Application of Geofoam in Thermal Encapsulation of Foundations

Center for Integration of Composites into Infrastructure

Project (Leader): Surya Sarat Chandra Congress
Associate Research Scientist

Team: Hiramani Chimauriya, Nripojyoti Biswas, Doctoral Students

PI: Anand J. Puppala
Professor | A.P. and Florence Wiley Chair
Associate Director – Center for Infrastructure Renewal

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December 2, 2020

THERMAFOAM LLC

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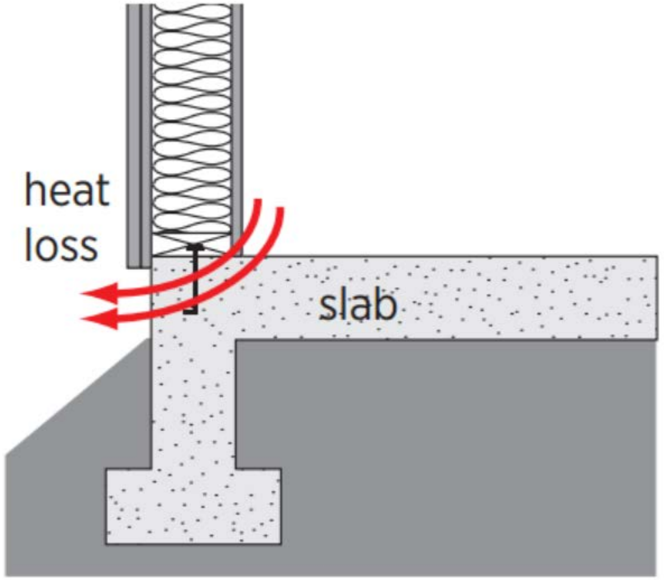
Presentation Outline

- Introduction
- Thermal Encapsulation using Geofoam
  - Research Plan
  - Test Setup
  - Laboratory Testing Setups
  - Demo Simulation
- Future Work

Introduction

- Temperature fluctuations inside the dwellings typically occur from advection, diffusion and radiation at foundation superstructure joints
- About 15% of all heat loss in a home is through floors or basements
- Thermal Encapsulation using Geofoam
  - Research Plan
  - Laboratory Testing Setups



Heat loss

The stack effect

Source: EPA, US DOE (2011, 2012)

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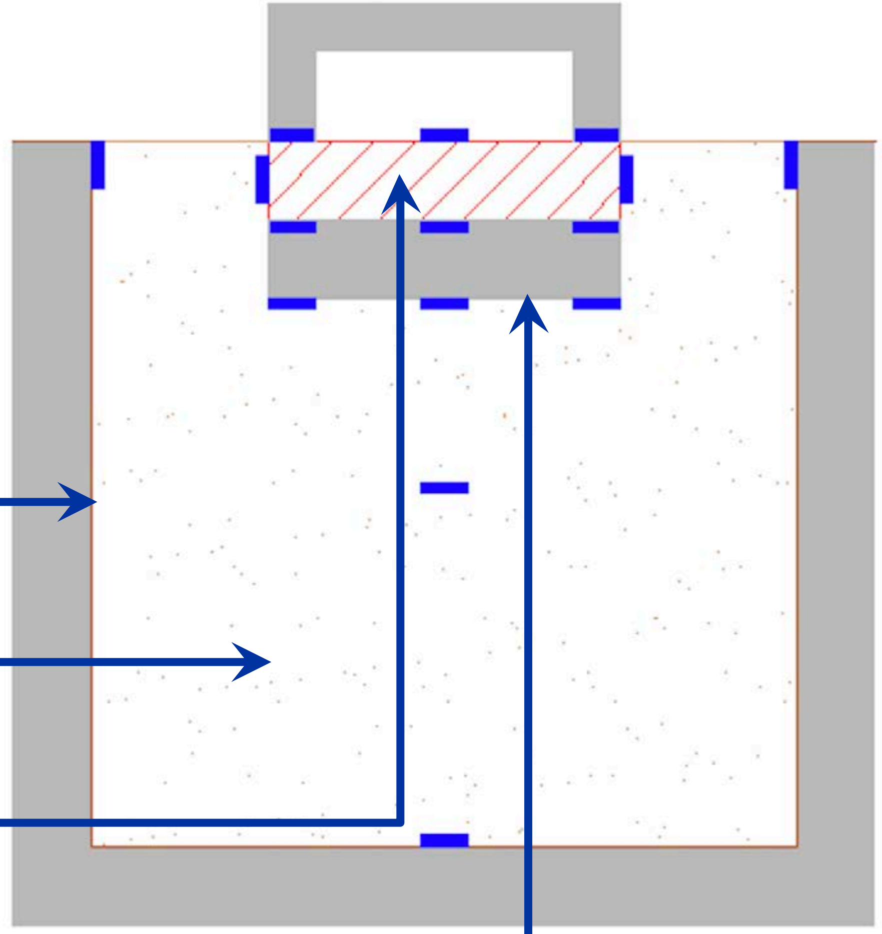
Thermal Encapsulation using Geofoam: Research Plan

- The category "Geofoam" includes polymeric and non-polymeric foams used in geotechnical applications.
- Expanded Polystyrene (EPS) is a rigid plastic geofoam.
- The coefficient of thermal conductivity of soil is approximately 20-40 times greater than that of EPS (Horvath, 1993)
- Thermal encapsulation performance will be studied in following scenarios:
  - Control Setup: Set a baseline response for given temperature conditions
  - Scenario 1 – GBF: Test with **G**eofoam insulation placed **B**elow **F**oundation slab
  - Scenario 2 – GAF: Test with **G**eofoam insulation placed **A**round the **F**oundation slab

Thermal Encapsulation using Geofoam: Test Setup

- Box Size: 3’x3’x3’
- Slab Size: 1.5’x1.5’x4”
- Material
  - Wood
  - Backfill
  - Concrete Slab
  - Insulation Material: Geofoam



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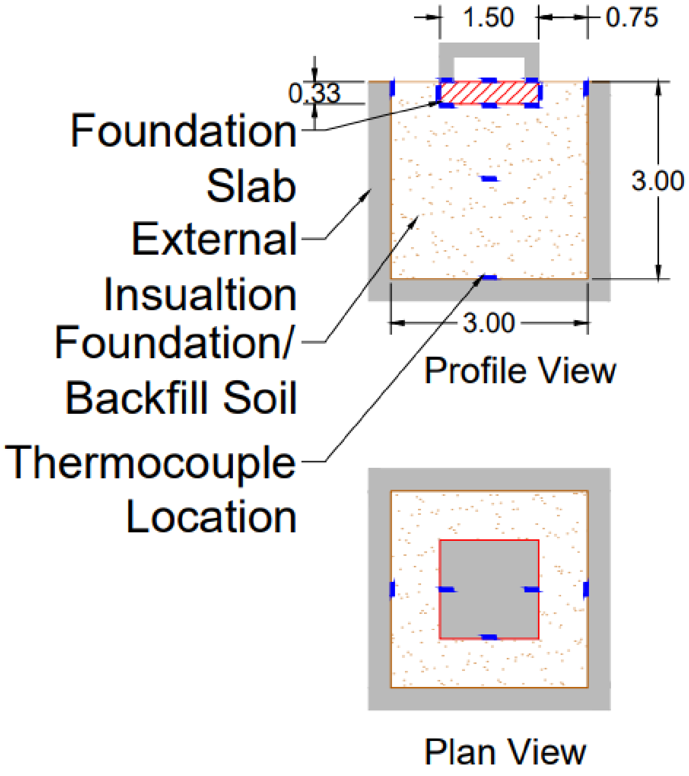
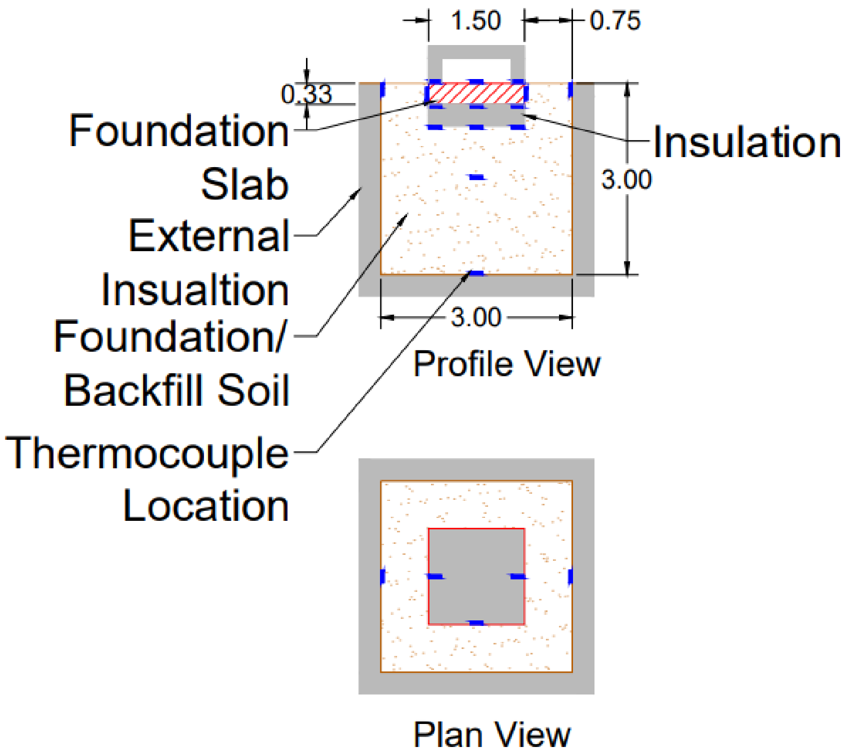
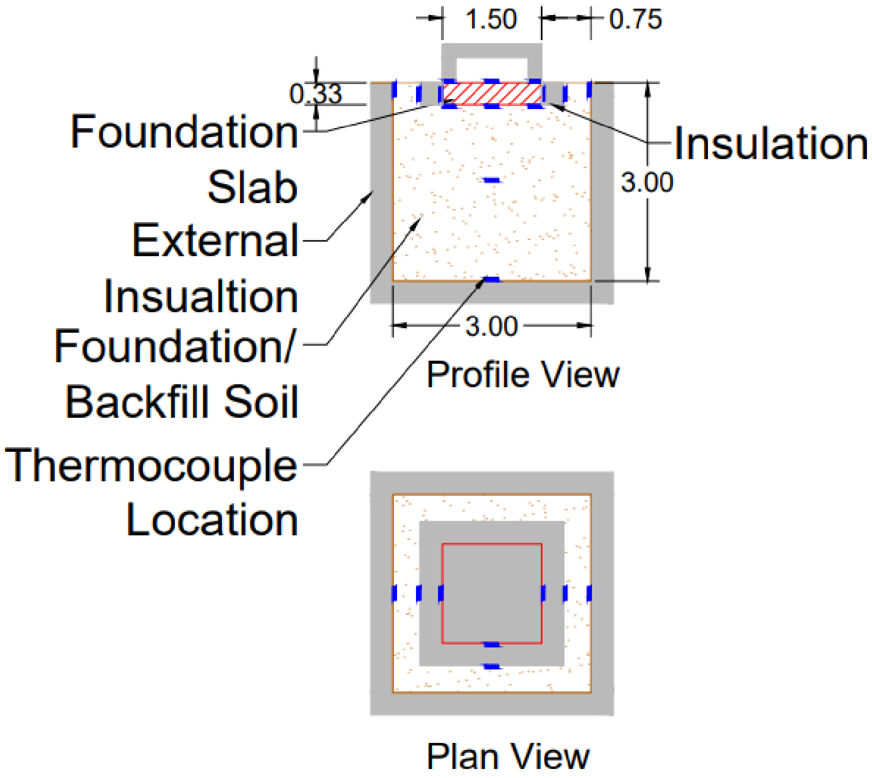
Thermal Encapsulation using Geofoam: Test Setup (Contd..)

- Testing Conditions
  - External insulation may be applied to all exposed sides of the box to reduce boundary effect
  - Maintain uniform density and moisture conditions throughout the setup
- Temperature Monitoring: Thermocouples (TJ394-CASS-116U-6)
- Data Acquisition System (cDAQ-9184, NI-9213)
- Indoor Temperature Control: Space Heater/Cooler

Thermal Encapsulation using Geofoam: Laboratory Testing Setups







All dimensions are in ft.

CONTROL TEST

GBF

GAF

Material Characterization

Backfill material

- % Passing No. 4 Sieve: 100%
- % Passing No. 200 Sieve: 80.7%
- Liquid Limit (LL): 39.4
- Plasticity Index (PI): 20.6
- Classification (USCS): Lean Clay (CL)
- Coefficient of Thermal Conductivity: (Under testing)

Thermal Encapsulation using Geofoam: Demo Simulation

COMSOL Input Parameters		
Material	Density (kg/m³)	Thermal Conductivity (W/m.K)
Concrete Slab	2300	1.8
Soil	2016	1.5
Geofoam (EPS)	11.5	0.05
Wood	500	0.22

Future work

- ❑Material Acquisition
- ❑Build test setups
- ❑Performance Monitoring
- ❑Numerical Simulation
- ❑Small Scale Cost Benefit Analysis

LIFE FORMS

Project: **Application of Geofoam in Thermal Encapsulation of Foundations**

Number: **1**

Center for Integration of Composites into Infrastructure

Design and Testing of IFI Geosynthetic Products

Graduate Student: Md Ashrafuzzaman Khan

Team: Nripojyoti Biswas, Sayantan Chakraborty & Surya S.C. Congress

PI: Anand J. Puppala

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Objectives

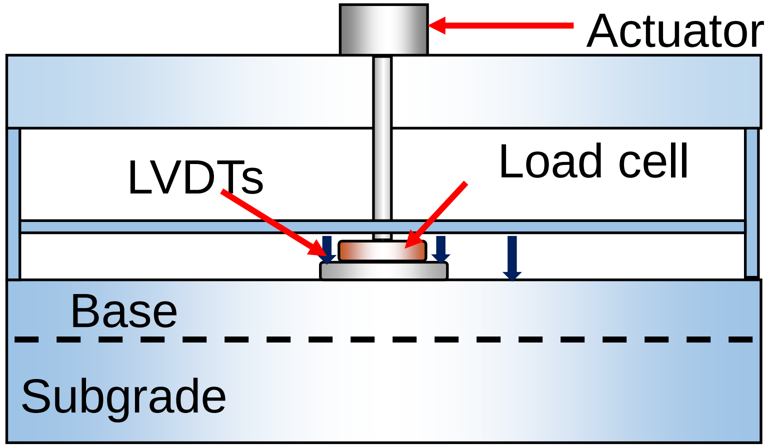
Part I

Performing repeated load tests on geosynthetic reinforced base layers built on different weak subgrades and then use the test data to calibrate parameters that can be used with Giroud and Han (G&H) designs

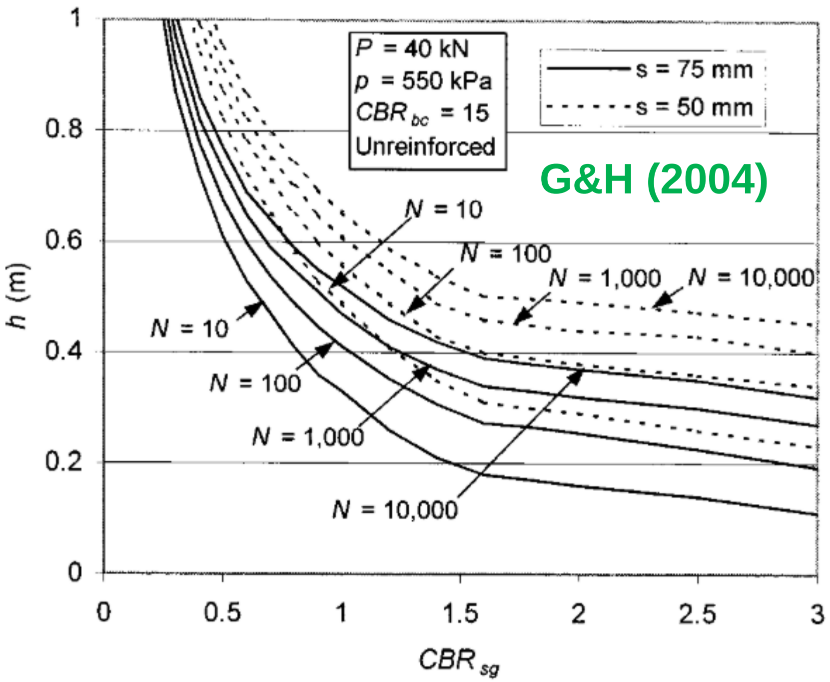
Part II

Developing various design charts and methods for IFI, Inc Geosynthetic Products based on the results and calibration studies from Part I

IFI geocells and fabgrids (composite geogrid-geotextile layers) will be considered for proposed tests



Large-scale box size: 6'x6'x2.5'



Literature

The mechanisms by which geosynthetics provide reinforcement include the following:

(i) restraint of lateral movement of base,
(ii) increase in modulus of base aggregate
(iii) improved vertical stress distribution
(iv) reduced strain along the top of the subgrade

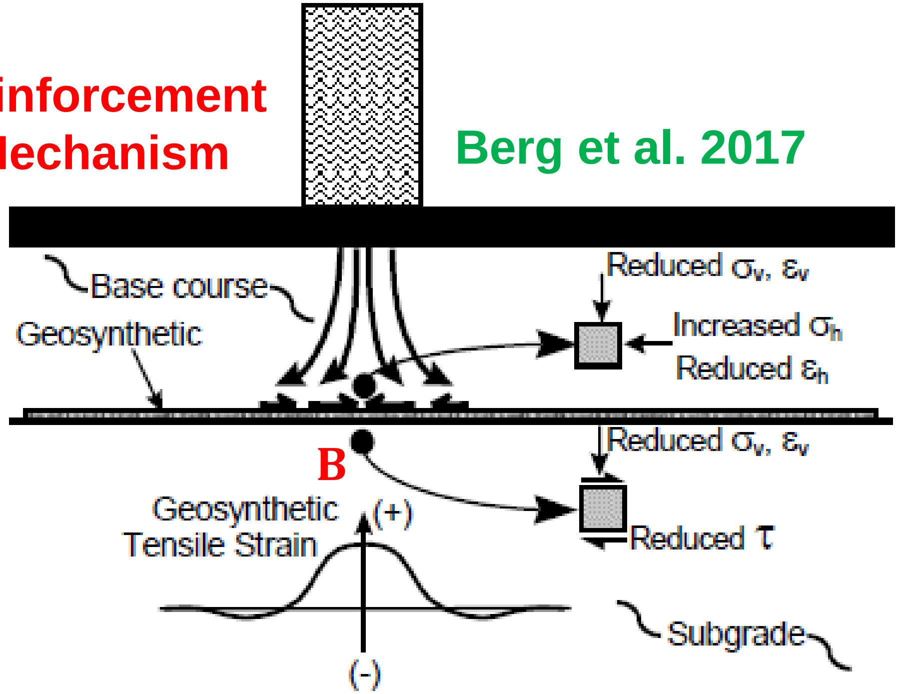
Rutting life (Nd) from the following equation

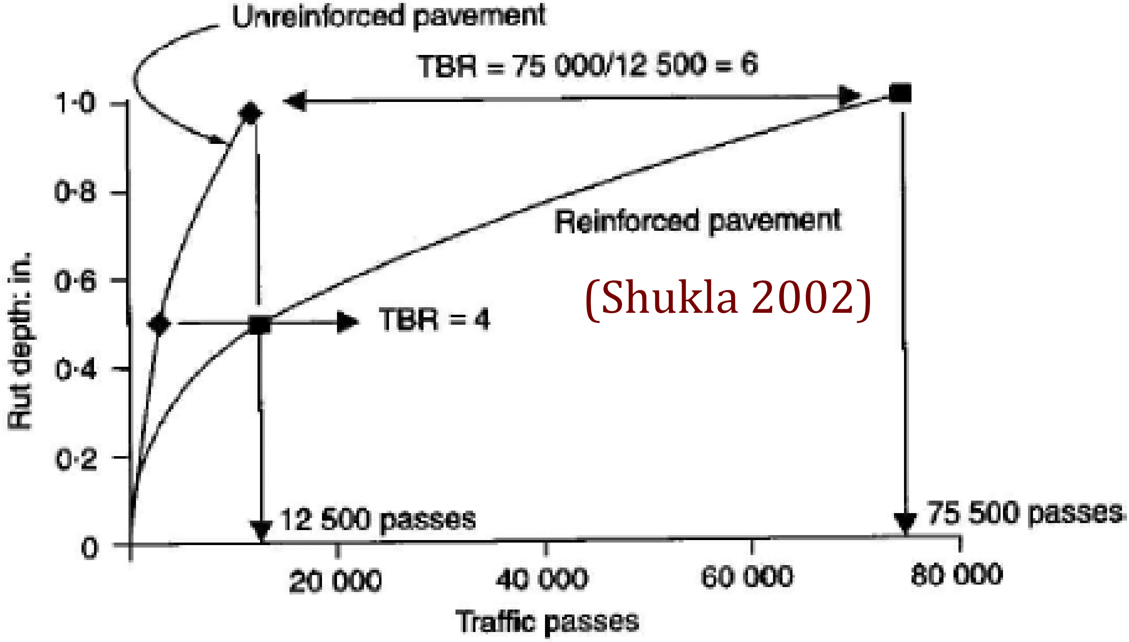
$$N_d = f_4\ (\varepsilon_v)^{-f_5}$$

Here,
ε_v is vertical compressive strain on subgrade (**B**)
f_4 and f_5 are the constants

Reinforcement Mechanism

Berg et al. 2017





(Shukla 2002)

Test Plan for Large-scale Tests

Table 2: Large-Scale Cyclic Plate Load Testing Plan Note: UR- Unreinforced; GC- Geocell; FG- Fabgrid				
Testing Sequence	Test Designation	Geosynthetic type	Subgrade Soil: CBR value	Number of tests
1	Unreinforced (Control)	-	1 & 3	2
2	GC	Geocell (2 types)	1 & 3	4
3	FG	Fabgrid (5 types)	1 & 3	10
4	FG:GC (1 Configuration)	Geocell + Fabgrid	1 & 3	2
Total number of testing:				18

FabGrid™ is a next generation composite

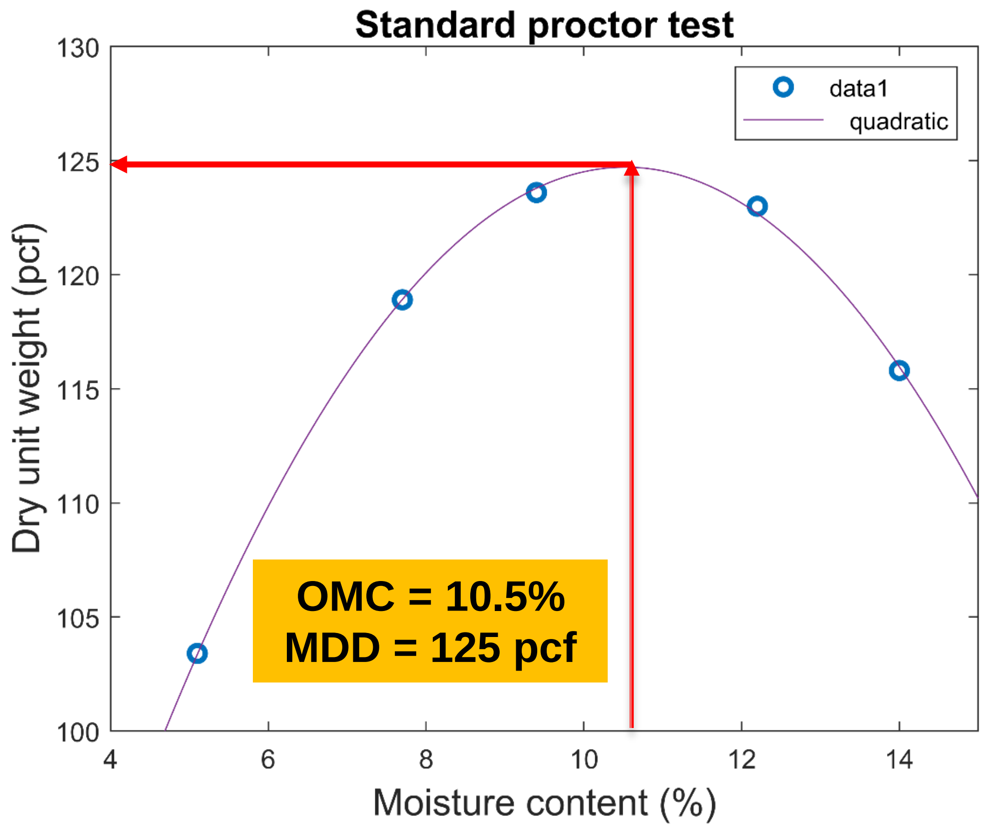
https://ind-fab.com/geogrids/

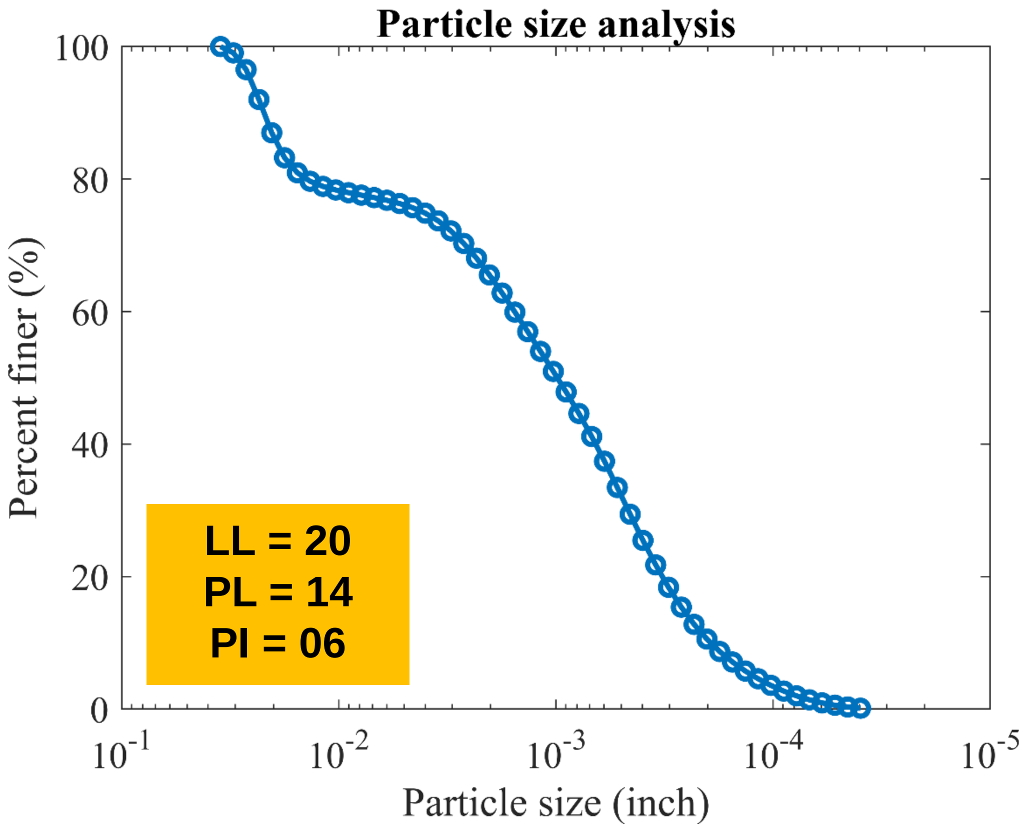
Test Plan for Material Characterizations

Material Types

- Soil
  - Grain-size
  - Standard Proctor
  - Atterberg limit
  - CBR
  - LWD-CBR
- Unbound Aggregates
  - Grain-size
  - Standard Proctor
  - Atterberg limit
  - CBR
- Geosynthetics
  - Source: IFI

Subgrade Characterization





Soil Type: CL
OMC = 10.5%
MDD = 125 pcf
LL = 20
PI = 06

Subgrade Characterization

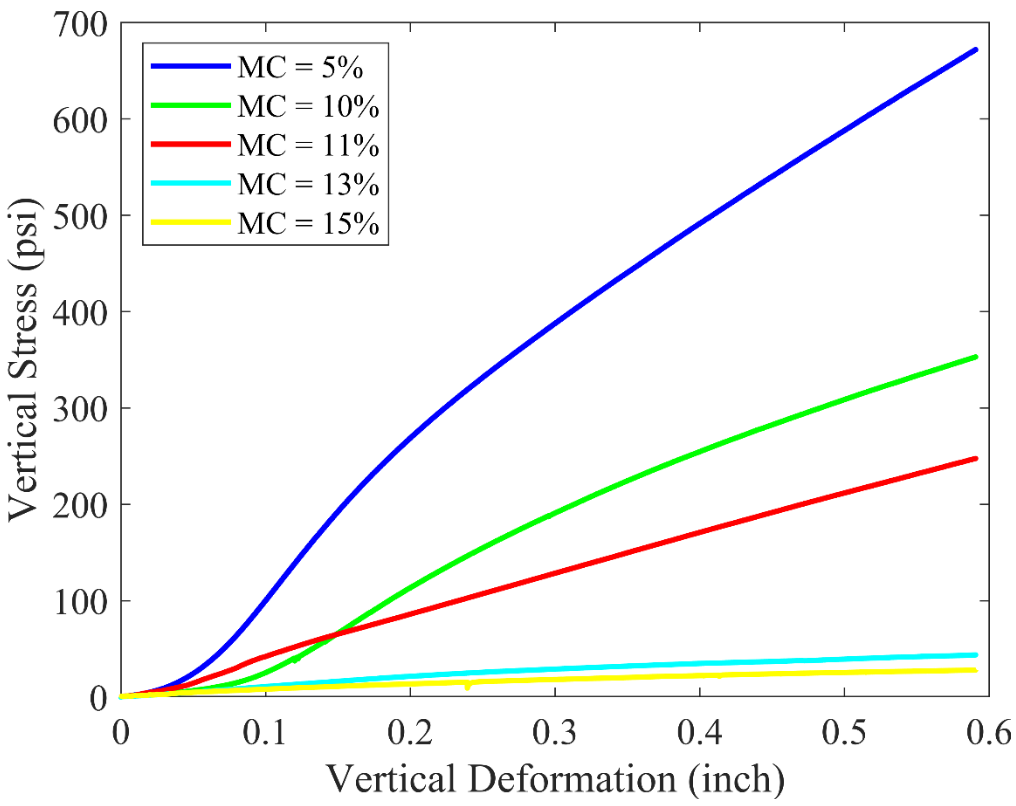
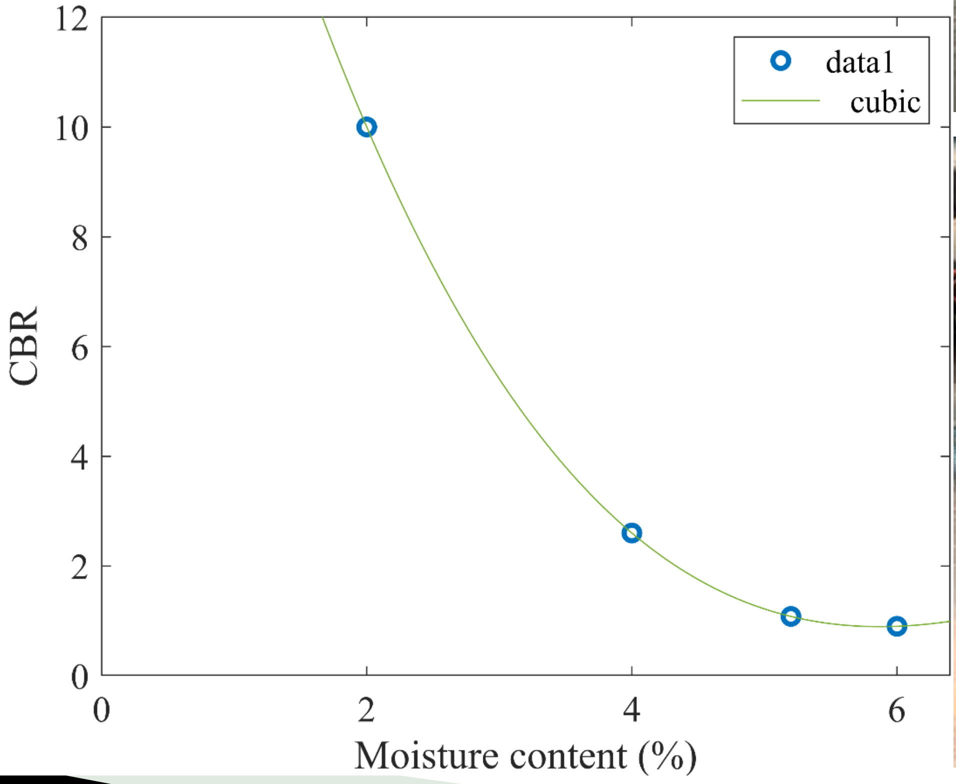
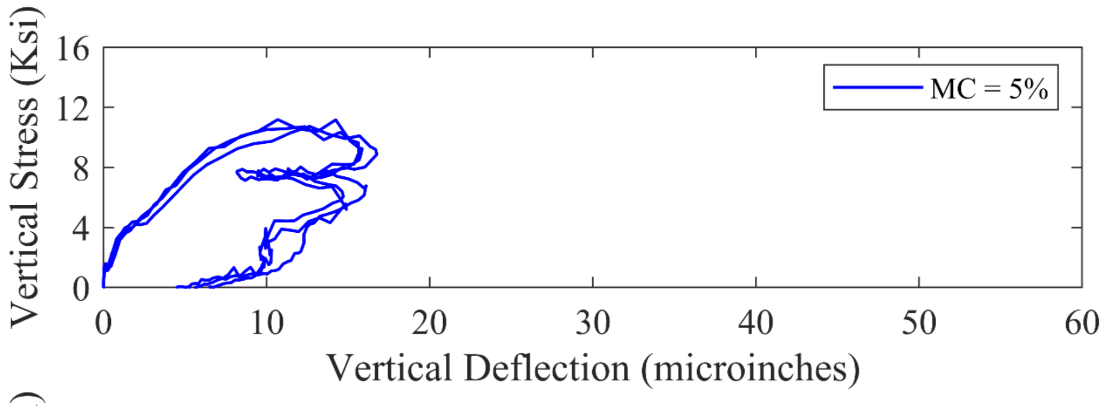


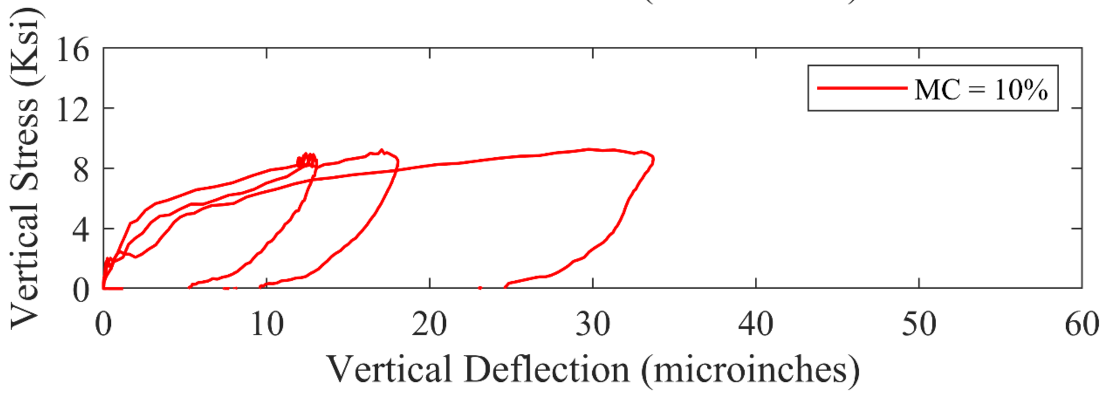
Table: CBR for Subgrade		
Test No.	MC (%)	CBR
1	5.0	10
2a*	**9.2**	**3**
2b	10.0	2.6
3a*	**12.5**	**1.0**
3b	15.0	0.9

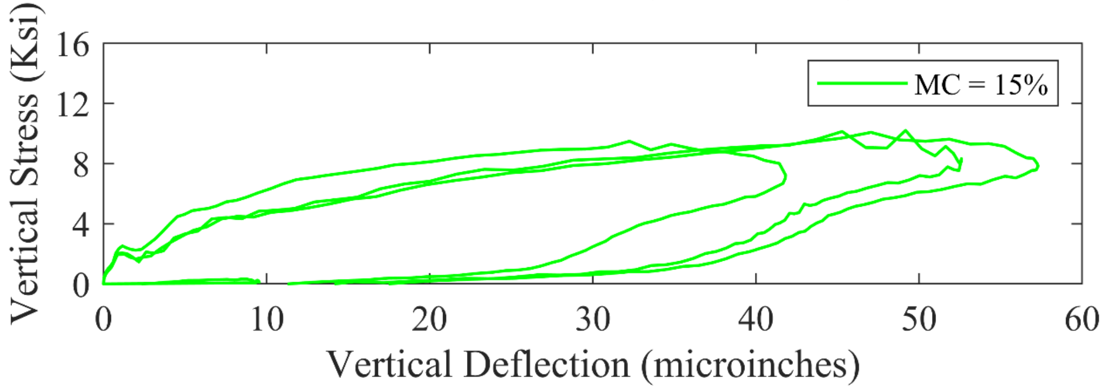


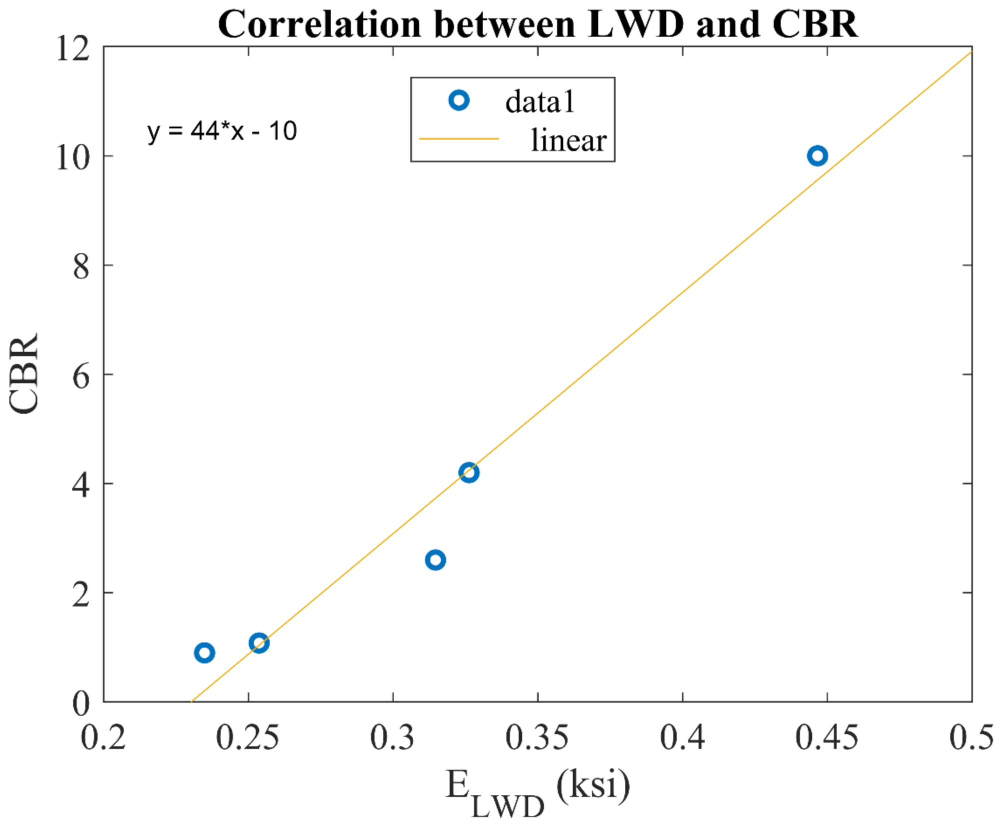
An increase of moisture content beyond the optimum limit drastically reduces the stiffness of the soil

Summary









Summary

- ❑ Completion of Soil characterization
- ❑ Development of some useful correlations for subgrade material

LIFE FORMS

Project: Design and Testing of IFI Geosynthetic Products

Number: 2

Performance of pavement sections with H_2Ri geosynthetics

Graduate Student: Nripojyoti Biswas

Team member: Md Ashrafuzzaman Khan, Sayantan Chakraborty, and Surya Sarat Chandra Congress

PI: Anand J. Puppala

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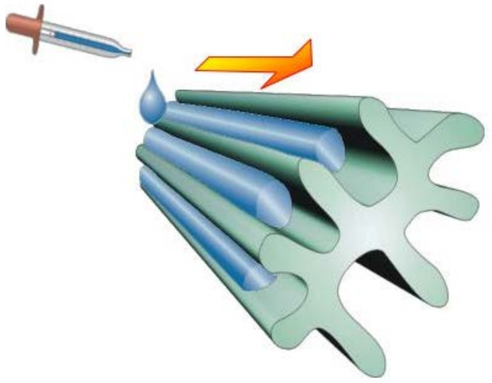
Introduction

- **Objective**
  - **To address the feasibility/efficiency of H_2Ri geosynthetic drainage and strengthening layer to improve the performance of pavement sections built on high-PI soil**

- **Single wicking geotextile layer - serves various functions**
  - **Drainage through capillary action**
  - **Reinforcement**
  - **Separation**



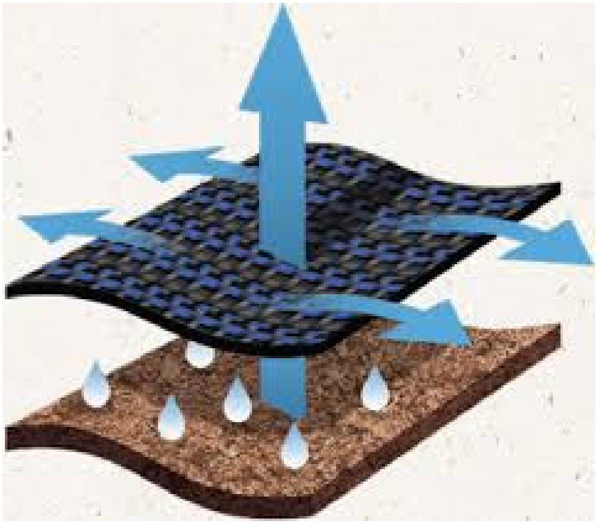
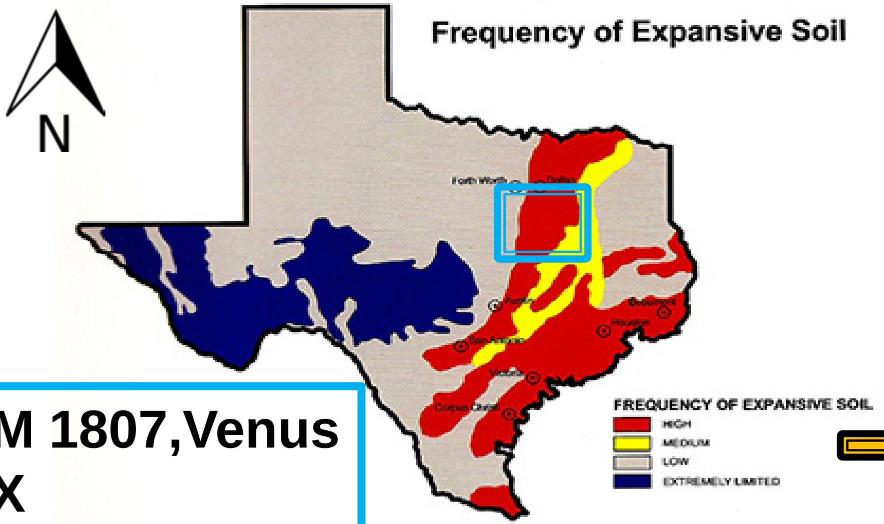


Figure-TenCate, Inc.

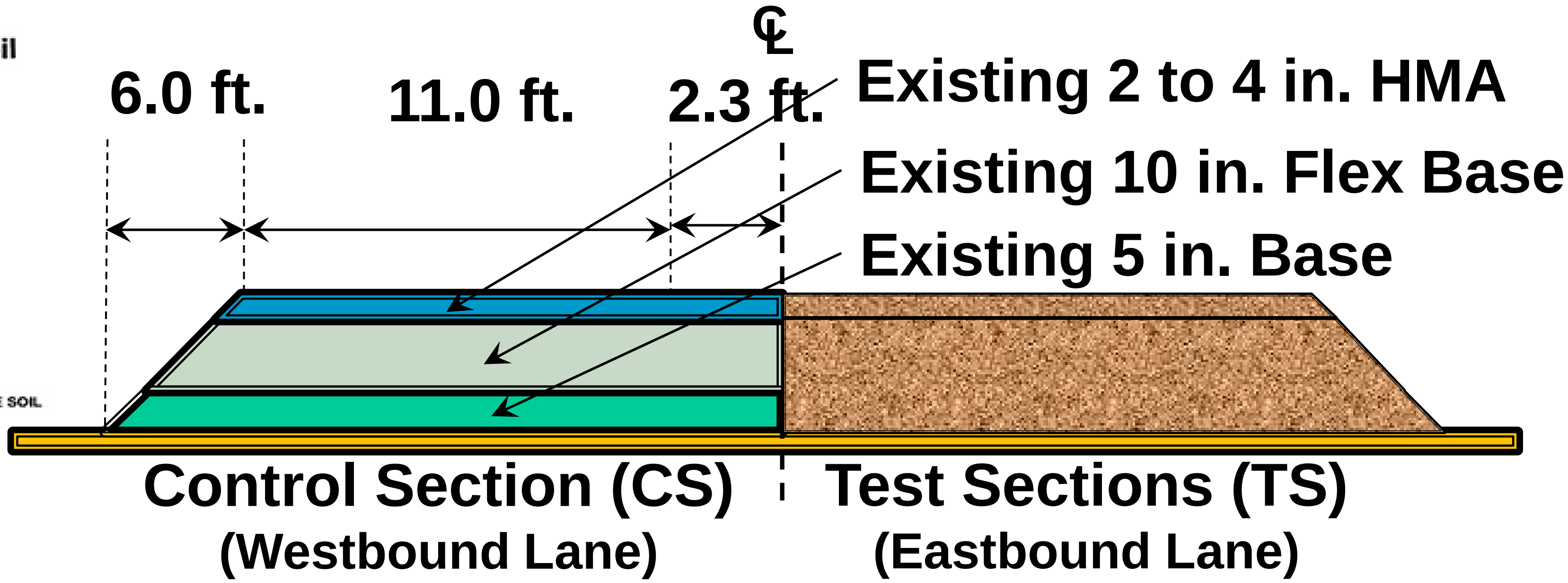
Task Plan

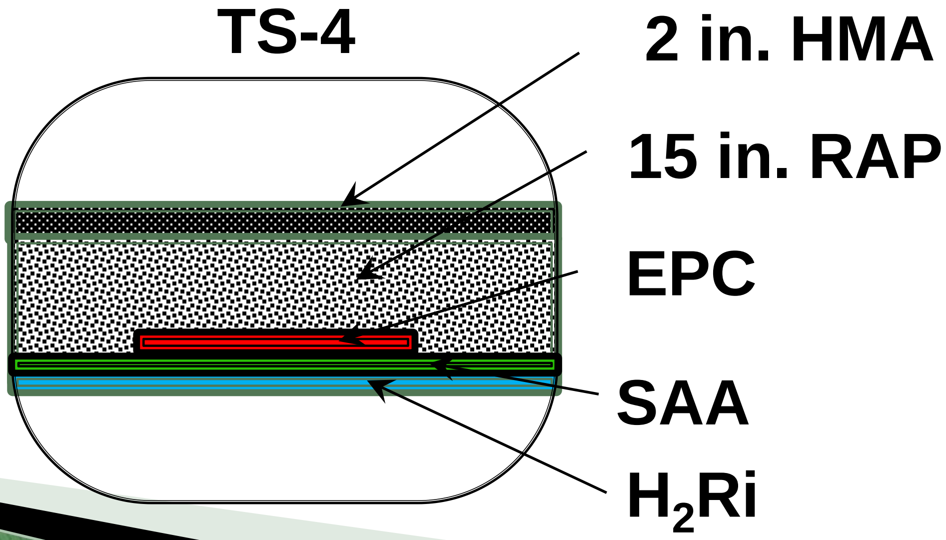
- **Task 1:**
  - **Construction and instrumentation of pavement test sections at FM 1807, Venus, TX - Completed**
- **Task 2:**
  - **Monitor performance of test sections ➔ For 2.5 years**
  - **Compare with control section**
- **Task 3:**
  - **Laboratory study and numerical validation - Ongoing**
- **Task 4:**
  - **Design and construction guidelines**
  - **Life Cycle Cost Analysis (LCCA)**

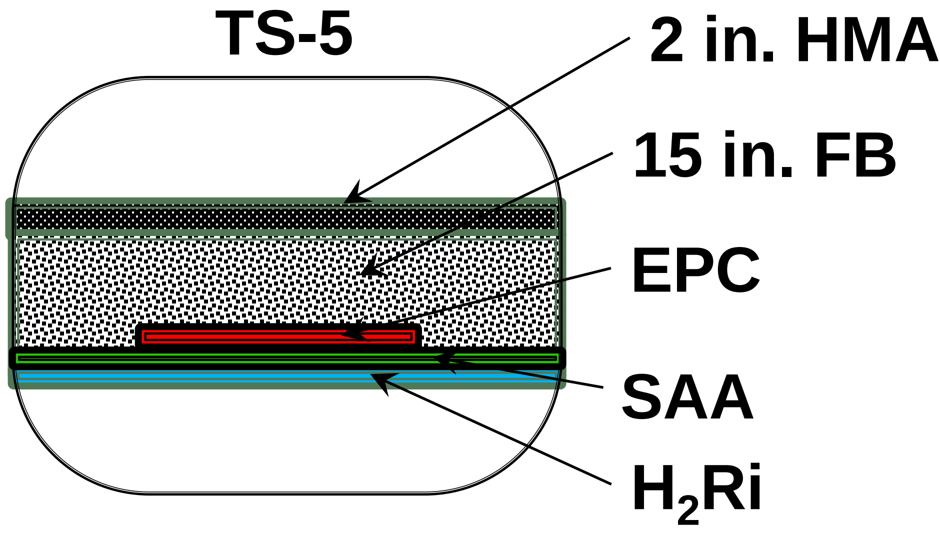
Project Location and Section Details



FM 1807,Venus TX





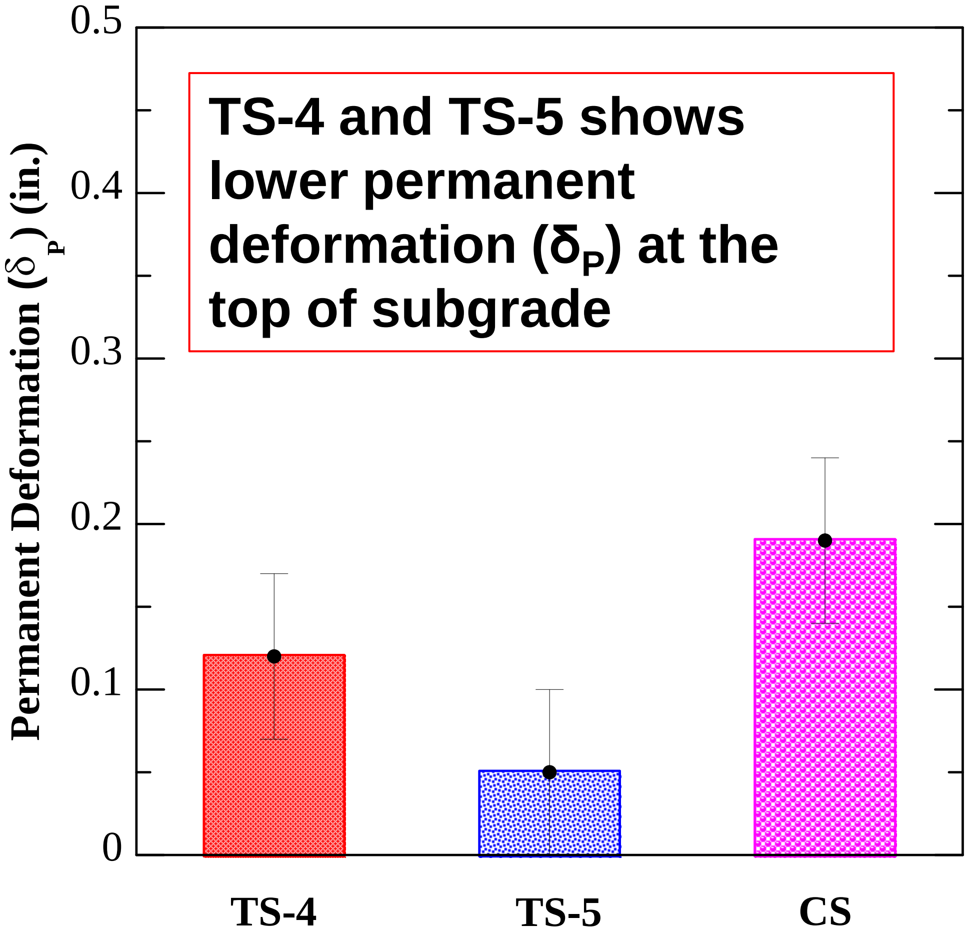


HMA - Hot Mix Asphalt
RAP - Reclaimed Asphalt Pavement Aggregates
FB - Flex Base

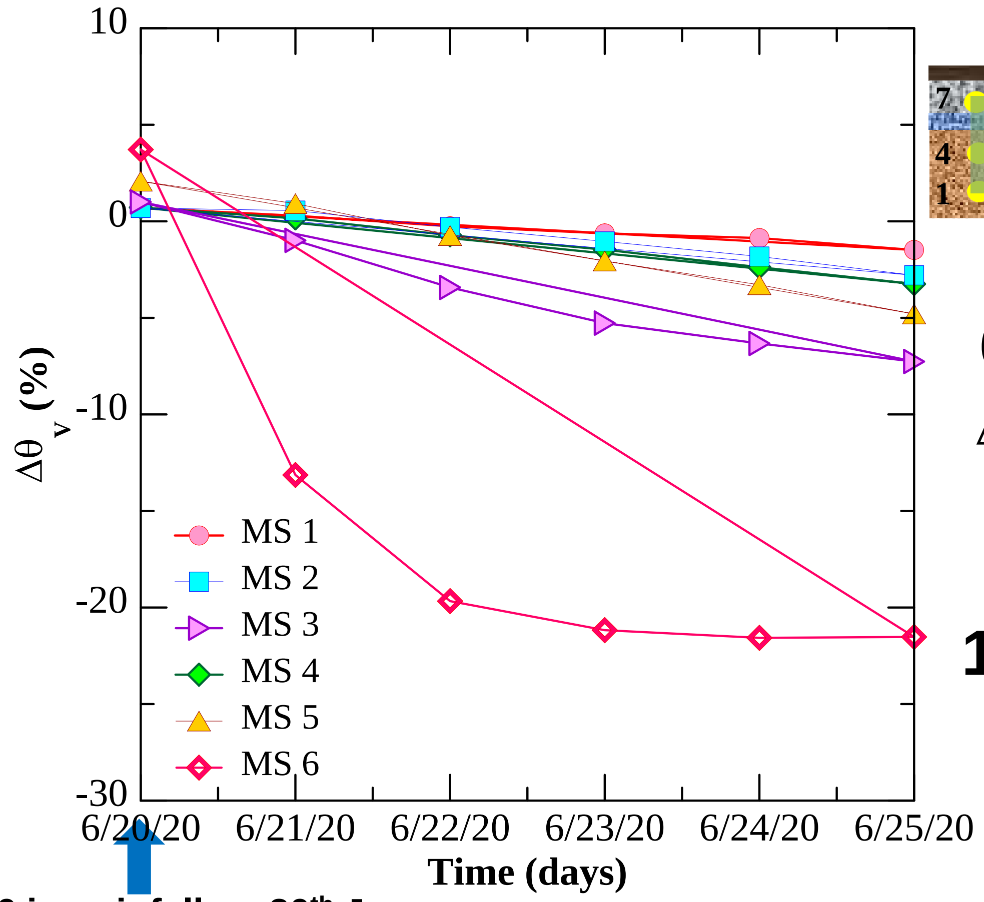
EPC - Earth Pressure Cells
SAA - Shape Array Sensors

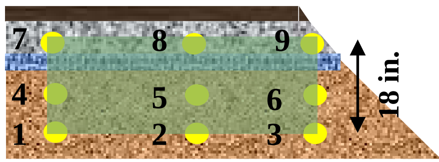
Pavement Performance

Permanent Deformation



Subsurface Moisture





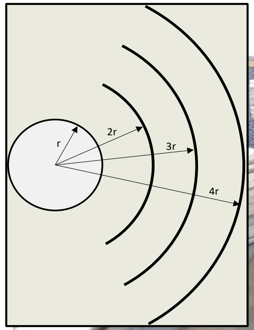
6 in. depth
$\Delta\theta_{V6}$ = 22%
$\Delta\theta_{V4}$ = 3%

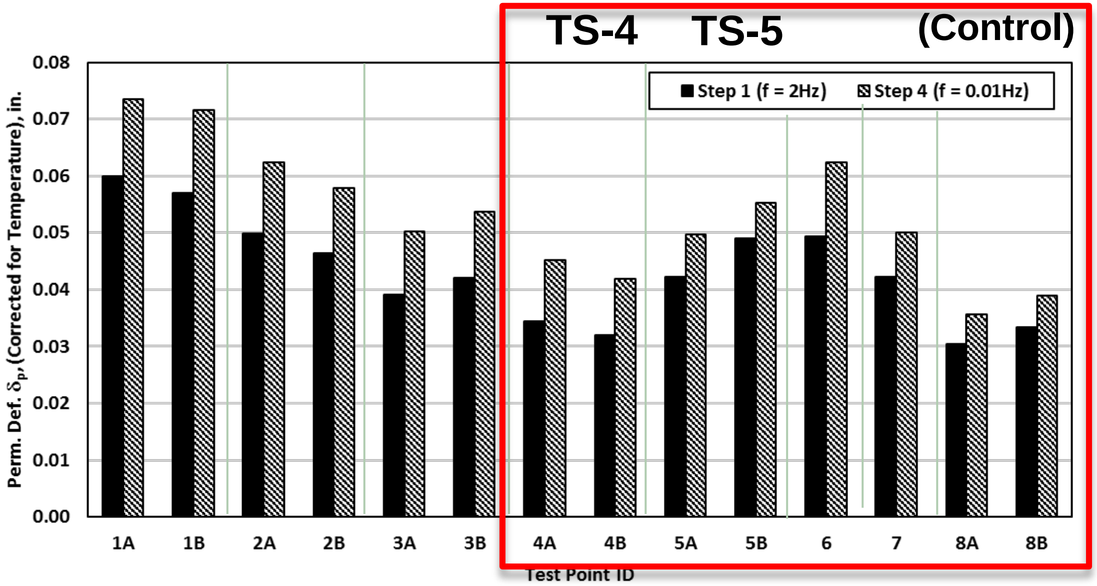
12 in. depth
$\Delta\theta_{V3}$ = 8%
$\Delta\theta_{V4}$ = 2%

Zone of influence extends to about 12 in. near crown and more than 12 in. near shoulder

Automated Plate Load Testing (APLT)

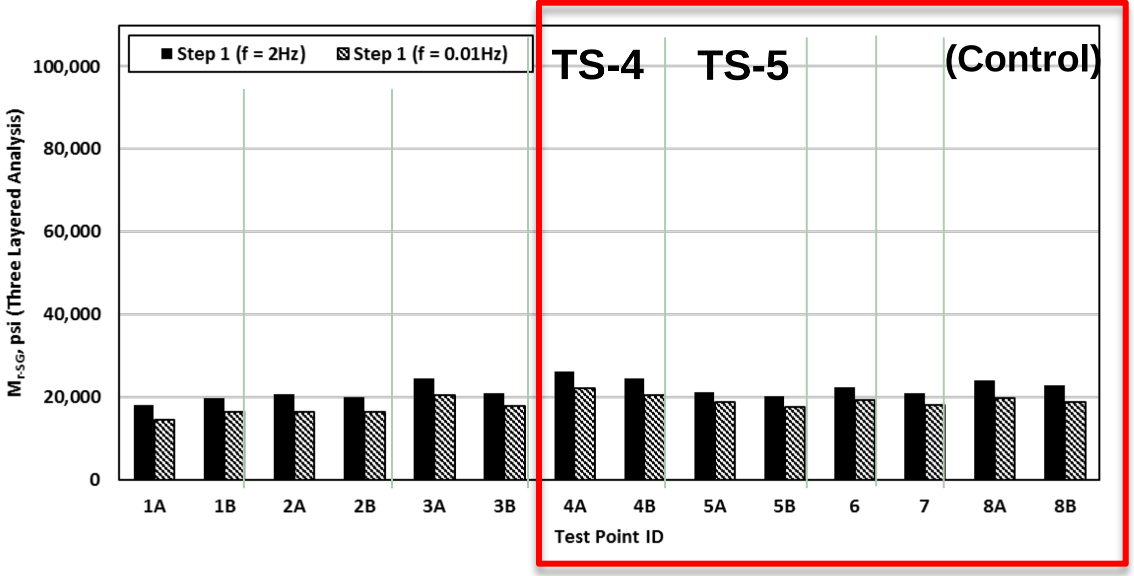
ingios GEOTECHNICS





TS-4 and TS-5 shows minimum permanent

Permanent deformation δ_p at the end of first step 1 (100 cycles) at end of Step 4 at each test location

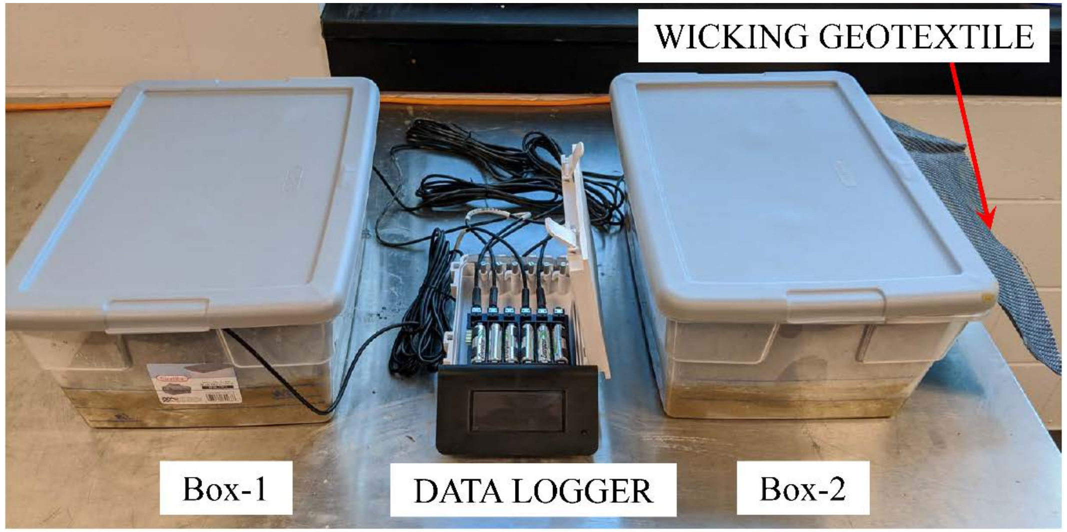


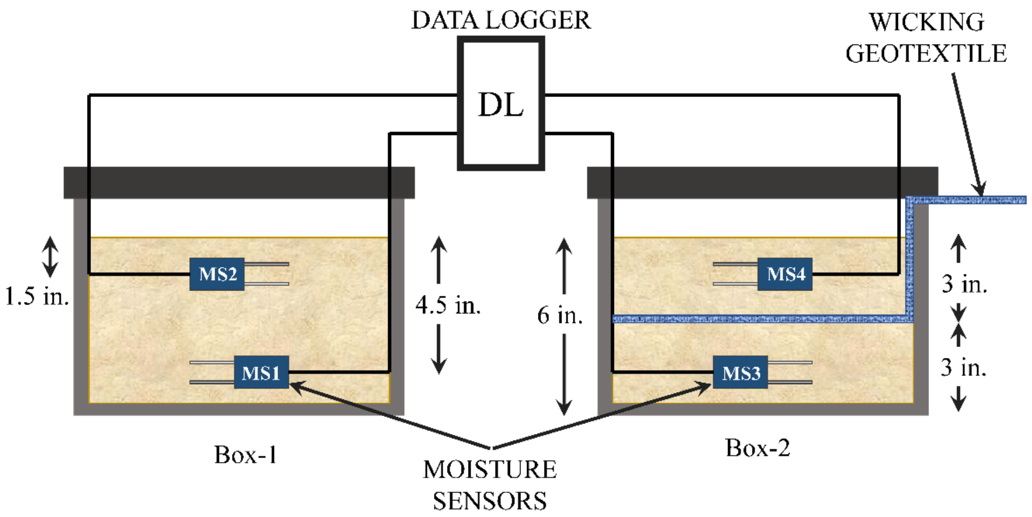
TS-4 and TS-5 shows similar Resilient Modulus

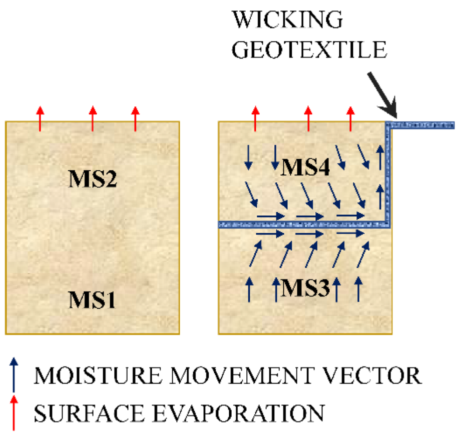
Back-calcuated $M_{r\text{-}SG}$ at the end of first step 1 (100 cycles) ant end of Step 4 at each test location

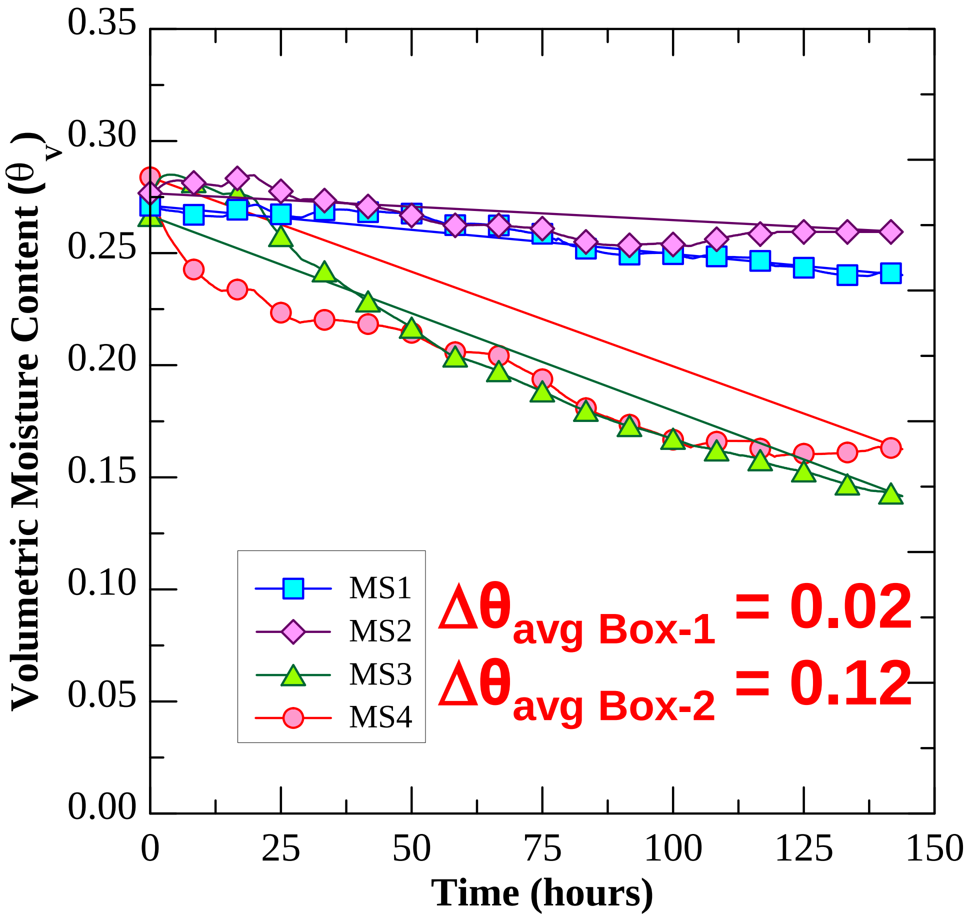
Laboratory Setup

❖ **Objective: To understand the moisture movements in subsoil due to the placement of H_2Ri in a control environment**









Higher lateral drainage due to wicking fiber observed

Laboratory setup for big box testing – Construction

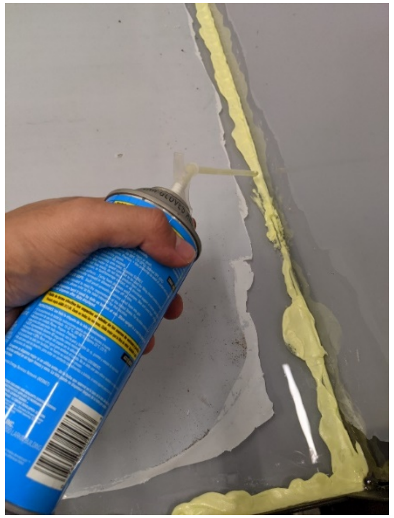
Frame Construction

Panel Cutting

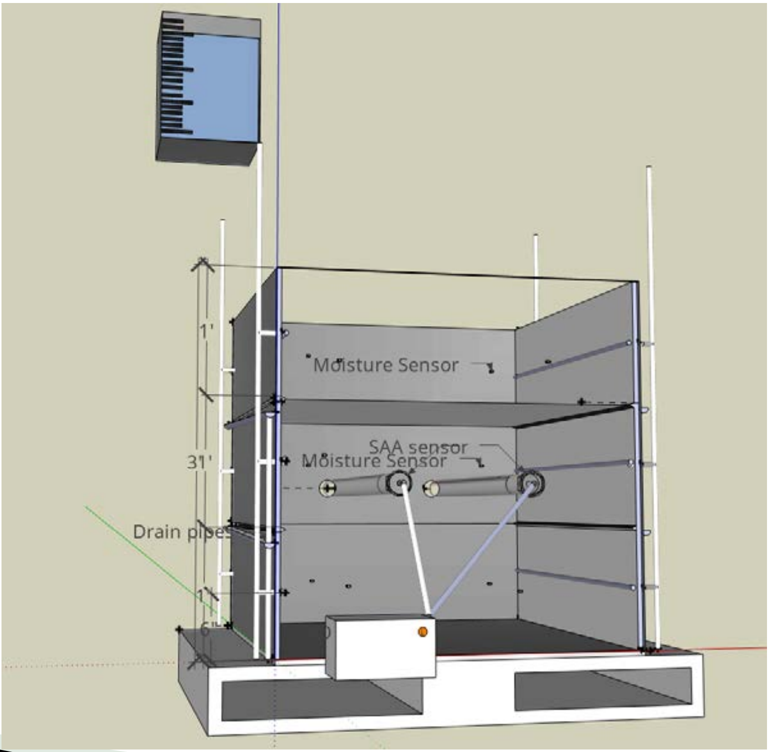
Drainage Pipes

SAA sensors

SAA Cover



Edge Glue



Proposed Model

After Construction

Water Sealant

LIFE FORMS

Project: Performance of pavement sections with H2Ri geosynthetics

Number: 3

Center for Integration of Composites into Infrastructure

Mitigating Sulfate Heaving Using Novel Admixtures

Project Leader: Sayantan Chakraborty

Team: Nripojyoti Biswas and Jungyeon Jang

PI: Anand J. Puppala
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HVJ ASSOCIATES

Terracon

Dec 2, 2020

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Research Need: Mitigating Sulfate Heaving Using Novel Admixtures

- **Problem**
  - Sulfate heaving has a detrimental impact on overlying infrastructure

- **Objective**
  - Study alternate sustainable co-additives for stabilizing sulfate-rich soils

- **Co-additive studied**
  - Crystalline silica admixture
    - Quarry fines
    - High surface area → facilitate pozzolanic reaction
    - Suppress ettringite-induced heaving

Source: Reed, R.F., 2005. Alternative Explanation of “Lime-Induced Heave”. In *PanAm Unsaturated Soils 2017* (pp. 118-130).

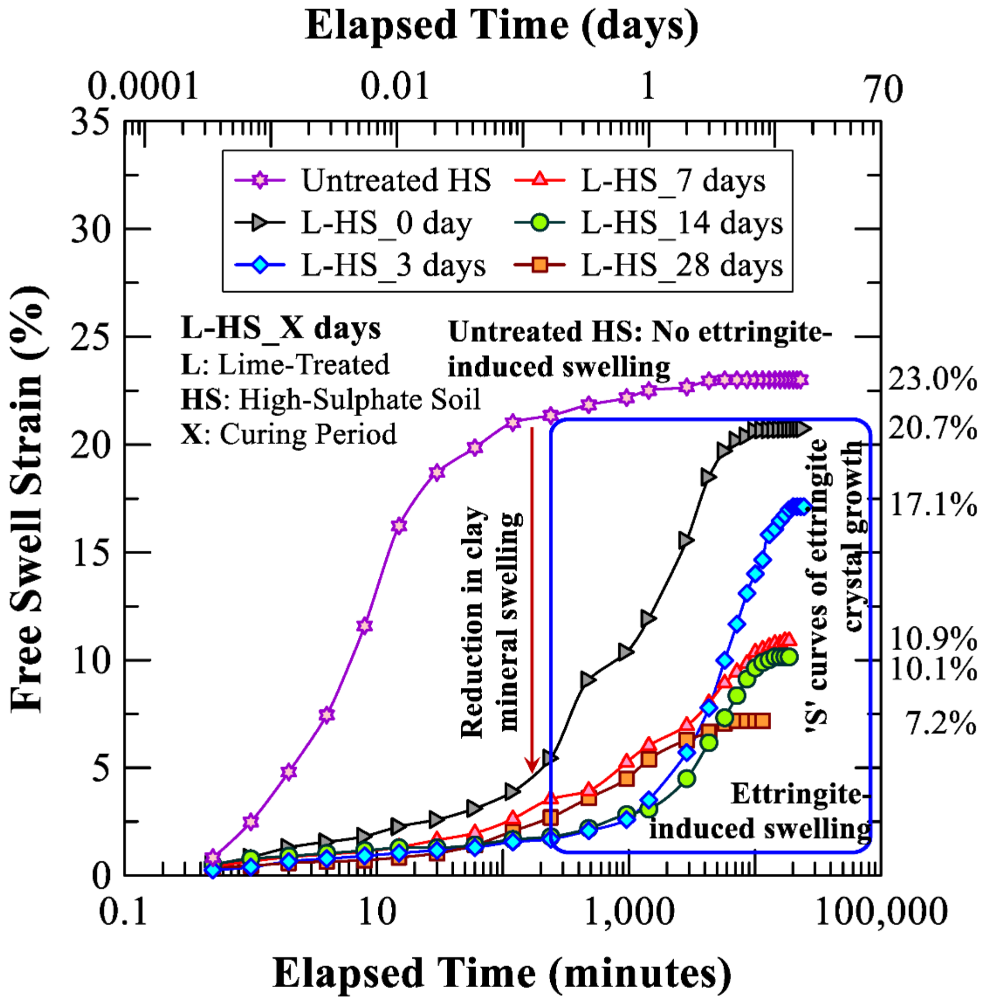
Research Plan: Mitigating Sulfate Heaving Using Novel Admixtures

- **Evaluate improvements in engineering properties**
  - Free swell, unconfined compressive strength, and resilient modulus tests
- **Mineralogical and microstructural analyses**
  - Identify chemical reaction products in treated soils
  - XRD, FESEM, and DSC
- **Sustainability and resiliency studies**
  - Resource consumption, environmental impact, and socio-economic impact
  - Resilience of infrastructure to withstand normal and extreme events

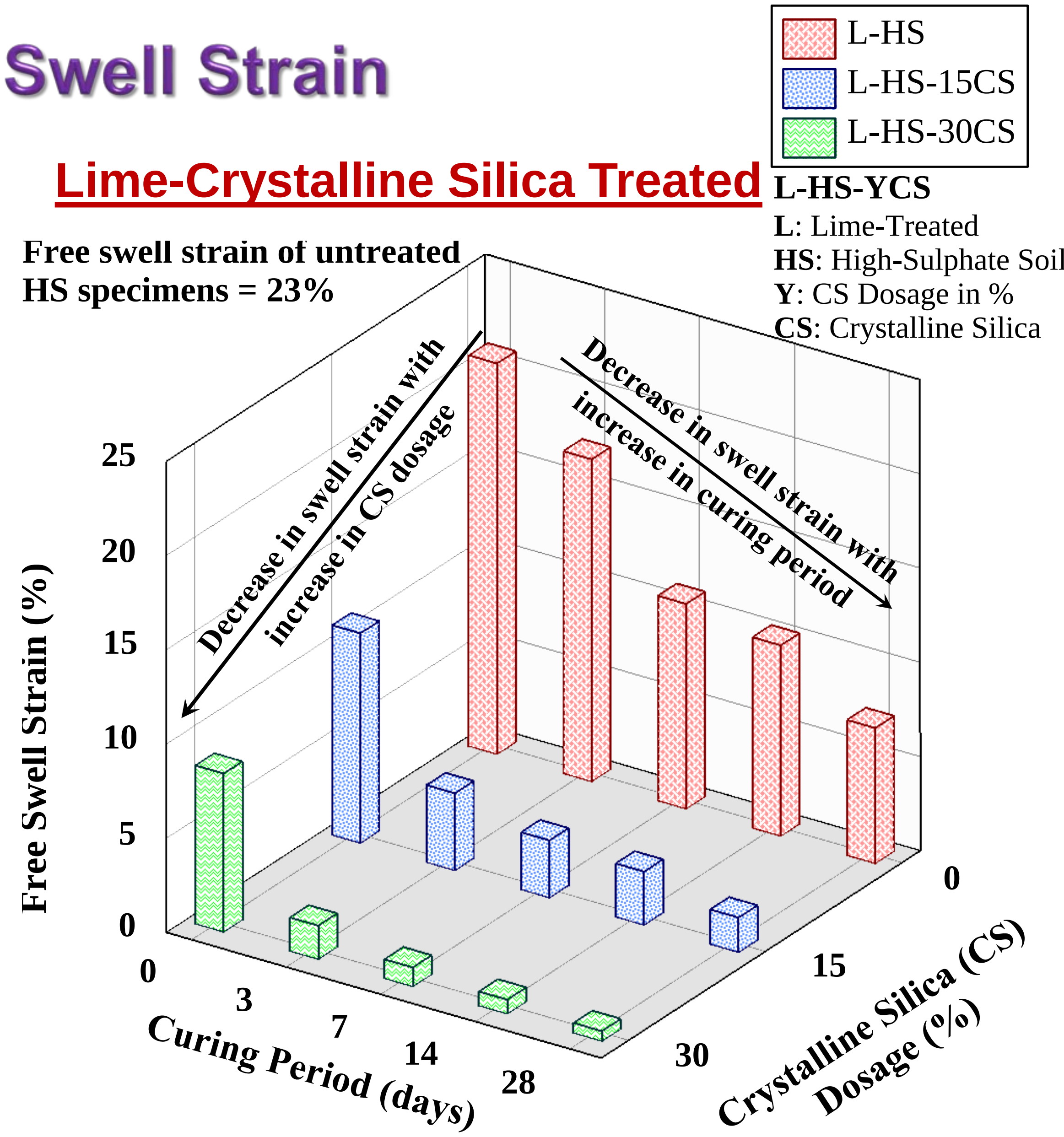
XRD – X-Ray Diffraction
FESEM – Field Emission Scanning Electron Microscopy
DSC – Differential Scanning Calorimetry

Test Results: Free Swell Strain

Lime Treated

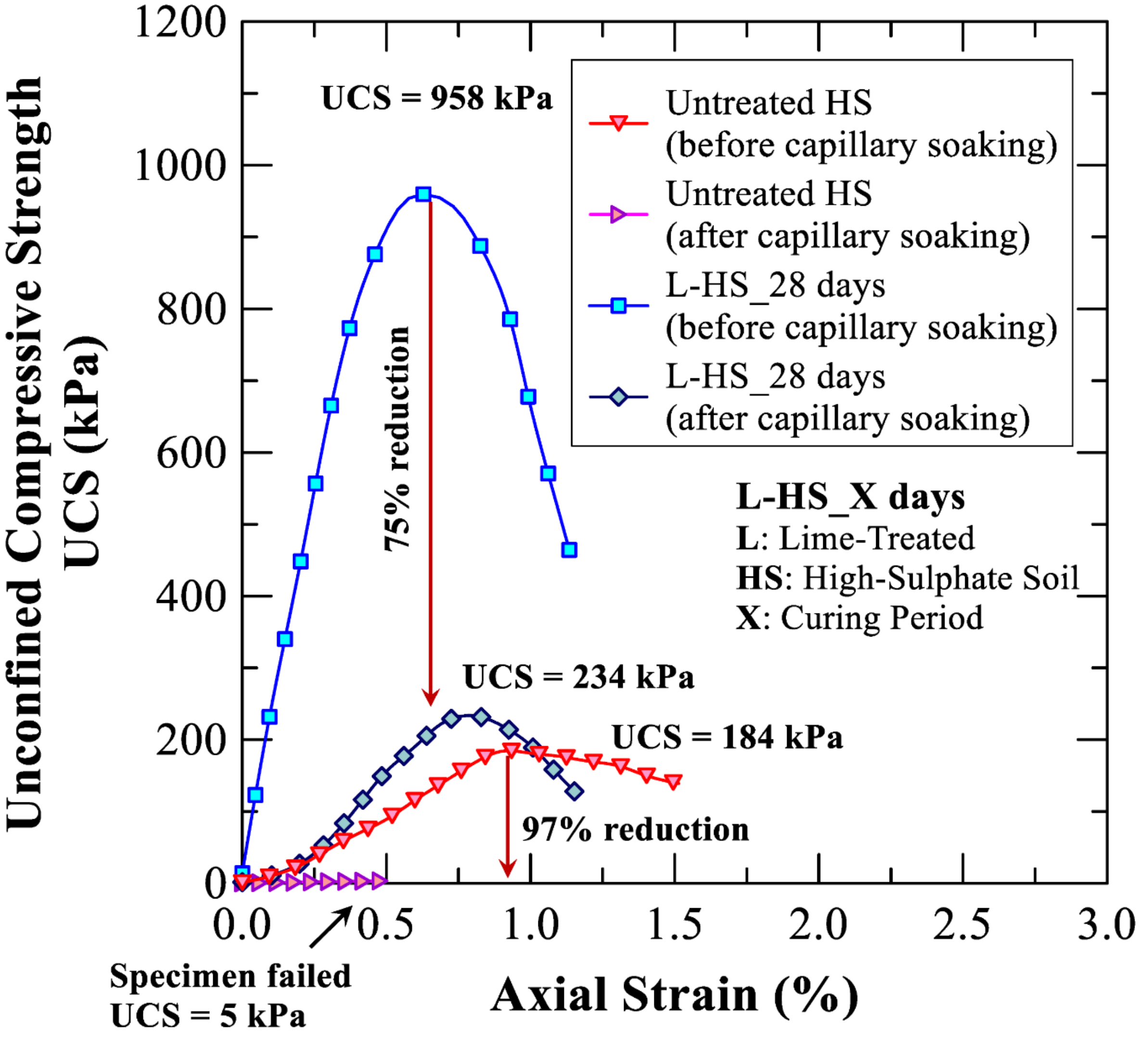


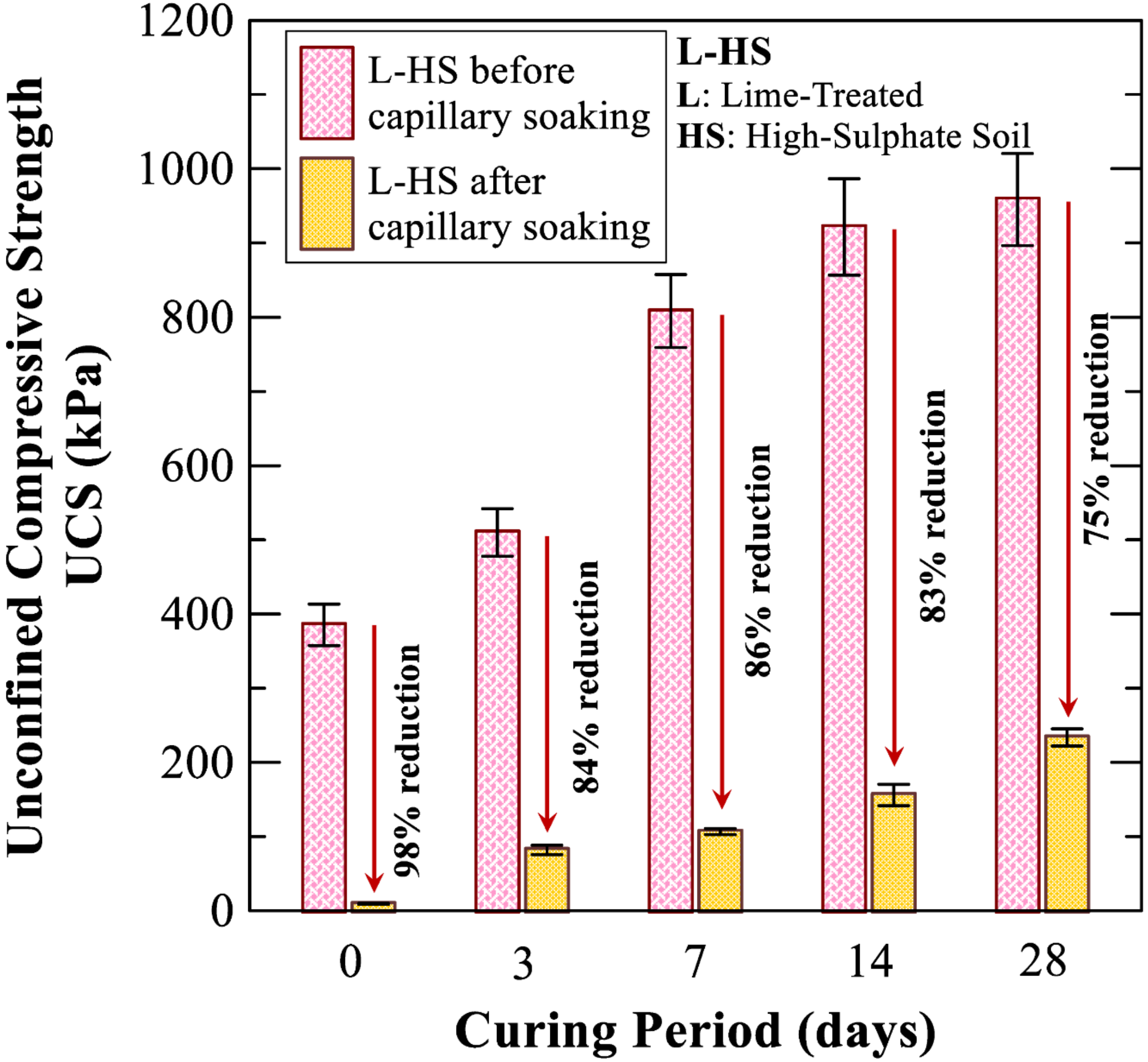
Lime-Crystalline Silica Treated



- Lime treatment → ineffective for high-sulfate soil
- Crystalline silica reduces ettringite-induced swelling

Test Results: Unconfined Compressive Strength

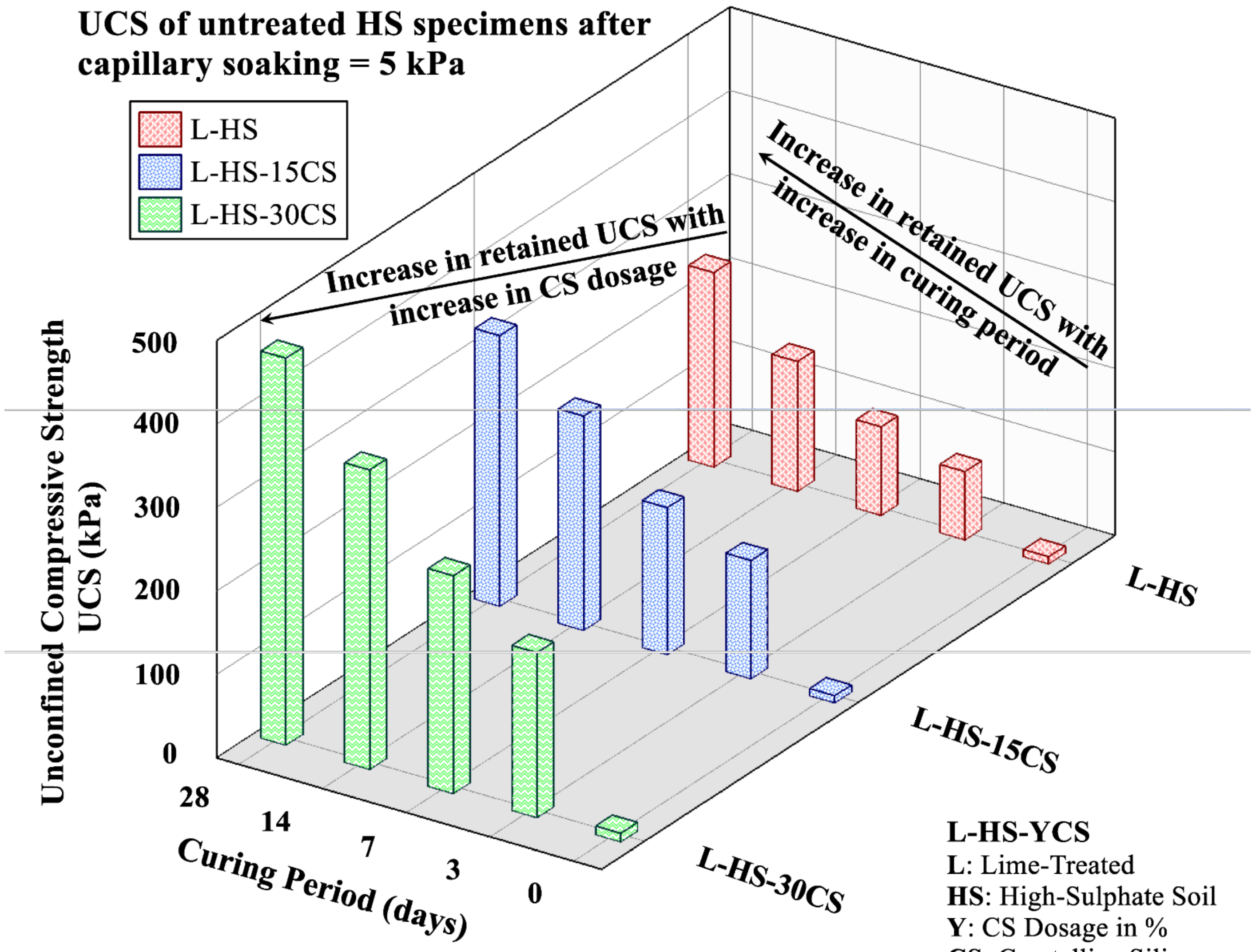




- Lime treatment → ineffective for high-sulfate soil
- Significant strength loss after moisture conditioning

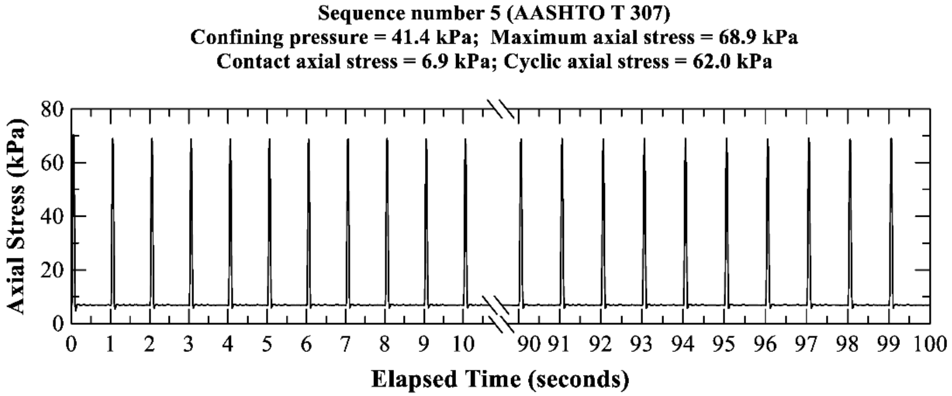
Test Results: Unconfined Compressive Strength

After Moisture Conditioning

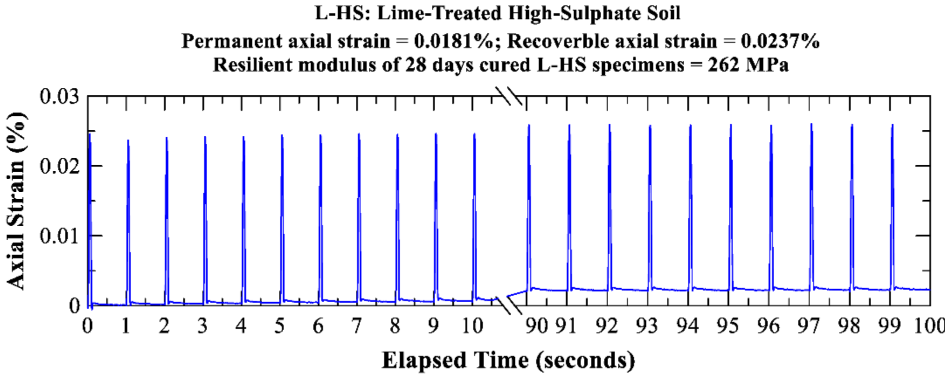


- Crystalline silica reduces ettringite-induced swelling
- Retained strength ↑ after moisture conditioning

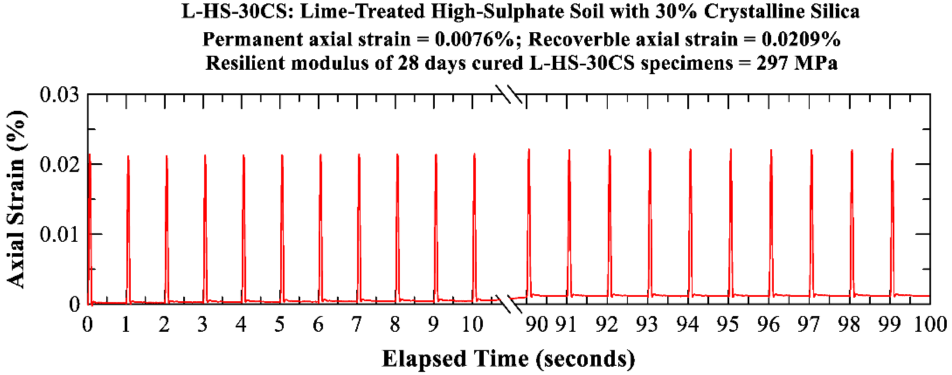
Test Results: Resilient Modulus



(a)



(b)



(c)

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left[\left(\frac{\tau_{oct}}{P_a}\right) + 1\right]^{k_3}$$

Where, M_r = resilient modulus; k_1, k_2 and k_3 = model constants; θ = bulk stress; P_a = atmospheric pressure; and τ_{oct} = octahedral shear stress

Curing period (days)	k_1		k_2		k_3		R^2	
	L-HS	L-HS-30CS	L-HS	L-HS-30CS	L-HS	L-HS-30CS	L-HS	L-HS-30CS
0	1473	1449	0.128	0.175	0.161	0.358	0.90	0.94
3	1676	1684	0.131	0.171	0.233	0.383	0.97	0.96
7	1877	1920	0.169	0.138	0.310	0.413	0.94	0.93
14	2002	2136	0.127	0.169	0.499	0.505	0.91	0.91
28	2049	2147	0.151	0.152	0.562	0.797	0.90	0.93

- Lime + Crystalline silica → Resilient modulus↑
- Curing time ↑ → Pozzolanic reaction ↑ → M_r ↑

Future Studies

- ❖ Mineralogical and microstructural analyses
- ❖ Optimize stabilizer dosages
- ❖ Sustainability and resiliency studies

LIFE FORMS

Project: **Mitigating Sulfate Heaving Using Novel Admixtures**

Number: **4**