Master Class # 2

Advances in Design and Construction with Geosynthetics for Retaining Structures, Slopes and Roadways

GEOANZ #1
ADVANCES IN GEOSYNTHETICS
7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE
www.geoanzconference.com.au

Introduction

Jorge G. Zornberg, Ph.D., P.E.
The University of Texas at Austin, USA
Past - President, IGS

www.acigs.org

Learning Objectives

On completion of this class, attendees should be able to:

- Choose the different functions relevant for the applications involving geosynthetics in civil infrastructure
- Identify the different types of infrastructure where the use of geosynthetics can lead to improved design
- Single out general concepts in your own infrastructure background or experience that can benefit from adopting geosynthetics
- Familiarize yourself with recent advances on the use of geosynthetics in civil infrastructure projects

Outline of Topics in this Master Class

- **Geosynthetic-reinforced Soil Walls**
  - Introduction, relevant functions
  - Focus on soil retention under unusual configurations
- **Embankments on Soft Foundations**
  - Introduction, relevant functions
  - Focus on different basal reinforcement techniques
- **Geosynthetic-reinforced Load Transfer Platforms**
  - Introduction, relevant functions
  - Focus on practice guide and associated case study
- **Geosynthetics in Roadways**
  - Multiple applications of geosynthetics in roadways
  - Focus on geosynthetics for roadways on expansive clays
- **Geosynthetics in Railways**
  - Multiple applications of geosynthetics in roadways
  - Focus on laboratory tests and field measurements

Schedule

Schedule MasterClass 2

		Topic	Presenters
1:00-1:10	10 mins	Introduction to MC2	Jorge Zornberg
1:10-1:50	30 mins presentation 10 mins Q & A	Topic 1: Geosynthetic-reinforced Soil Walls	Allan Garrard, Jorge Zornberg
1:50-2:30	30 mins presentation 10 mins Q & A	Topic 2: Embankments on Soft Foundations	Chris Lawson, Jorge Zornberg
2:30-2:45	15 mins	Sponsor Case Study	Global Synthetics
2:45-3:15	**30 mins**	**Coffee Break**	
3:15-3:55	30 mins presentation 10 mins Q & A	Topic 3: Geosynthetic-reinforced Load Transfer Platforms.	Rajesh Bhavsar, Jorge Zornberg
3:55-4:35	30 mins presentation 10 mins Q & A	Topic 4: Geosynthetics in Roadways	Jorge Zornberg
4:35-5:05	30 mins presentation 10 mins Q & A	Topic 5: Geosynthetics in Railways	Amir Shahkolahi, Jorge Zornberg
5:05-5:15	10 mins	Q and A / Wrap up	Jorge Zornberg

Questions?

Jorge G. Zornberg, Ph.D., P.E.
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Reinforced Soil Walls

Introduction

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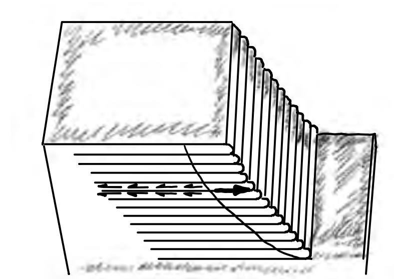
Geosynthetic Functions

- Separation
- Reinforcement
- Stiffening (a.k.a Stabilization)
- Filtration
- Barrier
- Drainage
- Protection

Reinforcement Function

The geosynthetic develops tensile forces intended to maintain or improve the stability of the soil-geosynthetic composite.

Source: Zornberg et al. (1997)

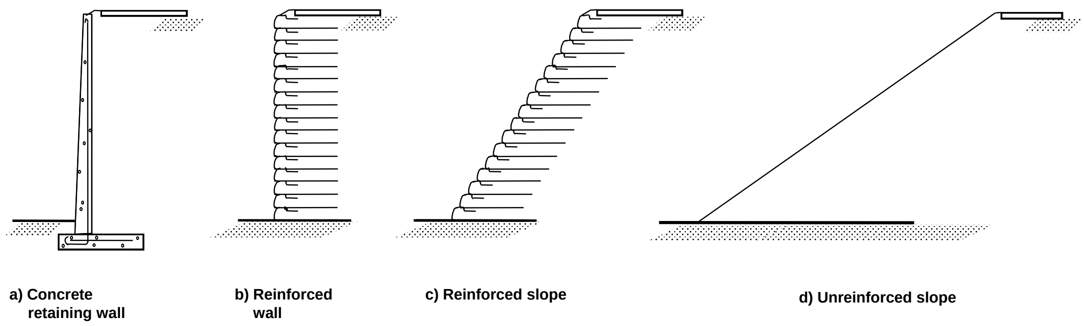


Example: Geosynthetics used to increase the margin of safety of a steep earth slope.

Key properties:

- Ultimate tensile strength
- Interface shear strength
- Reduction factors:
  - Creep
  - Installation damage
  - Durability

Reinforcement Function



Source: Zornberg and Christopher (2007)

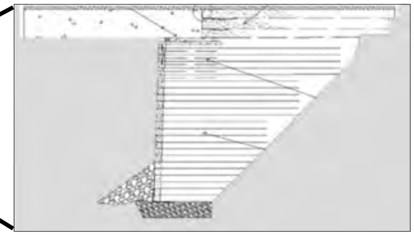
Construction of a geosynthetic-reinforced steep slope to widen roadway through Idaho National Forest

Courtesy: Jorge Zornberg

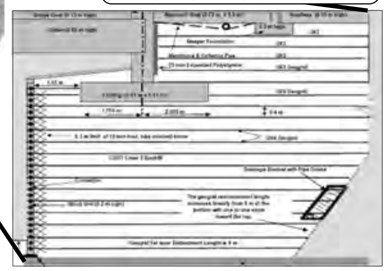
Load-carrying GS-reinforced Bridge Abutments

GRS-IBS

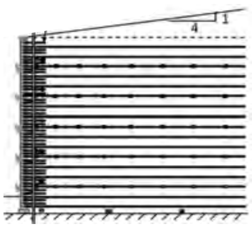
Source: Evans et al. (2011)



Generic Load-carrying GMSE Abutment

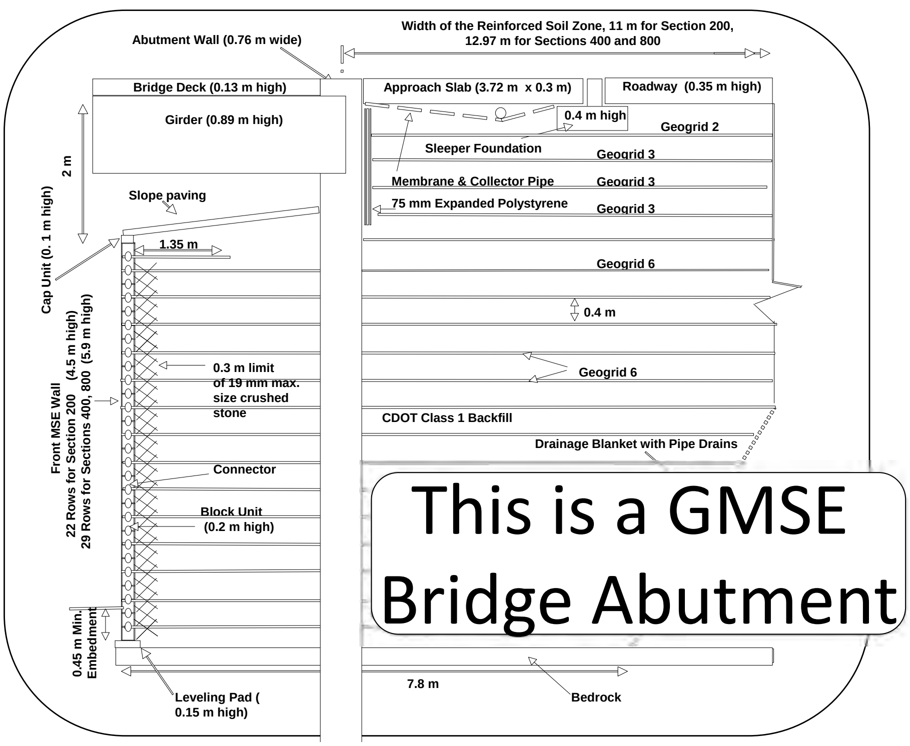


Source: Abu-Hejleh et al. (2002)

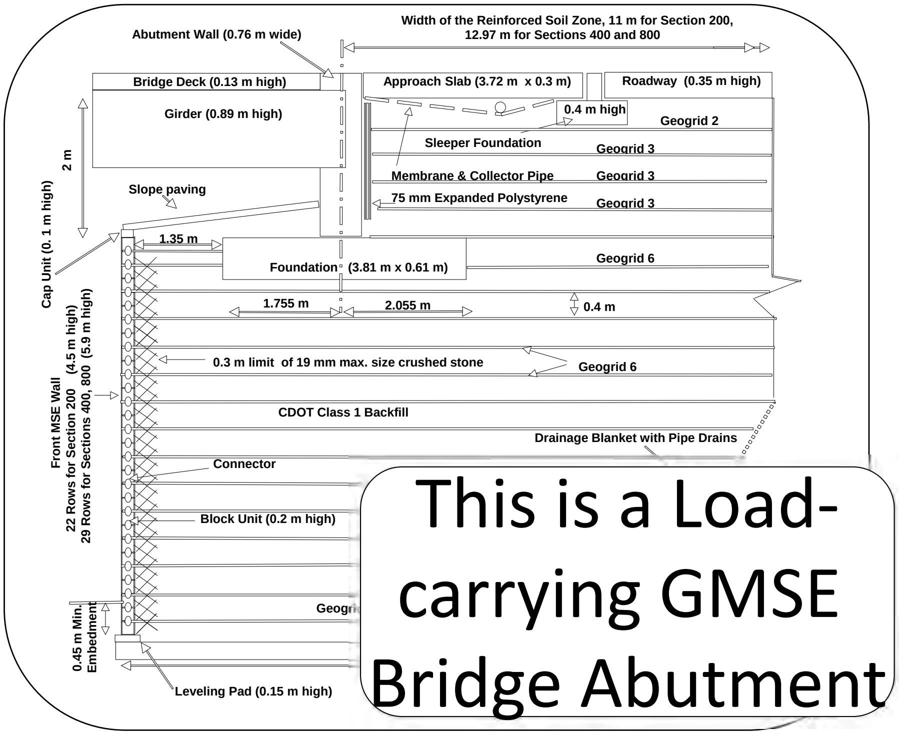


Generic GMSE with Closely-spaced Reinforcement

Source: Jiang et al. (2019)



This is a GMSE Bridge Abutment



This is a Load-carrying GMSE Bridge Abutment

Australian Experience

Courtesy: Doulala-Rigby

Barney's Point Bridge
Chinderah, NSW,
Australia

Questions?

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Master Class #2

Type of wall selection and analysis in non-conventional situations

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Allan Garrard

Senior Principal Geotechnical Engineer
CMW Geosciences

CMW Geosciences

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Type of wall selection and analysis in non-conventional situations

- Nigg Dry Dock – Scotland

- Design Issues:

I. Wall needed to be robust for a long life in a coastal environment
II. Wall designed to carry heavy crane loading
III. Wall designed for rapid water drawdown due to high tidal range and dock de-watering

Type of wall selection and analysis in non-conventional situations

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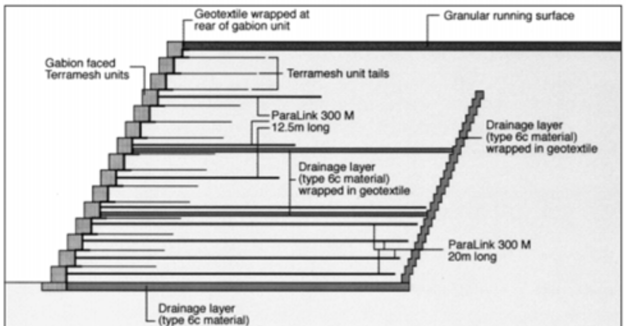


Typical Cross Section


Construction of the hybrid Terramesh & Paralink wall

Type of wall selection and analysis in non-conventional situations

* Nigg Dry Dock – Scotland

* Construction and testing


Structure nearing completion

Type of wall selection and analysis in non-conventional situations

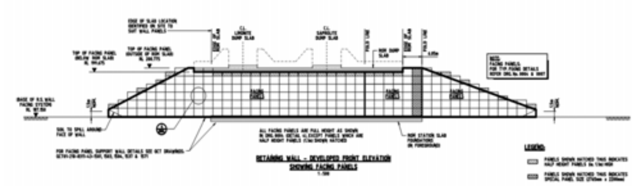
- Nigg Dry Dock – Scotland

- Operational Dock

Type of wall selection and analysis in non-conventional situations

- Goro ROM wall
- Design Criteria:

I. Wall components needed to be containerized and shipped from Australia to New Caledonia.
II. Wall components needed to be handled by no more than 2 people.
III. Wall needed to be able to be built without the use of a crane.
IV. Wall system needed to incorporate temporary works features.



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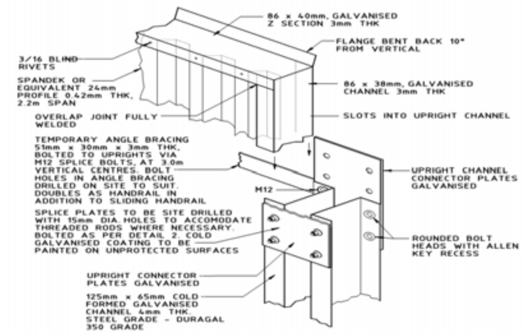

Type of wall selection and analysis in non-conventional situations

- Goro ROM wall
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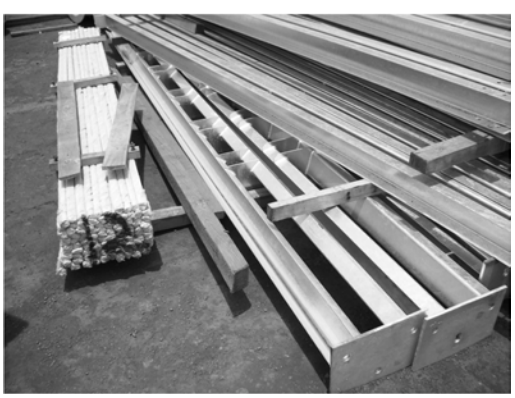

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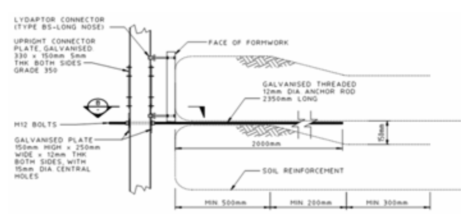
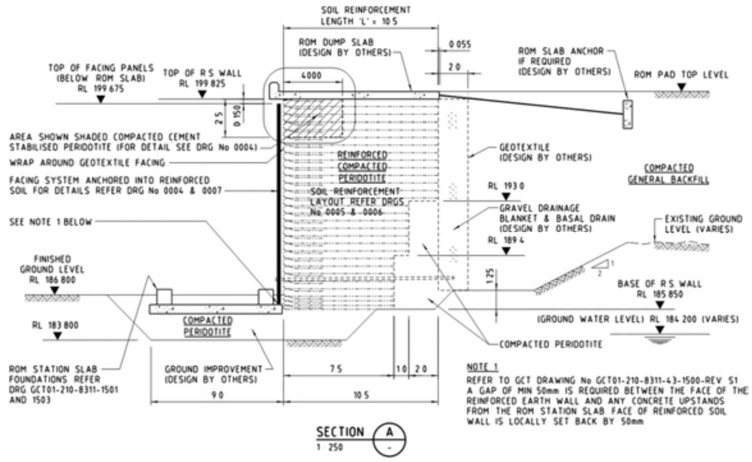


Type of wall selection and analysis in non-conventional situations

- Goro ROM wall
- Wrap around high strength fabric design

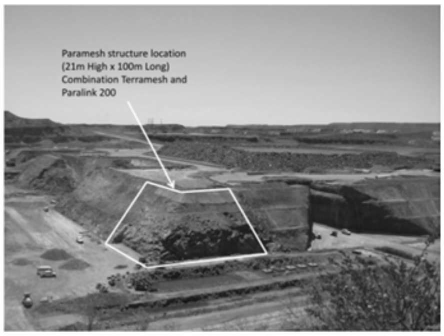


Type of wall selection and analysis in non-conventional situations

- Goro ROM wall
- Completed wall

Type of wall selection and analysis in non-conventional situations

* Cape Preston Buttress Wall
* Design criteria:
* A more cost effective design than the original design.
* Provide buttressing of an over blasted rock face.
* Provide a turning area for 600T trucks.



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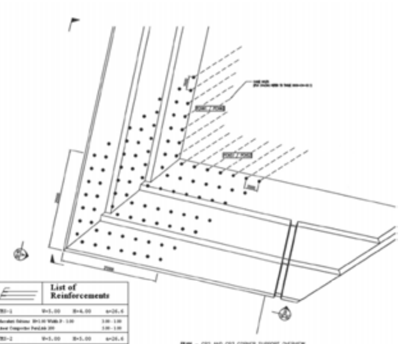

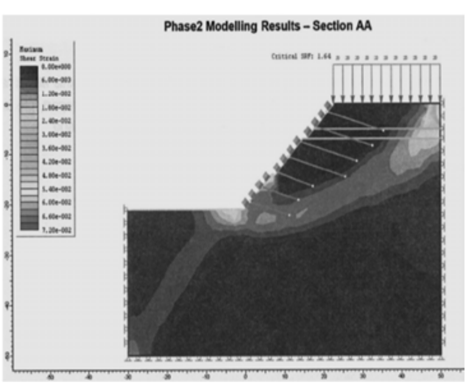

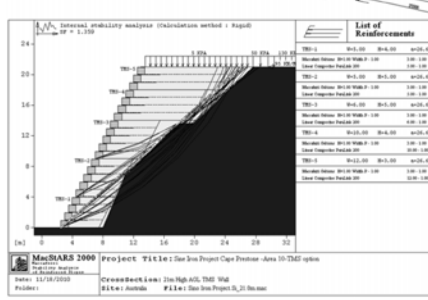

Type of wall selection and analysis in non-conventional situations

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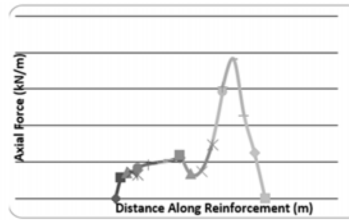
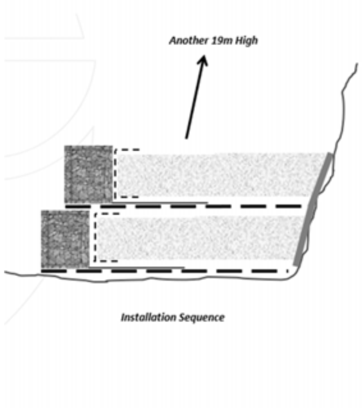
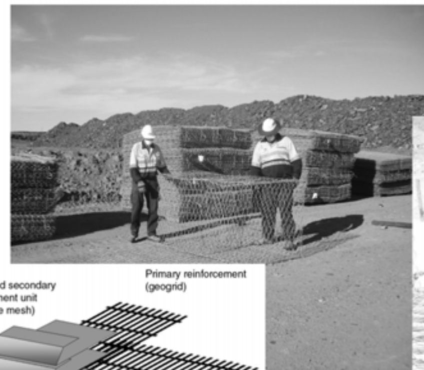
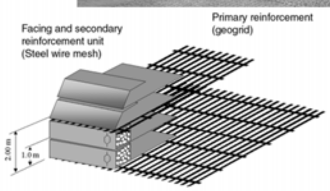
* Design criteria:

ii. Provide buttressing of an over blasted rock face.





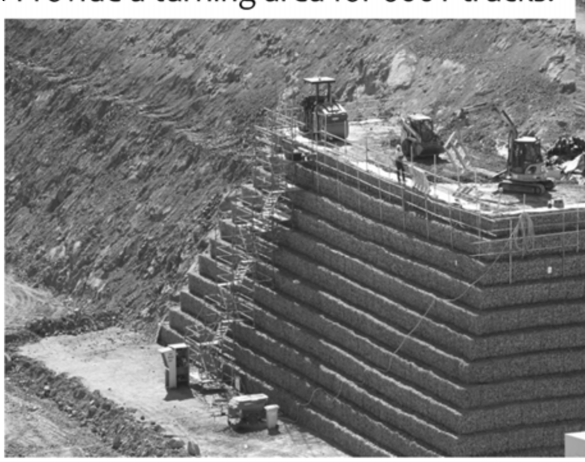




Type of wall selection and analysis in non-conventional situations

* Cape Preston Buttress Wall
* Design criteria:

iii. Provide a turning area for 600T trucks.



Questions?

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Basal Reinforced Embankments on Soft Foundations

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Introduction

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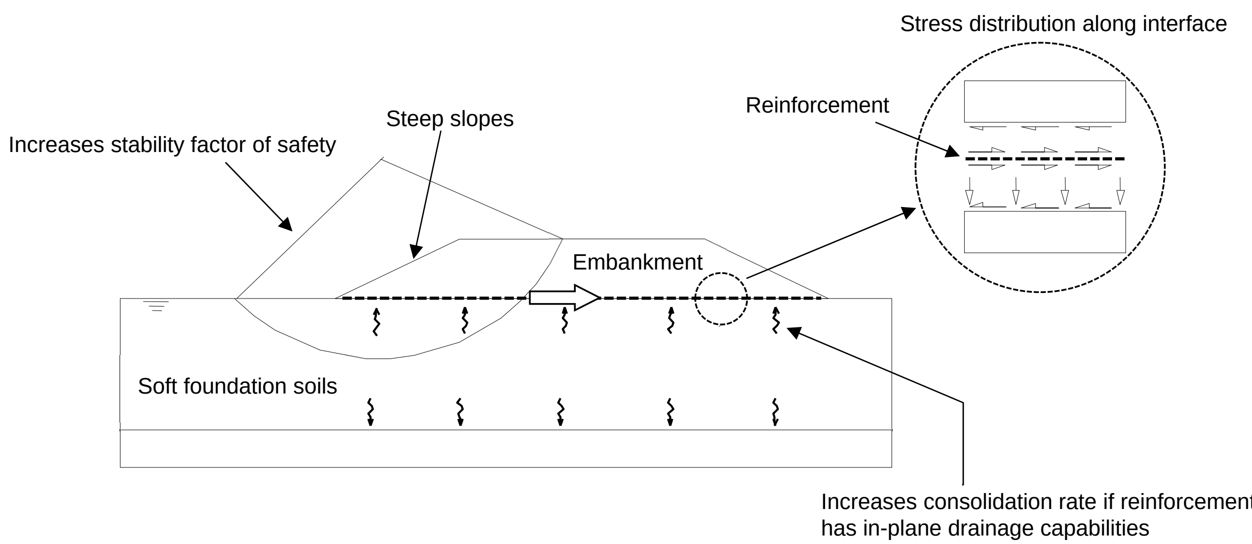
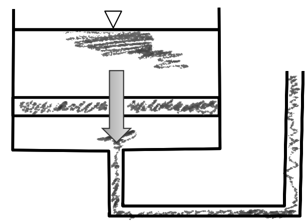
Basal Reinforced Embankments on Soft Foundations



Filtration Function

The geosynthetic allows liquid flow across its plane while retaining fine soil particles on its upstream side.

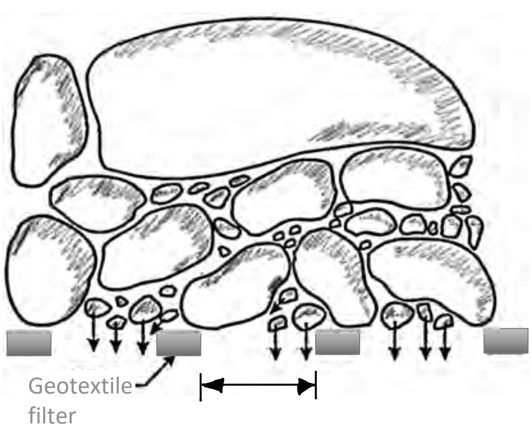
Example: Geotextiles used to prevent soils from migrating into the aggregates in a road drainage system while maintaining adequate liquid flow.



Key properties:

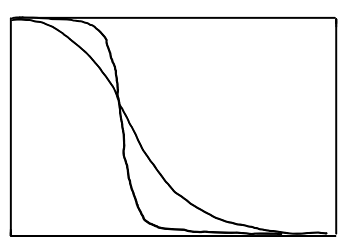
- Permittivity
- Apparent Opening Size (AOS)

Filtration Function



Retention Criterion:

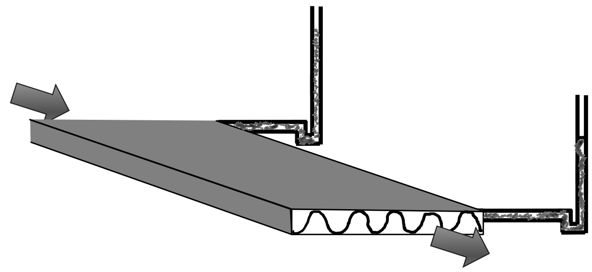
$$AOS \leq B\, d_{85}$$



Source: Zornberg and Christopher (2007)

Drainage Function

The geosynthetic allows liquid (or gas) flow within the plane of its structure.

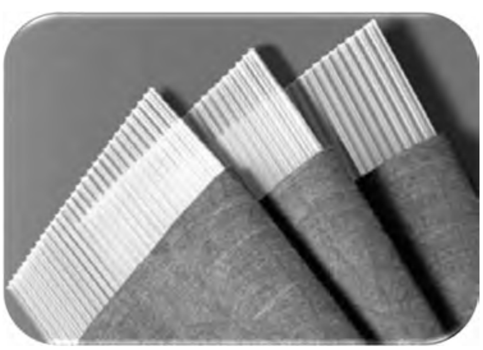


Example: A geocomposite drainage layer used to convey liquids overlying a barrier in a waste containment facility.

Key properties:

- Transmissivity

Prefabricated Vertical Drains



Relevant Reinforcement Properties

Important factors to consider in material selection:

- Tensile strength
- Tensile stiffness
- Tensile deformations

  → Wide-width tensile testing following relevant test standard. Use appropriate reduction factors to determine design strength
- Permitivitty, filtration characteristics
- Transmissivity

  → Relevant hydraulic tests to characterize cross-plane flow, in-plane flow and pore size distribution
- Interaction with adjacent soils → Direct shear or pullout tests, depending on the type of reinforcement
- Creep behavior → Creep tests, as provided by manufacturer. Otherwise, use appropriate reduction factors
- Resistance to installation damage → Use appropriate reduction factor appropriate
- Durability → Check aggressiveness of soils in contact with the reinforcement, manufacturer's information, available test results. Use appropriate reduction factors.

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Master Class # 2

Basal Reinforced Embankments on Soft Foundations

Chris Lawson

Managing Director

Solmax / TenCate Geosynthetics Asia

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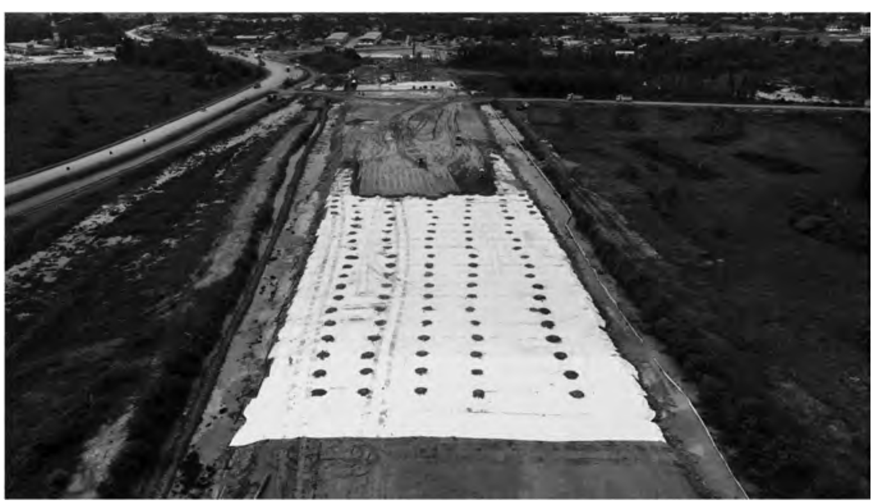
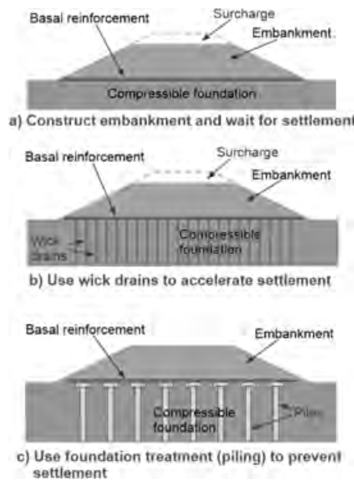
Basal Reinforced Embankments on Soft Foundations



Introduction: basal reinforced embankments on soft foundations

* Three basal reinforced embankment techniques to enhance stability and control settlements
  * Basal geosynthetic reinforcement alone
    * Provides short term stability until foundation has consolidated
  * Basal geosynthetic reinforcement with wick drains
    * Accelerates stability/settlement within construction project timeframe
  * Basal geosynthetic reinforcement with piled foundations
    * Minimises settlements while enhancing stability
* We will go quickly through these three applications in the presentation

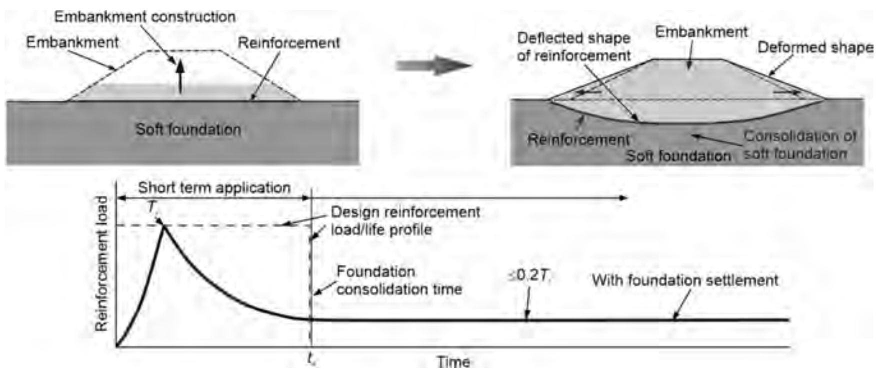
Controlling stability & settlements with basal reinforcement



Basal geosynthetic reinforcement alone

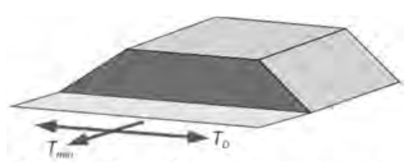
Tensile load profile in basal reinforcement over time

* The tensile load in basal reinforcement reaches a maximum on reaching maximum embankment height
* As soft foundation consolidates it can support more of the embankment loading and tensile load in reinforcement declines
* Basal reinforcement required until such time as the soft foundation has consolidated and can support the embankment loading fully
  * 10 to 15 years (depending on full consolidation time)
  * Therefore, "short term" reinforcement application
* Variety of analysis methods available to determine T_r



Basal reinforcement layout

* In the direction across the embankment the geosynthetic reinforcement has to support the major reinforcement design strength T_D
* In the direction along the embankment the geosynthetic reinforcement has to support only the loads caused by the embankment fill construction procedure
  * T_{min} = 20 to 50 kN/m
* Therefore, uniaxial geosynthetic reinforcement should be installed in direction across the width of the embankment ($T_D \approx 10 \times T_{min}$)
  * No joins in this direction
* Adjacent lengths can either be overlapped or sewn together
  * Size of overlaps depends on softness of soil beneath geosynthetic
  * Sewn seams can only achieve a percentage of fabric strength



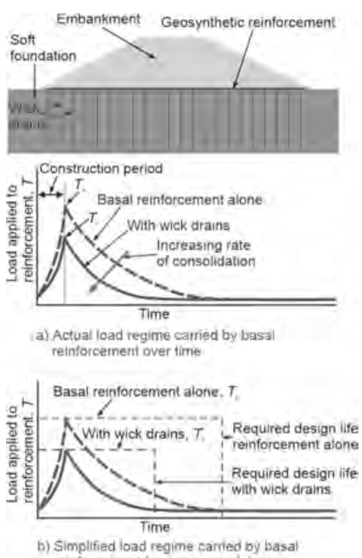
a) Direction of tensile load regime in embankment

b) Direction of installing geosynthetic reinforcement

Basal geosynthetic reinforcement with wick drains

Tensile load profile in basal reinforcement over time when using wick drains

- Without wick drains the load regime in the basal reinforcement over time follows the profile already discussed (blue dashed line)
- With wick drains, the soft foundation consolidates at a much quicker rate, even during initial construction of the embankment
  - Thus, the maximum tensile load generated in the basal reinforcement is less than without wick drains
- Also, since wick drains accelerate the rate of consolidation of the soft foundation soil the foundation supports the embankment in a shorter period of time
  - Thus, the geosynthetic reinforcement is only required for this shorter time period
- This enables considerable flexibility in choice of reinforcement type
  - Both in terms of reinforcement strength and required design life
- But, it has to be designed carefully



a) Actual load regime carried by basal reinforcement over time

b) Simplified load regime carried by basal reinforcement for purposes of design

Typical applications



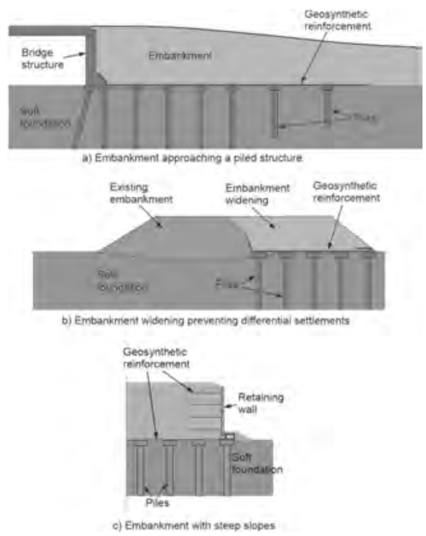





Basal geosynthetic reinforced piled embankments

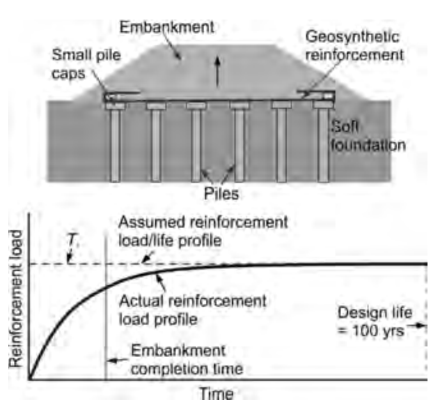
Basal reinforced piled embankments: applications

- Major applications are where speed of construction is important and to prevent differential settlements
  - Transition between piled and non-piled structures
  - Extending the extent of existing embankments
  - Sometimes used for normal embankments where there is need to prevent large settlements
  - Used where speed of construction is important
    - Can construct embankment side-slopes independent of foundation shear strength
    - Do not have to wait for foundation consolidation to occur

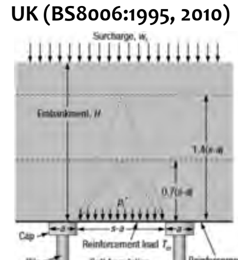


Basal reinforced piled embankments: tensile load profile over time

- As the embankment fill height is increased the tensile load increases in the basal reinforcement
- When the embankment is completed the reinforcement load is still increasing
- At some point in time an equilibrium condition is reached between the load applied to the reinforcement and the consolidation of the soft foundation between adjacent pile caps
- From this point on the reinforcement load remains constant with time
  - Reinforcement is required for 100 to 120 year design life



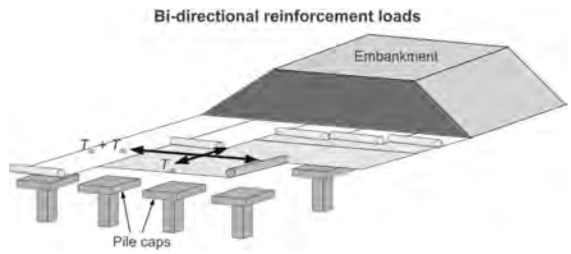
UK (BS8006:1995, 2010)



- Model used: Positive projecting conduit model (modified for 3D)
- Assumes no foundation support (conservative)
- Uniform vertical stress assumed acting on reinforcement between pile caps
- Deflected reinforcement shape approximates a parabola

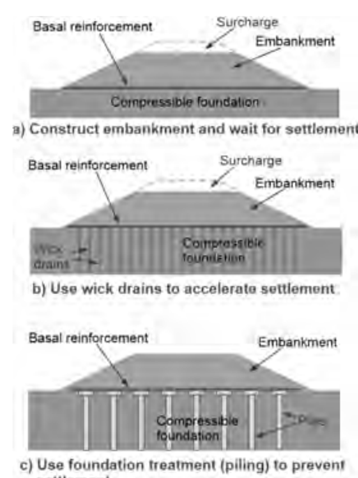
Basal reinforced piled embankments: basal reinforcement layout

* Reinforcement loads have to be carried both along and across the basal reinforced piled embankment
  * Along: due to embankment arching (T_{rp})
  * Across: due to embankment arching ***plus*** horizontal outward thrust of embankment ($T_{rp} + T_{ds}$)
* Also, loads must be transferred continuously across base of embankment
* The most efficient way of doing this is to use two layers of uniaxial geosynthetic reinforcement laid at right angles to each other
* Along embankment edges use thrust block to ensure reinforcement bond resistance in this location



Concluding remarks: basal reinforced embankments on soft foundations

* The use of basal reinforcement enables embankments on soft soils to be constructed higher and/or with steeper side-slopes than without basal reinforcement
* Basal geosynthetic reinforcement alone enhances short term stability of embankments until such time as soft foundation can fully support full loading of embankment
* The use of wick drains with basal reinforcement enables accelerated foundation consolidation (within the construction project timeframe) with little later maintenance costs
* Basal reinforced piled embankments prevent the effects of foundation consolidation
  * Embankment structures can be constructed to any height, at any speed and at any side-slope independent of foundation shear strength



Questions?

Chris Lawson
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Solmax / TenCate Geosynthetics Asia

Master Class # 2

Geosynthetic-reinforced Load Transfer Platforms

ADVANCES IN GEOSYNTHETICS
7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE
www.geoanzconference.com.au

Introduction

Jorge G. Zornberg, Ph.D., P.E.
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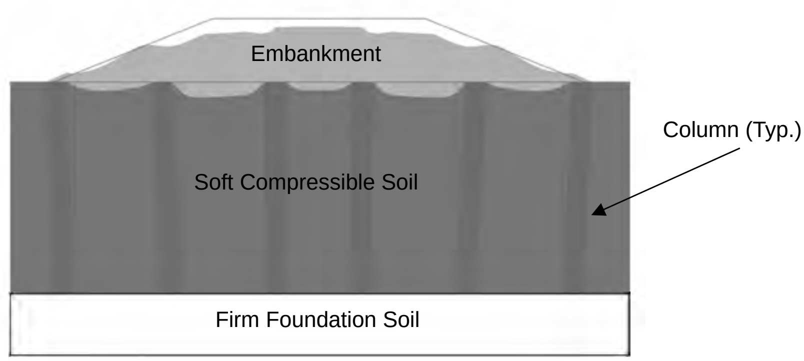
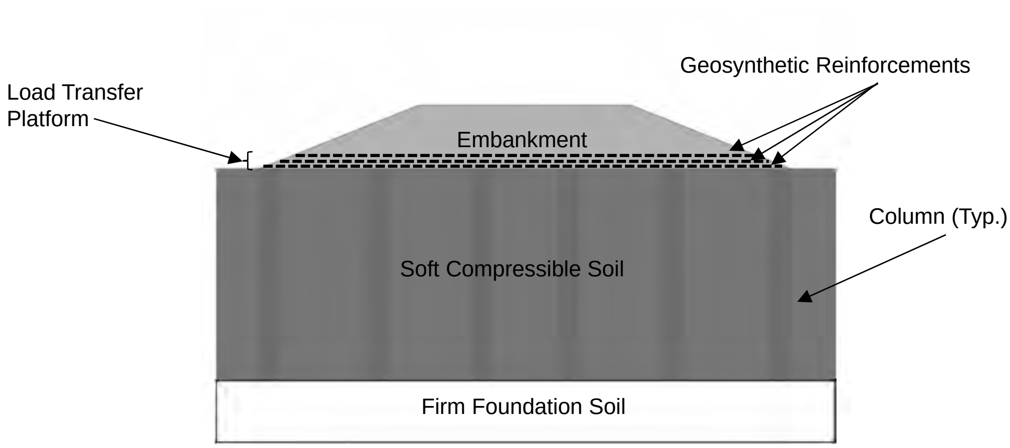
www.acigs.org

Geosynthetic-reinforced Load Transfer Platform



Geosynthetic-reinforced Load Transfer Platform



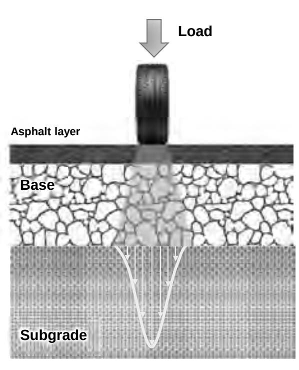
Stiffening Function

The geosynthetic develops tensile forces intended to control deformations in the soil-geosynthetic composite.

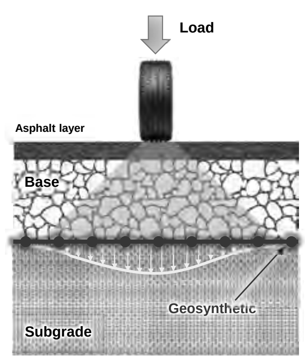
Example: A geosynthetic used to improve the mechanical properties of the unbound aggregate in a roadway.

Key properties:

- Geosynthetic stiffness
- Soil-geosynthetic interaction
- Confined stiffness of the soil-geosynthetic composite



Without geosynthetic stabilization

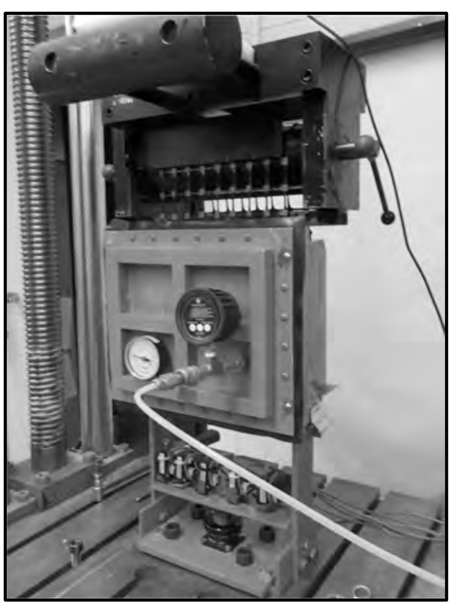


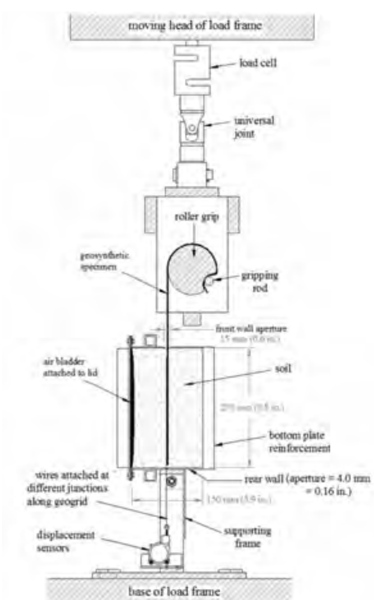
With geosynthetic stabilization

Test Method to Quantify the Stiffness of the Confined Soil-Geosynthetic Composite

- It involves laboratory equipment that is generally available in geosynthetic laboratories (e.g., equipment used to conduct wide width tensile tests)
- It is comparatively expeditious
- It aims at quantifying the composite stiffness at the onset of load mobilization in the geosynthetic
- It can quantify the composite stiffness of both geogrids (of different configurations) and geotextiles
- If used with a standardized aggregate, it can be used to establish thresholds of performance in specifications

Soil-Geosynthetic Composite Test Setup





Analytical Framework: Solution

$$K_{SGC} = 4\ \tau_y \cdot J_c = \frac{T(x)^2}{u(x)}$$

- K_{SGC} = Stiffness of the soil-geosynthetic composite
  - τ_y = Yield shear stress (soil-geosynthetic interaction)
  - J_c = Confined geosynthetic stiffness
    - $T(x)$ = Unit tension at location x
    - $u(x)$ = Geosynthetic displacement at location x

Zornberg et al. (2017)

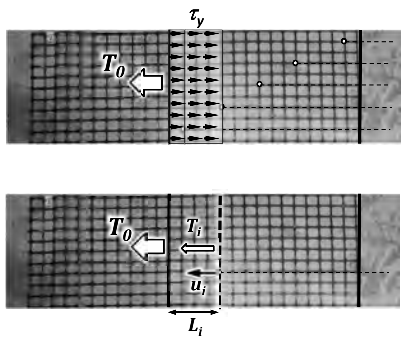
About KSGC …

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

- A high degree of soil-geosynthetic interaction is necessary, but not sufficient
  - Note: A product with superb interaction (e.g. high interlocking, friction) but low stiffness (e.g. rubber band-like) will result in a low K_{SGC}
- A high geosynthetic stiffness is necessary, but not sufficient
  - Note: A product with superb stiffness (e.g. steel) but particularly low soil-geosynthetic interaction (e.g. Teflon coating band) will result in a low K_{SGC}
- Good balance of adequate soil-geosynthetic interaction and geosynthetic stiffness results in high K_{SGC}

Experimental Determination of Model Parameters

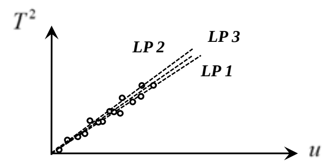
Determination of K_{SGC} from T^2 *vs.* u curves:



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)

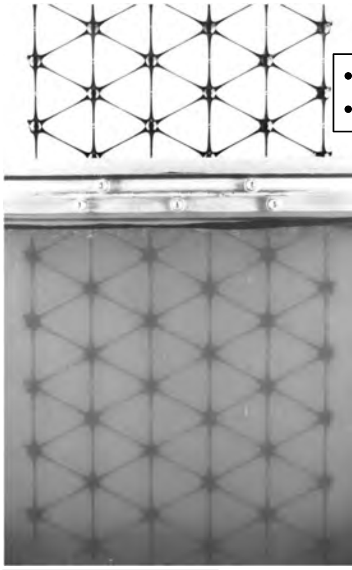


$$K_{SGC} = \frac{{T_i}^2}{u_i}$$

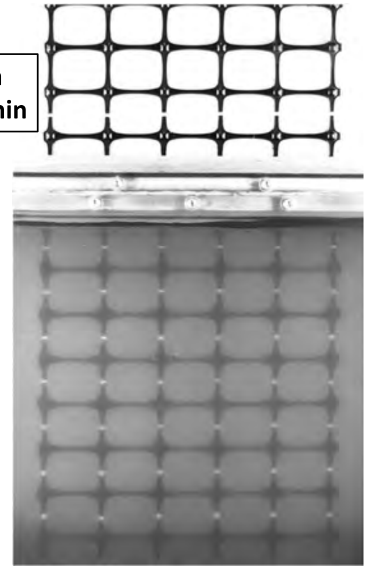
Additional Evidence: Transparent Soil Investigation

Courtesy: Dawie Marx

Geogrid Testing using Transparent Soil



- 27.6 kPa
- 1 mm/min



Geosynthetic A

Geosynthetic B

Questions?

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Master Class # 2

Geosynthetic-reinforced Load Transfer Platforms

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Outline

* Introduction - working platforms
* Why working platform is warranted – Safety, Safety and Safety
* Available design guides and limitations
* Recent developments - Case study
* Summary

INTRODUCTION

Introduction

- Working platforms?
  - Are temporary geotechnical structures made of compacted crushed granular material over weak soils
  - Geosynthetics can offer savings in time and material cost
  - Could be used For piling rigs, mobile cranes, construction machineries and other heavy construction equipment
  - Provide a stable working surface
- 33% of all Dangerous Occurrences reported in the piling industry are related to working platforms (UK Reference)
- Working Platforms must be designed and constructed properly according to design requirement
- BR470 report- probably first guideline specific to design of WP - June 2004

WHY SAFETY IS IMPORTANT?

Safety, Safety, Safety

* **Why is SAFETY important?**
* Let us look at the effects of some poor working platforms on piling rigs…
* **What can go wrong!!!???**

Safety, Safety, Safety

* Piling rig collapsed over power lines and parked cars due to development of soft spot in platform

Safety, Safety, Safety

* Crane rig being mobilised on poorly prepared platform

Safety, Safety, Safety

* 1,200t crane strayed off working platform over soft ground

Safety

CFA rig collapsed across main London – Paris railway line

Safety, Safety, Safety

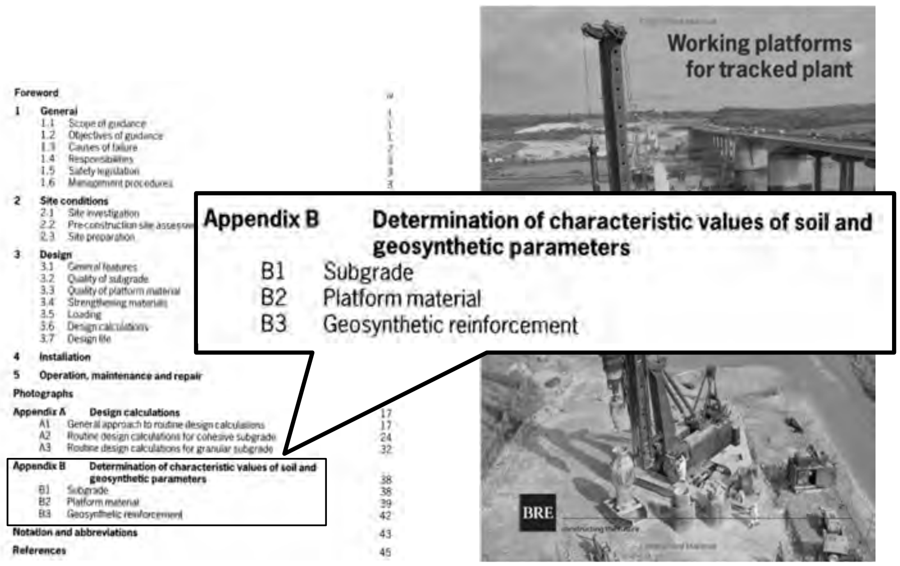
Tracked plant

Crane outriggers

ACCEPTABLE DESIGN GUIDELINES

BR470 Background

BR470 WORKING PLATFORMS FOR TRACKED PLANT



BR470 - 2004

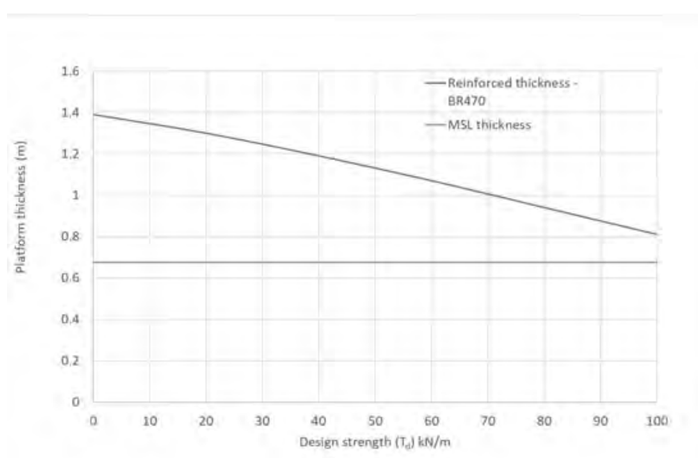
- Widely used method for design of working platforms.
- Based on the work done by Meyerhof (1974) and Hanna (1981) on small scale footings.
- Assumes punching shear failure.
- Punching shear failure coefficient K_s required to determine the platform contribution.
- K_s derived based on small scale 1g tests and presented in charts.
- Charts are not non-dimensional and appropriate only for the granular layer density and thickness used in their preparation (Burd and Frydman, 1997).
- The method considers geosynthetic contribution based on the design tensile strength and footing width ($2T_D/W$)
- In reality, tensile force mobilised in the geosynthetic depends on footing settlement (Sitharam and Hegde (2015)).
- Doesn't provide any guidance on including multiple geosynthetic layers.
- Valid for c_u between 20 - 80 kPa in case of cohesive subgrade.
- Can over predict the ultimate bearing capacity as the strength of clay layer increases relative to the platform layer (Shiau et. al. 2003)

T-value method

- Need for T-value method → Limitations associated with BR 470 and load spread method (what load spread angle to use?)
- $\frac{q_u}{q_s} = 1 + T\frac{H}{B} \leq \frac{q_g}{q_s}$ (strip footing, B/L = 0)
- $\frac{q_u}{q_s} = (1 + T\frac{H}{B})^2 \leq \frac{q_g}{q_s}$ (square or circular footing, B/L = 1)
- For rectangular shapes interpolate q_u between B/L = 0 and 1.
- *T* is the load spread efficiency and is non-dimensional.
- T-value method for cohesive subgrade based on existing centrifuge and numerical studies (FEA and FELA).
- Validated based on full scale field testing (load taken to failure).
- T-value method for granular subgrade based on an extensive numerical parametric study (FEA and FELA).
- The method in simple, practical, can be used for any shape (circular/square or rectangular).
- Possible to incorporate the benefit of mechanical stabilisation.
- With mechanical stabilisation, it is possible to design thinner platforms without compromising safety
- No limitation on the undrained shear strength.

BR470 vs T-value method

- 85T piling rig
- p = 275 kPa
- L = 2.32m
- W = 0.90m
- c_u = 20 kPa
- ϕ = 40° (BR-470)
- γ = 20 kN/m^3
- Thickness presented for LC1 (FS = 1.6)



RECENT CASE STUDY WITH DIFFERENT CHECKS AND BALANCES

Mt Gellibrand – Case study

Mt Gellibrand – Case study

Location: 25 kilometers east of Colac and 17 kilometers west of Winchelsea in Victoria

Project Configuration: Up to 44 x AW3000 3MW turbines

Start of construction: Major civil construction works commenced April 2017

Expected completion: Mid-2018

Expected capacity: Up to 132 MW

Energy production: Equivalent to 60,000 households

Project value: Up to A$258M
To develop the windfarm, 27km of internal access track roads, 92,000m2 of turbine hardstand areas; and Over 16,000m3 of structural concrete associated with the turbine foundations

Mt Gellibrand – Access Road Design Criteria

The site presented a number of challenges for the design team:

- The requirement for access roads to withstand heavy construction vehicles plus trafficking by the 600 t tracked crane and a 500 t wheeled crane required to mobilise the turbine engines;
- Cost of good quality fill material
- Very poor subgrade condition
- Construction during VIC Winter season
- Thick pavement if poor quality fill material is used (numerous truck movements)

Mt Gellibrand – Hardstand Design Criteria

The following methods presented in this preliminary design are:

- Working Platforms for tracked plants European Methodology (Based on Meyerhof Bearing Capacity Analysis).
- Limit Equilibrium (Bishop, Spencer two-part wedge)
- Finite Element Analysis

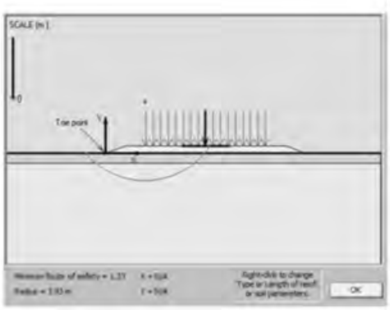
Geotechnical Values

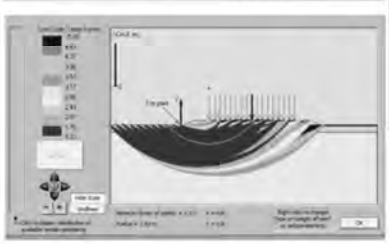
Granular Fill
CBR = 60%
Gamma = 1.7 ton/m3
Cohesion = 0
Phi = 35°- 40°

Foundation Soil Correlations
Gamma = 1.4 ton/m3
Cohesion= 4 ton/m2
Phi = 0°

Mt Gellibrand – Hardstand Design Criteria

Bishop Modified
Fs = 1.33



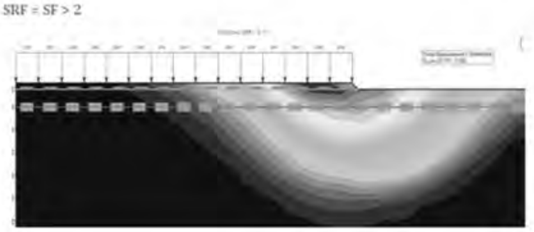


European Methodology
Requires 420 mm

Finit Element Analysis

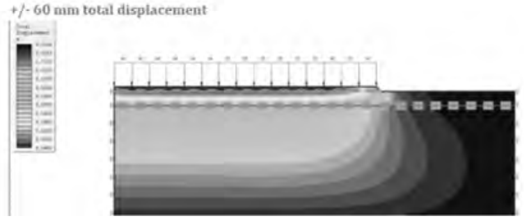
Equilibrium

SRF = SF > 2

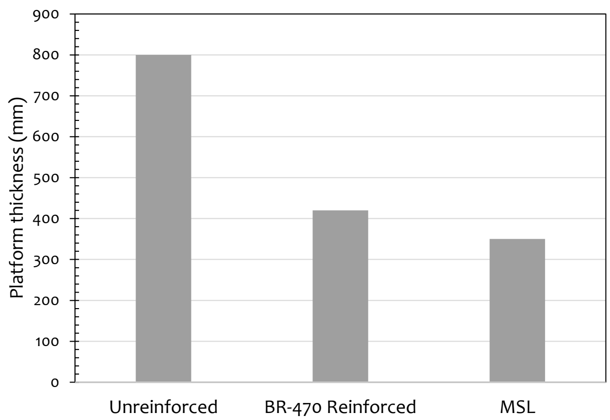


Superficial Displacement

+/- 60 mm total displacement



Mt Gellibrand – Hard Stand



Mt Gellibrand – Access Roads + Hardstand areas – Operational

Mt Gellibrand – Access Roads + Hardstand – Operational

Mt Gellibrand – Access Roads + Hardstand – Operational

SUMMARY

Working platform can be designed

- Geosynthetics can reduce construction costs
- Geosynthetics can reduce construction timeframes
- Geosynthetics can increase lifecycle and maintenance cycles
- Geosynthetics offer design flexibility
- Investigation on site is important
- Constructability is important

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- Burd HJ and Frydman S (1997) Bearing capacity of plane-strain footings on layered soils. *Canadian Geotechnical Journal* **34(2):**241-253
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- Hanna AM (1981) Foundations on strong sand overlying weak sand. *Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers* **107(GT7)**: 915-927.
- Meyerhof GG (1974) Ultimate bearing capacity of footings on sand overlying clay. *Canadian Geotechnical Journal* **11(2)**: 223-229.
- Shiau JS, Lyamin AV and Sloan SW (2003) Bearing capacity of a sand layer on clay by finite element limit analysis. *Canadian Geotechnical Journal* **40(5)**:900-915

Questions?

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Master Class # 2

Geosynthetics in Roadways

GEOANZ #1
ADVANCES IN GEOSYNTHETICS
7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE
www.geoanzconference.com.au

Introduction

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Geosynthetics in Roadway Applications

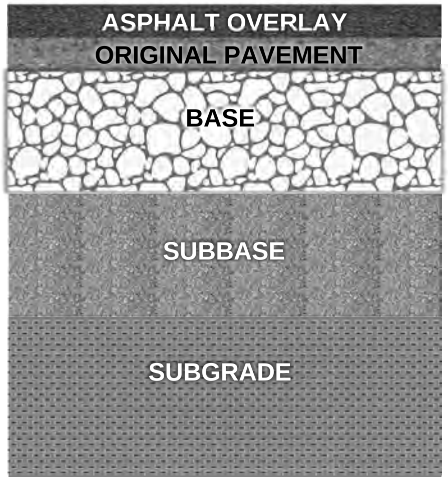
Good News!

There is a huge number of **geosynthetics** with a wide range of **properties** that can be used in numerous **roadway applications** to fulfill many different **functions** through a large variety of **mechanisms**.

Not So Good News…

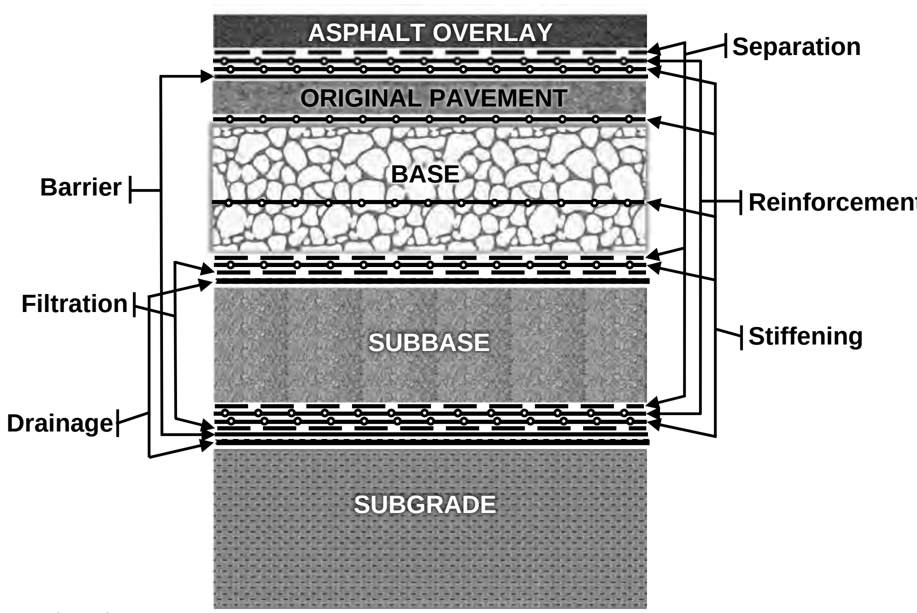
There is a huge number of **geosynthetics** with a wide range of **properties** that can be used in numerous **roadway applications** to fulfill many different **functions** through a large variety of **mechanisms.**

Geosynthetic Functions in Roadways



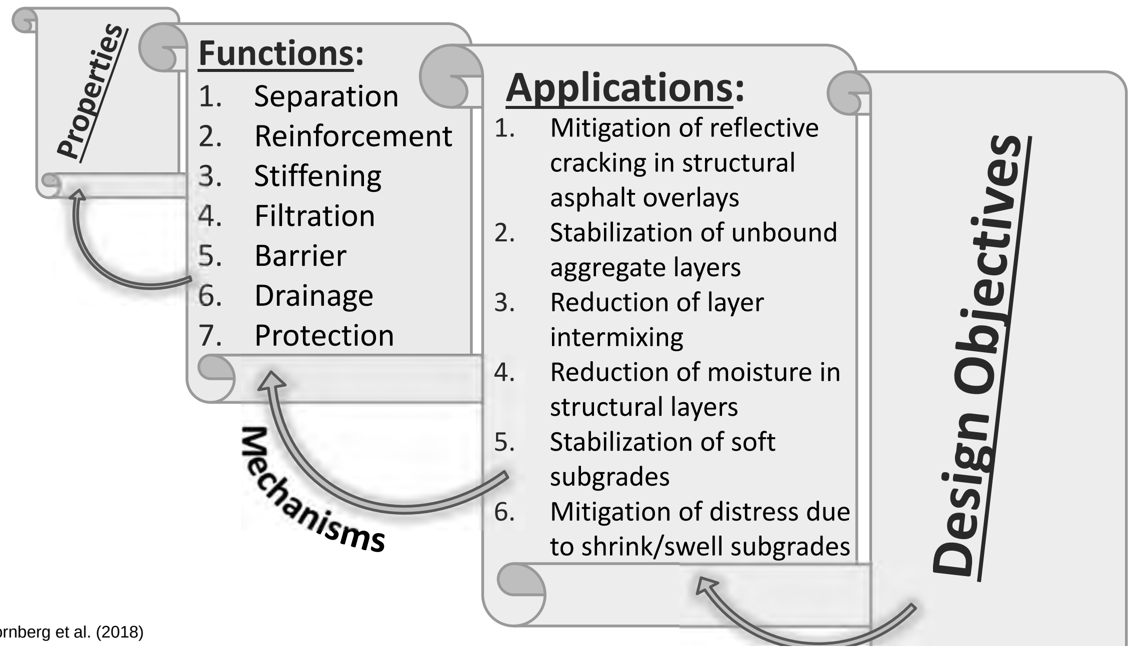
Zornberg (2017)

Geosynthetic Functions in Roadways



Zornberg (2017)

Geosynthetics in Roadway Applications



Source: Zornberg et al. (2018)

July 2021
Zornberg and Tutumluer

Summary of Applications Involving Geosynthetics in Transportation Infrastructure

Application	Objective(s)	Mechanism(s)	Geosynthetic Function(s) Primary	Geosynthetic Function(s) Secondary	Benefits in Roadway Performance
Mitigation of reflective cracking in structural asphalt overlays[1,2]	Retard or eliminate reflective cracking into structural asphalt overlays triggered by pre-existing cracks in old surface layer[1,2]	(1) Develop tension to enhance stress redistribution within asphalt overlays in the vicinity of pre-existing cracks[3]	Reinforcement	Barrier[2]	Maintain the integrity of the structural asphalt overlay by retarding the development of reflective cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the reflective cracks[5]
		(2) "Stress relief" to allow crack propagation along the geosynthetic interlayer[3]	Separation[4]		
Stabilization of unbound aggregate layers[7]	Provide initial increase, and minimize time-dependent decrease, in the modulus of unbound aggregate layers	Develop lateral restraint through tension and shear transfer, which minimize the tendency of unbound aggregates to displace laterally	Stiffening[6]		Decrease time-dependent rutting by (a) providing an increased modulus of unbound aggregates at the time of construction, and (b) minimizing degradation of the modulus of unbound aggregates over time
Reduction of layer intermixing	Avoid contamination of unbound aggregate layers with fine-grained subgrade soil particles	Minimize (a) loss of unbound aggregate particles into underlying soft subgrade, and (b) migration of fine-grained soil particles into overlying unbound aggregate layers	Separation	Filtration	Maintain the as-designed structural capacity by minimizing/eliminating (a) time and serviceability related decrease in thickness of the unbound aggregate layers, and (b) reduction in the quality of unbound aggregate materials
Reduction of moisture in structural layers	Provide in-plane drainage to minimize accumulation of moisture within structural layers	Provide (a) conventional, gravity-driven drainage (saturated soil conditions), and/or (b) enhanced, suction-driven drainage (unsaturated soil conditions)	Drainage	Filtration Separation	Avoid or minimize (a) generation of positive pore water pressures (due to traffic loading over near-saturated layers), and (b) decrease in the modulus and shear strength of structural layers resulting from moisture accumulation under unsaturated conditions
Stabilization of soft subgrades[6,7]	Increase the bearing capacity of soft subgrade soils	Develop (a) vertical restraint beyond the wheel path, and (b) some membrane-induced tension under the wheel path	Reinforcement[6]	Stiffening Separation Filtration	Decrease time-dependent rutting by (a) minimizing vertical and shear stresses in the subgrade under the wheel path, and (b) redistributing shear and normal stresses beyond the wheel path
Mitigation of distress induced by shrink/swell subgrades	Retard or eliminate environmental longitudinal cracks induced by volume changes in expansive or frost-susceptible subgrade soils	(1) Minimize stress concentration that triggers longitudinal cracks	Stiffening		Maintain the integrity of the asphalt surface course by retarding the development of longitudinal cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the longitudinal cracks
		(2) Promote moisture redistribution within subgrade to minimize differential volumetric changes[8]	Drainage	Stiffening[9]	

Notes

[1] A possible additional objective involving the use of geosynthetics in asphaltic layers is to increase the structural capacity of the roadway airfield, a benefit that would add to that of mitigating the development of reflective cracking.

[2] Another possible objective involving the use of geosynthetics in asphaltic layers is to provide a moisture barrier that will minimize water infiltration if cracks end up being reflected into the structural overlay. In some cases, the barrier function serves as possible secondary function to the primary ones.

[3] Tension development and stress relief are alternative mechanisms (i.e., they are not mechanisms that can be combined).

[4] While "stress relief" has been treated sometimes as an additional function, it is considered a specific case of the "separation" function in the framework described in this table.

[5] Even if the geosynthetic is selected with the objective of mitigating reflective cracking, an additional benefit is the increase in structural capacity of the roadway/airfield if the mechanism that is pursued is that of tension development (ongoing research is expected to quantify magnitude of the increased structural capacity).

[6] When placed at the interface of the unbound aggregate layer and a soft subgrade, the same geosynthetic would serve two applications: (a) Stabilization of the overlying unbound aggregate layer, with stiffening as the geosynthetic primary function, and (b) Stabilization of the underlying soft subgrade, with reinforcement as the geosynthetic primary function.

[7] It should be noted that while available methods for the design of unpaved roads focus on cases involving soft soil subgrades, they consider mechanisms that are identified as corresponding to two applications in this table: (a) stabilization of unbound aggregate layers, and (b) stabilization of soft subgrades.

[8] Geosynthetics that aim at minimizing access of moisture to subgrade soils (barrier as primary function) have been considered in limited occasions.

[9] For some geosynthetic products, the in-plane drainage and stiffening functions may be equally relevant.

Modified after Zornberg (2017)

Geosynthetics in Roadway Applications

- **Applications:** What?
- **Objectives:** Why?
- **Mechanisms:** How?
- **Functions:** For which action(s) should the GS be specially fitted?

→ **Properties**

Questions?

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Master Class # 2

Geosynthetics for Mitigation of Distress due to Expansive Clays

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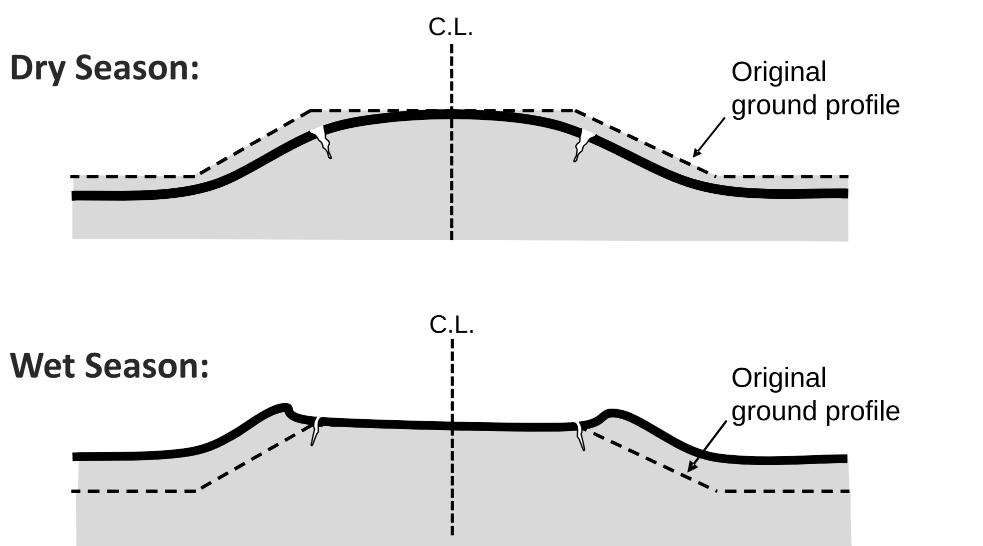
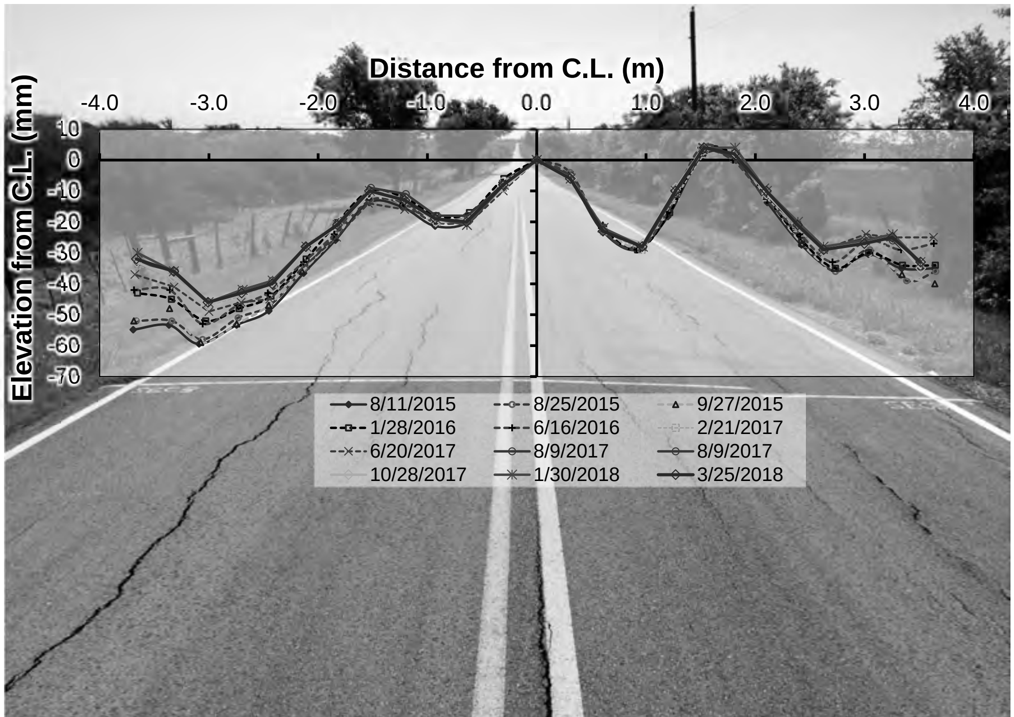
Understanding an Old Problem: Roadways over Expansive Clay Subgrades



Zornberg and Roodi (2021)



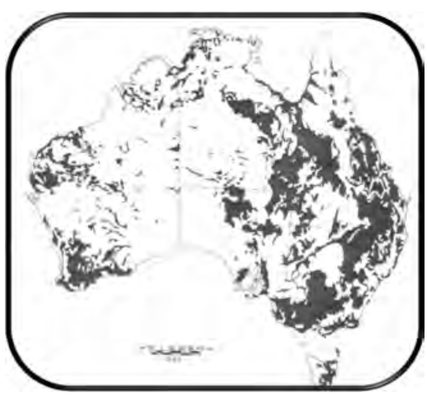
Zornberg and Zhang (2021)

Expansive Clays

Unit contains abundant clay having high swelling potential

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

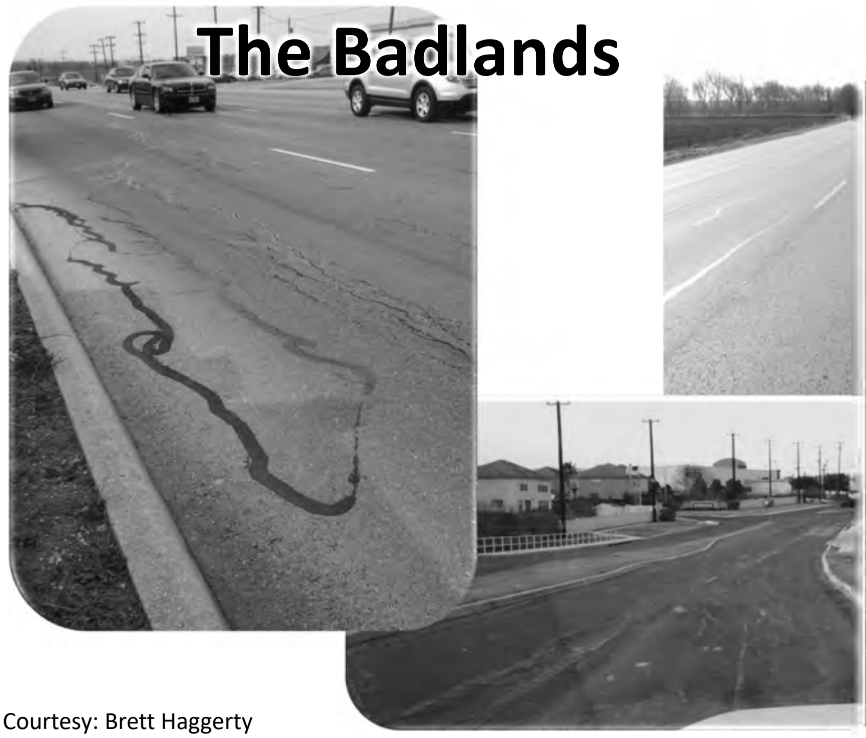
Source: USGS 1989

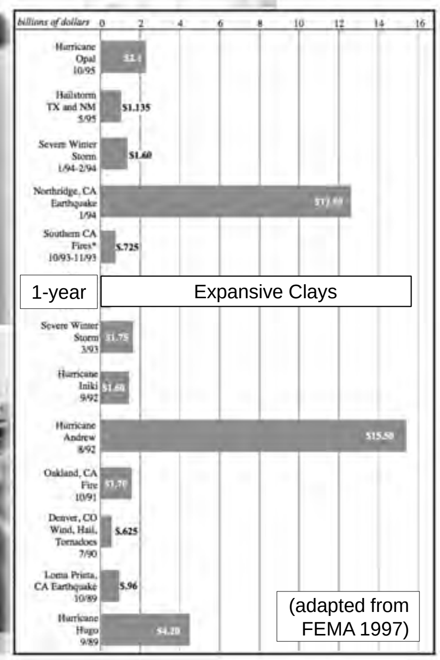


Source: Richards 1990

Source: The University of Waikato

The Badlands

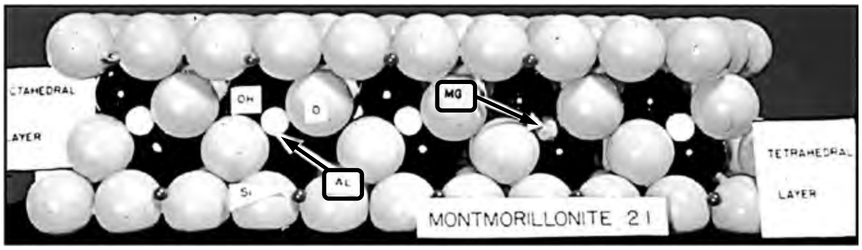




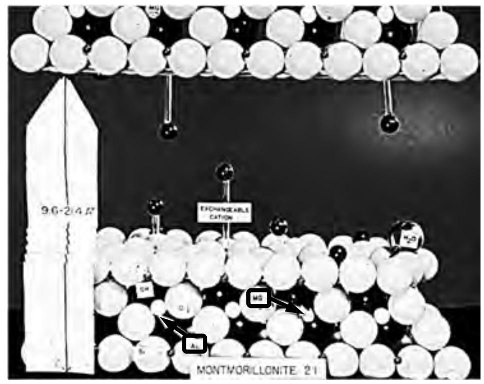
Courtesy: Brett Haggerty

Smectites

Smectites



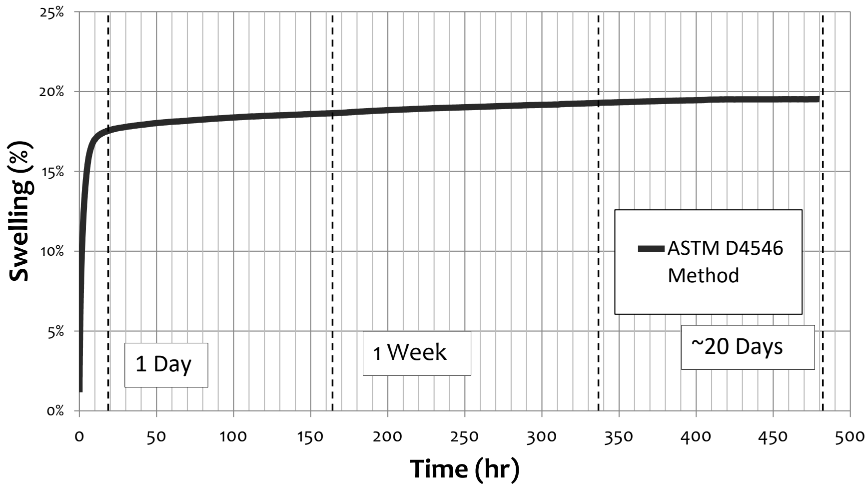
- Corresponds to the 2:1 type of clay minerals
- Montmorillonite is a smectite where every sixth Al^{3+} has been replaced by a Mg^{2+}
- n. H_2O + cations between layers
- Interlayer water can come and go easily



Conventional Swell Test

- ASTM D4546
- Conventional tests performed using consolidation frames
- Specimens are compacted, load applied
- Specimens are then inundated
- Vertical deflections measured

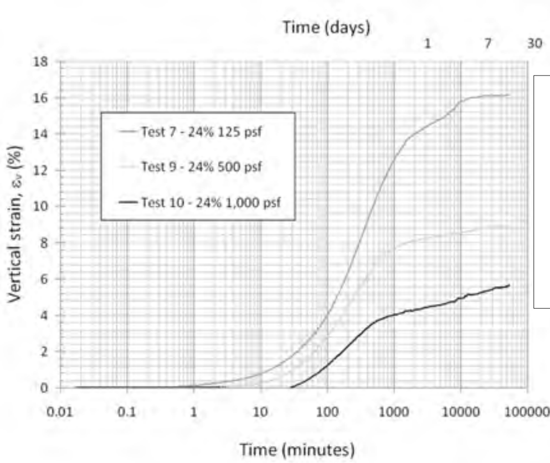
Typical Swell Test Results

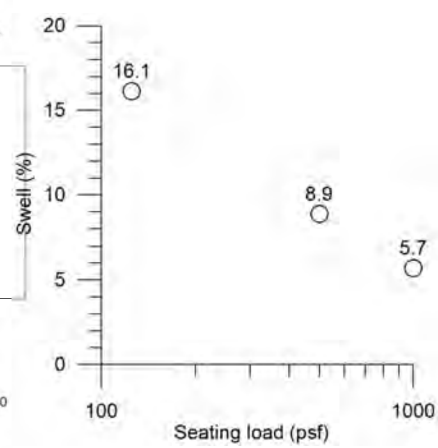


Source: Zornberg et al. (2017)

Conventional Swell Testing (ASTM D4546)

Impact of overburden pressure:





TxDOT Procedure Tex-124-E (or 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 Procedure Tex-124-E (or AASHTO T258-81)

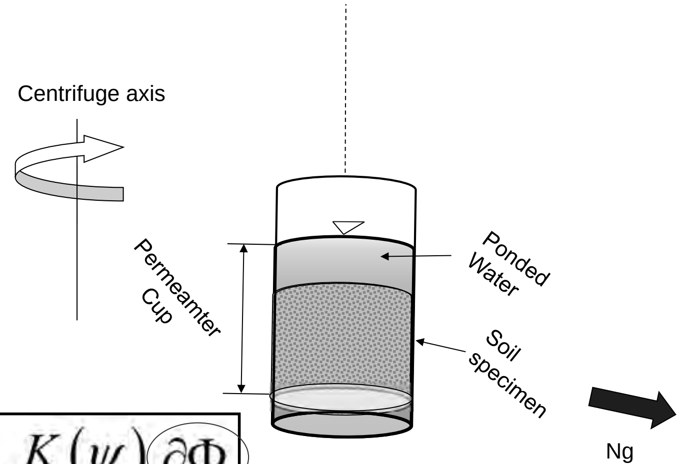
Pluses:

- 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 volumetric change (1 psi surcharge) from PI
  - To define free swell from volumetric change under 1 psi
  - To obtain linear swell from 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

Characterization Centrifuge for Direct Measurement of Swelling



$$v = \frac{Q}{A} = -\frac{K(\psi)}{g}\frac{\partial \Phi}{\partial z}$$

Characterization Centrifuge for Direct Measurement of Swelling

Centrifuge Device:

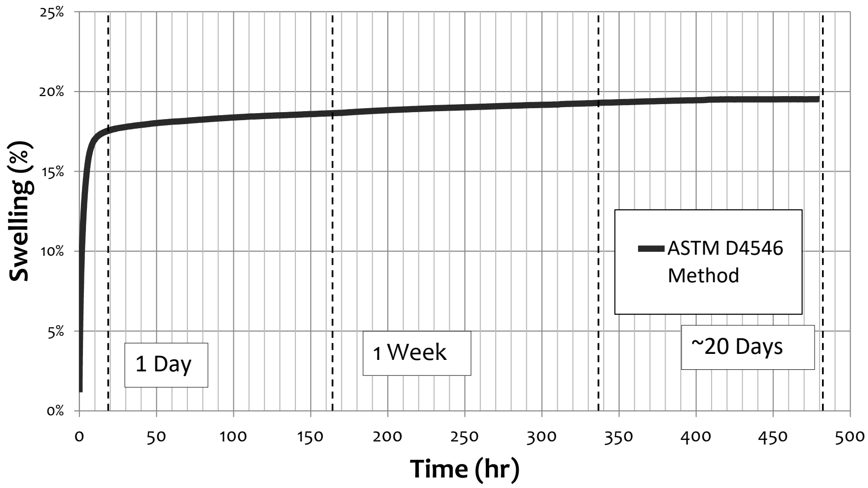
- Floor-mounted
- Comparatively low cost
- Can achieve very high g-levels
- In-flight data acquisition system

Measurements:

- Vertical displacements
- G-level
- Six specimens tested simultaneously

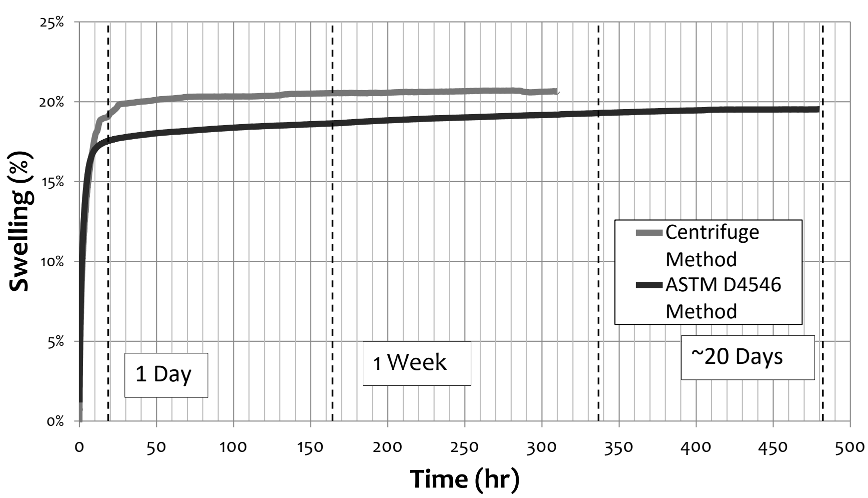
Source: Zornberg et al. (2017)

Typical Swell Test Results: Eagle Ford Clay



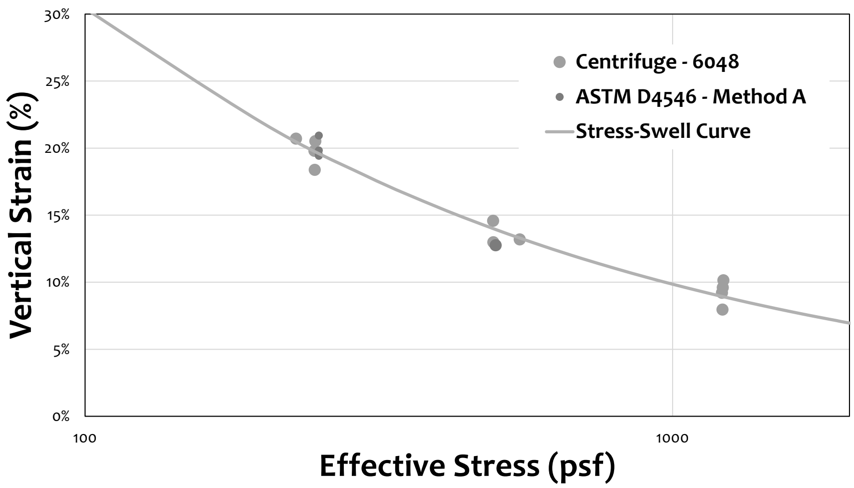
Source: Zornberg et al. (2017)

Typical Swell Test Results: Eagle Ford Clay



Source: Zornberg et al. (2017)

Swell-stress Curve for Eagle Ford Clay



Mitigation of Distress Induced by Shrink/Swell Subgrades: Strategies

Possible **strategies** include:

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

Mitigation of Environmental Distress

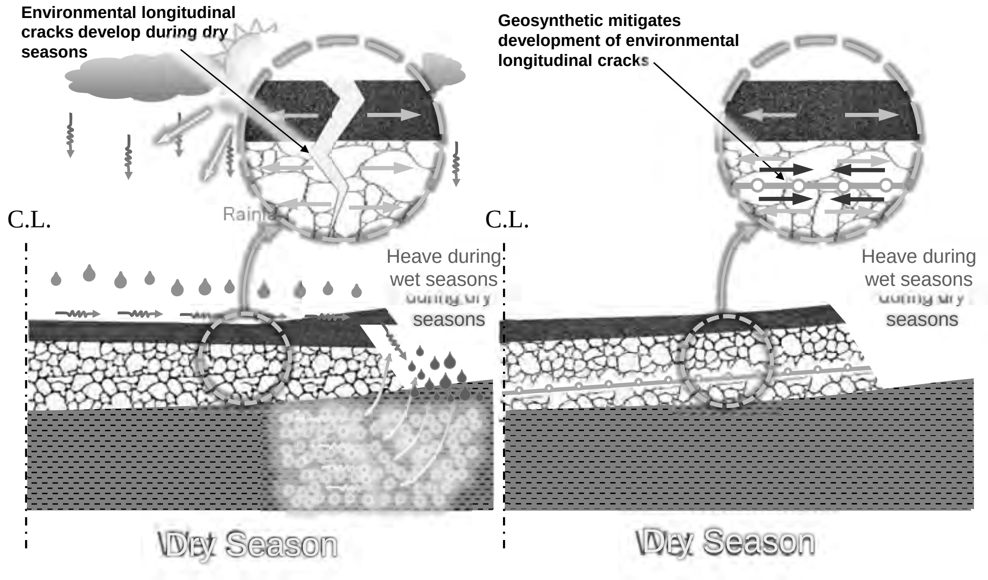
(by Maintaining Integrity of Unbound Aggregates): Mechanisms

Identified **mechanisms** include:

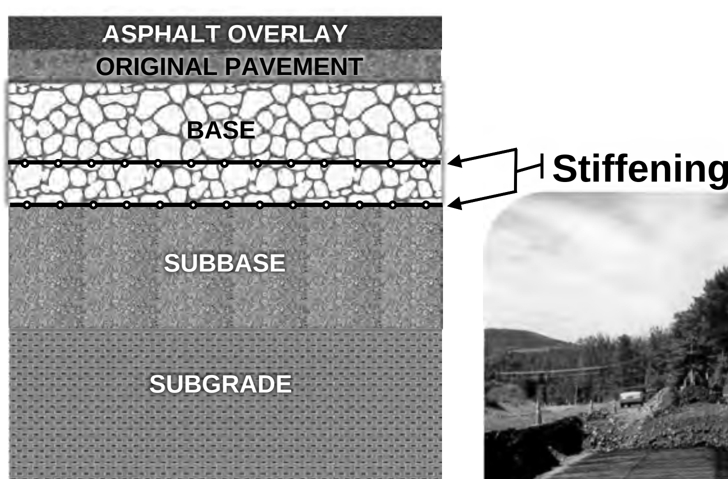
- Providing lateral restraint to the base layer:
  - Maintaining the base lateral confinement
  - Maintaining homogeneity in base mechanical properties
- Adding ductility to the base layer:
  - Minimizing the concentration of stresses responsible for triggering longitudinal cracks
  - Maintaining the integrity of the base layer

Mitigation of Environmental Distress (by maintaining integrity of unbound aggregates): Mechanisms

Non-Stabilized Roadway | GS-Stabilized Roadway



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



Source: Zornberg (2017b)

Mitigation of Environmental Distress (by Maintaining Integrity of Unbound Aggregates): GS Properties

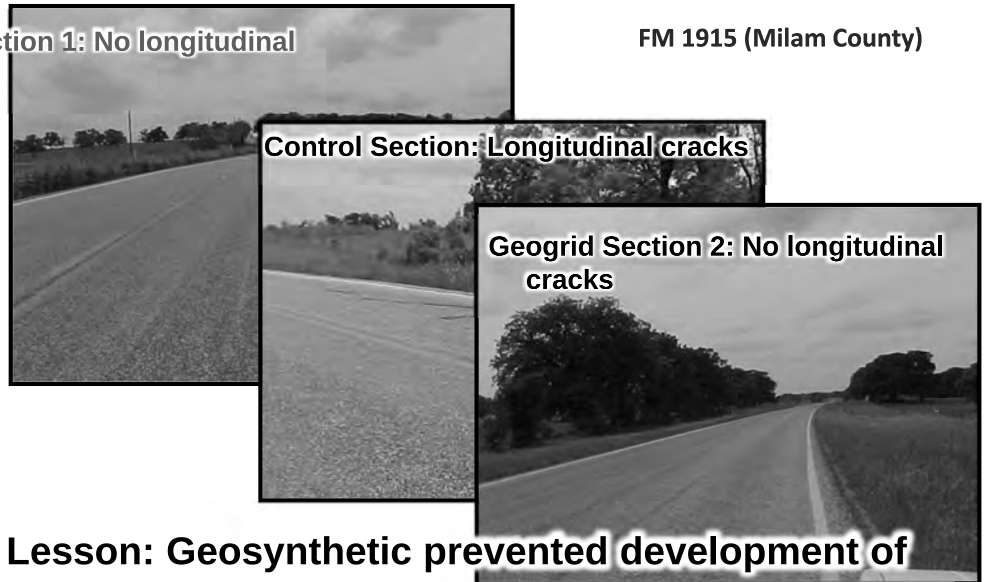
- Stiffness of the soil-geosynthetic composite under small displacements
- Unconfined tensile stiffness
- Soil-geosynthetic interaction properties
- Junction strength

Mitigation of Environmental Distress (by Maintaining Integrity of Unbound Aggregates): Benefits

- Maintain integrity of asphalt surface course
- Reduce/eliminate degradation mechanisms, such as environmental longitudinal cracks along roadways, which are triggered by water content fluctuations and frost action in the subgrade

Effect of Geosynthetic Stabilization

FM 1915 (Milam County)



Lesson: Geosynthetic prevented development of longitudinal cracks

Source: Zornberg et al. (2020)

To Be or Not to Be?

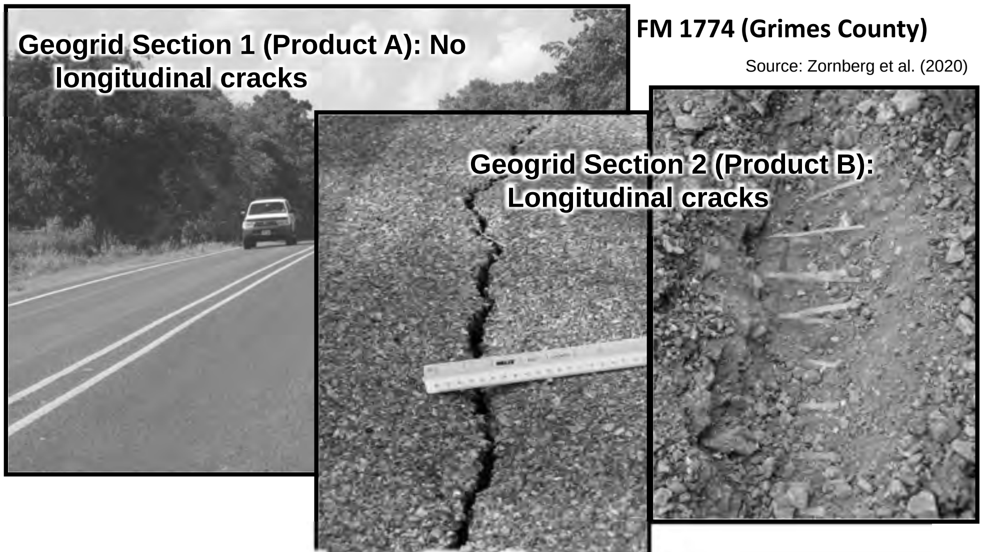
SH7 (Bryan District)

Lesson: Geogrids appear to work … if in place.

To Spec or not to Spec?

FM 1774 (Grimes County)

Source: Zornberg et al. (2020)



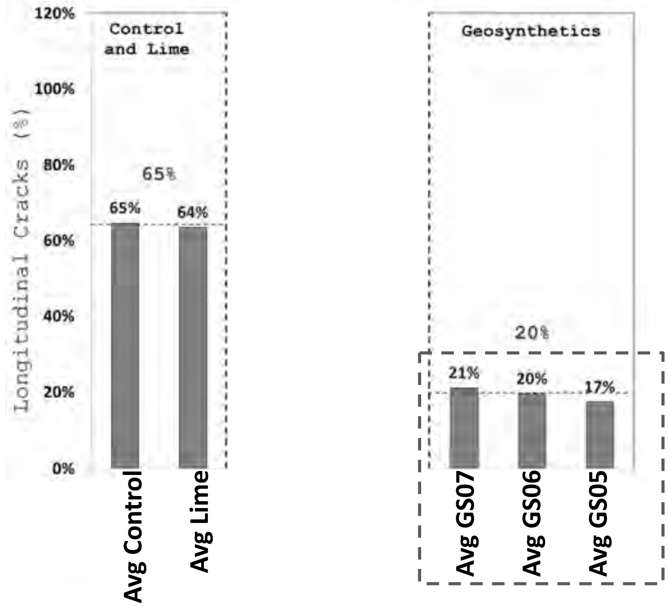
Lesson: Geogrid specifications available at the time had not led to consistent performance

Seeing is Believing…

Geosynthetic-stabilized Section

Control Section

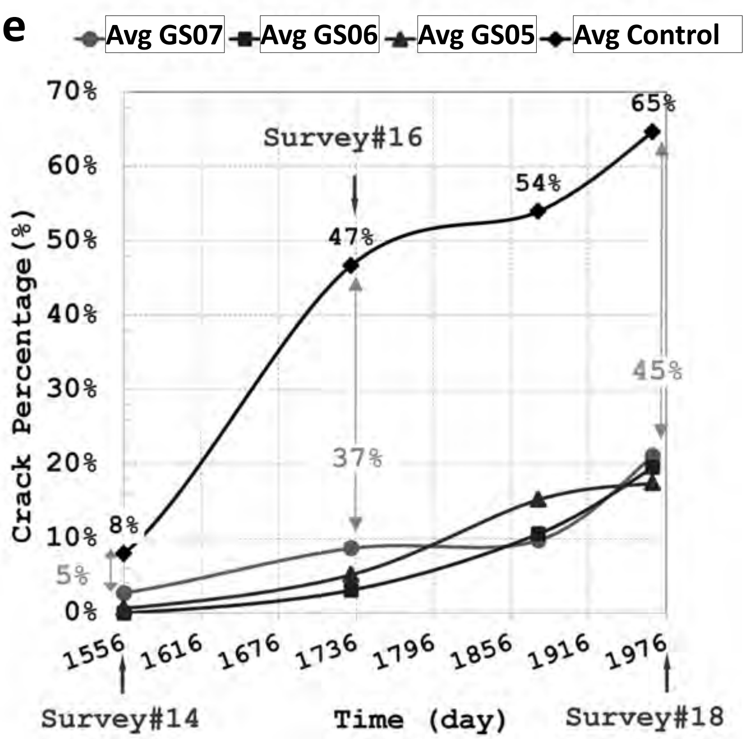
FM2: Distress Level



Roodi and Zornberg (2020)

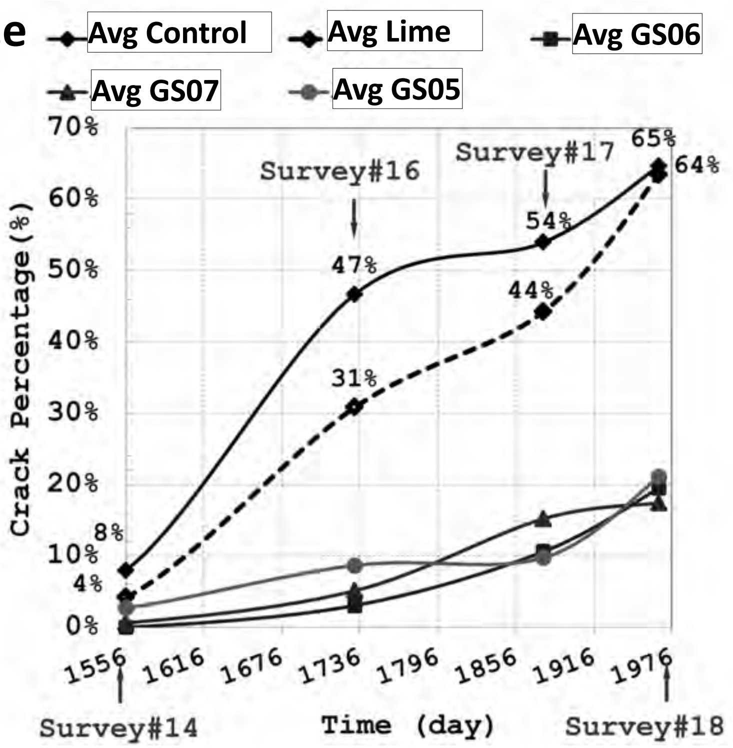
Performance over Time

Control vs. Geosynthetic-stabilized



Roodi and Zornberg (2020)

Performance over Time

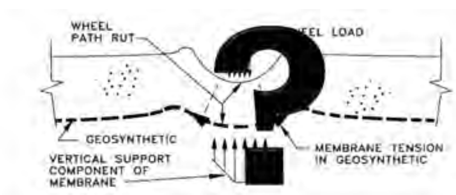


Control vs. Lime-treated vs. Geosynthetic-stabilized

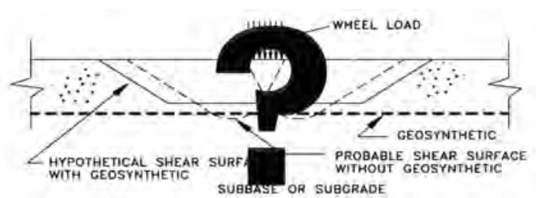
Roodi and Zornberg (2020)

A New Property: Why?

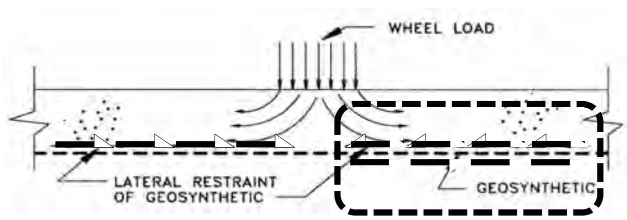
Back to the basics:



Membrane tension support



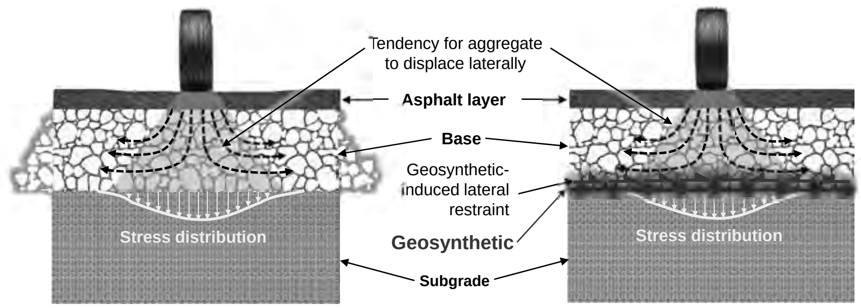
Bearing capacity increase



Lateral restraint

Haliburton et al. (1981)

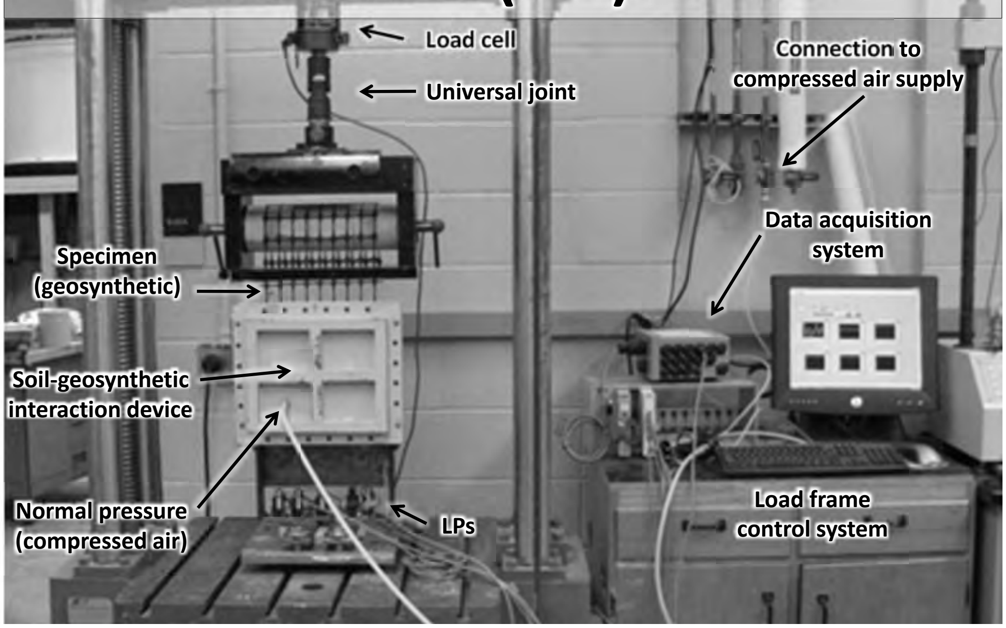
Stabilization Mechanisms: Lateral Restraint



Non-stabilized Road Base Stabilized Road Base

Zornberg (2017)

Small Soil Geosynthetic Interaction (SGI) Device



TxDOT Test Procedure Tex-136-E

GEOSYNTHETIC COMPOSITE STIFFNESS VALUE *TXDOT DESIGNATION: TEX-136-E*

Test Procedure for

GEOSYNTHETIC COMPOSITE STIFFNESS VALUE

TxDOT Designation: Tex-136-E

Effective Date: DRAFT

Texas Department of Transportation

1. **SCOPE**

1.1 The Geosynthetic Composite Stiffness (K_{SGC}) value is a performance index that characterizes the interaction of geosynthetics with aggregate material in a modified pull-out box assembly performed in a laboratory. The K_{SGC} quantifies the mechanical properties of geosynthetics based on their tensile behavior and their interaction with aggregates. It may also be used to evaluate the interaction of geosynthetics with in-situ materials.

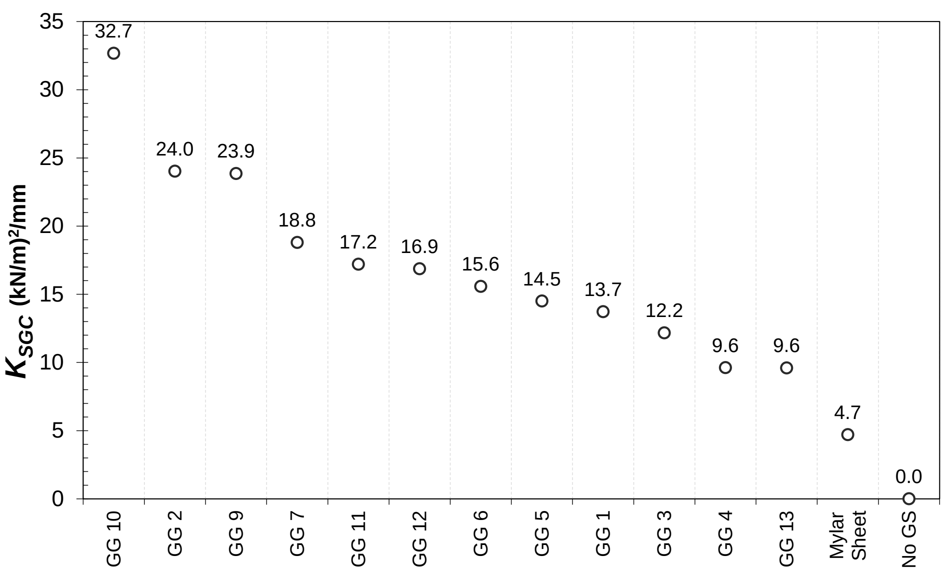
1.2 The K_{SGC} is quantified using a performance-based test that involves applying a tensile load to a confined geosynthetic sample at a constant displacement rate. The K_{SGC} is used to assess the potential of geosynthetics to quantify their stiffening function in applications such as stabilization of soft subgrade and stabilization of unbound aggregates.

1.2.1 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. **DEFINITIONS**

2.1 *Constant aggregate weight* - oven dry aggregate at a temperature of 230 ± 9°F such that it will not

Results from GG Testing Program



Source: Roodi et al. (2018)

Consistency between Experimental and Field Results

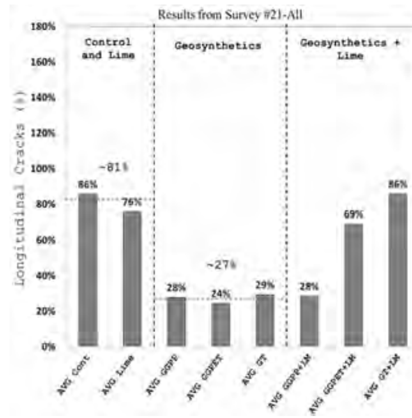
FM2

GG1: $K_{SGC} = 13$ ✓

GG5: $K_{SGC} = 11$ ✓

GT2: $K_{SGC} = 10$ ✓

Control: ✗



Roodi et al. (2020)

Consistency between Experimental and Field Results

SH21

GG1: $K_{SGC} = 13$ ✓

GG7: $K_{SGC} = 24$ ✓

GG10: $K_{SGC} = 32$ ✓

Control: ✗

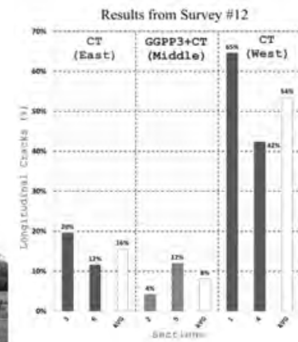
Zornberg and Roodi (2021)

Consistency between Experimental and Field Results

FM1644

GG6: $K_{SGC} = 14$ ✓

Control: ✗



Zornberg et al. (2020)

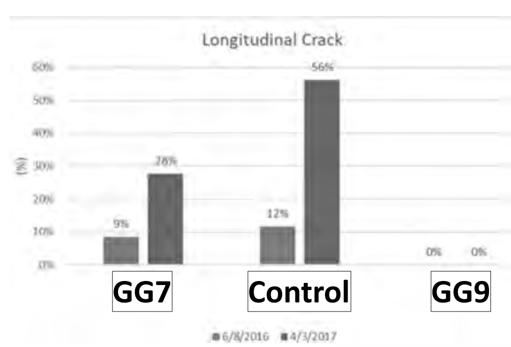
Consistency between Experimental and Field Results

Cabeza Road

GG7: $K_{SGC} = 19$ ✓

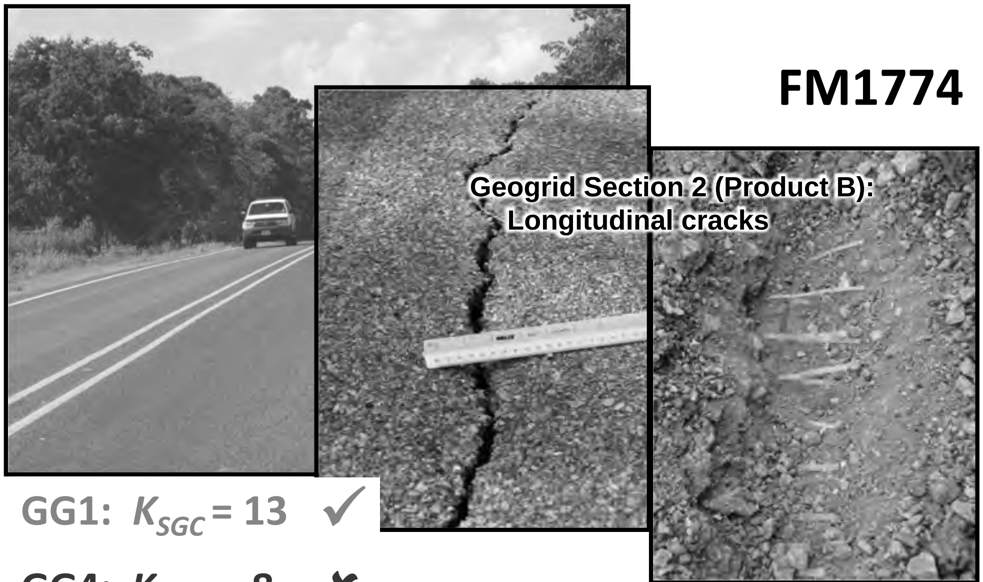
GG9: $K_{SGC} = 24$ ✓

Control: ✗



Roodi et al. (2018)

Consistency between Experimental and Field Results



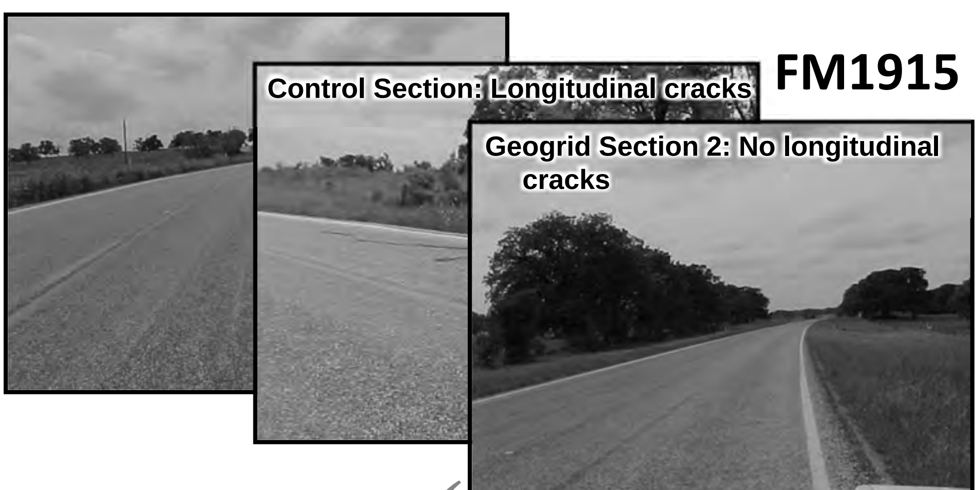
FM1774

GG1: $K_{SGC} = 13$ ✓

GG4: $K_{SGC} = 8$ ✗

Zornberg and Roodi (2021)

Consistency between Experimental and Field Results



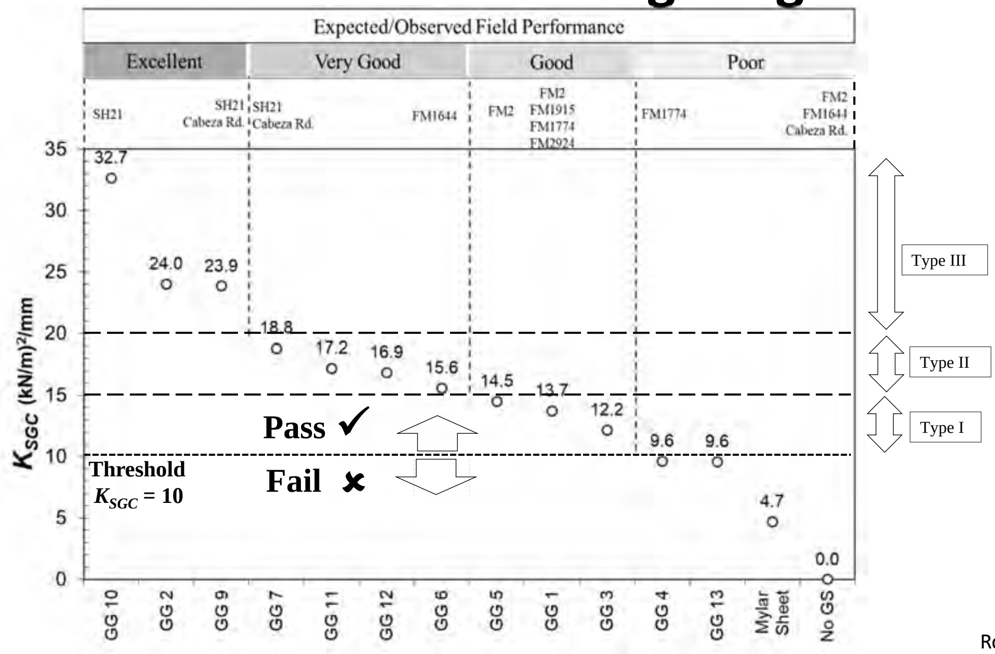
FM1915

GG1: $K_{SGC} = 13$ ✓

Control: ✗

Zornberg and Roodi (2021)

Results from GG Testing Program



Roodi et al. (2018)

TxDOT's DMS 6240

Property	Test Method	Type 1	Type 2	
Aperture Size, mm (in.)	Tex-621-J	25–51 (1.0–2.0)	25–51 (1.0–2.0)	
Percent Open Area, %	Tex-621-J	70 Min	70 Min	
Thickness, mm (in.) MD ribs CMD ribs Junctions	Tex-621-J	0.77 (0.03) Min 0.64 (0.025) Min 1.50 (0.06) Min	1.27 (0.05) Min 1.15 (0.045) Min 2.54 (0.10) Min	
Junction Efficiency, % of rib ultimate tensile strength MD & CMD	Tex-621-J	90 Min	90 Min	
Aperture Shape	—	Square or Rectangular	Square or Rectangular	Equilateral Triangular
Ribs per Node	—	4	4	6
Tensile Modulus @ 2% elongation[1], N/m (lb./ft.) MD & CMD	Tex-621-J	204,260 (14,000) Min	291,000 (20,000) Min	175,080 (12,000) Min

1. Determined as a secant modulus without offset allowances.

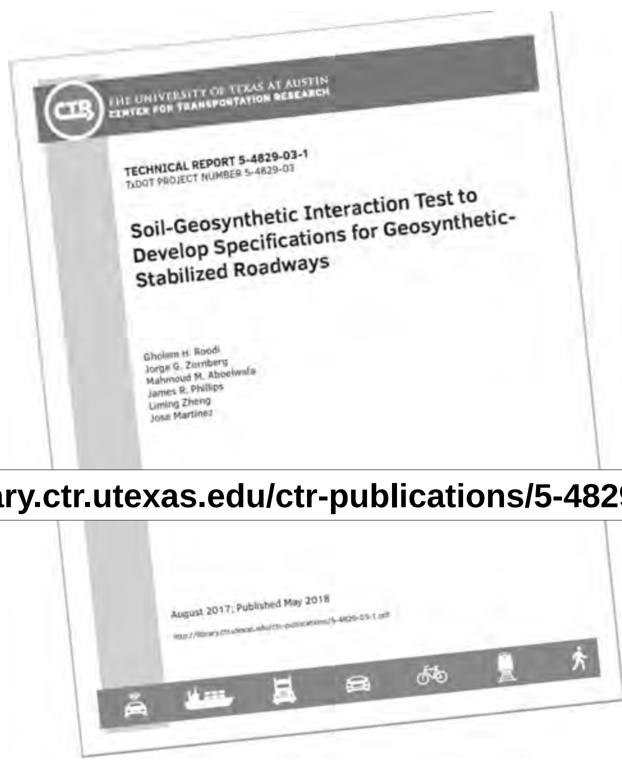
Note—MD and CMD do not necessarily refer to the machine (warp) and cross machine (fill) directions in the manufacturing process. They refer, for drawn products, to the more (CMD) or less (MD) highly drawn ribs where the aperture dimensions are unequal.

TxDOT's Revised DMS 6240

Property	Test Method	Type 1	Type 2		Type 3	
Aperture Size, mm (in.)	Tex-621-J	25–51 (1.0–2.0)	25–51 (1.0–2.0)		25–51 (1.0–2.0)	
Percent Open Area, %	Tex-621-J	70 Min	70 Min		70 Min	
Thickness, mm (in.) MD ribs CMD ribs Junctions	Tex-621-J	0.77 (0.03) Min 0.64 (0.025) Min 1.50 (0.06) Min	1.27 (0.05) Min 1.15 (0.045) Min 2.54 (0.10) Min		1.4 (0.055) Min 1.4 (0.055) Min 3.5 (0.14) Min	
Junction Efficiency, % of rib ultimate tensile strength MD & CMD	Tex-621-J	90 Min	90 Min		90 Min	
Stiffness of soil-geosynthetic composite (K_{SGC})[2] (kN/m)^2/mm CMD	Tex-1xx-E	10 Min	15 Min		20 Min	
Aperture Shape	—	Square or Rectangular	Square or Rectangular	Equilateral Triangular	Square or Rectangular	Equilateral Triangular
Ribs per Node	—	4	4	6	4	6
Tensile Modulus @ 2% elongation[1], N/m (lb./ft.) MD & CMD	Tex-621-J	204,260 (14,000) Min	291,000 (20,000) Min	175,080 (12,000) Min	291,000 (20,000) Min	175,080 (12,000) Min

1. Determined as a secant modulus without offset allowances.
2. Determined using washed and dried aggregates with rounded particles that retain between ¼" (6.35 mm) sieve and Sieve No.4 (4.75 mm). A dry density of 102.5 pcf and a normal stress of 3 psi shall be used. A minimum of 6 repeat tests shall be conducted.

Note—MD and CMD do not necessarily refer to the machine (warp) and cross machine (fill) directions in the manufacturing process. They refer, for drawn products, to the more (CMD) or less (MD) highly drawn ribs where the aperture dimensions are unequal.



https://library.ctr.utexas.edu/ctr-publications/5-4829-03-1.pdf

July 2021
Zornberg and Tutumluer

Summary of Applications Involving Geosynthetics in Transportation Infrastructure

Application	Objective(s)	Mechanism(s)	Geosynthetic Function(s): Primary	Geosynthetic Function(s): Secondary	Benefits in Roadway Performance
Mitigation of reflective cracking in structural asphalt overlays[1,3]	Retard or eliminate reflective cracking into structural asphalt overlays triggered by pre-existing cracks in old surface layer[1,2]	(1) Develop tension to enhance stress redistribution within asphalt overlays in the vicinity of pre-existing cracks[1,3]	Reinforcement	Barrier[2]	Maintain the integrity of the structural asphalt overlay by retarding the development of reflective cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the reflective cracks[2]
		(2) "Stress relief" to allow crack propagation along the geosynthetic interlayer[3]	Separation[4]		
Stabilization of unbound aggregate layers[6]	Provide initial increase, and minimize time-dependent decrease, in the modulus of unbound aggregate layers	Develop lateral restraint through tension and shear transfer, which minimize the tendency of unbound aggregates to displace laterally	Stiffening[6]		Decrease time-dependent rutting by (a) providing an increased modulus of unbound aggregates at the time of construction, and (b) minimizing degradation of the modulus of unbound aggregates over time
Reduction of layer intermixing	Avoid contamination of unbound aggregate layers with fine-grained subgrade soil particles	Minimize (a) loss of unbound aggregate particles into underlying soft subgrade, and (b) migration of fine-grained soil particles into overlying unbound aggregate layers	Separation	Filtration	Maintain the as-designed structural capacity by minimizing/eliminating (a) time and serviceability related decrease in thickness of the unbound aggregate layers, and (b) reduction in the quality of unbound aggregate materials
Reduction of moisture in structural layers	Provide in-plane drainage to minimize accumulation of moisture within structural layers	Provide (a) conventional, gravity-driven drainage (saturated soil conditions), and/or (b) enhanced, suction-driven drainage (unsaturated soil conditions)	Drainage	Filtration Separation	Avoid or minimize (a) generation of positive pore water pressures (due to traffic loading over near-saturated layers), and (b) decrease in the modulus and shear strength of structural layers resulting from moisture accumulation under unsaturated conditions
Stabilization of soft subgrades[6,7]	Increase the bearing capacity of soft subgrade soils	Develop (a) vertical restraint beyond the wheel path, and (b) some membrane-induced tension	Reinforcement[6]	Stiffening Separation	Decrease time-dependent rutting by (a) minimizing vertical and shear stresses in the subgrade under the wheel path, and (b)
Mitigation of distress induced by shrink/swell subgrades	Retard or eliminate environmental longitudinal cracks induced by volume changes in expansive or frost-susceptible subgrade soils	(1) Minimize stress concentration that triggers longitudinal cracks	Stiffening		Maintain the integrity of the asphalt surface course by retarding the development of longitudinal cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the longitudinal cracks
		(2) Promote moisture redistribution within subgrade to minimize differential volumetric changes[8]	Drainage	Stiffening[9]	

Notes:

[1] A possible additional objective involving the use of geosynthetics in asphaltic layers is to increase the structural capacity of the roadway/airfield, a benefit that would add to the mitigation of reflective cracks when the mechanism of tension development is involved.

[2] Another possible objective involving the use of geosynthetics in asphaltic layers is to provide a moisture barrier to minimize water infiltration if cracks end up being reflected into the structural overlay. The barrier function may serve as secondary function.

[3] Tension development and stress relief are alternative mechanisms (i.e., these two mechanisms cannot be combined).

[4] While "stress relief" has been regarded in some cases as an additional function, it is considered a mechanism in the framework described in this table, with "separation" as the function involved in such mechanism.

[5] Even if the geosynthetic is selected with the objective of mitigating reflective cracking, an additional benefit is that of increasing the structural capacity of the roadway/airfield if the mechanism involved is that of tension development.

[6] When placed at the interface of the unbound aggregate layer and a soft subgrade, the same geosynthetic would serve two applications: (a) Stabilization of the overlying unbound aggregate layer, with stiffening as the geosynthetic primary function, and (b) Stabilization of the underlying soft subgrade, with reinforcement as the geosynthetic primary function.

[7] While available methods for the design of unpaved roads focus on cases involving soft soil subgrades, they involve mechanisms corresponding to two applications in this table: (a) Stabilization of unbound aggregate

[8] Geosynthetics that aim at minimizing access of moisture to subgrade soils (barrier as primary function) have been considered on a few occasions.

[9] For some geosynthetic products, the in-plane drainage and stiffening functions may be equally relevant.

Modified after Zornberg (2017)

Final Remarks

- The use of geosynthetics was found to effectively minimize the detrimental effects of expansive soil subgrades on flexible pavements
- Geosynthetic-stabilized pavement sections on expansive clay subgrades showed significantly better field performance than control (non-reinforced) sections
- lime treatment was found not to still result in longitudinal cracks if treatment is incomplete
- The Confined Stiffness of the S-G Composite under Small Displacements (K_{SGC}) was identified as a relevant property
- The relative values of K_{SGC} were found to be consistent with the relative field performance of pavement sections subjected to environmental loads

Questions?

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The University of Texas at Austin, USA
Past - President, IGS
zornberg@mail.utexas.edu

Summary of Applications Involving Geosynthetics in Transportation Infrastructure

Application	Objective(s)	Mechanism(s)	Geosynthetic Function(s)		Benefits in Roadway Performance
			Primary	Secondary	
Mitigation of reflective cracking in structural asphalt overlays[1,2]	Retard or eliminate reflective cracking into structural asphalt overlays triggered by pre-existing cracks in old surface layer[1,2]	(1) Develop tension to enhance stress redistribution within asphalt overlays in the vicinity of pre-existing cracks[1,3] (2) "Stress relief" to allow crack propagation along the geosynthetic interlayer[3]	Reinforcement Separation[4]	Barrier[2]	Maintain the integrity of the structural asphalt overlay by retarding the development of reflective cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the reflective cracks[5]
Stabilization of unbound aggregate layers[6]	Provide initial increase, and minimize time-dependent decrease, in the modulus of unbound aggregate layers	Develop lateral restraint through tension and shear transfer, which minimize the tendency of unbound aggregates to displace laterally	Stiffening[6]		Decrease time-dependent rutting by (a) providing an increased modulus of unbound aggregates at the time of construction, and (b) minimizing degradation of the modulus of unbound aggregates over time
Reduction of layer intermixing	Avoid contamination of unbound aggregate layers with fine-grained subgrade soil particles	Minimize (a) loss of unbound aggregate particles into underlying soft subgrade, and (b) migration of fine-grained soil particles into overlying unbound aggregate layers	Separation	Filtration	Maintain the as-designed structural capacity by minimizing/eliminating (a) time and serviceability related decrease in thickness of the unbound aggregate layers, and (b) reduction in the quality of unbound aggregate materials
Reduction of moisture in structural layers	Provide in-plane drainage to minimize accumulation of moisture within structural layers	Provide (a) conventional, gravity-driven drainage (saturated soil conditions), and/or (b) enhanced, suction-driven drainage (unsaturated soil conditions)	Drainage	Filtration Separation	Avoid or minimize (a) generation of positive pore water pressures (due to traffic loading over near-saturated layers), and (b) decrease in the modulus and shear strength of structural layers resulting from moisture accumulation under unsaturated conditions
Stabilization of soft subgrades[6,7]	Increase the bearing capacity of soft subgrade soils	Develop (a) vertical restraint beyond the wheel path, and (b) some membrane-induced tension under the wheel path	Reinforcement[6]	Stiffening Separation Filtration	Decrease time-dependent rutting by (a) minimizing vertical and shear stresses in the subgrade under the wheel path, and (b) redistributing shear and normal stresses beyond the wheel path
Mitigation of distress induced by shrink/swell subgrades	Retard or eliminate environmental longitudinal cracks induced by volume changes in expansive or frost-susceptible subgrade soils	(1) Minimize stress concentration that triggers longitudinal cracks (2) Promote moisture redistribution within subgrade to minimize differential volumetric changes[8]	Stiffening Drainage	 Stiffening[9]	Maintain the integrity of the asphalt surface course by retarding the development of longitudinal cracks and, in turn, reduce/eliminate degradation mechanisms caused (or accelerated) by water intrusion through the longitudinal cracks

Notes:

[1] A possible additional objective involving the use of geosynthetics in asphaltic layers is to increase the structural capacity of the roadway/airfield, a benefit that would add to the mitigation of reflective cracks when the mechanism of tension development is involved.

[2] Another possible objective involving the use of geosynthetics in asphaltic layers is to provide a moisture barrier to minimize water infiltration if cracks end up being reflected into the structural overlay. The barrier function may serve as secondary function.

[3] Tension development and stress relief are alternative mechanisms (i.e., these two mechanisms cannot be combined).

[4] While "stress relief" has been regarded in some cases as an additional function, it is considered a mechanism in the framework described in this table, with "separation" as the function involved in such mechanism.

[5] Even if the geosynthetic is selected with the objective of mitigating reflective cracking, an additional benefit is that of increasing the structural capacity of the roadway/airfield if the mechanism involved is that of tension development.

[6] When placed at the interface of the unbound aggregate layer and a soft subgrade, the same geosynthetic would serve two applications: (a) Stabilization of the overlying unbound aggregate layer, with stiffening as the geosynthetic primary function, and (b) Stabilization of the underlying soft subgrade, with reinforcement as the geosynthetic primary function.

[7] While available methods for the design of unpaved roads focus on cases involving soft soil subgrades, they involve mechanisms corresponding to two applications in this table: (a) Stabilization of unbound aggregate layers, and (b) Stabilization of soft subgrades.

[8] Geosynthetics that aim at minimizing access of moisture to subgrade soils (barrier as primary function) have been considered on a few occasions.

[9] For some geosynthetic products, the in-plane drainage and stiffening functions may be equally relevant.

Modified after Zornberg (2017)

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Master Class # 2

Geosynthetics in Railways

Introduction

Jorge G. Zornberg, Ph.D., P.E.

The University of Texas at Austin, USA

Past - President, IGS

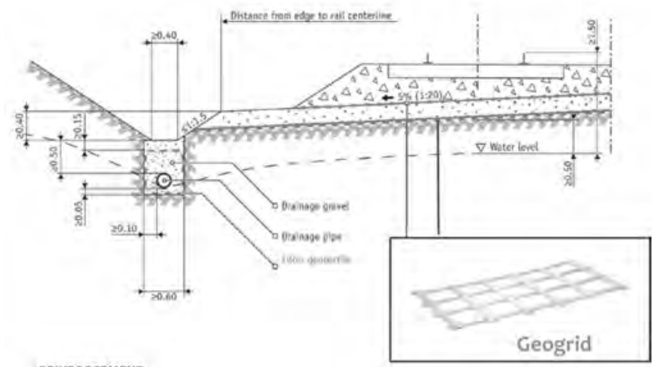
acigs

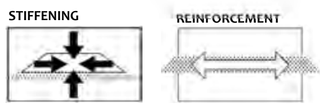
www.acigs.org

Geosynthetics in Railway Applications

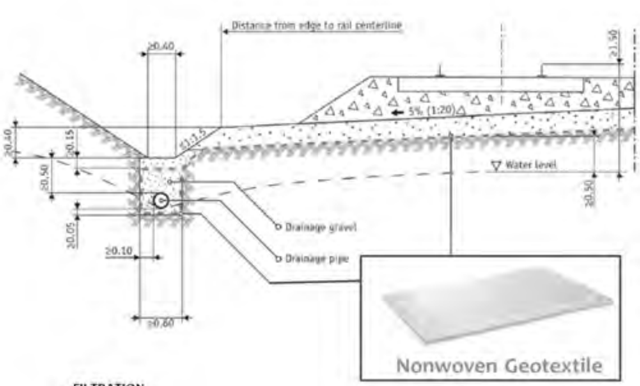
Amir Shahkolahi, Jörg Klompmaker, Global Synthetics, NAU

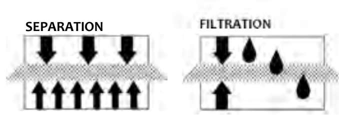
Stabilization of Unbound Aggregate Layers



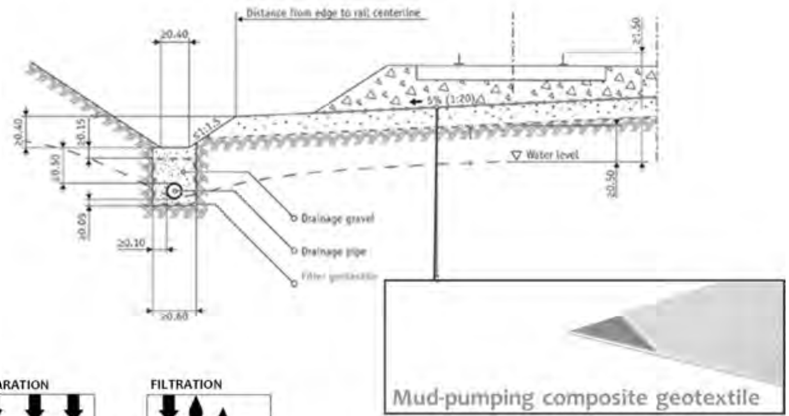


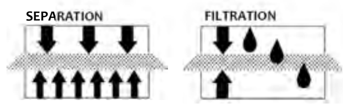
Reduction of Layer Intermixing (Subballast capping)



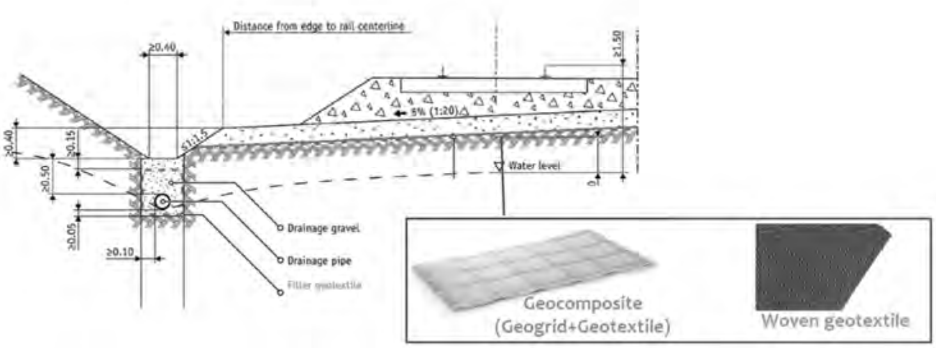


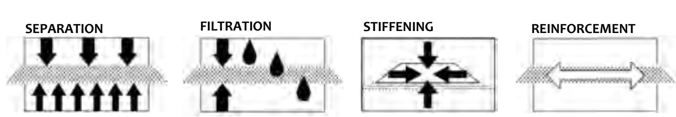
Reduction of Layer Intermixing (Ballast capping)



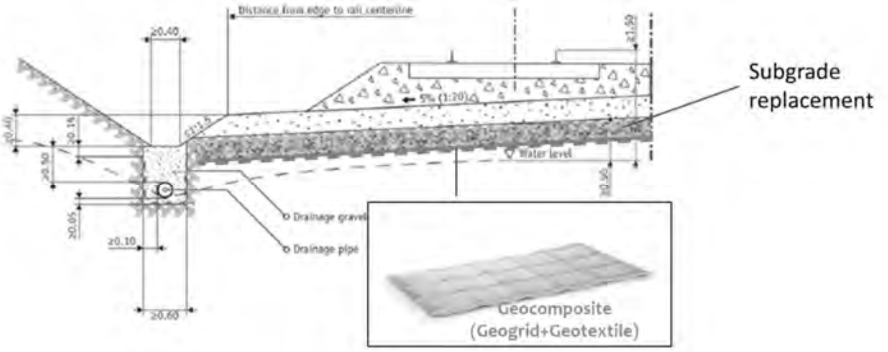


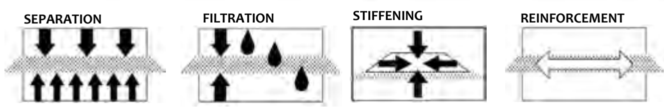
Stabilization of Soft Subgrades



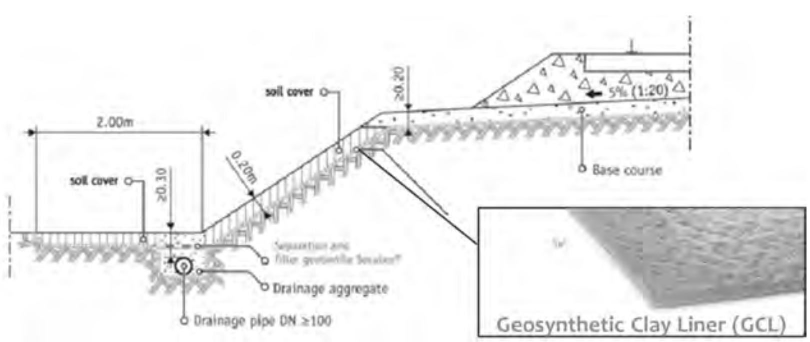


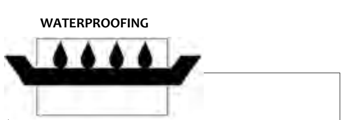
Stabilization of Soft Subgrades (w/Replacement)



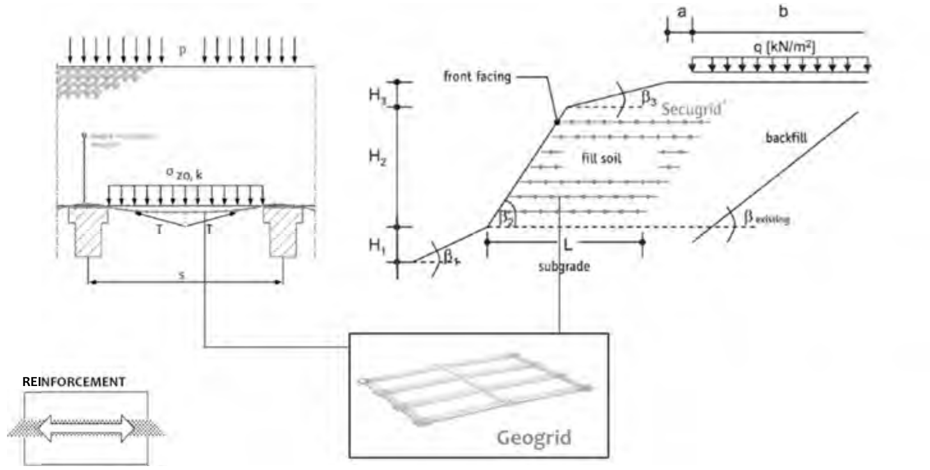


Reduction of Moisture in Structural Layers





Reinforcement in Rail Embankments



Questions?

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Master Class # 2

Considerations for Designing and Modelling Geogrid Reinforced Rail Tracks

Amir Shahkolahi
National Technical Manager
Global Synthetics

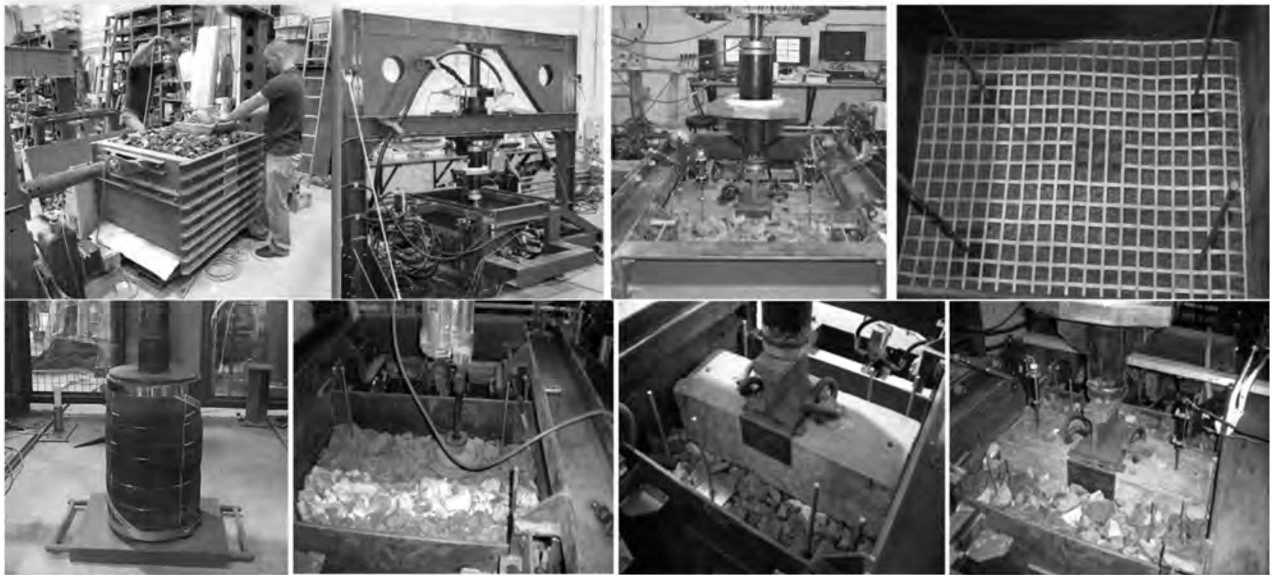
Global Synthetics
LEADERS IN GEOSYNTHETICS

acigs
www.acigs.org

Content:

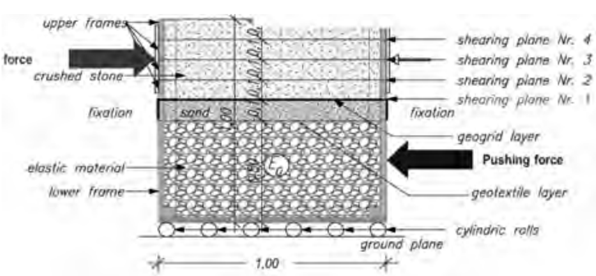
1. **Applications of geosynthetics in railways**
2. **Benefits of geogrid reinforcement/stabilization – Part 1: Laboratory tests**
3. **Benefits of geogrid reinforcement/stabilization – Part 2: Field measurements**
4. **Geogrid-ballast interaction**
5. **Geogrid performance and behavior during operation**

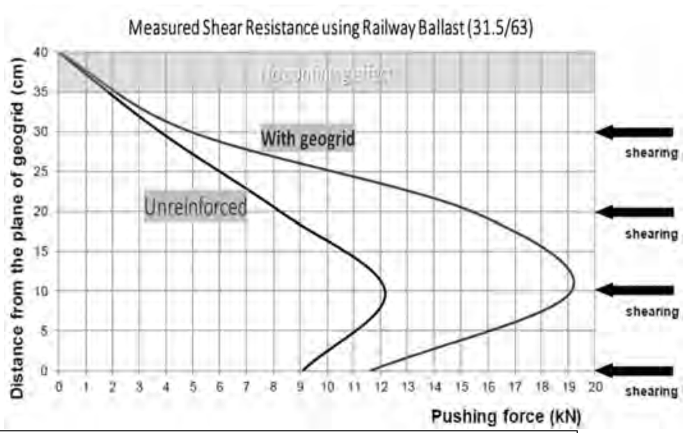
Benefits of geogrid reinforcement/stabilization
Part 1: Laboratory tests



Large-Scale Laboratory Multi-Level Shear Box Test

Széchenyi István University, Hungary



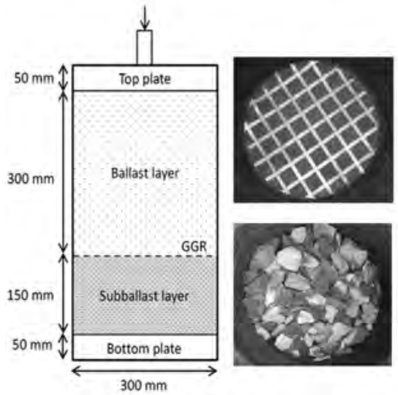


Geogrid successfully provides interlocking and confinement to the aggregates

Large-Scale Laboratory Impact Test

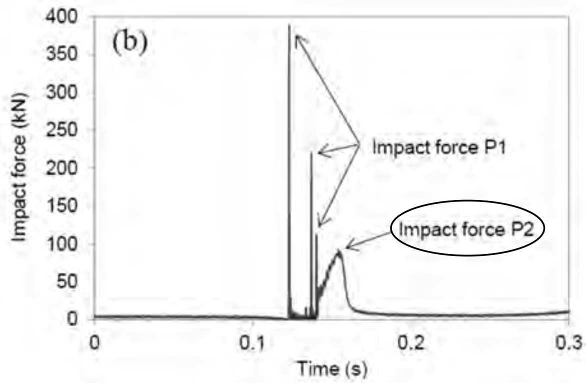
University of Wollongong, Australia (2017-2020)

Free-fall hammer: 5.81 kN
Maximum drop height: 6 m



High-capacity Drop-weight Impact Testing Apparatus

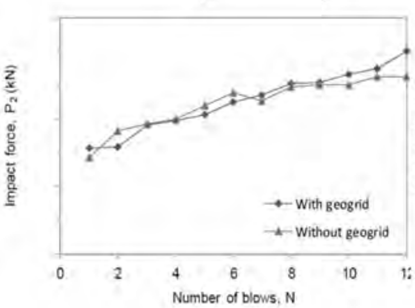
Typical transient force responses under a single impact blow



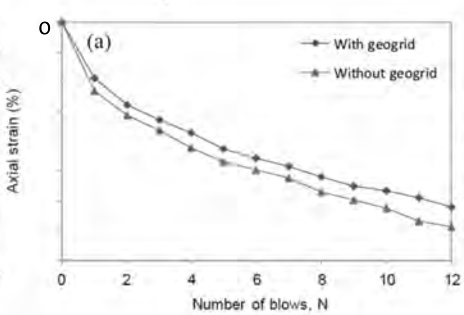
Large-Scale Laboratory Impact Test

University of Wollongong, Australia (2017-2020)

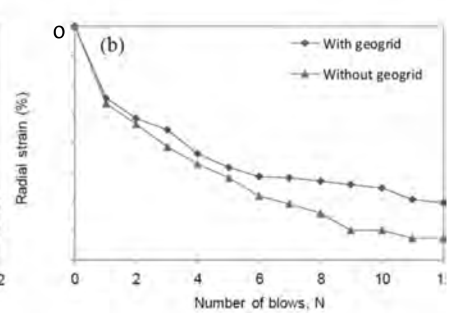
Impact force P_2



Axial/Vertical deformation



Radial deformation



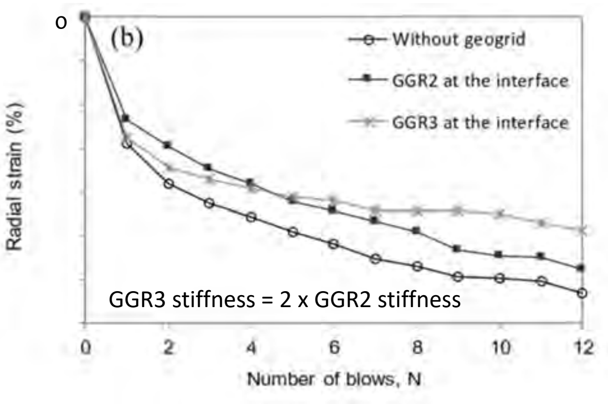
- Geogrid does not reduce the impact load.
- Although impact load is the same, the vertical and radial deformations are less for geogrid reinforced/stabilised ballast.

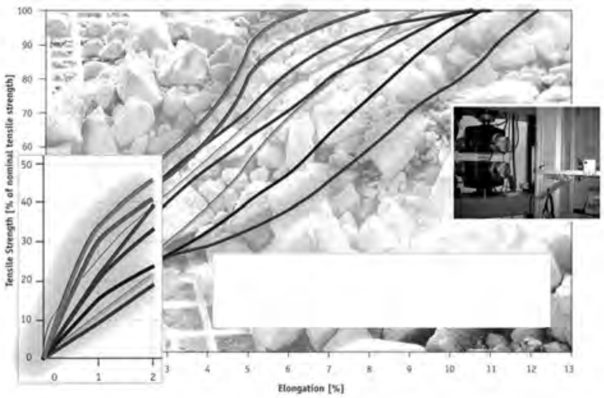
Not published

Large-Scale Laboratory Impact Test

University of Wollongong, Australia (2017-2020)

Effect of geogrid stiffness :

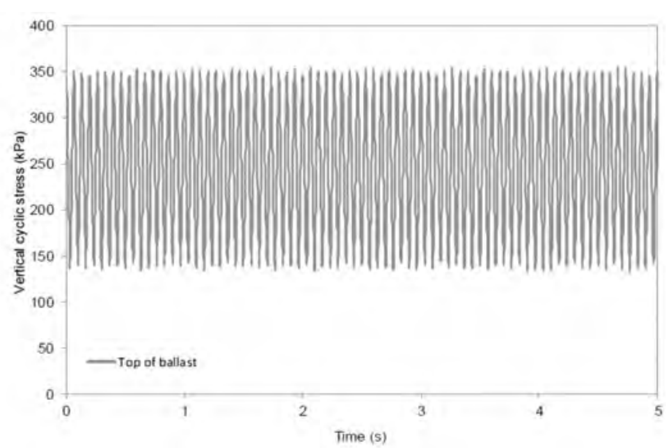




Not published

Large-Scale Laboratory Cyclic Load Test

University of Wollongong, Australia (2017-2020)

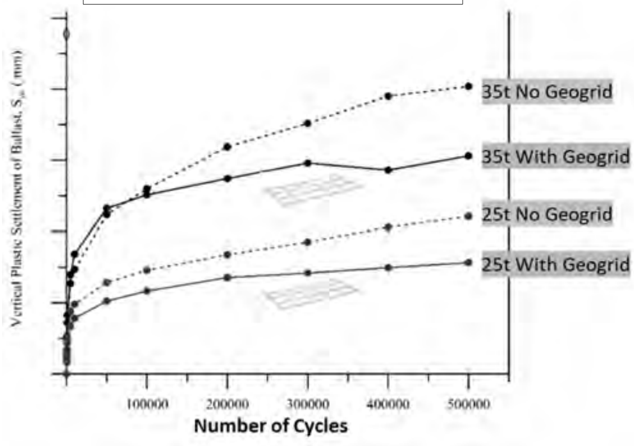


Large-Scale Laboratory Cyclic Load Test

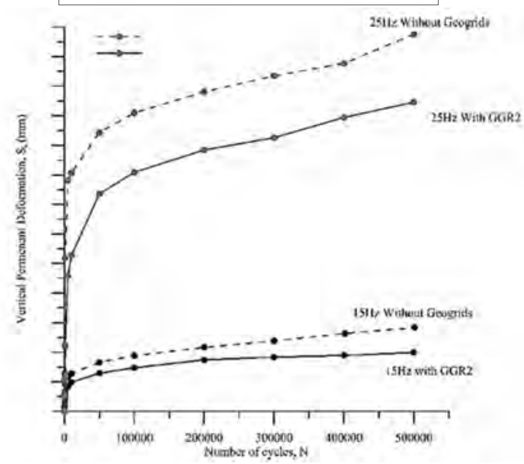
University of Wollongong, Australia (2017-2020)

Vertical Plastic Settlement of Ballast

Effect of geogrid and load:



Effect of geogrid and train speed:

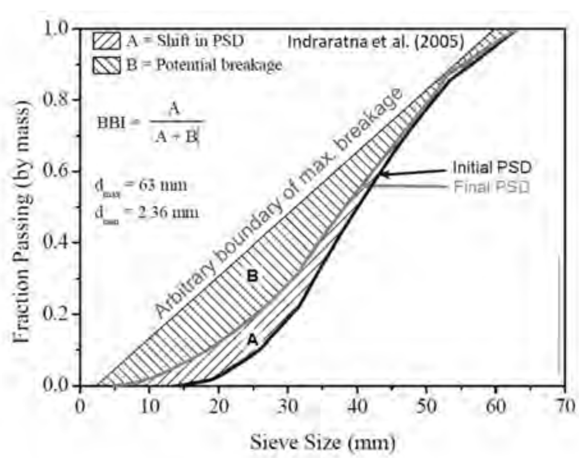


Not published

Large-Scale Laboratory Cyclic Load Test

University of Wollongong, Australia (2017-2020)

Ballast breakage:



BBI

Geogrids successfully reduce ballast breakage

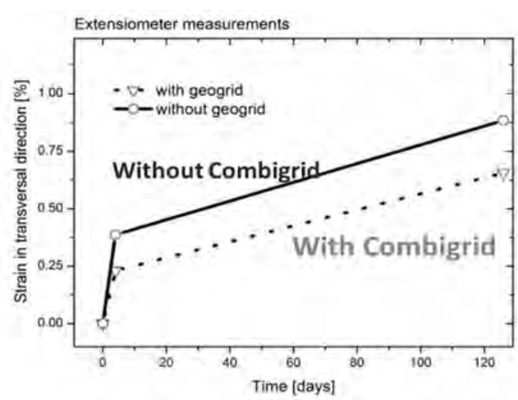
Not published

Benefits of geogrid reinforcement/stabilization
Part 2-Field measurements

Ballast Reinforcement-Sava, Slovenia

Lenart & klompmaker (2014)

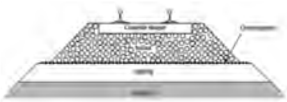
Lateral strain of the ballast layer:



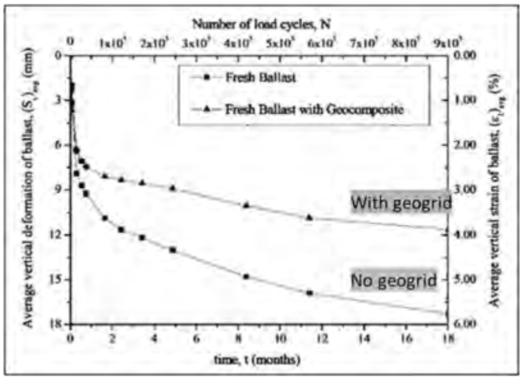
Geogrid composite has reduced lateral strain of the ballast and provided Lateral Confinement to the ballast

Ballast Reinforcement-Bulli, New South Wales, Australia

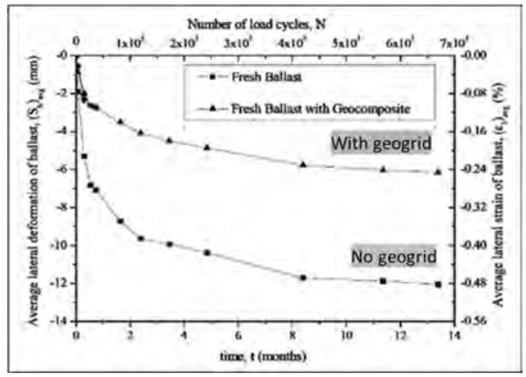
Indraratna et al (2010)



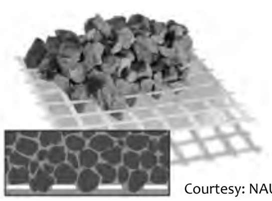
Ballast average vertical deformation



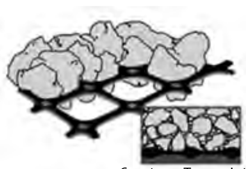
Ballast average lateral deformation



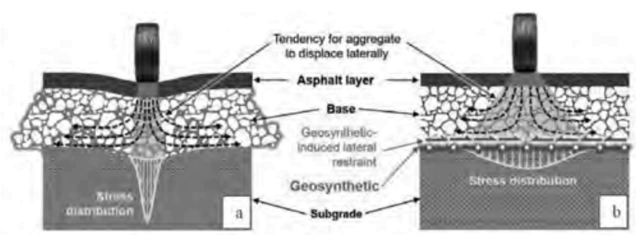
How?



Courtesy: NAUE

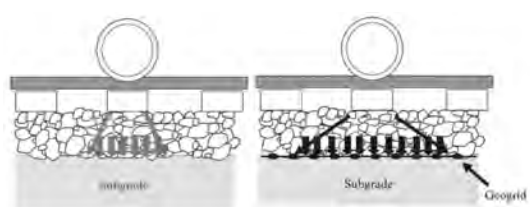


Courtesy: Tensar Int.



Zornberg (2017)

- Interlocking (and friction for some geogrids) between aggregate & geogrid
- Lateral Confinement of the aggregate
- Higher stiffness for the reinforced/stabilized layer
- Less deformation and settlement
- Less pressure on subgrade



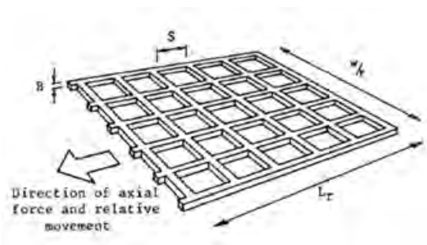
(Indraratna et al. 2011)

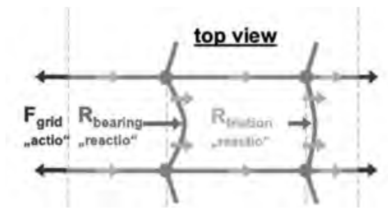
Geogrid-ballast interaction

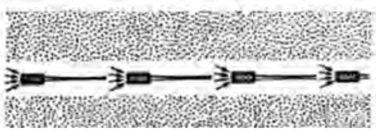
Geogrid-aggregate interaction is a combined effect of :

* Geogrid type
* Rib properties
* Aperture properties
* The ratio between aperture size to gravel size
* Rib stiffness
* Soil density

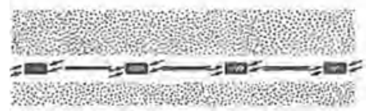
Geogrid-aggregate interaction mechanisms:



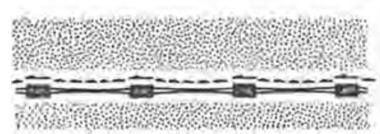




Bearing resistance of the geogrid ribs



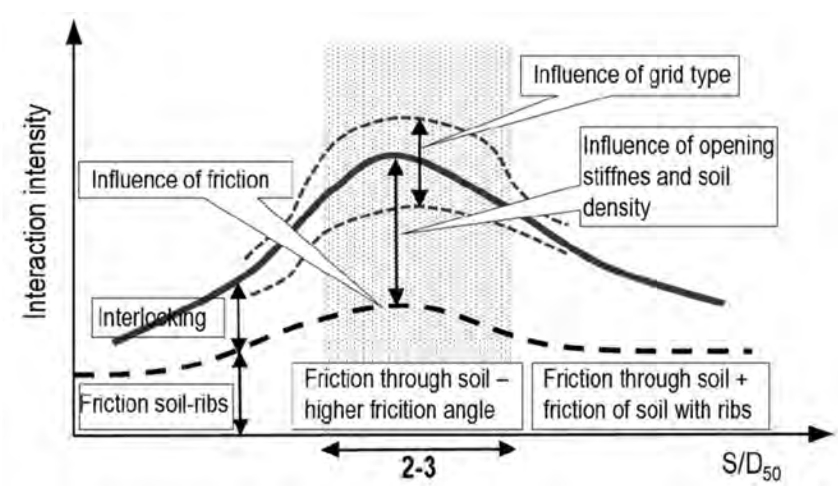
Resistance due to rotation of transverse ribs



Surface friction on longitudinal & transverse ribs

After Jewell et al. (1984); Ziegler & Timmers (2004)

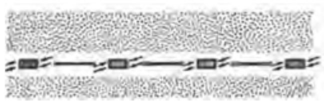
Pull-out test results on different geogrid types:



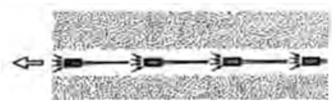
Large pull-out apparatus, (Mulabdić1 et al., 2018)

Ref.: Mulabdić et al. (2018)

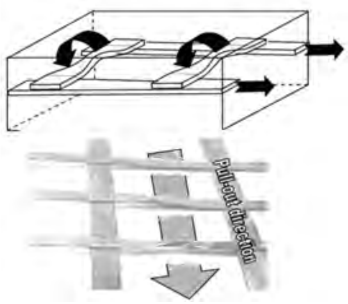
Geogrids after Pull-out Test:



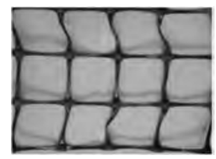
Resistance due to rotation of cross-elements



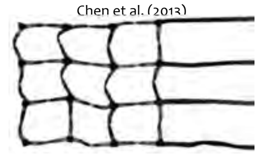
Resistance in front of the geogrid ribs



Welded geogrid



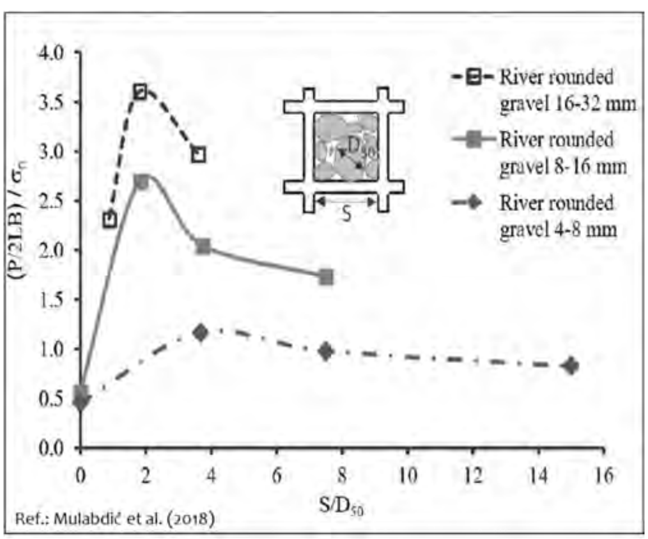
Chen et al. (2013)



Extruded geogrid

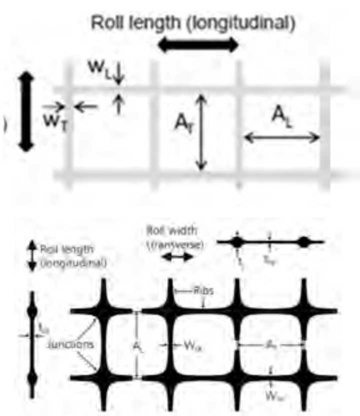
- **Different geogrids interact with ballast in a different way.**
- **Test results for one geogrid type may not be directly applicable to other geogrid types.**

Ratio between aperture size and soil particle size

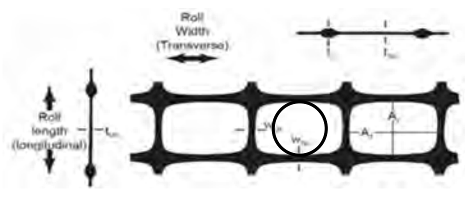


- Gravel size can affect the test results
- Test results for one gravel size may not be directly applicable to other gravel sizes
- Gravel size to aperture size ratio is important
- The effect of “gravel size to aperture size ratio” can be different for different geogrids (due to different soil-geogrid interaction mechanism discussed previously)

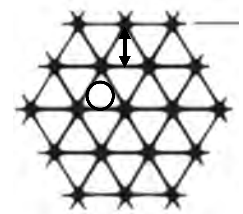
What is the definition of “aperture size” for different geogrids?



Biaxial



Rectangular

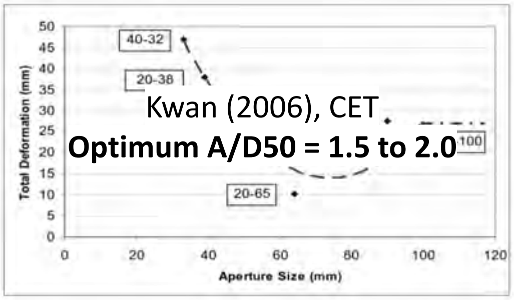

Triaxial

Optimum aperture size?

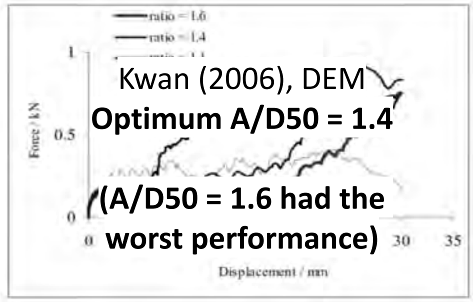
Some Published Ballast-Geogrid Aperture Tests:

- Large-scale Triaxial Test: Indraratna & Salim (2003), Indraratna et al. (2006)
- Composite Element Test (CET): Kwan (2006)
- Pull-Out Test: Kwan (2006), Brown et al. (2007)
- Multi-Layer Shear Test: Fisher & Horvat (2011)
- Direct Shear Test: Indraratna et al. (2012)
- Track Process Simulation Apparatus (TPSA): Indraratna et al. (2013)
- Modified Process Simulation Test (MPST): Husseini (2013)
- Discrete Element Modelling (DEM): Konietzky et. al (2004), Kwan (2006)/McDowell et. al (2006), Ngo et al. (2014; 2016)
- Imaging-Based DEM: Tutumluer et al. (2009; 2012), Qian et al. (2011; 2013)

Different results from each test for the optimum aperture size

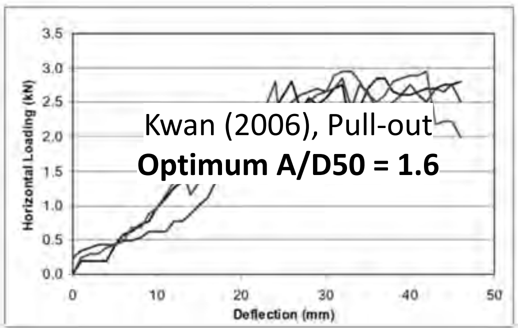


Kwan (2006), CET
Optimum A/D50 = 1.5 to 2.0

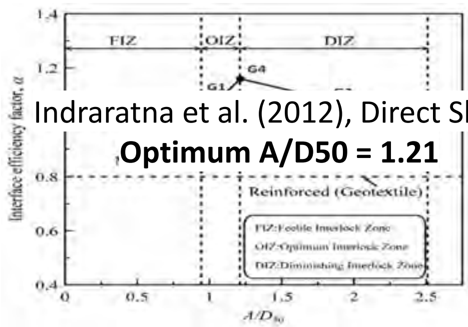


Kwan (2006), DEM
Optimum A/D50 = 1.4

(A/D50 = 1.6 had the worst performance)



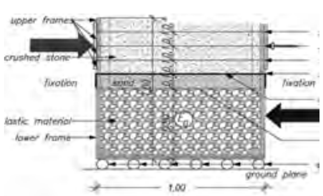
Kwan (2006), Pull-out
Optimum A/D50 = 1.6



Indraratna et al. (2012), Direct Shear
Optimum A/D50 = 1.21

Multi-Level Shear Box Test, Széchenyi István University, Hungary

Ballast Reinforcement with geogrid

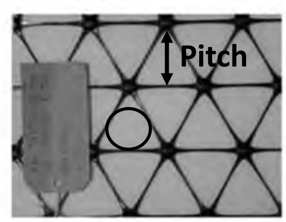


<u>Welded</u> <u>biaxial</u> 30/30

Aperture = 32mm
Rib thickness = 1.0mm
Rib width = 7.0mm

<u>Extruded</u> <u>biaxial</u> 30/30
(Large Aperture)

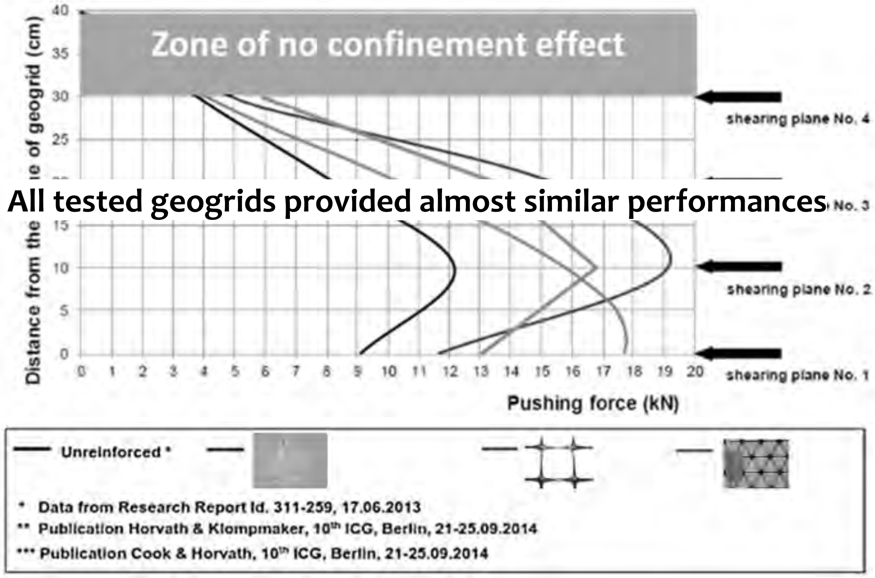
Aperture = 65mm
Rib thickness = 1.5-1.7mm
Rib width = 4.0mm



<u>Extruded</u> <u>triaxial</u>
(Large Aperture)

Rib Pitch = 60mm
Internal radius = 40mm
Rib thickness = 1.6-1.9mm
Rib width = 1.6-2.5mm

Ref.: Tensar technical note TN/SSspec/18.11.11
Tensar technical note TN/PR_Triax_TX_190L

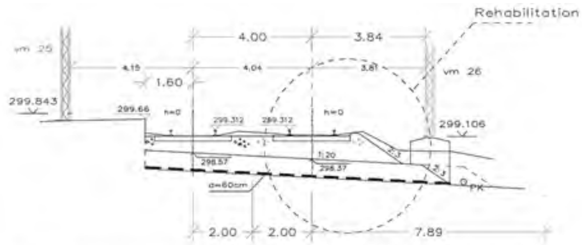


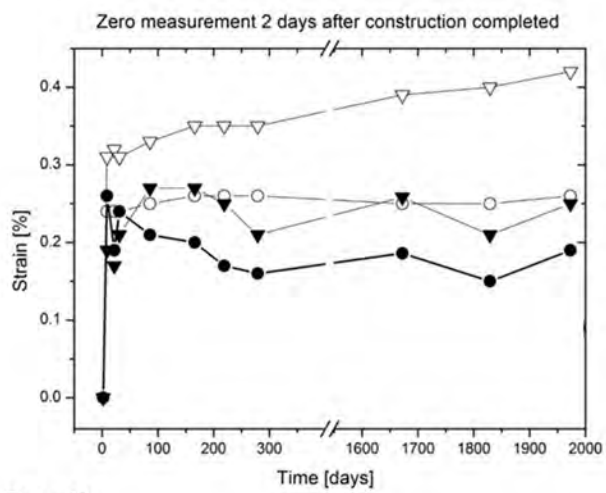
All tested geogrids provided almost similar performances

- **Different geogrids may interact with ballast aggregate in a different way.**
- **Test results for one geogrid type may not be directly applicable to other geogrid types.**
- **If the geogrid type is changed, the optimum aperture size may change as well.**

Capping/Subballast Reinforcement, Sava, Slovenia

Lenart & klompmaker (2014)

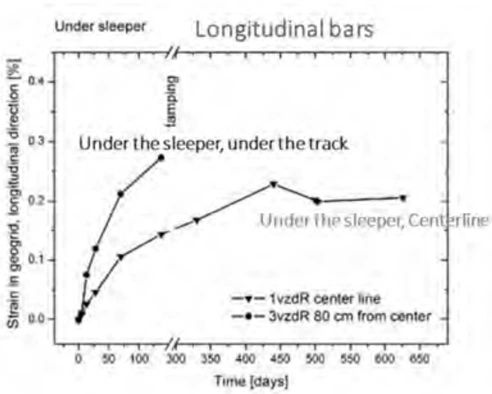


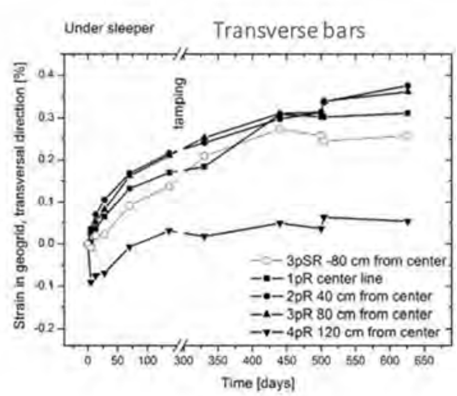


Result:
Maximum Strain in geogrid was less than 0.5%

Ballast Reinforcement, Sava, Slovenia

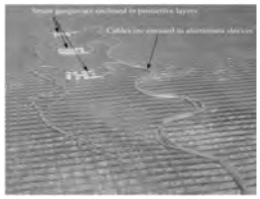
Lenart & klompmaker (2014)





Result:
Maximum Strain in geogrid bars was less than 0.5%

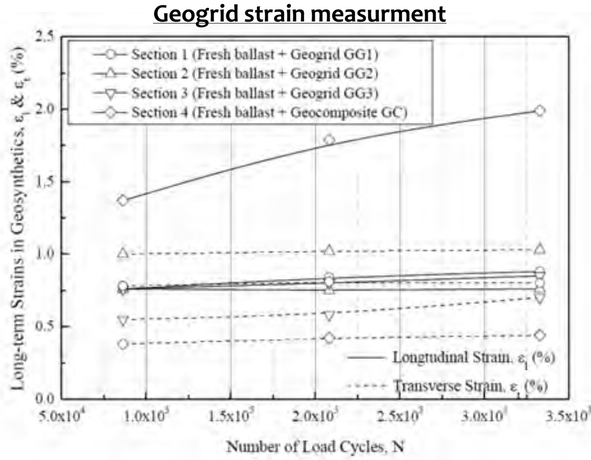
Ballast Reinforcement, Singleton, NSW, Australia



	Geogrid 1	Geogrid 2	Geogrid 3	Geocomposite	
Physical characteristics					
Material	Polypropylene			Polypropylene	
Type	Biaxial	Biaxial	Biaxial	(Grid) biaxial	(Fabric) non-woven
Technical characteristics					
Tensile stiffness[a]: MN/m	1·8/1·8	1·5/1·5	1·5/1·5	2·0/2·0	0·3/0·5
Tensile strength[a]: kN/m	36/36	30/30	30/30	40/40	6/10
Strain at break[a]: %	15/15	15/15	15/15	15/15	60/40
Dimensional characteristics					
Aperture size[a]: mm	44/44	65/65	40/40	31/31	—
Thickness: mm	3	3	4	3	2·9
Specific mass: g/m^2	—	—	—	—	150

Indraratna et al. (2014)

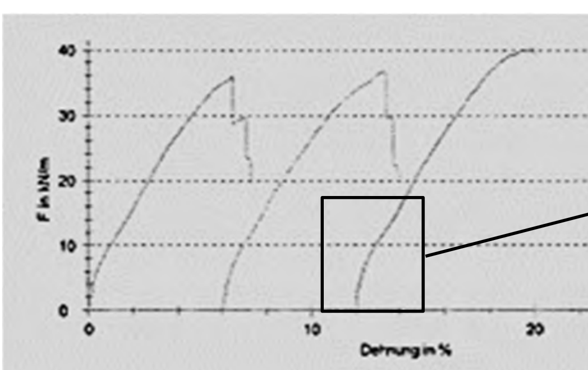
Geogrid strain measurment

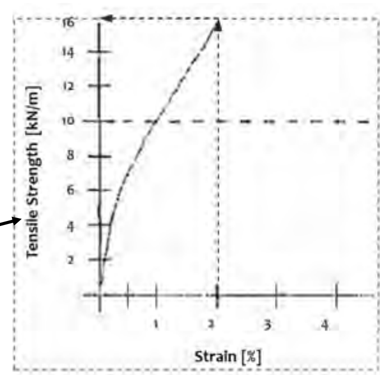


The strain in the geogrids was between 0.5% and 2.0%

Filed monitoring conclusion:

* Full scale measurements show that geogrid elongation is 0.5%-2%.
* The most important performance parameter is: **Geogrid stiffness (strength at low elongation) at 0.5% and 2% strain**

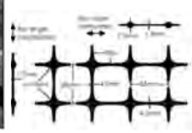




$J_{2\%}$ = 16 kN/m / (0.02)

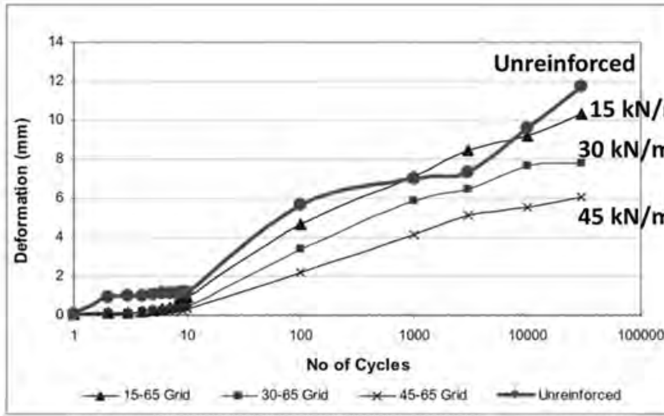
$J_{2\%}$ = 800 kN/m

Kwan (2006) - Composite Element Test (CET)



New ID	Aperture Size (mm)	Manufacturer Quoted Tensile Strength (kN/m)	
		Machine Direction	Transverse
15-65	65	17.1	17.3
20-65	65	20	20
30-65	65	30	30
45-65	65	46.1	46.8

- Same geogrid type
- Same aperture seize (65mm)
- Just different strength/stiffness



- **Stiffer geogrid resulted in less ballast deformation**

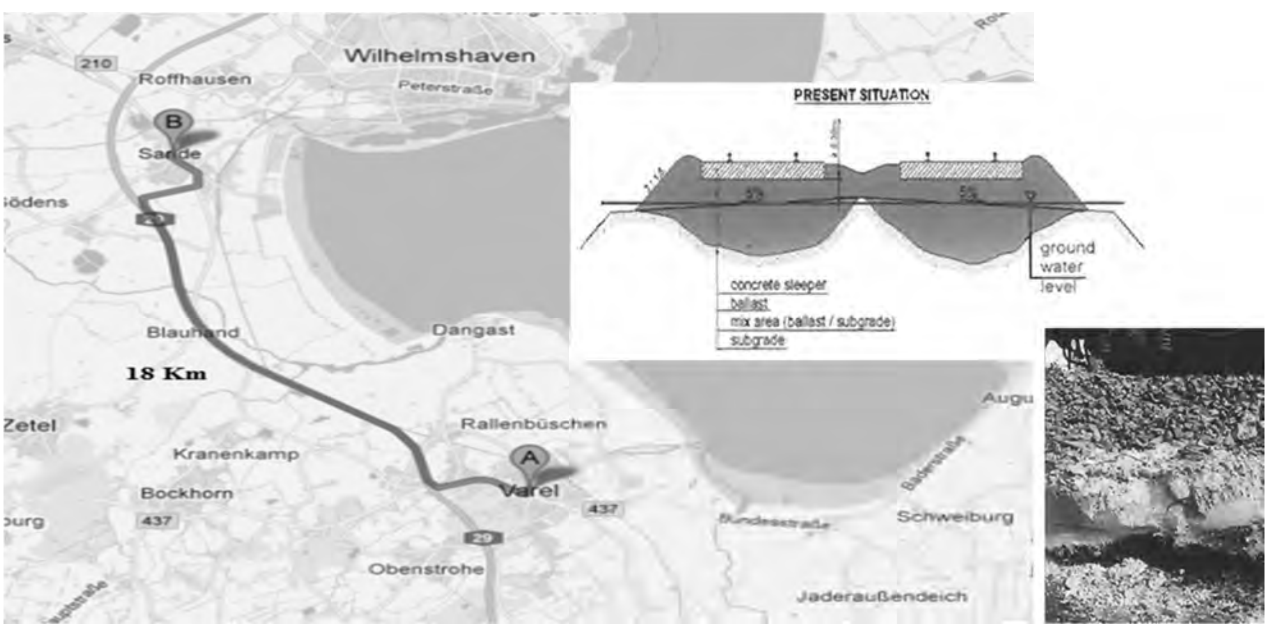
:- Geogrid Stiffness is important

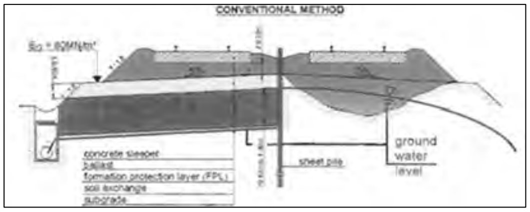
Local geogrid specifications:

Common design methods for geogrid reinforced/stabilized rail tracks:

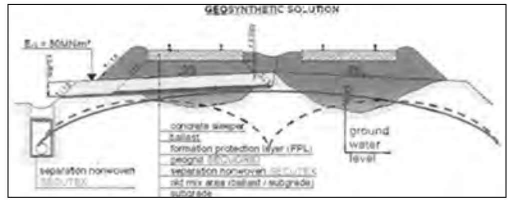
- Australia
- DB - Germany
- NR-L2-TRK-4239 – UK
- AREMA - USA

Example:





Original solution without geogrid:
Excavate and replace the yellow and pink area



Geogrid solution:
Excavate and replace only the yellow area by using Combigrid Geogrid Composite underneath

Summary

* Geogrid-aggregate interaction is a combined effect of Geogrid type, Rib properties, Aperture properties, The ratio between aperture size to gravel size, Rib stiffness, and Soil density
* Different geogrid types provide interaction with ballast/aggregate through different mechanisms.
* Test results for one type of geogrids may not be directly applicable to other geogrid types.
* Aperture size is not a single component and should be studied along with other relevant ballast-geogrid interaction parameters, not as a single component.
* Suitable/optimum aperture size can be different for each geogrid type

Summary

- Geogrids can
  - o improve the bearing capacity of the subgrade/rail track.
  - o reduce the normal stress on the subgrade.
  - o reduce the thickness of subballast/capping.
  - o reduce the lateral and vertical deformation of ballast.
  - o reduce the settlement of the rail track.
  - o reduce the breakage of ballast and so the relevant maintenance costs.
  - o control differential settlements.

- Geogrid stiffness (strength at 0.5% and 2%) is one of the most important performance parameter.