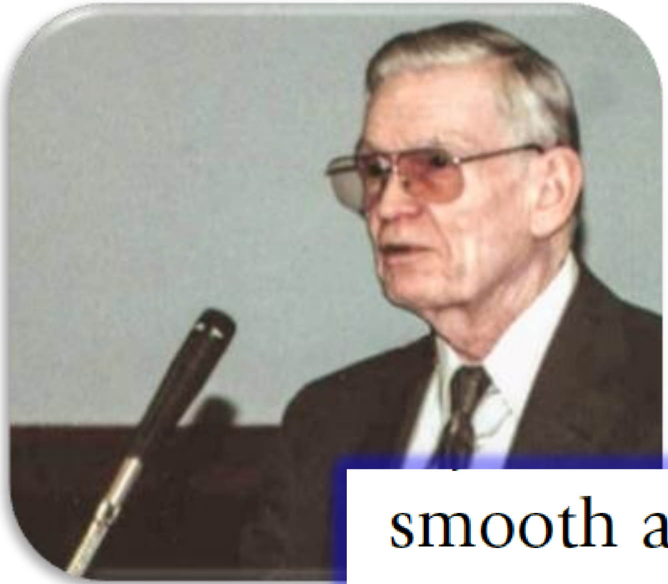
07 November 2024
Lawrence, KS

Roadways on Expansive Clays: Characterizing the Problem and Solving it with Geosynthetics

Jorge G. Zornberg, Ph.D., P.E., BC.GE., F.ASCE
Professor and Joe J. King Chair in Engineering
The University of Texas at Austin

Ralph B. Peck



Geo-Congress 1

A Regular Guy:

Ralph at the Podium - Always the Master of the Situation

The highlight of the 19th Central Pennsylvania Geotechnical Conference program in Hershey, PA, May 2002, was "Dinner with Dr. ... Rion Bri...

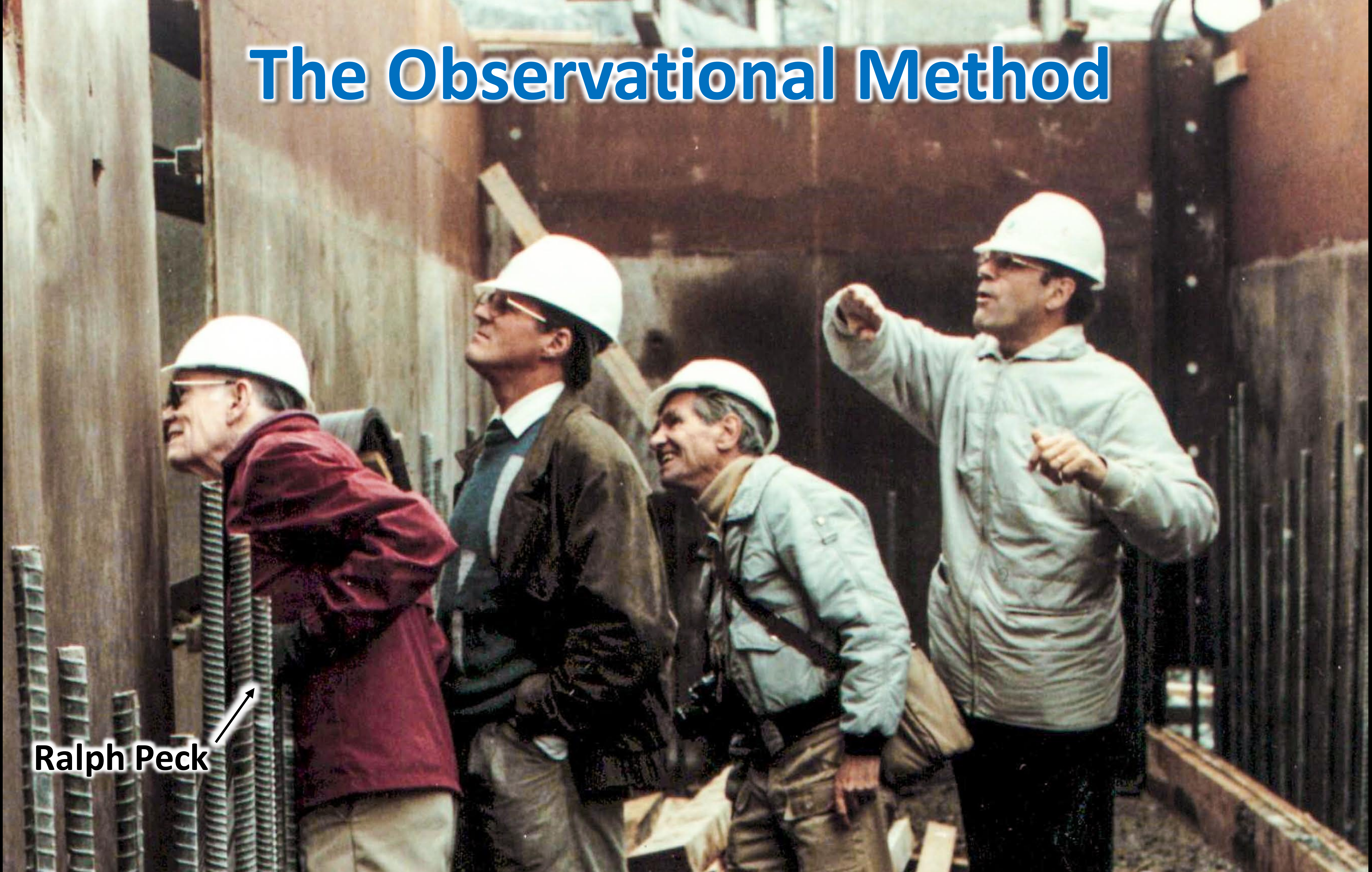
His presentation then moved forward as smooth as silk. His knowledge of the details and the points to be made was so complete that it was not necessary for him to see them on the screen. His presentation was so clear and the flow so logical that it was unnecessary for him to say "Next slide, please." I always knew when it was time to move forward.

It was an honor to be his assistant.

Jim Mitchell, Ph.D., P.E., Hon.M.ASCE

Geo-Congress 20...

The Observational Method



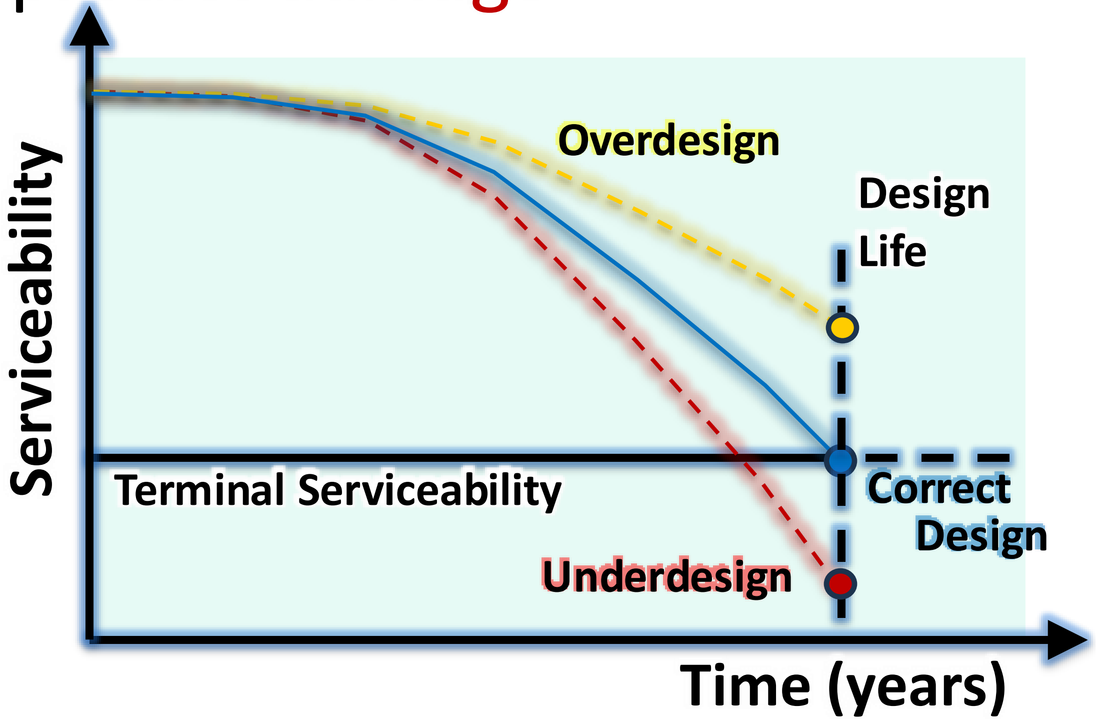
Design of Roadways on Expansive Clays

Total roadway length in USA: 4,245k mi

(Circumference of the Earth: 25k mi)

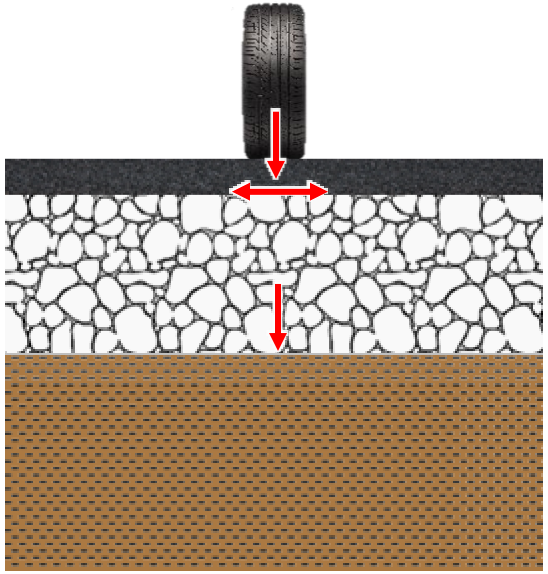
Design of Roadways for Traffic Loads

- Design is for serviceability, not limit state
- Pavements are designed to fail!
- The most current design methods (ME) focus on calculating response parameters for which we have adequate prediction methods but use empiricism to predict damage



Design of Roadways for Traffic Loads

Mechanistic | Empirical



Damage Accumulation

Transfer Function

Response

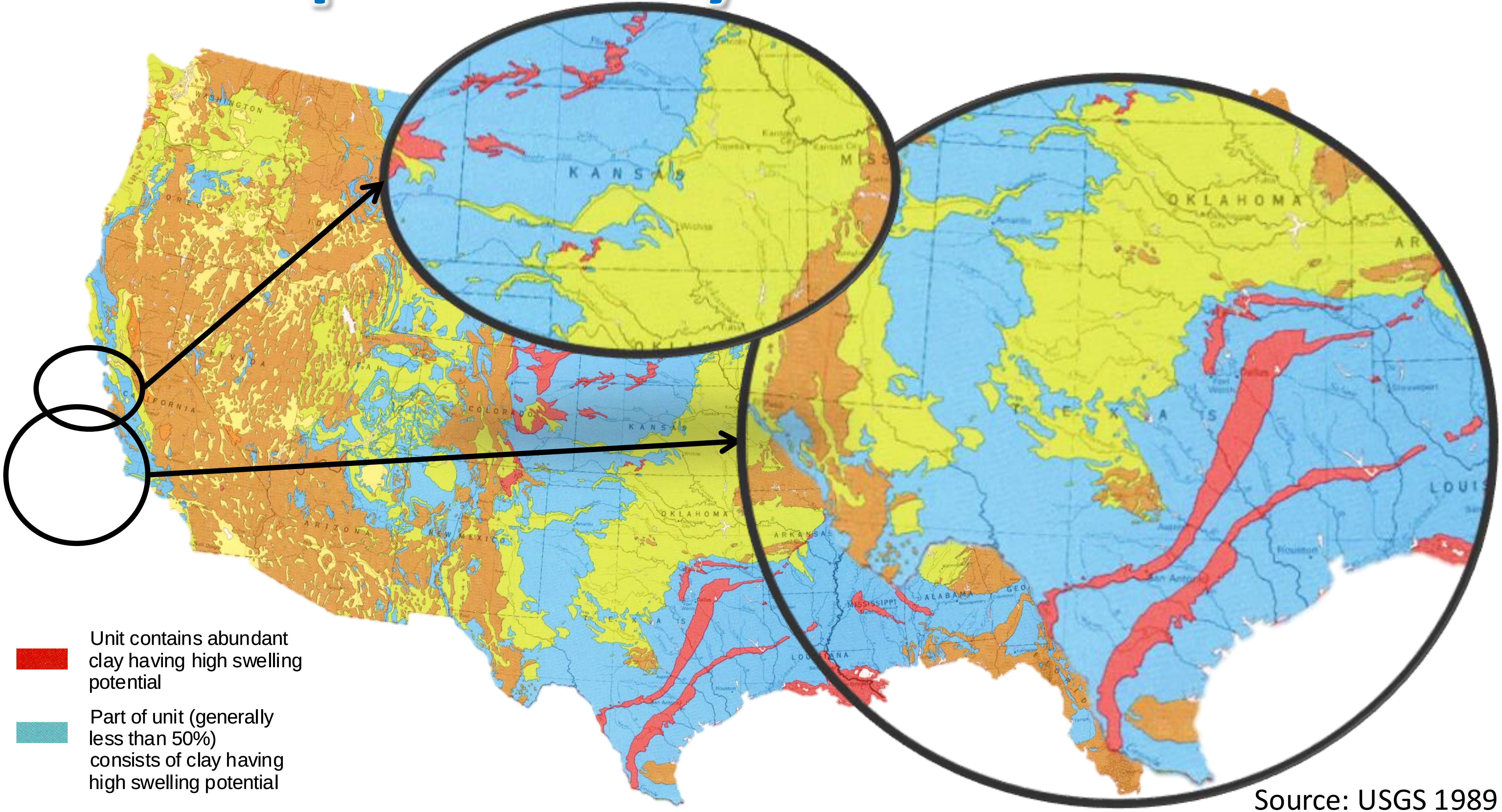
Distress

Observational Approach!

Roadway Design for Environmental Loads (?)

Courtesy: TxDOT

Expansive Clays in the US



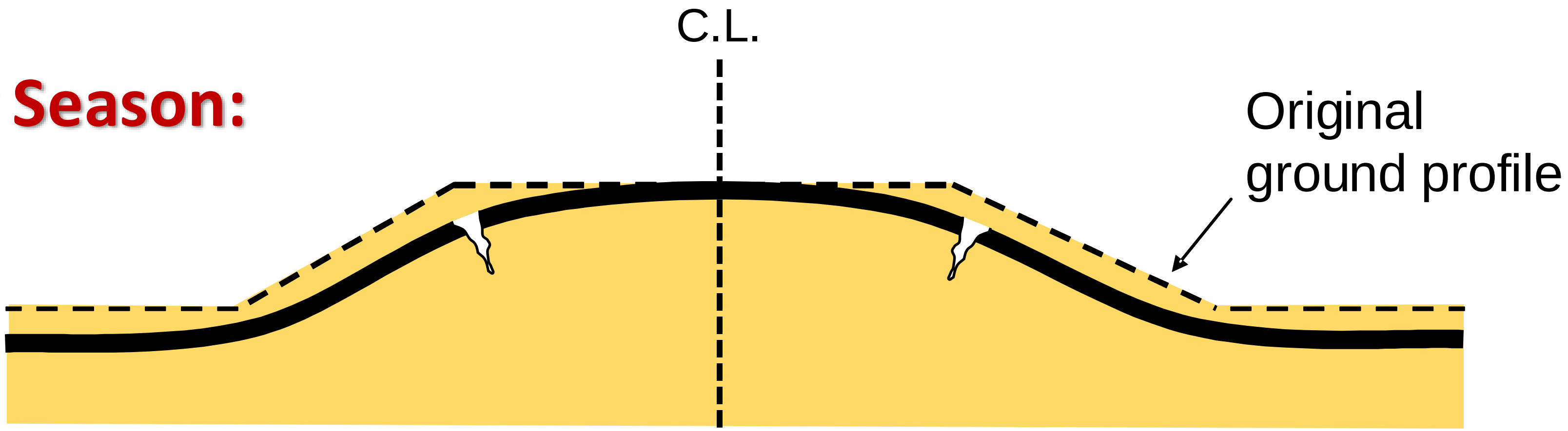
Unit contains abundant clay having high swelling potential

Part of unit (generally less than 50%) consists of clay having high swelling potential

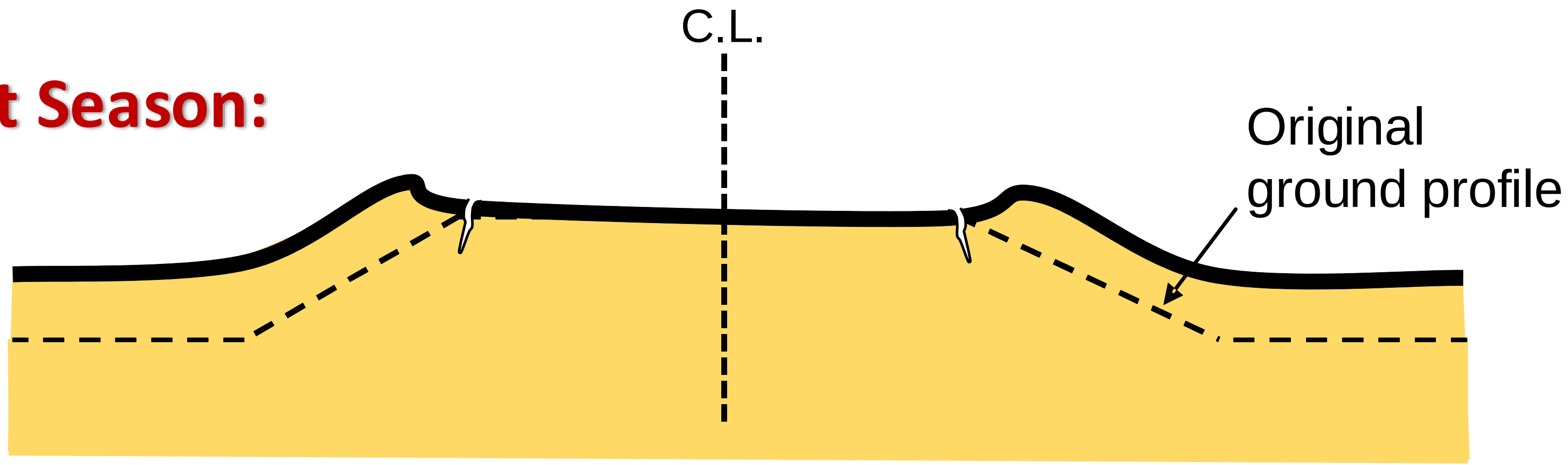
Source: USGS 1989

Understanding an Old Problem: Roadways over Expansive Clay Subgrades

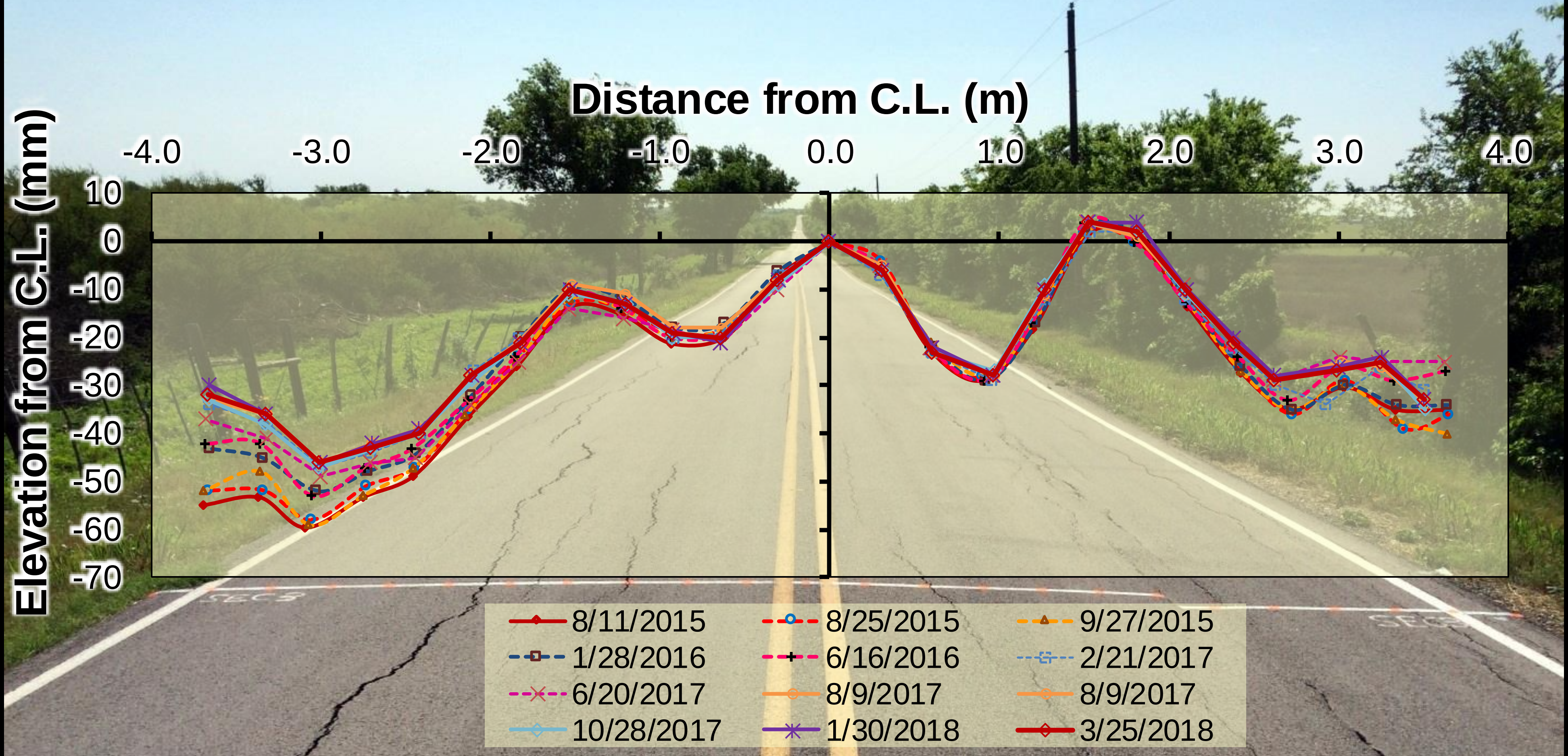
Dry Season:



Wet Season:



Zornberg and Roodi (2021)

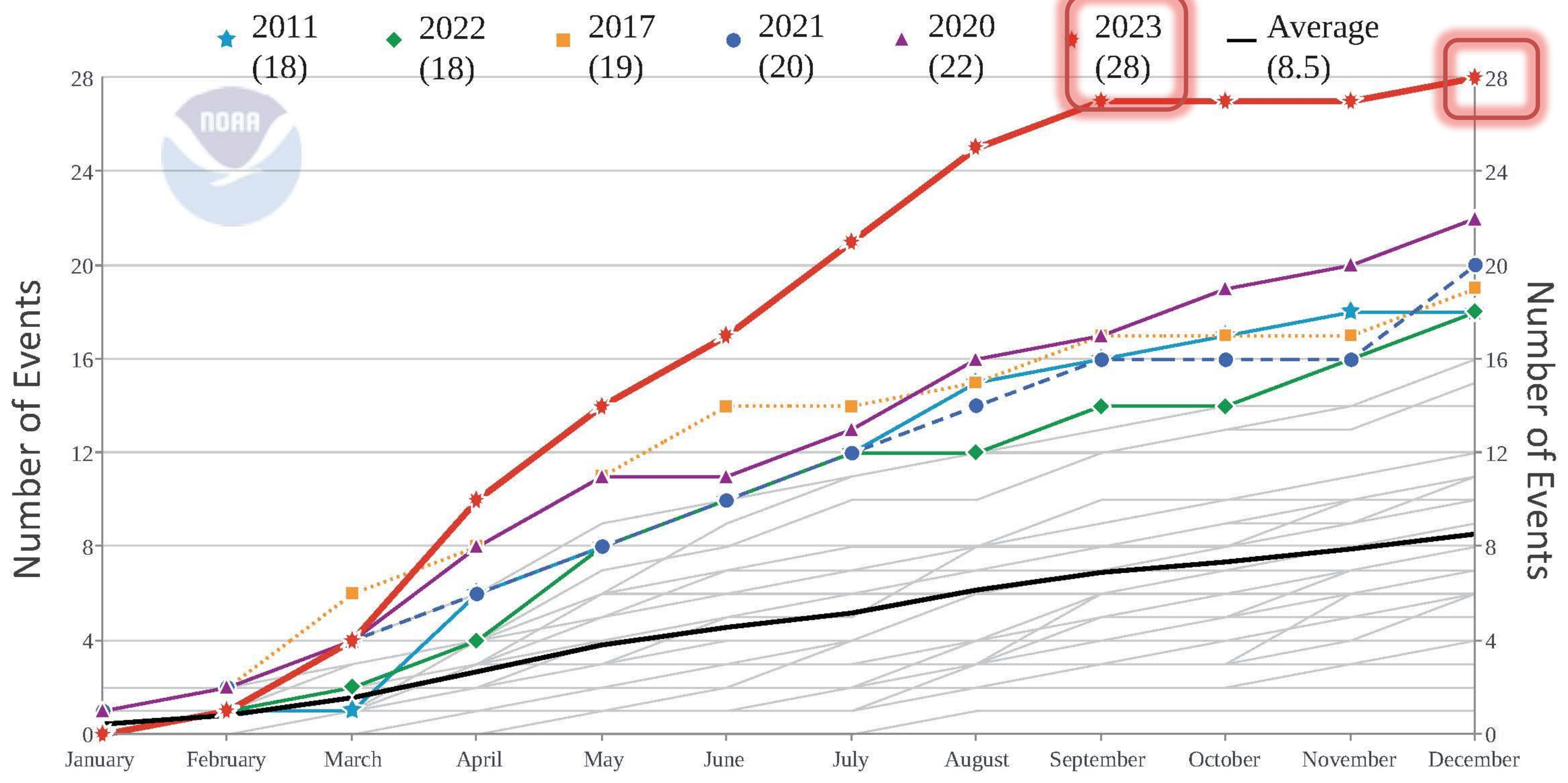


The estimated total annual damage from **expansive clays** exceeds **US$ 15 billion** in the US

Zornberg and Zhang (2021)

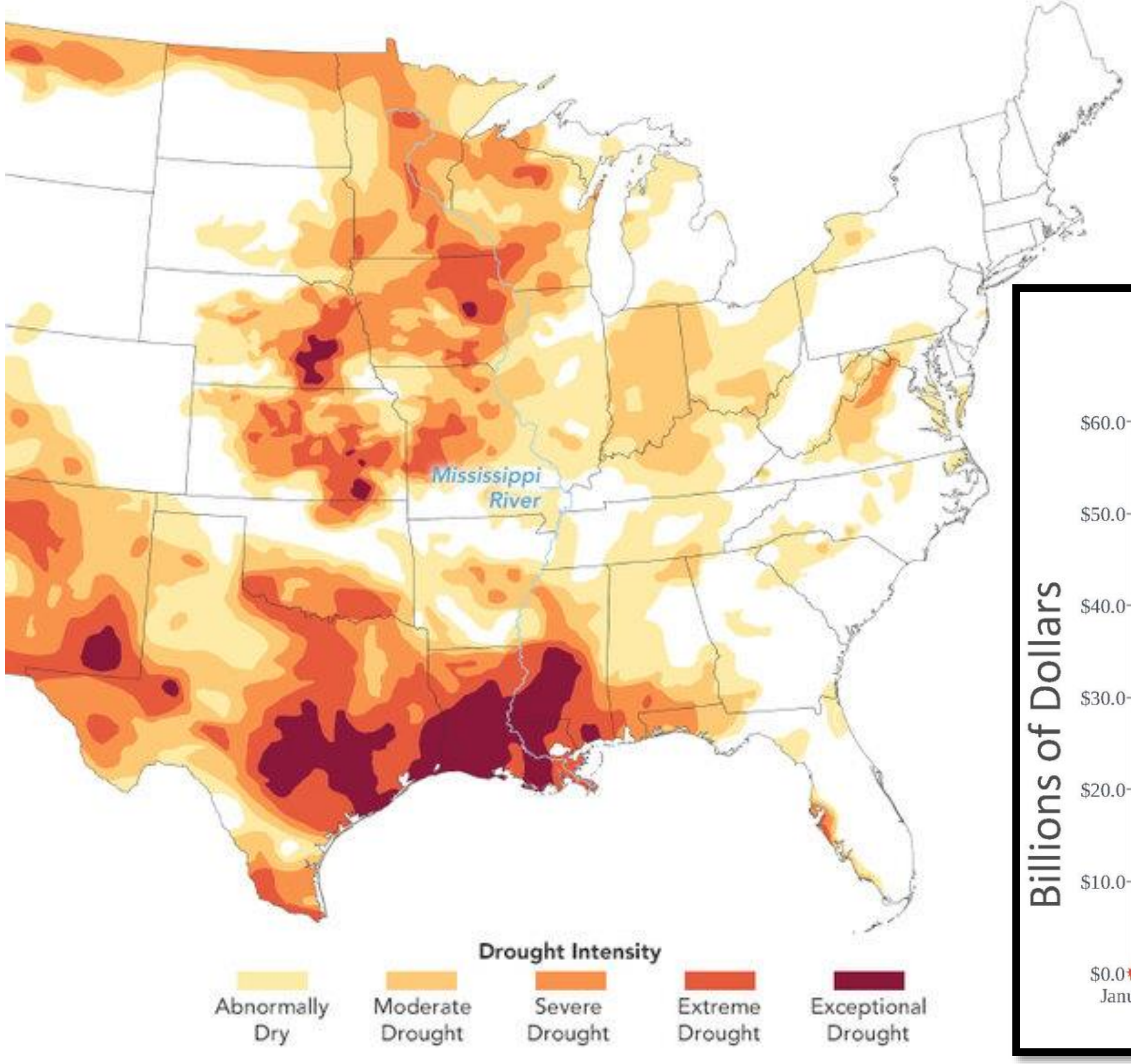
U.S. Billion-dollar Weather Disasters: 2023 in Historical Context

Number of Events



Source: NOAA National Centers for Environmental Information (2024)

Drought was the Costliest Billion-dollar Weather Disaster in 2023



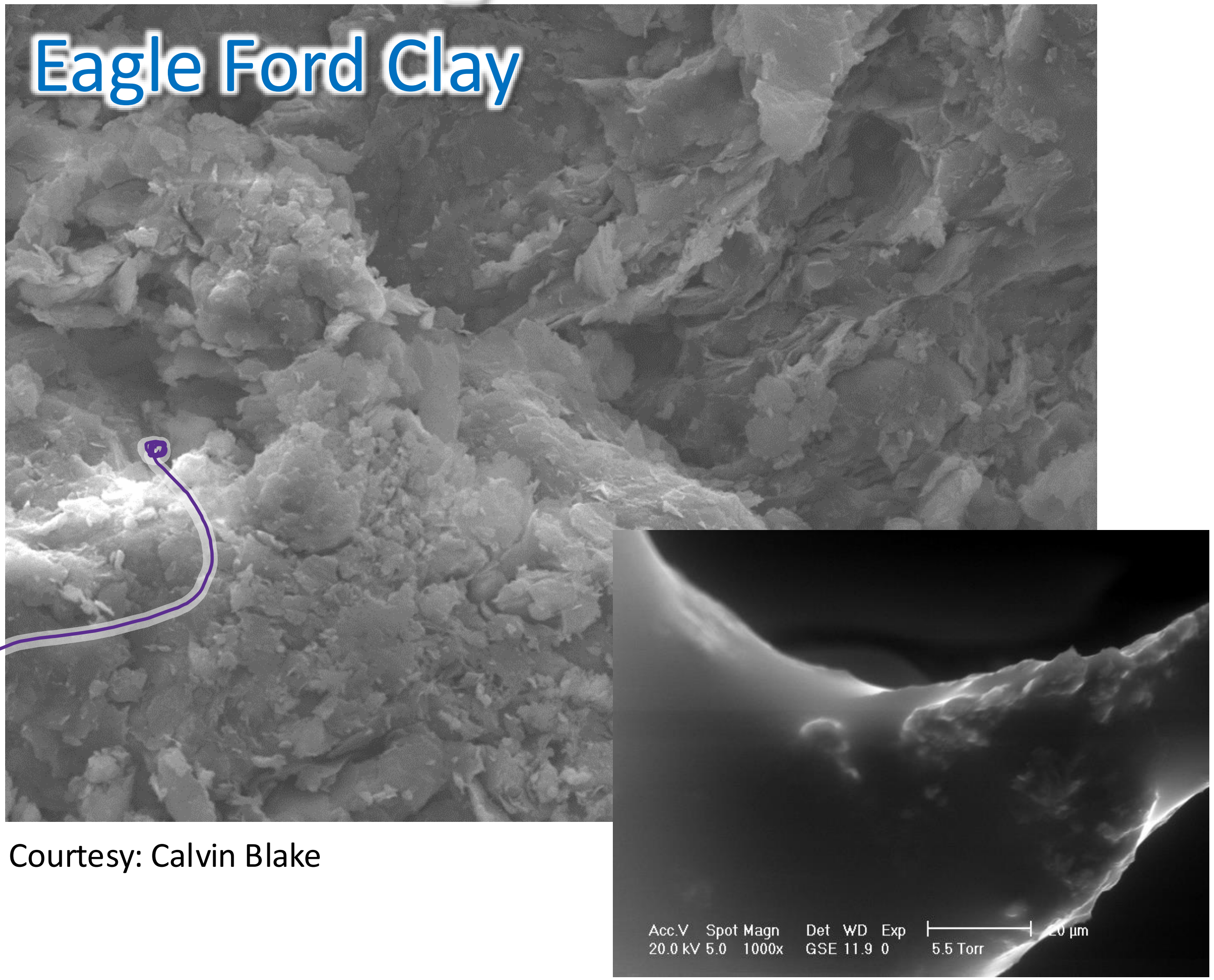
2023 Southern / Midwestern Drought and Heat Wave:

$14.5 billion

Source: NOAA National Centers for Environmental Information (2024)

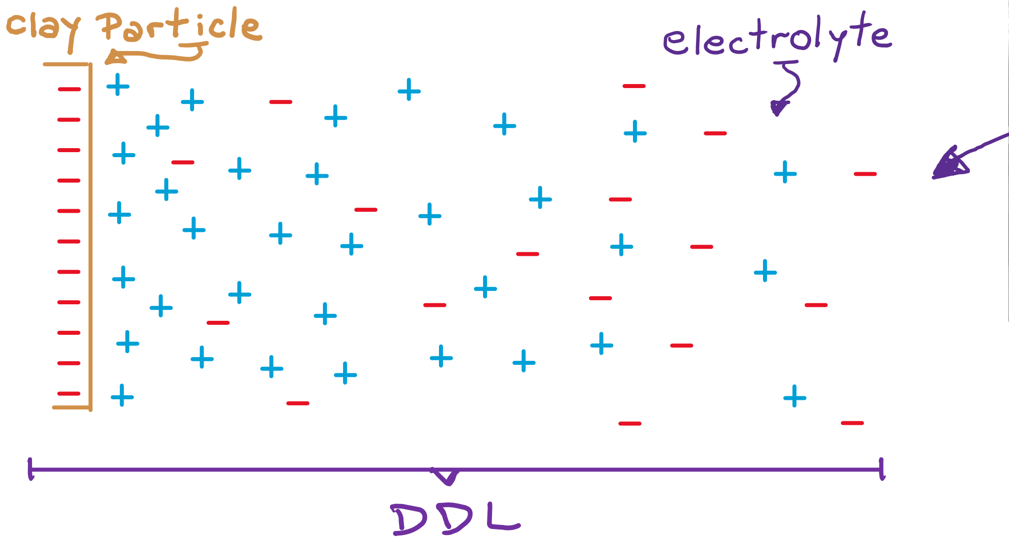
Characterizing the Problem: Sites on Expansive Clays

Characterizing the Problem: Sites on Expansive Clays

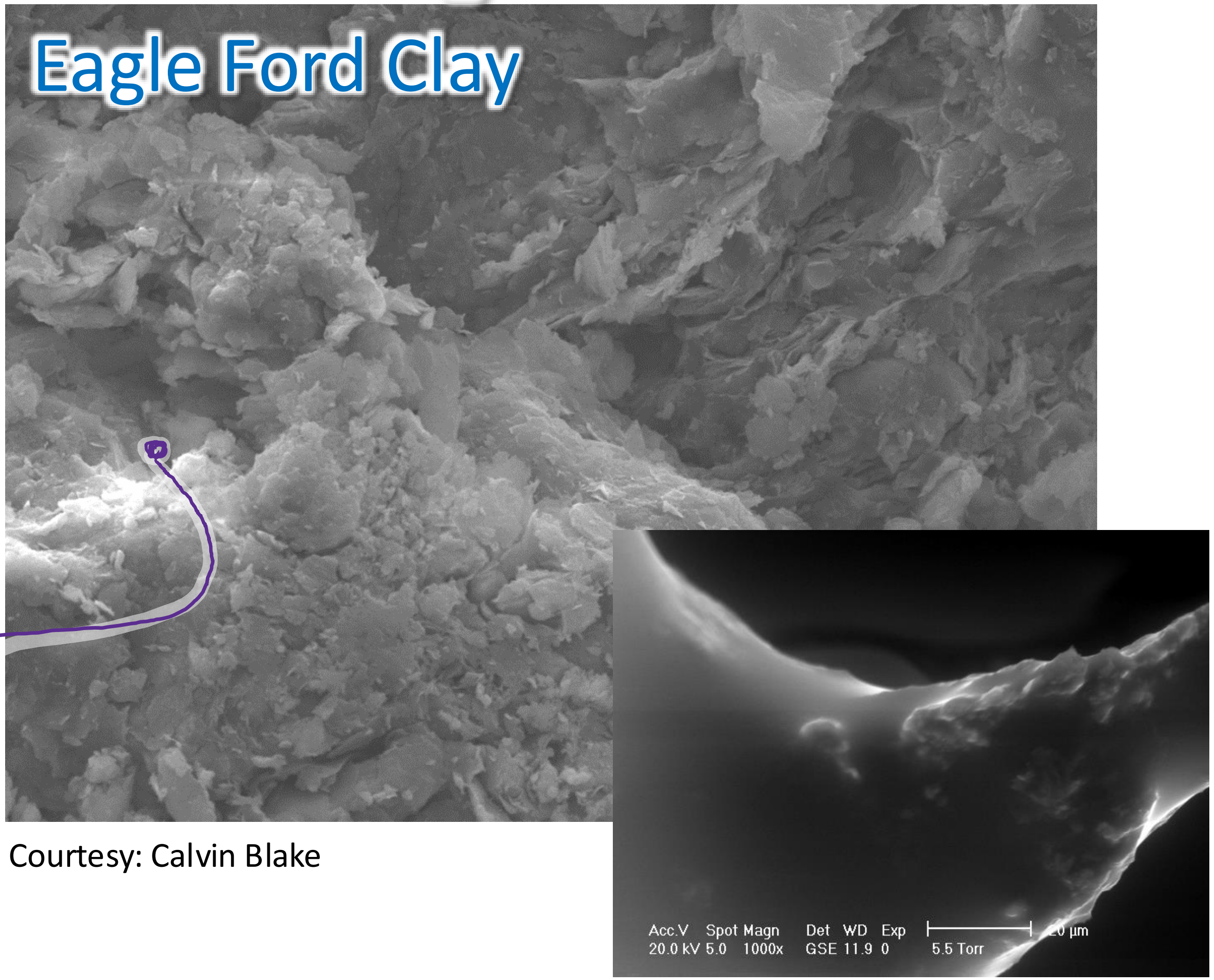


Courtesy: Calvin Blake

Courtesy: Chris Armstrong



Characterizing the Problem: Sites on Expansive Clays



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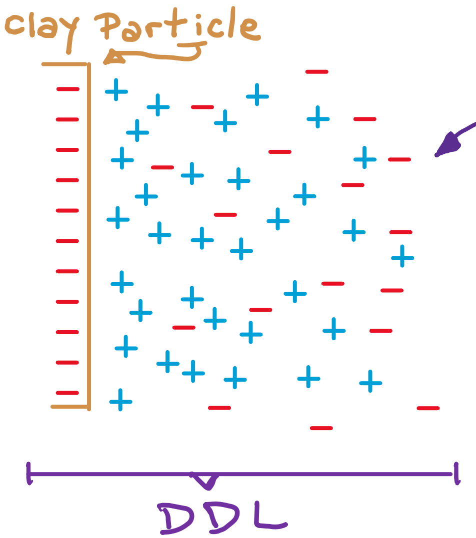
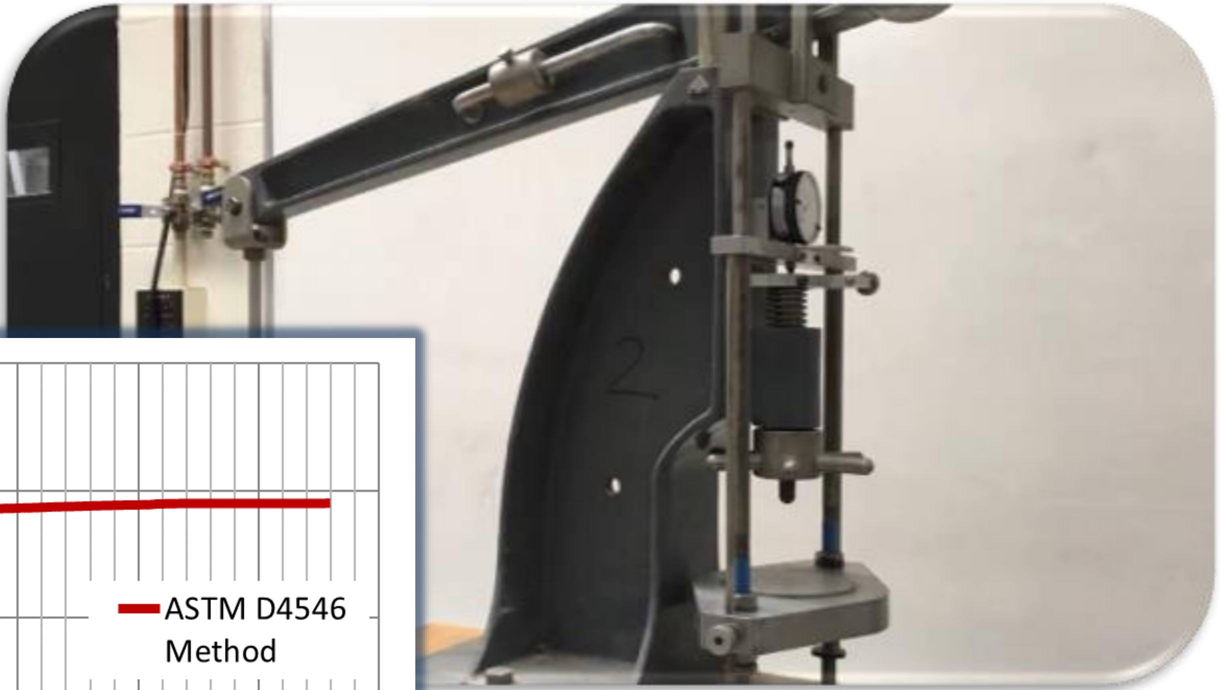
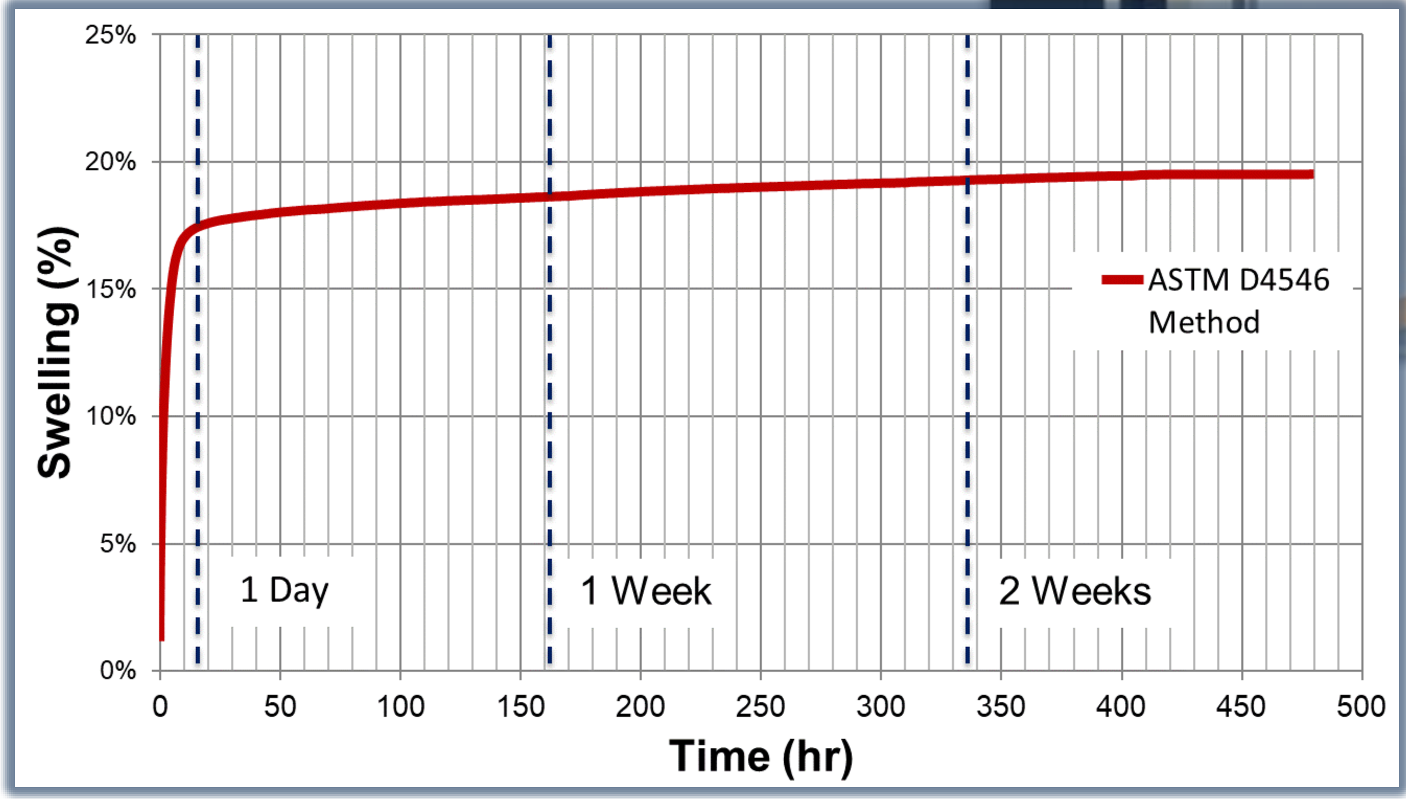


Soil Characterization: Conventional Swell Tests

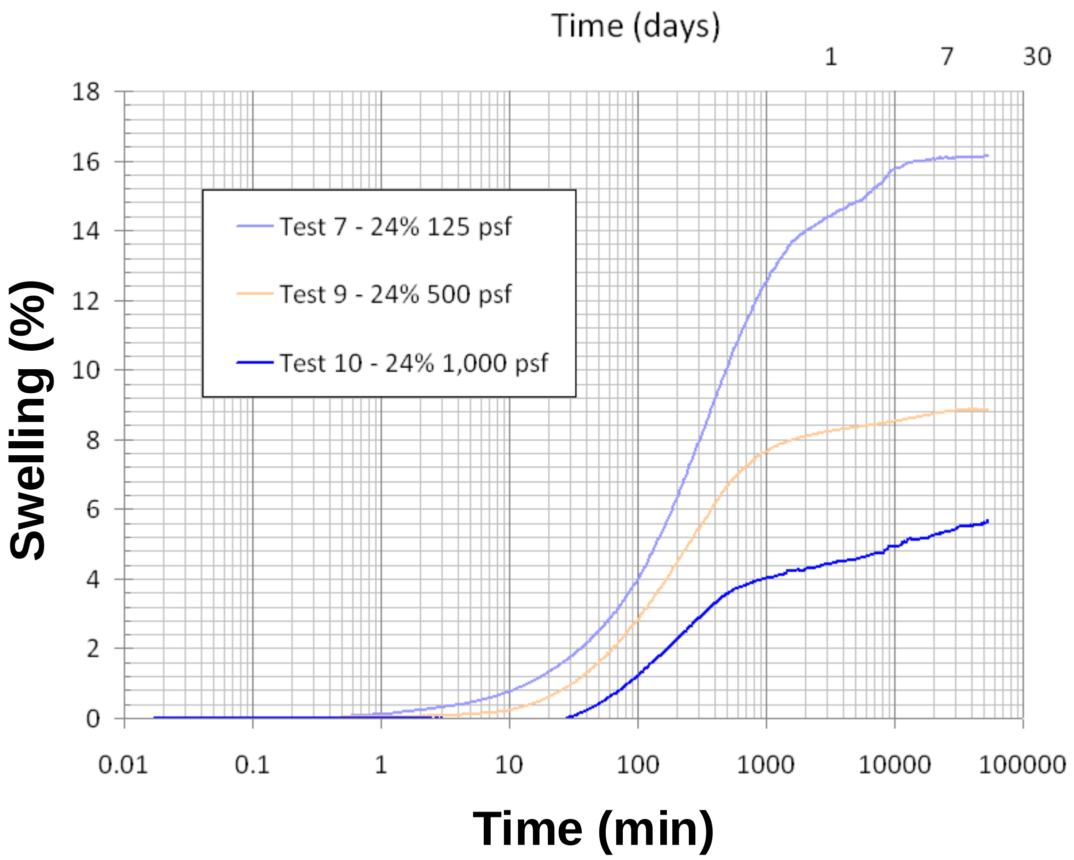
- ASTM D4546: Standard Test Method for One-dimensional Swell or Collapse of Soils
- Conducted using consolidation frames

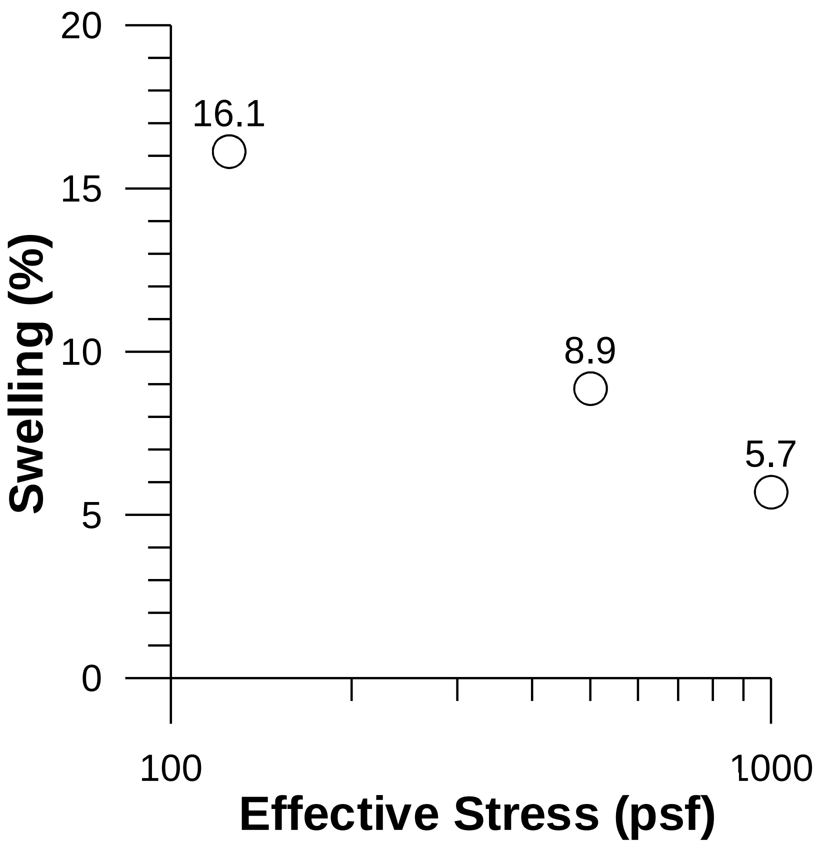




Soil Characterization: Conventional Swell Tests

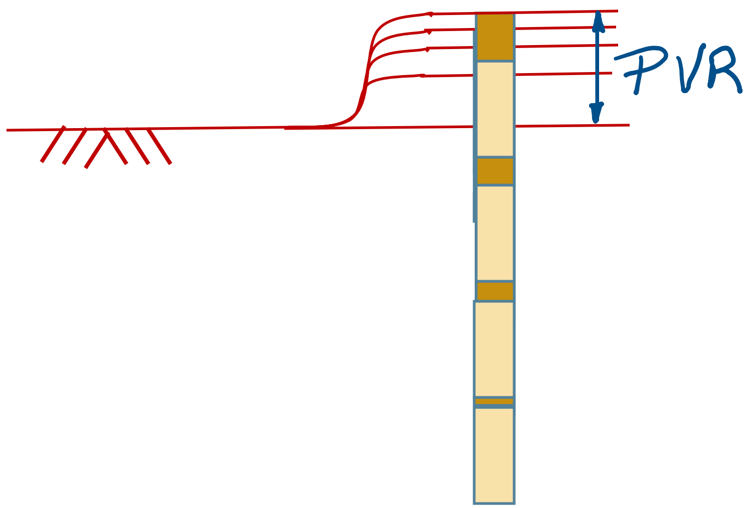
Impact of overburden pressure:

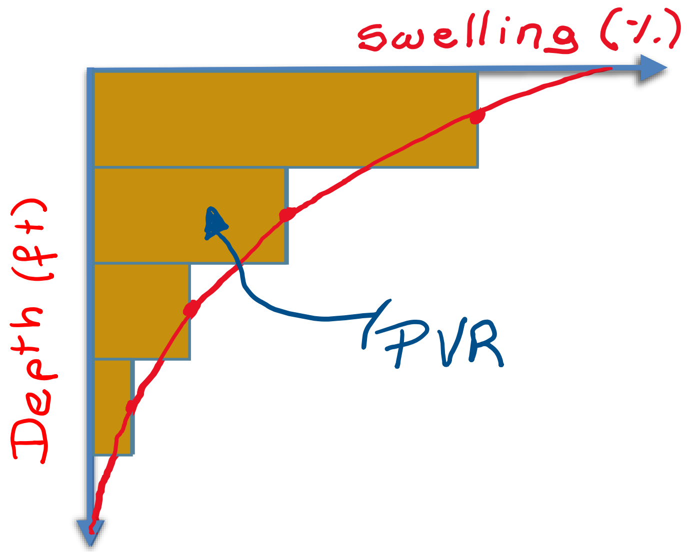




Source: Zornberg et al. (2017)

Site Characterization:
Potential Vertical Rise (PVR)

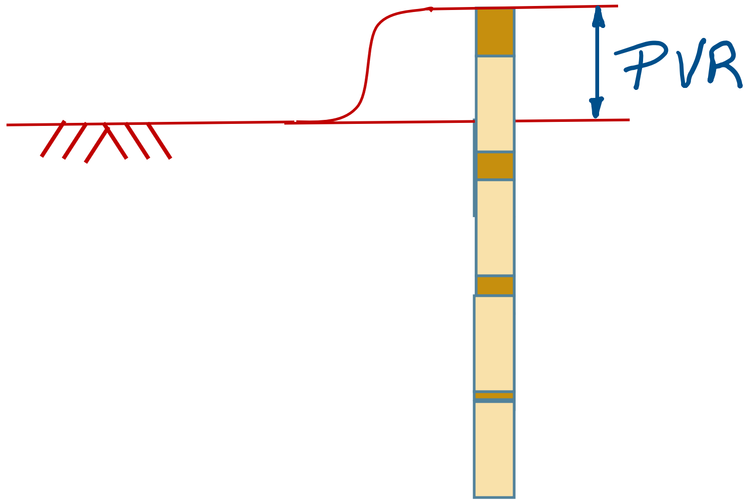


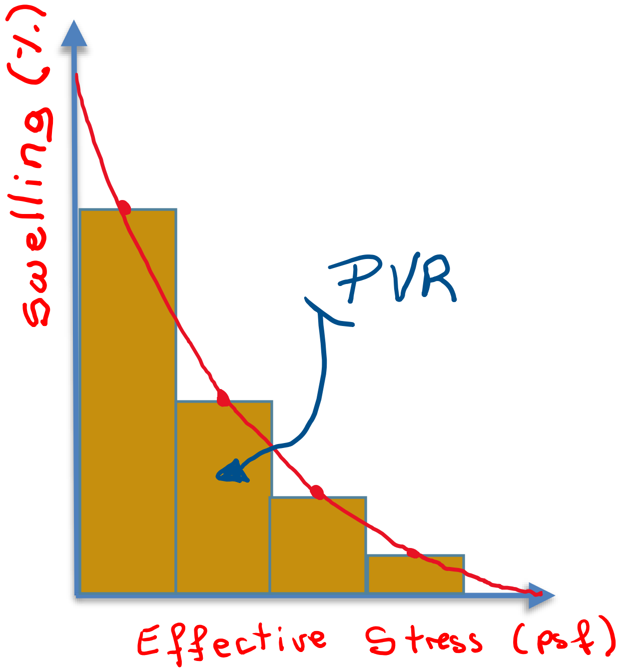


Relevant Site Information:

- Soil characteristics
- Stratigraphy
- Initial moisture content
- Confining stresses

Site Characterization: Potential Vertical Rise (PVR)





Relevant Site Information:

- Soil characteristics
- Stratigraphy
- Initial moisture content
- Confining stresses

TxDOT Procedure Tex-124-E

(Also: AASHTO T258-81)

TxDOT PDM:

Chapter 3, Section 2

Tex-124-E, "Determining **Potential Vertical Rise**," is the recommended procedure for determining PVR. A 15-foot soil column is recommended for the analysis to determine PVR. The least amount of **PVR for design is 1.5 inches** for main lanes (2.0 inches for frontage roads, when allowed), or as established by the district SOP identifying the requirements.

TxDOT Tex-124-E (Also: AASHTO T258-81)

Pluses:

- Good practical implications:
  - Outcome (i.e., PVR) easy to grasp by designers
  - Outcome can be related to performance
- Accounts for the relevant variables:
  - Soil characteristics
  - Stratigraphy
  - Initial moisture content
  - Confining stresses

Minuses:

- Too many correlations:
  - To determine the volumetric change under 1 psi **from the soil's PI**
  - To define the free swell from the volumetric change under 1 psi
  - To obtain the linear swell from the free swell
  - To obtain linear swell for applied confinement
  - To correct for unit weight
  - To correct for % binder
- Problematic experimental data:
  - Too little
  - Too old
  - Correlations extrapolated beyond available data

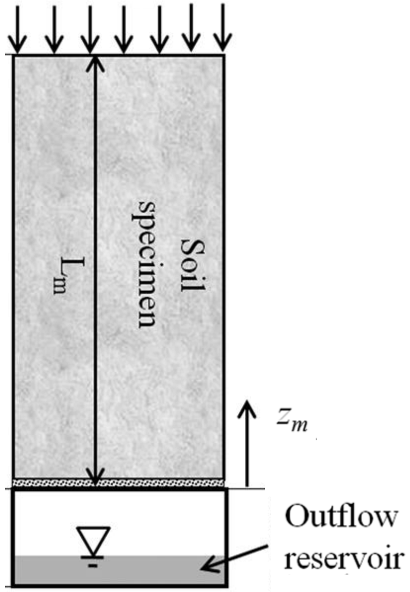
Unsaturated Flow in a Centrifuge

1D Flow:

$$h = z + \psi$$

$$\frac{\partial h}{\partial z} = 1 + \frac{\partial \psi}{\partial z}$$

$$v_z = -k(\psi)\left(1 + \frac{\partial \psi}{\partial z}\right)$$



1D Flow in a centrifuge:

Unsaturated Flow in a Centrifuge

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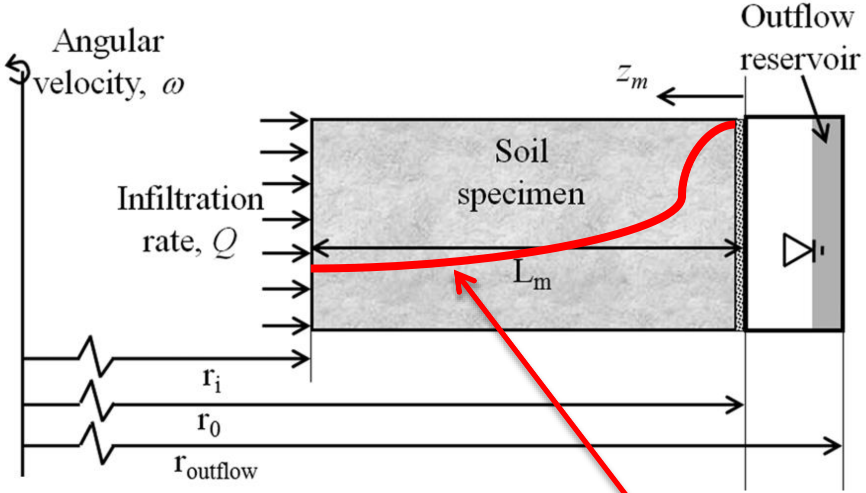
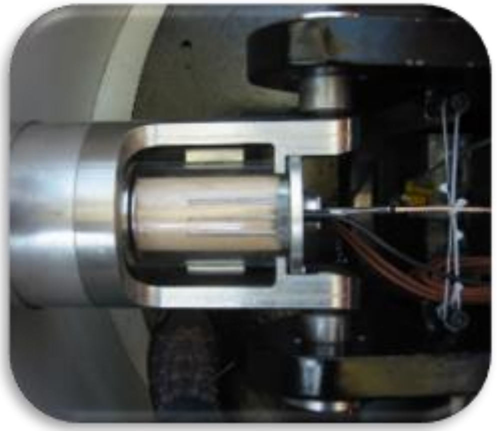


1D Flow in a centrifuge:

$$v_m = -k(\psi)\left(N_r + \frac{\partial \psi}{\partial z}\right)$$



Measured

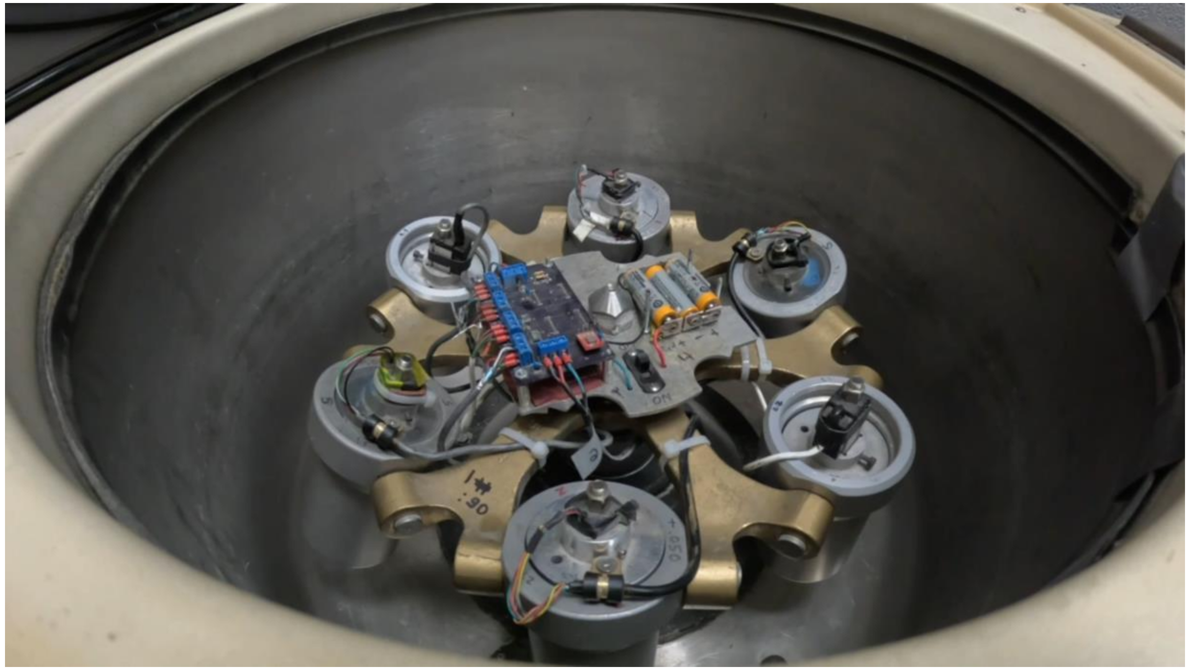
Imposed

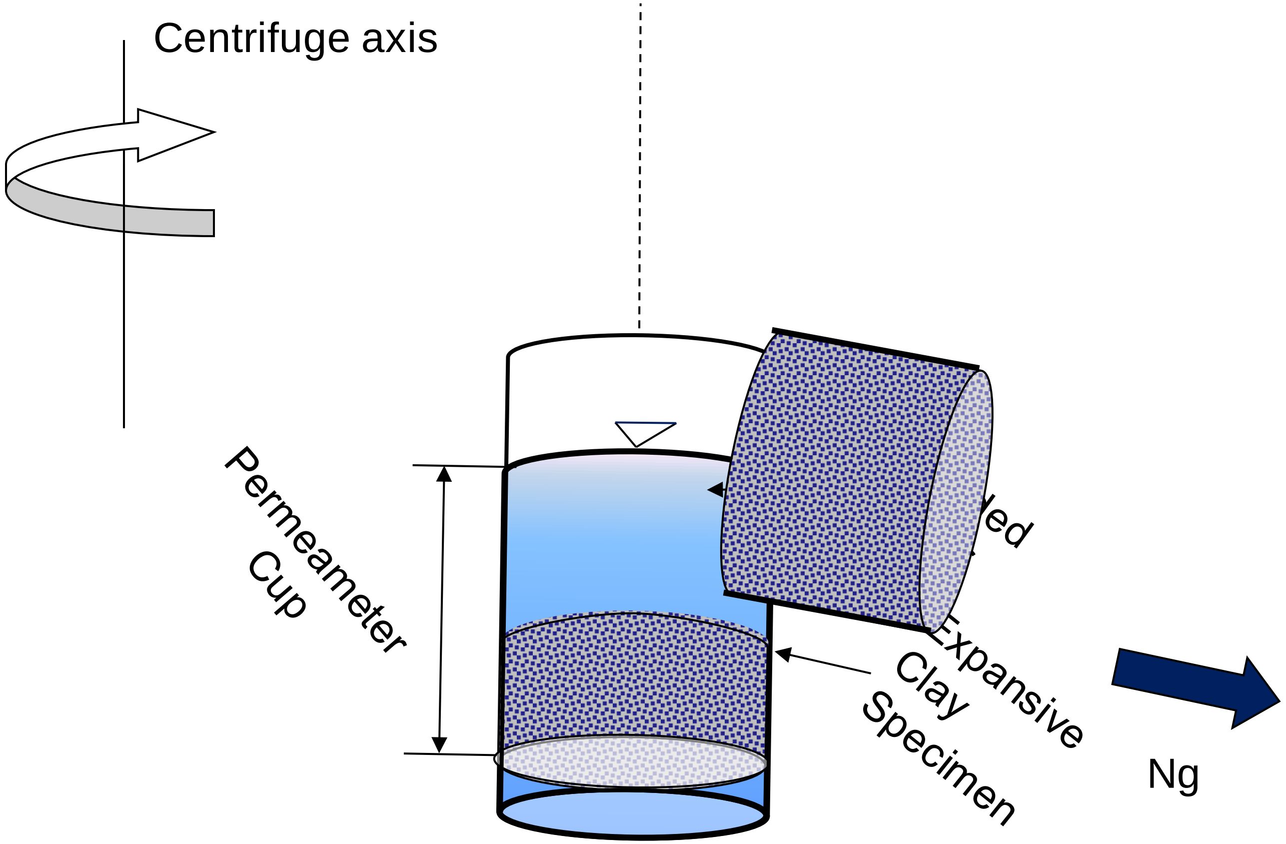
$$v_m = -k(\psi)\left[\frac{\omega^2}{g}(r_0 - z_m) + \frac{\partial \psi}{\partial z_m}\right]$$

Predicted

Zornberg and McCartney (2010)

Centrifuge for Direct Measurement of Swelling





Zornberg et al. (2017)

- Linear Position Sensors (LPS) used to measure changes in specimen height
- Accelerometer used to measure g-level
- JeeNode Arduino unit adopted to transmit data wirelessly to external storage unit

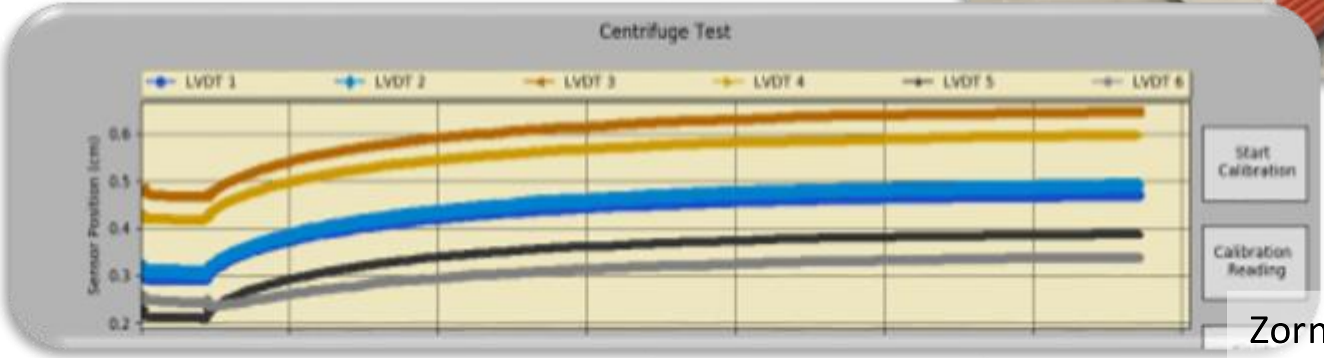
Centrifuge Testing for Direct Measurement of Swelling

Centrifuge Device:

- Floor mounted
- Low cost
- Can achieve very high G-levels
- In-flight data acquisition system

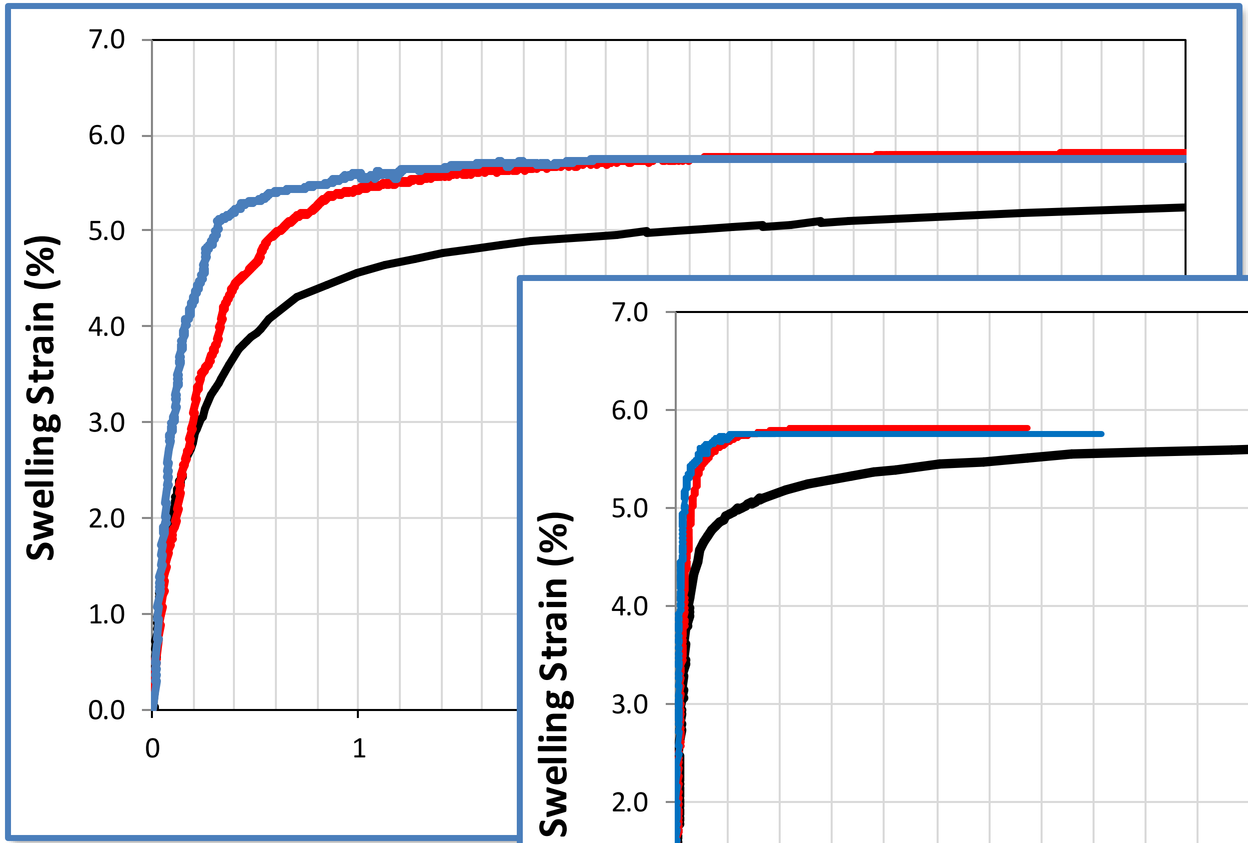
Measurements:

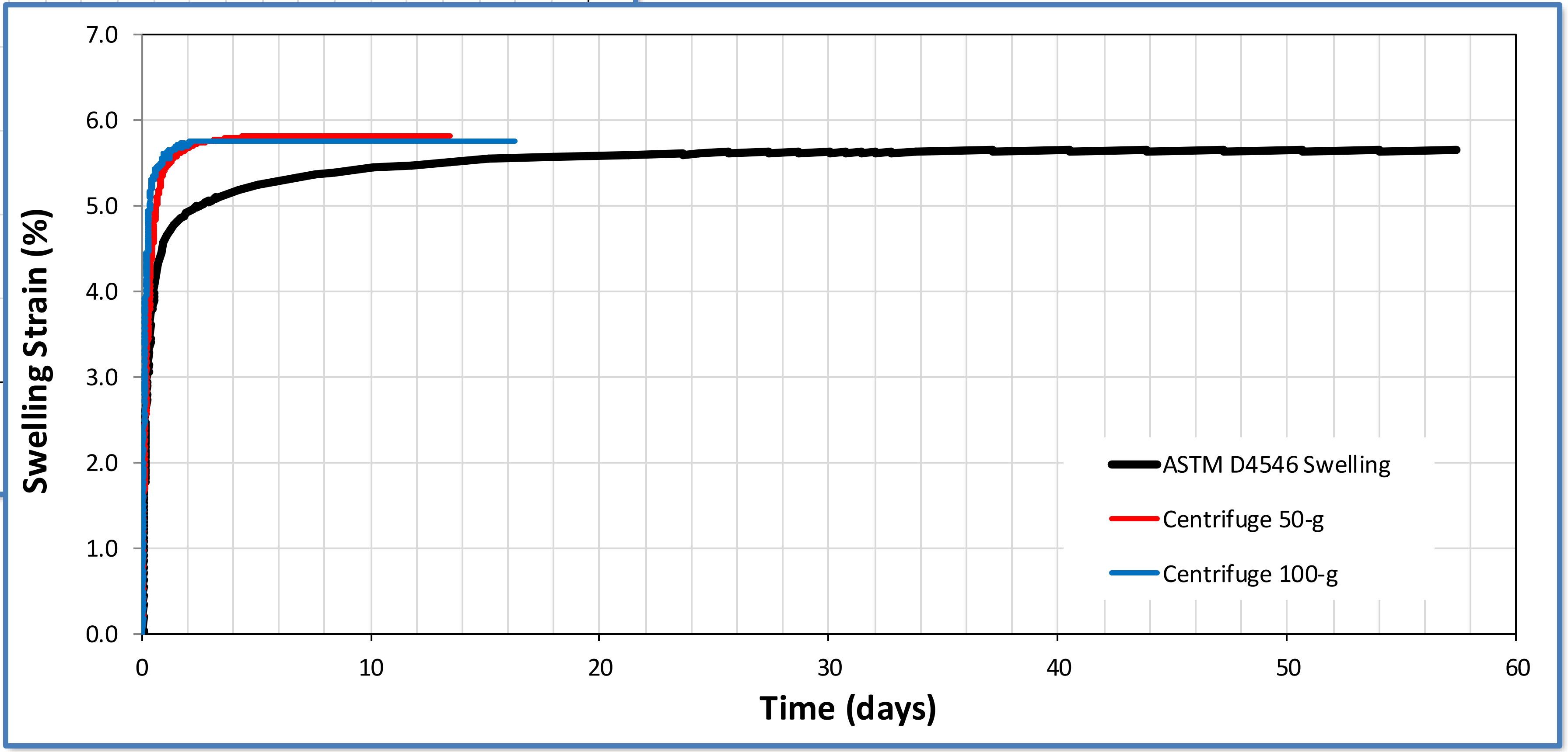
- Six simultaneous specimens tested
- Real-time, in-flight measurements:
  - Vertical displacements
  - G-level



Zornberg et al. (2017)

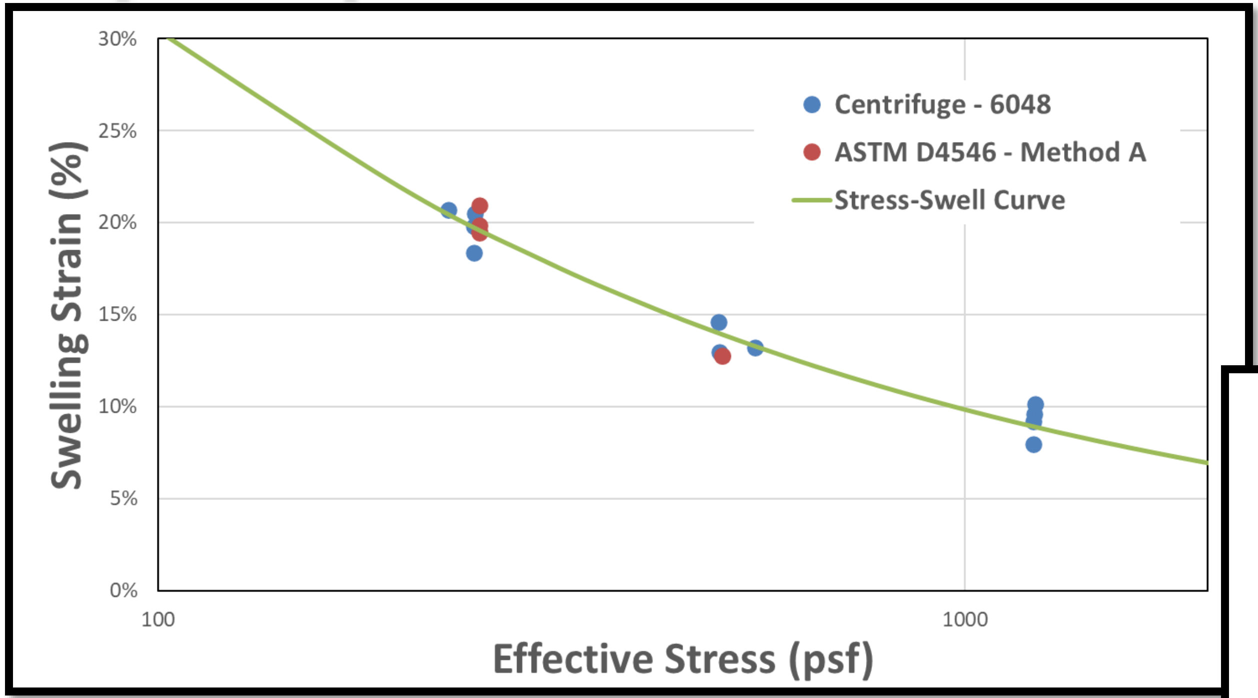
Typical Swell Test Results



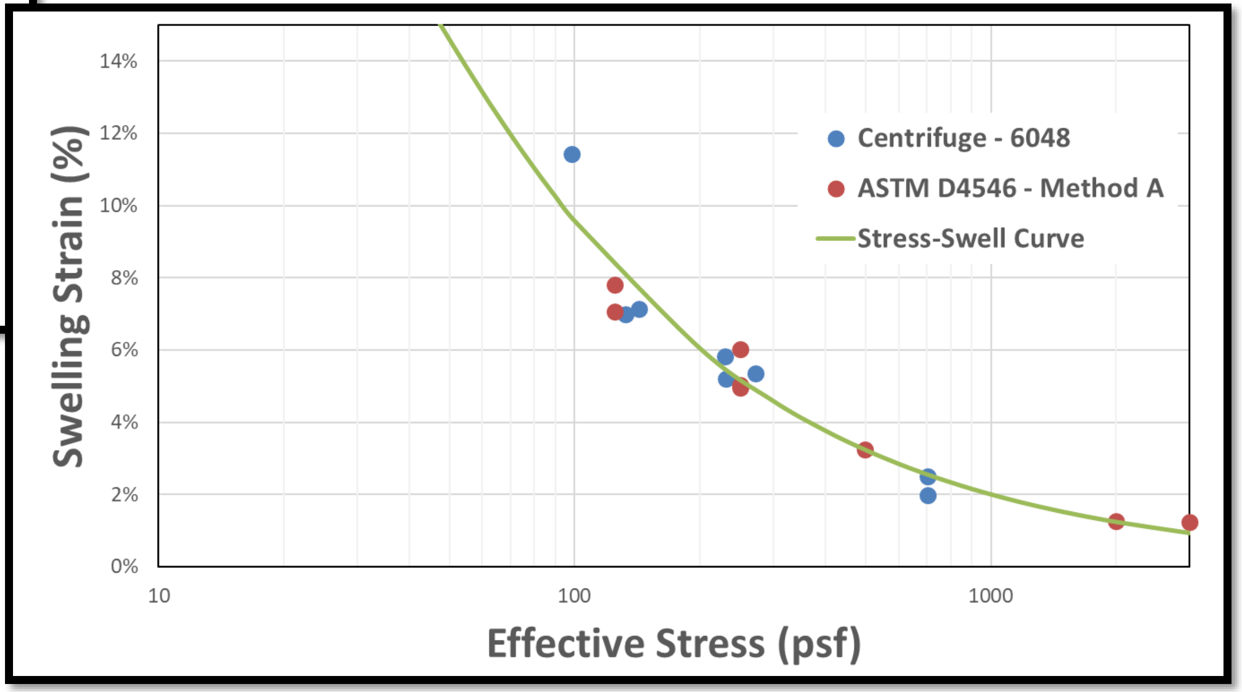


Comparison of Swell-stress Curves

Eagle Ford Clay:



Cook Mountain Clay:

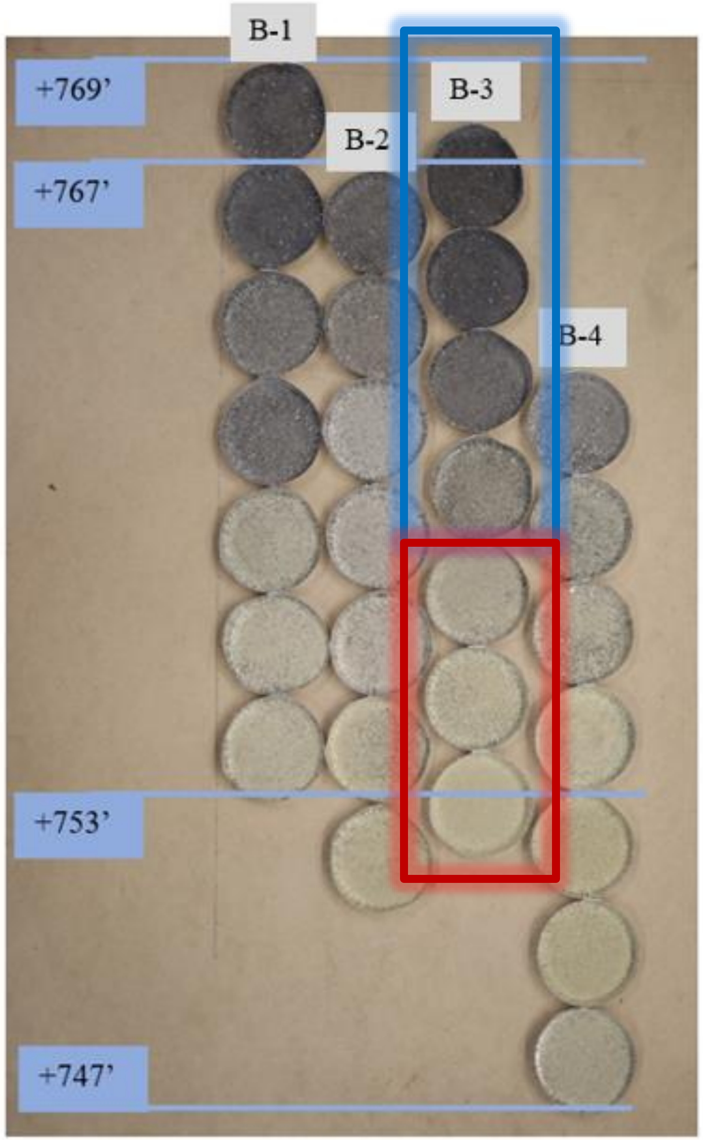


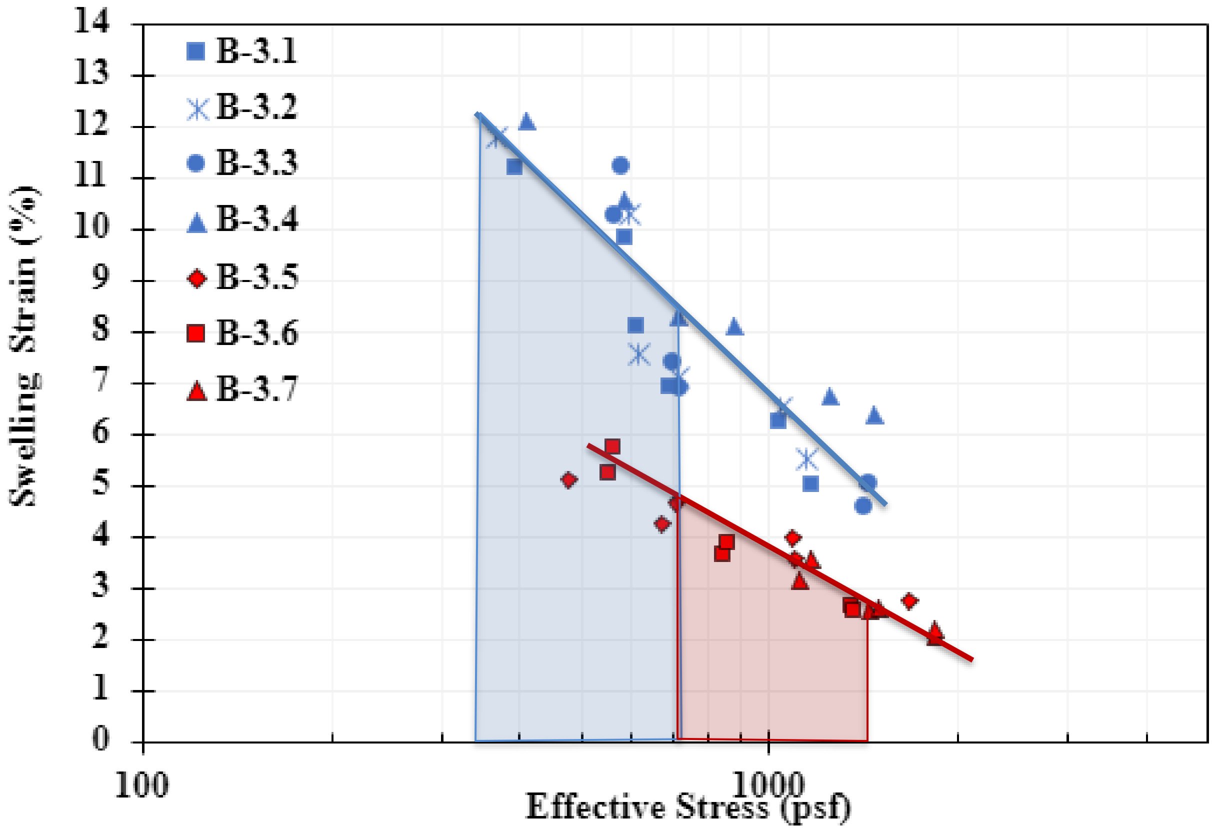
Zornberg et al. (2017)

Benefits of the Centrifuge Testing Approach

- Expeditious
- Highly repeatable test results
- Generates swell data from multiple soil specimens in a single spin
- Requires comparatively small laboratory space
- Provides direct measurement of swelling:
  - No need for correlations with index properties
  - Generates soil-specific, project-specific data
- Results can be readily used for the prediction of PVR

How is the PVR Calculated?

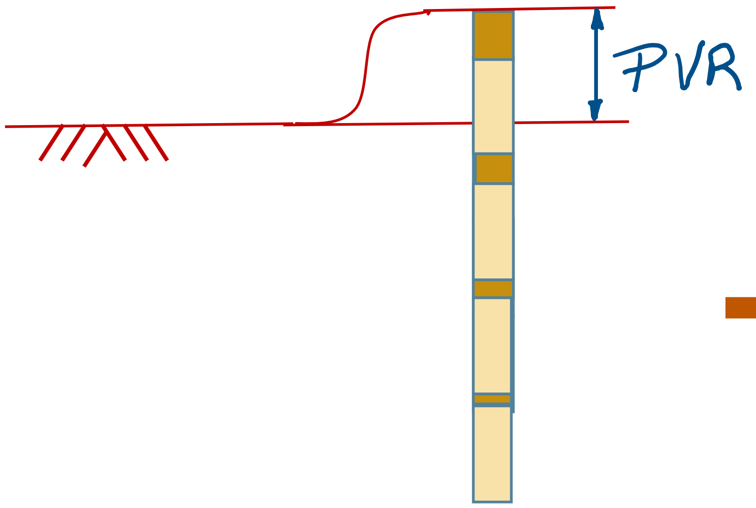




Integration of the strains over the relevant depths (i.e., the area under the swell-stress curve) corresponds to the PVR at the boring location.

Roadway Design for Environmental Loads

Mechanistic ↔ Empirical



Response

Damage Accumulation

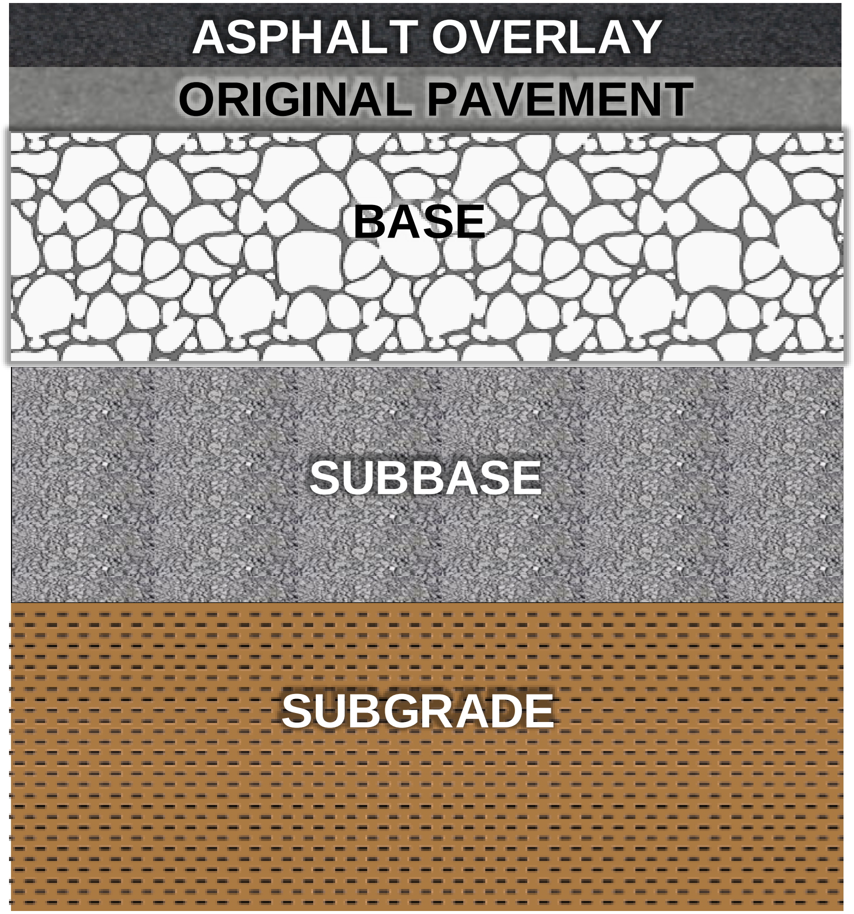
Transfer Function

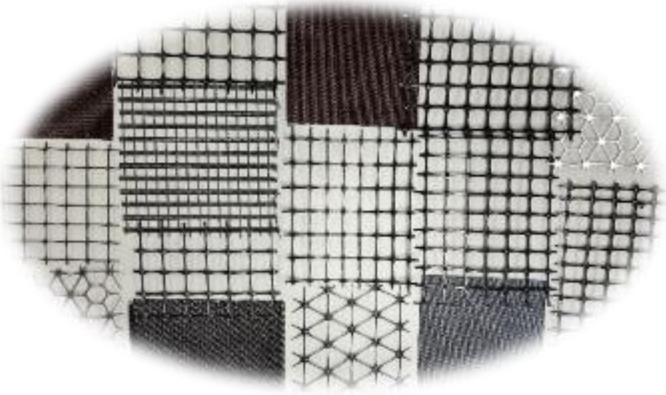
Distress

Observational Approach!

An Innovative Solution: Geosynthetic Stabilization

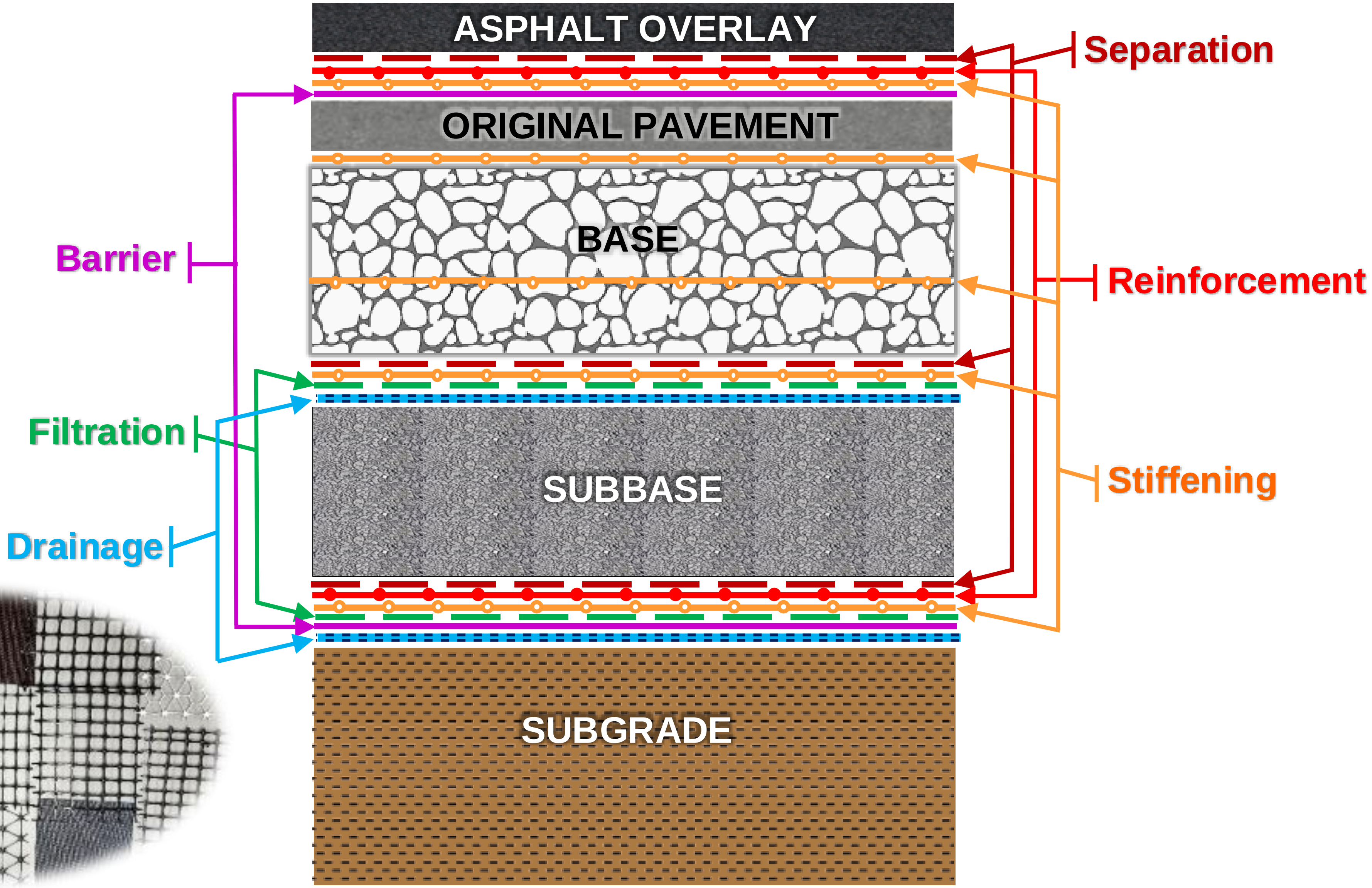
Geosynthetics in Roadway Applications

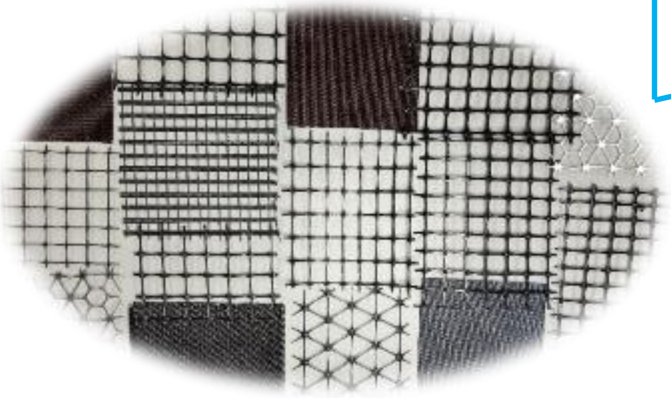




Zornberg (2017)

Geosynthetics in Roadway Applications





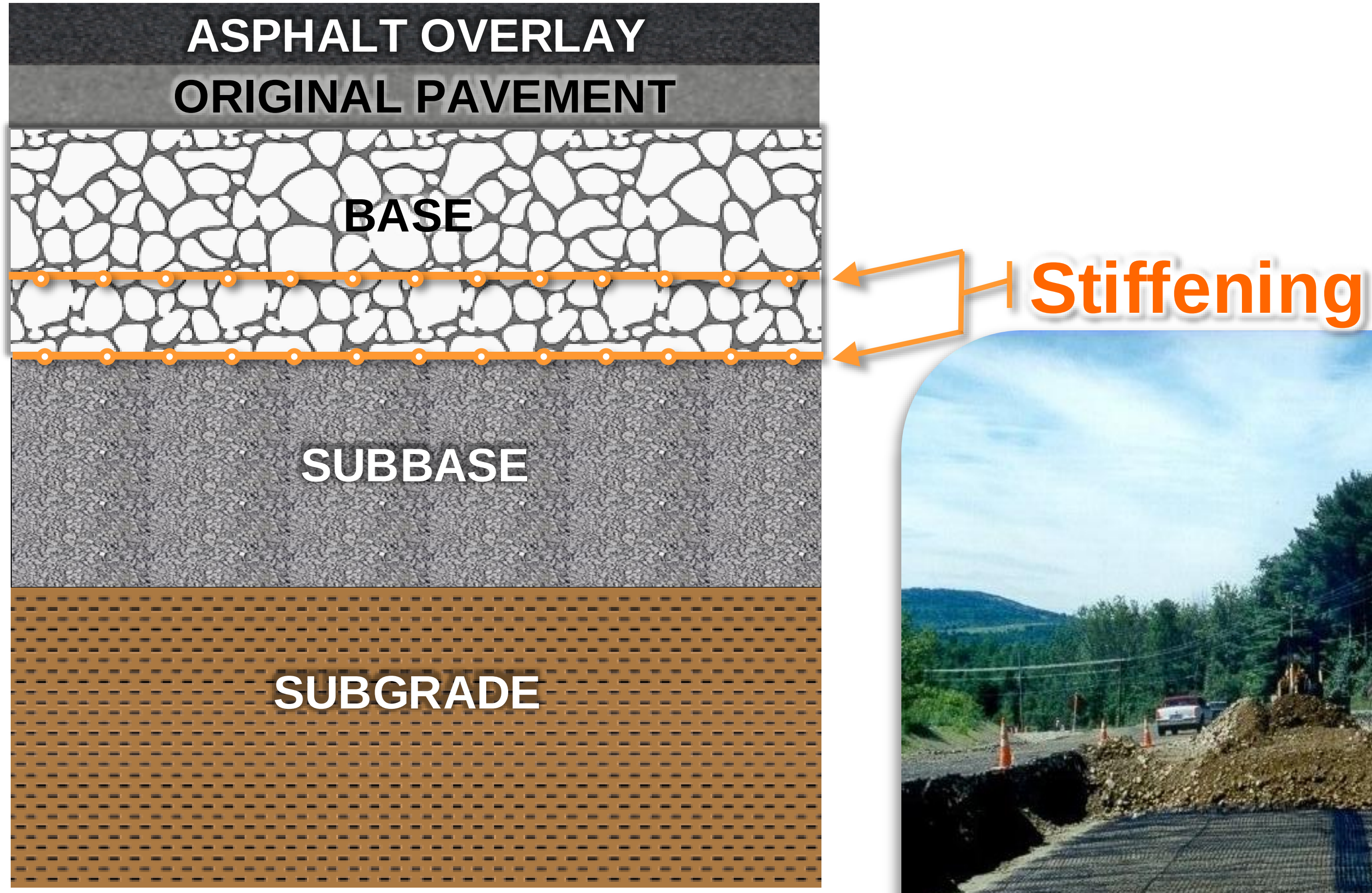
Zornberg (2017)

Mitigation of Distress Induced by Expansive Clays: Mechanisms

Different **strategies** tap into different **mechanisms**:

- Maintain the **integrity of the unbound aggregate layer** to minimize stress concentration:
  - By providing lateral restraint and increasing the ductility of unbound aggregate layers
- Control **moisture distribution** on top of subgrade:
  - Aim at minimizing differential settlements across the with of the roadway
- Maintain the integrity of the **asphaltic layer**
  - Aim distributing strains to minimize stress concentration
- Minimize **moisture access** to subgrade soils
  - Aim to avoid moisture fluctuations within the subgrade

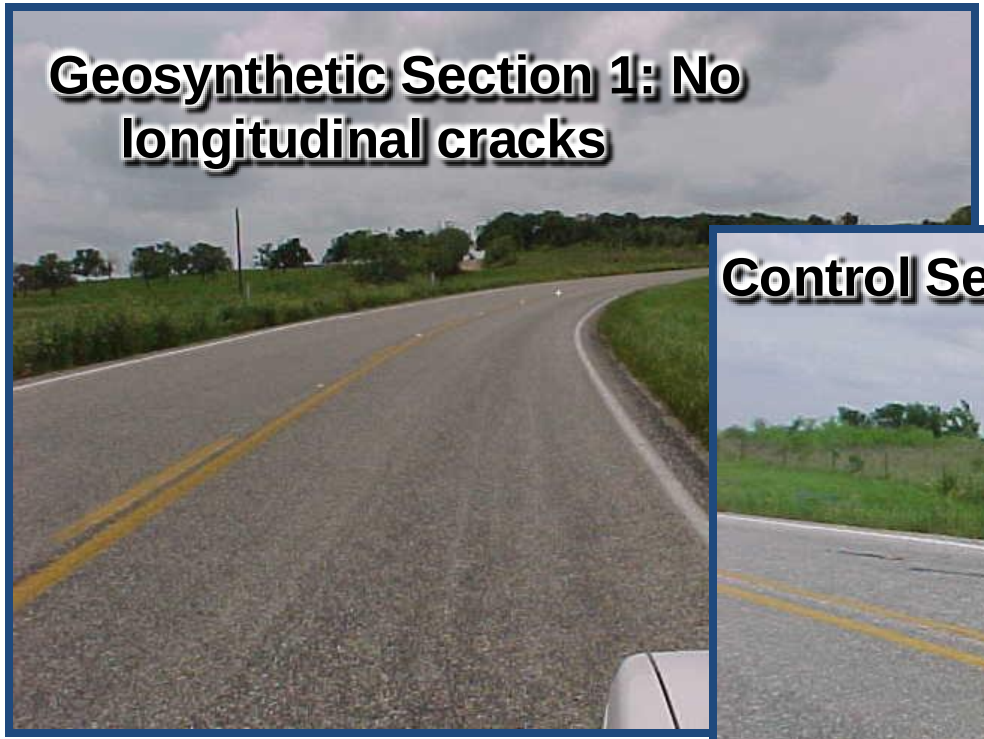
Mitigation of Distress Induced by Expansive Clays (by Maintaining Integrity of Unbound Aggregates): GS Functions



Source: Zornberg (2017b)

Do Geosynthetics Help?

FM 1915 (Milam County)



Lesson: Geosynthetic prevented the development of longitudinal cracks

Zornberg and Roodi (2021)

To Be or Not to Be?

SH7 (Bryan District)

Geosynthetic Section: Longitudinal cracks soon after construction

No Geosynthetic!

What are they laughing at?

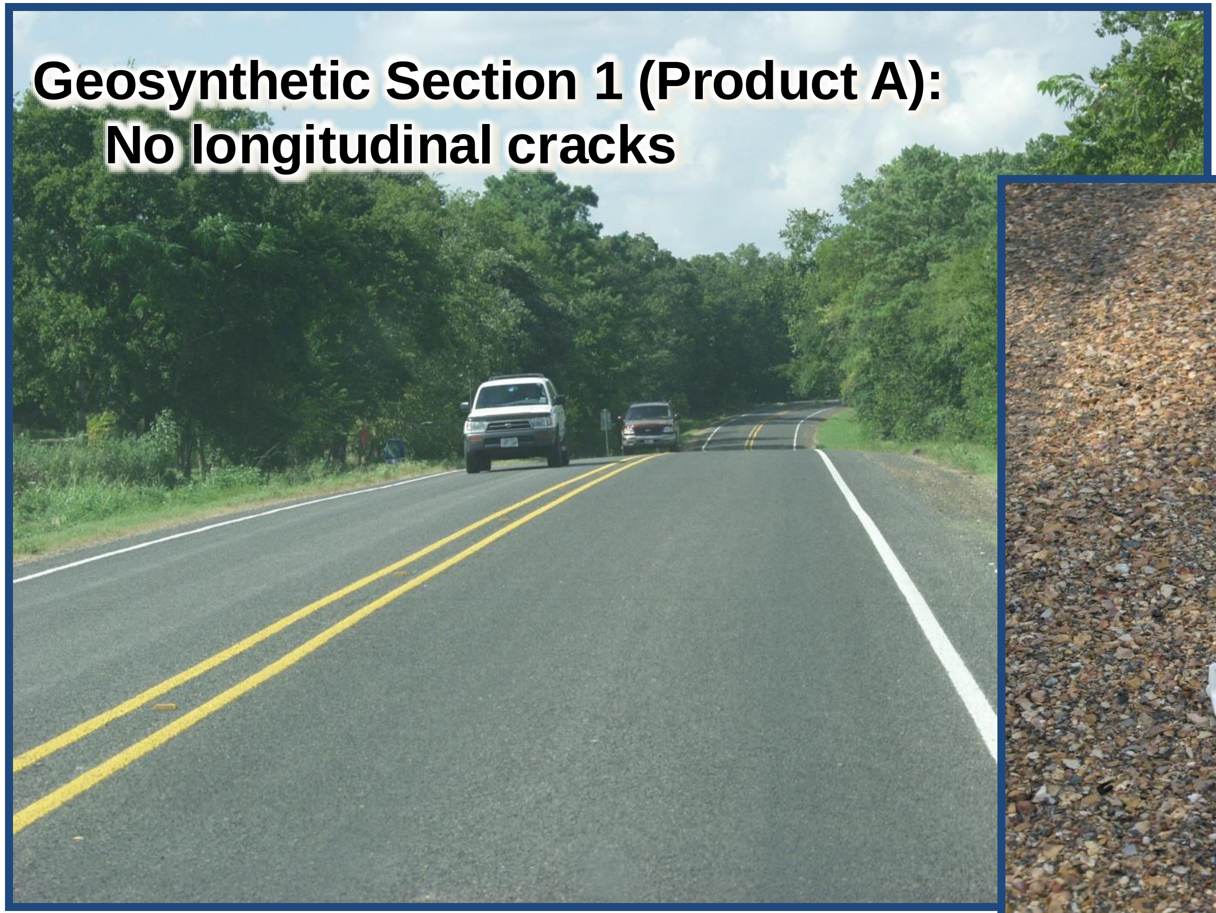
Geosynthetic is there, but 1.2 m short…

Lesson: Geogrids appear to work … if in place.

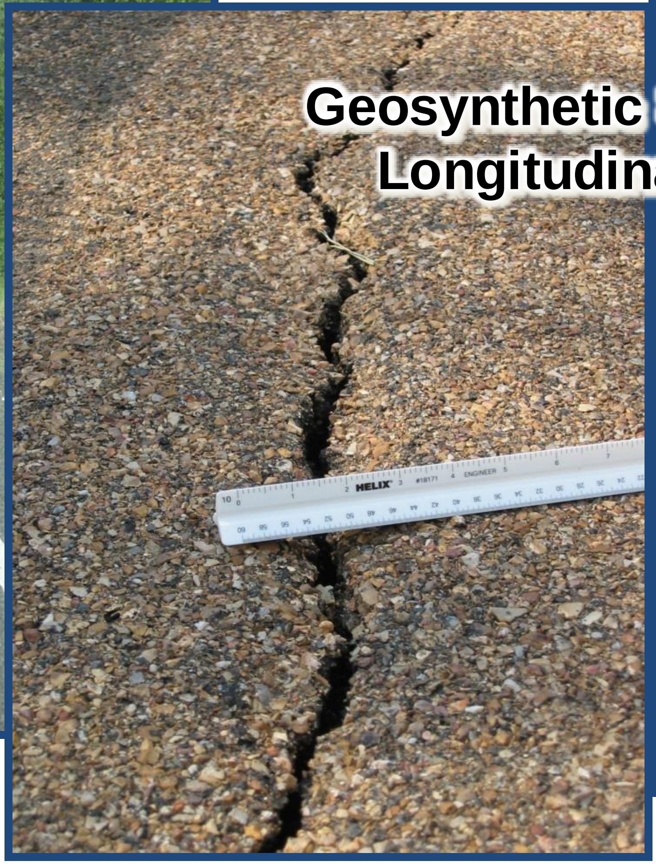
To Spec or not to Spec?

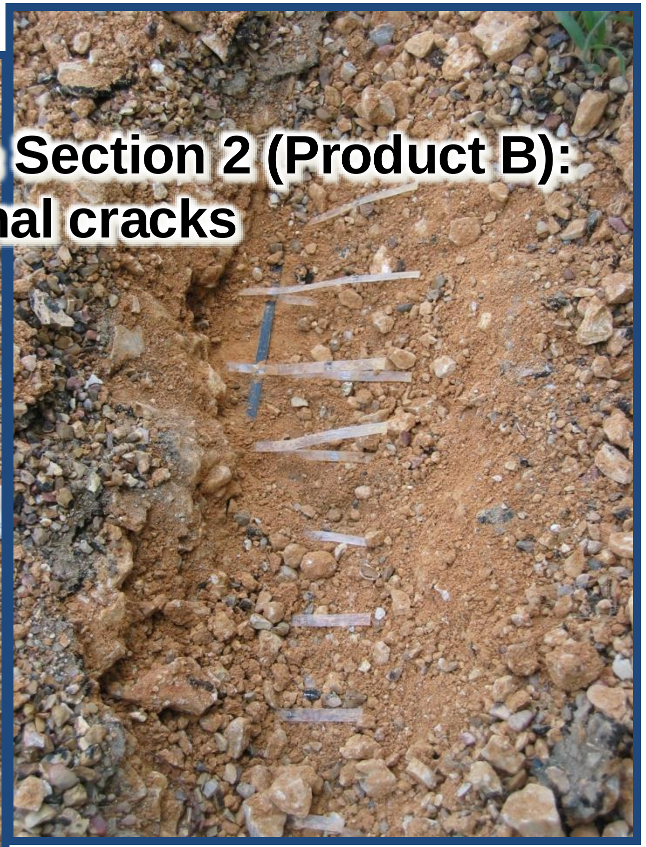
FM 1774 (Grimes County)

Geosynthetic Section 1 (Product A):
No longitudinal cracks



Geosynthetic Section 2 (Product B):
Longitudinal cracks



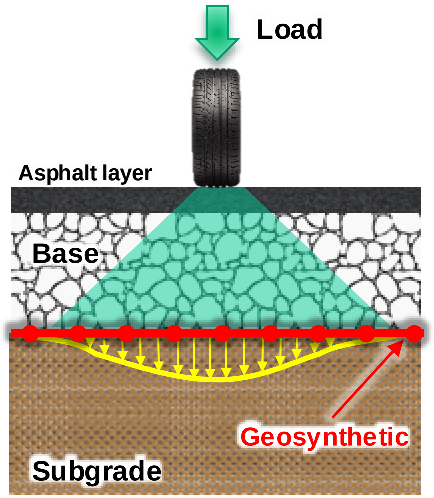


Lesson: Geosynthetic specifications available at the time had not led to consistent performance

Zornberg and Roodi (2021)

A Different Geosynthetic Application…

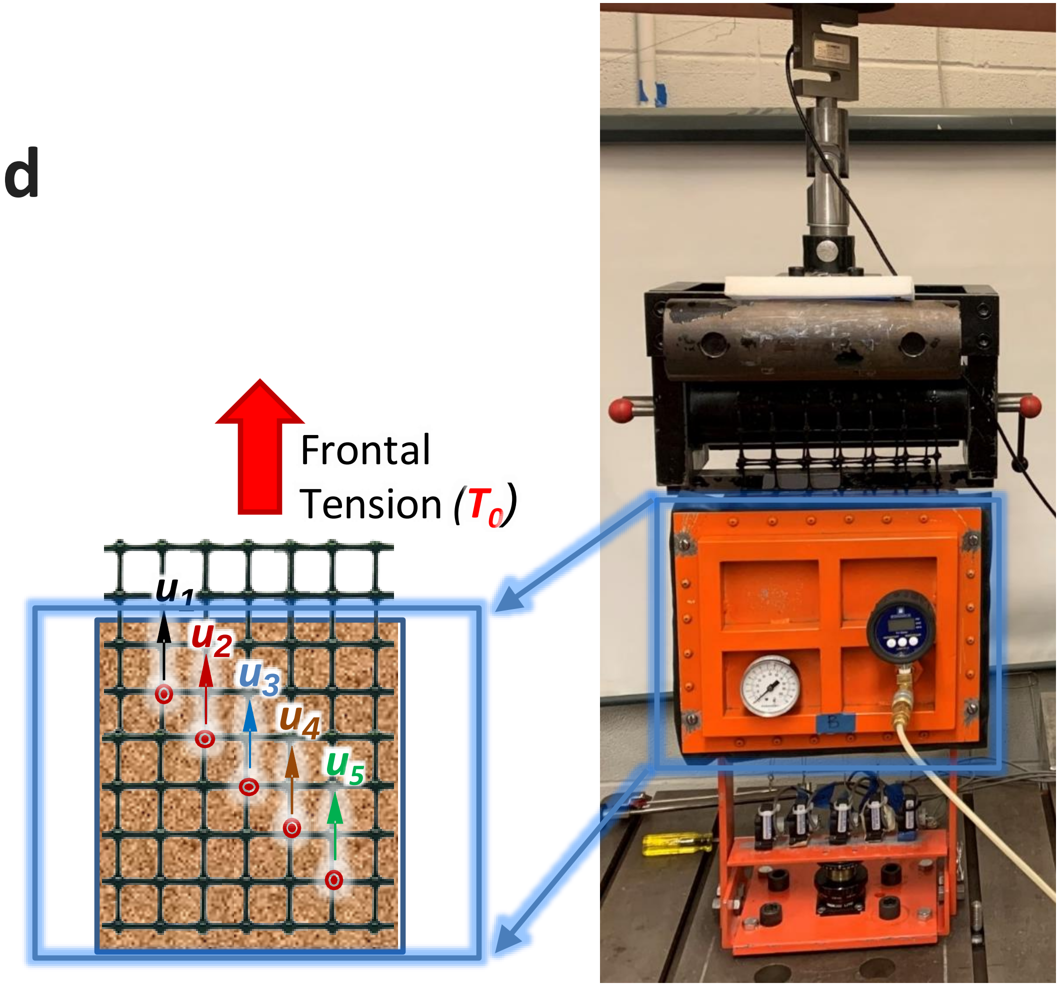
… which may be governed by the same relevant property



With geosynthetic stabilization

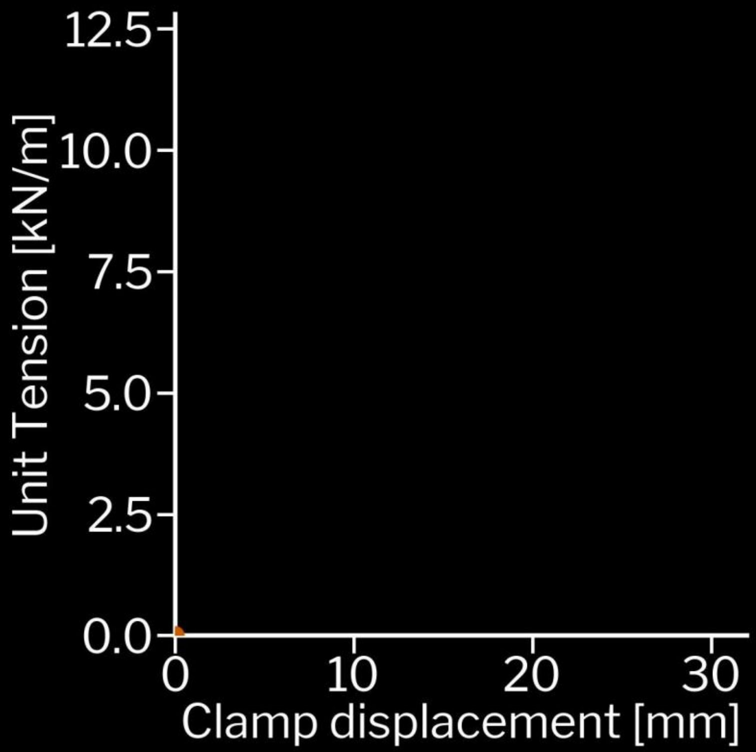
The Application:
Geosynthetic-stabilization of Unbound Aggregate Layers

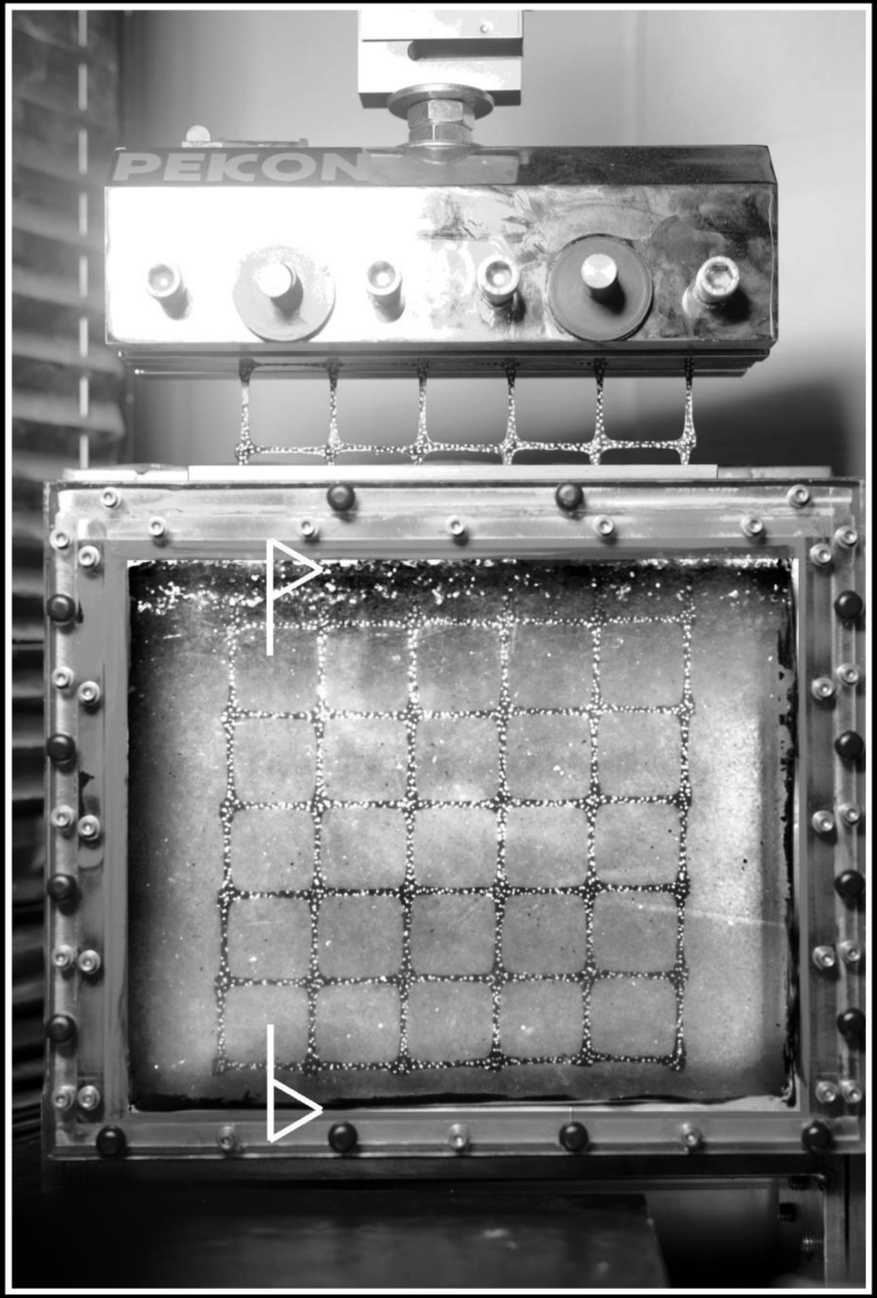
The Relevant Property:
Stiffness of the Soil-geosynthetic Composite (K_{SGC})

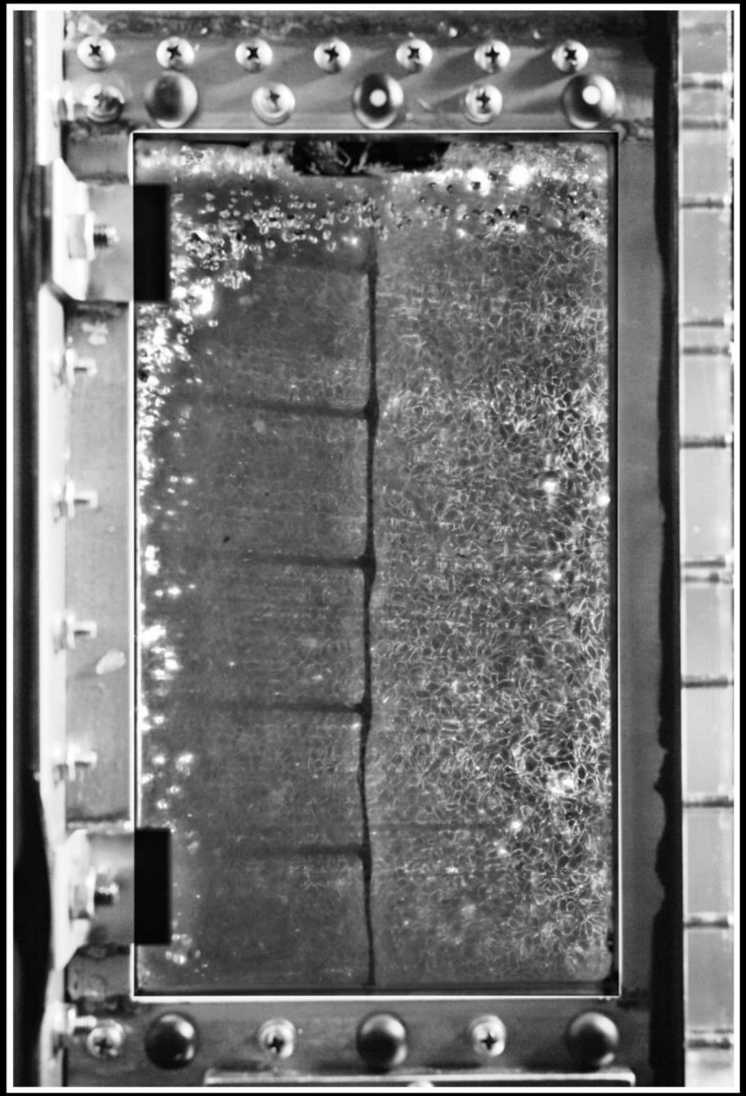


The University of Texas at Austin
Maseeh Department of
Civil, Architectural and
Environmental Engineering
Cockrell School of Engineering

David Marx & Jorge Zornberg (2024)







Section

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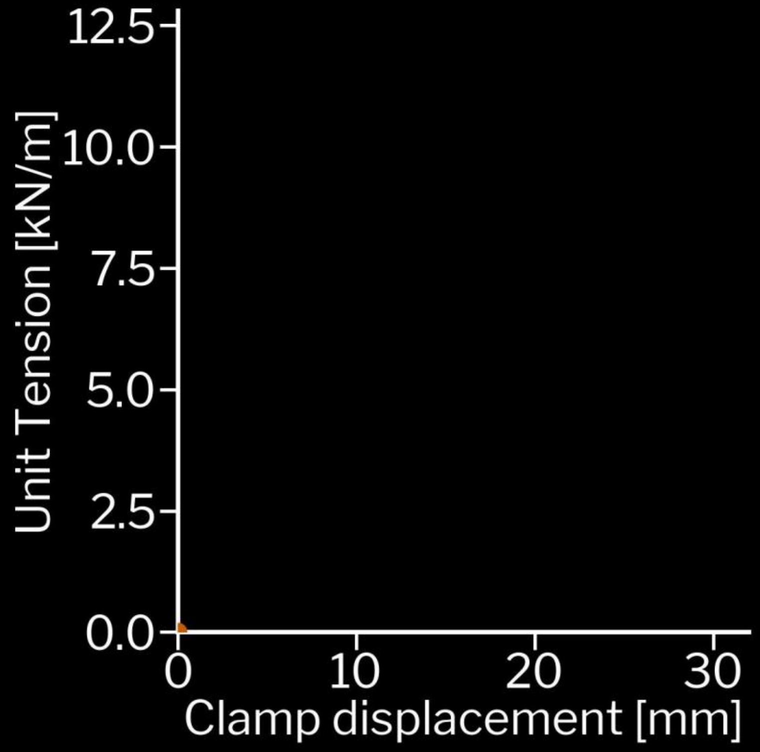
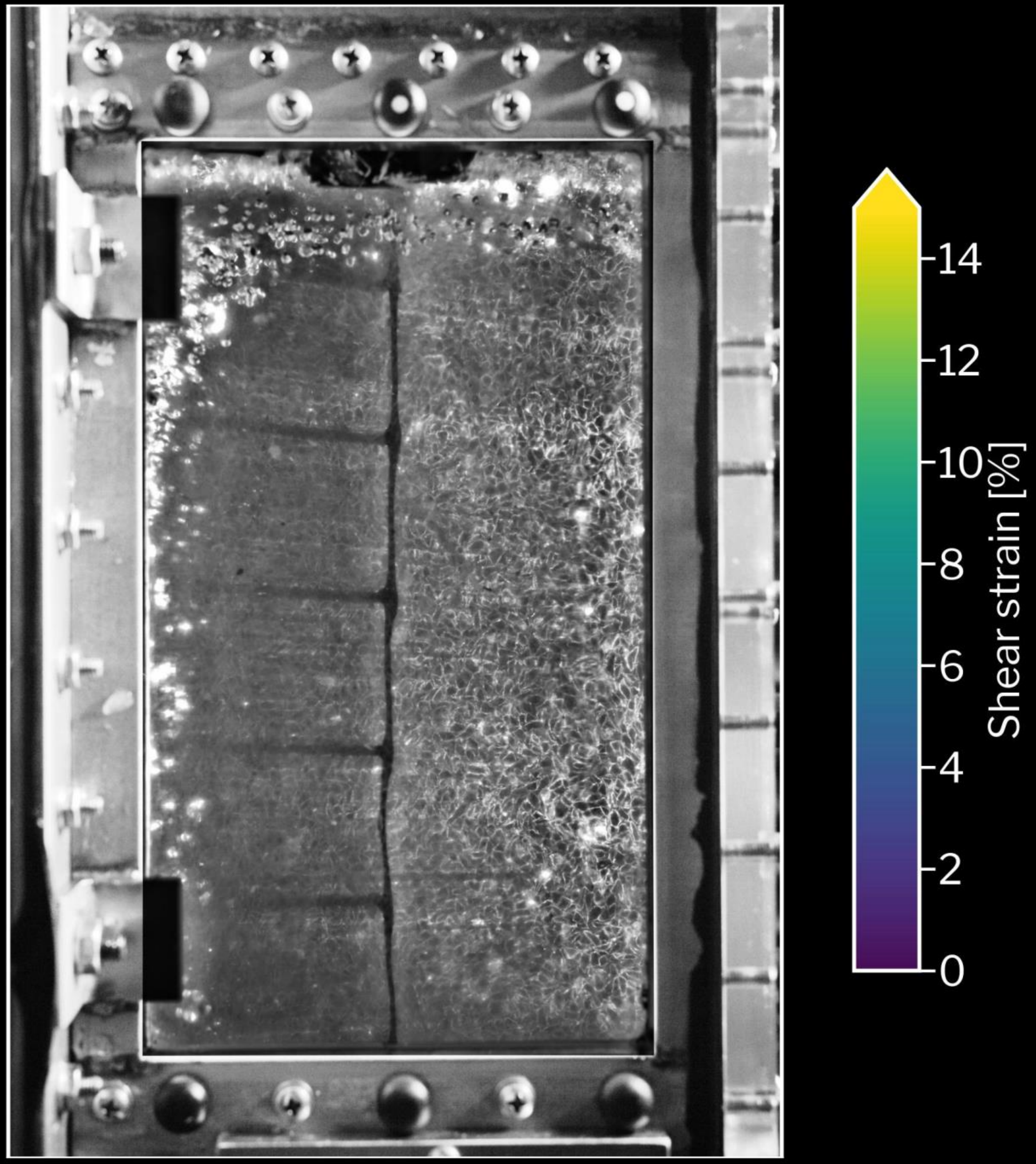
David Marx & Jorge Zornberg (2024)





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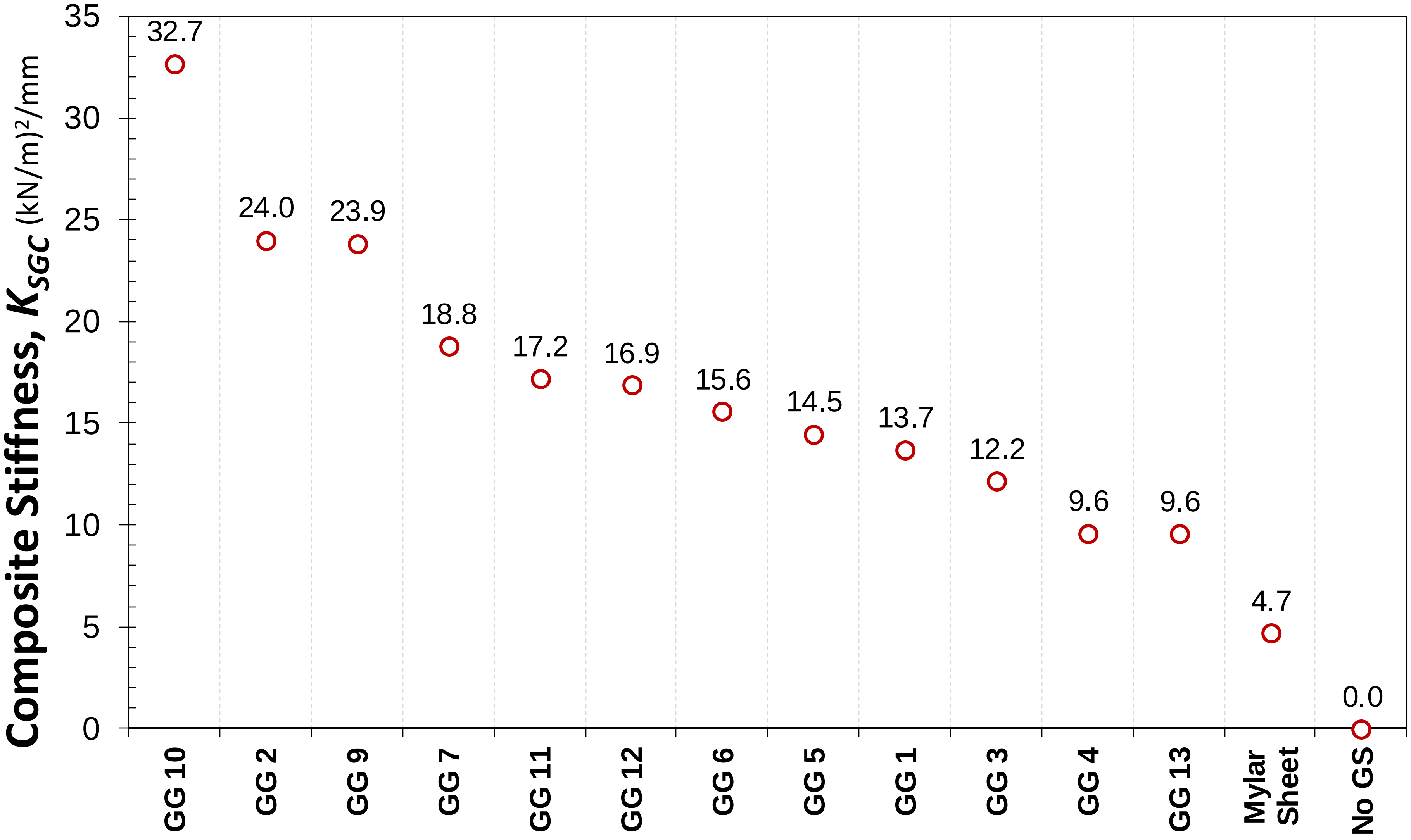
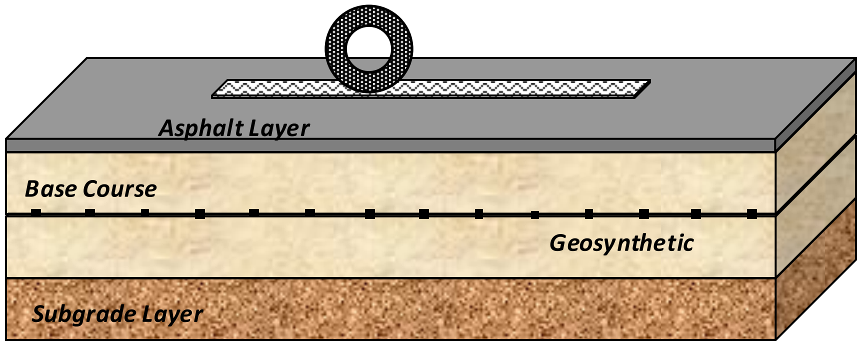
Composite Stiffness: Results

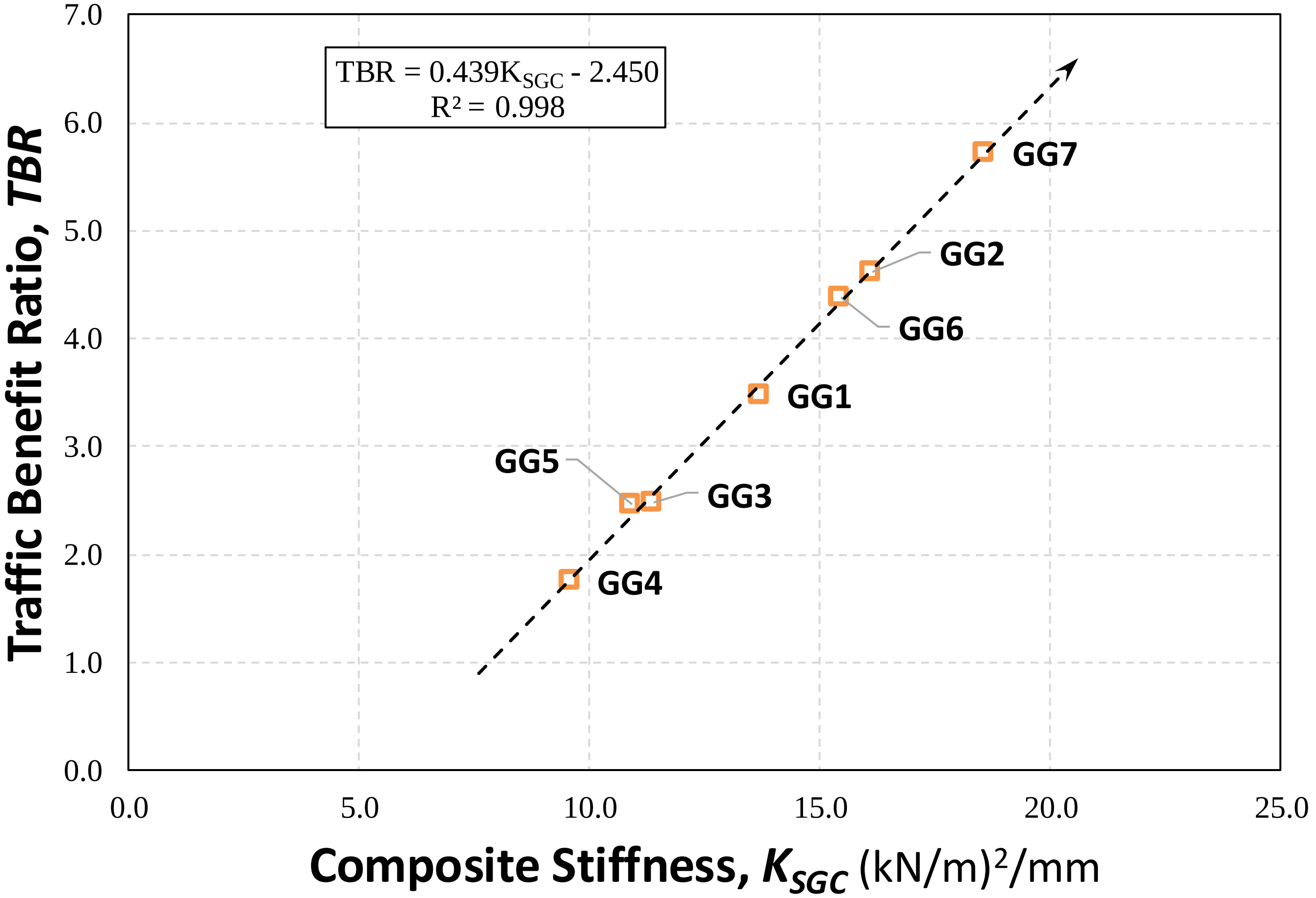


Roodi et al. (2018)

Geosynthetics for Base Stabilization (Pavement Performance vs. K_{SGC})

$$TBR = \frac{N_S}{N_{NS}}$$

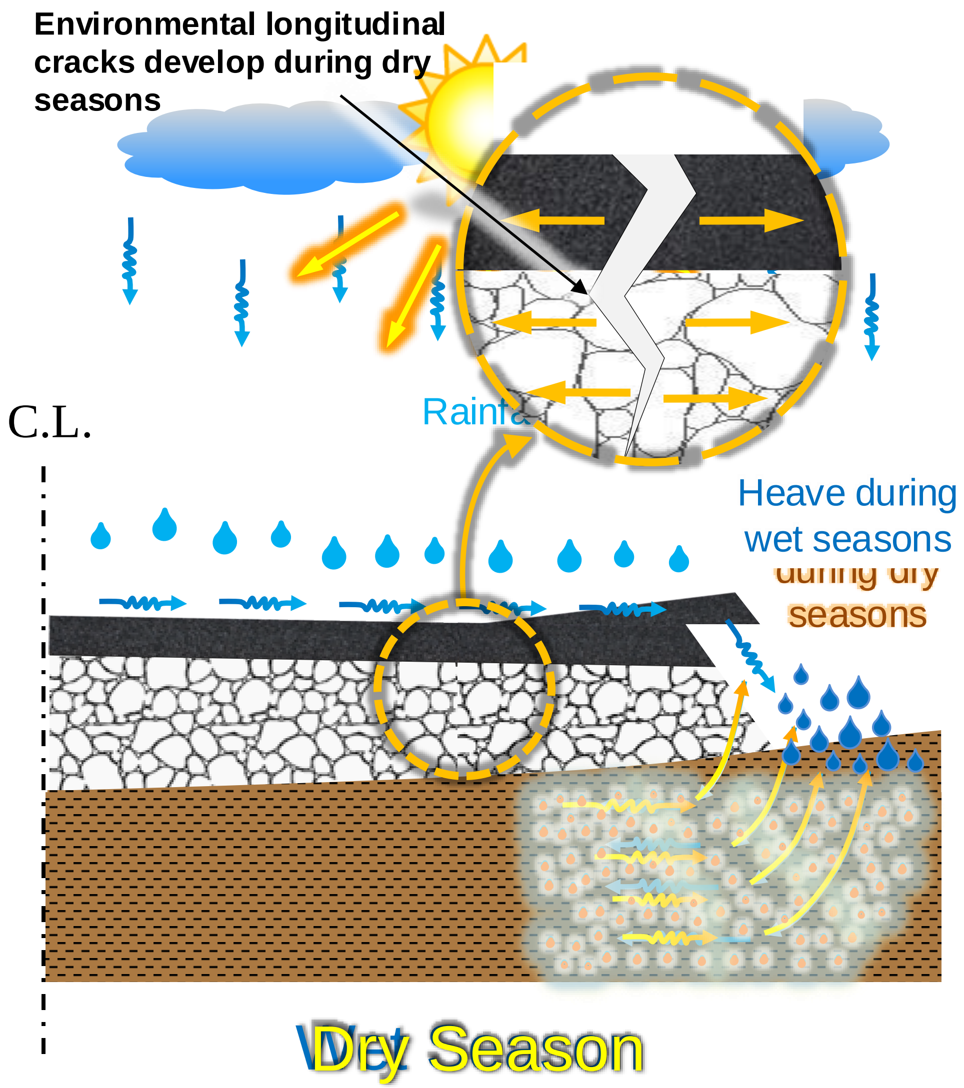




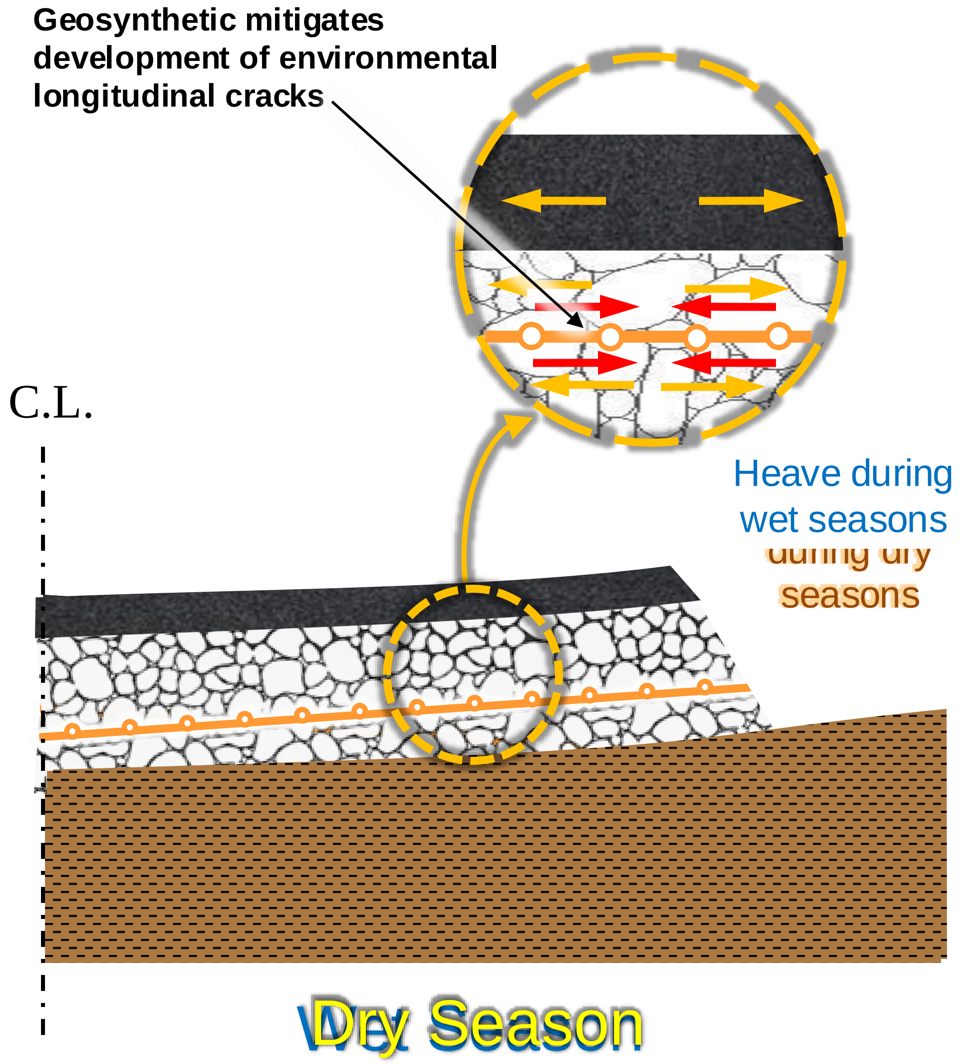
Somasundaram and Zornberg (2024)

Geosynthetics for Roads on Expansive Clays

Non-Stabilized Roadway



GS-Stabilized Roadway



Closing the Loop: Validation Against Field Performance

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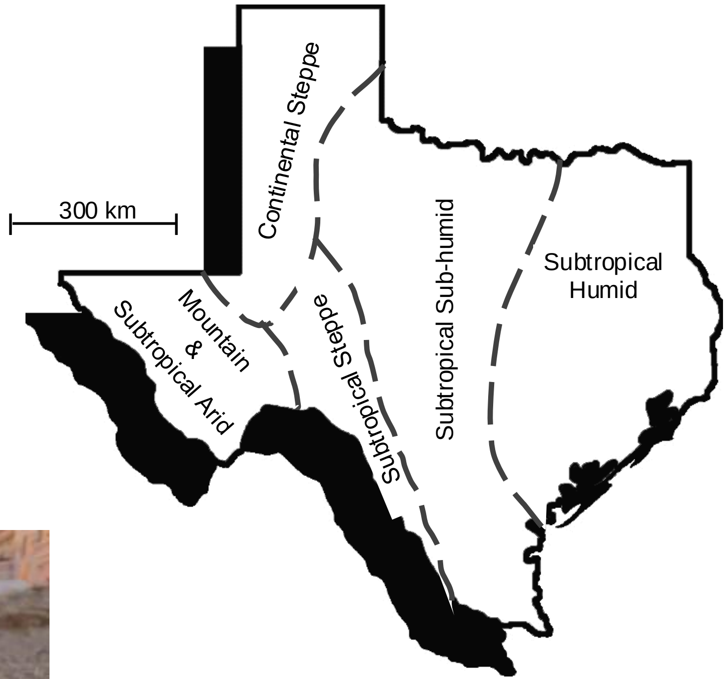
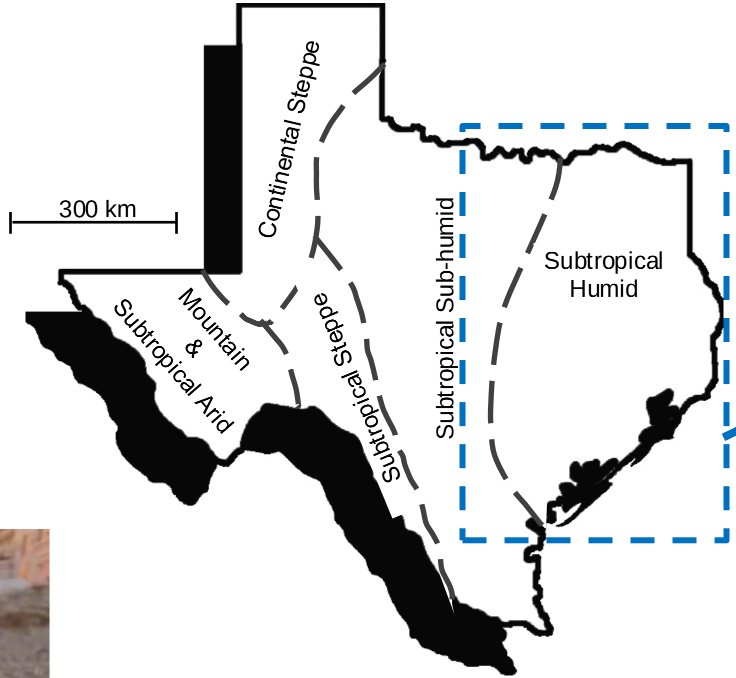
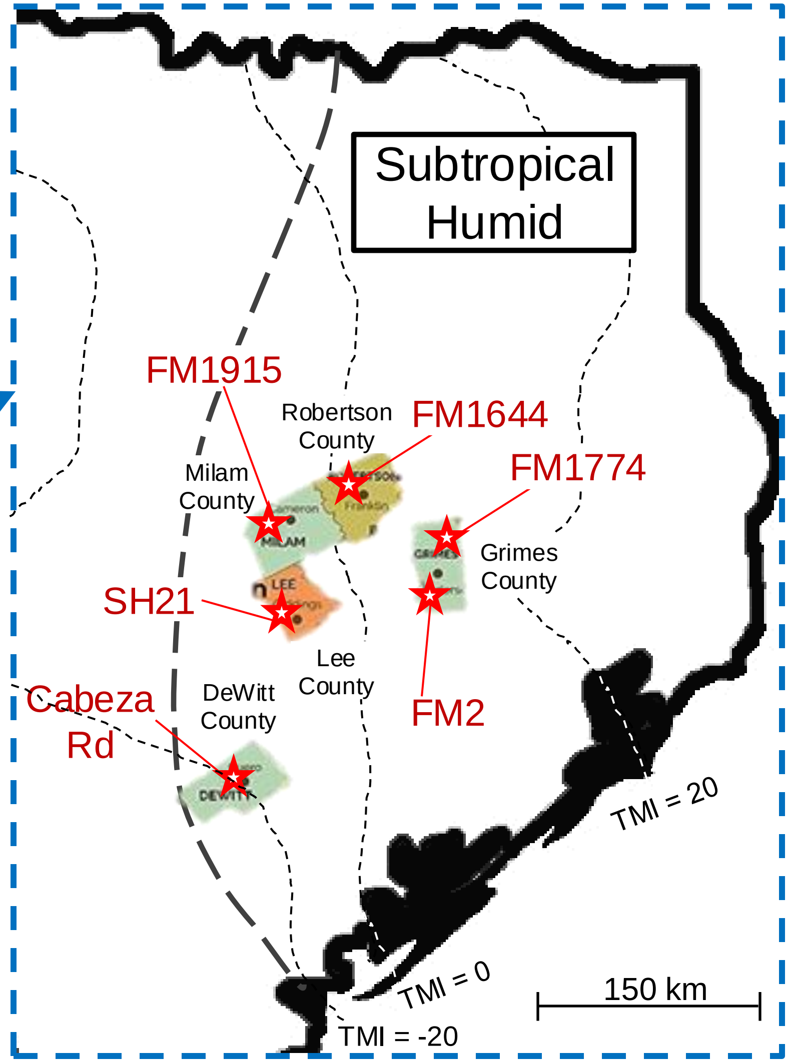


Closing the Loop: Validation Against Field Performance

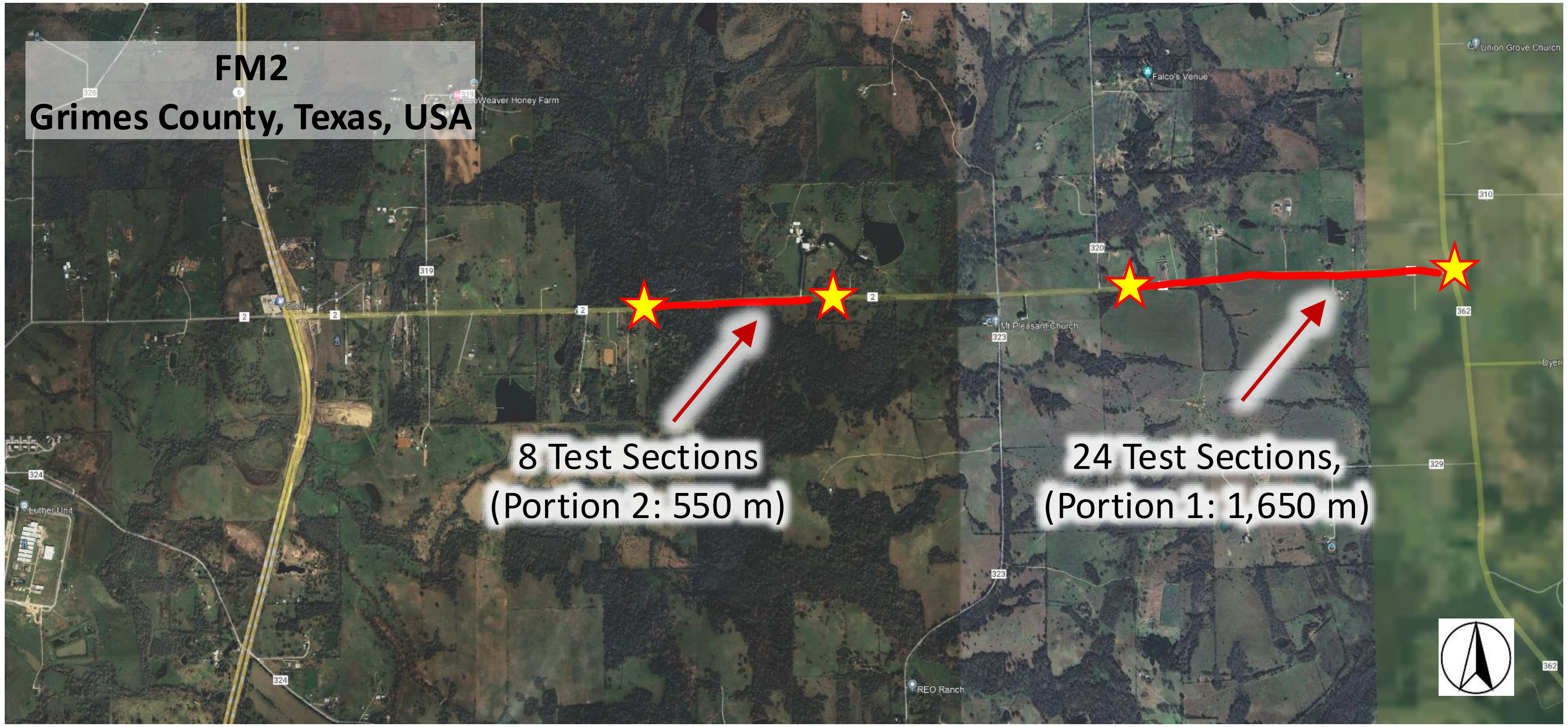




FM2: Test Sections Evaluation

FM2, Grimes County, Texas

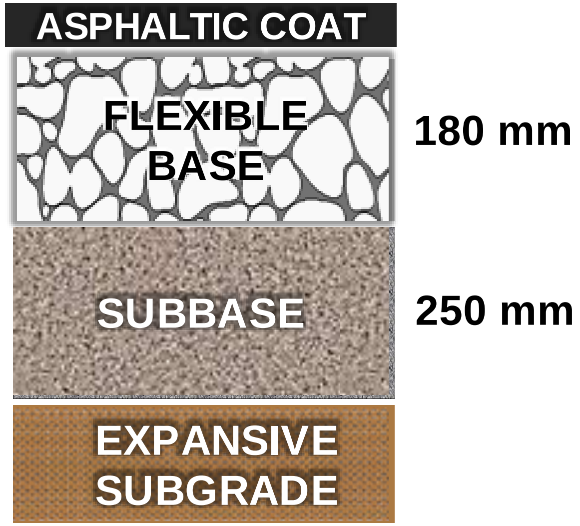
- **What?** **34 Test Sections**, including (1) Control, (2) Lime-stabilized, (3) Geosynthetic-stabilized base, and (4) Lime- and Geosynthetic-stabilized base
- **Why?** Need to compare relative benefits of different **chemical and mechanical stabilization** approaches for roadways on expansive clay subgrade



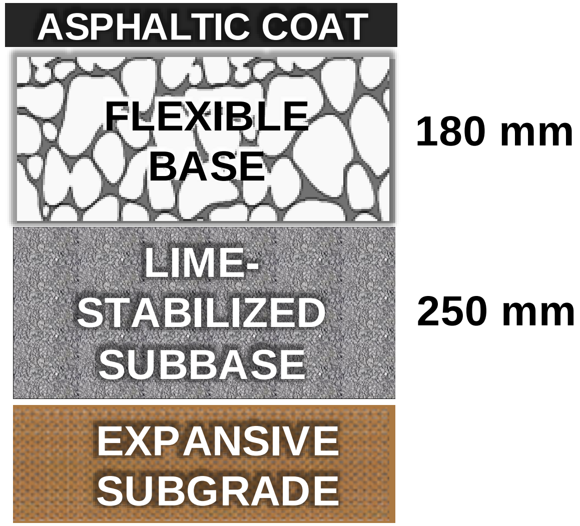
Roodi and Zornberg (2020)

FM2: Test Sections Evaluation

Control:

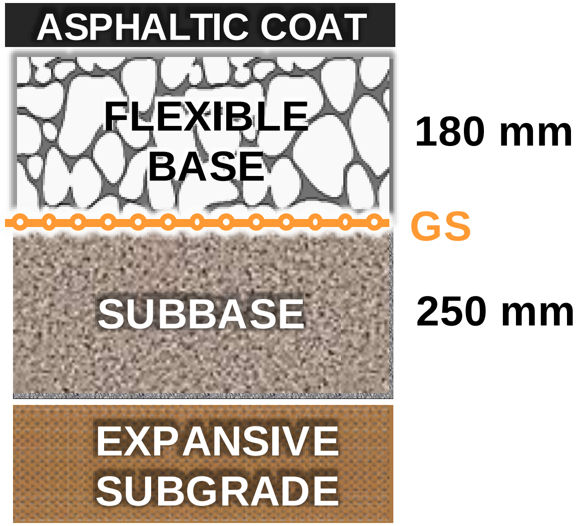


Lime-stabilized:



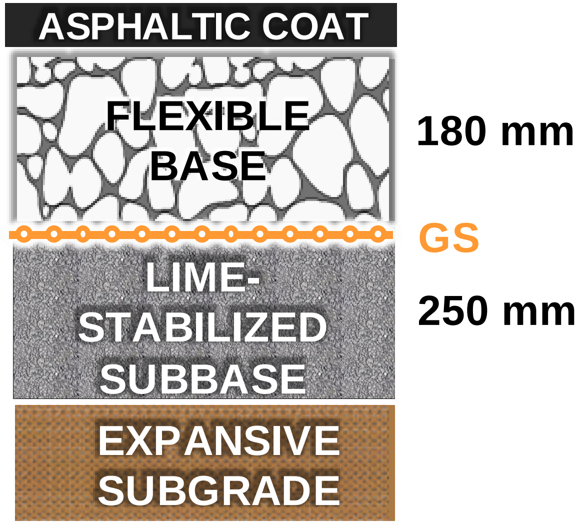
GS-stabilized:

- GG1
- GG5
- GT2



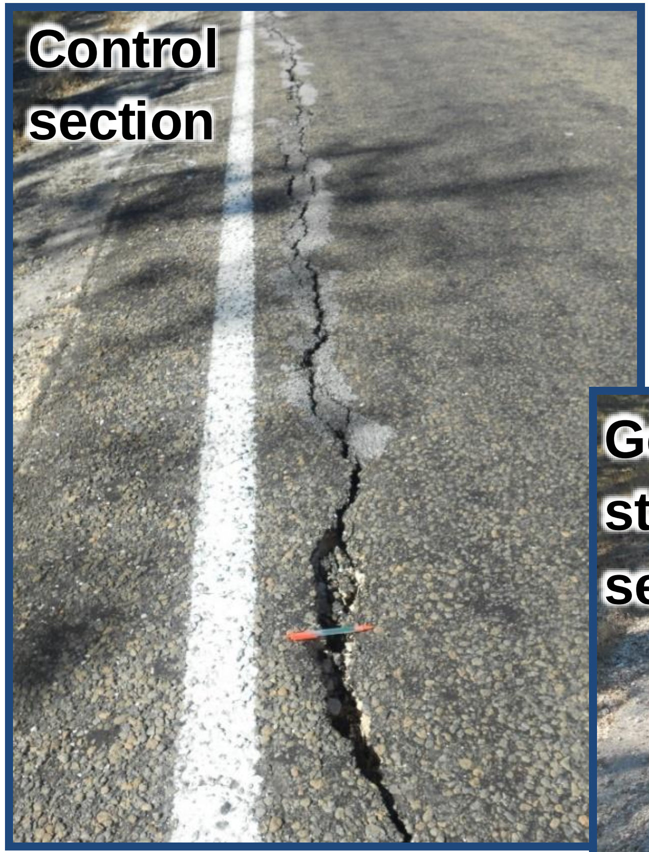
GS- & Lime-stabilized:

- GG1
- GG5
- GT2

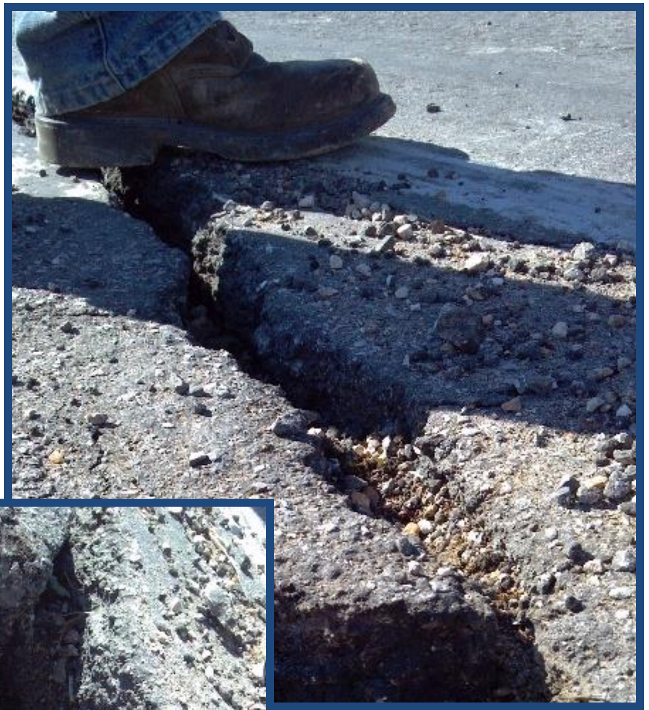


Roodi and Zornberg (2020)

FM2: Test Sections Evaluation



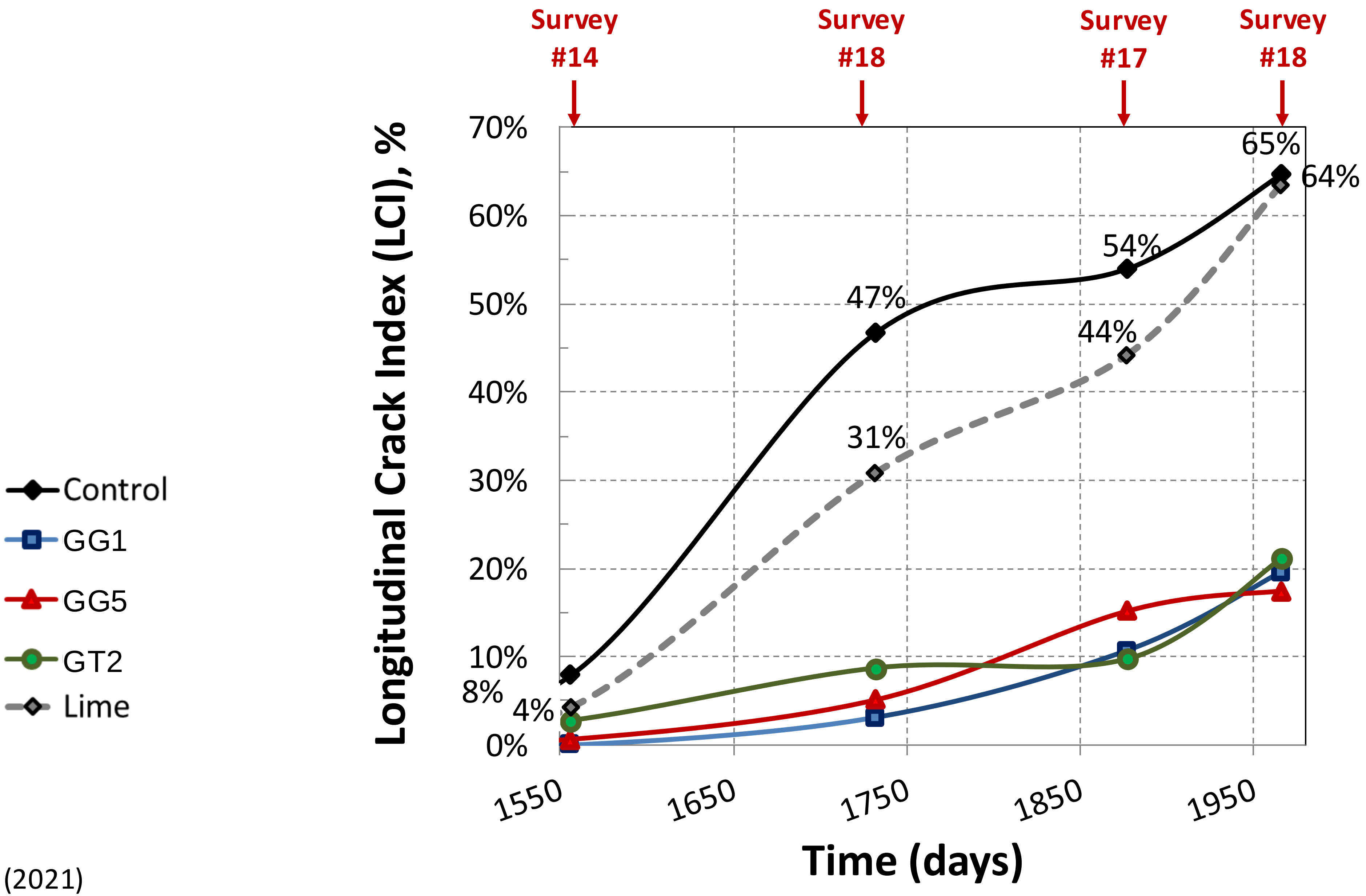
Crack before excavation



Crack after excavation

Roodi and Zornberg (2020)

FM2: Performance over Time



Zornberg and Roodi (2021)

FM2: Seeing is Believing…

FM2: Consistency between Experimental and Field Data

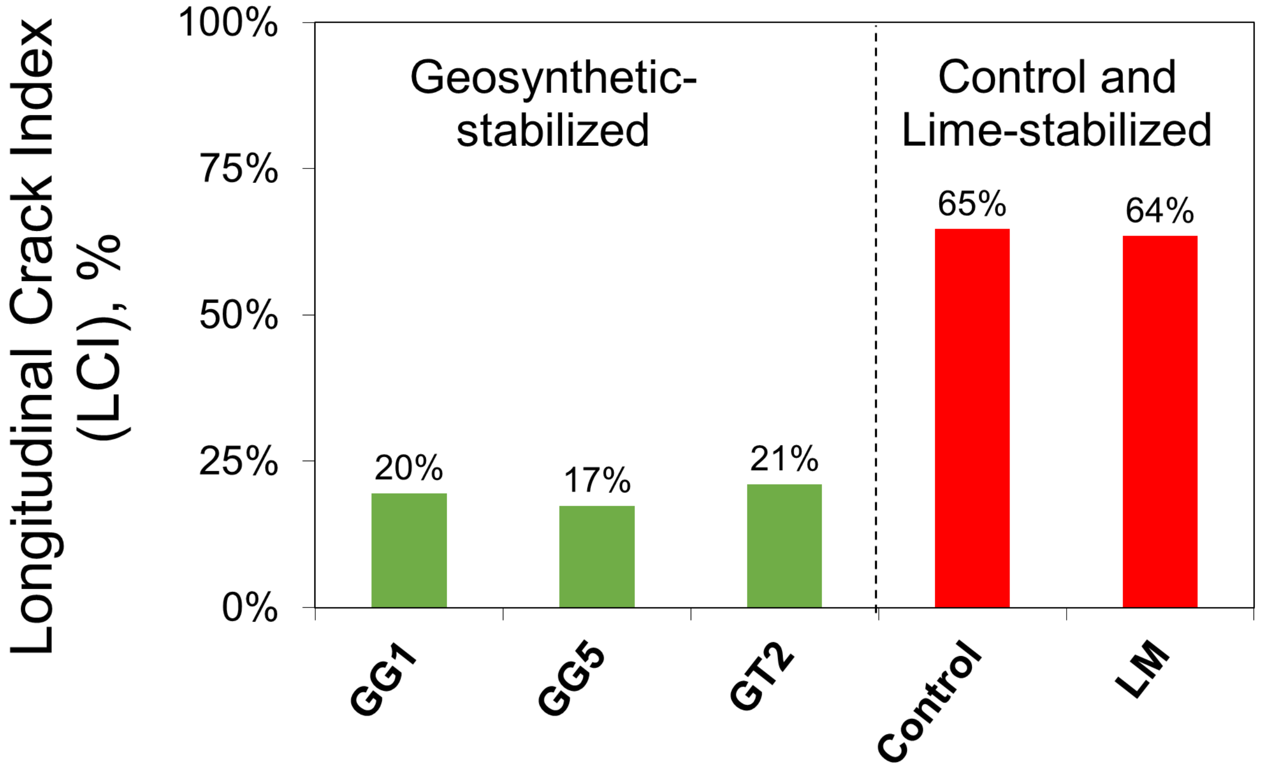
FM2

GG1: $K_{SGC} = 13$ ✓

GG5: $K_{SGC} = 11$ ✓

GT2: $K_{SGC} = 10$ ✓

Control: ✗

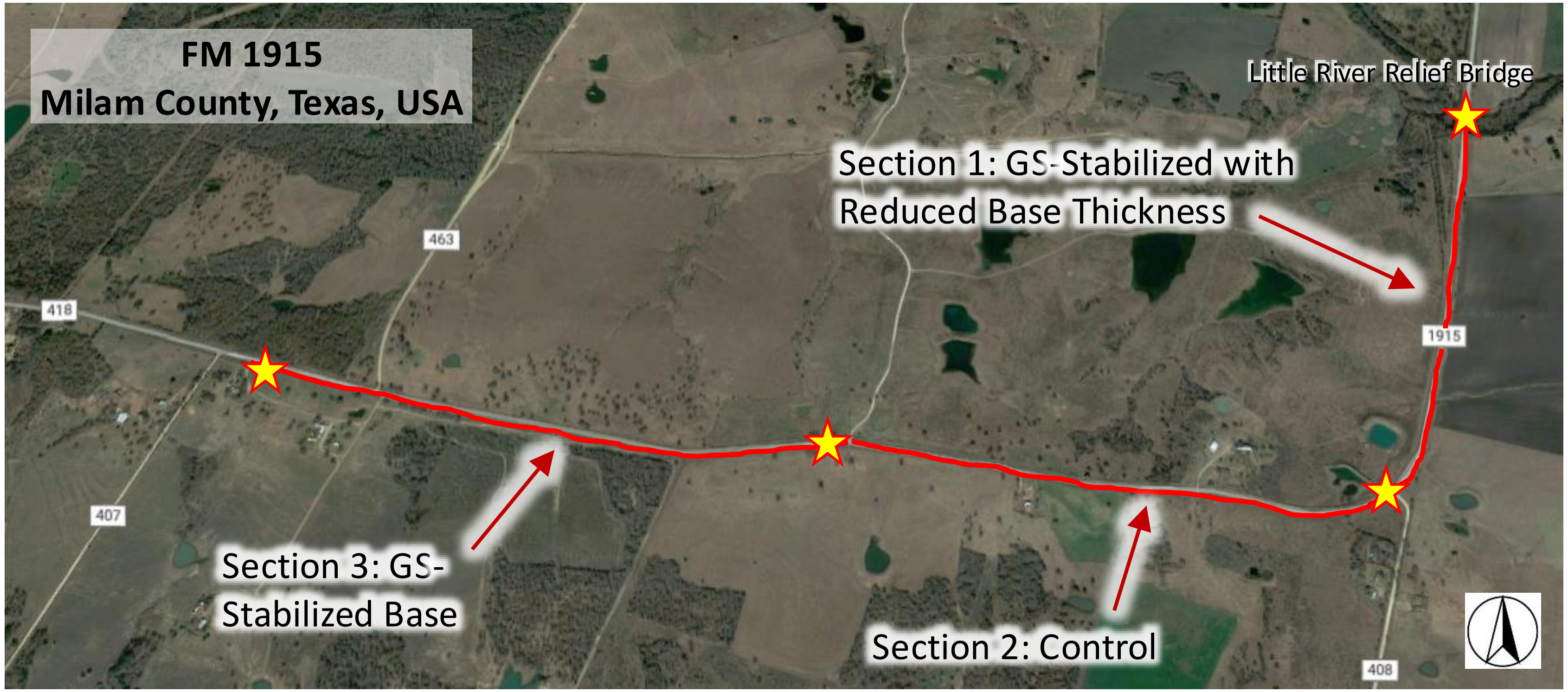


Zornberg and Roodi (2021)

FM1915: Test Sections Evaluation

FM 1915, Milam County, Texas

- **What? 3 Test Sections**, including (1) Control, (2) Geosynthetic-stabilized base, and (3) Geosynthetic-stabilized base with reduced thickness
- **Why?** Interest in optimizing **Life Cycle Costs** in a road plagued by recurring maintenance needs due to expansive clay subgrade

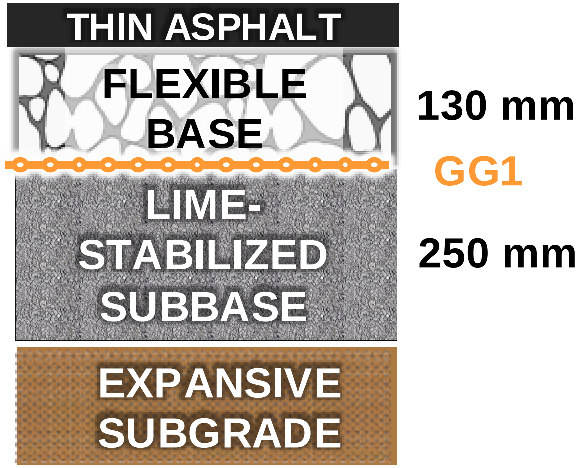


Zornberg and Roodi (2021)

FM1915: Test Sections Evaluation

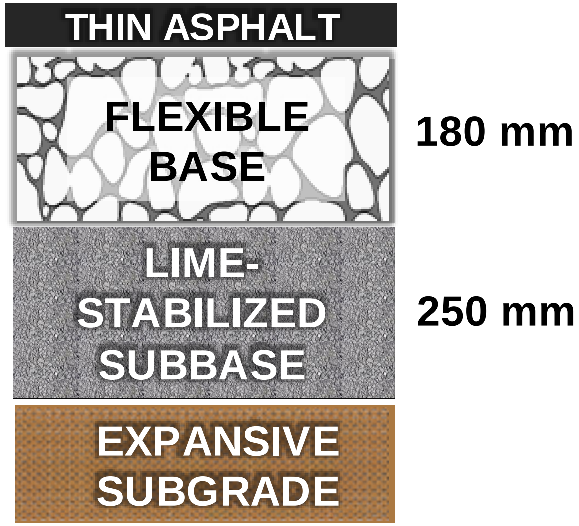
Section A1:

- GS-stabilized
- Reduced base thickness



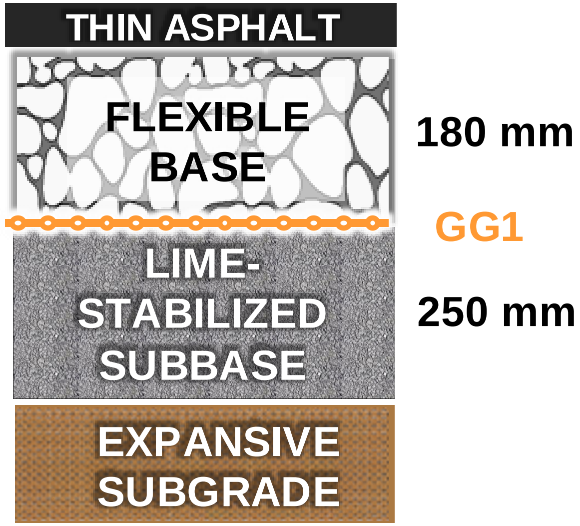
Section A2:

- Control



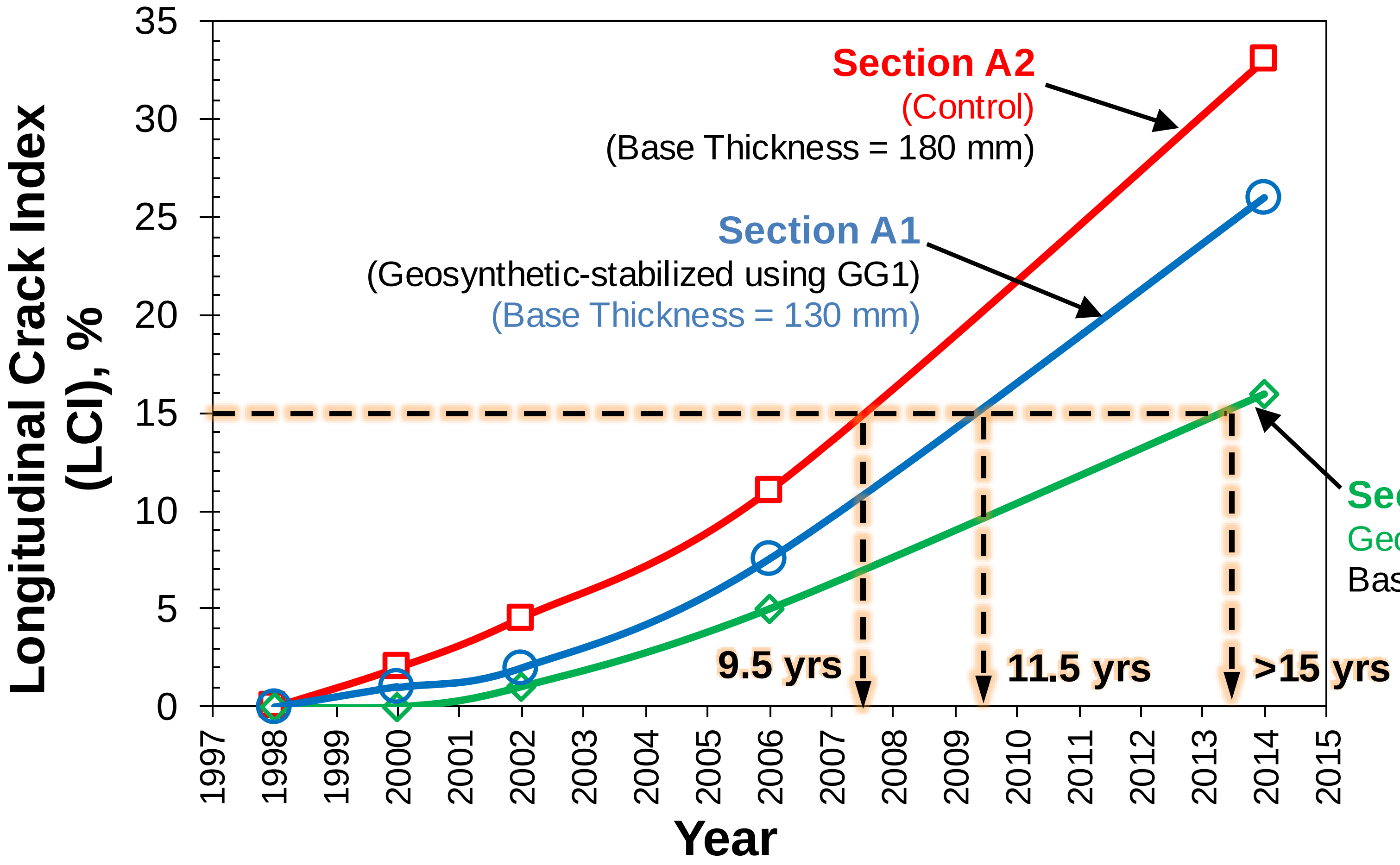
Section A3:

- GS-stabilized



Zornberg and Roodi (2021)

FM1915: Test Sections Evaluation



- Failure Criterion: LCI = 15%
- Design Life: DL = 15 years

GG1: $K_{SGC} = 13$ ✓

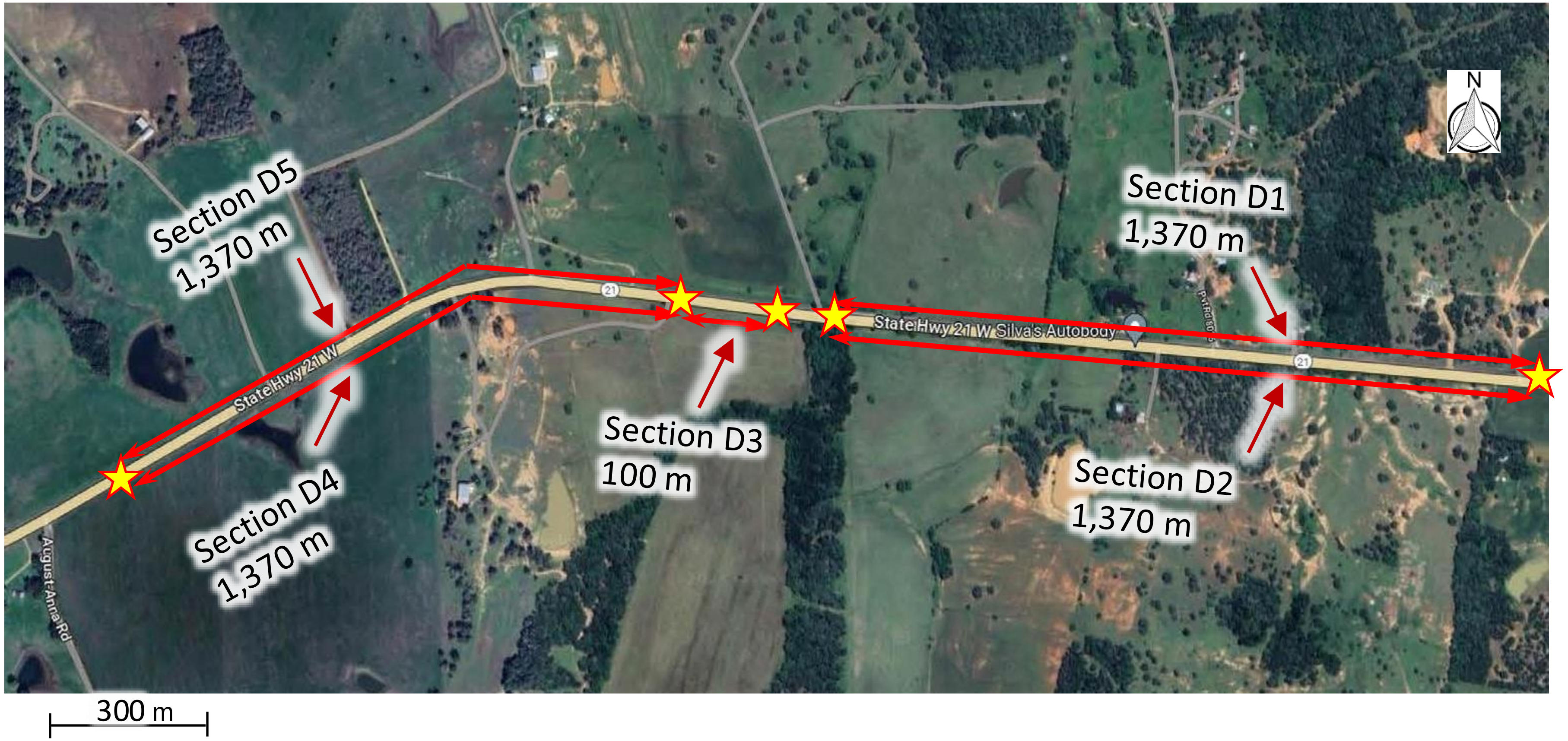
Control: ✗

Zornberg and Roodi (2021)

SH21: Test Sections Evaluation

SH21, Lee County, Texas

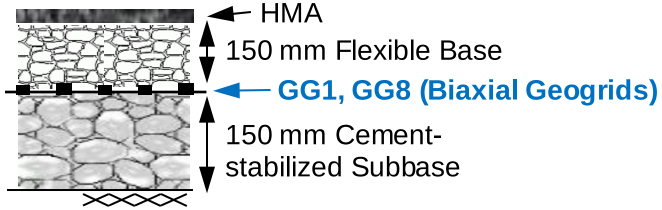
- **What? 5 Test Sections**, including biaxial geogrids and multiaxial geogrids
- **Why?** The focus was on quantifying differences in performance for **different types of geogrid products**

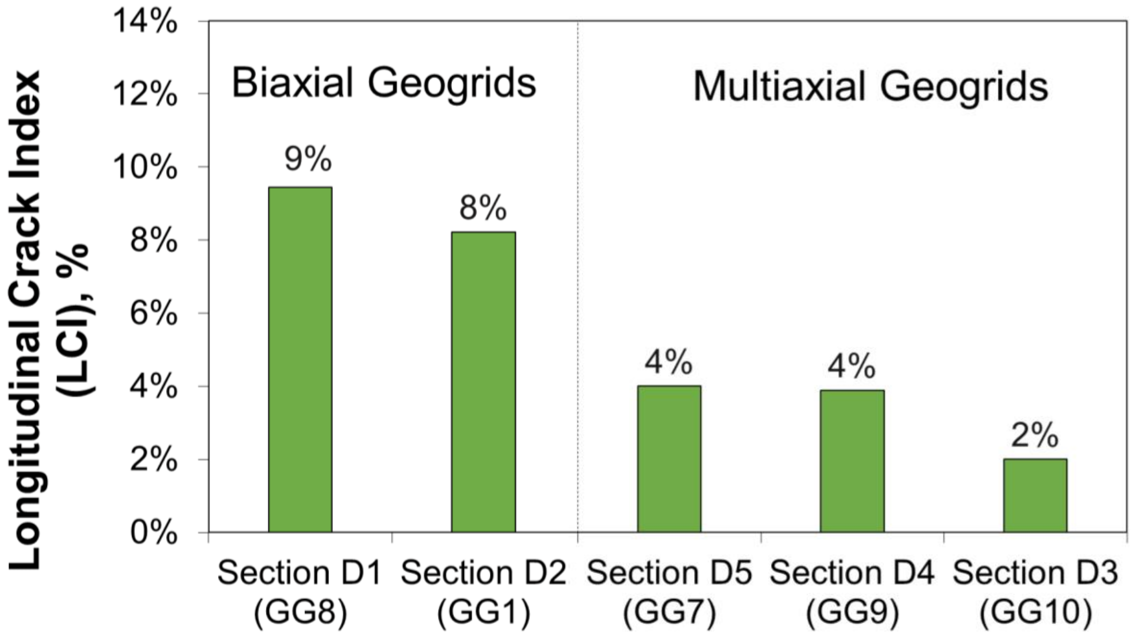


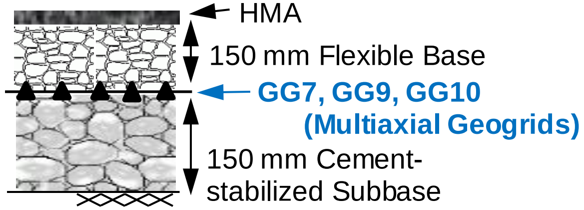
Zornberg and Roodi (2021)

SH21: Test Sections Evaluation

SH21







Zornberg and Roodi (2021)

SH21: Consistency between Experimental and Field Data

SH21

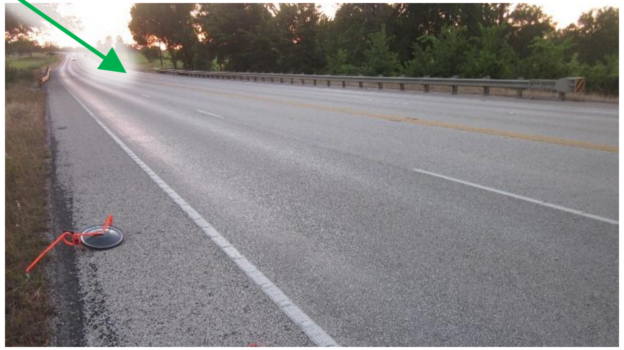
GG1: $K_{SGC} = 13$ ✓

GG7: $K_{SGC} = 19$ ✓

GG9: $K_{SGC} = 24$ ✓

GG10: $K_{SGC} = 32$ ✓

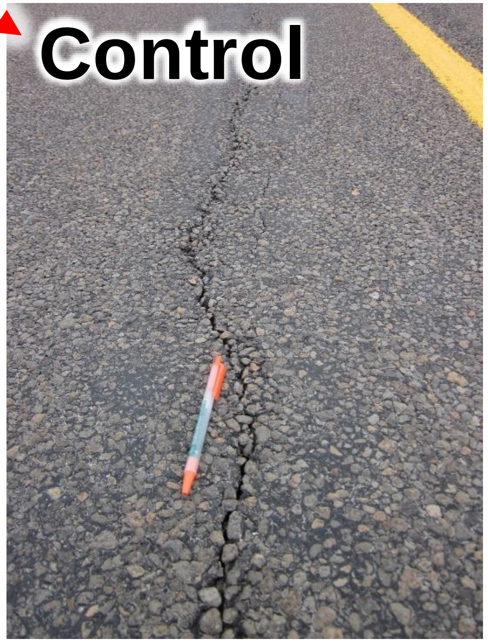
Control: ✗

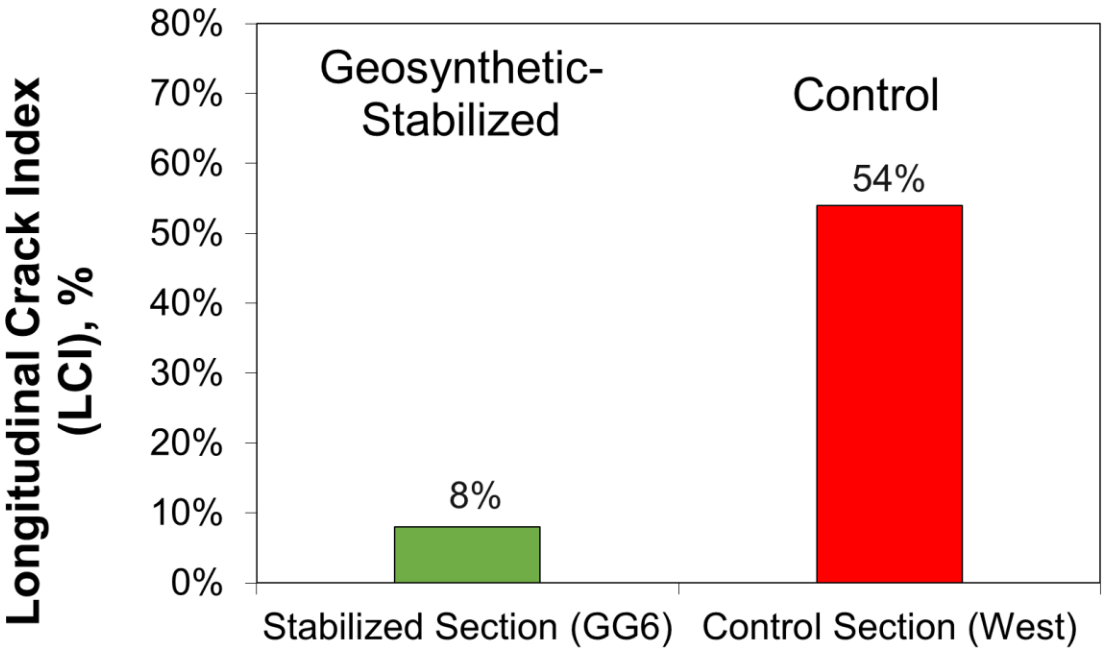


FM1644: Consistency between Experimental and Field Data

GG6: $K_{SGC} = 14$ ✓

Control: ✘



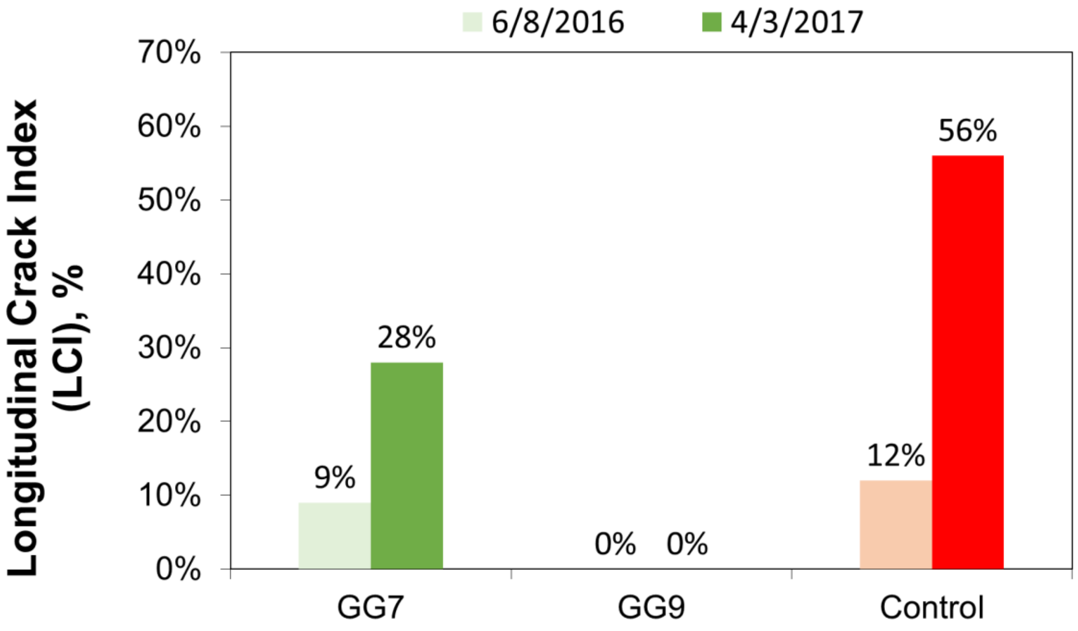


Cabeza Rd: Consistency between Experimental and Field Data

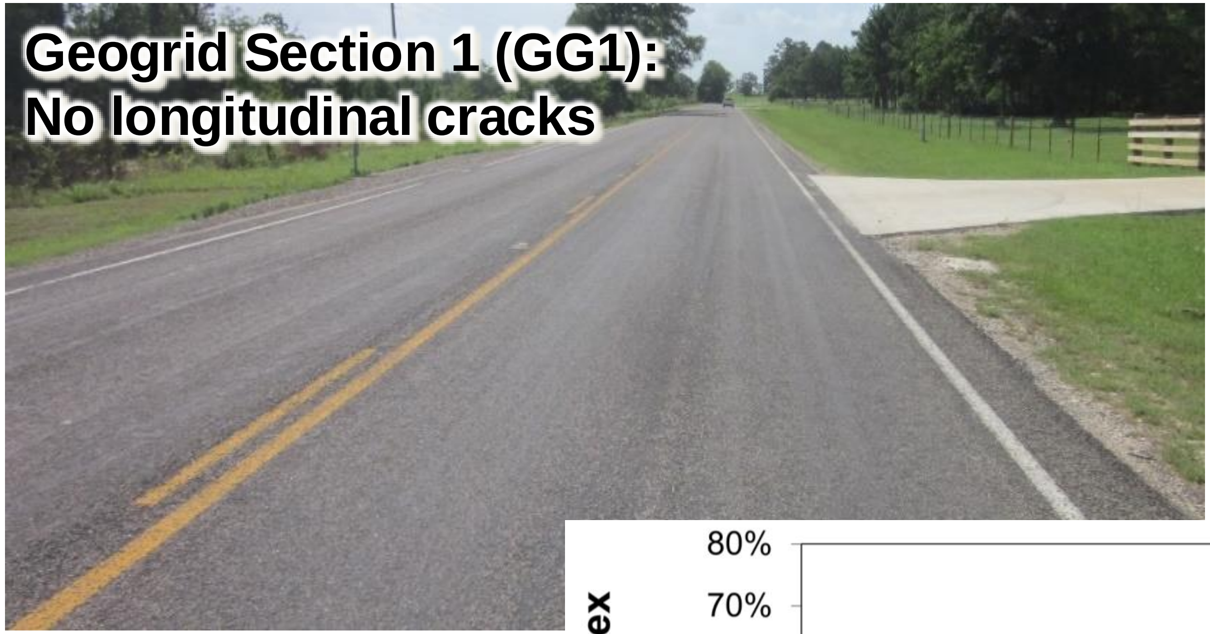
GG7: $K_{SGC} = 19$ ✓

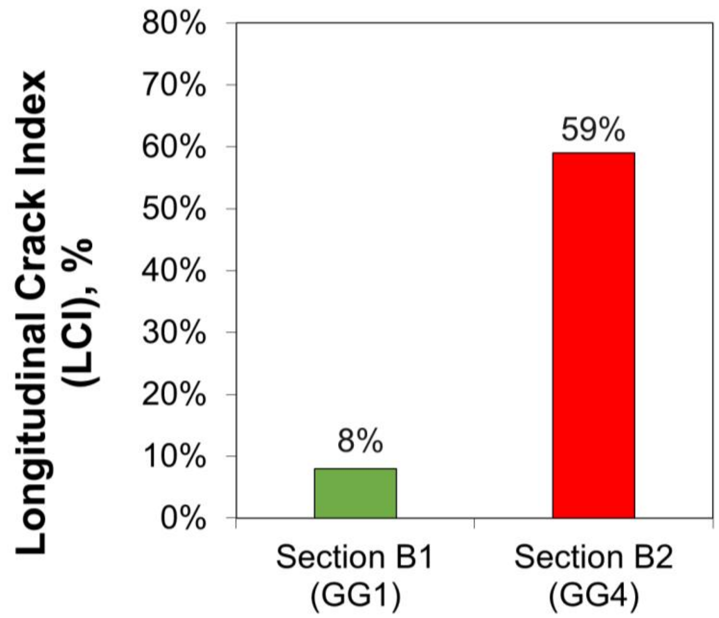
GG9: $K_{SGC} = 24$ ✓

Control: ✗



FM1774: Consistency between Experimental and Field Data





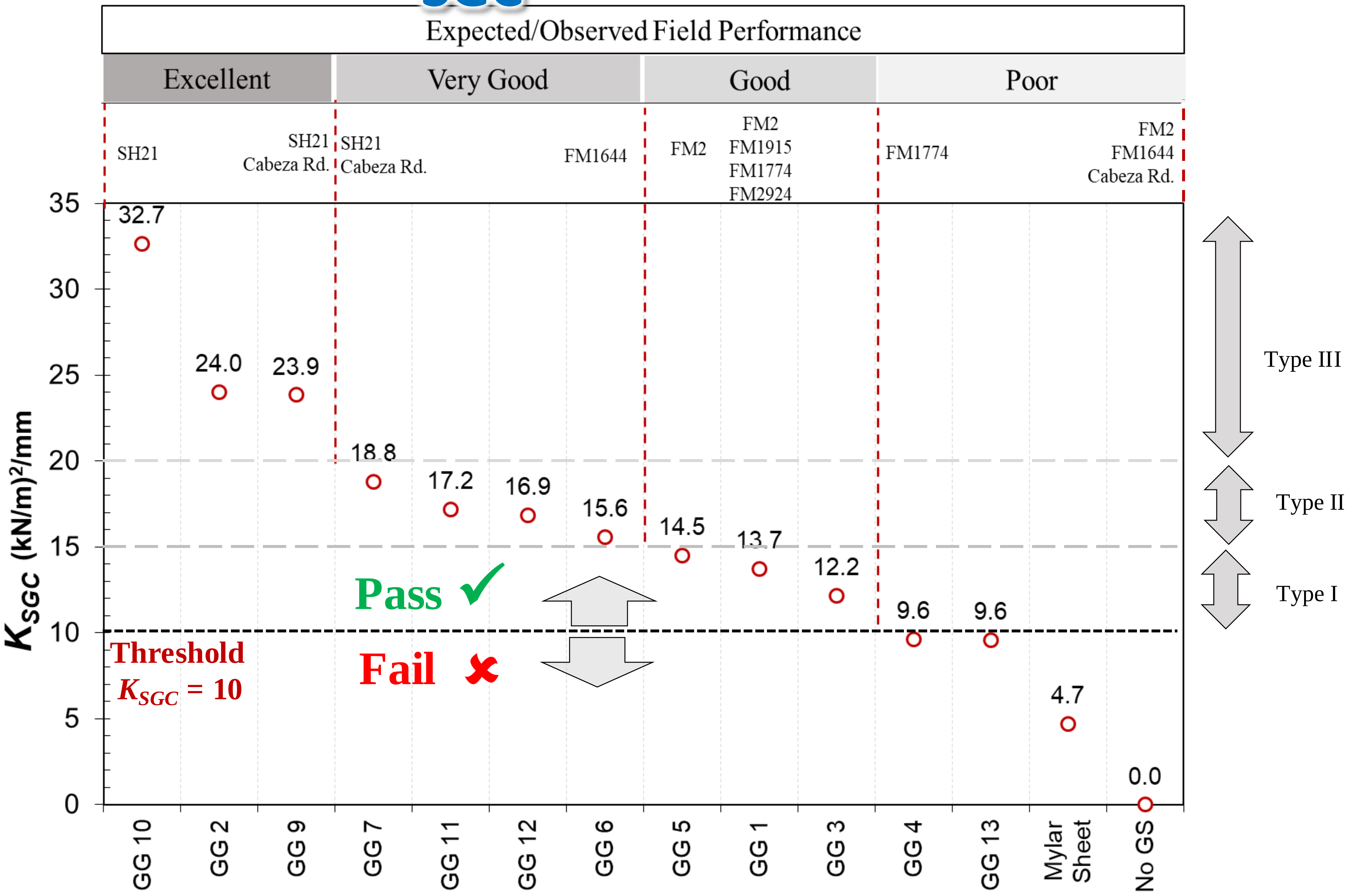
Geogrid Section 2 (GG4):
Longitudinal cracks

GG1: $K_{SGC} = 13$ ✓

GG4: $K_{SGC} = 8$ ✗

Zornberg and Roodi (2021)

Correlation of K_{SGC} with Field Performance



Roodi et al. (2018)

Acknowledgements:

Texas Department of Transportation

NSF

Tensar

SOLMAX

IF since 1981 INDUSTRIAL FABRICS, INC.

HUESKER

TDM GRUPO

My Students:
(Only PhD shown here)

Conclusions

- Use of centrifuge technology led to practical and expeditious determination of the swell-stress relationship of expansive clays

- Centrifuge-generated swell-stress curves match those obtained using conventional techniques
- The expeditious centrifuge approach is particularly appropriate for practical design, including PVR quantification

Conclusions (Cont.)

- The use of geosynthetics was found to effectively minimize the detrimental effects of expansive soil subgrades on flexible pavements

- Mechanical stabilization of expansive clay sites represents a much-needed alternative to chemical stabilization
- The Confined Stiffness of the Soil-Geosynthetic Composite (K_{SGC}) is a property suitable for the selection of geosynthetics used in the design of roadways on expansive clays

Final Remarks

- Consistent with Prof. Peck's teachings, this presentation illustrates the value of observational approaches to develop recommended practices and design methods

- Case histories can provide an adequate roadmap to associate seemingly unconnected topics such as roadway design, expansive clays, centrifuge technology, and geosynthetics

Thank You

Jorge G. Zornberg, Ph.D., P.E., BC.GE., F.ASCE

Professor and Joe J. King Chair in Engineering

The University of Texas at Austin