Mercer Lecture: Stabilization of Roadways using Geosynthetics

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SUMMARY:

This Mercer lecture provides an overview of experimental, analytical and field monitoring studies conducted to evaluate the use of geosynthetics in roadway stabilization. This includes the stabilization of roadways founded on expansive clay subgrades. The quantification of stiffness parameters, identified to assess the lateral restraint mechanism, is found to provide a good basis to evaluate the field performance of geosynthetic-stabilization paved roads.

Mercer Lecture Presentations:

- *Fifteenth Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*, ISSMGE, Fukuoka, Japan, 09 November 2015.
- *Fifteenth PanAmerican Conference on Soil Mechanics and Geotechnical Engineering*, ISSMGE, Buenos Aires, Argentina, 17 November 2015.
- *Third Pan-American Conference on Geosynthetics*, GeoAmericas 2016, IGS, Miami Beach, Florida, 13 April 2015.
- *Third International Conference on Transportation Geotechnics,* ISSMGE, Guimarães, Portugal, 07 September 2016.
- *Sixth Asian Regional Conference on Geosynthetics,* IGS, New Delhi, India, 09 November 2016.
- *Geotechnical Frontiers 2017*, Geo-Institute of ASCE, Orlando, Florida, 12 March 2017.
- *Fourth National Congress on Geosynthetics,* Peruvian Geosynthetics Society, Lima, Peru, 29 March 2017.

VITA - JORGE G. ZORNBERG, Ph.D., P.E., F.ASCE

Dr. Zornberg, P.E., F.ASCE, is Professor and W. J. Murray Fellow in the Geotechnical Engineering program at the U. of Texas at Austin. He has over 30 years' experience in research and practice in geotechnical, geosynthetics, transportation, and geoenvironmental engineering. He earned his B.S. (Hons.) from the National U. of Cordoba (Argentina), his M.S. from PUC-Rio (Rio de Janeiro, Brazil), and his Ph.D. from the U. of California at Berkeley.

As part of his professional consulting experience, Prof. Zornberg has been involved in the analysis, design and forensic evaluation of retaining walls, reinforced soil structures, roadway systems, mining facilities, impoundment lining systems, as well as urban and hazardous waste containment facilities. He has served as expert witness in cases involving the collapse of earth retaining structures, failure of geosynthetic barrier systems, and failure of pavement and infrastructure founded on expansive clays. His consulting activities have involved the evaluation of geosynthetic-reinforced covers, new methods for geosynthetic drainage layers, wind uplift of exposed geomembranes, closure of mining waste facilities, vertical expansion of waste containment facilities, leakage through defects in liner systems, impoundments for the oil and gas industry, unsaturated flow in evapotranspirative covers, deformability and stability of earth structures, roadways founded on expansive clays, geosynthetic-reinforced bridge abutments, and liner alternatives for landfill and mining systems. Prof. Zornberg evaluated the closure of high-profile hazardous waste facilities, including the first evapotranspirative cover and the first triple-lined system in US Superfund sites. He was involved in the first integral geosynthetic-reinforced bridge abutment in a US highway.

As part of his academic experience, Prof. Zornberg conducts research on soil reinforcement, geosynthetics, earth retaining structures, unsaturated soils, liner systems, and numerical and physical (centrifuge) modeling of geotechnical and geoenvironmental systems. His research has been sponsored by the National Science Foundation, Federal Highway Administration, Transportation Research Board, Environmental Protection Agency, US Department of Education, Geosynthetic Institute, geosynthetic manufacturers, as well as the Departments of Transportation of Texas, Colorado and California. Prof. Zornberg's research in the area of soil reinforcement includes the evaluation of failure mechanisms of retaining walls, strain distribution within reinforced soil structures, fiber-reinforced soil, geosynthetic-reinforced bridge abutments, creep response of geosynthetics, geosynthetic stabilization of roadway systems, and use of geosynthetics to reinforce poorly draining fills. Prof. Zornberg's research in the area of environmental geotechnics includes the analysis of geosynthetic drainage layers, leakage through geomembrane defects, shear strength of geosynthetic clay liners, analysis of exposed geomembrane covers, hydraulic characterization of unsaturated soils, performance of unsaturated soil covers, benign reuse of waste, characterization of expansive clays, and the behavior of unsaturated geosynthetics. He has offered numerous short courses, and teaches graduate courses on Earth Retaining Structures and on Geoenvironmental Engineering at the U. of Texas at Austin.

In recognition to his contributions, Prof. Zornberg received the *Presidential Early Career Award for Scientists and Engineers* (*PECASE*) awarded by President George W. Bush in 2002. This Presidential Award is "the highest honor bestowed by the United States Government on outstanding scientists and engineers beginning their independent careers." In addition, Dr. Zornberg received the Mercer Lecture award (ISSMGE and IGS, 2015), the J. James R. Croes Medal from the *American Society of Civil Engineers* (ASCE, 2012), the *Best Paper Award* from the *Journal of GeoEngineering* (2011), the *Best Paper Award* from the *Geosynthetics International* Journal (2010), the *IGS Award* from the International Geosynthetics Society (2004), the *Award of Excellence* from the North American Geosynthetics Society (NAGS, 2003), the *Research Development Award* from the CE Department at the U. of Colorado (2003), the *CAREER Award* from the National Science Foundation (NSF, 2001), the *Young Researcher Award* from the Civil Engineering Department at the U. of Colorado (2001), the *Collingwood Prize* from the American Society of Civil Engineers (ASCE, 2000), the *Junior Faculty Development Award* from the University of Colorado (1999), and the *Young IGS Member Award* from the International Geosynthetics Society (1996).

Prof. Zornberg served as President of the International Geosynthetics Society (IGS), a non-profit organization with over 4,000 members worldwide (2010-14). In addition, he currently chairs the Technical Committee on Geosynthetics of the Geo-Institute of ASCE and co-chairs the 2017 Geo-Congress. Prof. Zornberg has authored over 400 technical publications. He has authored several book chapters and served as editor in *ASCE Geotechnical Special Publications.* Prof. Zornberg was awarded three patents. He is an Editorial Board member of the journals *Geosynthetics International*, *Geotextiles and Geomembranes*, *Soils and Rocks*, *GeoEngineering*, and *Transportation Geotechnics*. Prof. Zornberg chaired the *First Pan-American Geosynthetics Conference* (*GeoAmericas 2008)* held in Cancún, Mexico and co-chairs the *Geotechnical Frontiers 2017* Conference to be held in Orlando, FL. He has been invited to deliver keynote lectures in numerous events around the world, including the USA, Mexico, Honduras, Colombia, Brazil, Peru, Argentina, Chile, the UK, Spain, Portugal, Belgium, France, Germany, Poland, Russia, Turkey, Israel, India, South Korea, Japan, China, Taiwan, Australia, New Zealand, Ghana, Mozambique and South Africa.

Mercer Lecture: Stabilization of Paved Roads using Geosynthetics

J.G. Zornberg, Ph.D., P.E., F.ASCE
The University of Texas, Austin, Texas, USA

Executive Summary

Geosynthetics have been used as reinforcement inclusions to improve pavement performance. While there are clear field evidences of the benefit of using geosynthetic reinforcements, the specific conditions or mechanisms that govern the reinforcement of pavements are, at best, unclear and have remained largely unmeasured. Significant research has been recently conducted with the objectives of: (i) determining the relevant properties of geosynthetics that contribute to the enhanced performance of pavement systems, (ii) developing appropriate analytical, laboratory and field methods capable of quantifying the pavement performance, and (iii) enabling the prediction of pavement performance as a function of the properties of the various types of geosynthetics.

Geosynthetics have been used in pavement design to address the functions of separation, filtration, lateral drainage, sealing, and reinforcement. Specifically, geosynthetics have been used for separation in pavement projects to minimize intrusion of subgrade soil into the aggregate base or sub-base. Also, geosynthetics have been used to perform a filtration function by restricting the movement of soil particles from the subgrade while allowing water to move to the coarser adjacent base material. In-plane drainage function of a geosynthetic can provide lateral drainage within its plane. In addition, geosynthetics have been used to mitigate the propagation of cracks by sealing the asphalt layer when used in pavement overlays. Finally, geosynthetics have been used in flexible pavements for reinforcement, which is the main focus of this paper. While the reinforcement function has often been accomplished using geogrids, geotextiles have also been used as reinforcement inclusions in transportation applications. The geosynthetic reinforcement is often placed at the interface between the base and sub-base layers or the interface between the sub-base and subgrade layers or within the base course layer of the flexible pavement. This leads to lower stresses over the subgrade than in unreinforced flexible pavements.

The improved performance of the pavement due to geosynthetic reinforcement has been attributed to three mechanisms: (1) lateral restraint, (2) increased bearing capacity, and (3) tensioned membrane effect. The primary mechanism associated with the reinforcement function for flexible pavements is lateral restraint or confinement. The name of this mechanism may be misleading as lateral restraint develops through interfacial friction between the geosynthetic and the aggregate, thus the mechanism is one of a shear-resisting interface. When an aggregate layer is subjected to traffic loading, the aggregate tends to move laterally unless it is restrained by the subgrade or by geosynthetic reinforcement. Interaction between the base aggregate and the geosynthetic allows transfer of the shearing load from the base layer to a tensile load in the geosynthetic. The tensile stiffness of the geosynthetic limits the lateral strains in the base layer. Furthermore, a geosynthetic layer confines the base course layer thereby increasing its mean stress and leading to an increase in shear strength. Both frictional and interlocking characteristics at the interface between the soil and the geosynthetic contribute to this mechanism. Consequently, the geogrid apertures and base soil particles must be properly sized. A geotextile with good frictional capabilities can also provide tensile resistance to lateral aggregate movement.

The aforementioned mechanisms require different magnitudes of deformation in the pavement system to be mobilized. In the case of unpaved roads, significant rutting depths (in excess of 25 mm) may be tolerable. The increased bearing capacity and tensioned membrane support mechanisms have been considered for paved roads. However, the deformation needed to mobilize these mechanisms generally exceeds the serviceability requirements of flexible pavements. Thus, for the case of flexible pavements, lateral restraint is considered to contribute the most for their improved performance.

The results of field, laboratory and numerical studies have demonstrated the benefits of using geosynthetics to improve the performance of pavements. However, selection criteria for geosynthetics to be used in reinforced pavements are not well established yet. The purpose of this paper was to summarize information generated so far to quantify the improvement of geosynthetics when used as reinforcement inclusions in flexible pavement projects.

A Pullout Stiffness Test (PST) was recently developed at the University of Texas, Austin in order to quantify the soil-geosynthetic interaction in reinforced pavements. The equipment involves a modified large-scale pullout test modified to capture the stiffness of the soil-geosynthetic interface under small displacements. Research conducted using the PST has shown that monotonic pullout tests aimed at characterizing the soil-geosynthetic interaction under low displacements are promising. Although these pullout tests did not replicate the cyclic nature of traffic load conditions, it simulated the interface transfer mechanisms between soil and geosynthetic reinforcements that are expected in the field.

An analytical model was proposed to predict the confined load-strain characteristics of soil-geosynthetic systems under small displacements using the results obtained from the PST. This approach takes into account both the confined stiffness (J_c) and ability of geosynthetic to mobilize shear or interlock (τ_y), which are two important parameters governing the performance of geosynthetic interfaces. The two parameters can be combined to define a unique coefficient of soil-geosynthetic composite (K_{SGC}) that characterizes the soil-reinforcement interface. This coefficient is computed as:

$$K_{SGC} = 4.\tau_y.J_C \qquad (1)$$

A comprehensive field monitoring program is under way to relate the field performance to laboratory PST results for a number of geosynthetic reinforcements. While ongoing field monitoring is still in progress, good agreement has been obtained so far between the field performance and the properties defined from PST testing. Thus, a new performance-based test method in the form of a pullout stiffness test is promising as a performance-based test to evaluate the soil-geosynthetic confinement.

An overall assessment of the various tests developed so far for geosynthetic-reinforced pavements indicates that unconfined tests are simple, economical and expeditious, although they do not capture the important aspects associated with confinement and the type of soil. Also, unconfined tests have provided only index measures of the actual mechanisms, requiring subsequent correlations with field performance. It should be noted that field studies sometimes led to performance trends that contradicted the trends obtained using properties from unconfined tests. Accordingly, and based on the current body of literature, unconfined tests are considered inadequate for assessment of the performance of geosynthetic-reinforced pavements.

Previous research has led to a reasonably good understanding of the benefits achieved with the use of geosynthetics in pavement design but, for the most part, only from the empirical point of view. That is, while methods have been developed for designing geosynthetic-reinforced flexible pavements, quantification of the reinforcement mechanisms, identification of properties governing the pavement performance and, ultimately, acceptable design guidelines are yet unavailable.

Efforts are currently under way in the US to develop design models consistent with the AASHTO and mechanistic-empirical (M-E) approaches. The TBR and BCR ratios have been used in the AASHTO approach but are limited because the approaches are specific to the products and test conditions under which these ratios have been calibrated. Thus, M-E methods are considered more generic and, consequently, more promising as framework to incorporate the use of geosynthetics in current pavement design. However, due to the complex nature of flexible pavements, research to identify and quantify the properties governing the performance of reinforced pavements and its incorporation into M-E design is still under way.

The available literature involving field and laboratory test results is conclusive in that the mechanical properties of the geosynthetics used for pavement applications are improved under the confinement provided by the soil. Field test sections showed improved performance in the reinforced sections over the unreinforced sections in terms of reduced surface deflections. Overall, available experimental evidence indicates that the improved performance of geosynthetic-reinforced pavements can be attributed to lateral restraint mechanisms. Efforts are ongoing to quantify the lateral restraint in terms of the interface shear stiffness property of the soil-geosynthetic system.

Estabilización de Carreteras usando Geosintéticos

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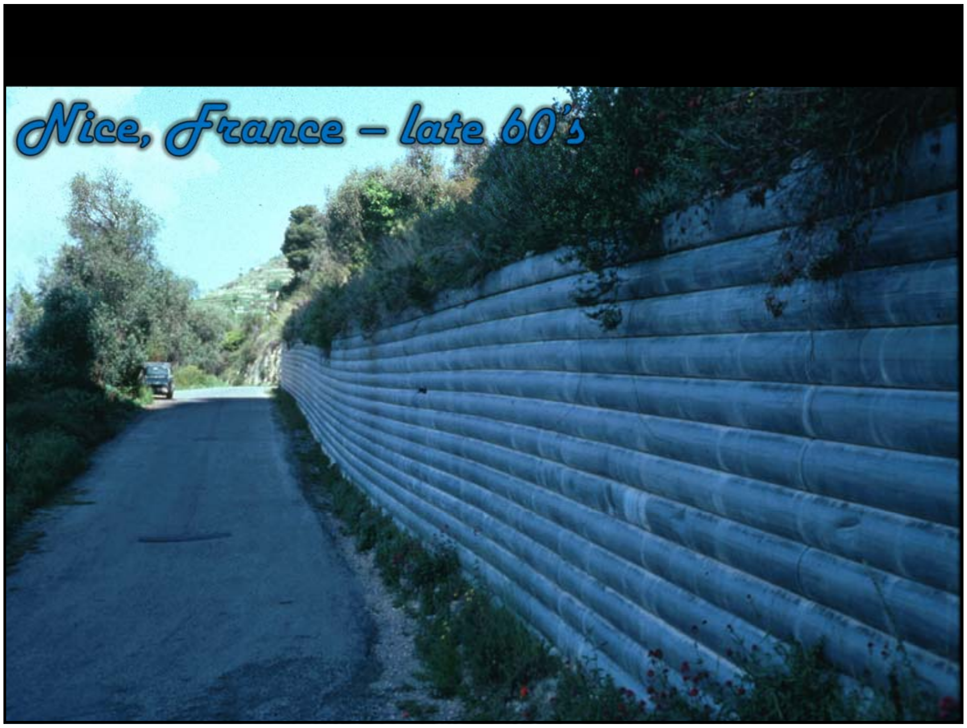
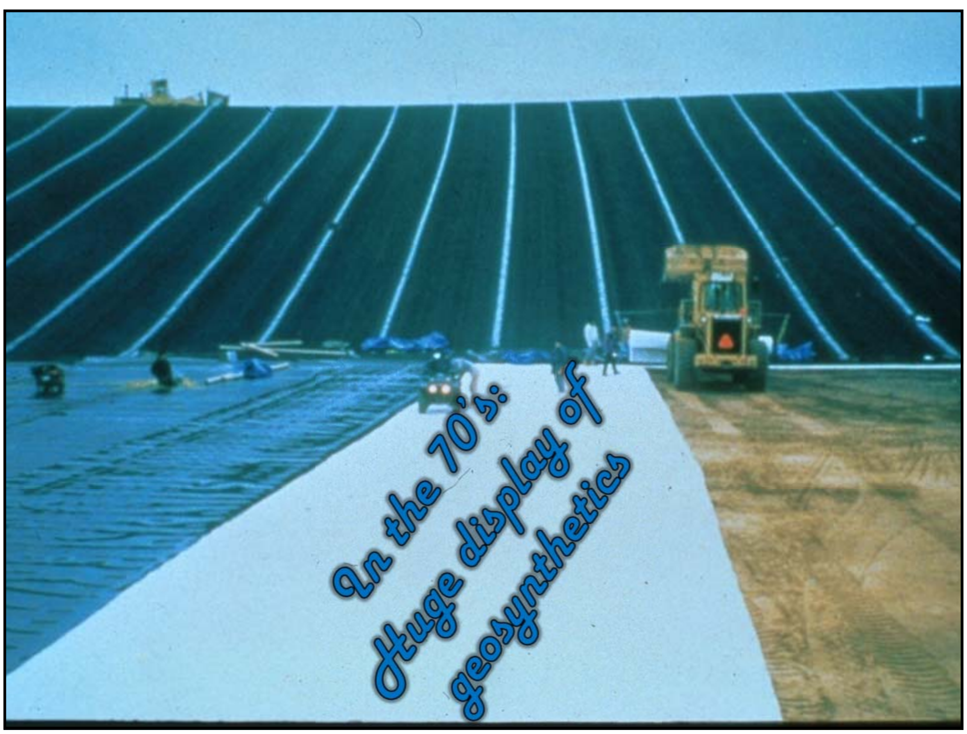
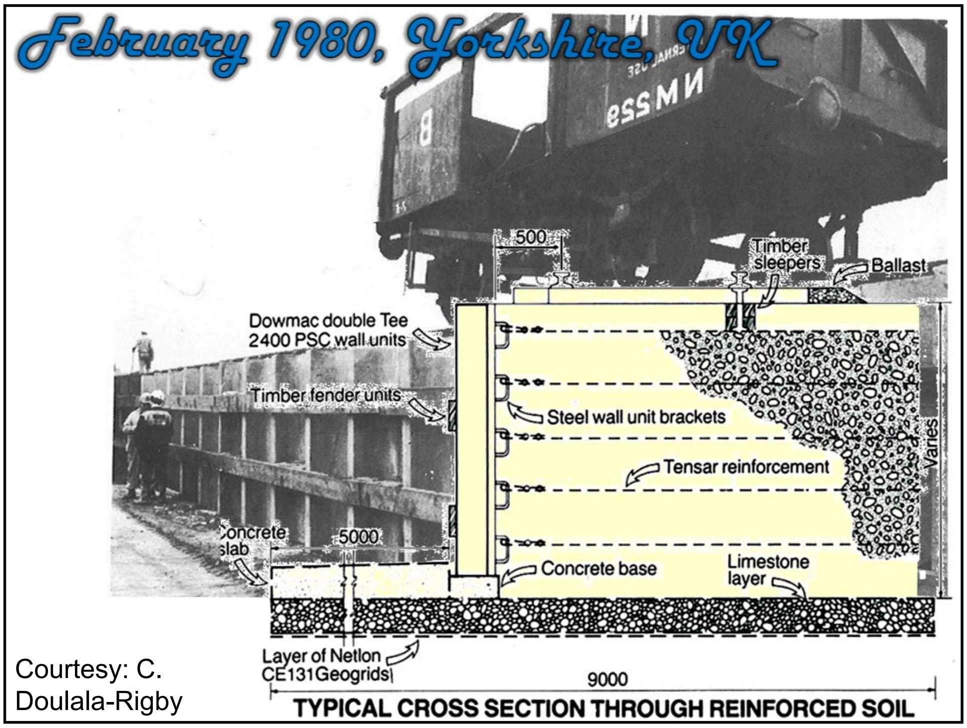
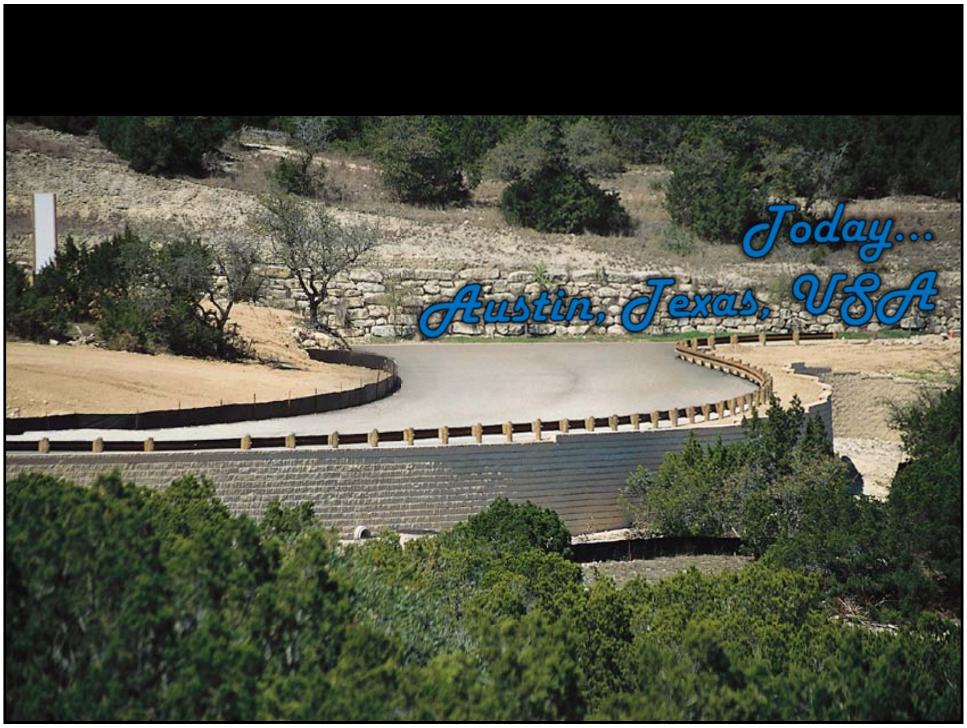
29 March 2017
Lima, Peru


Nice, France – late 60's


In the 70's:
Huge display of
geosynthetics


February 1980, Yorkshire, UK
500
Timber sleepers
Ballast
Dowmac double Tee 2400 PSC wall units
Timber fender units
Steel wall unit brackets
Tensar reinforcement
Varies
Concrete slab
5000
Concrete base
Limestone layer
Layer of Netlon CE131Geogrids
9000
TYPICAL CROSS SECTION THROUGH REINFORCED SOIL
Courtesy: C. Doulala-Rigby


In the 2000's: Widespread Use in Challenging Projects
Courtesy: Augusto Alza


Today…
Austin, Texas, USA


Trends for the Future…
Geosynthetic - stabilized Pavements
2001 8 27

Roadway Systems Worldwide

Circumference of earth:
40,075 km

World roads:
64,285,009 km

rounds:
1,604

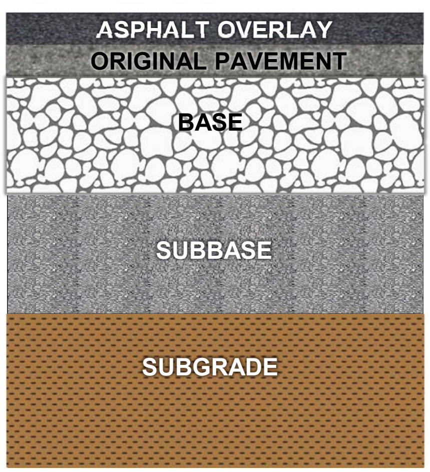
Rank	Country	Road length (km)	Expressway length (km)	Date of Information
1	United States	5,486,610	103,027	2013
2	India	5,472,144	1,324	2015
3	China	4,577,300	123,500	2016
4	Brazil	1,751,868	11,000	2013
5	Russia	1,396,000	806	2016
6	Japan	1,215,000	8,050	2012
7	Canada	1,042,300	17,000	2013
8	France	1,028,446	11,882	2013
9	South Africa	947,014	1,400	2014
10	Australia	823,217	3,132	2011
11	Spain	683,175	16,583	2013
12	Germany	644,480	12,917	2013
13	Sweden	579,564	2,050	2014
14	Indonesia	496,607	1,710	2014
15	Italy	487,700	6,758	2013
16	Finland	454,000	863	2015
17	Turkey	426,906	2,289	2010
18	Poland	423,997	3,050	2016
19	United Kingdom	394,428	3,519	2009
20	Mexico	389,345	15,283	2014
38	Peru	139,295	2,758	2012

Stabilization of Roadways using Geosynthetics

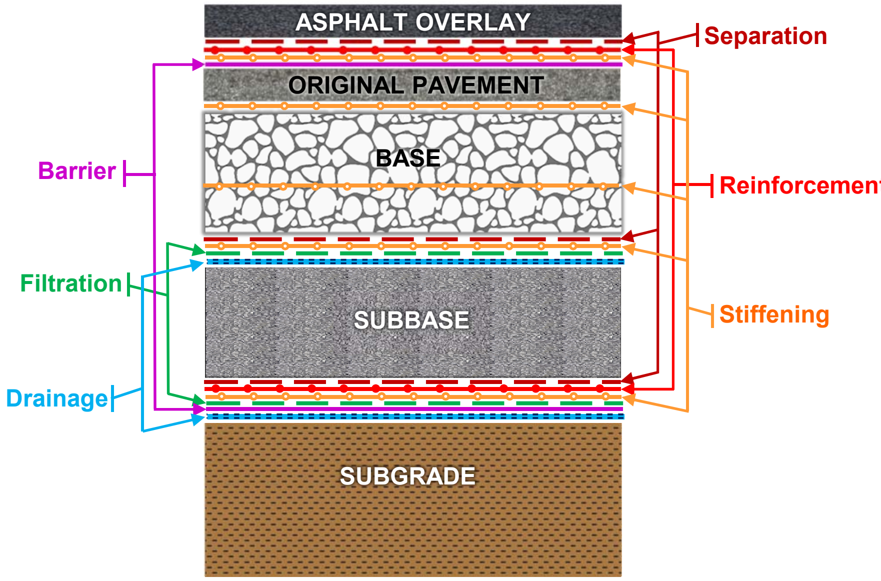
- Brief overview of geosynthetics in roadway stabilization
- A New Property – quantifying the performance of geosynthetics used for roadway stabilization
- A New Application – stabilization of paved roads over expansive clay subgrades using geosynthetics
- Final Remarks

Overview: Geosynthetics in Roadway Stabilization

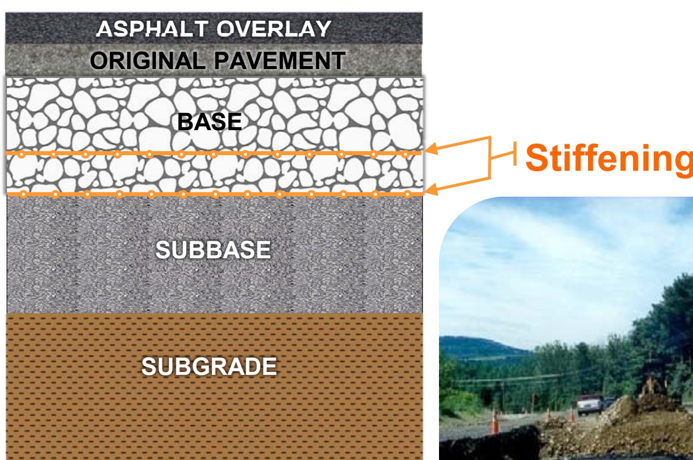
Geosynthetic Functions in Roadways



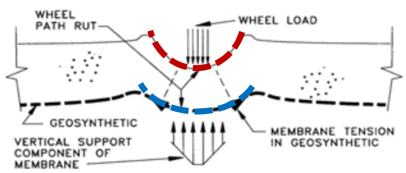
Geosynthetic Functions in Roadways



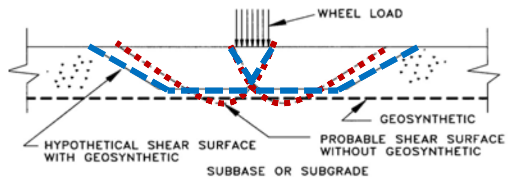
Stabilization of Road Bases



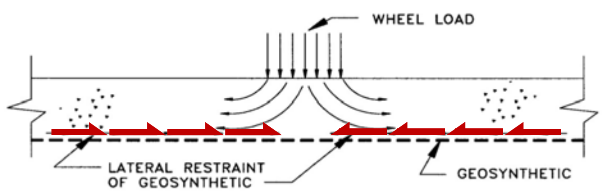
Stabilization Mechanisms



Membrane tension support



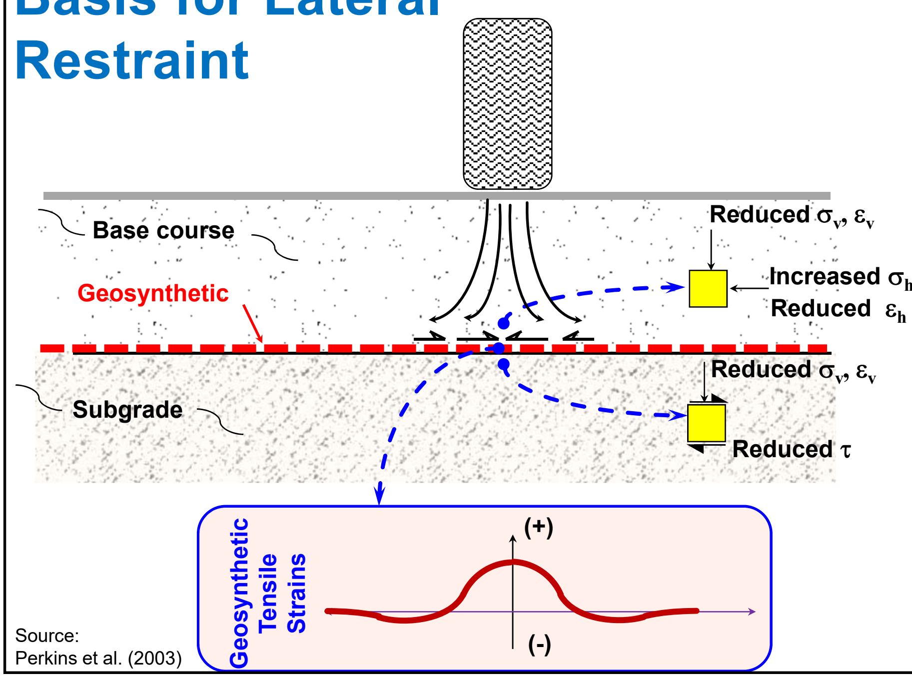
Bearing capacity increase



Lateral restraint

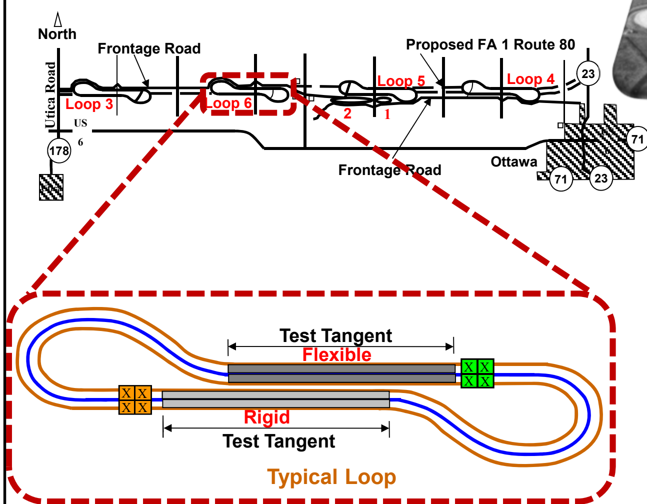
Source: Haliburton et al. (1981)

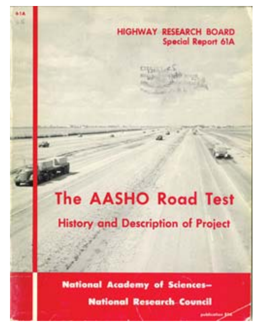
Basis for Lateral Restraint



Source:
Perkins et al. (2003)

AASHTO Pavement Design





AASHTO 93 Flexible Design Equation

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Structural Number

- W_{18} (loading)
  - Predicted number of ESALs over the pavement's life.
- SN (structural number)
  - Abstract number expressing structural strength
  - $SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$
- ΔPSI (change in present serviceability index)
  - Change in serviceability index over the useful pavement life
  - Typically from 1.5 to 3.0
- M_R (subgrade resilient modulus)
  - Typically from 3,000 to 30,000 psi (10,000 psi is pretty good)

Design Approaches

- Design objectives when using geosynthetics have been:
  - Increasing the design life for a given base thickness
  - Decreasing the base thickness for a given design life
- The benefit of using geosynthetics has been quantified using:
  - Traffic Benefit Ratio (TBR)
  - Base Course Reduction (BCR)
- Initiatives involving incorporating adequate geosynthetic properties within a M-E framework are promising

A new Property – Quantifying the Performance of Geosynthetics used for Roadway Stabilization

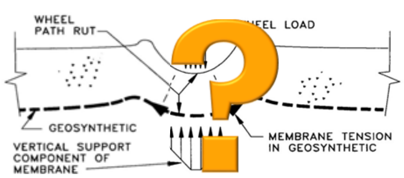
A New Property: Why?

Geosynthetic-reinforced Systems

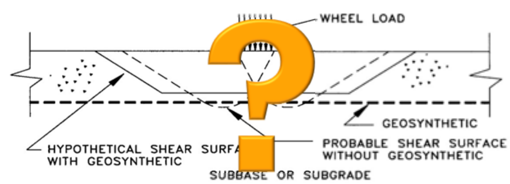
- **Earth Retention Systems** →
  - The ultimate goal is to minimize the risk of **collapse**
  - Design based on the performance of systems under **failure condition**
  - Relevant material properties correspond to **large displacement conditions**
- **Pavement Systems** →
  - The ultimate goal is to minimize excessive **distress**
  - Design is based on the performance of roads under **service conditions**
  - Relevant material properties correspond to **small displacement conditions**

A New Property: Why?

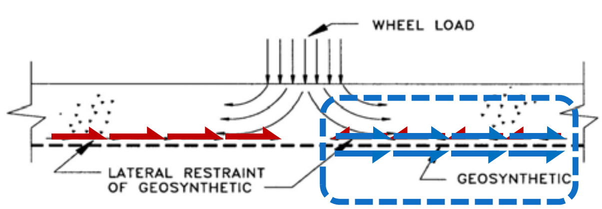
Back to the basics:



Membrane tension support



Bearing capacity increase

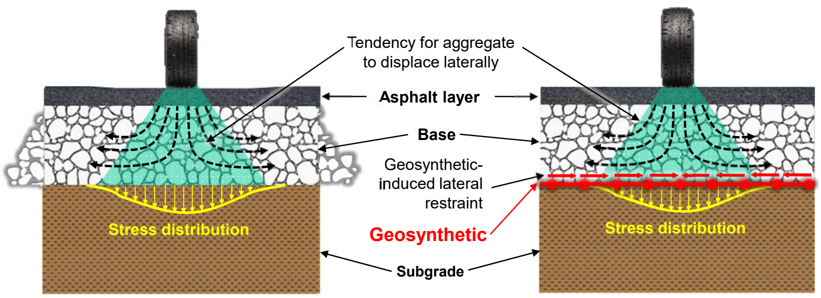


Lateral restraint

Source: Haliburton et al. 1981

A New Property: Why?

Objective: Stabilization of Road Bases



Non-stabilized Road Base   Stabilized Road Base

A New Property

An evaluation was conducted:

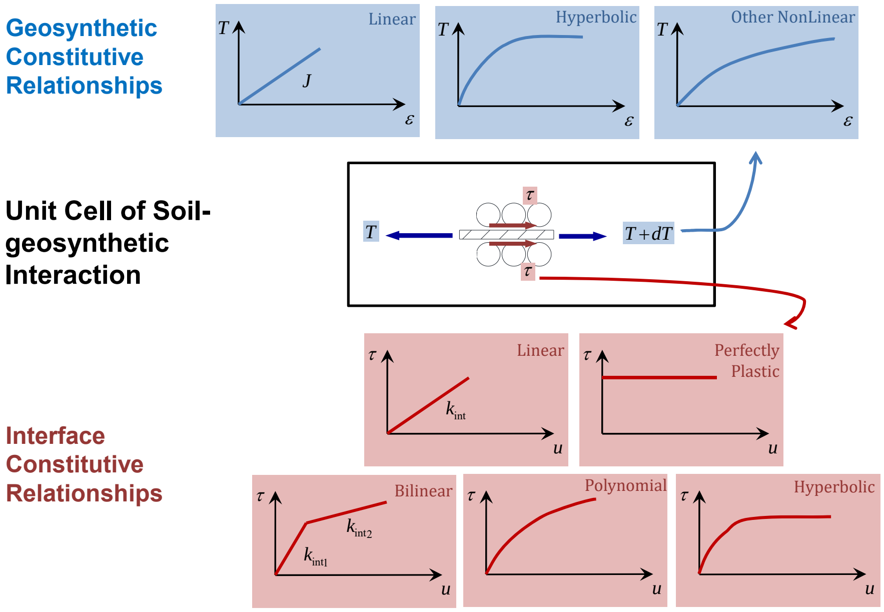
- **To identify:**
  - *a **single**, yet*
  - ***relevant** parameter,*

that quantifies the:

Confined Stiffness of the Soil-Geosynthetic Composite under Small Displacements

- **To develop a practical experimental approach to obtain it using:**
  - *Monotonic loading*
  - *Conventional load frame*
  - *Comparatively expeditious procedures*

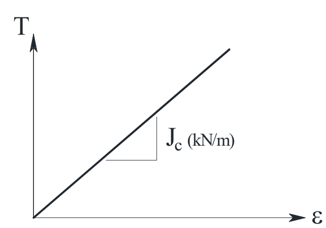
Analytical Framework



Analytical Framework: Assumptions

Geosynthetic Constitutive Relationship:

- A "**Linear**" model is considered to represent the geosynthetic Unit Tension vs. Strain response
- The stiffness of geosynthetics under confined conditions is characterized by a parameter J_c
- The potential influence of confinement is accounted for by using a confined stiffness, which may not be the same as the one under unconfined conditions



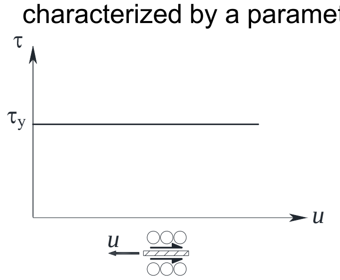
$$T(x) = J_C \times \varepsilon(x)$$

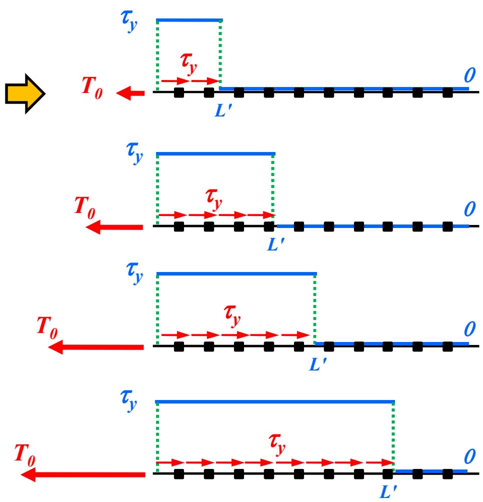
$$T(x) = J_C \times \frac{du(x)}{dx}$$

Analytical Framework: Assumptions

Interface Shear Constitutive Relationship:

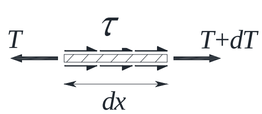
- A "**Rigid Perfectly Plastic**" model is adopted for the Interface Shear (τ) vs Relative Displacement (u) response
- The yield stress at the interface under confined conditions is characterized by a parameter τ_y





Analytical Framework: Formulation

(1) Considering Equilibrium of a differential geosynthetic segment:



$$\frac{dT}{dx} = -2\tau$$

dx: *Differential segment of the geosynthetic*

T: *Geosynthetic unit tension*

τ: *Interface shear between soil and geosynthetic*

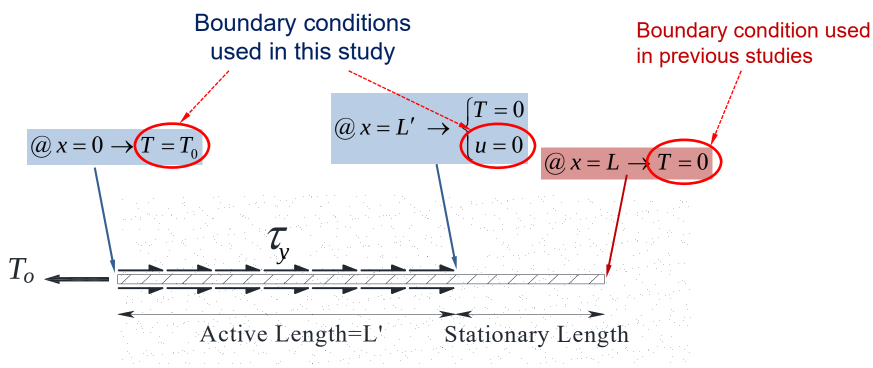
(2) Using the adopted geosynthetic constitutive model:

$$\frac{d(J_c \varepsilon)}{dx} = -2\tau \quad \text{or} \quad -J_c \frac{d^2 u}{d x^2} = -2\tau$$

(3) Considering the adopted interface shear model, the interface shear is a constant τ_y, and now the partial differential equation can be solved:

$$\frac{du}{dx} = \frac{2\tau_y}{J_c} x + c_1 \qquad u = \frac{\tau_y}{J_c} x^2 + c_1 x + c_2$$

Analytical Framework: Boundary Conditions



Analytical Framework: Solution

$$T(x)^2 = K_{SGC} \cdot u(x)$$

- K_{SGC} = Stiffness of the soil-geosynthetic composite
- $T(x)$ = Unit tension at location x
- $u(x)$ = Geosynthetic displacement at location x

with:

$$K_{SGC} = 4\ \tau_y \cdot J_c$$

- τ_y = Yield shear stress
- J_c = Confined stiffness of the geosynthetic reinforcement

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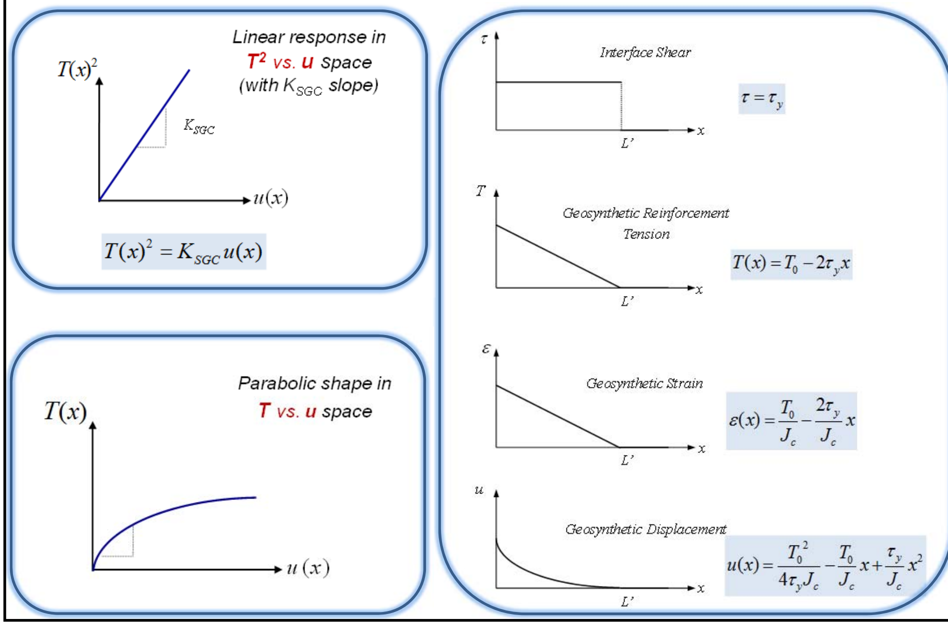
Analytical Framework: Predictions

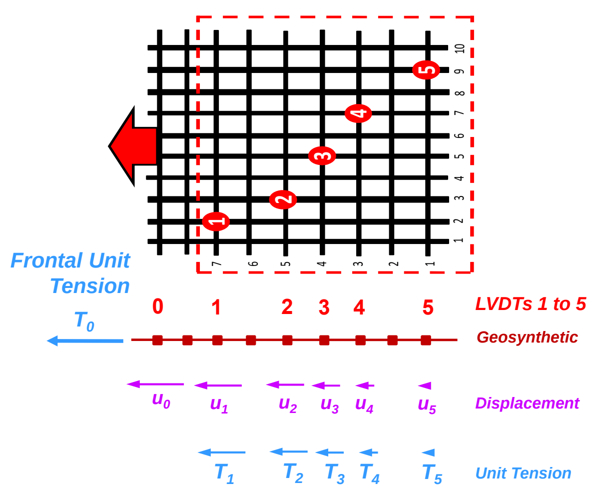


Experimental Setup

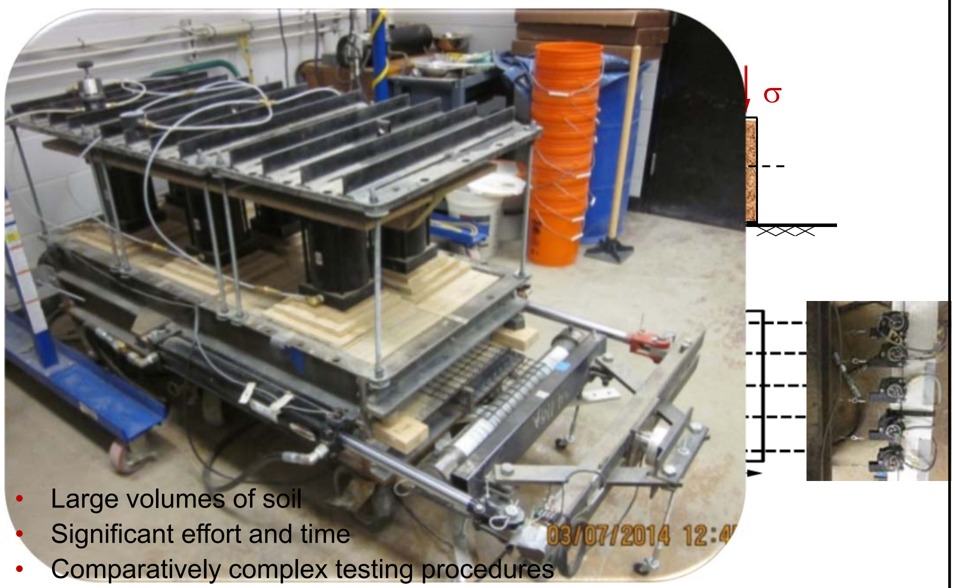
Approach:
- Interpretation of soil-geosynthetic interaction tests

Measurements:
- Frontal unit tension
- Displacements at specific locations within the geosynthetic
- Conditions at the onset of movement in each location

To define:
- Tension vs. displacement at each specific location within the geosynthetic



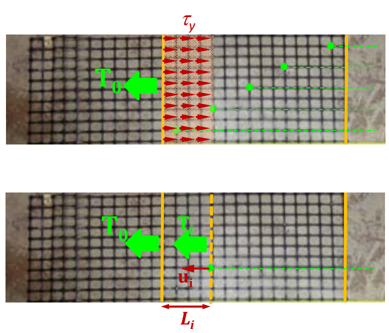
Experimental Setup (1st Generation): Large Soil-geosynthetic Interaction Device



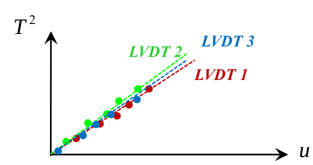
- Large volumes of soil
- Significant effort and time
- Comparatively complex testing procedures

Experimental Setup: Determination of Model Parameters

Determination of K_{SGC} from T^2 *vs.* u curves:



- u_i Displacement (measured directly at multiple locations)
- T_0 Frontal unit tension (measured directly)
- T_i Unit tension (estimated using T_0 and interface shear relationship)



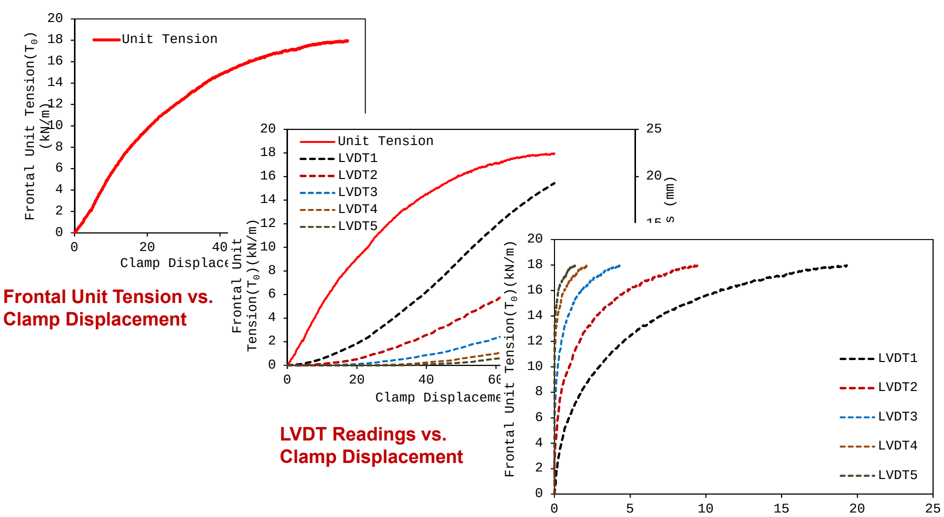
$$K_{SGC} = \frac{T_i^2}{u_i}$$

Experimental Setup: Typical Results

Results of test conducted with:

- Geogrid specimen of dimensions 300 x 1000 mm
- Uniform sand
- 5 LVDTs

Experimental Setup: Typical Results



Frontal Unit Tension vs. Clamp Displacement

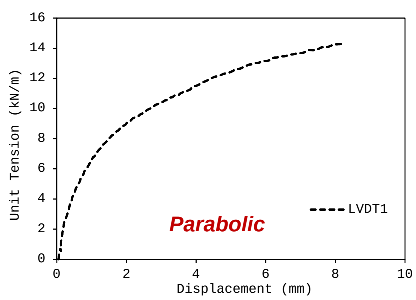
LVDT Readings vs. Clamp Displacement

Frontal Unit Tension vs. LVDT Readings

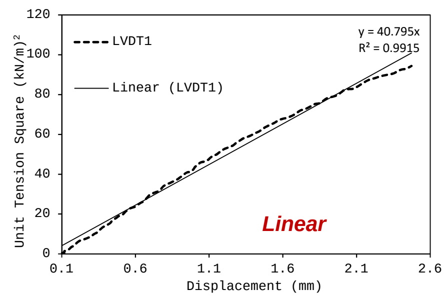
Experimental Setup: Typical Results

Approach to define K_{SGC} from T^2 vs. u curves:

T* vs. *u



T^2* vs. *u



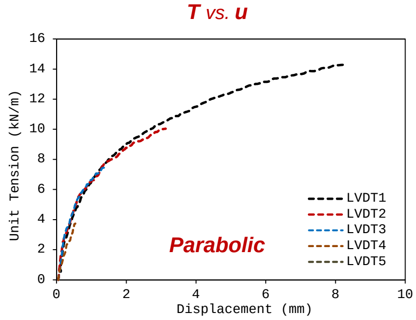
$$K_{SGC\ AVG} = 41.5\ \frac{(kN/m)^2}{mm}$$

σ_n = 3 psi

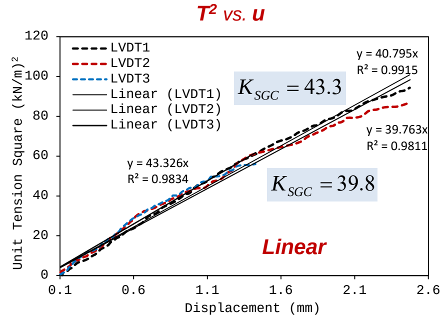
Experimental Setup: Typical Results

Approach to define K_{SGC} from T^2 vs. u curves:

T* vs. *u



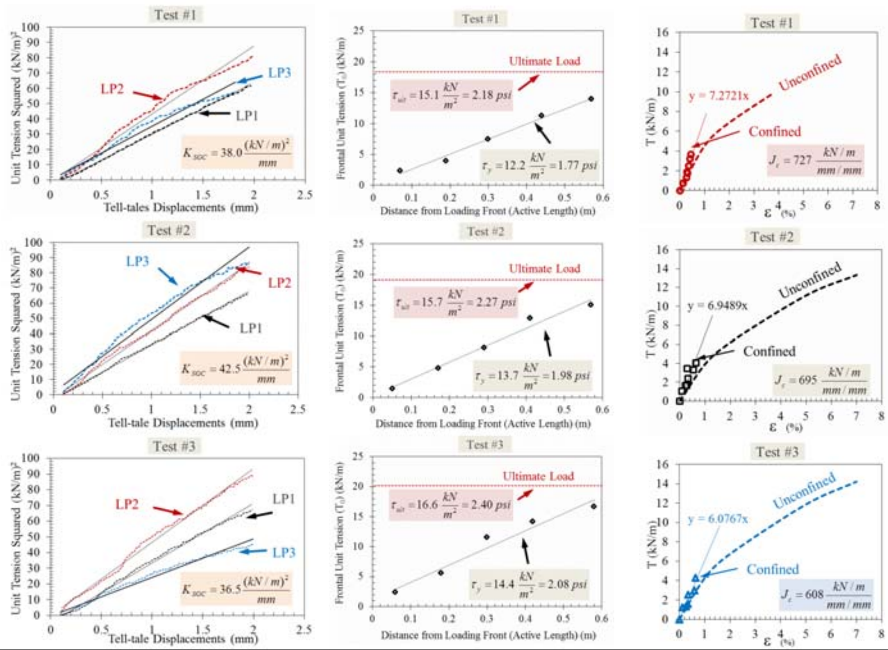
T^2* vs. *u



$$K_{SGC\ AVG} = 41.5\ \frac{(kN/m)^2}{mm}$$

σ_n = 3 psi

Typical Results (Repeatability Evaluation)



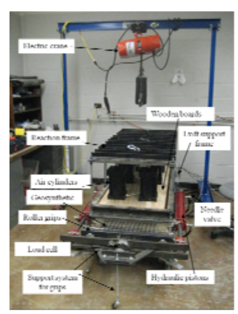
Experimental Setup (2nd Generation): Small Soil-geosynthetic Interaction Device

- The proposed parameter was obtained using a Large Soil-geosynthetic Interaction Device

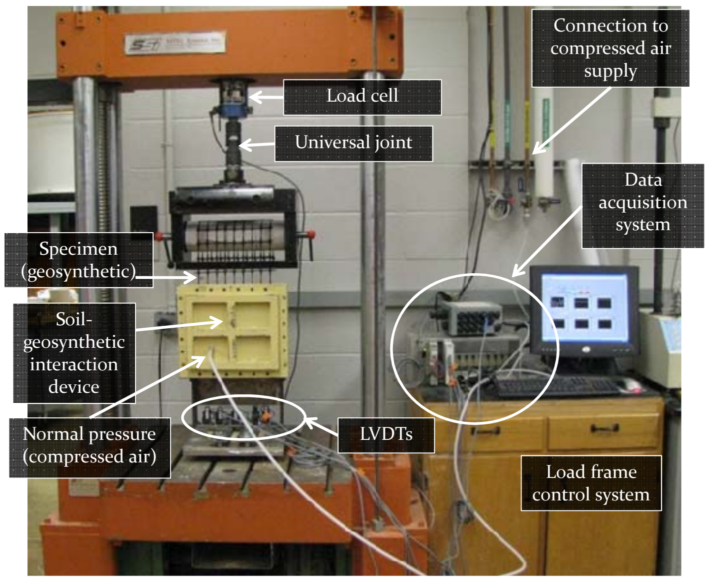
Yet,

- A new apparatus was developed: Small Soil-geosynthetic Interaction Device

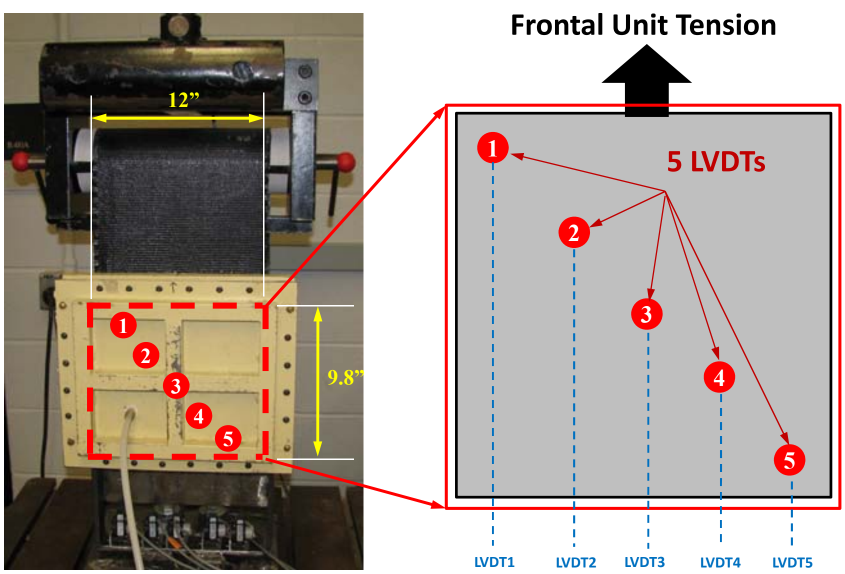
Benefits of this comparatively smaller box include:
  - Significantly smaller soil volume (0.0113 m^3 vs. 0.27 m^3)
  - Smaller geosynthetic specimens
  - Use of conventional loading frame
  - Use of conventional grips for tensile testing
  - Expeditious procedure



Small Soil-geosynthetic Interaction Device (2nd Generation)



Small Soil-geosynthetic Interaction Device



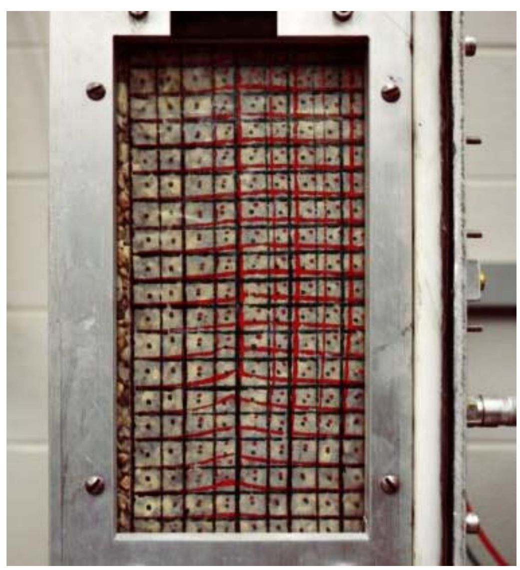
A New Property

A ***single***, yet ***relevant*** parameter that quantifies the "**Confined Stiffness of the Soil-Geosynthetic Composite under Small Displacements**" was identified, and validated experimentally using a practical experimental approach.

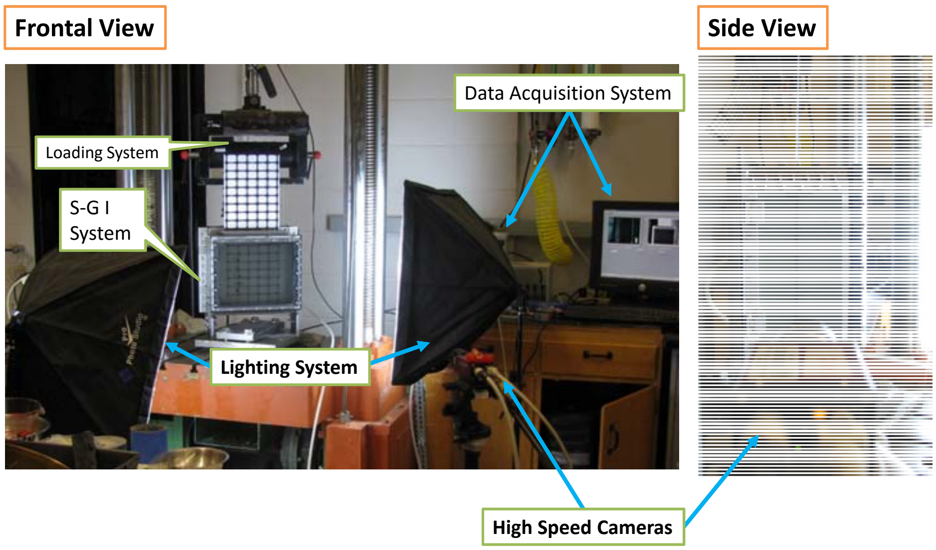
"Essentially, all models are wrong, but some are useful"

George E. P. Box

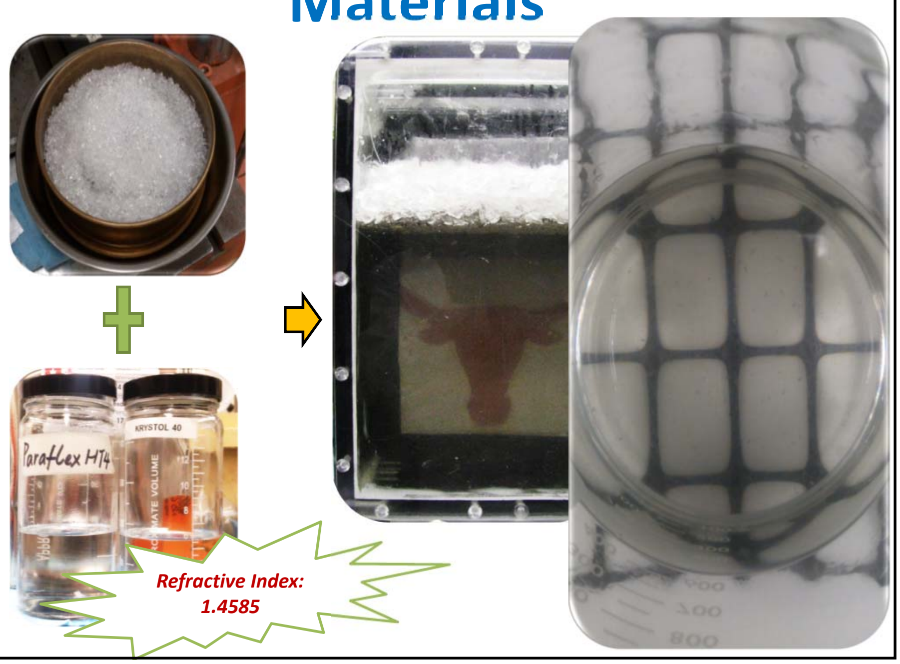
Small S-G Interaction Device, a Transparent Side Wall (3rd Generation)



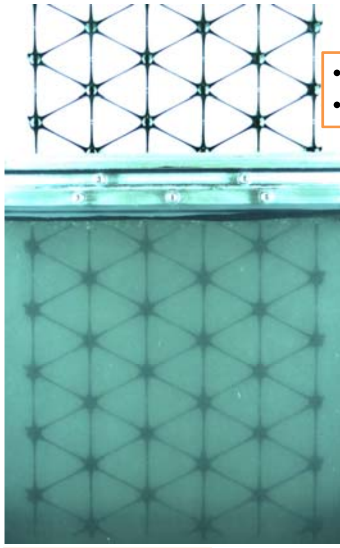
Small S-G Interaction Device, Transparent Soil (4th Generation)



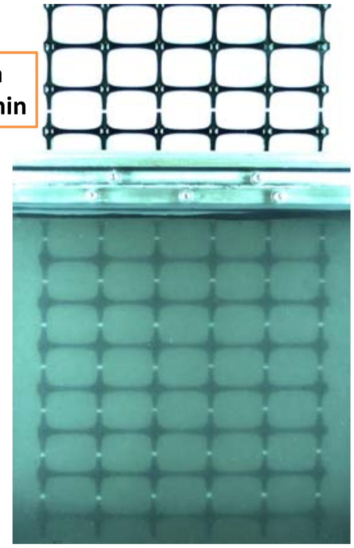
Materials



Geogrid Displacement Fields



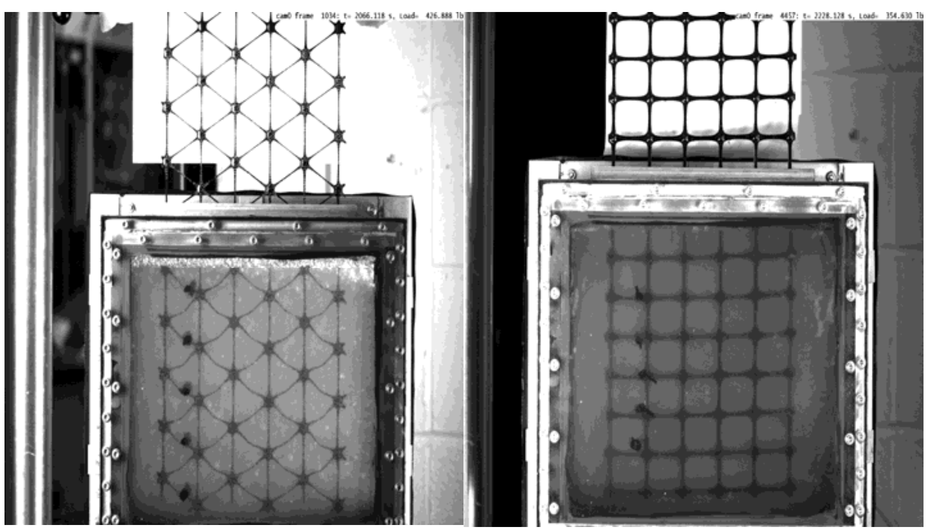
- 27.6 kPa
- 1 mm/min



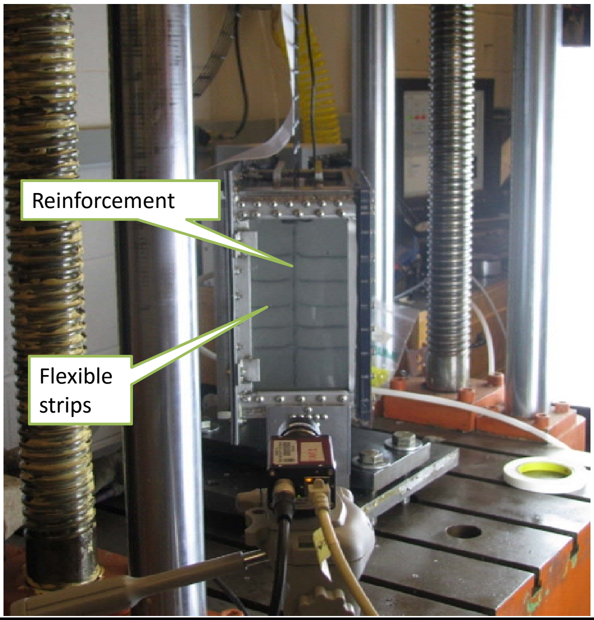
Geosynthetic A

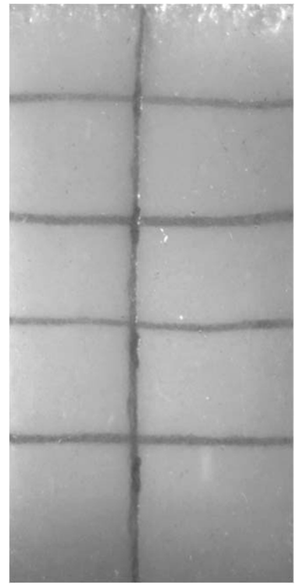
Geosynthetic B

Geogrid Displacement Fields



Shear Band Development

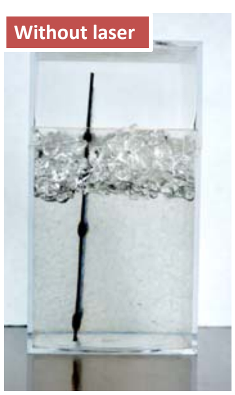


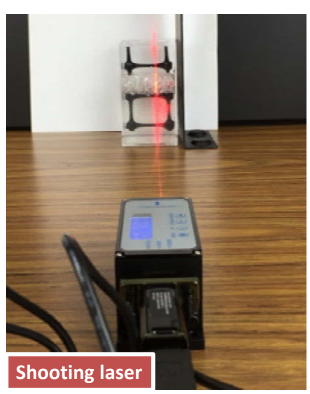


Laser and Transparent Soil

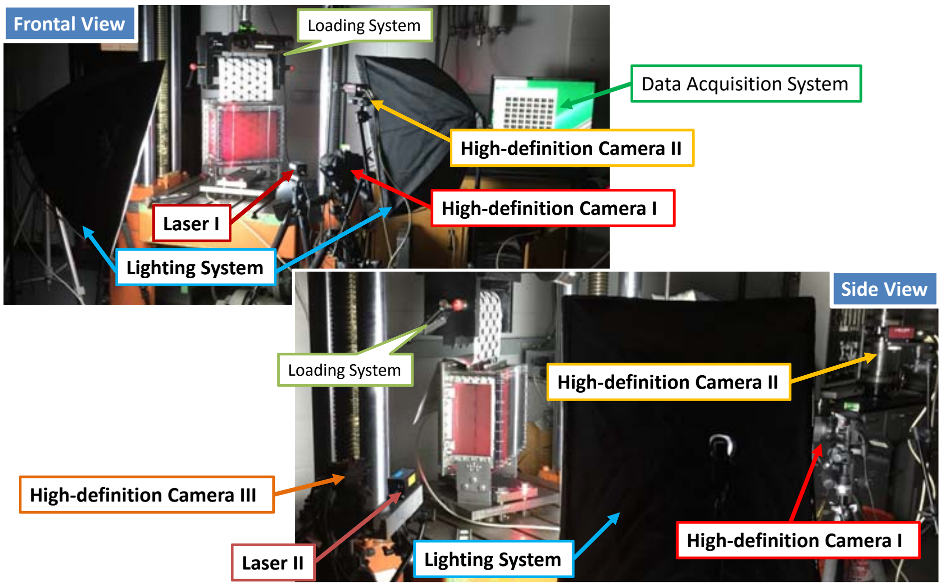
Use of laser:
- Monochromatic
- Coherent
- Collimated

Magnifies minor differences between the refractive index of liquid oil and solid particles

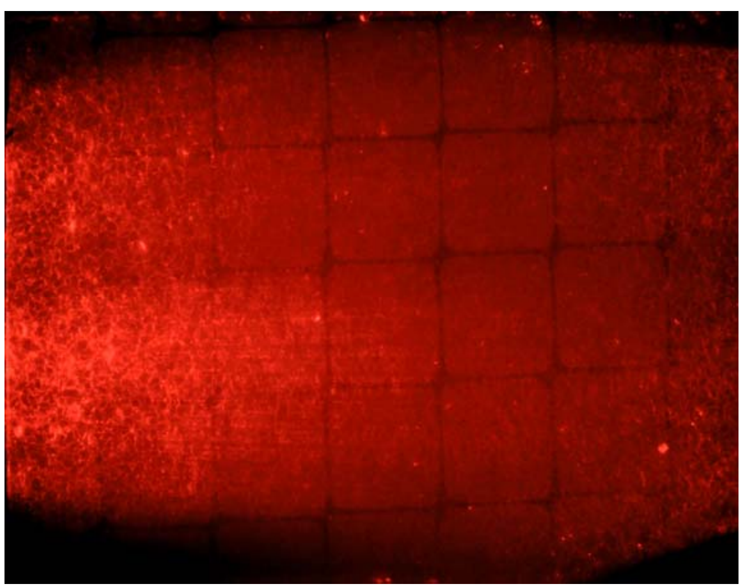




Small S-G Interaction Device, Transparent Soil with Lasers (5^{th} Generation)

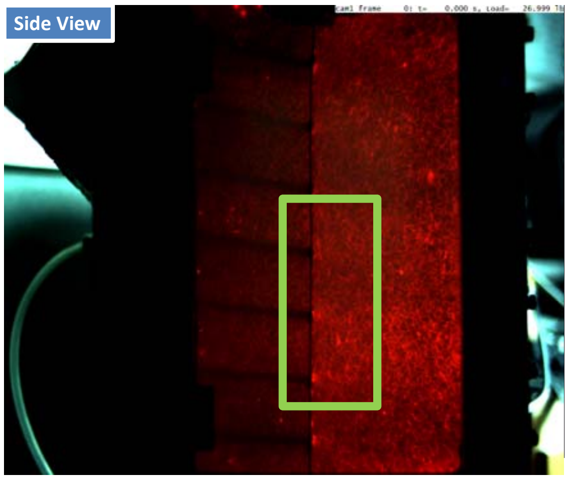


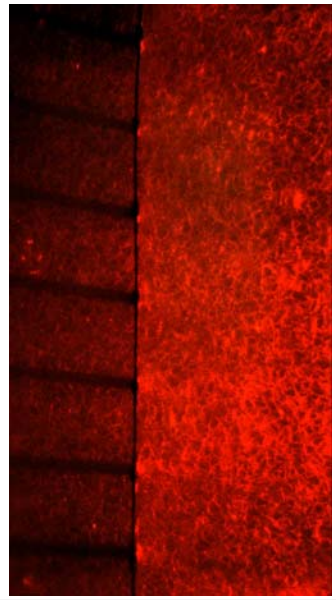
Tracking of Particle Displacements



Shear Band Development

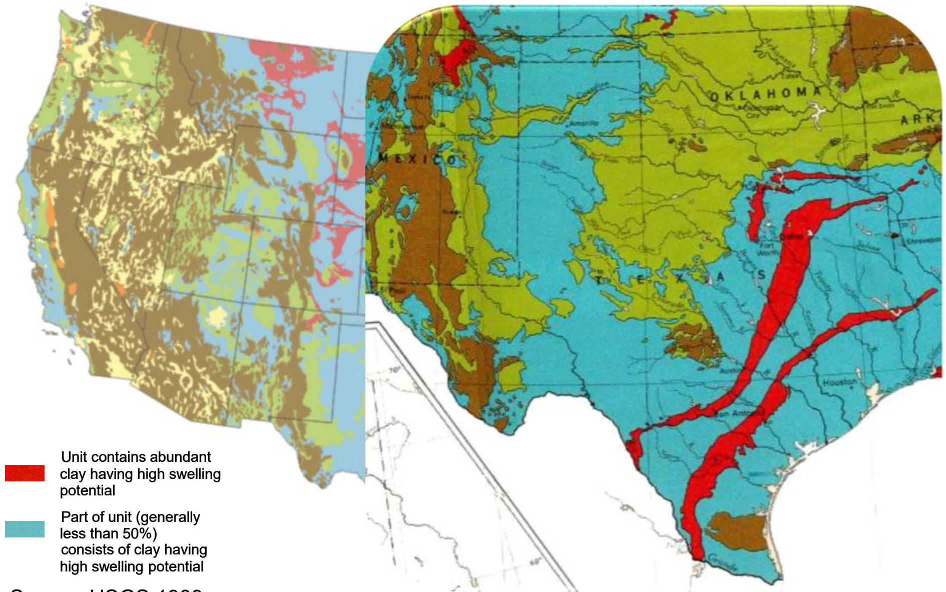
Tracking of shear band development





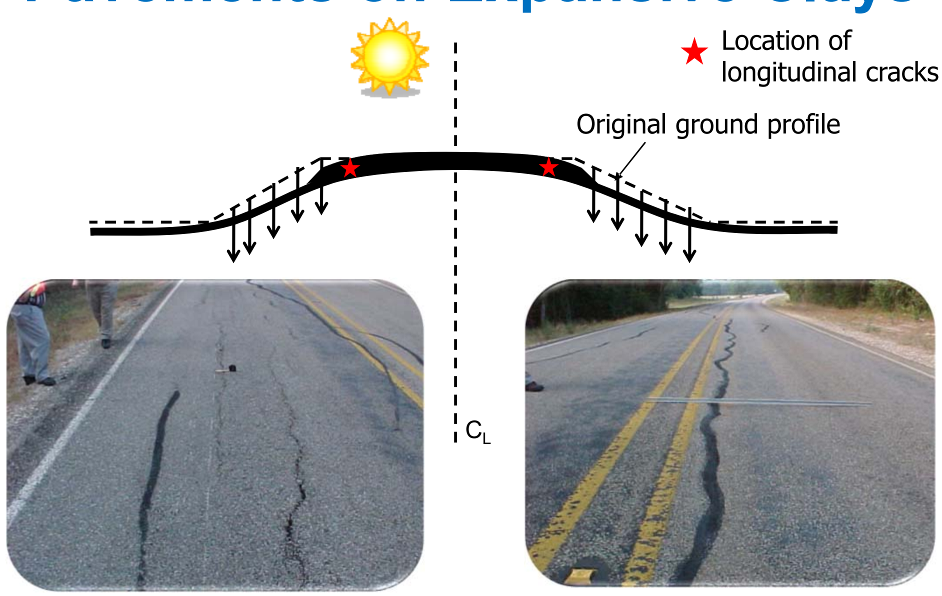
A New Application – Stabilization of Flexible Pavements over Expansive Clay Subgrades using Geosynthetics

Expansive Clays



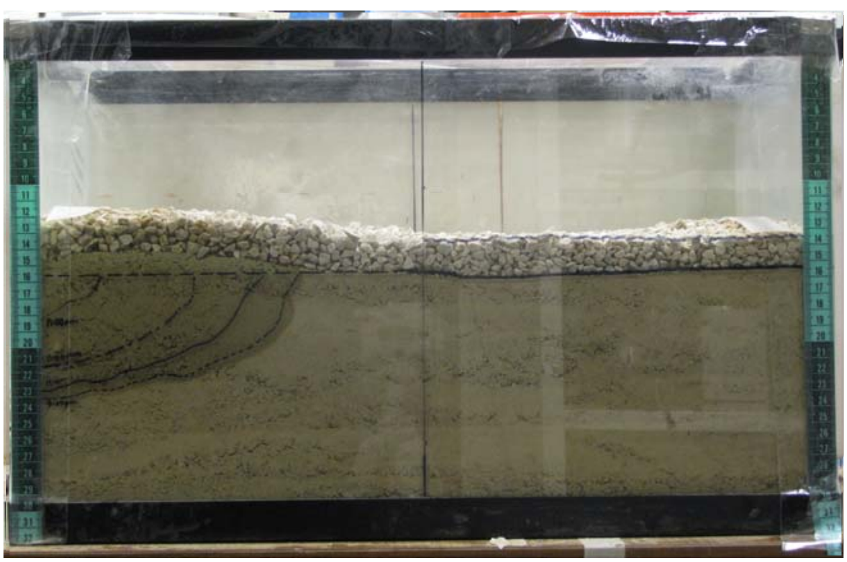
Source: USGS 1989

Pavements on Expansive Clays

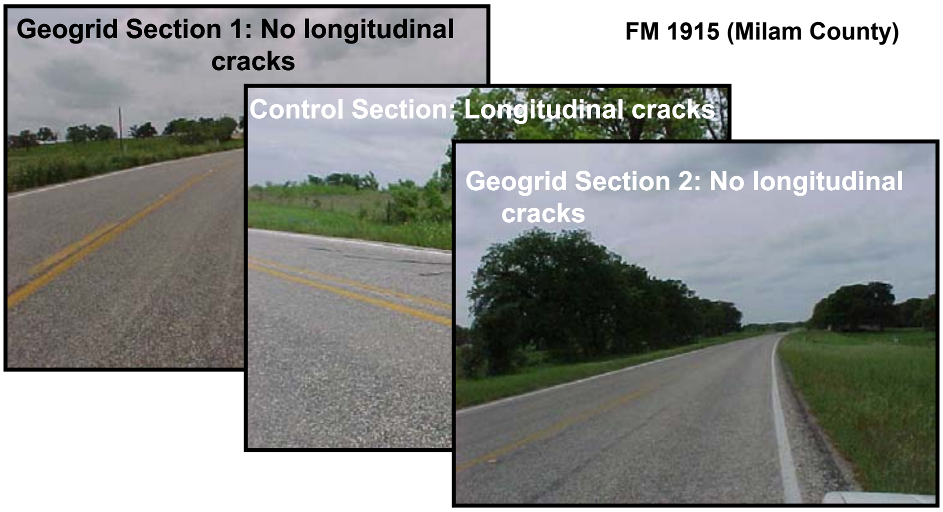


Source: Zornberg and Gupta (2009)

Pavements on Expansive Clays



Effect of Geosynthetic Reinforcement

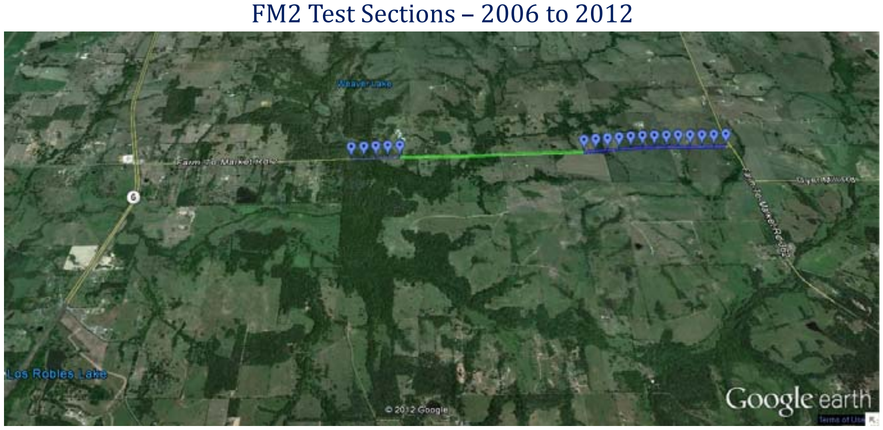


Lesson: Geosynthetic reinforcement prevented the development of longitudinal cracks

Source: Zornberg and Gupta (2009)

Field Evaluation

FM2 Test Sections – 2006 to 2012



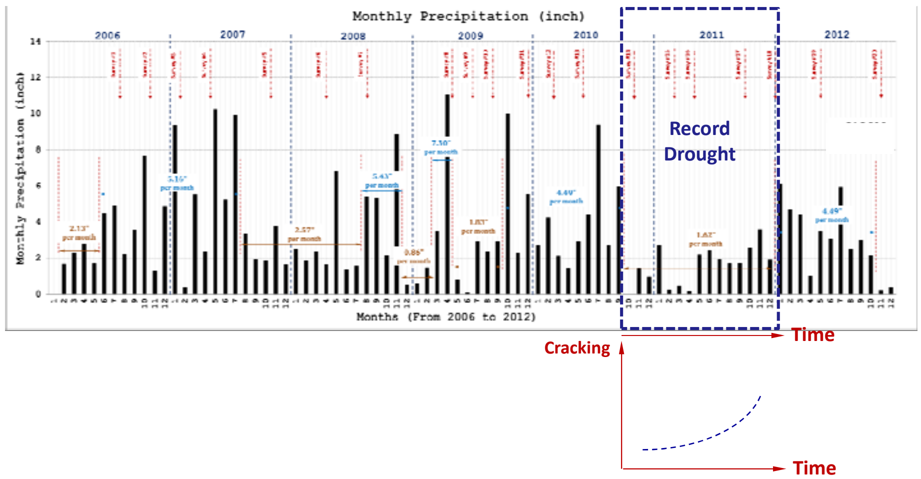
K6 ←	Sec 16 GT + Lime	Sec 15 GGPET + Lime	Sec 14 GGPP + Lime	Sec 13 Lime	←	←	Sec 12 GT	Sec 11 GGPET	Sec 10 GGPP	Sec 9 Cont	Sec 8 GT+Lime	Sec 7 GGPET+Lime	Sec 6 GGPP+Lime	Sec 5 Lime	Sec 4 GT	Sec 3 GGPET	Sec 2 GGPP	Sec 1 Cont	← K6
K1 →	Sec 32 GGPP + Lime	Sec 31 Lime	Sec 30 GT + Lime	Sec 29 GGPET + Lime	→	→	Sec 28 GGPP	Sec 27 Cont	Sec 26 GT	Sec 25 GGPET	Sec 24 Lime	Sec 23 GT+Lime	Sec 22 GGPET+Lime	Sec 21 GGPP+Lime	Sec 20 Cont	Sec 19 GT	Sec 18 GGPET	Sec 17 GGPP	→ K1

8 Groups:

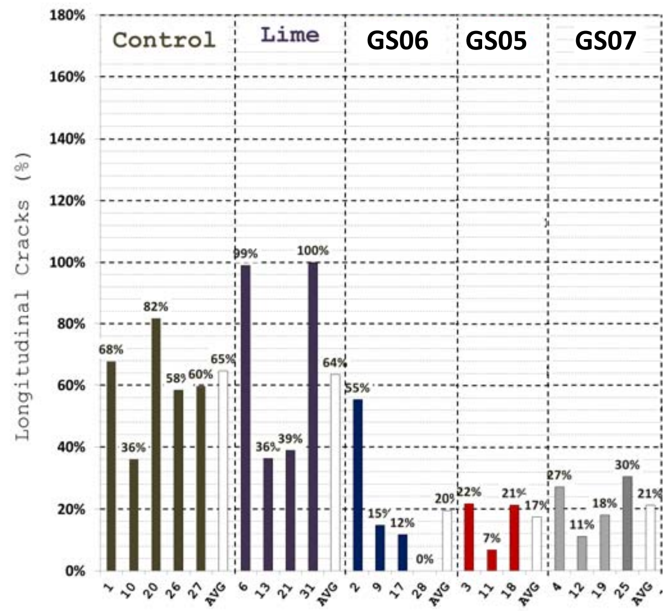
1. Control (Cont.)
2. Lime (LM)
3. GS06
4. GS06+ LM
5. GS05
6. GS05+LM
7. GS07
8. GS07+LM

Precipitation at FM2 Site

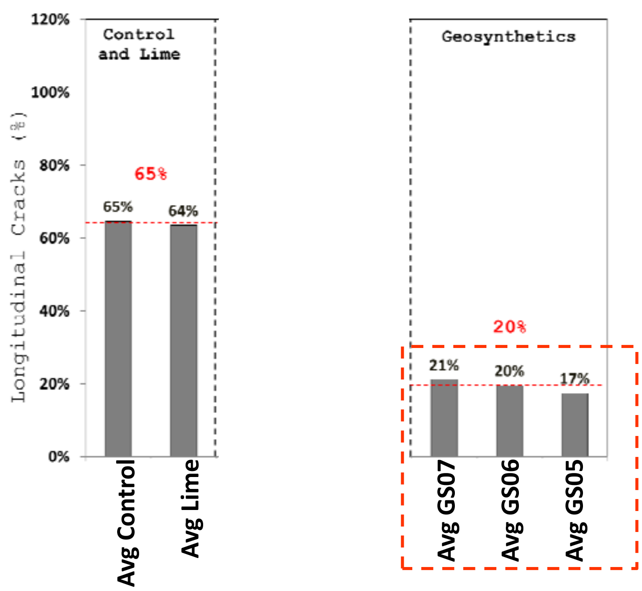
FM2 – 2006 to 2012



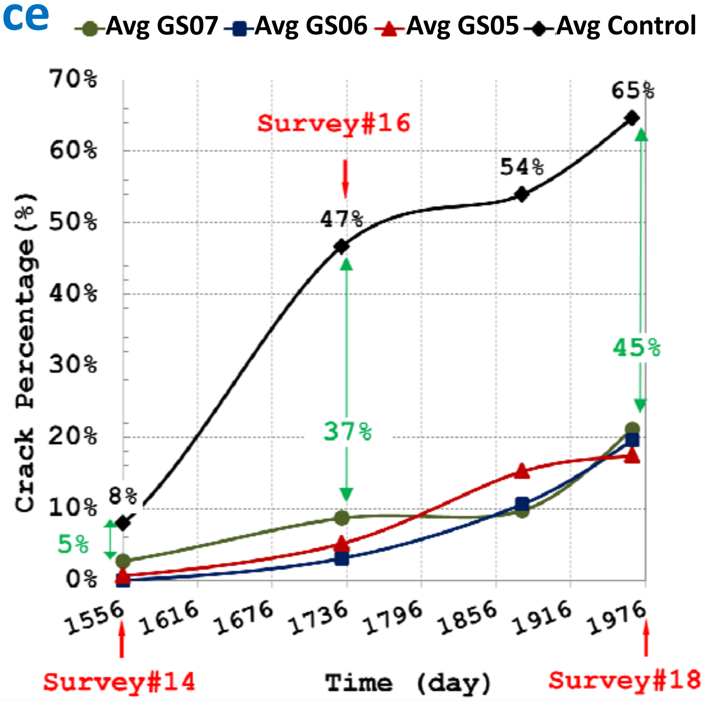
FM2: Distress Level



FM2: Distress Level

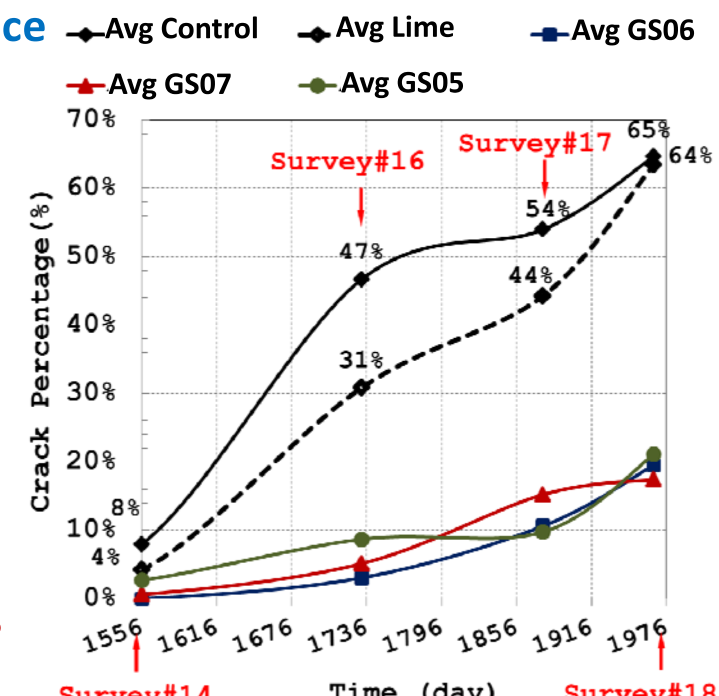


Performance over time



Control and Geosynthetic-stabilized Sections (Surveys #14 to #18)

Performance over Time



Control, Lime-treated, and Geosynthetic-reinforced Sections (Surveys #14 to #18)

Conclusions

Conclusions (New Property)

- An investigation was conducted to identify properties relevant for design of geosynthetics used for roadway stabilization
- The Confined Stiffness of the Soil-geosynthetic Composite under Small Displacements was identified as a relevant property
- An analytical framework was developed: Simple, realistic, and practical. It involves a single parameter: The Stiffness of the Soil-geosynthetic Composite (K_{SGC})
- The results from an experimental testing program involving a large soil-geosynthetic interaction test device showed the suitability of the K_{SGC} model
- A new small soil-geosynthetic interaction testing device was developed, which provides high-quality data in an expeditious manner

Conclusions (New Application)

- The use of geosynthetics was found to effectively minimize the detrimental effects of expansive soil subgrades on flexible pavements
- A field demonstration program involving 32 test sections demonstrated the beneficial effect of geosynthetic stabilization of pavements
- Geosynthetic-stabilized pavement sections on expansive clay subgrades showed significantly better field performance than control (non-reinforced) sections
- Compared to unreinforced sections, lime treatment was found not to minimize the development of longitudinal cracks
- The relative values of K_{SGC} were found to be consistent with the relative field performance of pavement sections subjected to environmental loads

Final Remarks

- Overall, geosynthetics have been demonstrated to improve, often significantly, the performance of roadways.
- The state of practice is rapidly improving as new research is identifying the properties governing the effect of geosynthetics in roadway stabilization.
- The use of geosynthetics in roadway engineering offers promising sustainable opportunities such as the stabilization of pavements over expansive clay subgrades.

Acknowledgments

- The following fantastic (current and former) students at UT-Austin:
  - Julio Ferreira,
  - Ranjiv Gupta,
  - Rutuparna Joshi,
  - Jose Martinez,
  - Xin Peng,
  - Ryan Phillips,
  - Hossein Roodi

- Texas Department of Transportation (TxDOT)
- ISSMGE, IGS and Tensar for their support to the Mercer Lecture

Muchas Gracias

29 March 2017
Lima, Peru

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Immediate Past-president, IGS