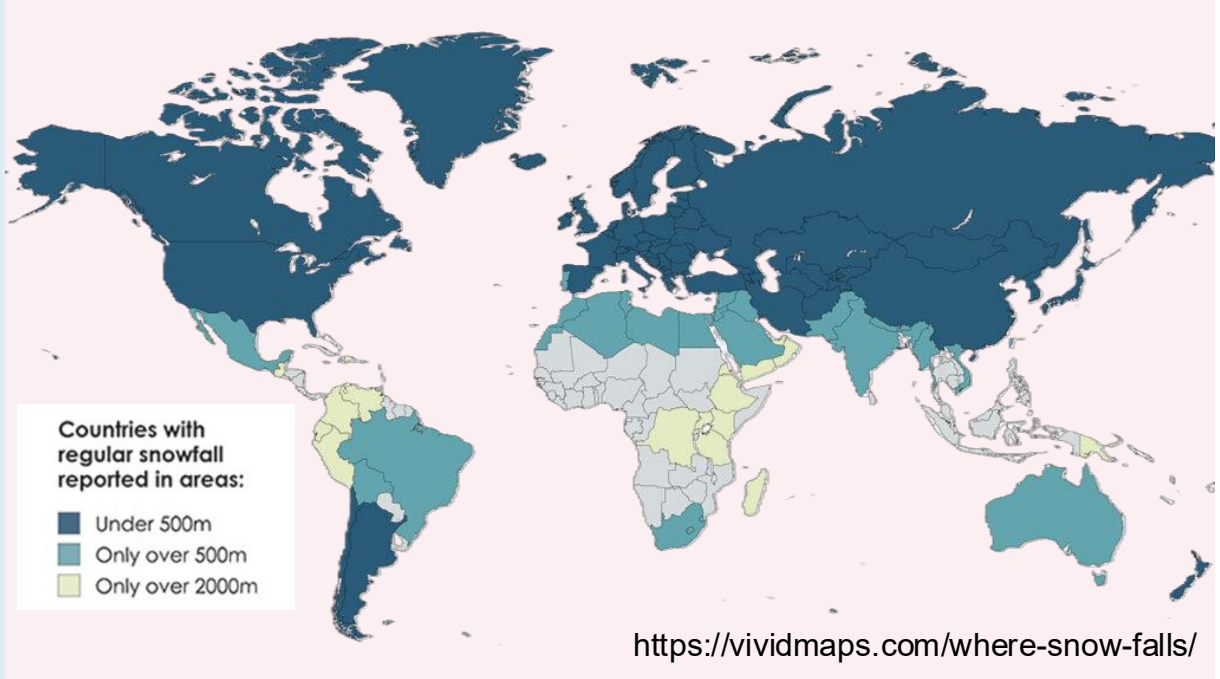
Modified coupled durability condition resulted in greater damage than the initial coupled condition.

I. Novel Durability to Screen Stabilization

Global map of highest recorded temperature



Global map of snow fall

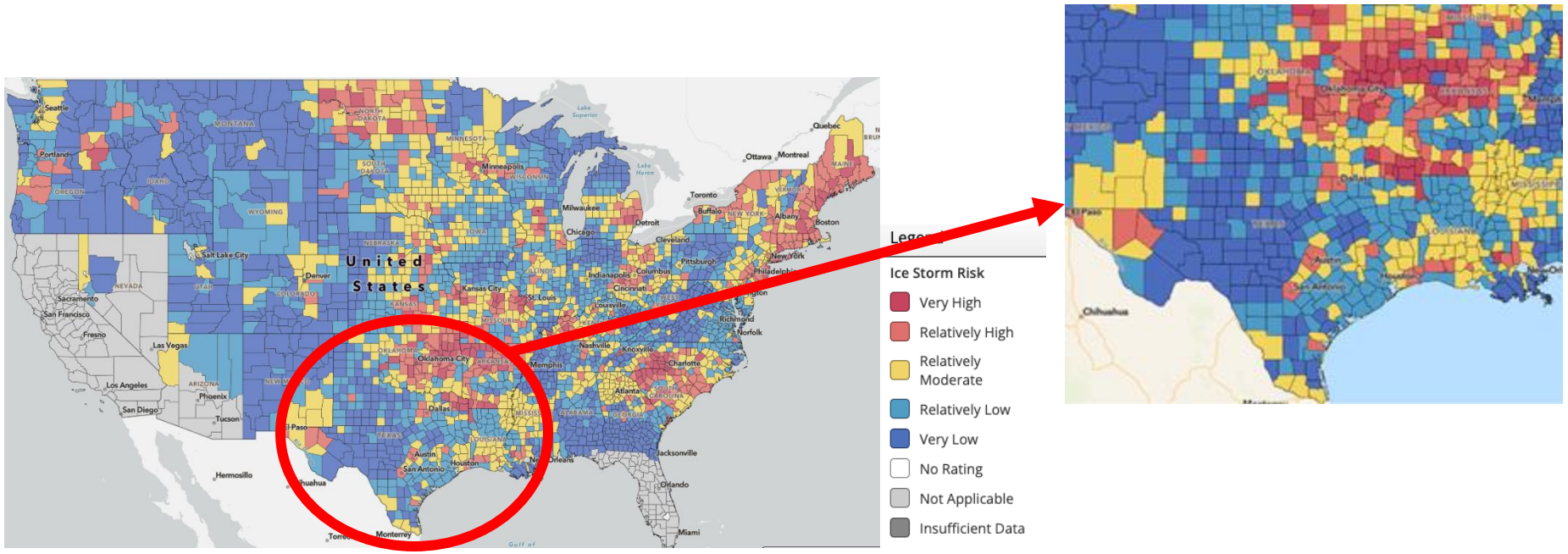


https://vividmaps.com/where-snow-falls/

- **4 phase durability protocols cover four-seasonal environment & extreme weather patterns**
- ***e-S$_r$* framework** establishes a **mechanistic link** between **soil structure** and **engineering performance**

II. Bridge Deicing Using Shallow Geothermal Energy

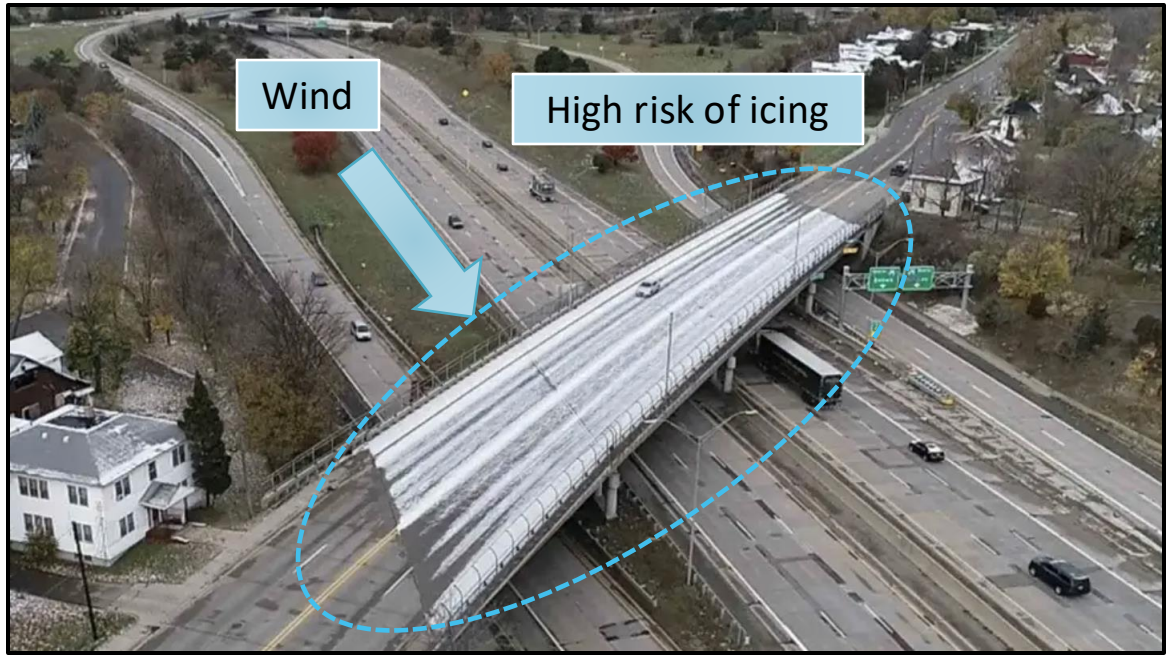
- **Snow and ice storms across the U.S. create a formidable test for resilience of transportation networks**
- **Effect of ice storms → Icing of road systems → Loss of productivity and livelihood**



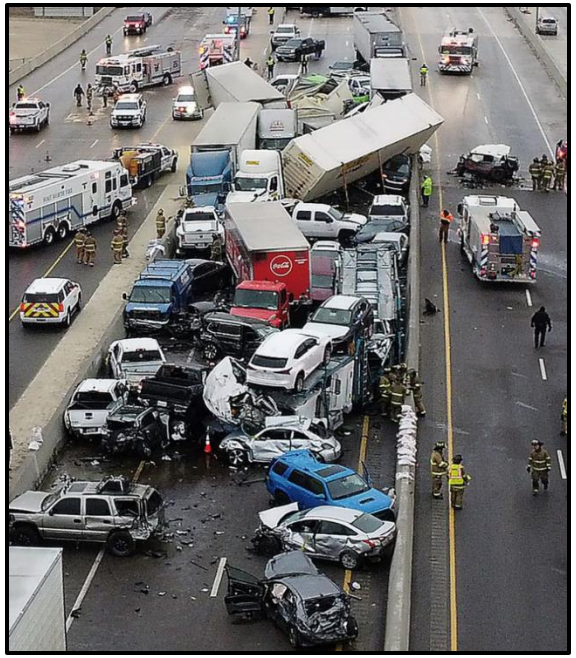
Ice Storm Risk Map of the United States
Source: Federal Emergency Management Agency (FEMA)

II. Bridge Deicing Using Shallow Geothermal Energy

Bridge decks must be kept ice-free in snow events due to elevated risk of bridge pavement icing compared to pavements constructed on the ground



Frozen overpass in Flint, Michigan (2019)
Image courtesy: Issac Scharrer (weather.com)



I-35 accident on frozen bridge pavement in Dallas, TX (2021)
Image courtesy: Dallas morning news

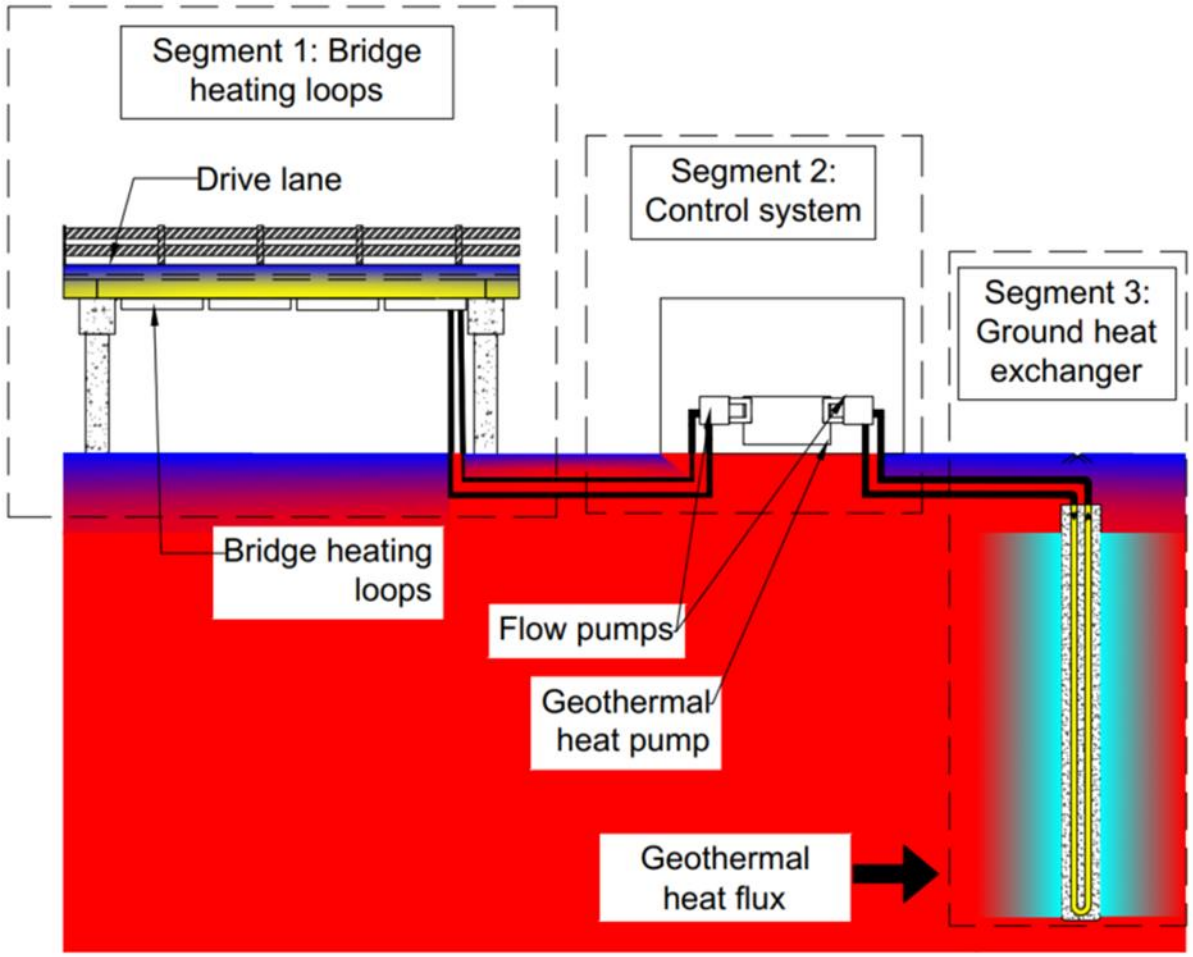
Need a sustainable and effective system for bridge deicing

II. Bridge Deicing Using Shallow Geothermal Energy

SYSTEM DESIGN

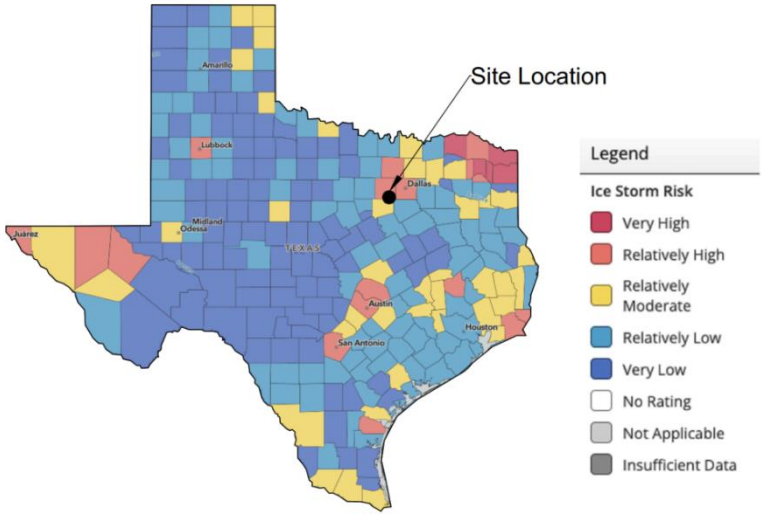
- Energy is harvested from the subsurface layers and transported to the bottom of the bridge deck using hydronic loops

- Shallow geothermal bridge deicing system (SGBDS) can be divided into three components:
  - Bridge heating loops
  - Control system
  - Ground heat exchanger (GHE)



II. Bridge Deicing Using Shallow Geothermal Energy

SITE LOCATION

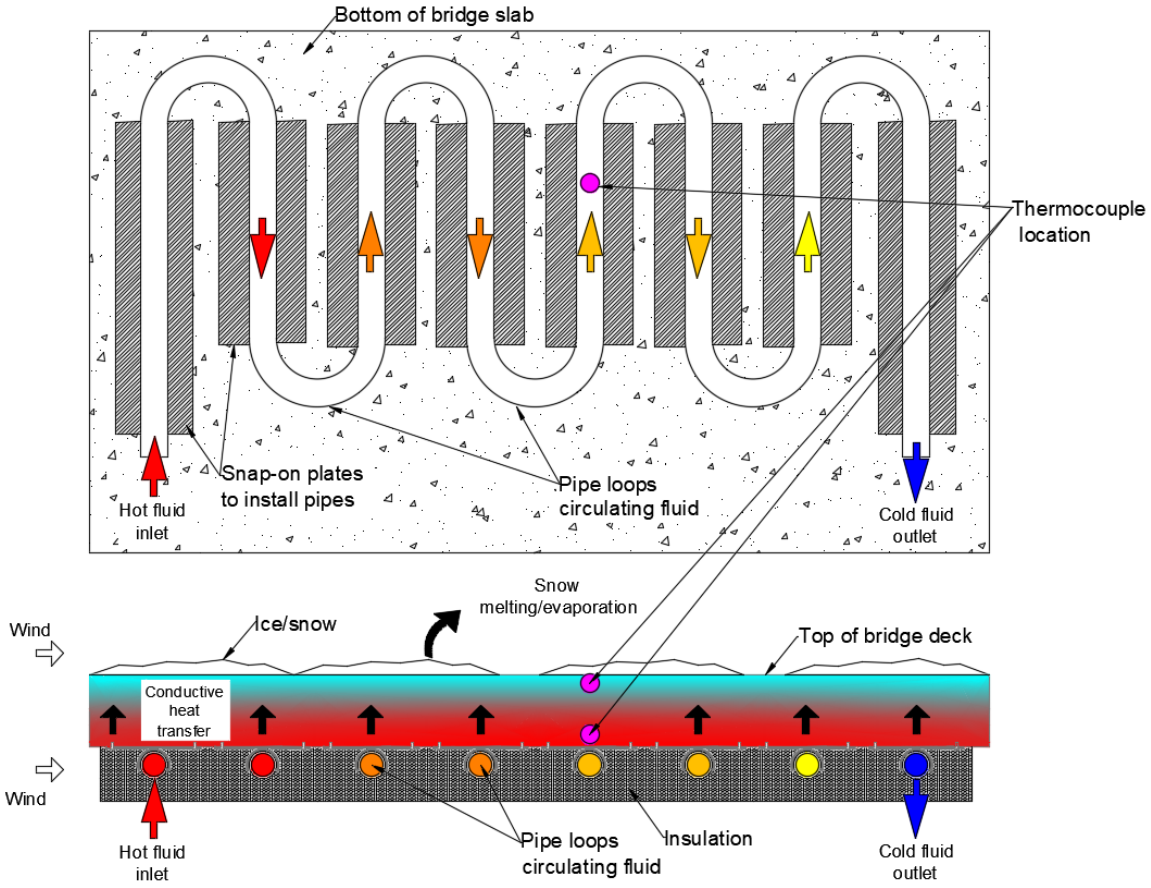


Site location	Arlington, Texas
Bridge deicing area	557.4 m^2
Bridge length	64 m
Bridge height	3 m



II. Bridge Deicing Using Shallow Geothermal Energy

INSTRUMENTATION





Flow Meter



Bridge Thermocouples



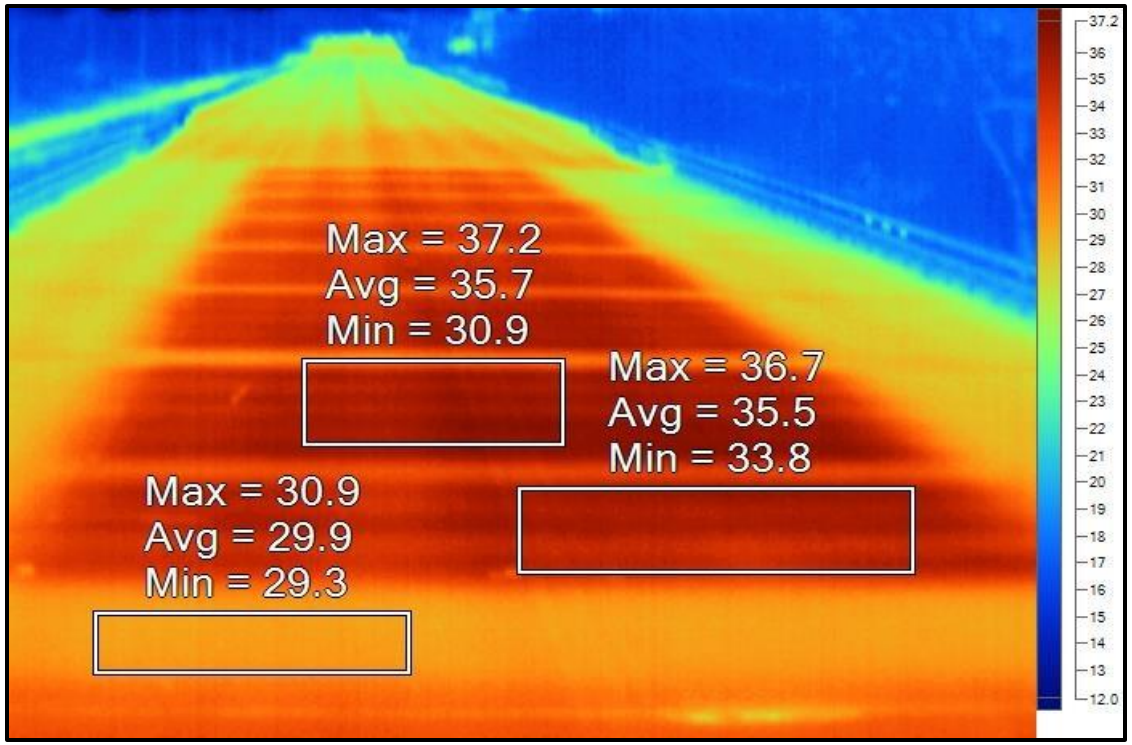
Pete's Plugs

II. Bridge Deicing Using Shallow Geothermal Energy

PERFORMANCE ASSESSMENT



Ice Free Bridge Deck during Snowstorm



Thermal Image of Bridge Deck during Winter 2024

SGBDS Provided Effective Deicing on Bridge Infrastructure

Our Research Outputs on Extreme Weather Resiliency Studies



Case Study

ASCE

Design and Performance of a Shallow Geothermal Energy–Supplemented Bridge Deicing System on an In-Service Bridge in North Texas

Aditya Deshmukh, S.M.ASCE[1]; Anand J. Puppala, Ph.D., P.E., D.GE, Dist.M.ASCE[2]; Puneet Bhaskar, Ph.D., A.M.ASCE[3]; Xinbao Yu, Ph.D., P.E., M.ASCE[4]; Alireza Fakhraibadi, S.M.ASCE[5]; and Gang Lei, Ph.D., A.M.ASCE[6]

Abstract: With the escalating challenges posed by climate-induced stressors, the design and operation of transportation infrastructure face new challenges such as subsoil freezing, pavement and bridge icing, road cracking, and structural damage to pavements and bridges due to extreme temperature fluctuations. Extreme weather events necessitate innovative approaches to increase infrastructure resiliency while keeping sustainability aspects in mind. One of the many challenges posed by climate is the unsafe driving conditions caused by icing bridge pavements in winter events leading to traffic delays, road accidents, and potential deaths. It is essential to develop innovative ways of deicing bridges such that they do not become hazard zones during wintry weather conditions. This study demonstrates an energy-efficient way of deicing bridges in winter weather conditions. A bridge deicing system supplemented with a renewable energy source, such as shallow geothermal energy, has been comprehensively studied with a full performance assessment of the system. The paper demonstrates the evaluation of design parameters of the geothermal system, which includes ground heat exchangers (GHEs) used to exchange energy from the subsurface, bridge deck heating loop design responsible to deliver the required energy to the bridge for deicing, and ground source heat pumps (GSHPs), which help deliver the design load to the bridge deck. The effectiveness of the design has been evaluated by presenting the performance analysis of the system for the winter weather events of January 2024. The performance analysis of the system showed that the geotechnical parameters evaluated for the design of GHEs as well as the bridge deck are adequate to keep the bridge deck ice free using shallow geothermal energy, thus improving the sustainability characteristics of the bridge deicing operation. This case study is a demonstration of the first well documented operation of a deicing system utilizing geothermal energy from subsoils on a full-scale bridge. **DOI: 10.1061/JGGEFK.GTENG-13218.** © 2025 American Society of Civil Engineers.

Introduction

Climate-related stressors present new challenges to the construction, operation, and maintenance of transportation assets. The increasing frequency of extreme weather events, rising sea levels, intensified precipitation, and hurricanes, as highlighted in a report by the committee on climate change, brings new challenges to the operation of existing transportation systems and the design of the transportation networks of the future (Miller 2008). One such challenge is the icing of pavements due to extreme winter events.

Ice accumulation on roads and bridges creates hazardous driving conditions and traffic delays leading to road accidents and fatalities (Abdalla et al. 2018). Within transportation infrastructure, bridge decks are particularly vulnerable to icing compared to other structures. During winter storm events, the pavement temperature of bridge decks is typically lower than the temperature of pavements constructed on the ground (Chen et al. 2024). The relatively lower temperature of the bridge deck can be deduced by comparing the heat exchange mechanism of an elevated bridge deck to the pavements constructed on the ground. As the ambient temperature drops during a winter storm event, the relatively thin bridge structure exposed to cold ambient temperatures loses heat, resulting in a drop in ... (Graham et al. 1983). Alternately, ... ground experience a heat flux ... counteracts the heat flux ... maintain a higher pavement ... ment system is susceptible to ... ramps exhibit a higher risk of ... bridge deicing solutions are crucial ... quency of ice or winter storm ... safer for drivers.

[1]Graduate Research Assistant, Zachry Dept. of Civil and Environmental Engineering, Texas A&M Univ., College Station, TX 77843-3136. Email: ...
[2]A.P. & Florence Wiley Chair Professor, Zachry Dept. of Civil and Environmental Engineering, Texas A&M Univs., College Station, TX 77843-3136 (corresponding author). ORCID: https://orcid.org/0000-0003-0431-6283. Email: anandp@tamu.edu
[3]Postdoctoral Associate, Geotechnical Dept., Texas Transportation Institute, Bryan, TX 77843-3136. Email: p-bhaskar@tti.tamu.edu
[4]Professor, Dept. of Civil Engineering, Univ. of Texas at Arlington, Arlington, TX 76019. ORCID: https://orcid.org/0000-0003-3681-0390. Email: xinbao@uta.edu
[5]Graduate Student, Dept. of Civil Engineering, Univ. of Texas at Arlington, Arlington, TX 76019. Email: ...
[6]Postdoctoral Associate and Adjunct Professor, Dept. of Civil Engineering, Univ. of Texas at Arlington, Arlington, TX 76019. Email: gang.lei@mavs.uta.edu

Note. This manuscript was submitted on July 9, 2024; approved on March 6, 2025; published online on June 3, 2025. Discussion period open until November 3, 2025; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Geotechnical and Geoenvironmental Engineering*. © ASCE, ISSN 1090-0241.

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Research Paper

Thermal performance of a geothermally heated bridge deck during winter operations: A heat transfer analysis

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ARTICLE INFO

Keywords:
Shallow geothermal energy
Bridge deicing
Heat transfer efficiency
Insulation materials

ABSTRACT

Recent extreme weather events and the increasing severity of winter events have posed significant challenges to transportation infrastructure. Extreme cold conditions often lead to the accumulation of snow and ice on pavements and bridge decks, compromising roadway safety. As a result, innovative and sustainable deicing systems are essential to maintain safe driving conditions. Geothermal energy has shown promising potential for snow and ice melting applications. This study presents a field-scale comprehensive evaluation of a novel shallow geothermal bridge deicing system (SGBDS) implemented on an in-service bridge in North Texas, addressing the urgent need for energy-efficient winter road maintenance solutions. The system consists of four ground-source heat pumps (GSHPs) and sixteen vertical ground heat exchangers (GHEs), which circulate heated fluid through externally attached hydronic loops on a 50-cm-thick concrete bridge deck. Field operations conducted during the 2024 and 2025 winter seasons assessed the deicing performance and heat transfer efficiency (HTE) in the bridge deck. Results demonstrate that the SGBDS successfully maintained deck temperatures above freezing during ambient lows of −9.6 °C, preventing all snow and ice accumulation. Quantitative analysis revealed that optimized 30 °C setpoints achieved a peak heat transfer efficiency (HTE) of 64%, with an average heating efficiency of approximately 33%. The span insulated with Spray Polyurethane Foam (SPF) and the fiber-foam insulated (GF) span demonstrated excellent heat transfer into the bridge deck, with SPF providing slightly higher efficiency. Despite the challenge posed by the thick bridge deck, the findings confirm that retrofitting existing bridges with SGBDS is a feasible and sustainable approach to enhancing winter road safety.

1. Introduction

In recent years, due to extreme weather events and the increasing frequency of severe winter events, the need for effective methods for deicing of roads and pavements has become essential to ensure public safety, maintain reliable transportation, and inform future infrastructure design. Ice accumulation on bridge decks significantly reduces surface friction, increasing the risk of vehicular accidents and endangering public safety. Among all components of the transportation system, bridges are the most vulnerable [1]. This vulnerability arises mainly because bridges lack the natural insulation provided by the ground beneath regular roadways. Furthermore, cold air circulating beneath bridges causes their surface temperatures to drop lower than those of at-grade roads, making them more susceptible to freezing and hazardous conditions [2–4]. One notable example is the February 2021 snowstorm, during which freezing rain and sleet led to severe icing on nearly elevated structures. The event caused a 130-vehicle crash and six fatalities, underscoring the vulnerability of elevated concrete bridge decks to freezing conditions and the importance of improved thermal protection for critical transportation infrastructure [5].

Traditionally, conventional deicing methods such as applying chemical salts and installing electrical ... used to address winter road safety ch...

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Experimental study on engineering and microstructural behavior of lime sludge stabilized expansive soils under cyclic environmental stressors

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ARTICLE INFO

Keywords:
Expansive soil
Soil stabilization
Lime sludge
Coupled and uncoupled durability
Moisture content
Soil temperature fluctuations

ABSTRACT

Moisture- and temperature-induced changes in microstructure and stabilization products remain a concern, requiring further study to clarify their effects on the engineering behavior of stabilized soils. Thus, this study aims to evaluate the engineering response of stabilized high-plasticity clay to moisture- and temperature-driven environmental conditioning, using hydrated lime (L) and lime sludge (S) under four sequences: freezing-thawing (FT), wetting-drying (WD), freezing-thawing-wetting-drying (FTWD), and wetting-drying-freezing-thawing (WDFT). Expansive soils were treated with a total dosage of 8% of L and S mixtures (4L4S and 6L2S) and evaluated through UCS and repeated load triaxial tests, further supported by microstructural and mineralogical analyses. Both 4L4S- and 6L2S-treated specimens exhibited improved engineering performance compared to the untreated soil due to short-term strength gains and long-term pozzolanic reactions. Importantly, the addition of lime sludge, a calcite-rich material, did not hinder the stabilization process, as 4L4S specimens achieved UCS values comparable to those of specimens treated with 3% hydrated lime. Both the treated specimens retained their integrity throughout the environmental conditioning phases, whereas the untreated specimens collapsed during the early stages. Among these durability stages, FT caused the most severe deterioration, due to sub-stantial soil swelling during freezing. In contrast, coupled durability conditions caused relatively less damage, due to limited ice lens formation post drying phase, resulting in better engineering properties. Microstructural and mineralogical analyses were performed, which revealed the formation of cementitious gels, binding soil particles and enhancing the structural stability and durability of the treated specimens. Also, key variations in the mineral contents, and related microstructure of the stabilized soils through thermogravimetric analysis were observed after different environmental conditionings. This explains the influence of the mineral contents and microstructure of stabilized soils on the long-term performance.

1. Introduction

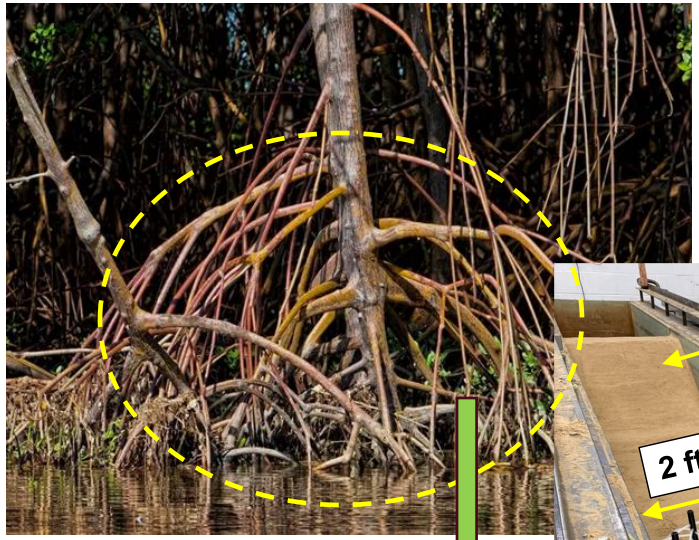
Calcium-based binders like cement and lime are known to significantly enhance the strength and durability of the soil by improving its resistance to moisture and temperature cycles (Prusty and Pujppala, 2021). However, the manufacturing process of these stabilizers is energy and resource-intensive in nature. Any additives, especially those obtained from waste materials and by-products, that could lower the required dosages of these stabilizers are a great value addition, as they reduce the overall costs, address the stockpiling and disposal issues, and at the same time contribute to sustainable development goals. In this context, chemical stabilization offers the dual benefits of performance improvement and the environmentally friendly utilization of industrial by-products.

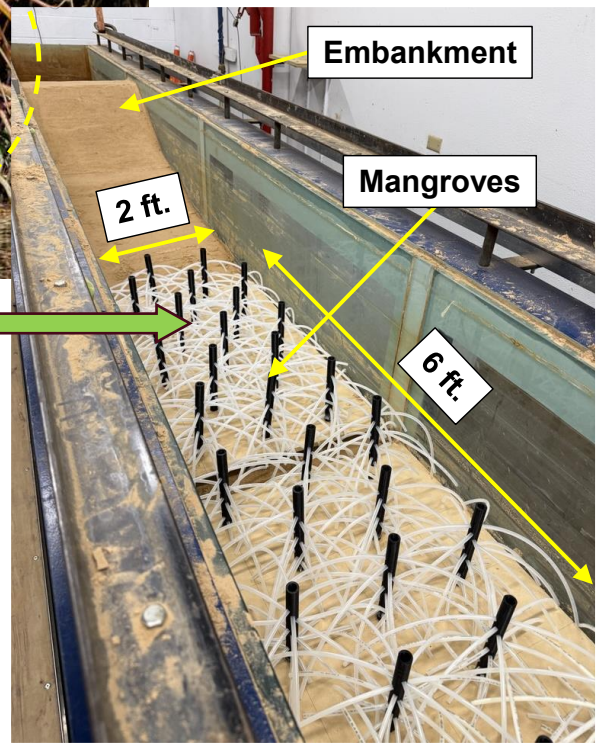
One such material, namely, lime sludge, which is essentially a waste product from water treatment plants and predominantly composed of calcite minerals, has attracted researchers' attention. It has already shown proven efficacy in cement production, power plant SOx treatment, wastewater neutralization, and as an infill material for road construction (Baker et al., 2005). Due to its abundance, lime sludge has also drawn interest from geotechnical engineers and researchers for its potential use in developing innovative ... (Chou and Kinoy, 2023; Thanikkodi ... Sharma, 2022; Yu et al., 2005).

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0013-7952/© 2026 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://...

Thematic Research Area - C







Coastal Transportation Infrastructure

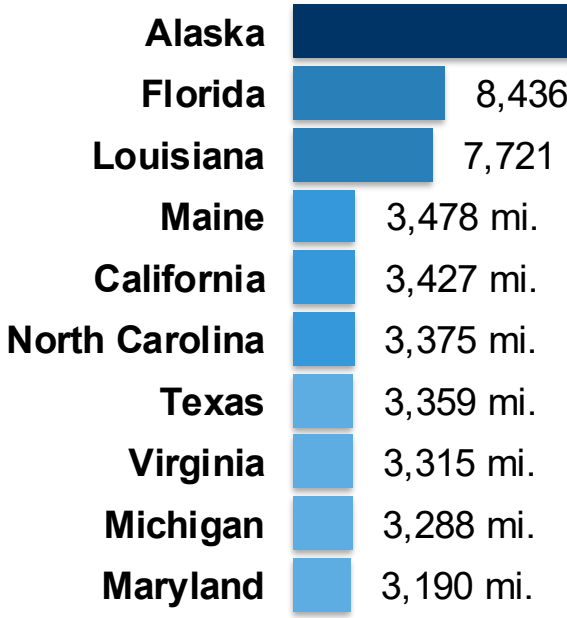
I. Artificial Mangrove Systems – Wave Induced Erosion

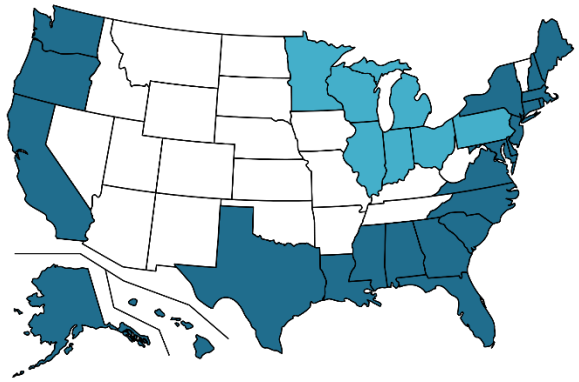
II. Erosion Resistant TRMs for Highways

Coastal Infrastructure Challenges

Growing Challenge of Coastal Region:

- U.S. coastline - Home to 40% of the nation's population - Spans over 95,400 mi
- Sea levels are rising at 0.1 in/yr, with projections of 0.9 to 3.3 ft rise by 2100 threatening coastal infrastructure
- Annual storm damage in the U.S → $ 5.3 Billions





U.S. Coastline

Extreme Weather ↑ + Coastal Urbanization ↑ = Heightened Risk ↑







Coastal Infrastructure Challenges

Impact on Coastal Highways:

- ❑ **60,000+** miles of coastal highways at risk
- ❑ Repair costs exceed **$ 2 Billions** annually







Storm-Driven Waves → Rapid Erosion → Structural Failure → Frequent Closures









Solution Needed →

Durability → **Scalable** → **Flexible** → **Rapid Deployment** → **Non-Invasive**

I. Artificial Mangrove Systems – Wave Induced Erosion

Why Artificial Mangroves?

- Artificial mangroves - Designed to **replicate the hydrodynamic benefits** of natural mangroves
- **Scalability** – Adaptable to different linear infrastructure
- **Immediate functionality** – Fully operational as soon as they are installed
- **Easy integration** – Can be easily integrated with existing coastal infrastructure
- **Rapid implementation** –Time required for implementation is significantly reduced

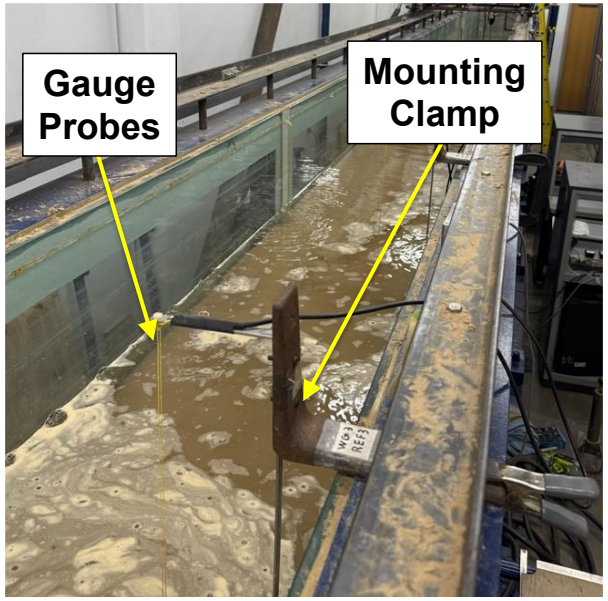


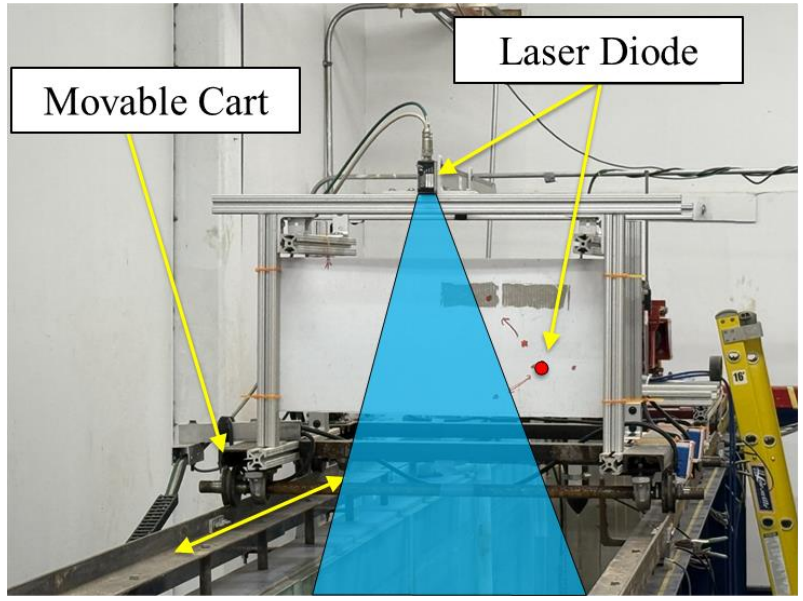
Rhizophora Mangle **(Red Mangrove)**

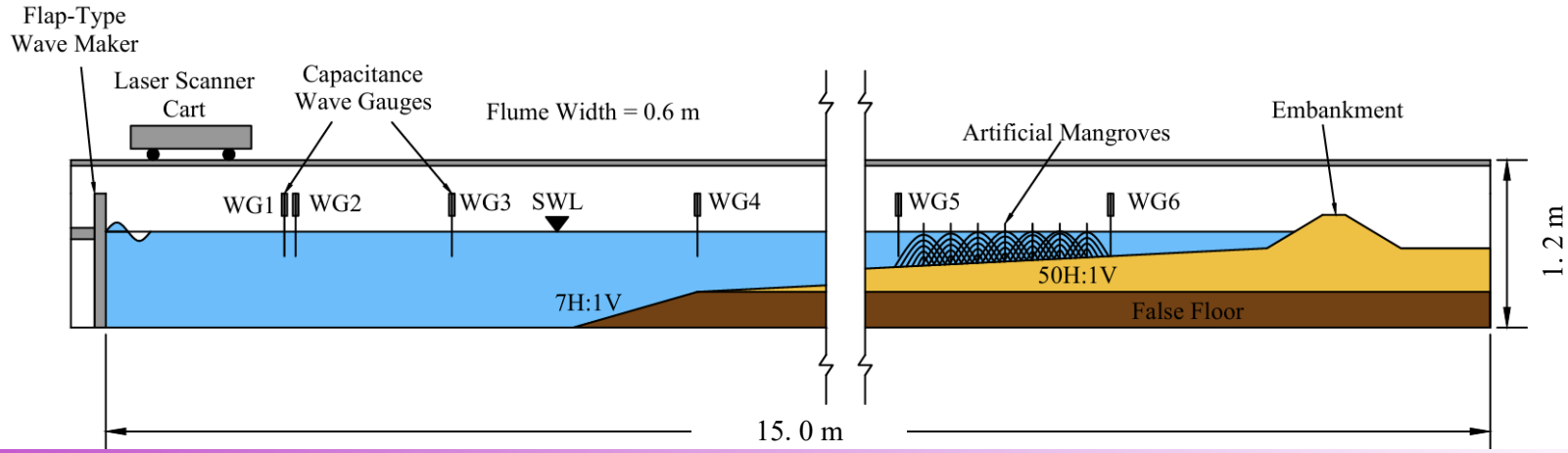
I. Artificial Mangrove Systems – Wave Induced Erosion

Wave Flume Tests

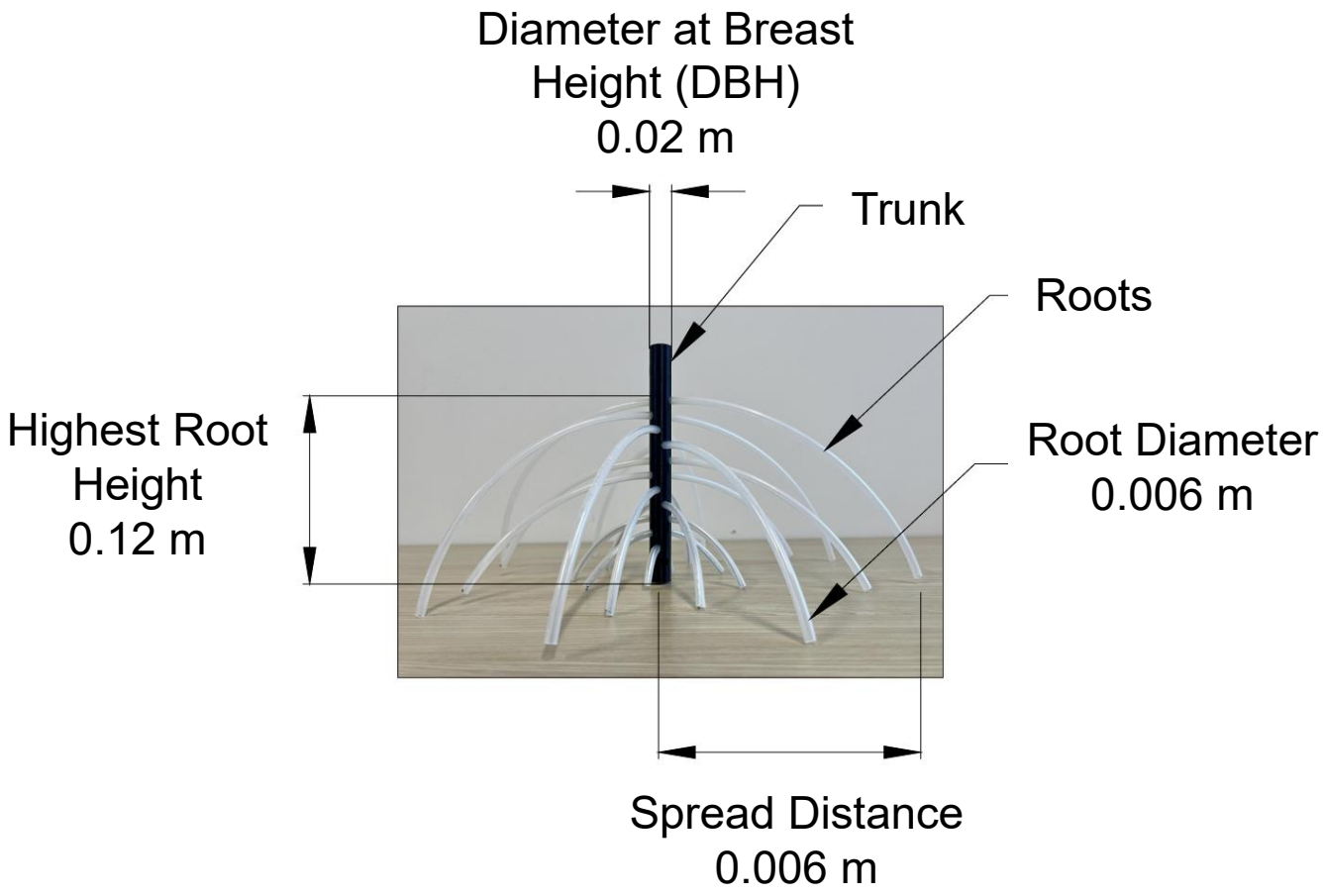








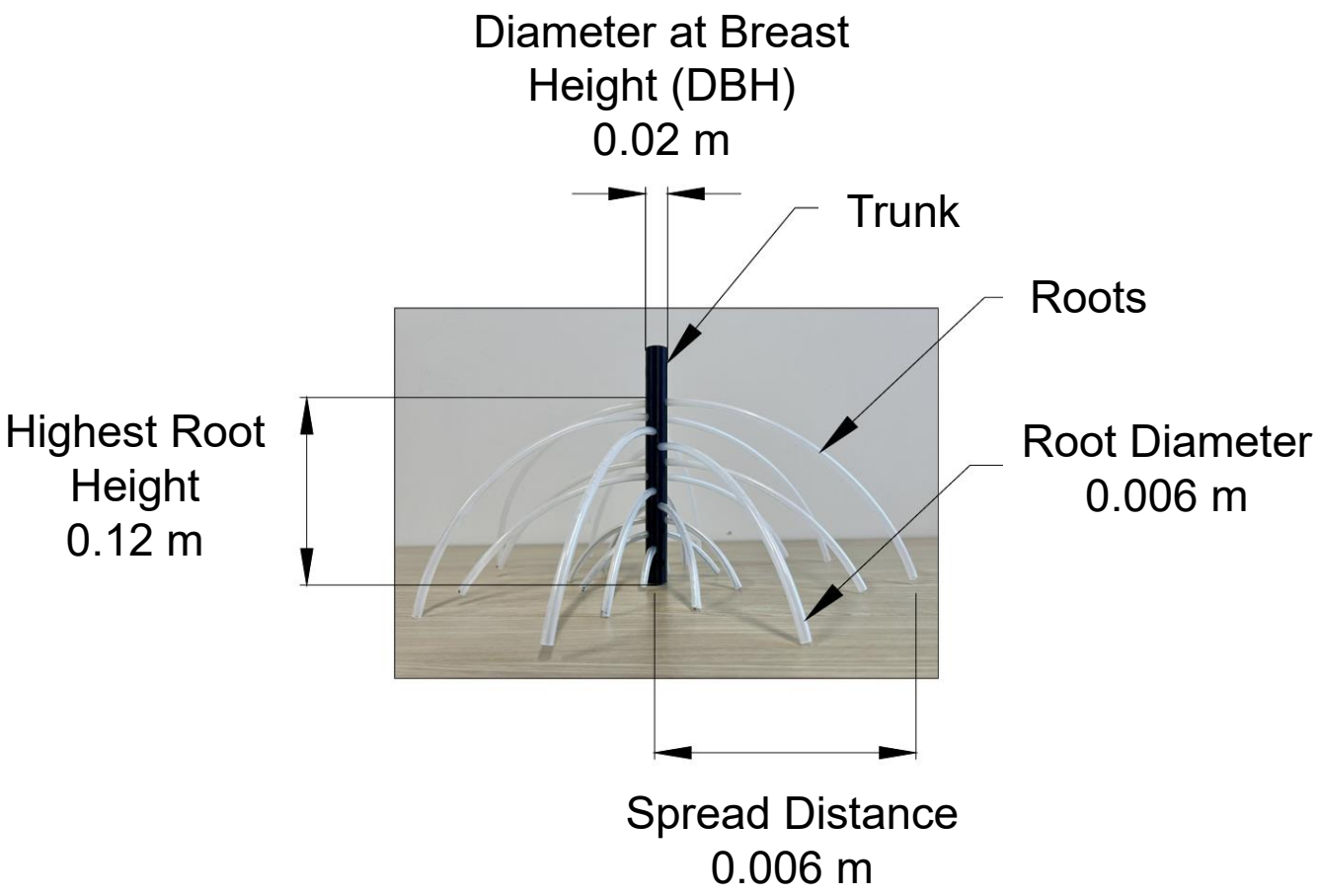
Mangrove Design



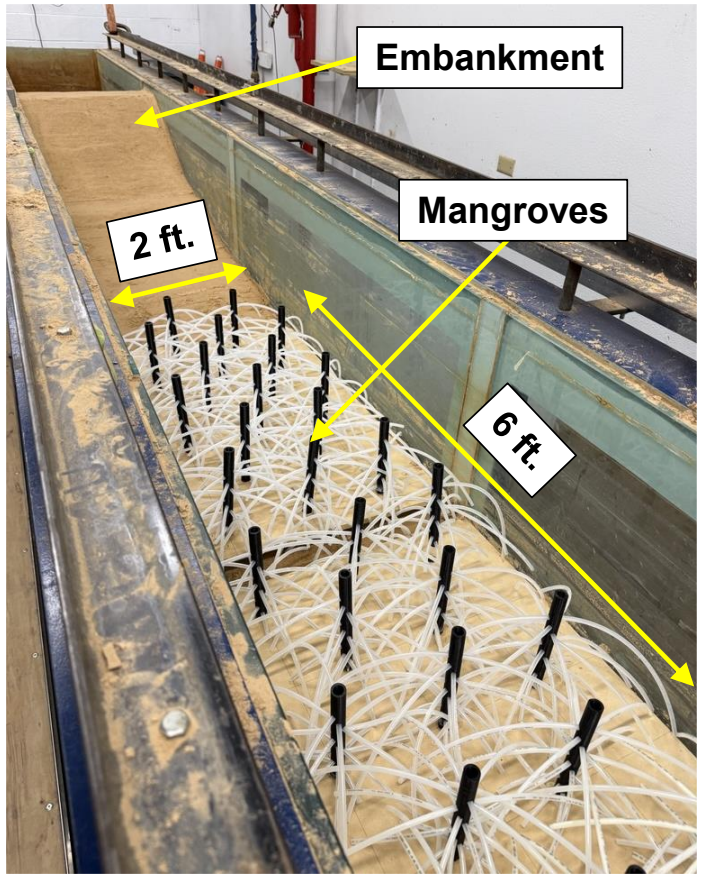
Trunk → **Polyethylene Terephthalate Glycol (PETG)**

Roots → **Crosslinked Polyethylene (PEX)**

Mangrove Design



Scaled down - 1:15

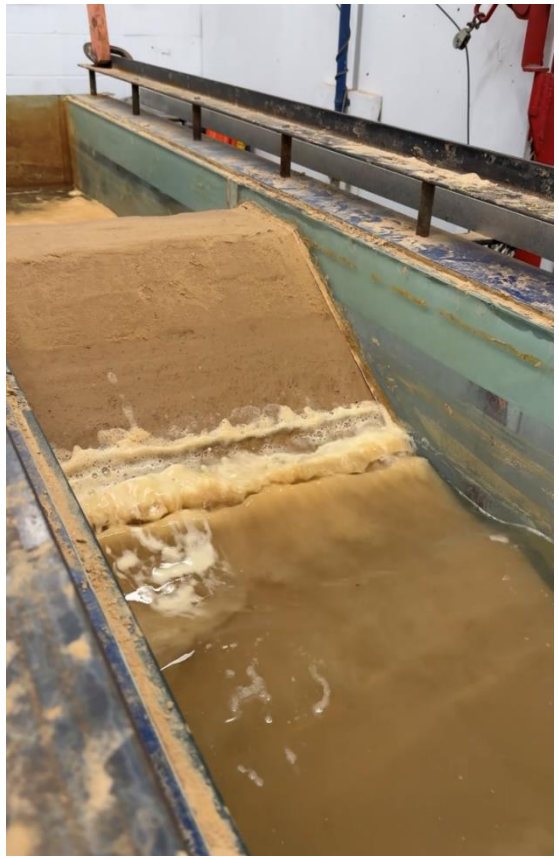


Trunk → Polyethylene Terephthalate Glycol (PETG)

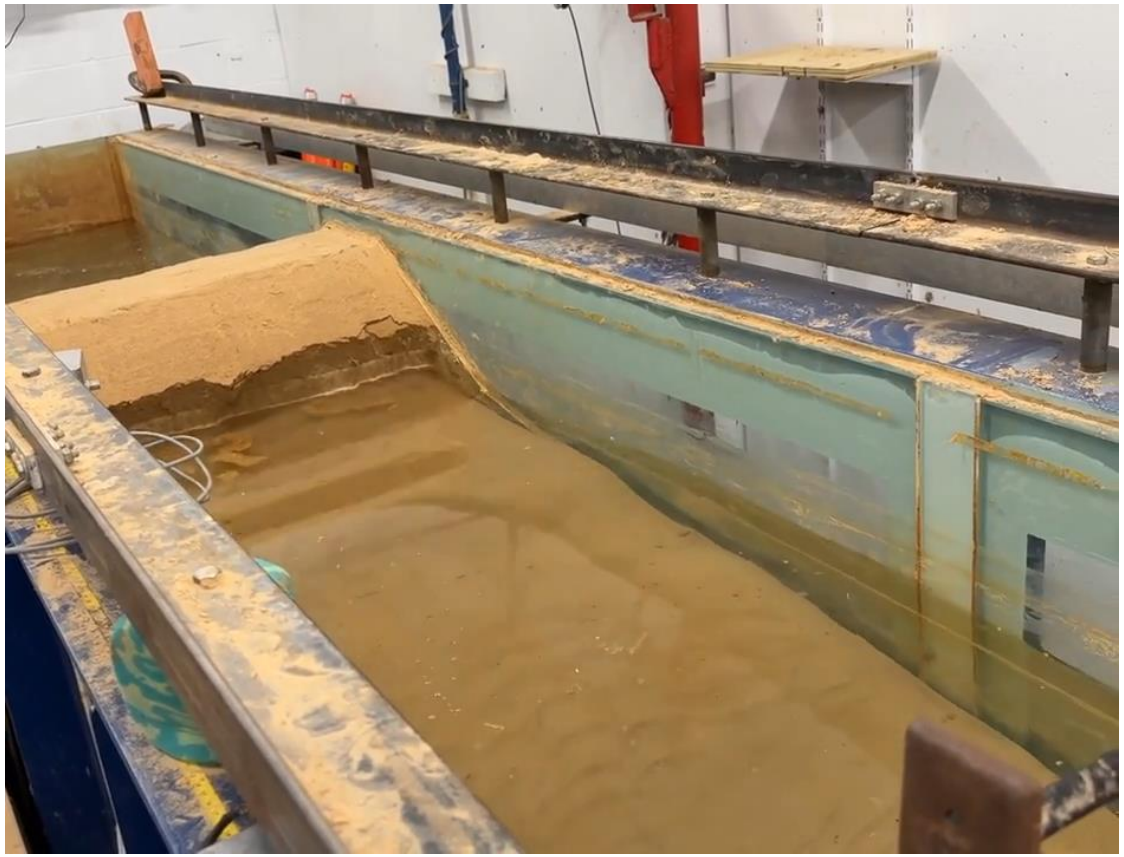
Roots → Crosslinked Polyethylene (PEX)

I. Artificial Mangrove Systems – Wave Induced Erosion

Erosion of embankment under regular wave loading (Without Mangrove)



Start of Cycle 1



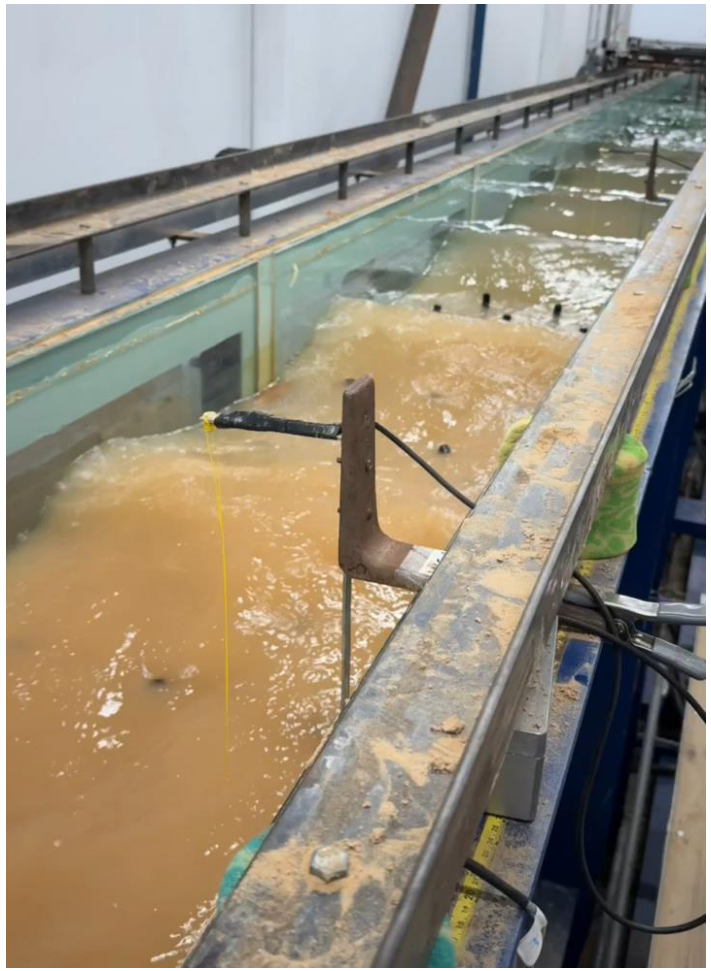
During Cycle 9



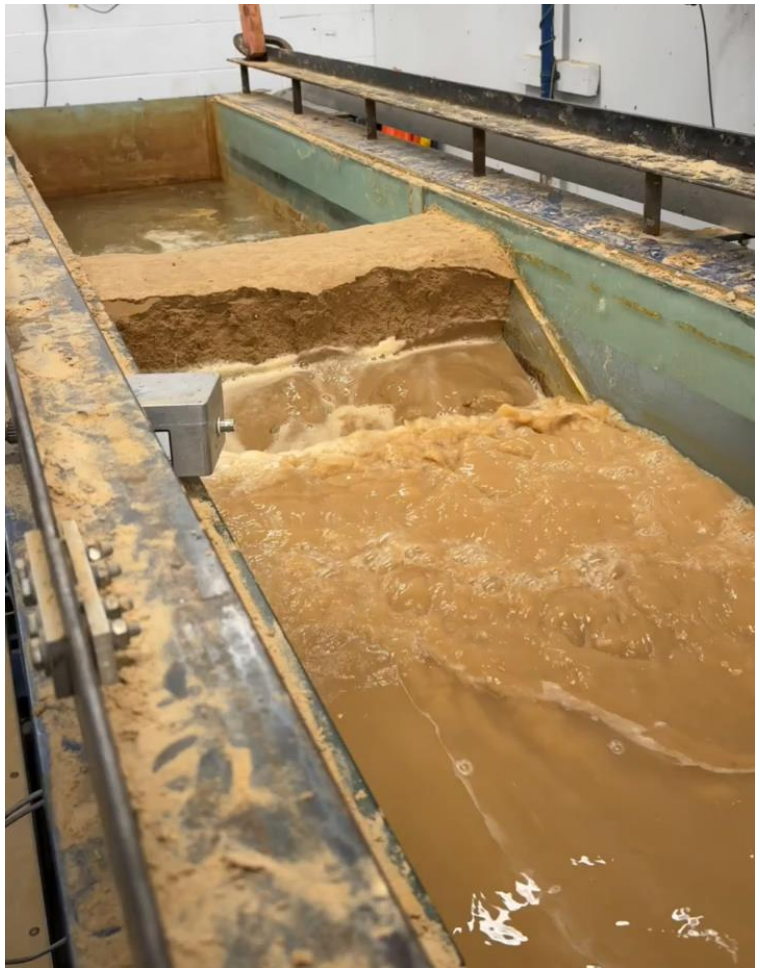
End of Cycle 10

I. Artificial Mangrove Systems – Wave Induced Erosion

Erosion of embankment under regular wave loading (With Mangrove)



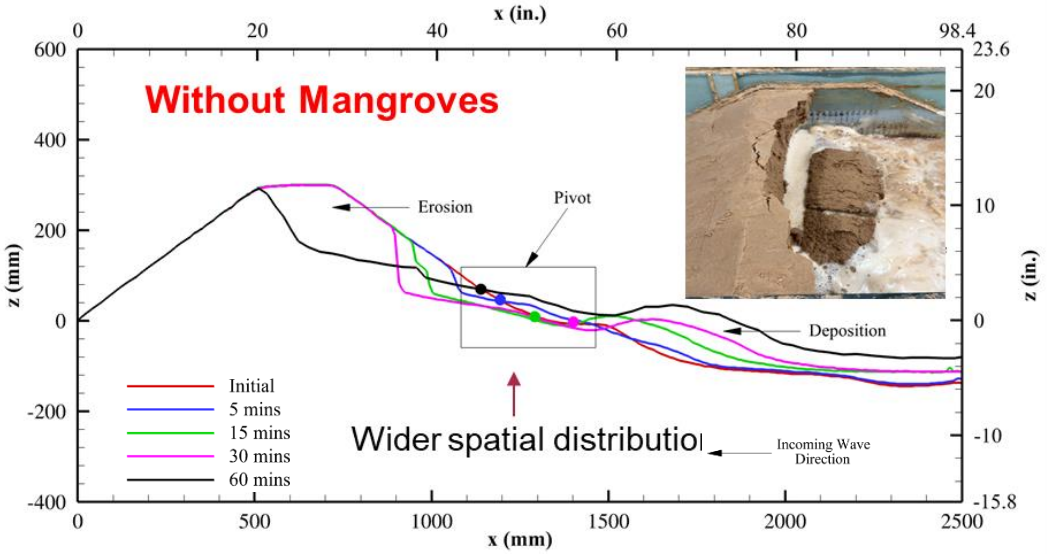
Artificial Mangrove – Wave Interaction

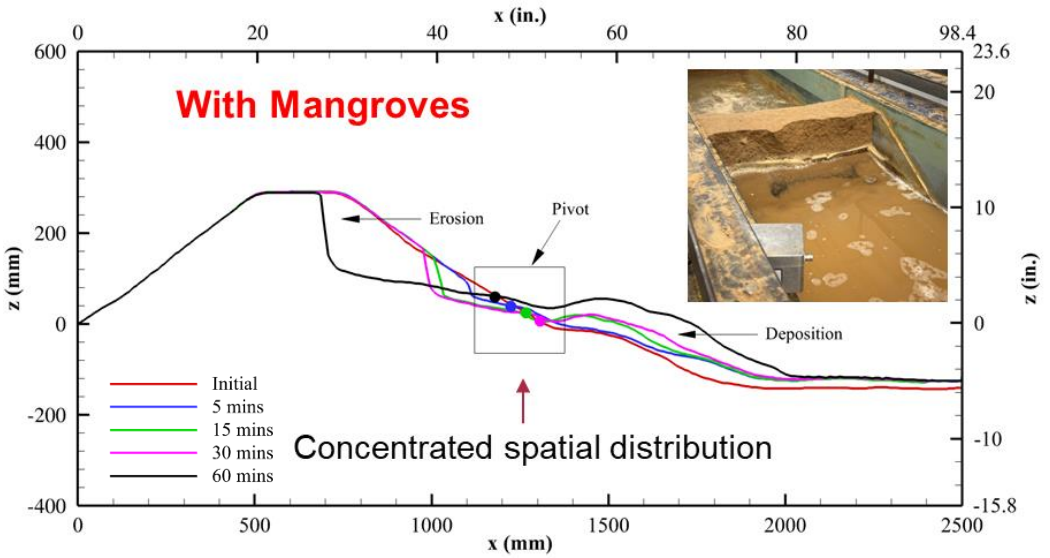


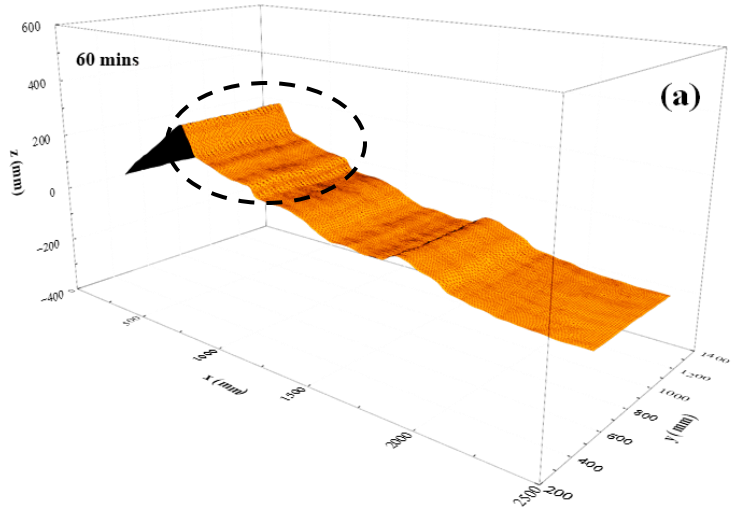
End of Cycle 10

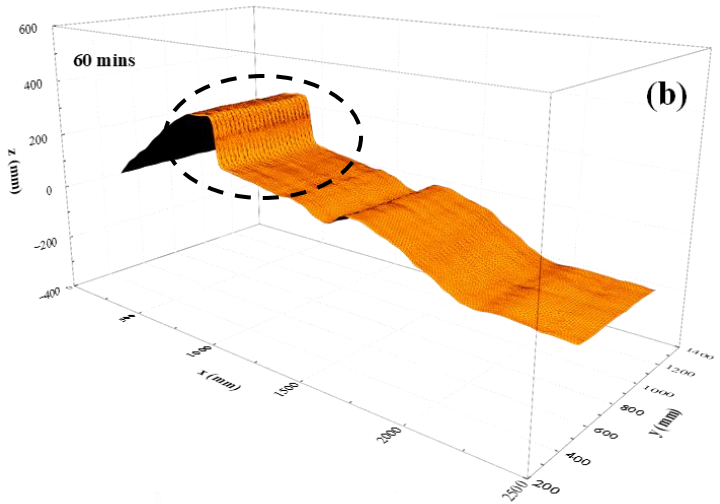
I. Artificial Mangrove Systems – Wave Induced Erosion

Profile Evolution and Erosion Mechanism









Artificial mangroves provided resistance to erosional forces and scarp progression and showed reduction in eroded volume

Embankments and Road Network – Erosion from Rainfall and Storm Surge

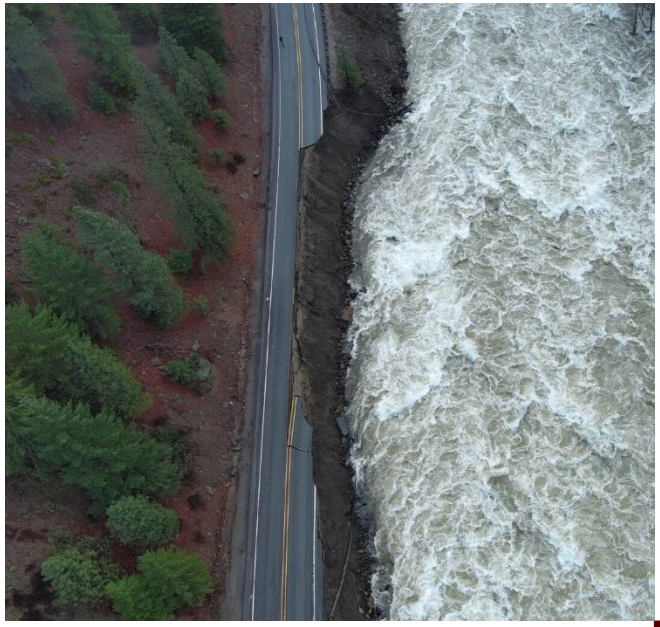
Embankment and roadwork distress from soil erosion – rainfall and extreme flooding

Events – Major disruptions and fatalities

Can we protect embankments and road networks?







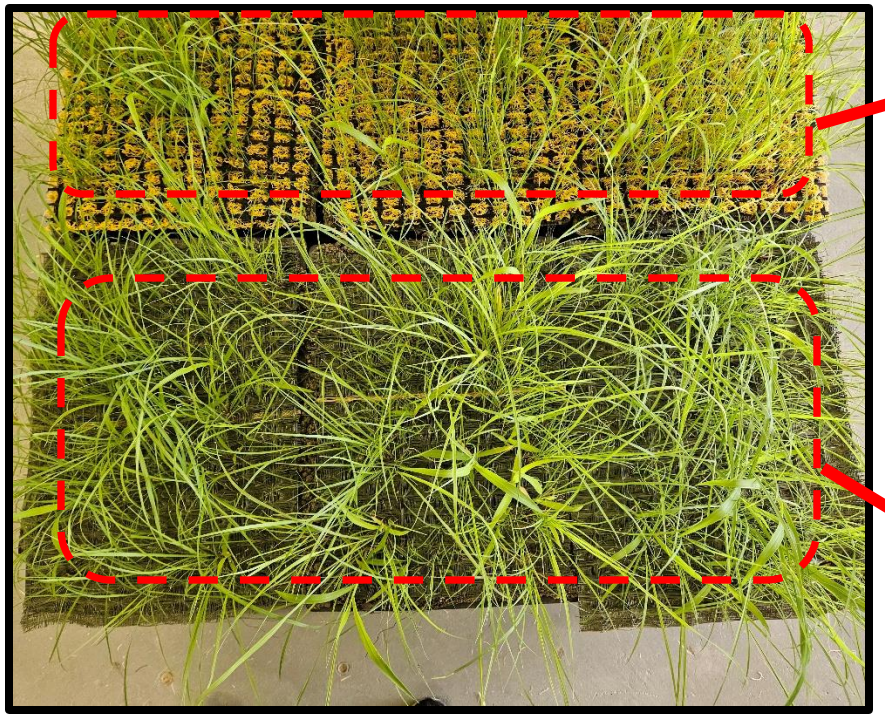
Images Source: Getty Images, Komonews.com, OPB.org

II. Erosion Resistant TRMs for Highways

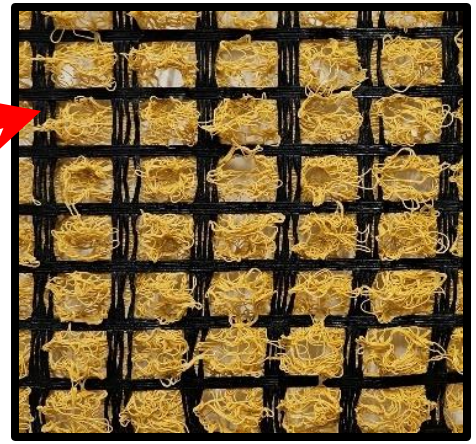
Turf Reinforcement Mats (TRMS) Protection Vegetation Studies

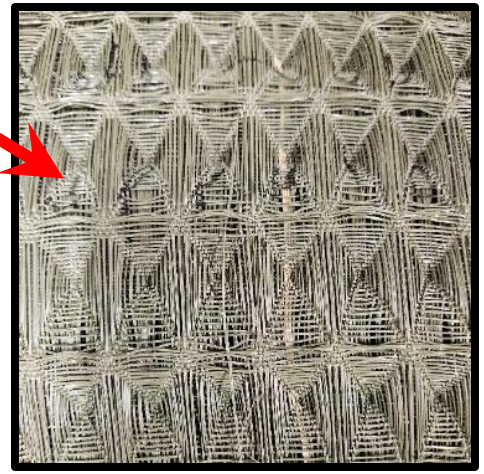


Control



TRMs



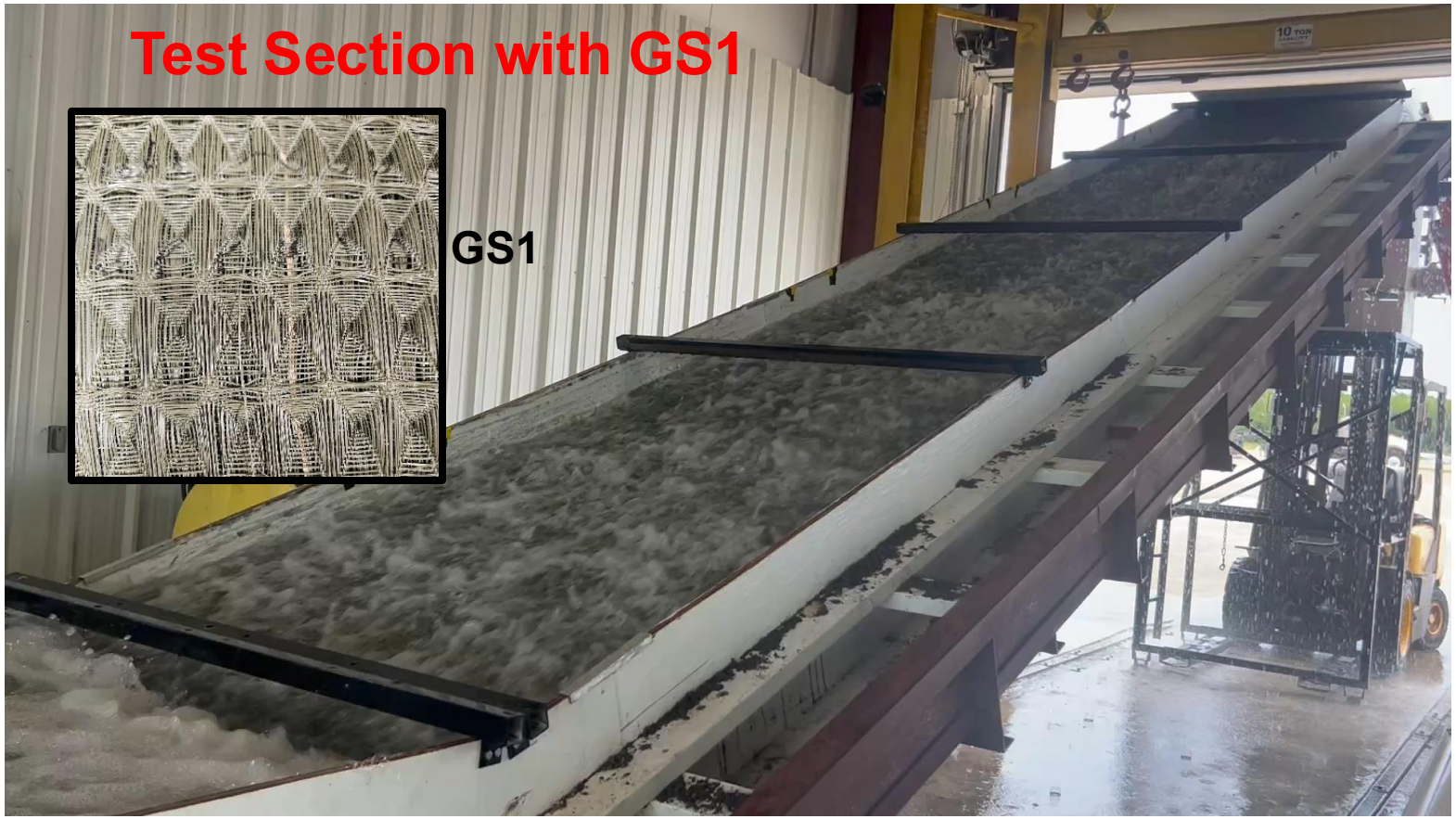


Credit: ERDC Study (PI – Briaud, TAMU)

II. Erosion Resistant TRMs for Highways

Flume Erosion Tests on TRMs at SEC Lab of TTI - TAMU





New Projects with the support of USDOT UTCs and Texas DOT – We are studying these TRMs on Highways

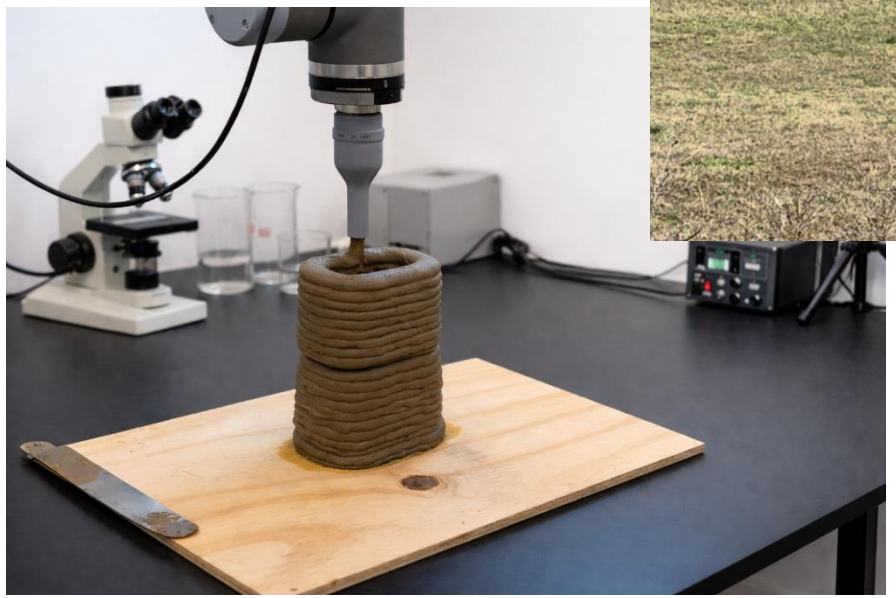
Credit: ERDC Research Study (PI – Briaud, TAMU)

Credit: Joshua Bell, TTI

Thematic Research Area - D







Tools and Technologies

I. Remote Sensing (UAV and SAR) and Unmanned Ground Vehicle (UGV) Robotic Inspections

II. Additive Manufacturing or 3D-Printing

TRANSPORTATION NETWORK IN THE U.S.



Embankments, cut-slopes, and bridges are critical to support the vast transportation infrastructure

U.S. transportation network has

- ~ 220 thousand miles of highways [*]
- ~3.26 trillion vehicle miles annual travel [*]
- ~ $5 trillion replacement values [#]

[*] USDOT. 2021. *National Transportation Statistics 2021*. Washington, DC.
[#] AASHTO. 2020. *AASHTO Transportation Asset Management Guide: A Focus on Implementation*. Washington, D.C.

Traditional Inspections:

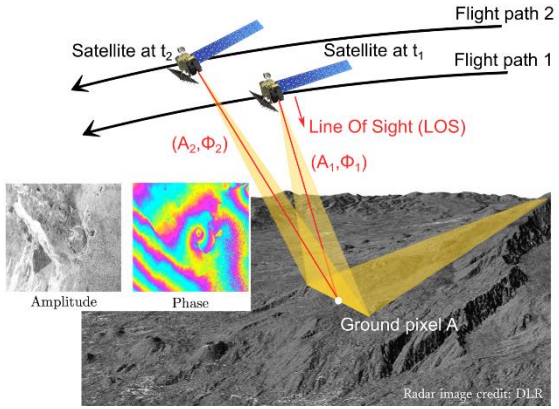
- Labor-intensive and costly
- Periodic inspections ~ not helpful!
- Reactive or Forensic works!

Remote Sensing ➔ Scalable and Proactive Monitoring ➔ Prevention of Slope Failure

Ia. Remote Sensing (UAV and SAR)

Orbital - Satellite Based Techniques

- **Synthetic Aperture Radar (SAR)** capable of screening surface regardless of weather or time ➔ InSAR ➔ Phase difference ➔ Deformation estimation
- **Multispectral Imagery** ➔**NDVI, NDWI**➔ surface condition, vegetation and surface moisture content





Sub Orbital - Aerial Based Techniques

- Variety of sensors mounted to Uncrewed Aircraft System (UAS)
- **Optical imagery (PS)** used to assess surface conditions
- **Thermal imagery (PS)** used to identify potential seepage areas



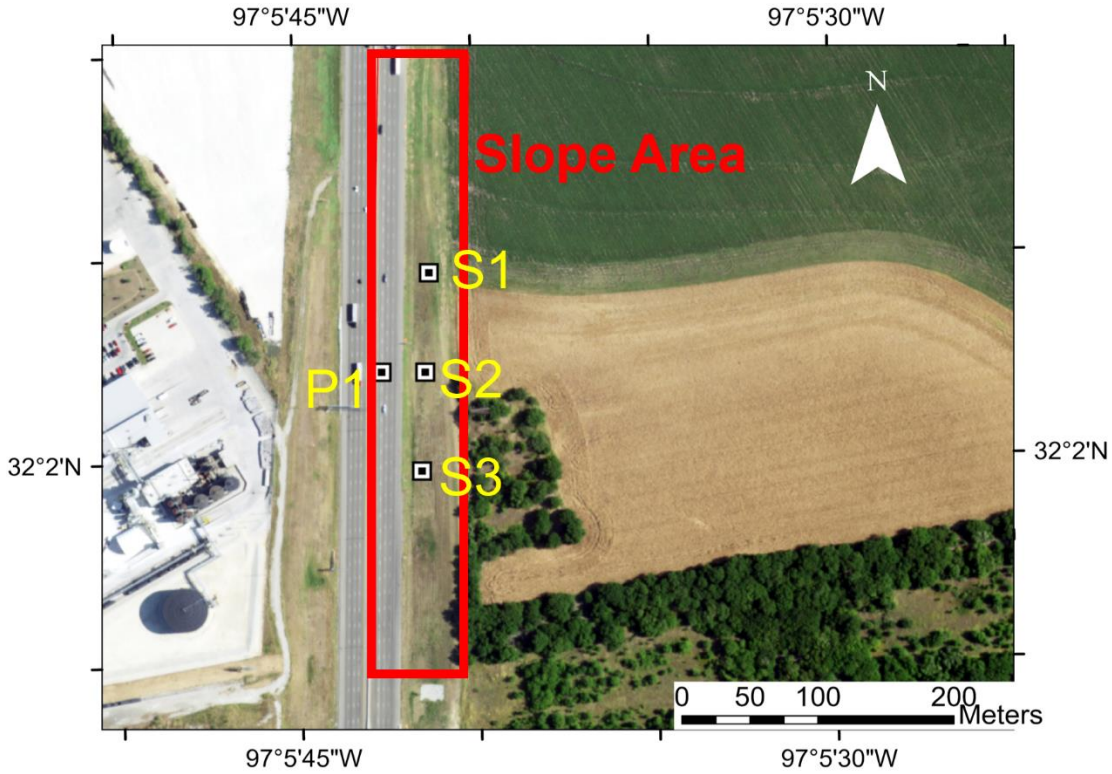


NDVI – Normalized Difference Vegetation Index, NDWI- Normalized Difference Water Index, InSAR- Interferometric SAR

IH-35 Slope Failure

Site Details:

- **Slope Location:** IH-35 corridor, near Hillsboro, Texas
- **Slope geometry:** 15 ft. high embankment with 1V:5H slope
- **Failure extent:** Surficial sliding along a 180 ft. section
- **Site conditions:** Adjacent agricultural field contributes runoff toward slope



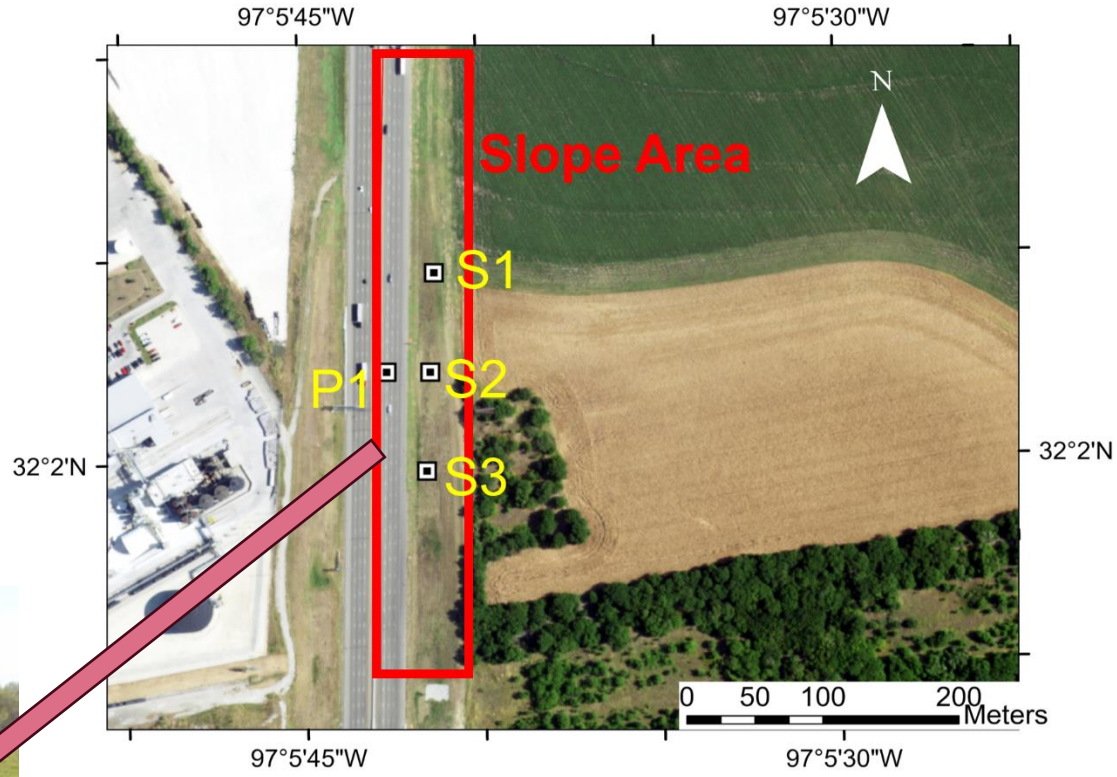
NAIP imagery, 2022

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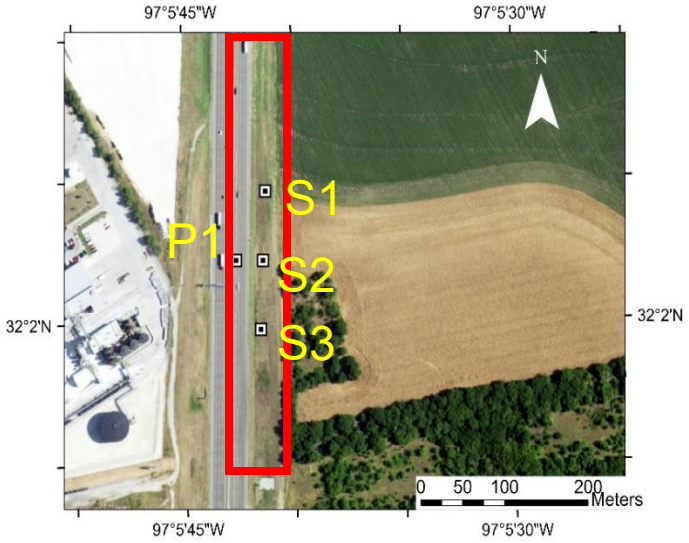


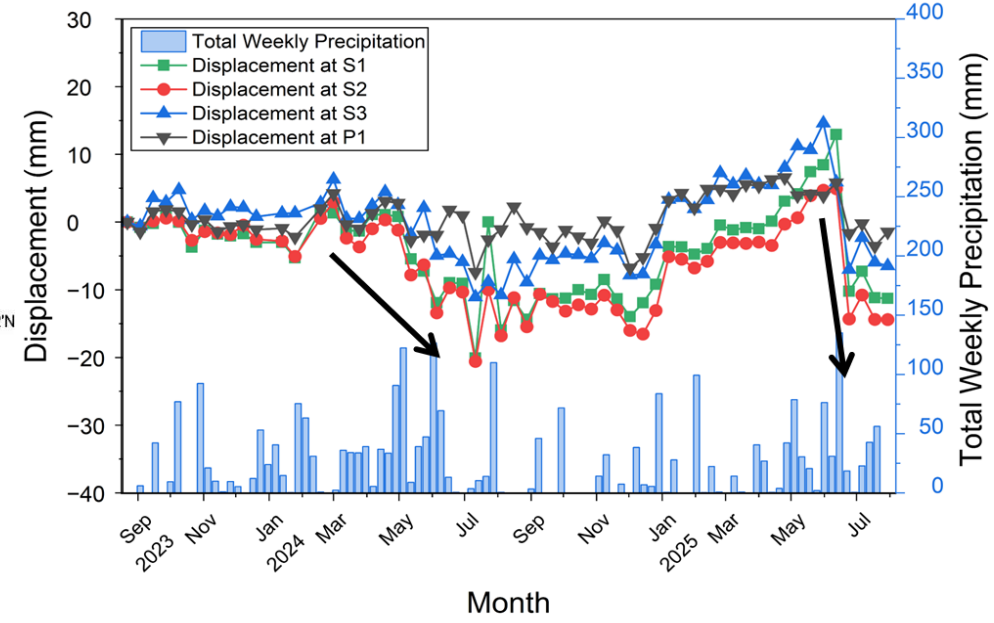
NAIP imagery, 2022

Ia. Remote Sensing (UAV and SAR)

SLOPE CONDITION MONITORING (Using InSAR-NDVI)

- Time series InSAR analysis can detect very slow ground movements (<1 mm/year)
- Settlement of the embankment detected using Small Baseline Subset (SBAS) InSAR
- NDVI time-series shows moisture-driven vegetation stress

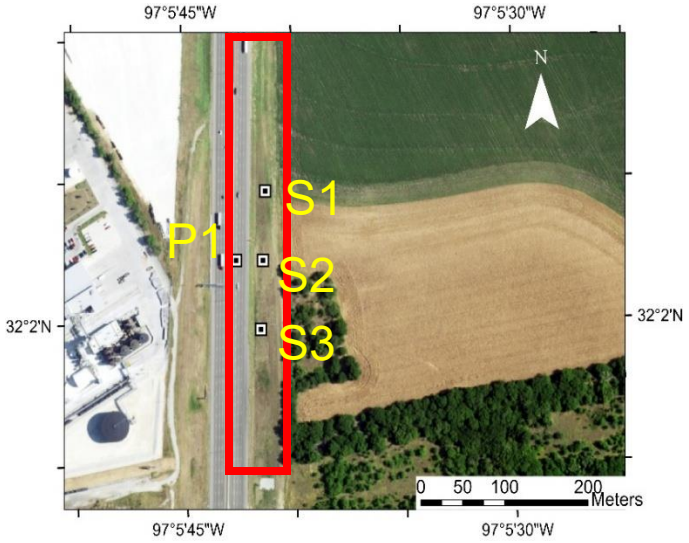


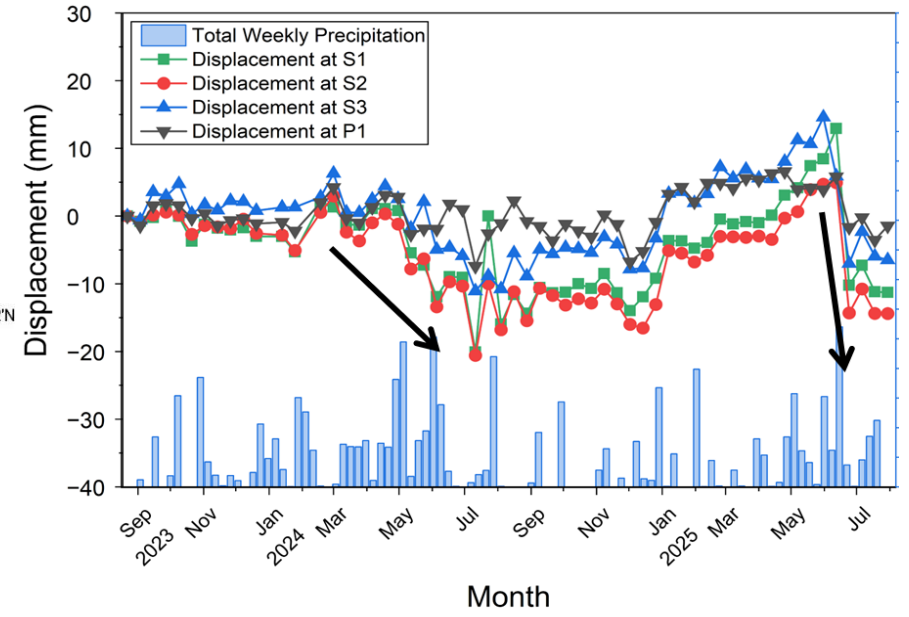


Time series displacement for ascending orbit

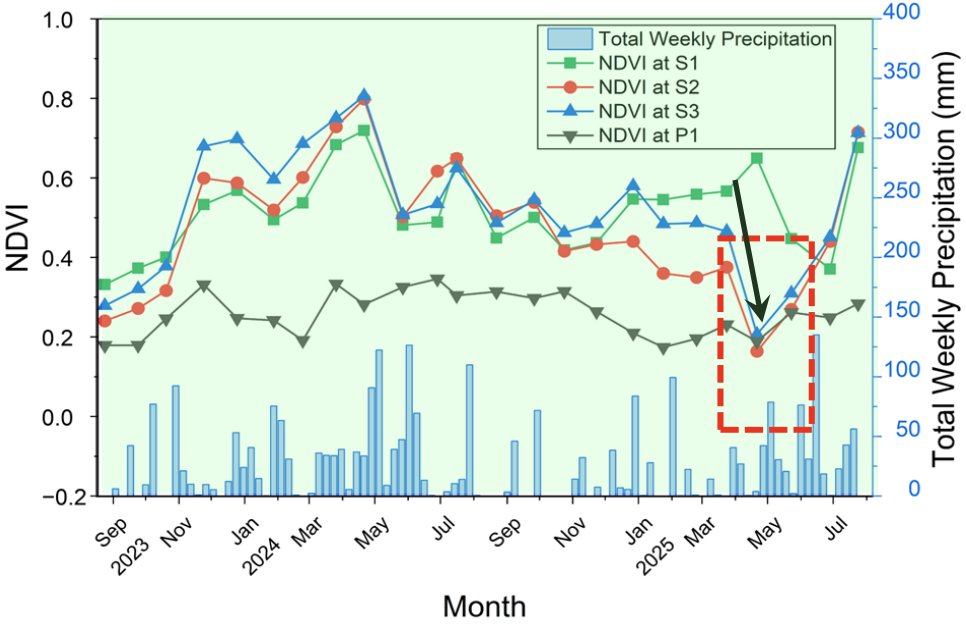
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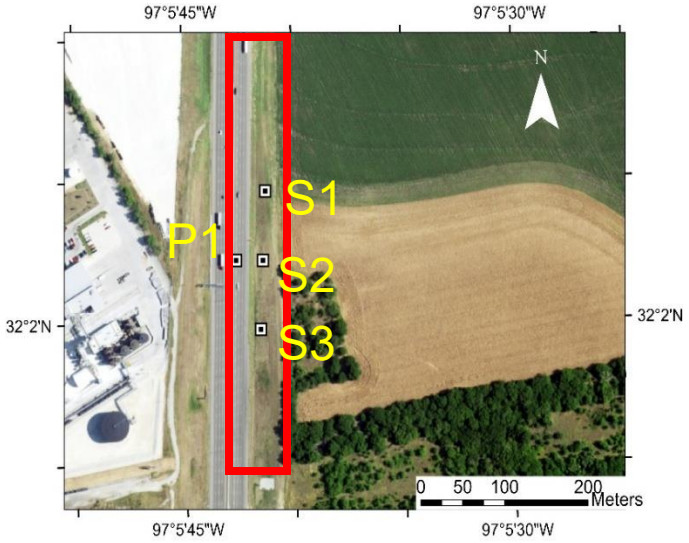
Time series displacement for ascending orbit

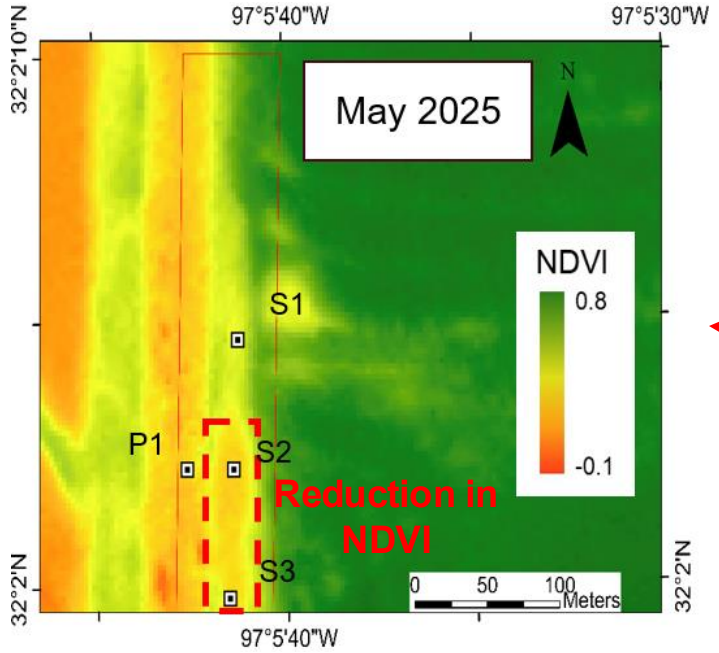


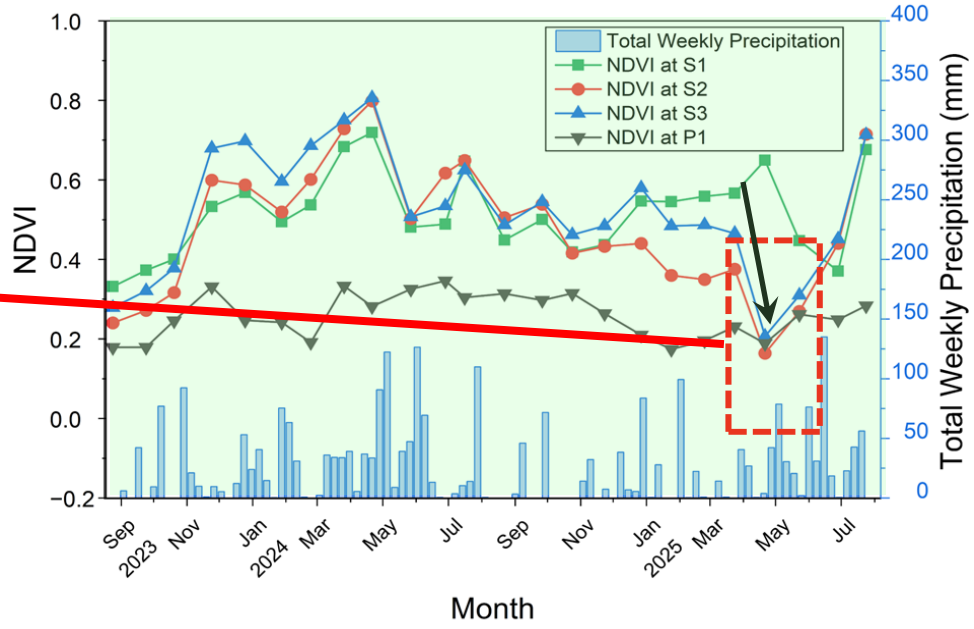
Time series NDVI

SLOPE CONDITION MONITORING (Using InSAR-NDVI)

- Time series InSAR analysis can detect very slow ground movements (<1 mm/year)
- Settlement of the embankment detected using Small Baseline Subset (SBAS) InSAR
- NDVI time-series shows moisture-driven vegetation stress







Time series NDVI

Ia. Remote Sensing (UAV and SAR)

UAV SURVEY

- Provided ground truth for satellite-based deformation and vegetation analysis
- UAV-derived photogrammetric DEM and 3D model ➔ Localized elevation changes



Orthoimagery of the failure from Skydio X10D



3D model of the slope

Integrated InSAR and NDVI ➔ Continuous Monitoring ➔ Detection of slope distress

Ia. Remote Sensing (UAV and SAR)

Bridge Inspection Using UAVs



Transverse Tie-Plate: ***Fracture critical Member on the South-West leg of bridge***

Deteriorated Plate ***due to corrosion caused by clogged water outlets***



Collapse of Fern Hollow Bridge, Pennsylvania



360^0 Bridge Inspection Framework and Development of ML Models to Extract Bridge Condition Information

Bridge Inspection Using UAVs



Transverse Tie-Plate: ***Fracture critical Member on the South-West leg of bridge***

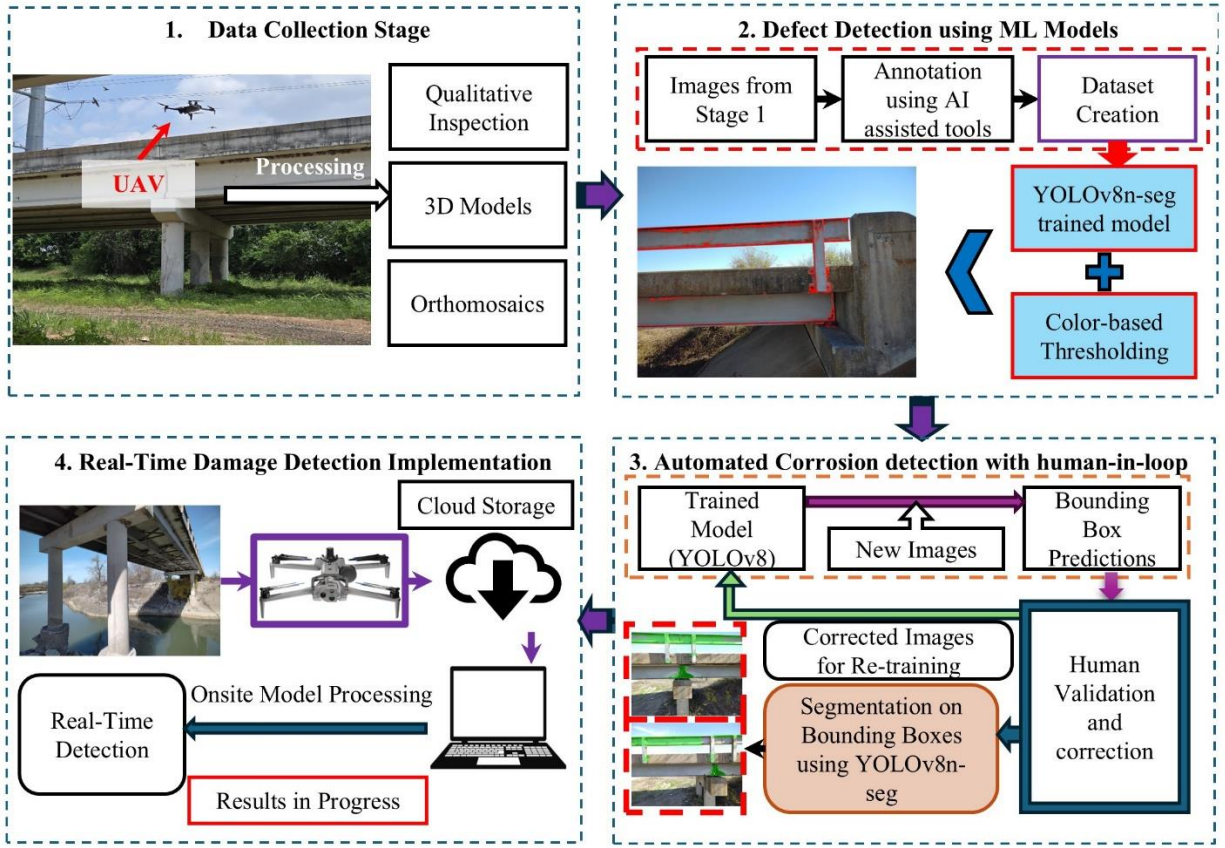
Deteriorated Plate ***due to corrosion caused by clogged water outlets***



Collapse of Fern Hollow Bridge, Pennsylvania

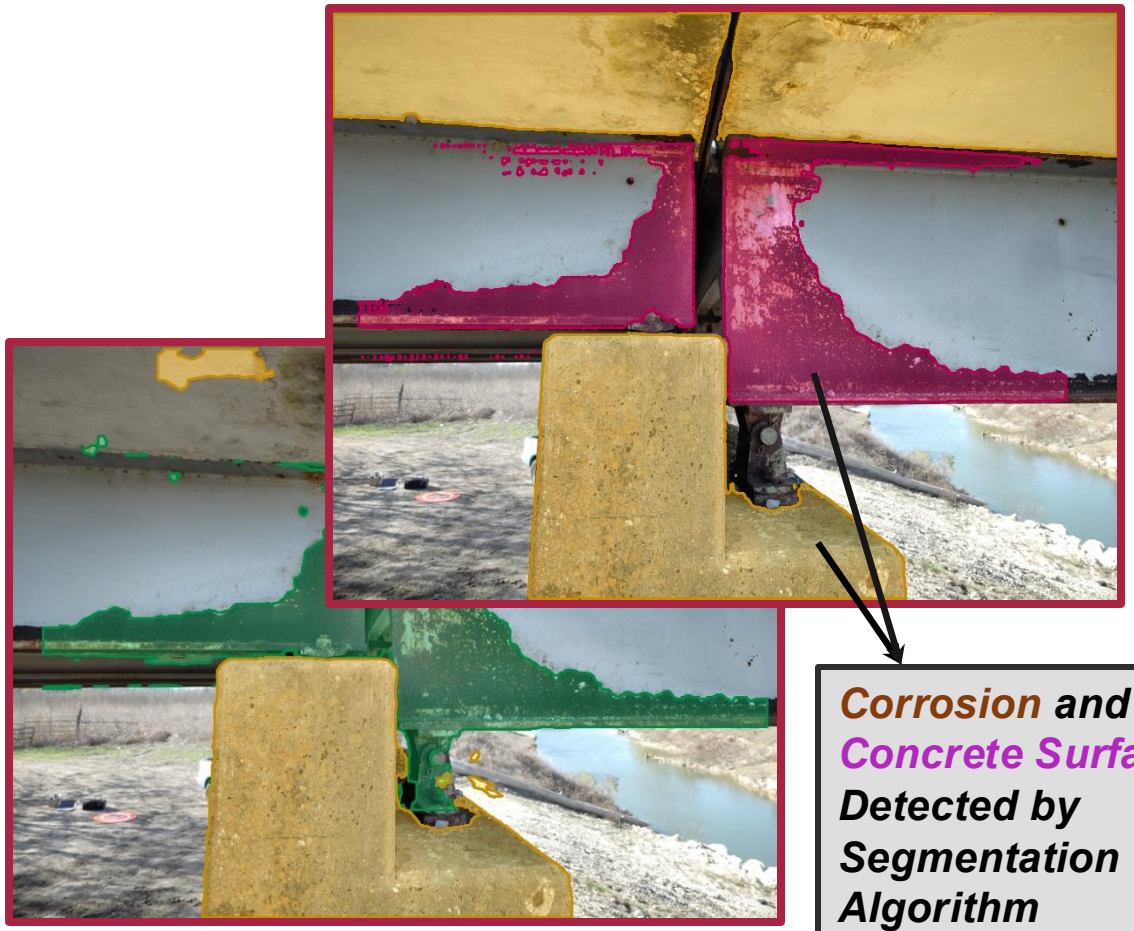
360⁰ Bridge Inspection Framework and Development of ML Models to Extract Bridge Condition Information

Real-time Distress Detection



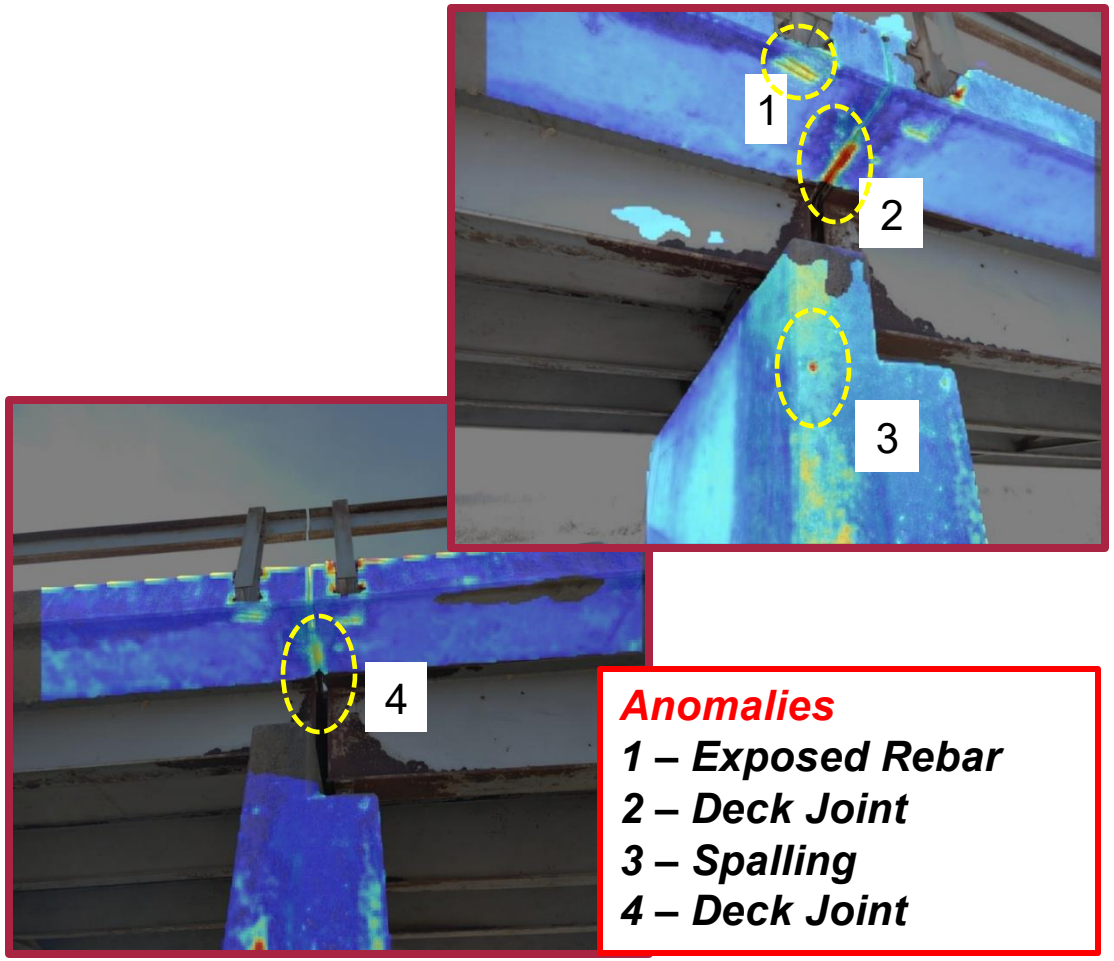
Distress Detection using ML Techniques

In Steel Elements



***Corrosion** and **Concrete Surface** Detected by Segmentation Algorithm*

In Concrete Elements



Anomalies
1 – Exposed Rebar
2 – Deck Joint
3 – Spalling
4 – Deck Joint

Ib. Unmanned Ground Vehicle Robotic Inspection

UGV – Robotic Platform

Major Distresses:

- Pavement longitudinal and transverse cracks
- Plastic Deformation or Rutting
- Water ponding area and Potholes
- Shoulder edge drop-off locations





Robot-1

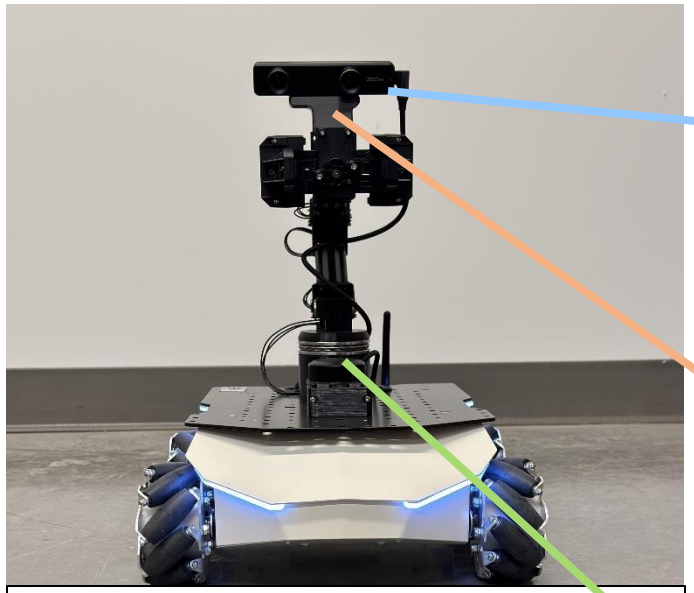
Ib. Unmanned Ground Vehicle Robotic Inspection

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- ❑ Water ponding area and Potholes
- ❑ Shoulder edge drop-off locations





Robot-1

Stereo Camera (Zed)
- Potholes
- Erosion
- Cracks

Thermal Camera (FLIR)
- Wet zones
- Potholes
- Spalling

LiDAR
- Differential settlement
- Rutting
- Erosion

Robotic inspection can be extended for:
- Culverts
- Embankments and Levees

Ib. Unmanned Ground Vehicle Robotic Inspection

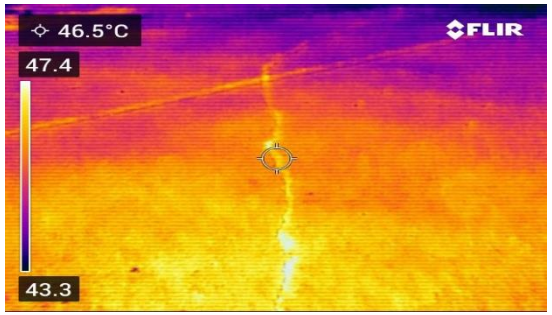
ROBOTIC PAVEMENT CONDITION ASSESSMENT

Deploy Robot → Scan Asset (RGB ● Thermal ● LiDAR) → Localize defects → ML-based Detection (Crack ● Pothole ● Rutting) → Severity Assessment





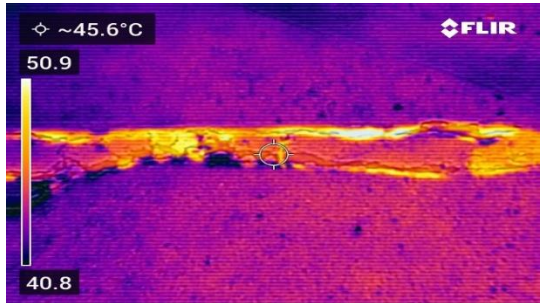
Cracks (RGB)



Cracks (Thermal)



Spalling (RGB)



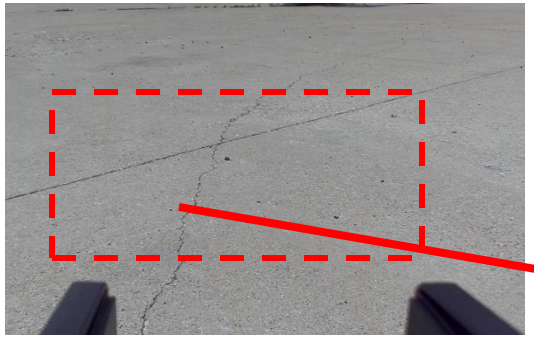
Spalling (Thermal)

Ib. Unmanned Ground Vehicle Robotic Inspection

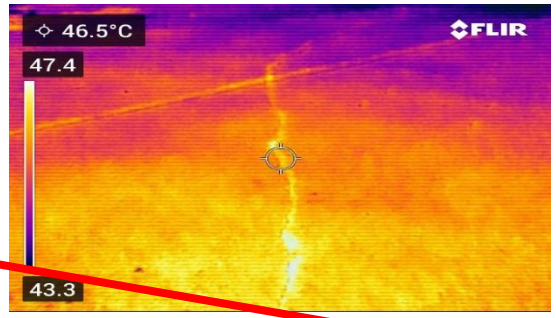
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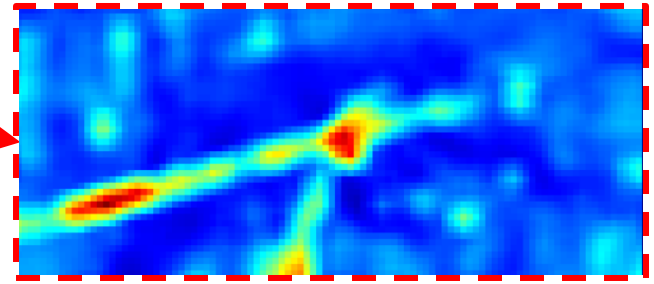


Cracks (RGB)



Cracks (Thermal)

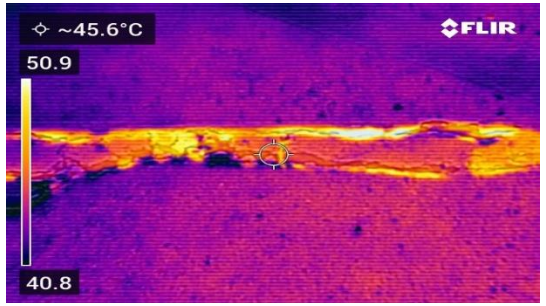
Concrete Anomaly Heatmap
Blue = normal; Red = Anomalous



Anomaly detection



Spalling (RGB)



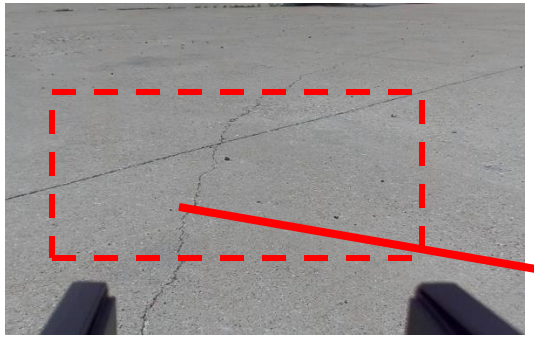
Spalling (Thermal)

Ib. Unmanned Ground Vehicle Robotic Inspection

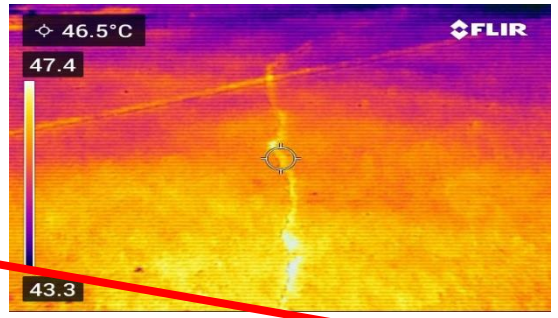
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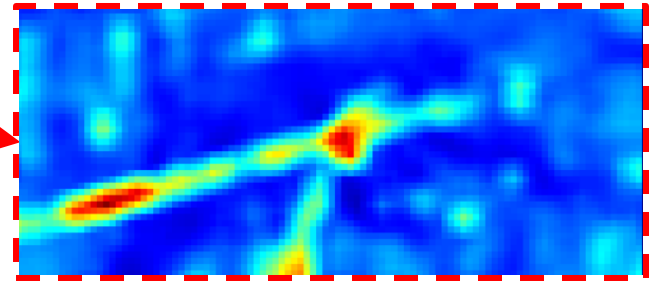


Cracks (RGB)



Cracks (Thermal)

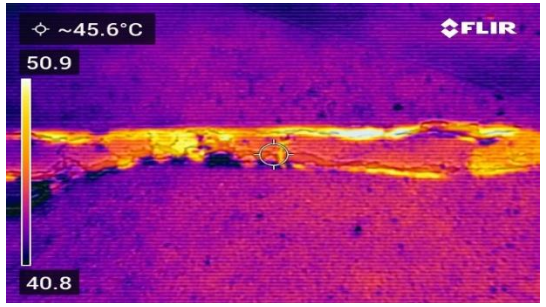
Concrete Anomaly Heatmap
Blue = normal; Red = Anomalous



Anomaly detection



Spalling (RGB)



Spalling (Thermal)

Two New USDOT Funded Studies: Researching on Automated Robotic Transportation Infrastructure Condition Assessment

ADDITIVE MANUFACTURING

- **Additive manufacturing**: **Layer-by-layer fabrication**
- **3D concrete printing: Controlled material extrusion to form complex geometries**
- **Advantages: Precise control, faster construction, waste and labor reduction**

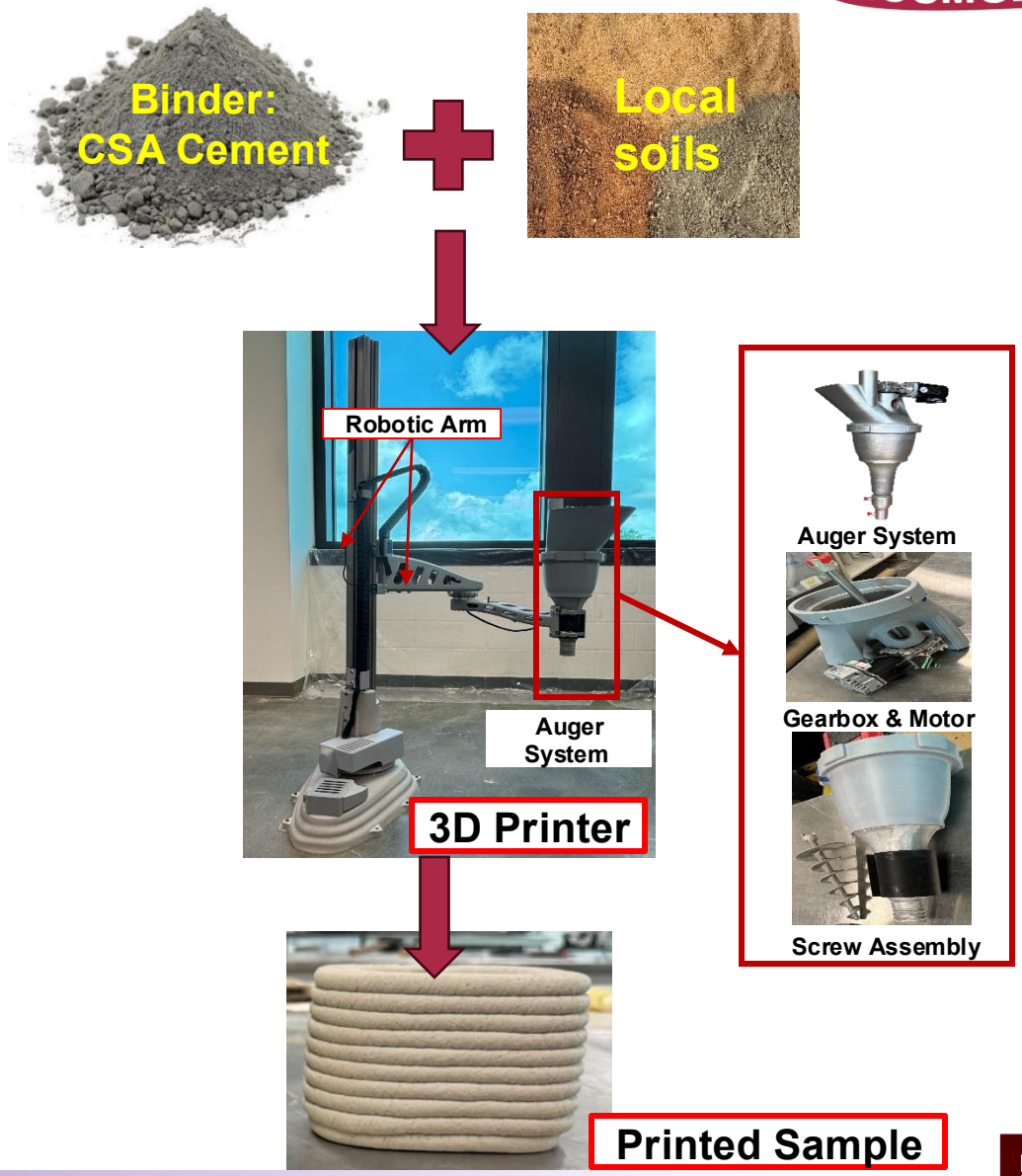
II. Additive Manufacturing or 3D-Printing

ADDITIVE MANUFACTURING

- Additive manufacturing: Layer-by-layer fabrication
- 3D concrete printing: Controlled material extrusion to form complex geometries
- Advantages: Precise control, faster construction, waste and labor reduction

3D-Printing Using Local Soils

- Develop Novel 3D-Printable mixes with adequate strength for infrastructure rehabilitation
- Utilization of Local Soils
- Adequate Printability & Mechanical Performance

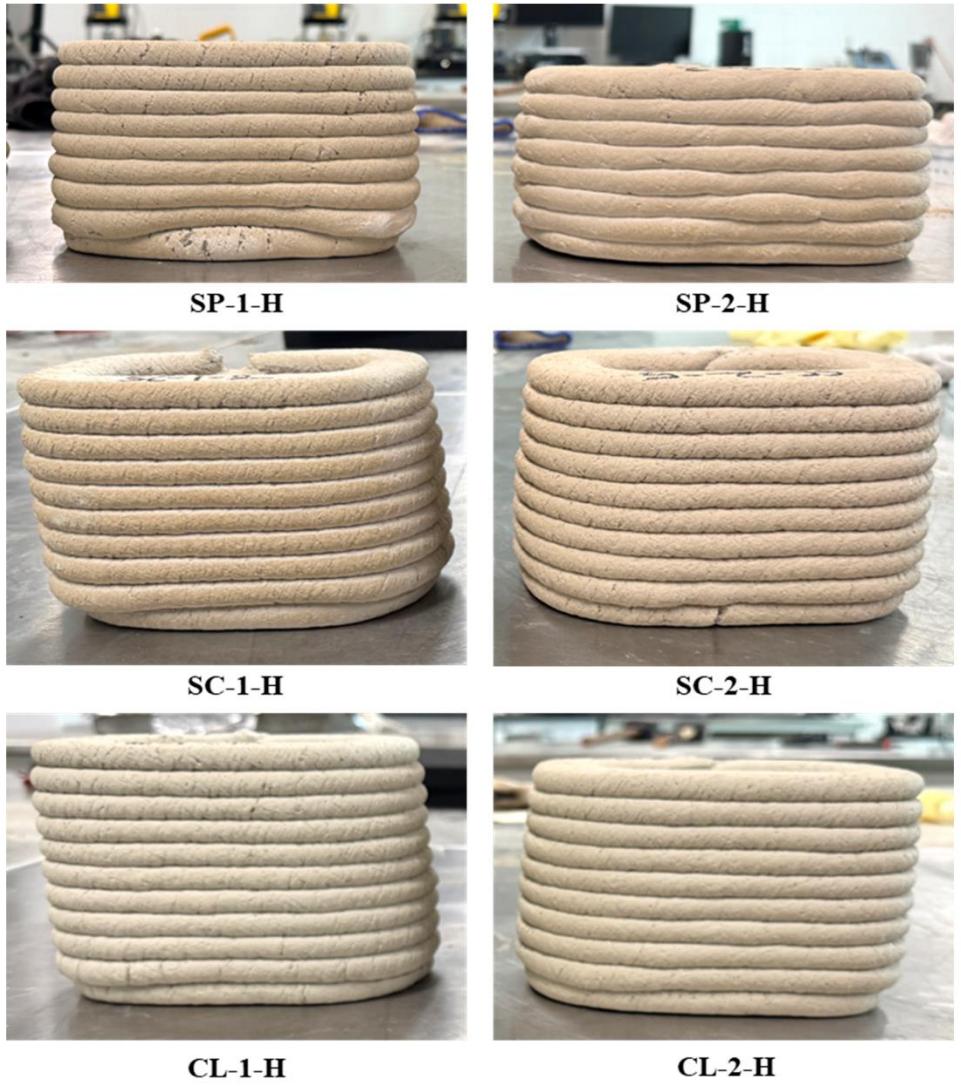


II. Additive Manufacturing or 3D-Printing

Demonstration of 3D Printing using local soils



Printed Samples

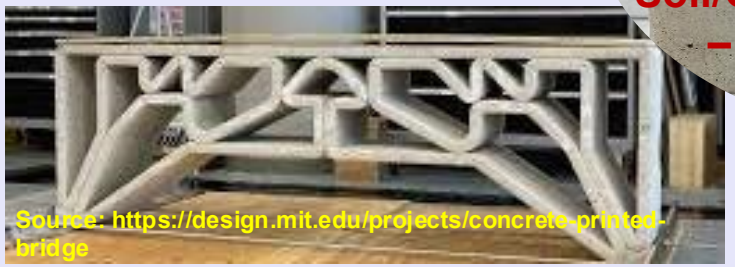


II. Additive Manufacturing or 3D-Printing

Application Areas



Controlled low strength material - trenches



Prefabricated 3D printed elements



Soil/Geomaterial Composites – 3D Printed Materials



Quick repair of distresses in the field



Backfill for approach slabs?

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Original Article

Transportation bridge infrastructure asset condition monitoring using uncrewed aerial vehicles (UAVs)

Surya Sarat Chandra Congress[a,*], Anand J. Puppala[b,*], Jesse Escamilla III[c], Raja Jaladurgam[a], Prince Kumar[d]

[a] Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824, United States
[b] Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, TX, 77843, United States
[c] Alaska Department of Transportation & Public Facilities, 3132 Channel Drive, Juneau, AK 99811-2500, United States
[d] Geotechnical Services, Terracon Consultants, Inc., Houston, TX 77043, United States

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Assessment of Wicking Geotextiles for Enhanced Drainage and Reinforcement in Flood-Prone Coastal Highway Slopes

Puneet Bhaskar[1], Jaime Suarez[2], Darlene Goehl[1], and Anand J. Puppala[2]

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Application of Unmanned Aerial Technologies for Inspecting Pavement and Bridge Infrastructure Assets Conditions

Surya Sarat Chandra Congress[1*], Anand J. Puppala[1], Md Ashrafuzzaman Khan[2], Nripojyoti Biswas[1], and Prince Kumar[1]

ASCE

Durability and Permanency Studies in Sulfate-Laden Soils Treated with Nano- and Crystalline Silica-Based Admixtures

Nripojyoti Biswas, Ph.D., A.M.ASCE[1]; Anand J. Puppala, Ph.D., P.E., D.GE, F.ASCE[2]; and Krishneswar Ramineni, S.M.ASCE[3]

Canadian Geotechnical Journal

Micro-mechanical behavior of nanosilica-treated high-sulfate soils

Nripojyoti Biswas[a], Anand J. Puppala[a], Sayantan Chakraborty[b], and Dallas N. Little[a]

[a]Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, TX, USA; [b]Birla Institute of Technology and Science, Pilani, Rajasthan, India

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Research Article

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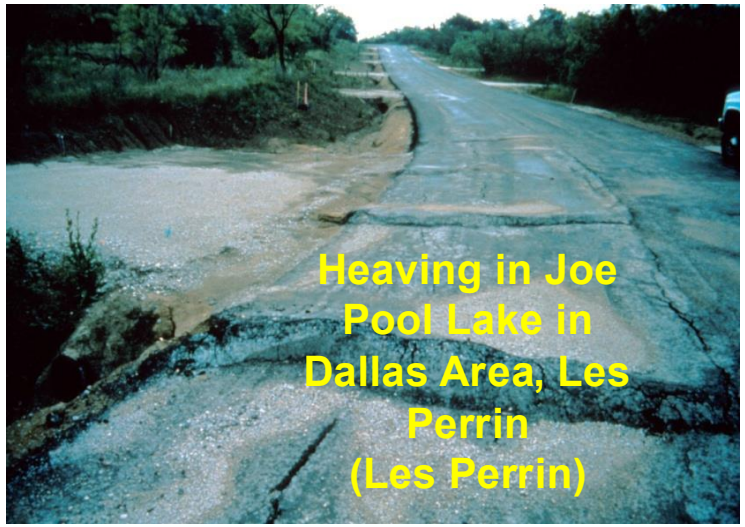
Application of Satellite-Based Remote Sensing for the Management of Pavement Infrastructure Assets

Amit Gajurel[1], Anand J. Puppala[1], Nripojyoti Biswas[1], and Hiramani Raj Chimauriya[1]

Concluding Remarks on Ralph Roscoe Proctor's Legacy…

Sulfate Soil Stabilization









- Sulfate Soils – Traditional Calcium Treatments - Ettringite Heaving – Major Distress
- Threshold sulfate levels – started from 5000 ppm to 3000 ppm to 2500 ppm to around 2000 ppm
- Heave comes from crystal growth and ettringite mineral heaving due to hydration
- In NSF funded study – certain treated clayey soils with 1000 ppm of soluble sulfates heaved as compaction void ratios are low!

Proctor's contributions are important in fundamental understanding of soil behavior, fabric links, strength, volumetric stability, drainage, erosion and vegetation growth!

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U.S. Department of Energy

Texas Department of Transportation

Department of Transportation

Center for Integration of Composites into Infrastructure

CREATE University Transportation Center

NCIT National Center for Infrastructure Transformation Led by: Prairie View A&M University

Southern Plains Transportation Center

National Consortium Centers at CIR

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IDEA Innovations Deserving Exploratory Analysis Programs HIGHWAY

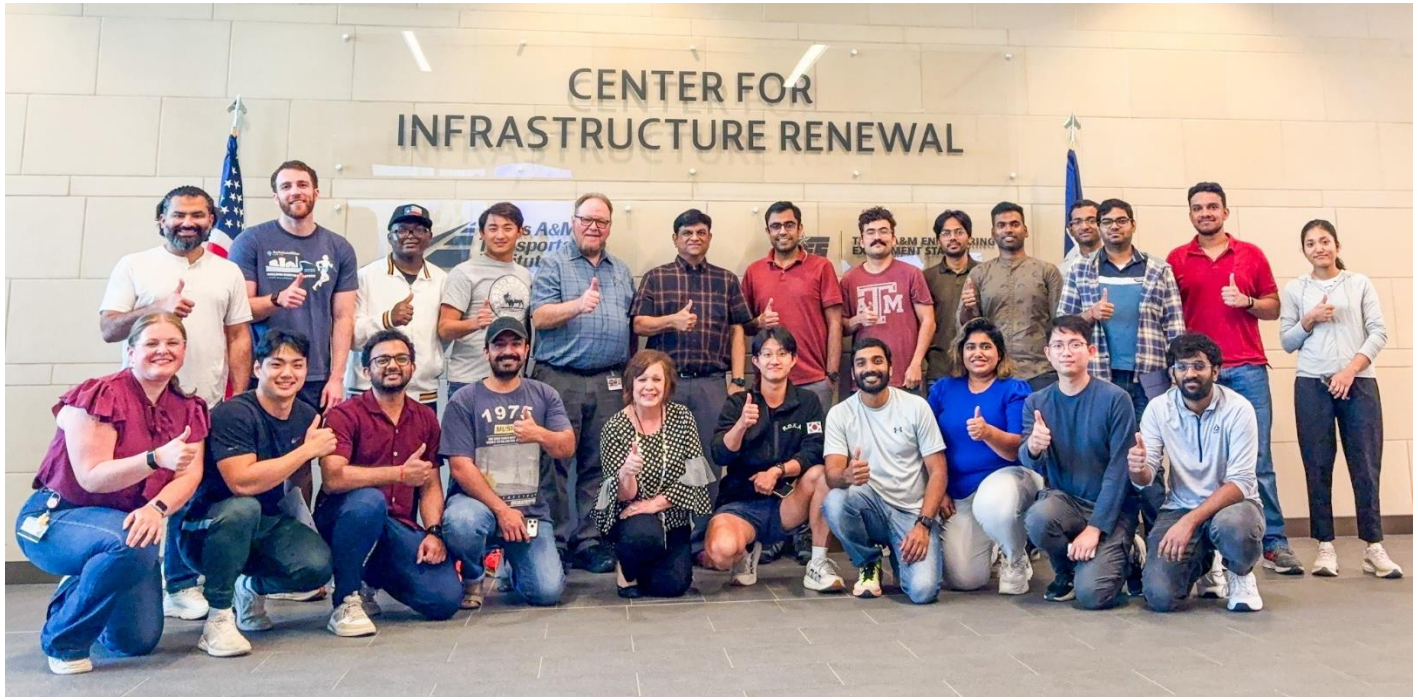
Arlington The American Dream City

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University of Texas Arlington

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- Proctor Honors Lecture - TC202 Transportation Geotechnics Committee - Drs. Tatusya Ishikawa (Chair), Mike Winter (Vice-Chair), Antonio Corriea, Erol Tutumluer, and All Committee Members
- 21st ICSMGE Conference Organizers – Drs. Schweiger Pistrol



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Vienna

Thank You!



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