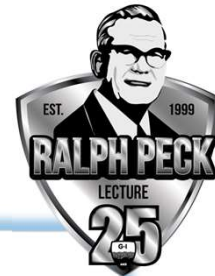


26 September 2024  
Balneário Camboriú, SC



## Rodovias sobre Argilas Expansivas: Caracterizando o Problema e Resolvendo-o com Geossintéticos

**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*



1



Geo-Congress 1997 (Logan, UT)

### Ralph B. Peck

#### Um Cara Normal: Ralph no Pódio - Sempre o Mestre da Situação

O destaque do programa da 19ª Conferência Geotécnica da Pensilvânia Central em Hershey, PA, maio de 2002, foi "Jantar com o Dr. Ralph B. Peck: Geotecnia - Fundações para a Ponte Rion, Grécia".

A grande sala de banquetes foi organizada de forma que a mesa principal e o alto-falante ficassem localizados no lado oposto da sala da tela de projeção, onde os slides meticulosamente preparados do Dr. Peck seriam



James K. Mitchell



Geo-Congress 2000 (Logan, UT)

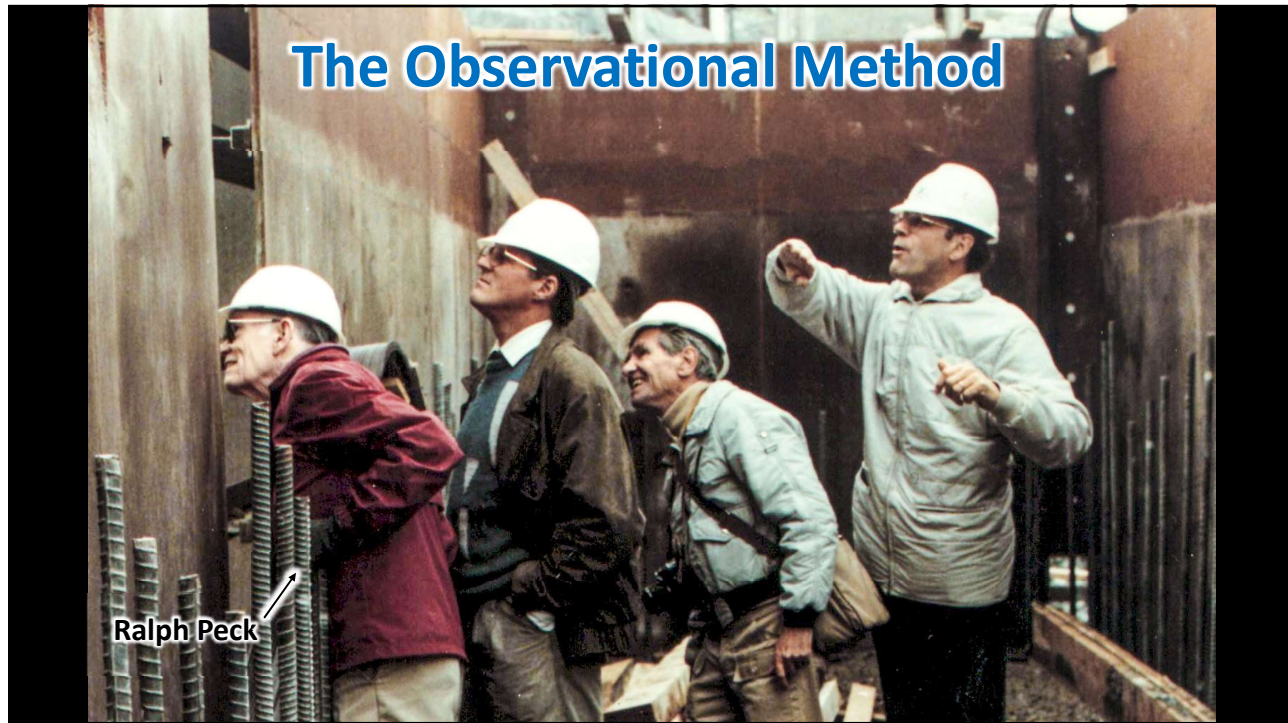
Sua apresentação então avançou tão suave quanto a seda. Seu conhecimento dos detalhes e dos pontos a serem feitos era tão completo que não era necessário vê-los na tela. Sua apresentação foi tão clara e o fluxo tão lógico que era desnecessário para ele dizer "Próximo slide, por favor". Eu sempre soube quando era hora de seguir em frente.

Foi uma honra ser seu assistente.

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

2

## The Observational Method



Ralph Peck

3

## Design of Roadways on Expansive Clays

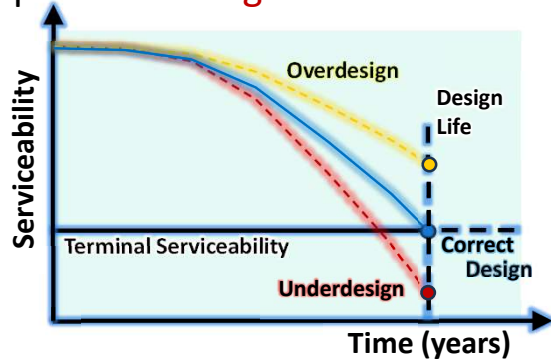


Total roadway length in Brazil: 2,000k km  
(Circumference of the Earth: 40k km)

4

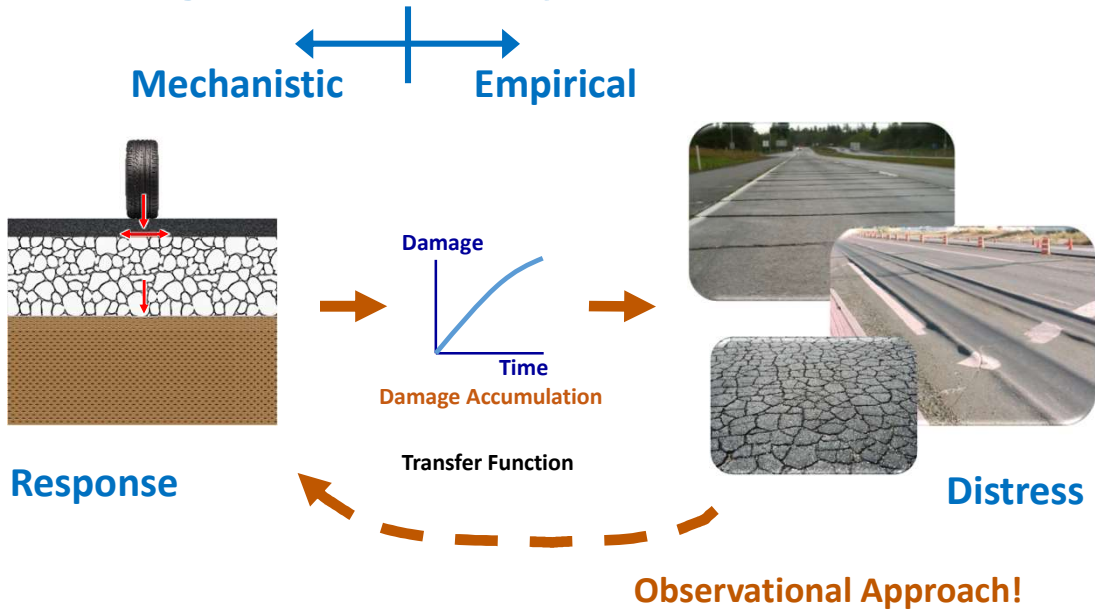
# Design of Roadways for Traffic Loads

- 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**



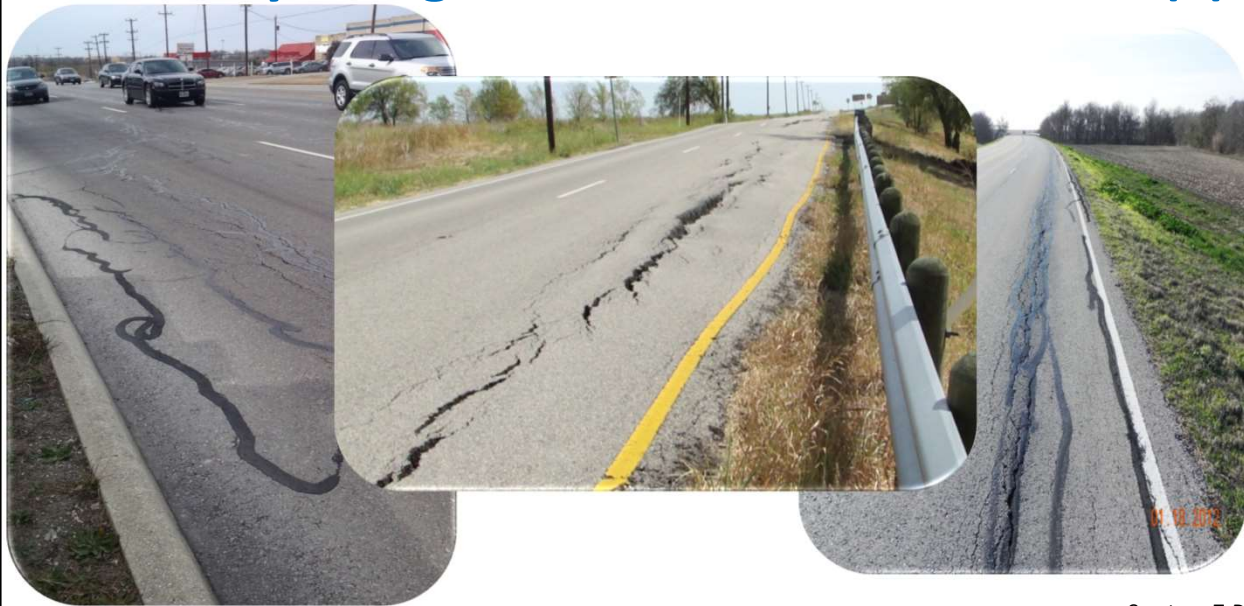
5

# Design of Roadways for Traffic Loads



6

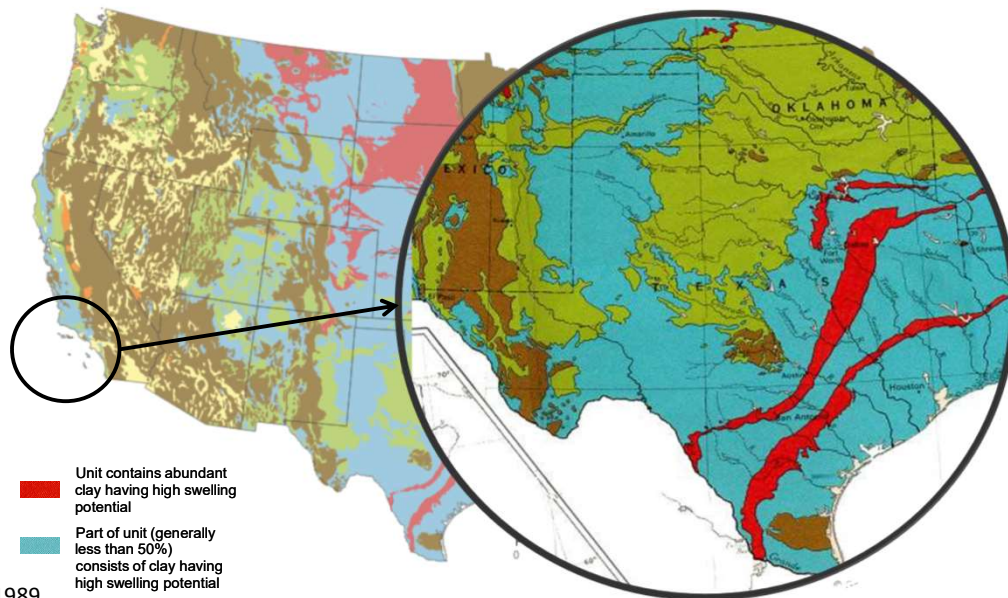
## Roadway Design for Environmental Loads (?)



Courtesy: TxDOT

7

## Expansive Clays in the US



Source: USGS 1989

8

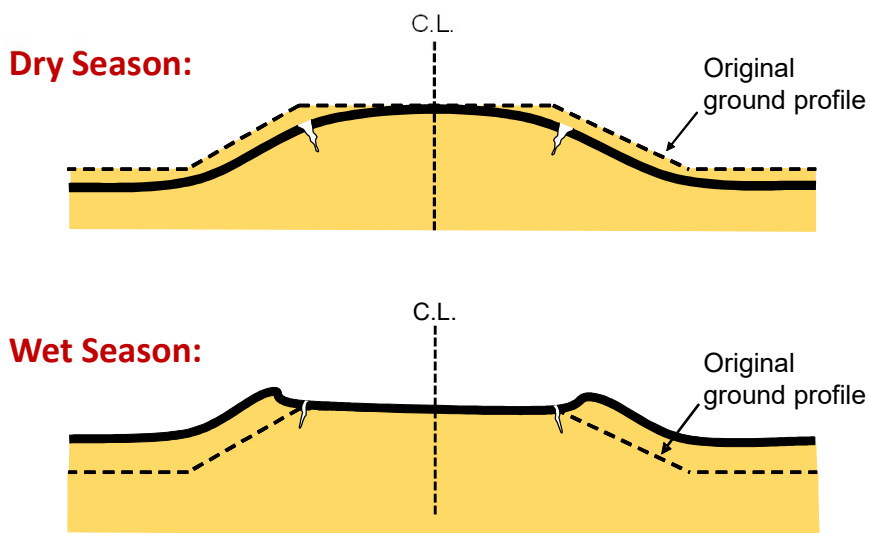
# Expansive Clays in Brazil



Source: Ferreira (2020)

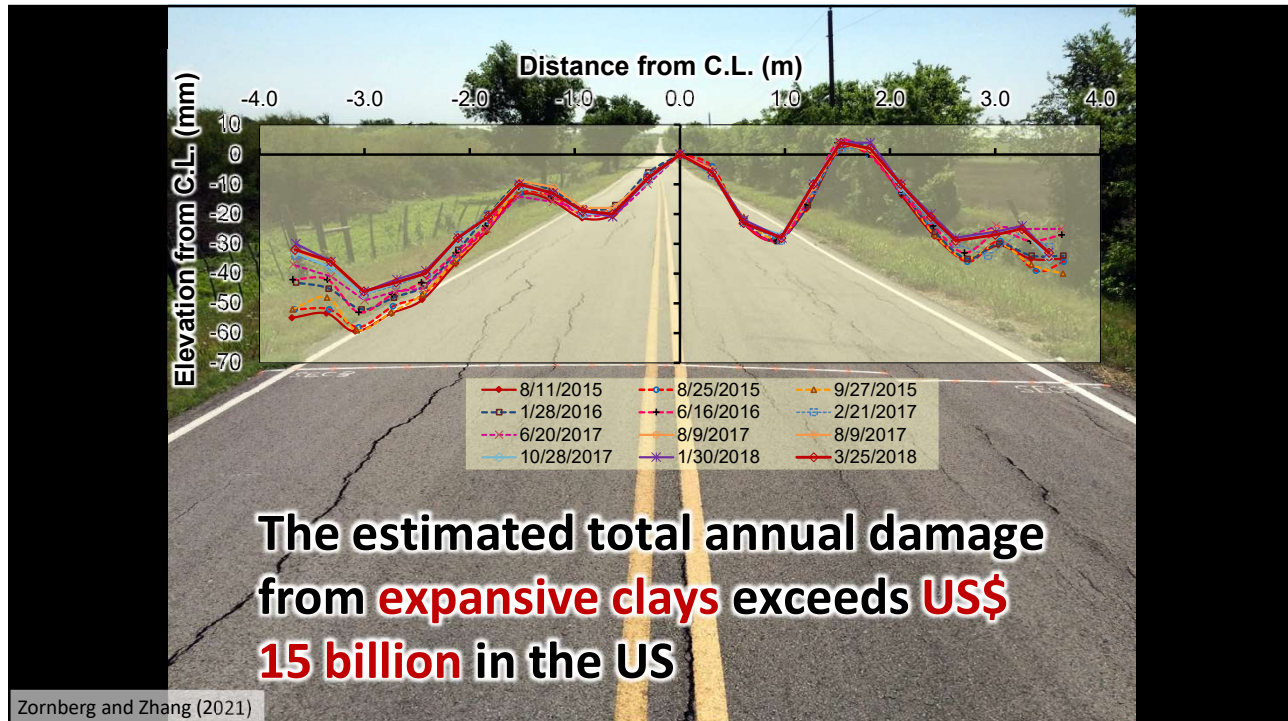
9

# Understanding an Old Problem: Roadways over Expansive Clay Subgrades

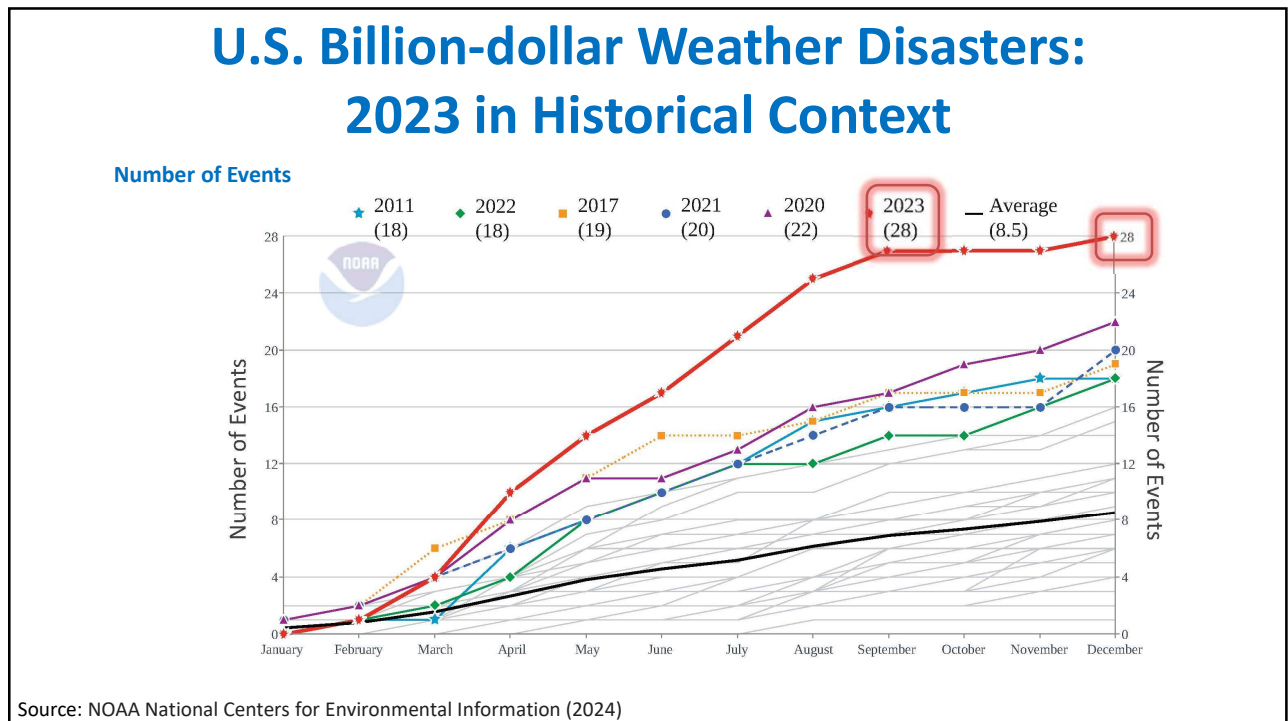


Zornberg and Roodi (2021)

10

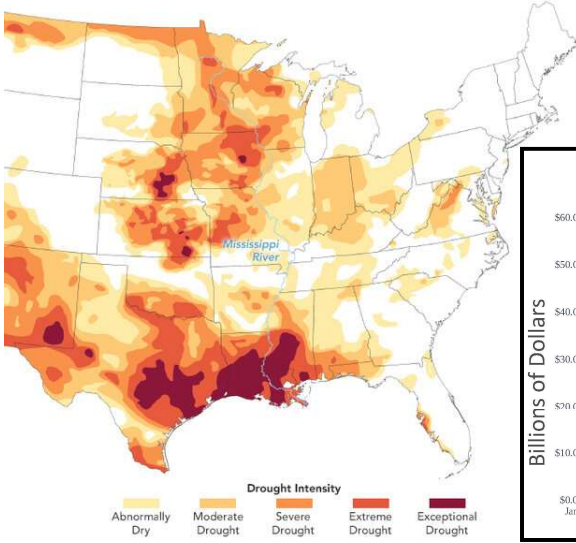


11



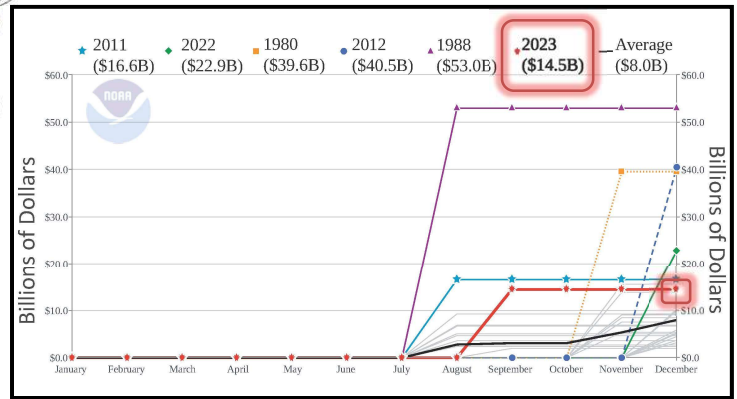
12

# 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)

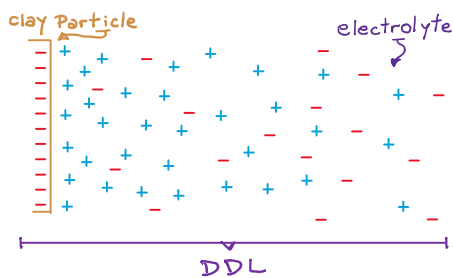
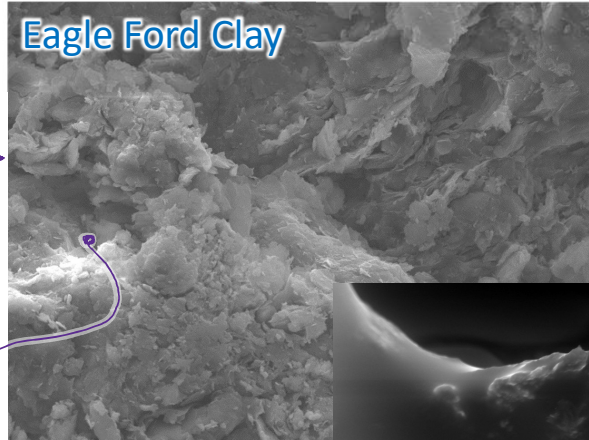
13

## Characterizing the Problem: Sites on Expansive Clays

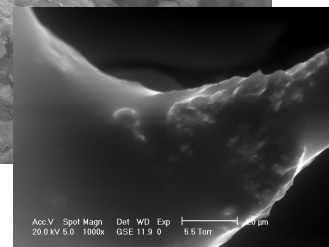


14

# Characterizing the Problem: Sites on Expansive Clays



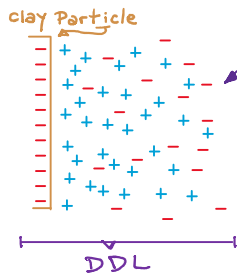
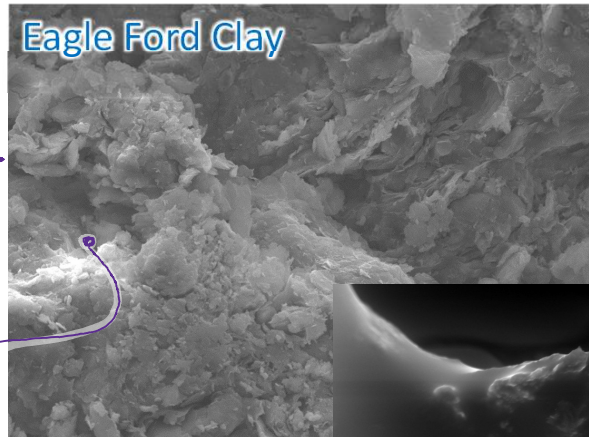
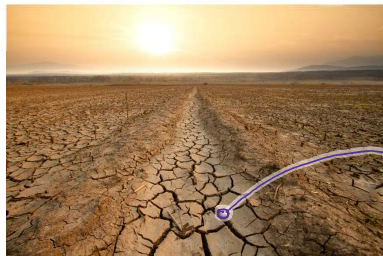
Courtesy: Calvin Blake



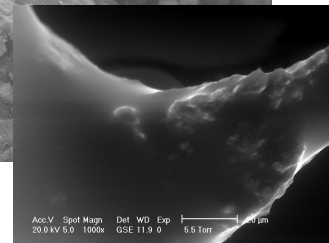
Courtesy: Chris Armstrong

15

# Characterizing the Problem: Sites on Expansive Clays



Courtesy: Calvin Blake



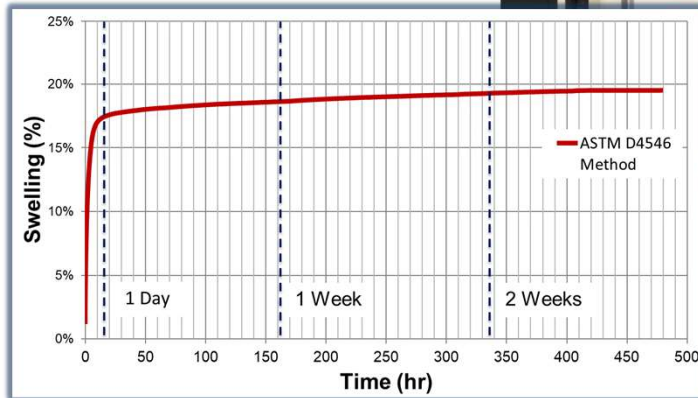
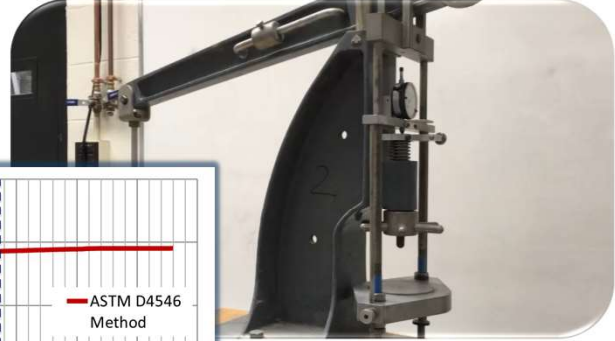
Courtesy: Chris Armstrong

16



# Soil Characterization: Conventional Swell Tests

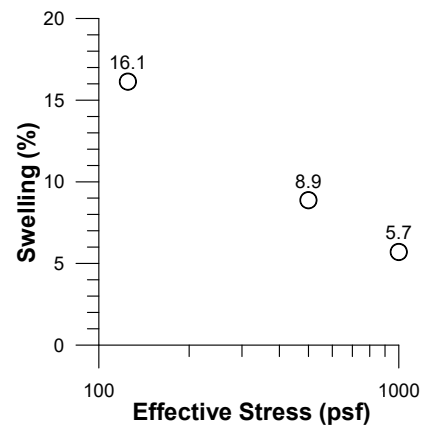
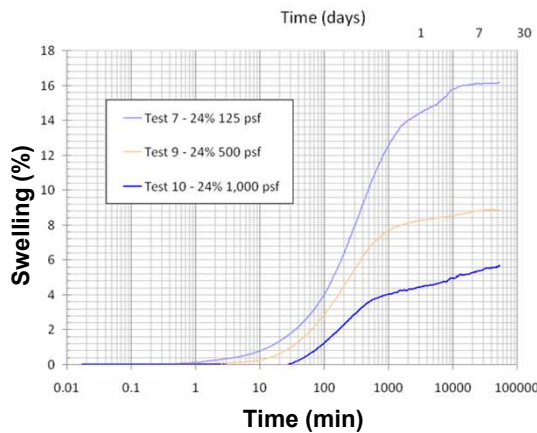
- ASTM D4546: Standard Test Method for One-dimensional Swell or Collapse of Soils
- Conducted using consolidation frames



17

# Soil Characterization: Conventional Swell Tests

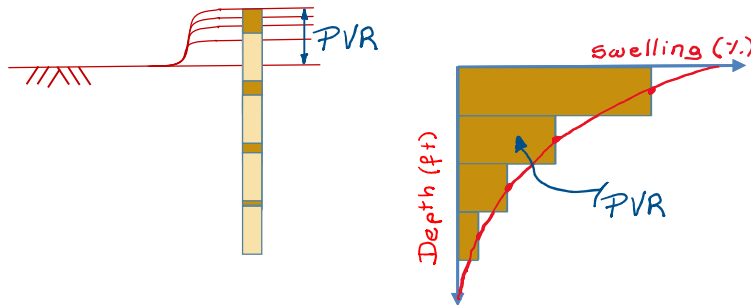
Impact of overburden pressure:



Source: Zornberg et al. (2017)

18

## Site Characterization: Potential Vertical Rise (PVR)

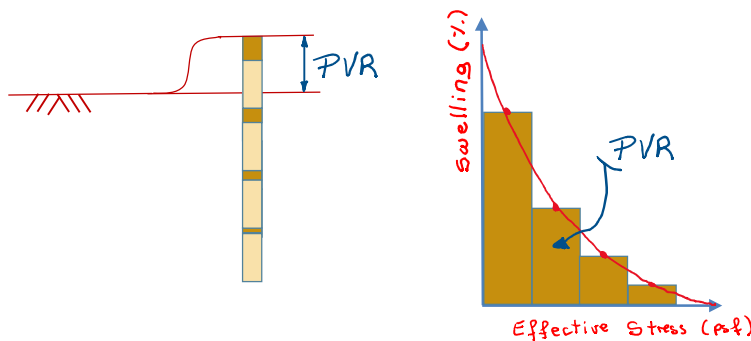


### Relevant Site Information:

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

19

## Site Characterization: Potential Vertical Rise (PVR)



### Relevant Site Information:

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

20

## 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.

21

## 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

22

# Unsaturated Flow in a Centrifuge

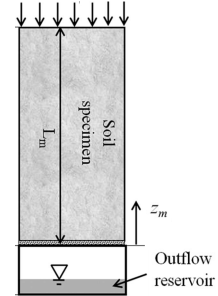
1D Flow:

$$h = z + \psi$$

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

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

1D Flow in a centrifuge:



23

# Unsaturated Flow in a Centrifuge

1D Flow:

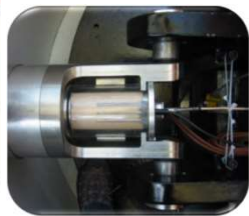
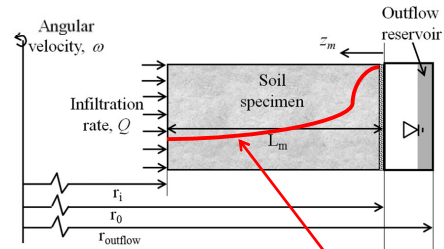
$$h = z + \psi$$

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

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

1D Flow in a centrifuge:

$$v_m = -k(\psi) \left( \omega^2 r + \frac{\partial \psi}{\partial z} \right)$$



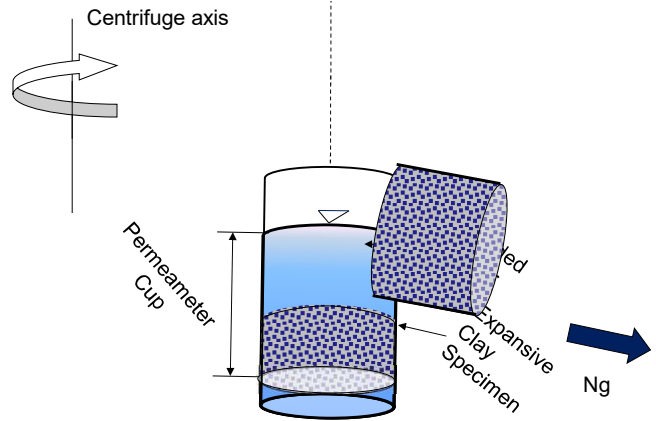
$$v_m = -k(\psi) \left[ \frac{\omega^2}{g} (r_o - z_m) + \frac{\partial \psi}{\partial z_m} \right]$$

Imposed Predicted Measured

Zornberg and McCartney (2010)

24

# Centrifuge for Direct Measurement of Swelling



- 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

Zornberg et al. (2017)

25

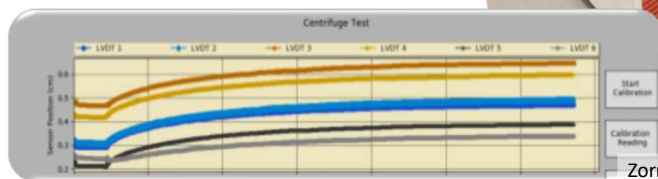
# Centrifuge Testing for Direct Measurement of Swelling

## Centrifuge Device:

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

## Measurements:

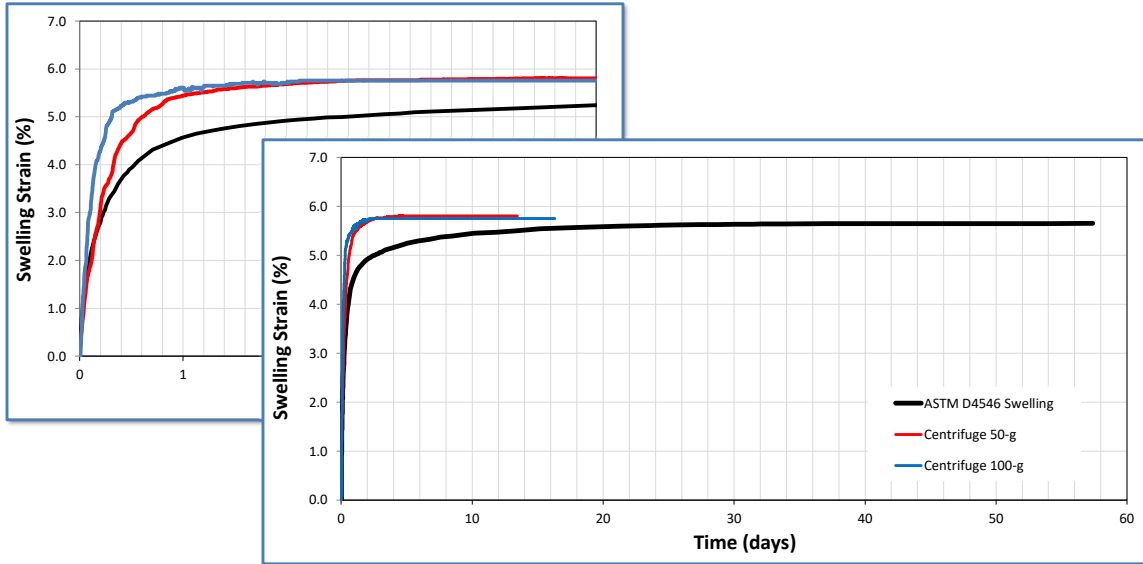
- Six simultaneous specimens tested
- Real-time, in-flight measurements:
  - Vertical displacements
  - G-level



Zornberg et al. (2017)

26

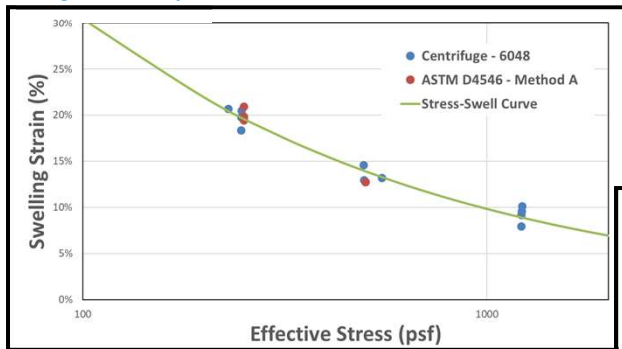
# Typical Swell Test Results



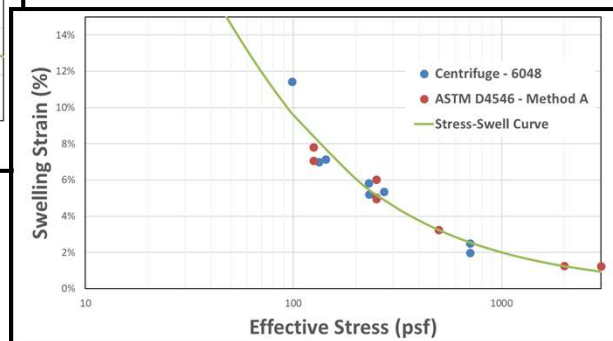
27

# Comparison of Swell-stress Curves

Eagle Ford Clay:



Cook Mountain Clay:



Zornberg et al. (2017)

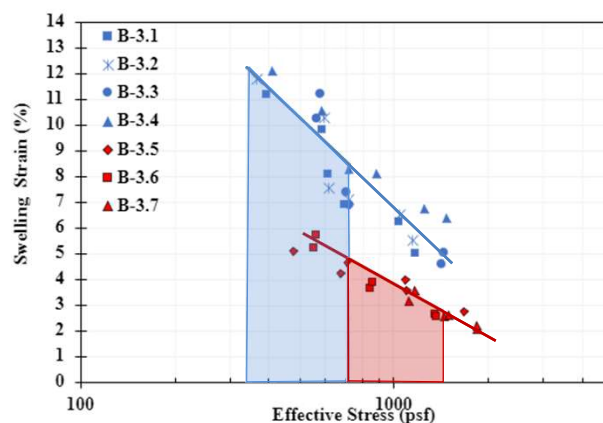
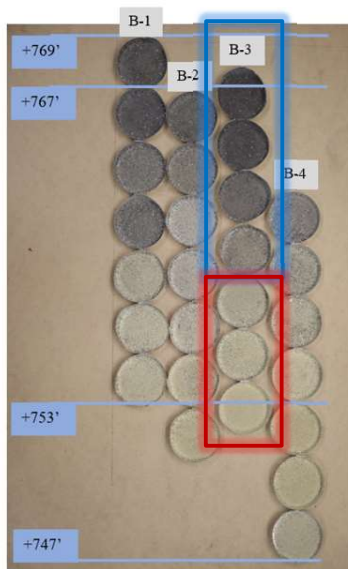
28

## 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**

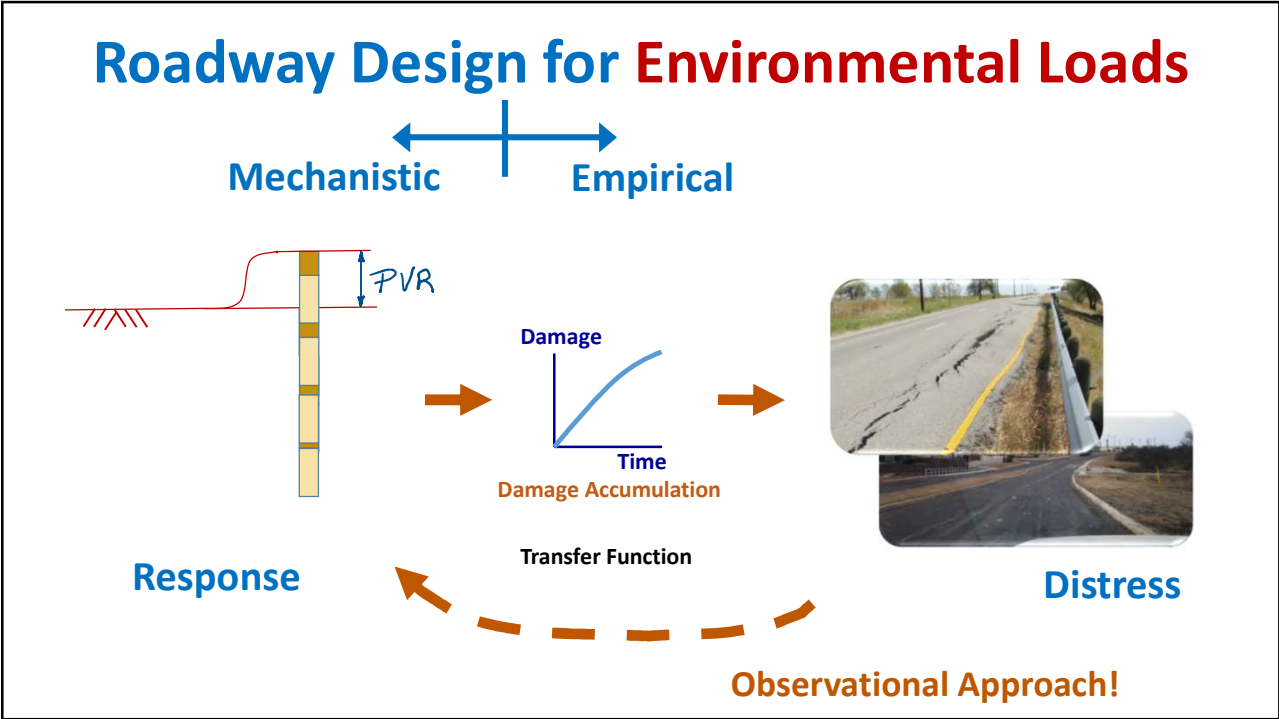
29

## 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.

30



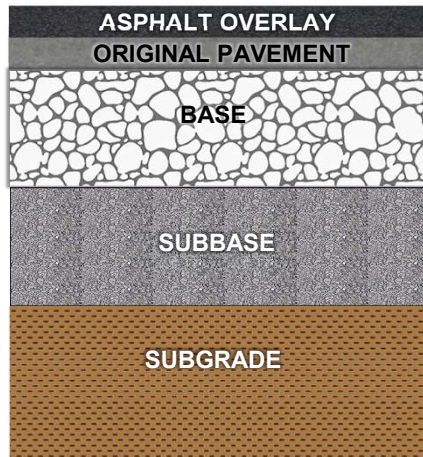
31



32



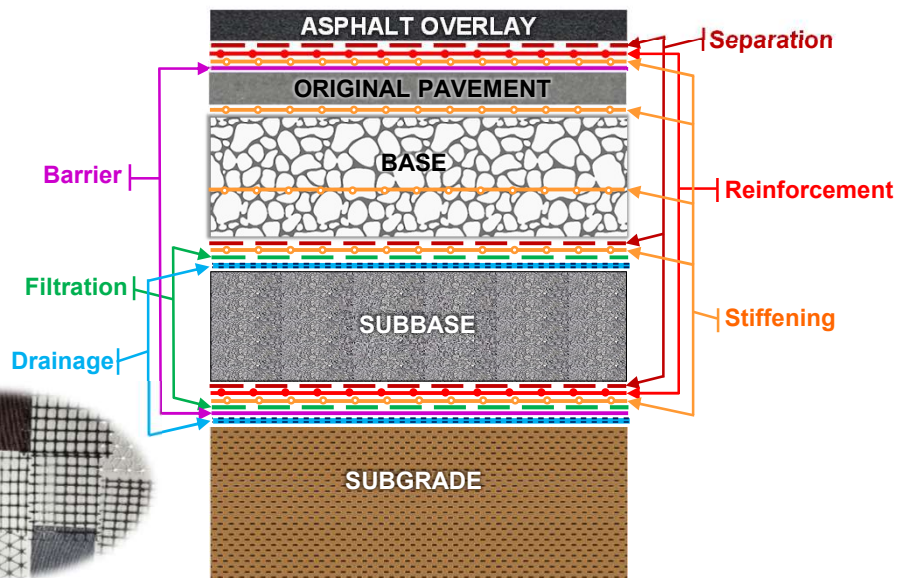
# Geosynthetics in Roadway Applications



Zornberg (2017)

33

# Geosynthetics in Roadway Applications



Zornberg (2017)

34

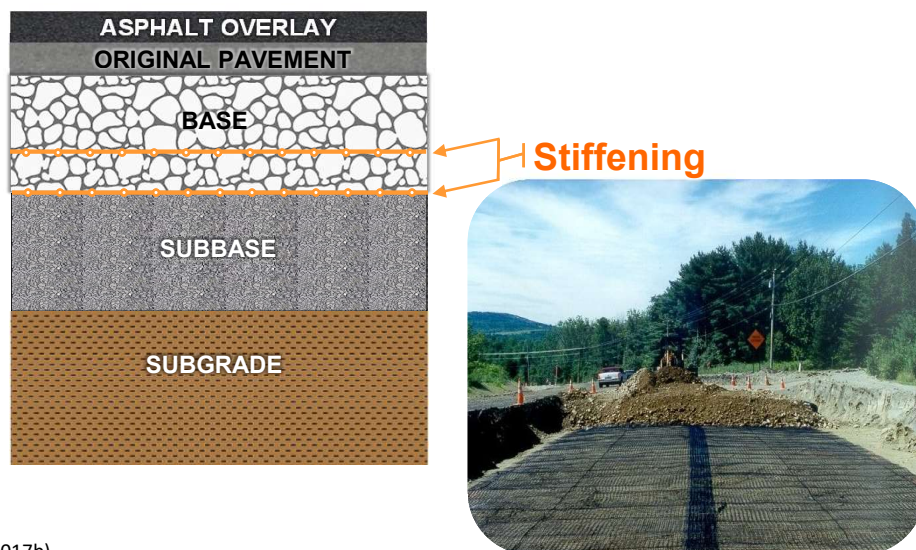
## Mitigation of Distress Induced by Expansive Clays: Mechanisms

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 width 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

35

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



Source: Zornberg (2017b)

36

# Do Geosynthetics Help?



FM 1915 (Milam County)



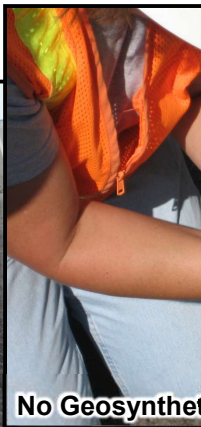
**Lesson: Geosynthetic prevented the development of longitudinal cracks**

Zornberg and Roodi (2021)

37

# To Be or Not to Be?

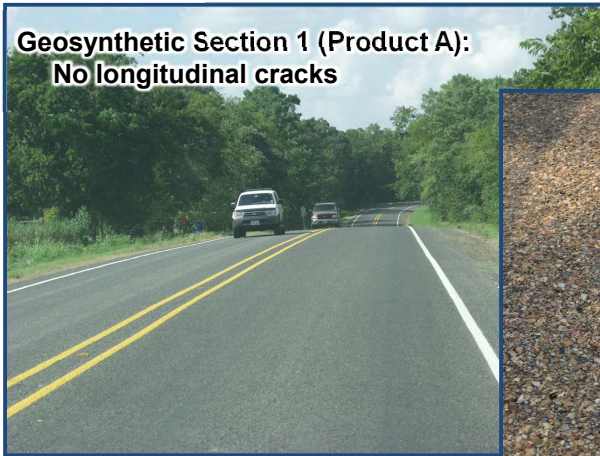
SH7 (Bryan District)



**Lesson: Geogrids appear to work ... if in place.**

38

# To Spec or not to Spec?



FM 1774 (Grimes County)



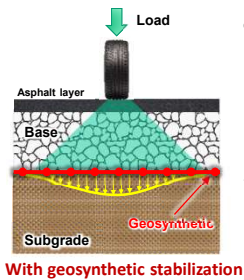
**Lesson: Geosynthetic specifications available at the time had not led to consistent performance**

Zornberg and Roodi (2021)

39

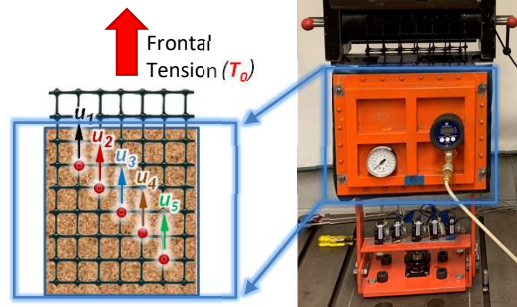
# A Different Geosynthetic Application...

... which may be governed by the same relevant property

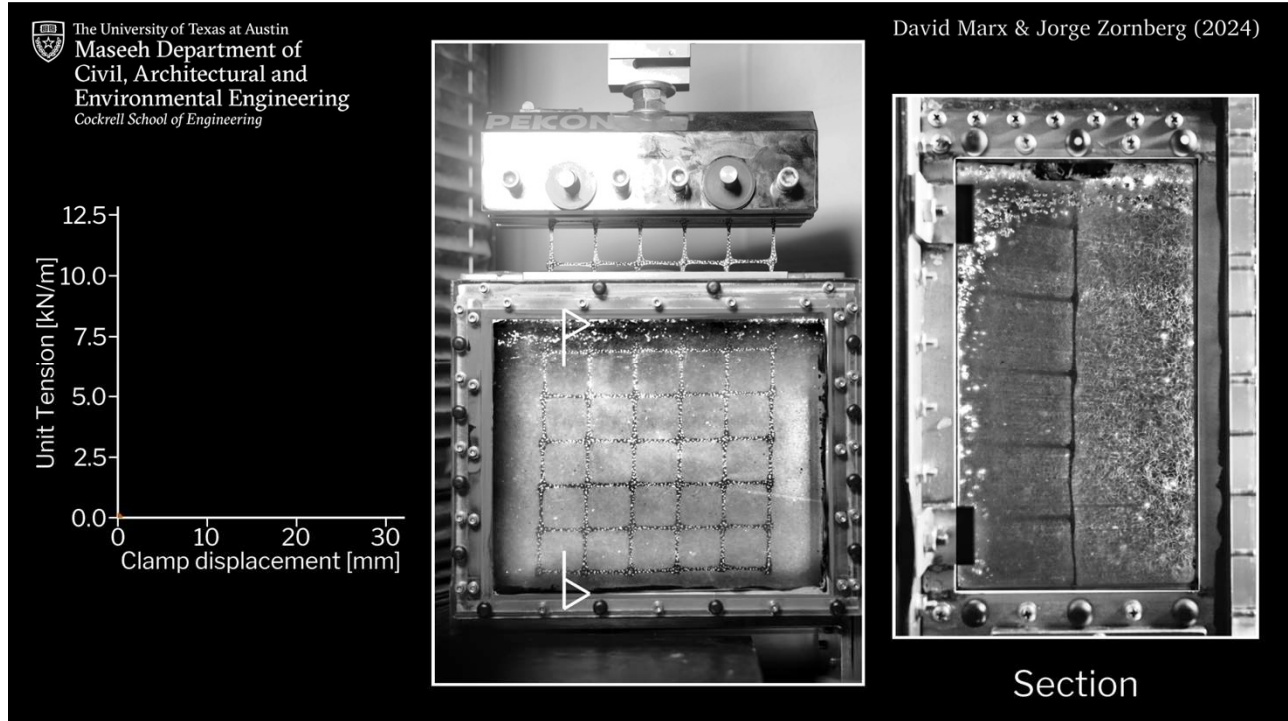


**The Application:**  
Geosynthetic-stabilization of Unbound Aggregate Layers

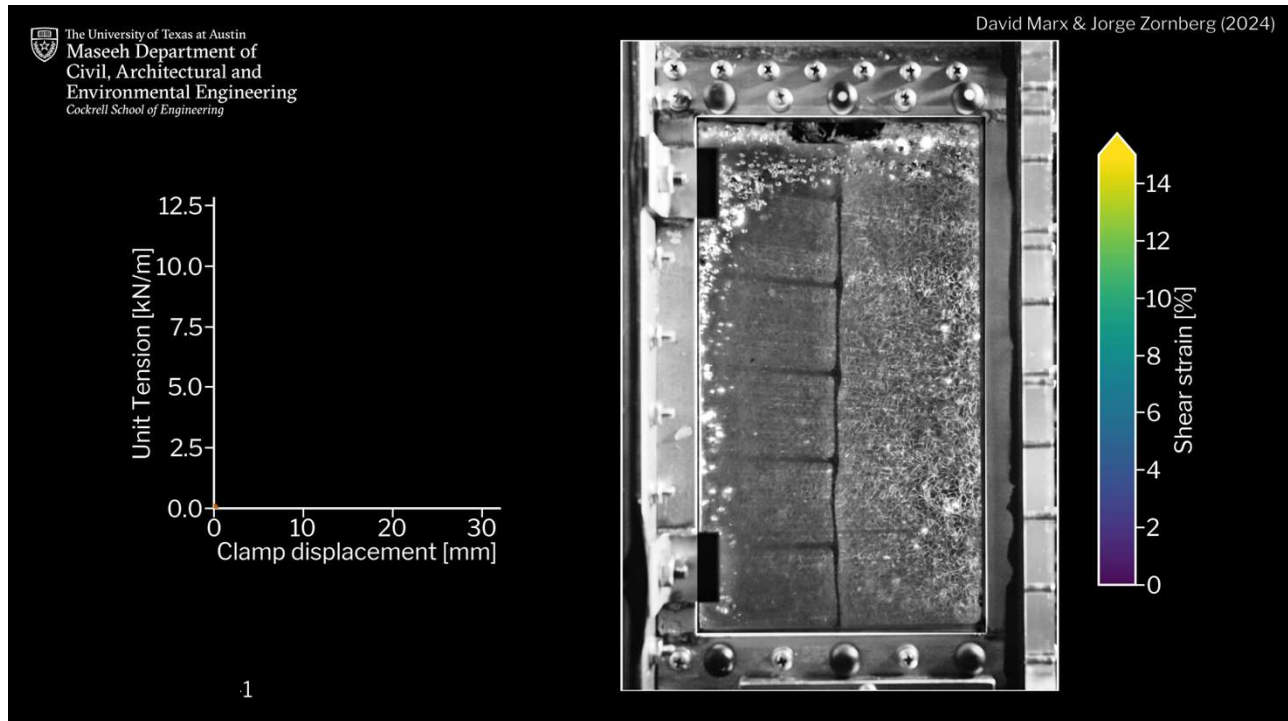
**The Relevant Property:**  
Stiffness of the Soil-geosynthetic Composite ( $K_{SGC}$ )



40

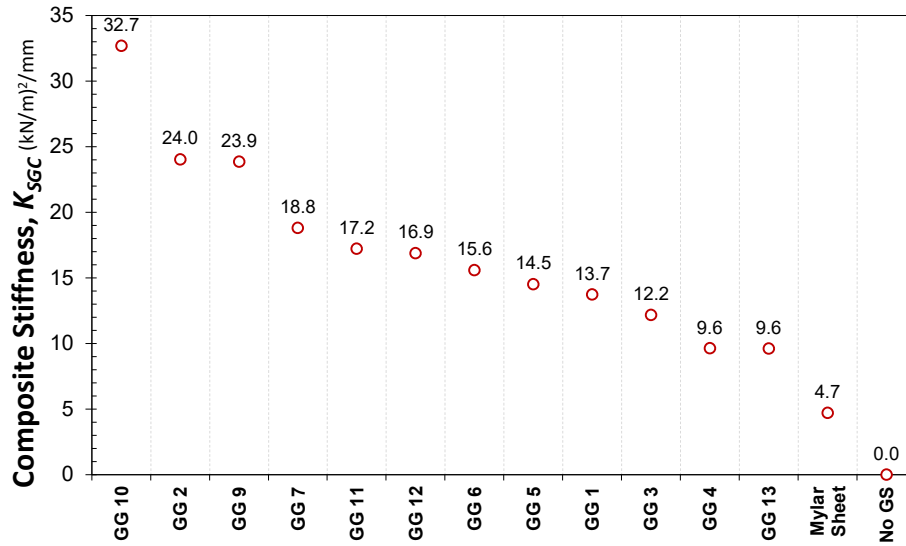


41



42

## Composite Stiffness: Results

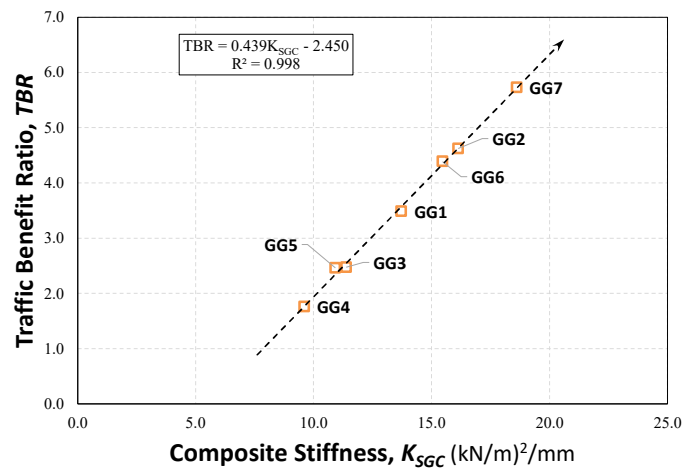
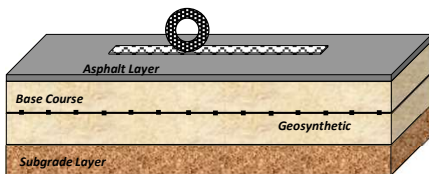


Roodi et al. (2018)

43

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

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

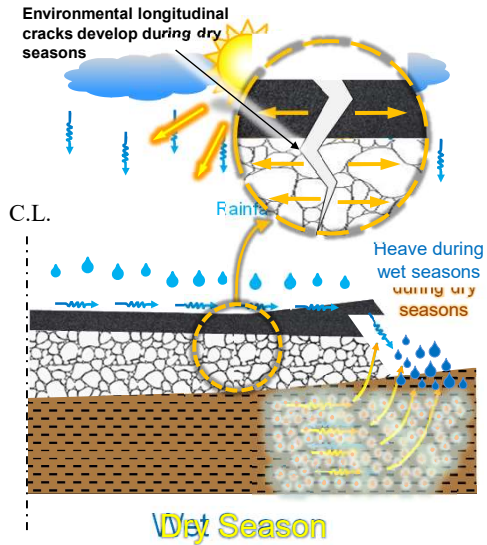


Somasundaram and Zornberg (2024)

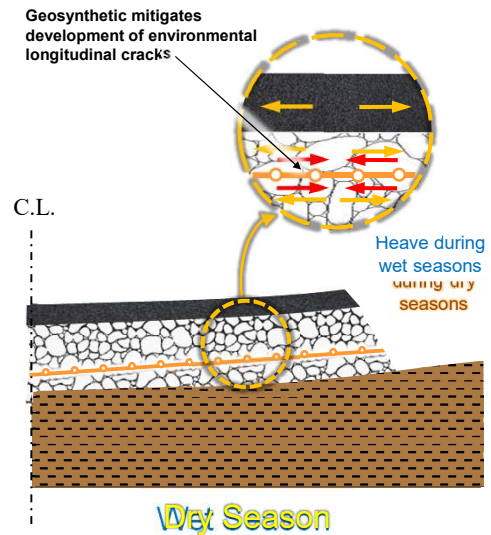
44

# Geosynthetics for Roads on Expansive Clays

## Non-Stabilized Roadway



## GS-Stabilized Roadway



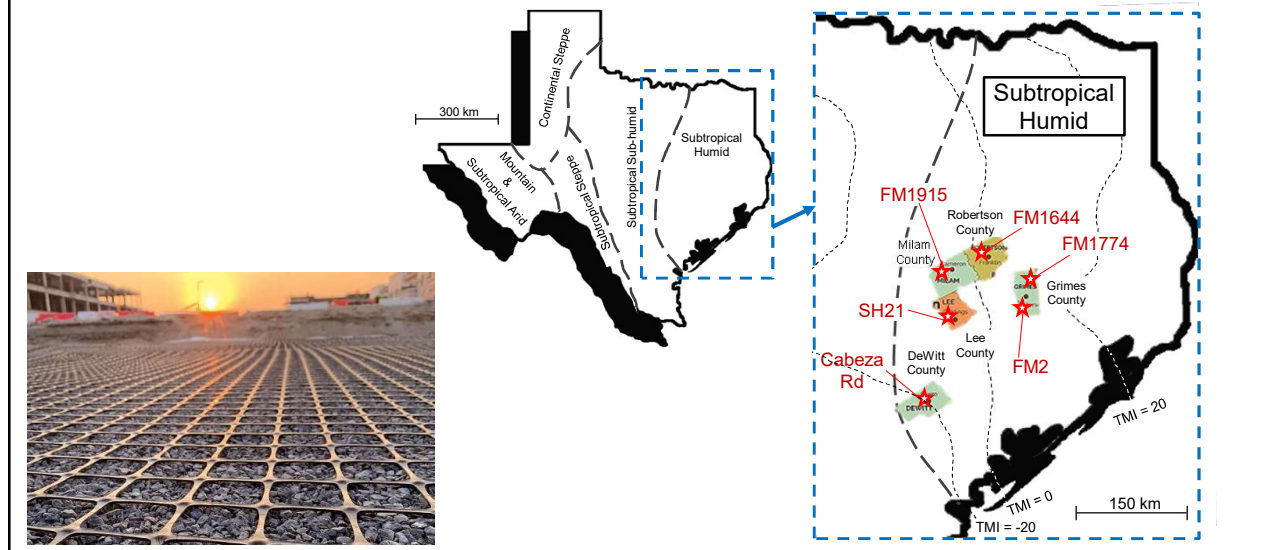
45

## Closing the Loop: Validation Against Field Performance



46

# Closing the Loop: Validation Against Field Performance

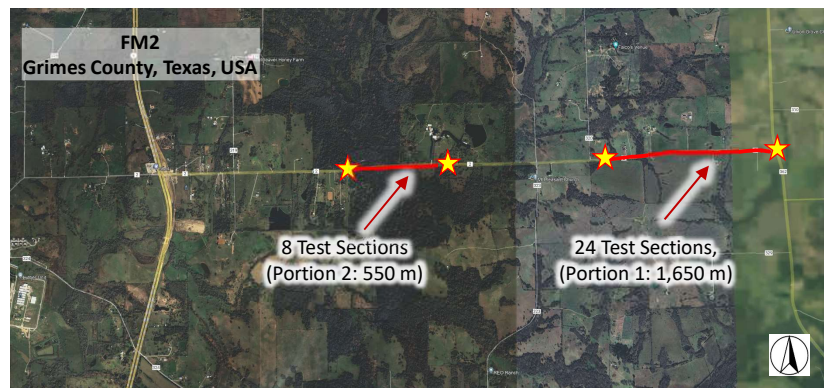


47

## 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

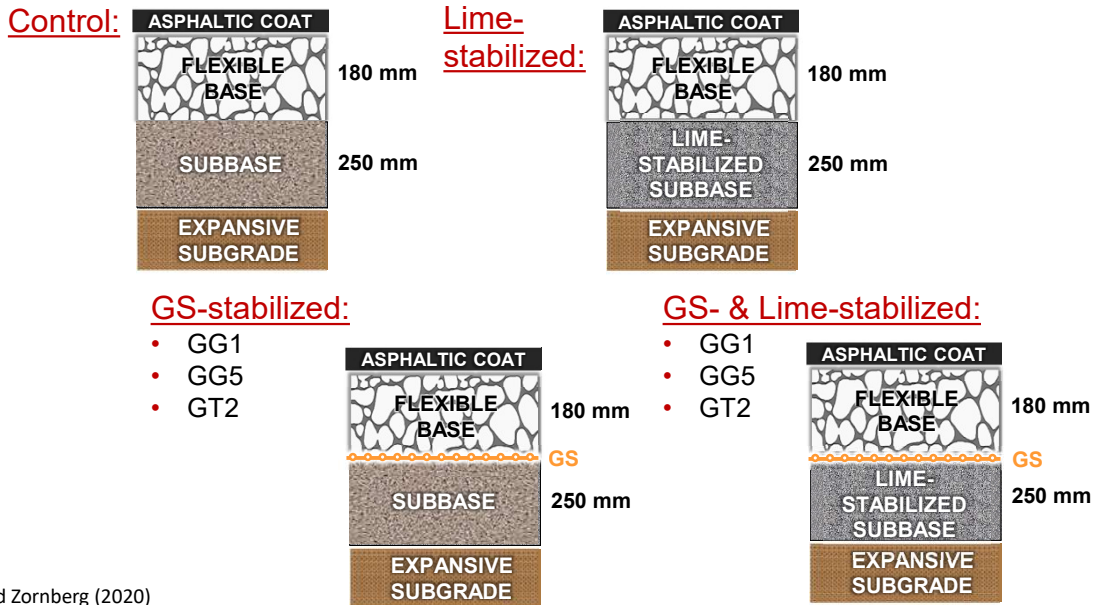


Roodi and Zornberg (2020)

48

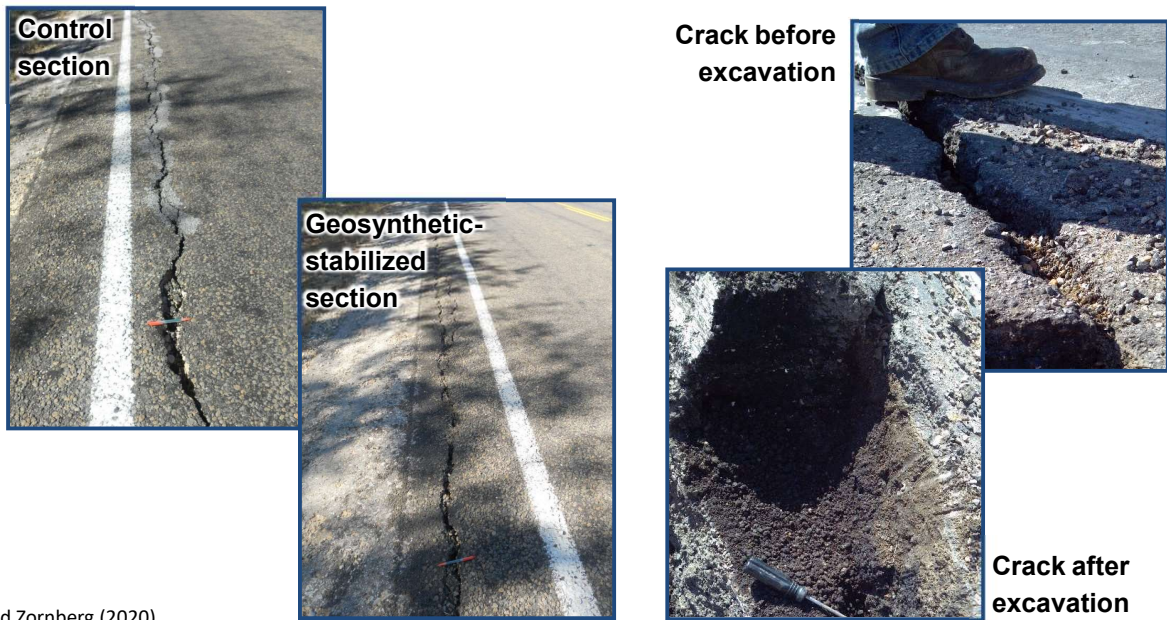


## FM2: Test Sections Evaluation



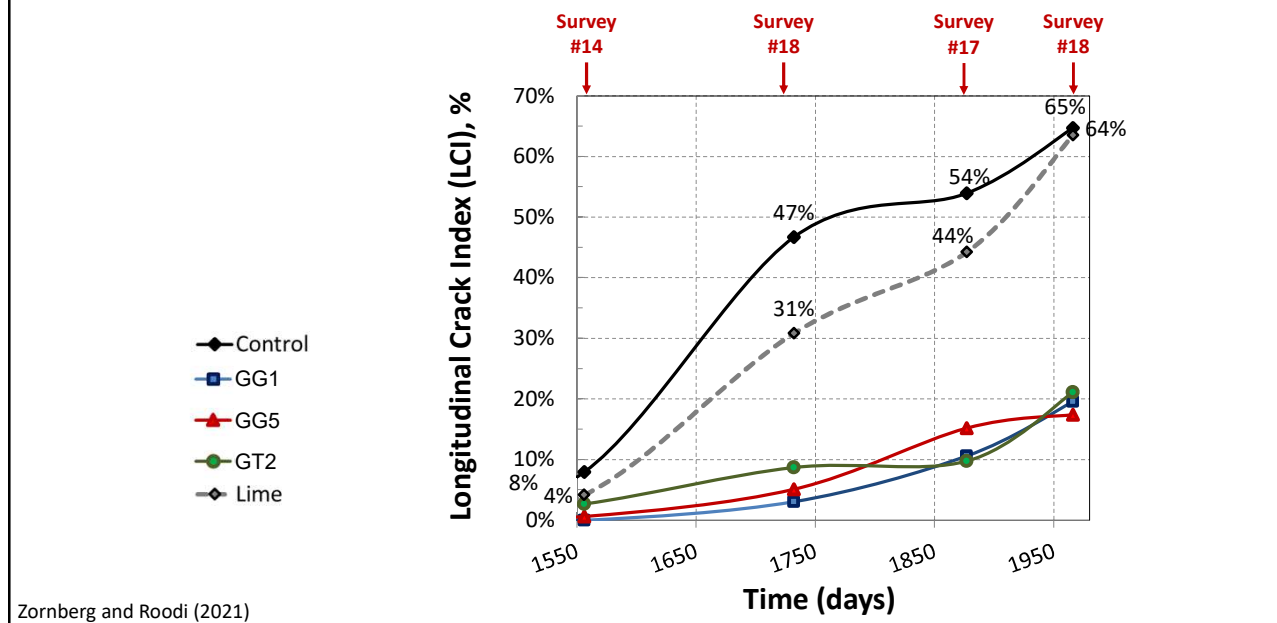
49

## FM2: Test Sections Evaluation



50

## FM2: Performance over Time



51

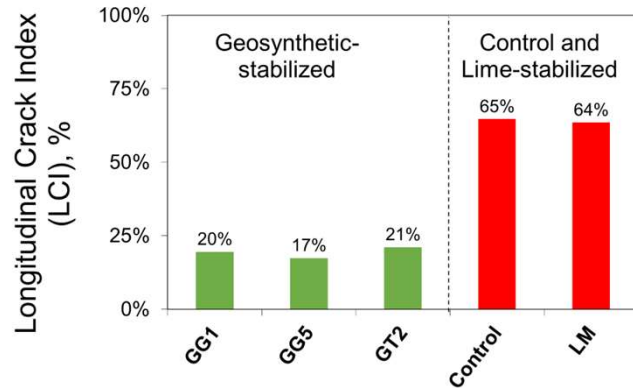


52

## 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)

53

## 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



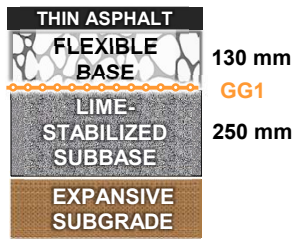
Zornberg and Roodi (2021)

54

# FM1915: Test Sections Evaluation

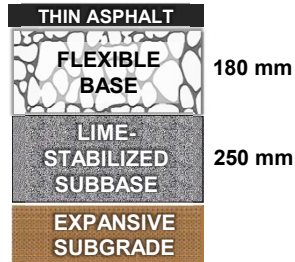
## Section A1:

- GS-stabilized
- Reduced base thickness



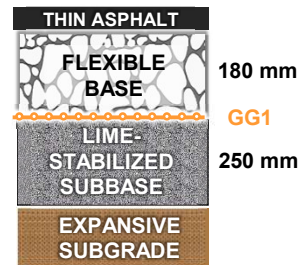
## Section A2:

- Control



## Section A3:

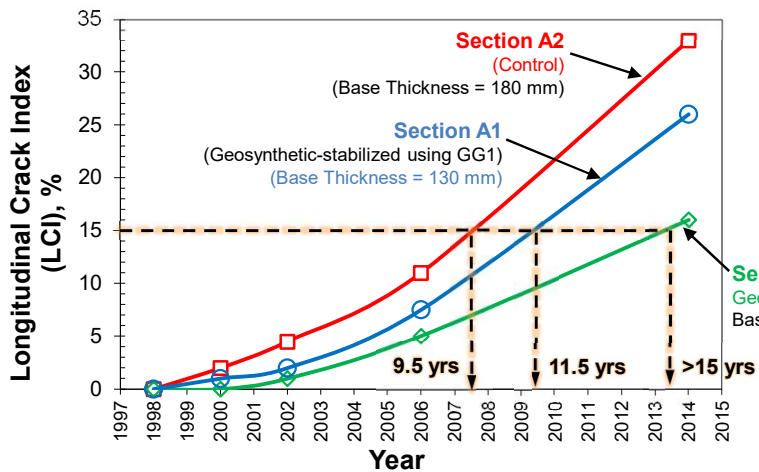
- GS-stabilized



Zornberg and Roodi (2021)

55

# FM1915: Test Sections Evaluation



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

GG1:  $K_{SGC} = 13$  ✓

Control: ✗

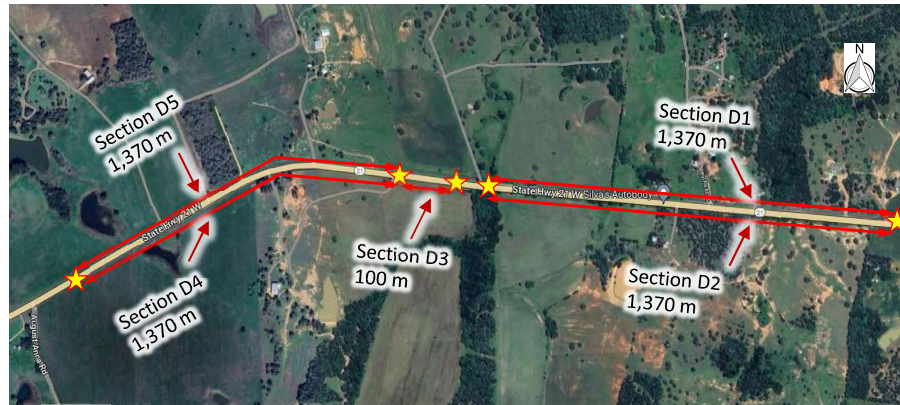
Zornberg and Roodi (2021)

56

# 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**

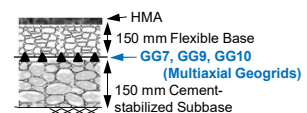
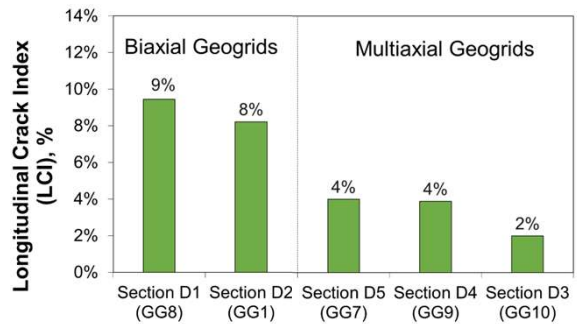
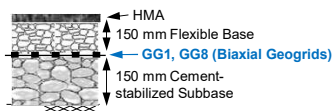


Zornberg and Roodi (2021)

57

# SH21: Test Sections Evaluation

## SH21



Zornberg and Roodi (2021)

58

# SH21: Consistency between Experimental and Field Data

SH21

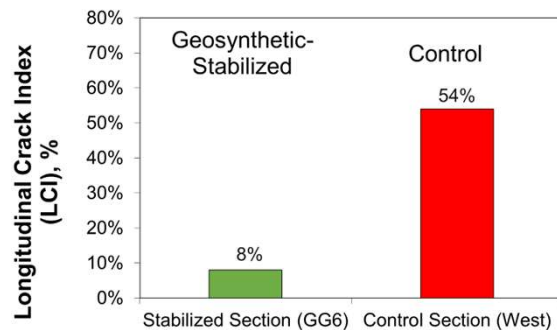
- GG1:  $K_{SGC} = 13$  ✓
- GG7:  $K_{SGC} = 19$  ✓
- GG9:  $K_{SGC} = 24$  ✓
- GG10:  $K_{SGC} = 32$  ✓
- Control:  $K_{SGC} = 32$  ✗



59

# FM1644: Consistency between Experimental and Field Data

- GG6:  $K_{SGC} = 14$  ✓
- Control:  $K_{SGC} = 32$  ✗



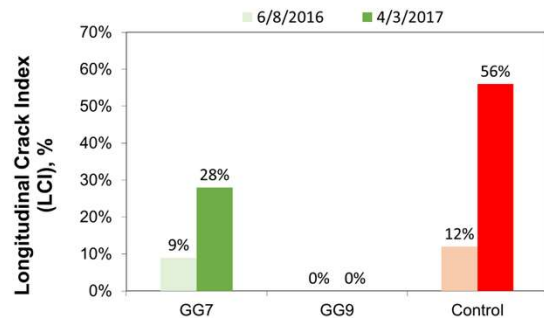
60

## Cabeza Rd: Consistency between Experimental and Field Data

GG7:  $K_{SGC} = 19$  ✓

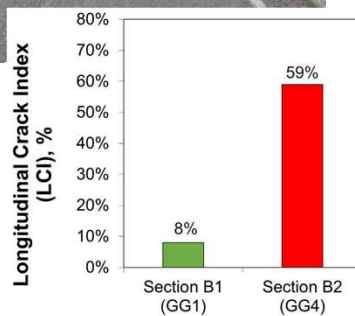
GG9:  $K_{SGC} = 24$  ✓

Control: ✗



61

## FM1774: Consistency between Experimental and Field Data



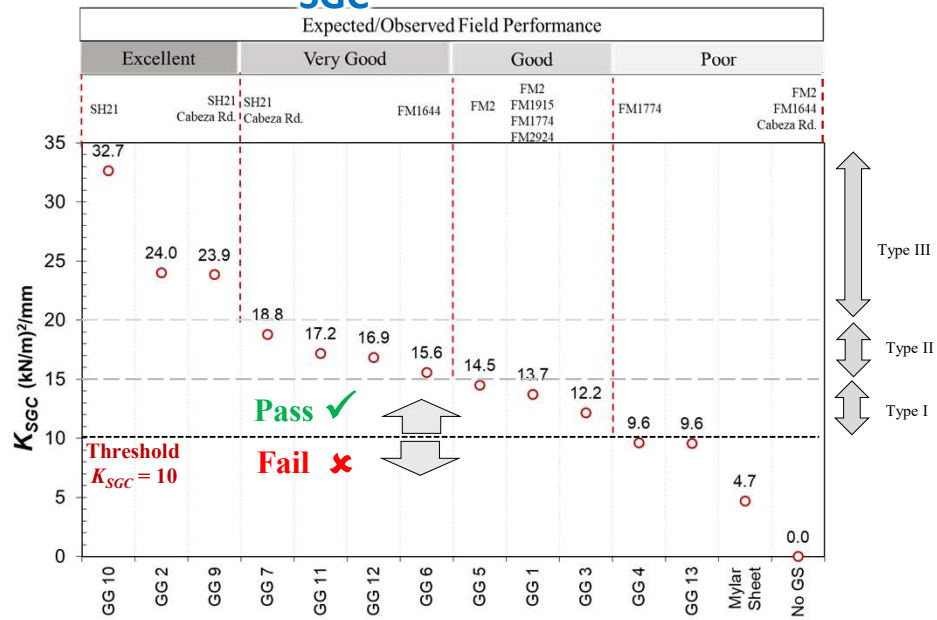
GG1:  $K_{SGC} = 13$  ✓

GG4:  $K_{SGC} = 8$  ✗

Zornberg and Roodi (2021)

62

# Correlation of $K_{SGC}$ with Field Performance



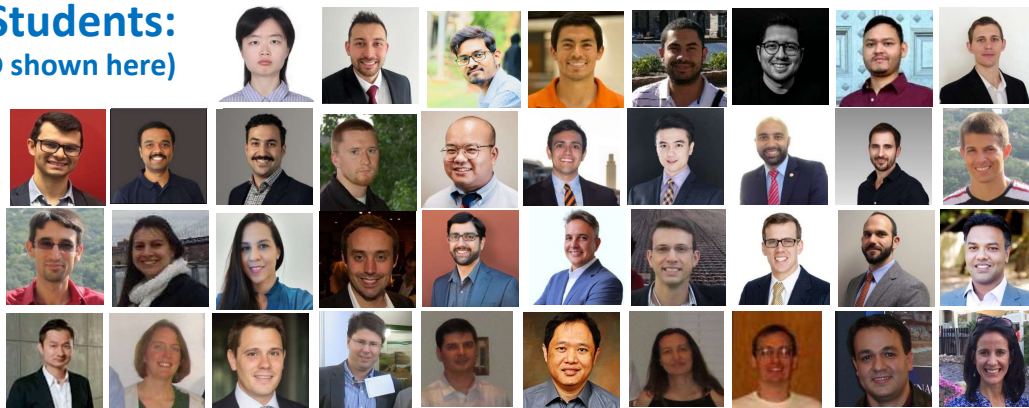
Roodi et al. (2018)

63

## Acknowledgements:



## My Students: (Only PhD shown here)

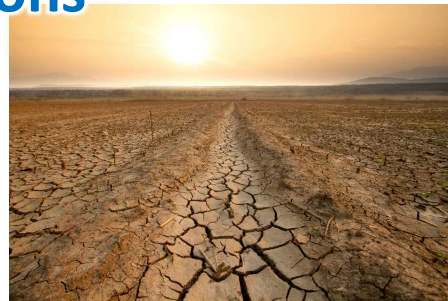


64



## 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**

65

## 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

66

## 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



67



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GEOTECNIA PARA O  
DESENVOLVIMENTO  
SUSTENTÁVEL



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# Muito Obrigado

**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*



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68



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## Realização



## Apoio Institucional



## Organização

