GEOANZ #1
ADVANCES IN GEOSYNTHETICS
7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE
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The Resourcefulness of Geotechnical Design when adopting Geosynthetics

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The Resourcefulness of Geotechnical Design when adopting Geosynthetics

1. Resourcefulness in earth dam design
2. Resourcefulness in the design of resistive barriers
3. Resourcefulness in unsaturated soil cover design
4. Resourcefulness in veneer design
5. Resourcefulness in the design of hydraulic protection
6. Resourcefulness in foundation design
7. Resourcefulness in bridge abutment design
8. Resourcefulness in the design of retaining walls
9. Resourcefulness in reinforced embankment design
10. Resourcefulness in roadway design

Case 1: Resourcefulness in Earth Dam Design

Case 1: Resourcefulness in Earth Dam Design

Where?

Valcros dam, France

What?

Design of critical components of earth dams where adequate granular materials are not readily available

How?

By using geotextiles in order to satisfy the multiple filter criteria

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Valcros Dam

Source: Giroud (1992)

- First earth dam designed with geotextile filters
- Constructed in 1970
- 17 m-high homogeneous dam
- Nonwoven geotextile used as filter of the downstream drain
- Performance of the drain has been satisfactory since its construction

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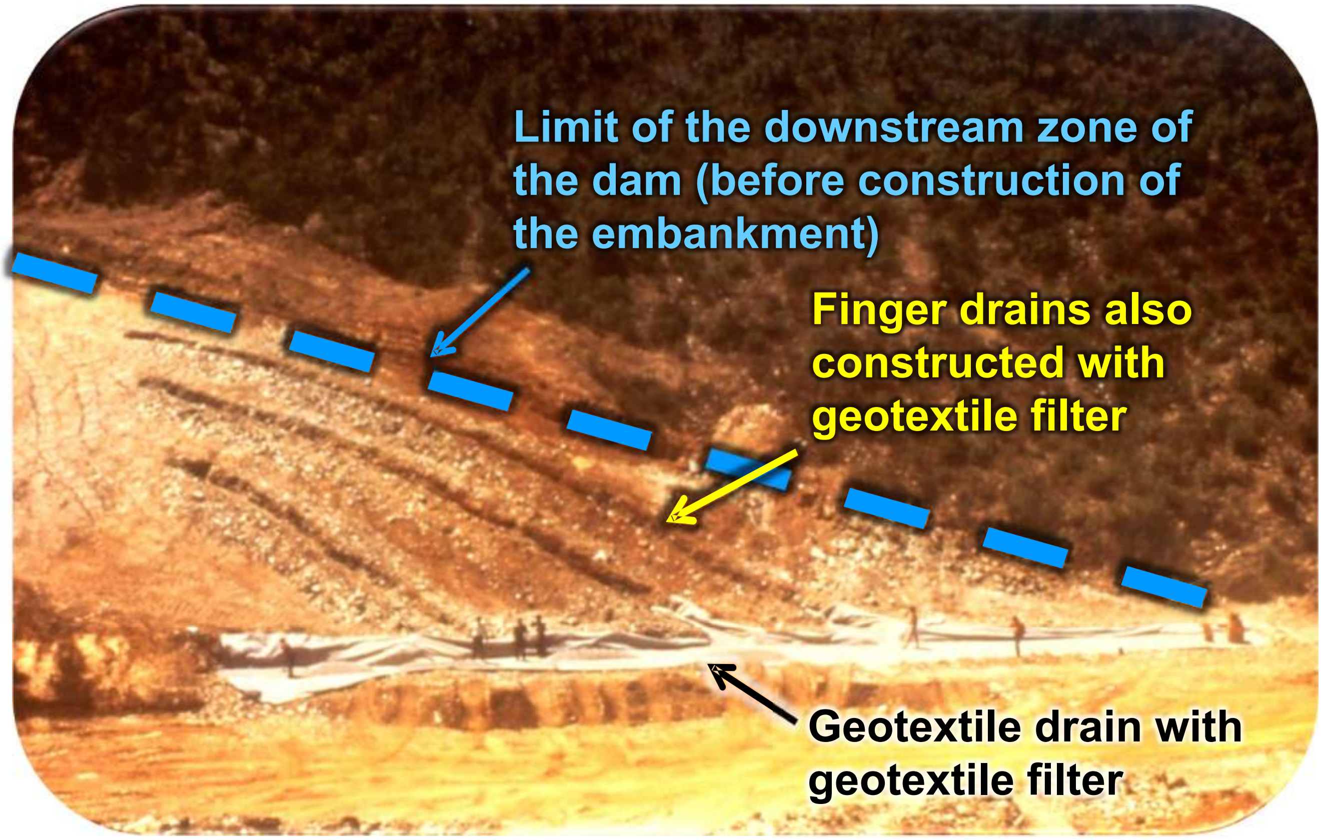


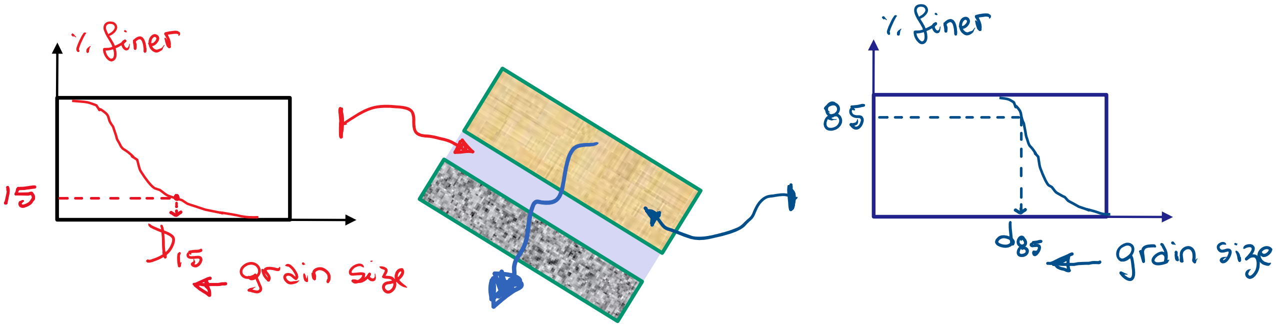
Limit of the downstream zone of the dam (before construction of the embankment)

Finger drains also constructed with geotextile filter

Geotextile drain with geotextile filter

Source: Giroud (2006)

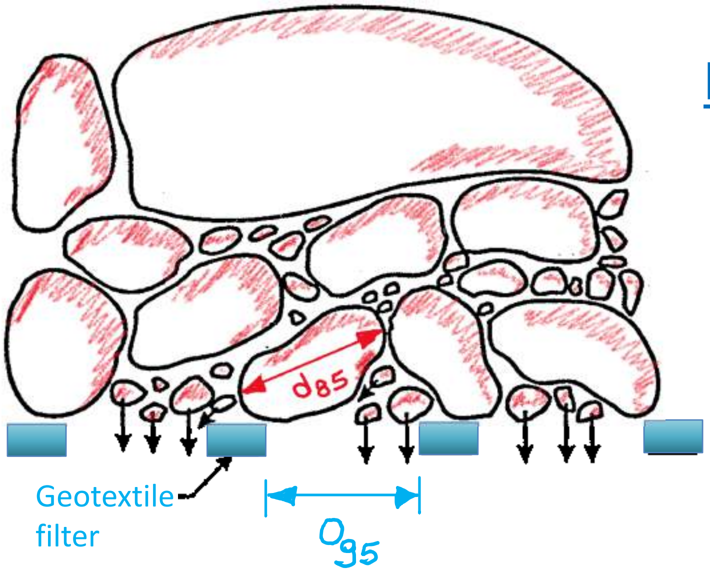
Retention Requirement



Retention Criterion:

$$D_{15} < 5\ d_{85}$$

Geosynthetic Filter Requirements

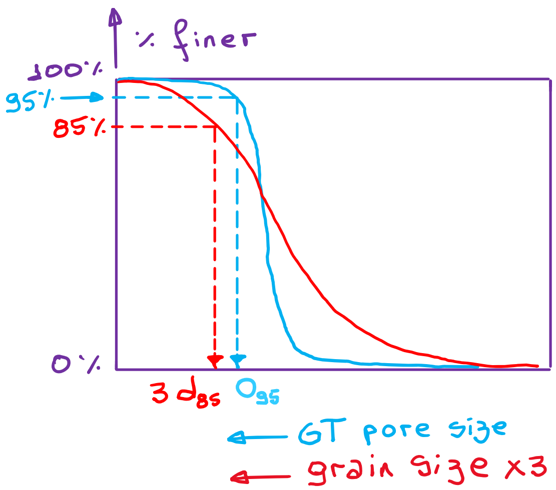


Retention Criterion:

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

O_{95}

e.g. B=3



Source: Zornberg and Christopher (2007)

Retention Requirement

- The geotextile filter in Valcros dam was selected without using a design method!
- Filter criteria were subsequently developed, including internal stability evaluation of the retained soil (JPG's 2008 Terzaghi Lecture)
- A recent re-evaluation of the design of the filter at Valcros Dam confirmed that it satisfies the internal stability criterion
- Granular filters have been designed using criteria that do not account for aspects of the internal stability of the retained soil

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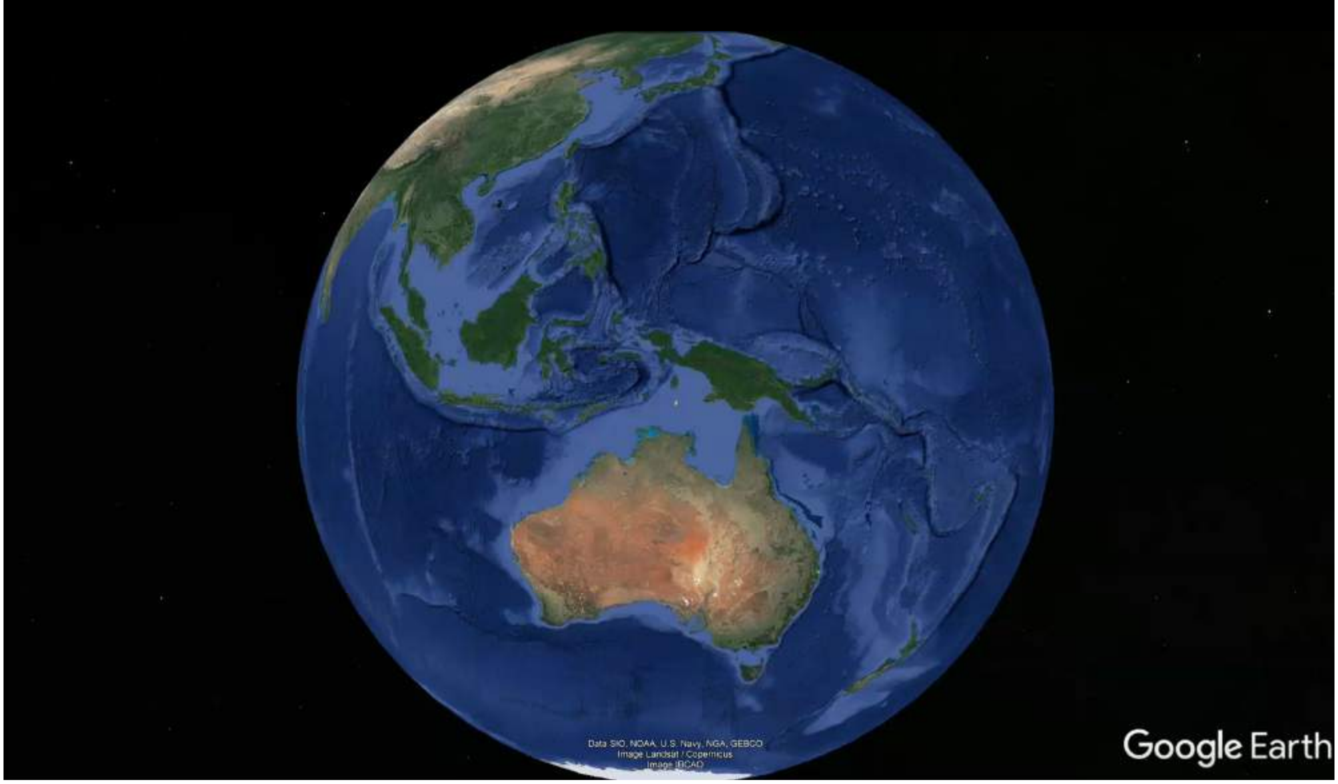
What is the Significance of the Ingenious Design of Valcros Dam?

- Use of the retention criterion developed for geotextile filters resulted in improvement in the design of granular filters (relevant for soils with a large coefficient of uniformity)
- Quoting J.P. Giroud:

  "What started as technology transfer from geotechnical engineering to geosynthetics engineering ended as technology transfer from geosynthetics engineering to geotechnical engineering"

Case 2: Resourcefulness in the Design of Resistive Barriers



Case 2: Resourcefulness in the Design of Resistive Barriers

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Coastal protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

Tessman Road Landfill, San Antonio, Texas, USA

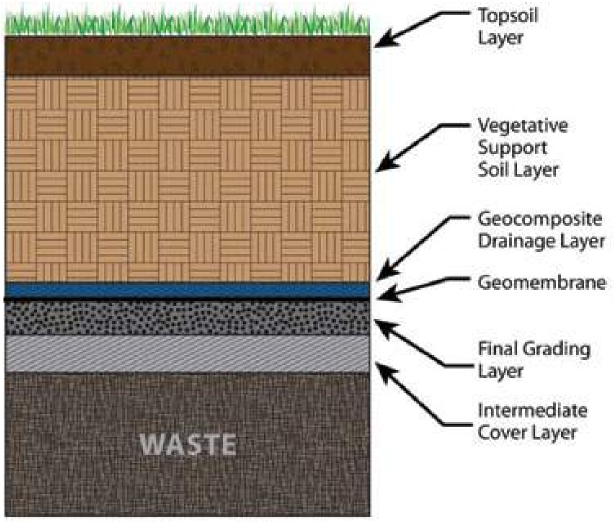
What?

Generation of alternative energy in landfill closures

How?

By designing and constructing an exposed geomembrane cover system

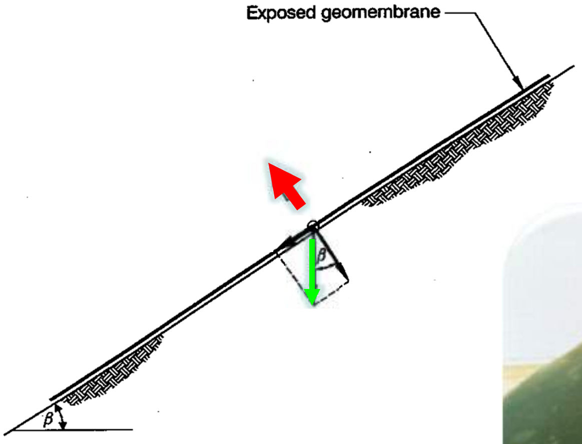
Exposed Geomembrane Covers (EGCs)



Subtitle D Cover

Source: HDR

Wind Uplift of Geomembranes



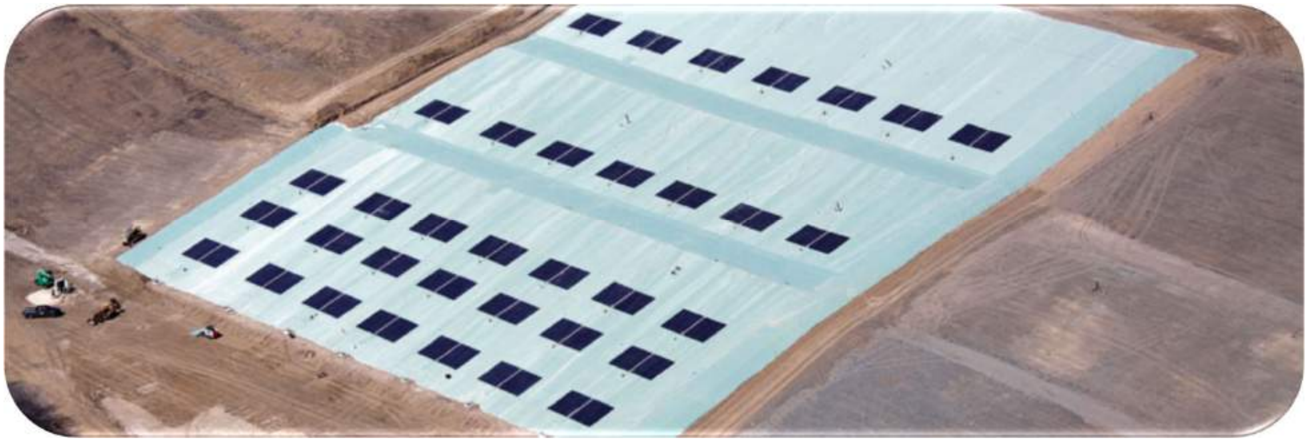
$$\mu_{GM}\ g\cos\beta \geq S$$

Source: Zornberg and Giroud (1997)

Tessman Road Landfill (Cont.)

- GM with good mechanical properties (design against wind uplift)
- Installed in 2 months (2009)
- Particularly straightforward installation of flexible solar laminate panels
- It is the first solar energy cover
- Now generates 135 kW

Tessman Road Landfill (Cont.)



- GM is a green 60-mil, fiber-reinforced product
- Initial phase involves a total of 30 solar panels
- Expanded solar generation capacity planned

Tessman Road Landfill: Preventing Wind Uplift

What is the Significance of the Ingenious Design of Tessman Landfill?

- Design of cover systems involving exposed geomembranes have been particularly attractive in projects implementing generation of alternative energy
- The design at Tessman Landfill is a sustainable investment, with a high benefit-to-cost ratio, low risk and increased energy efficiency

Case 3: Resourcefulness in Unsaturated Soil Cover Design

Case 3: Resourcefulness in Unsaturated Soil Cover Design

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

Rocky Mountain Arsenal, Denver, Colorado, USA

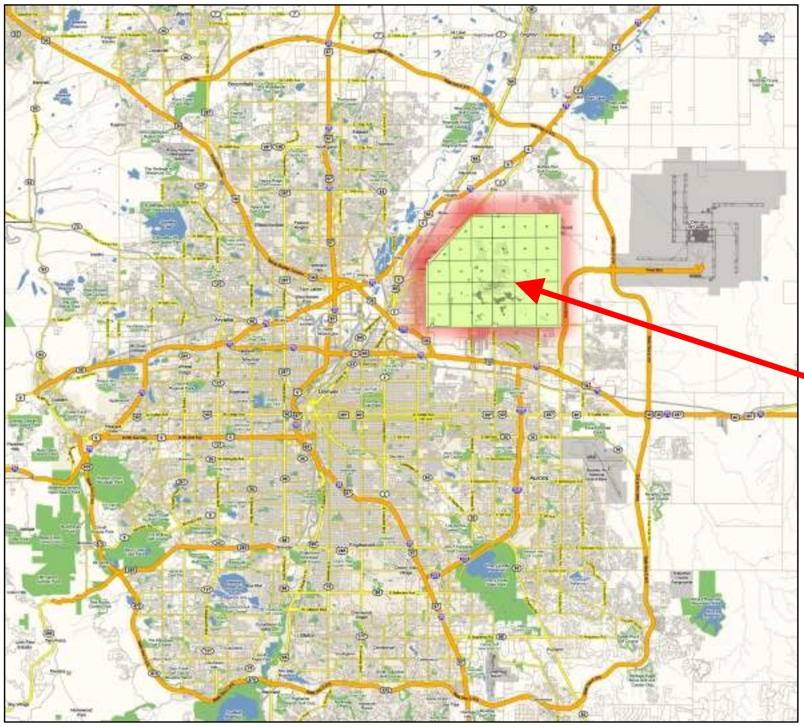
What?

Establish the largest urban wildlife refuge in a highly contaminated site

How?

Designing and constructing a geosynthetic capillary barrier within unsaturated soil system

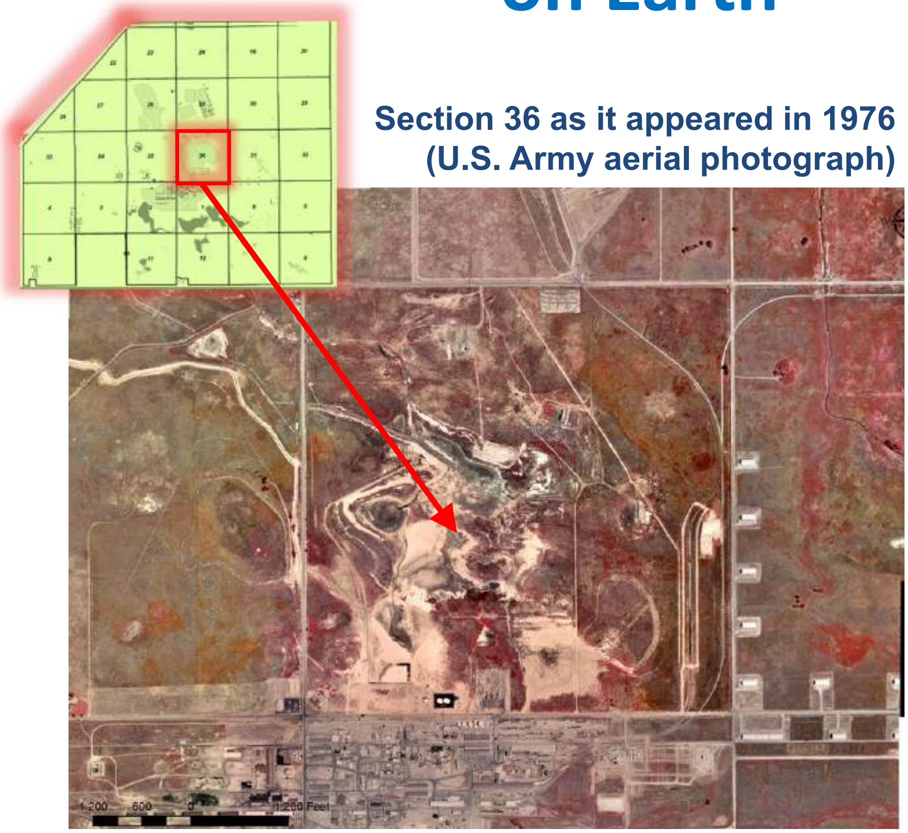
The Rocky Mountain Arsenal



RMA was originally about 27 square miles (69 km²)

“The Most Contaminated Square Mile on Earth”

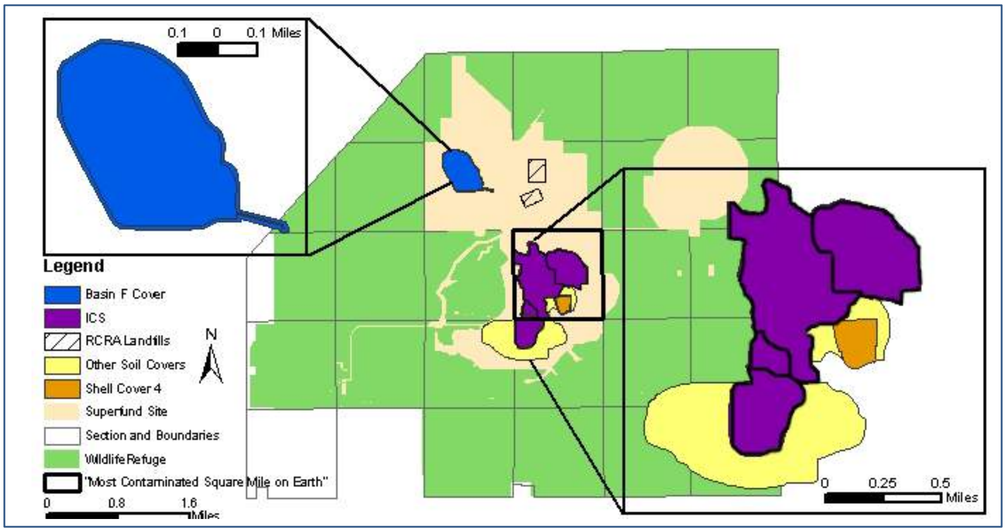
Section 36 as it appeared in 1976 (U.S. Army aerial photograph)



Sarin bomblet showing relative size (USFWS photograph)

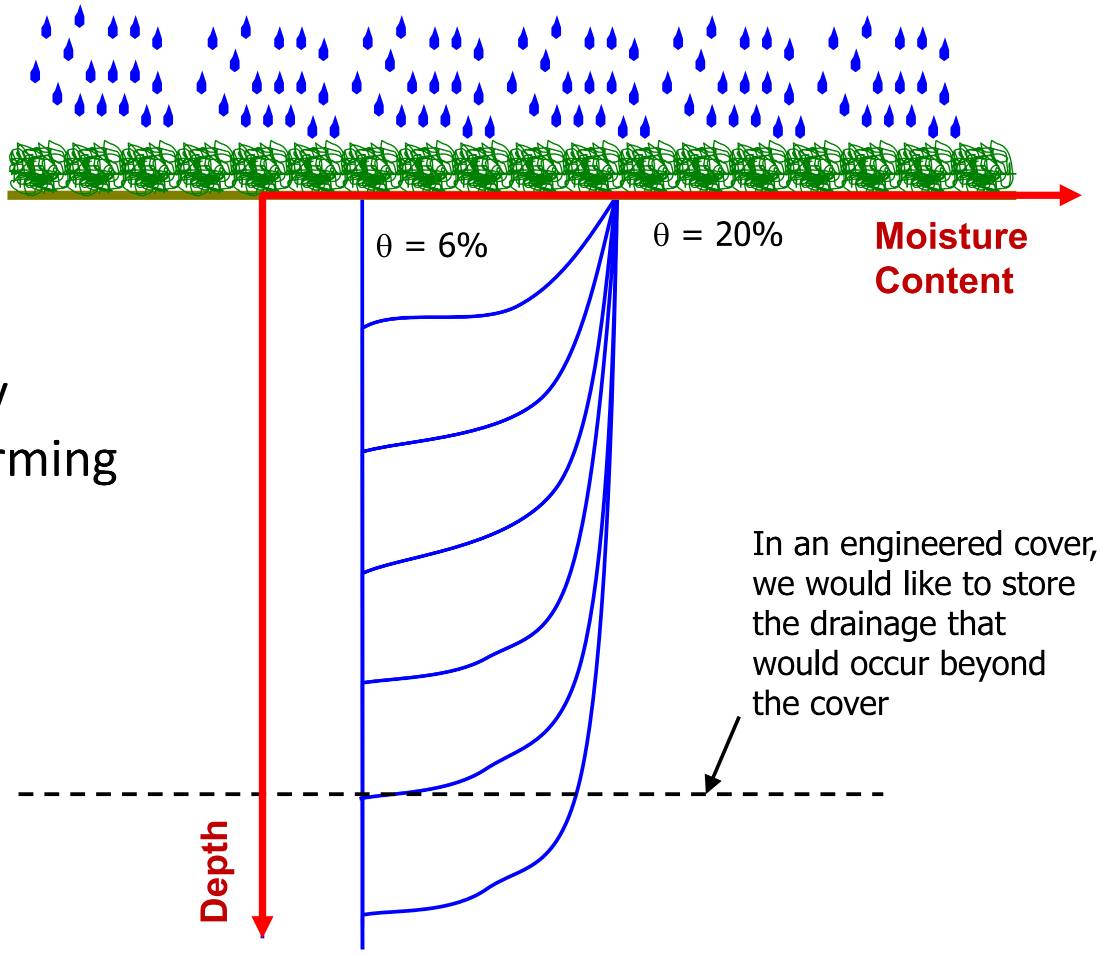
Sarin bomblet recovered from a debris pile at the RMA (U.S. Army photograph)

Rocky Mountain Arsenal



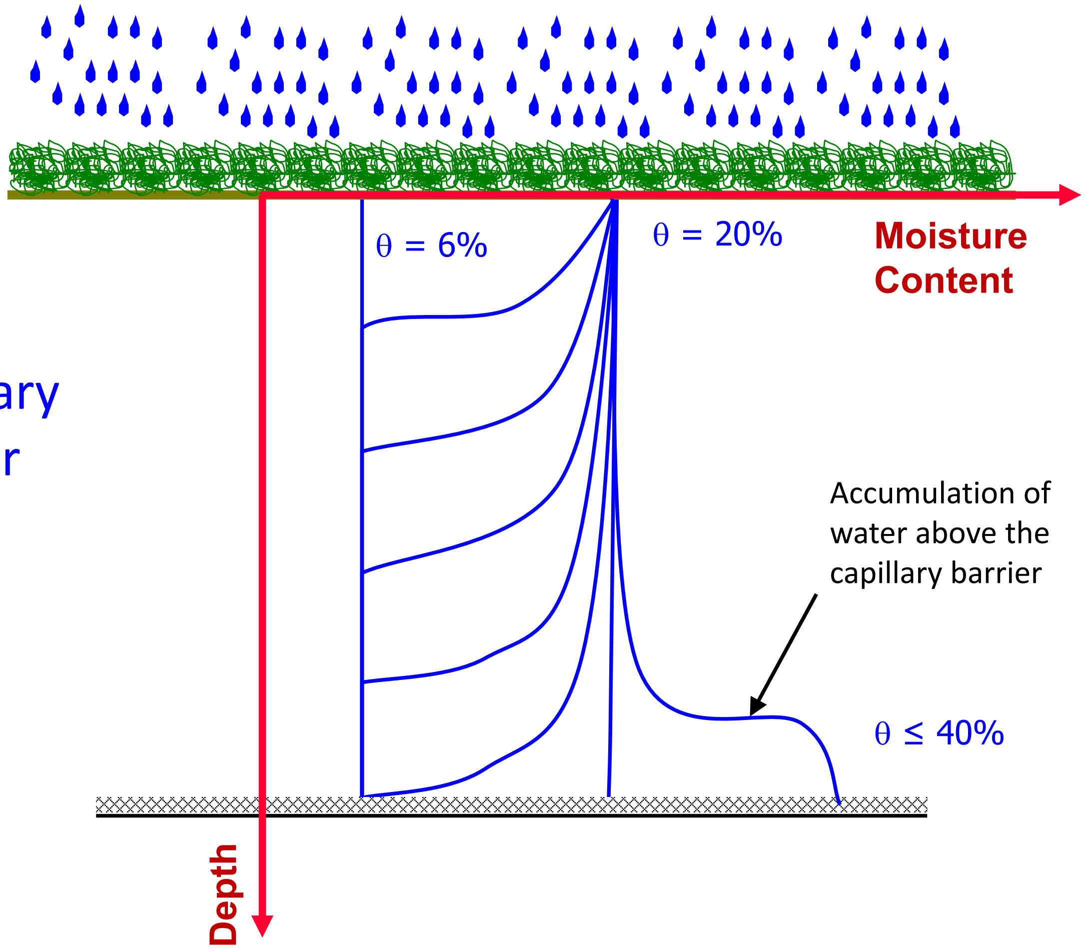
- Hazardous waste: Disposed in landfills (34 ha) that include both double and triple liners, leachate collection systems, leak-detection systems, and multi-layer covers
- Contaminated soils and demolished structures: Consolidated in-situ below "unsaturated soil" covers (183 ha)

Poorly performing cover

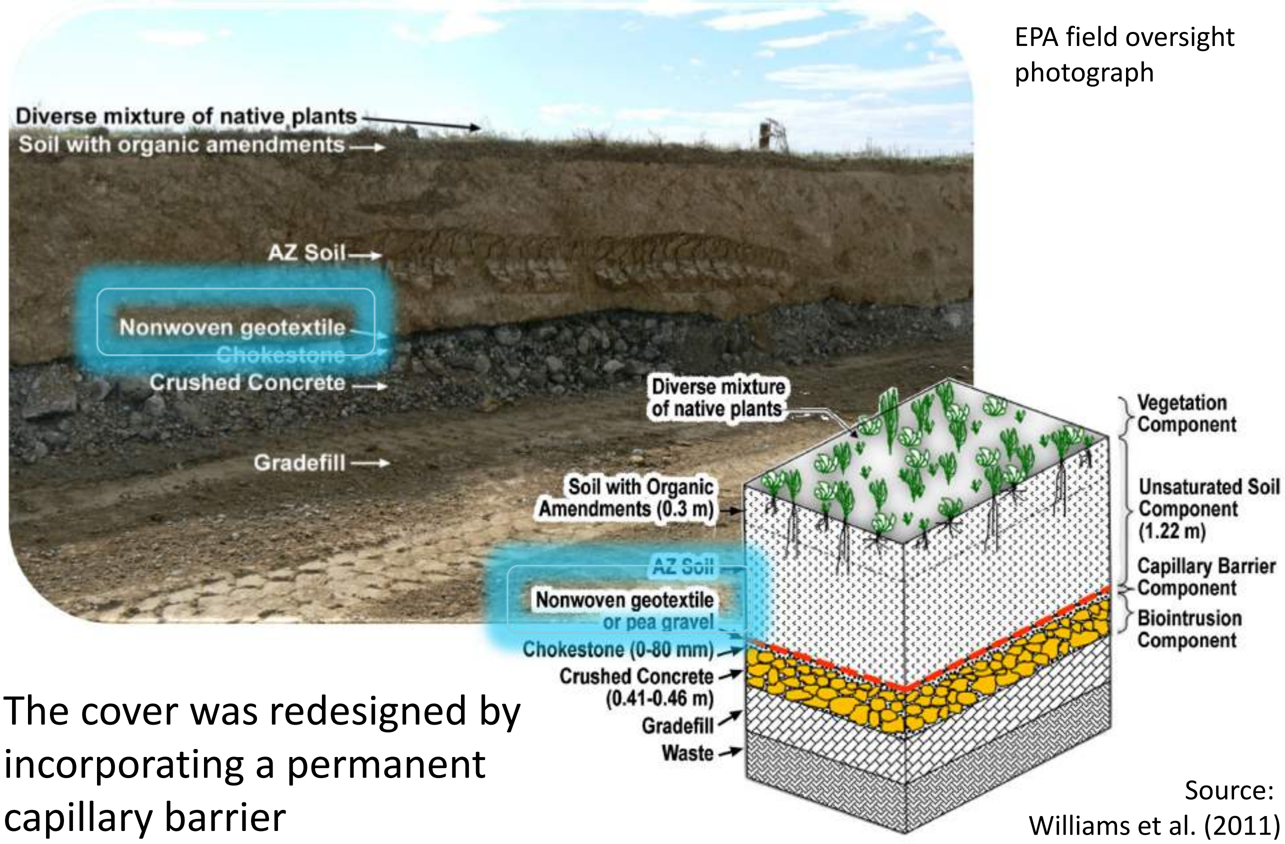


In an engineered cover, we would like to store the drainage that would occur beyond the cover

Capillary Barrier



FINAL COVER DESIGN



EPA field oversight photograph

The cover was redesigned by incorporating a permanent capillary barrier

Source: Williams et al. (2011)

RMA Urban Wildlife Refuge

© Dawn Wilson

RMA National Wildlife Refuge

Case 4: Resourcefulness in Veneer Design

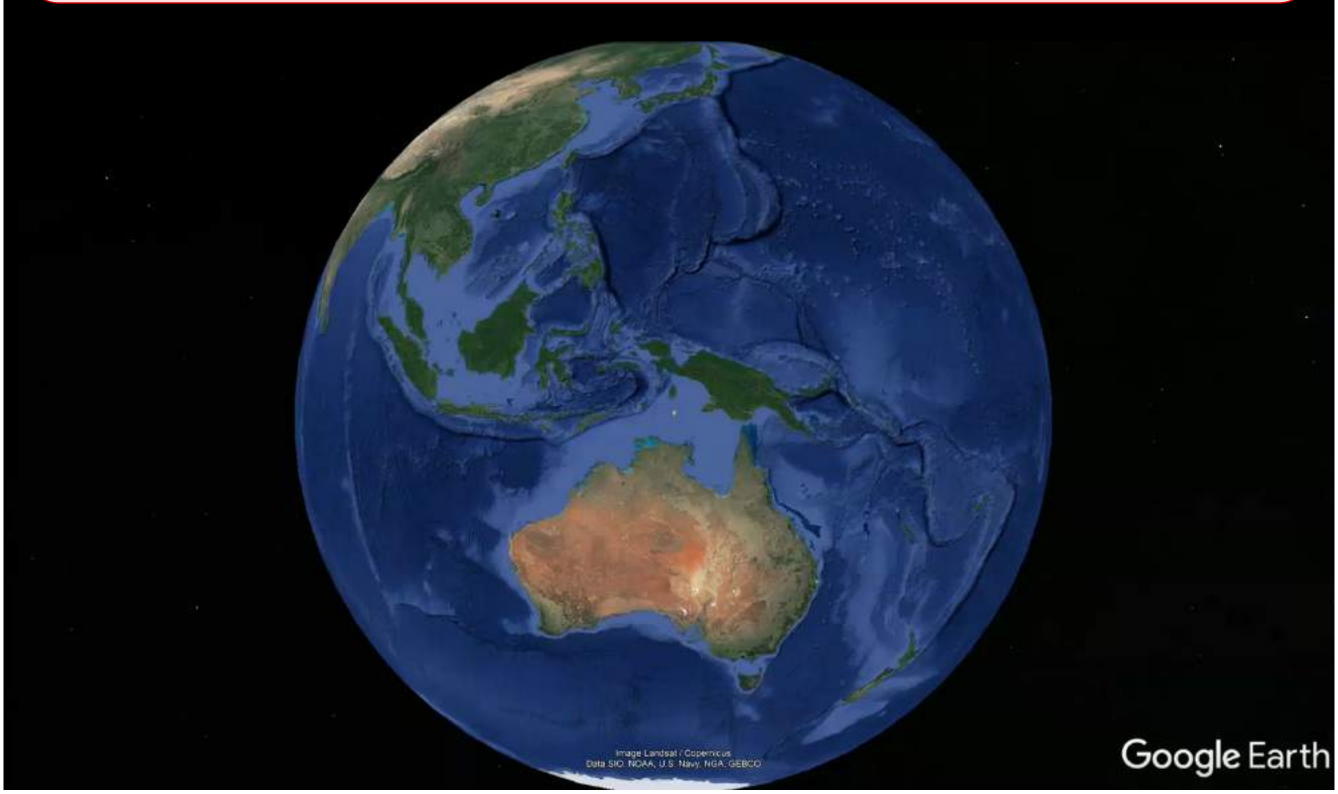


Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Case 4: Resourcefulness in Veneer Design

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

OII Superfund site, near Los Angeles, California

What?

Stabilization of steep, long covers of waste containment facilities (in seismic areas)

How?

Use of geosynthetic reinforcements anchored into solid waste

OII Superfund Landfill

- Old, unlined landfill
- Stability: A major concern
- Slopes: Inclination of 1.5:1 (H:V), height of 65 m
- Location: Area of high seismicity
- Climate: Semi-arid
- Timeline: Construction completed in 2000

Considered Design Options:

- Soil cover over geomembrane: Difficulty in satisfying stability
- Exposed GM: Satisfies stability but not accepted by neighbors
- Reinforced cover using geosynthetics parallel to slope: Not suitable because of long, steep slopes

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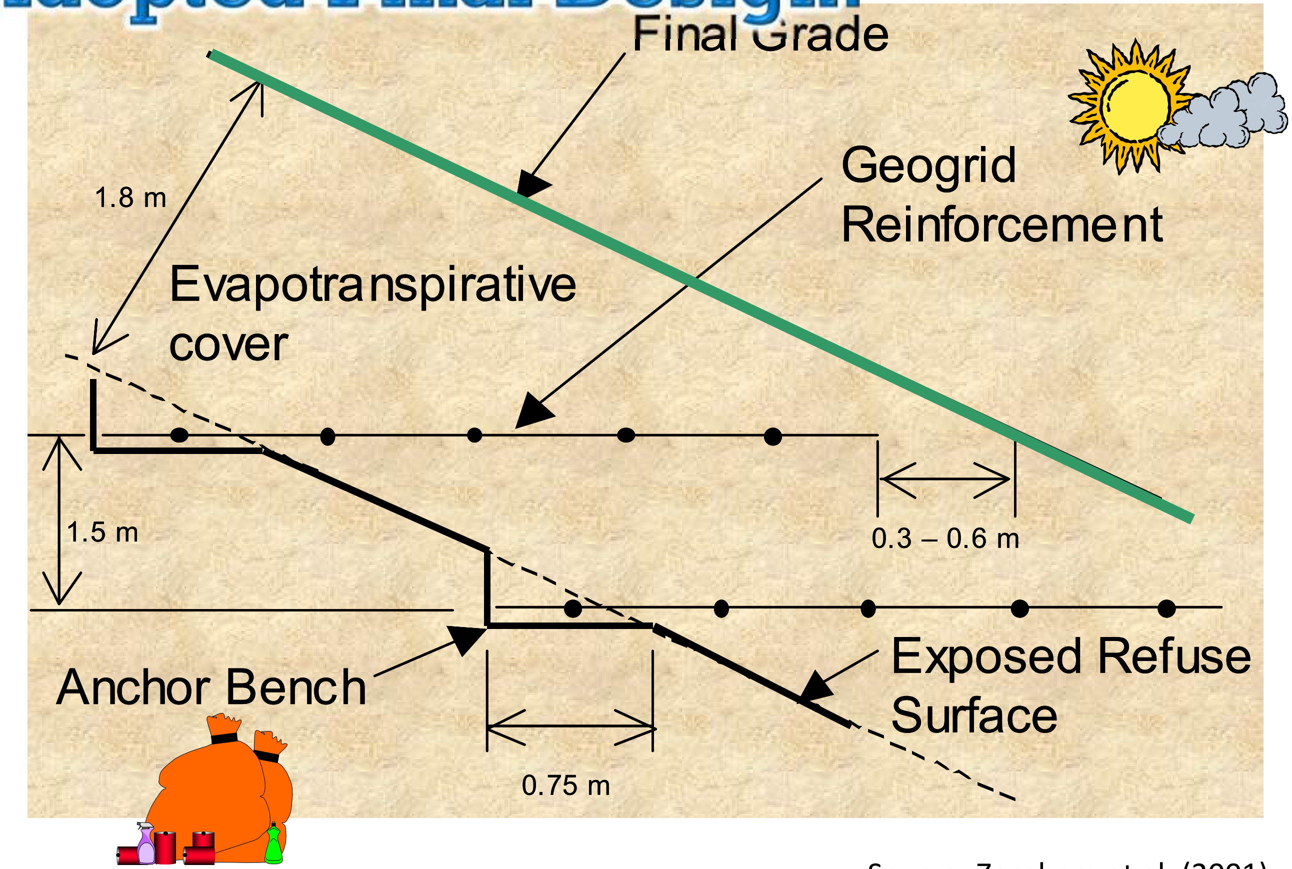
Adopted Final Design:



Source: Zornberg et al. (2001)

What is the Significance of the Ingenious Design at the OII Superfund Site?

- Reinforcement of thin veneers is not limited to the (conventional) use of geosynthetics placed along the slope and anchored at the crest
- The covers at the OII Superfund site have shown good performance since its construction

Case 5: Resourcefulness in Hydraulic Protection Design

Case 5: Resourcefulness in Hydraulic Protection Design

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

Las Bambas copper mine, near Cusco, Peru

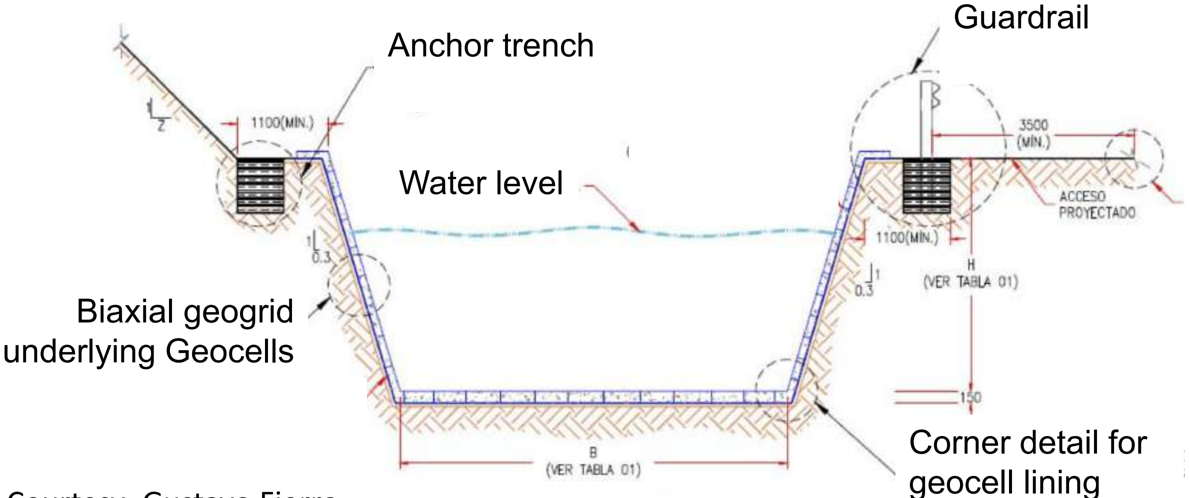
What?

Rapid relocation of water reservoir for mine operations

How?

Construction of a high-capacity canal involving geocells with shotcrete infill

Las Bambas Copper Mine

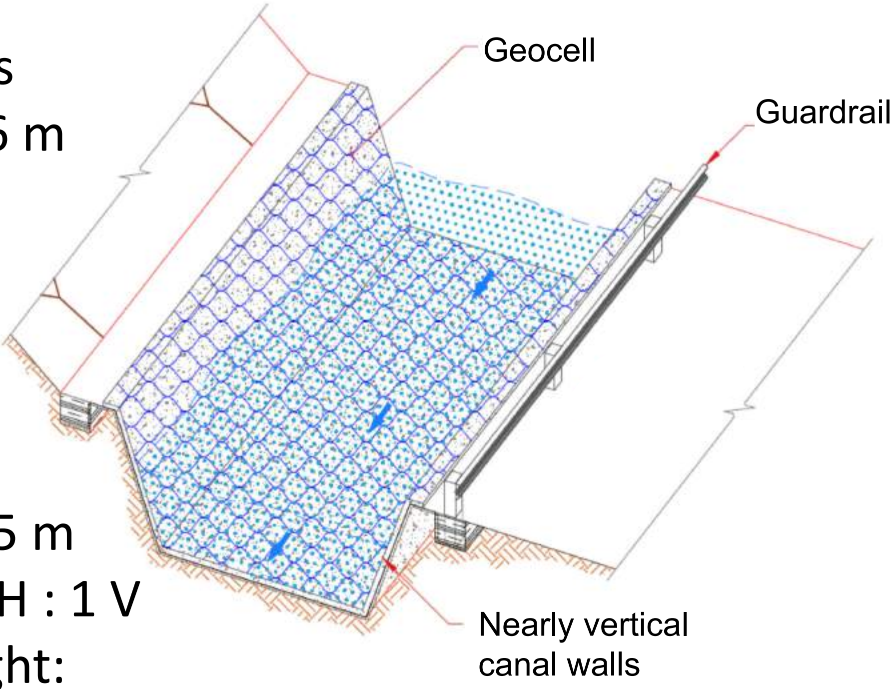


Courtesy: Gustavo Fierro

- Rapid growth on the use of geocells with concrete infill for canals in mining (over 1,000 km in Peru)
- Main drivers: Space constrains, construction efficiency
- Remaining constraint: Placement of concrete in nearly vertical walls

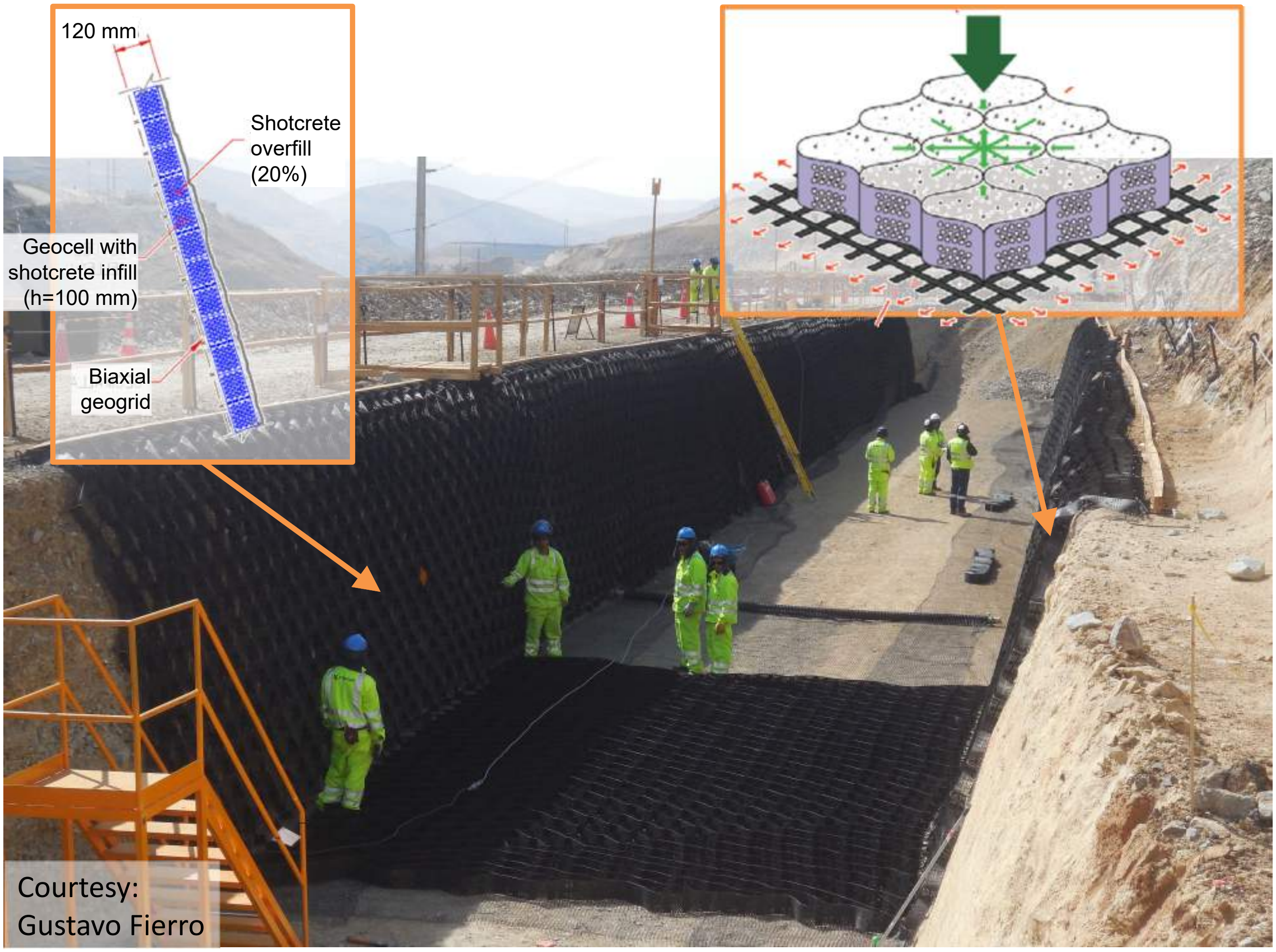
Las Bambas Copper Mine

- Flow: 70 m^3/s
- Base width: 6 m



- Side walls:
    - Height: 5.5 m
    - Slope: 0.3H : 1 V
- Geocells height:
    - Side walls: 100 mm
    - Base: 150 mm

Courtesy: Gustavo Fierro



Courtesy:
Gustavo Fierro

Las Bambas Copper Mine

Courtesy: Gustavo Fierro

Use of a robotic arm for placement of shotcrete on the steep slopes

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Las Bambas Copper Mine

Source: Stracon

Las Bambas Copper Mine

Courtesy:
Gustavo Fierro

What is the Significance of the Ingenious Canal Design at the Las Bambas Project?

- The use of geocells with concrete infill has become a well-accepted approach for canal revetment because of elimination of concrete joints and rapid construction
- Mining operations in general and Las Bambas operations in particular required rapid reallocation of water resources in mountainous terrain
- The ingenious use of shotcrete at Las Bambas as alternative to concrete infill placement, as well as the elimination of geocells pinning to subgrade, allowed the construction a canal with nearly vertical side walls

Case 6: Resourcefulness in Foundation Design

Case 6: Resourcefulness in Foundation Design

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

Kirsehir embankment, Kirsehir, Turkey

What?

A cost-effective approach for foundation of embankments on very soft soils, underwater, in area of high seismicity

How?

Use of geotextile encased columns (GECs)

Kirsehir Embankment

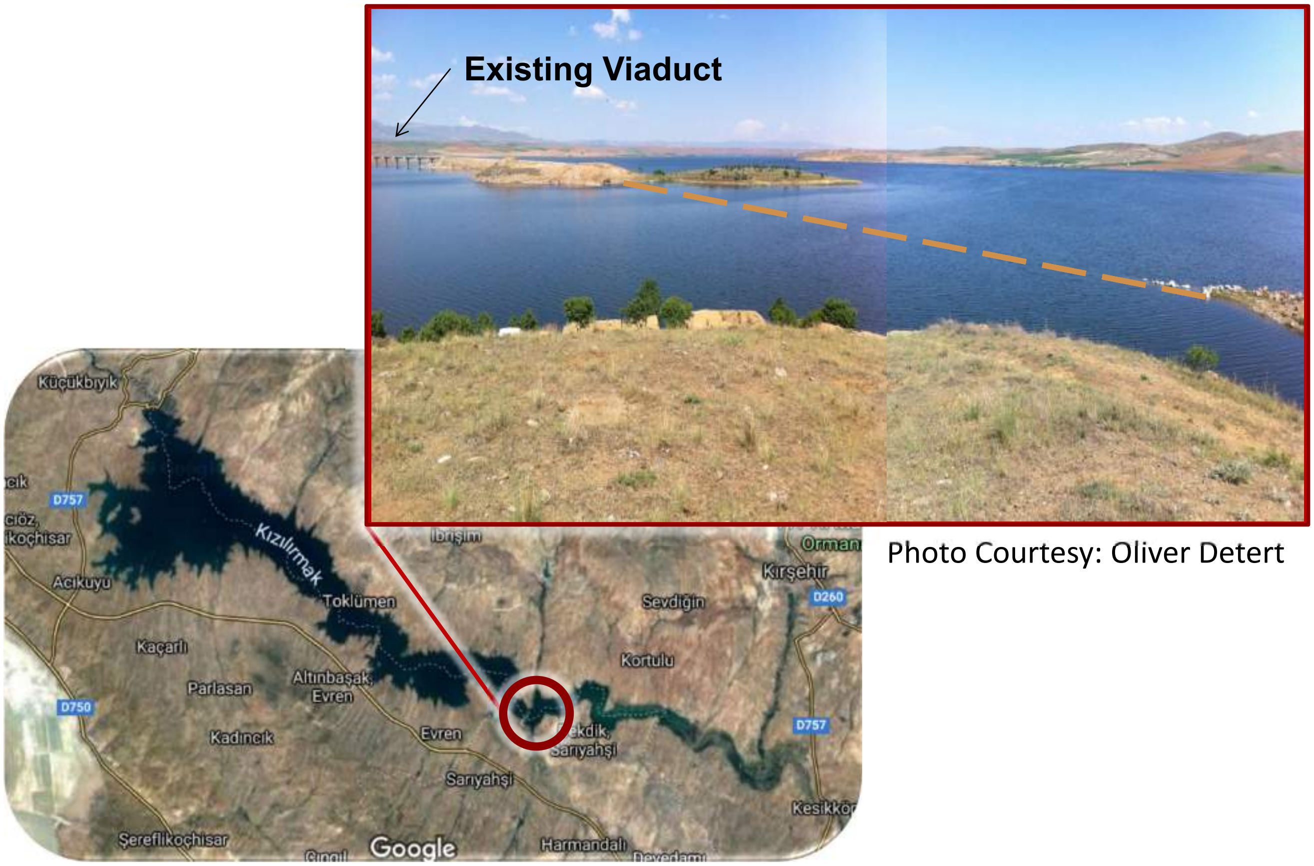


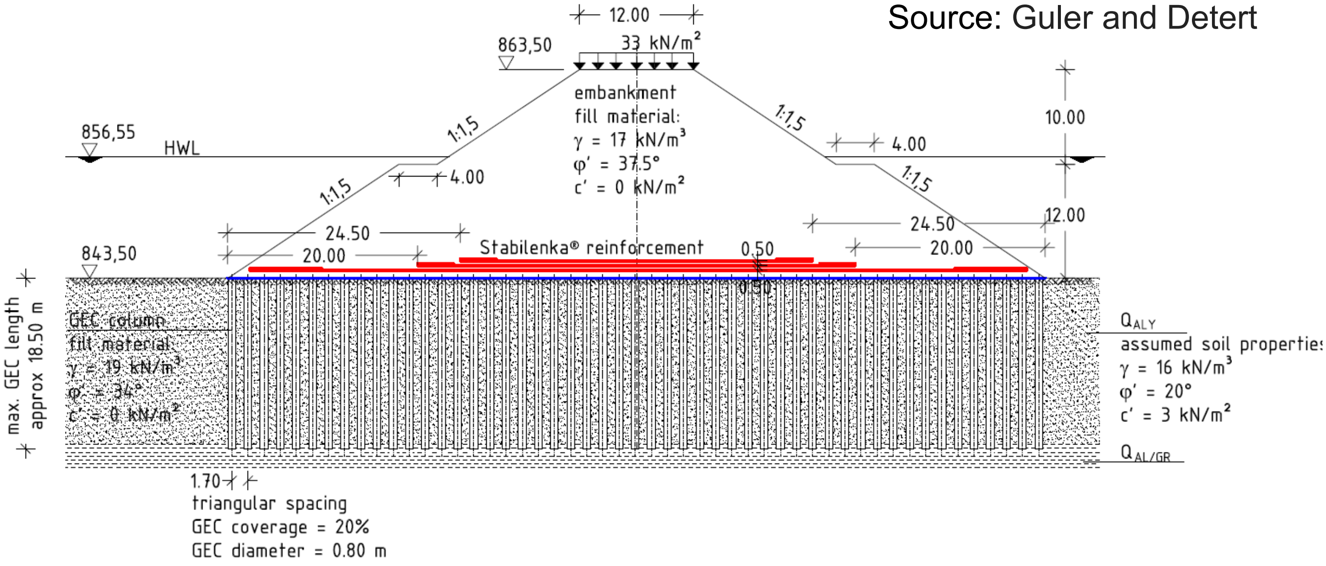
Photo Courtesy: Oliver Detert

Kirsehir Embankment

Photo Courtesy: Atlasyol

- 22 m high, 430 m long embankment
- Construction from 7 m below water level
- Main concerns: Very low undrained shear strength (SPT blow count 0 to 5), High seismicity (a = 0.4 g)
- For such low strength, even stone columns were deemed inadequate

Kirsehir Embankment



Source: Guler and Detert

- Important seismic design considerations (0.4 g)
- 200,000 m of GE columns installed (12,000 GECs)
- Separation of 1.7 m with triangular configuration

Kirsehir Embankment

Courtesy: Oliver Dietert

- Operations under 7 m of water
- Columns depths of 18.5 m into the sediments
- Successfully implemented between 2012 and 2015

Kirsehir Embankment

Courtesy: Huesker

What is the Significance of the Ingenious Design at the Kirsehir Embankment Project?

- The project illustrates the ability of using geosynthetics in foundation projects involving extremely soft soils
- Successful underwater installation of GEC was achieved during construction
- The vertical load carrying capacity of GECs is maintained, unlike that of conventional stone columns

Case 7: Resourcefulness in Bridge Abutment Design

Case 7: Resourcefulness in Bridge Abutment Design

Where?

Barney's Point bridge abutment,
Chinderah, NSW, Australia

What?

Bridge abutments that minimize the "bump at the end of the bridge"

How?

Use a Load-carrying geosynthetic-reinforced abutment rather than deep foundations to support bridge loads

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
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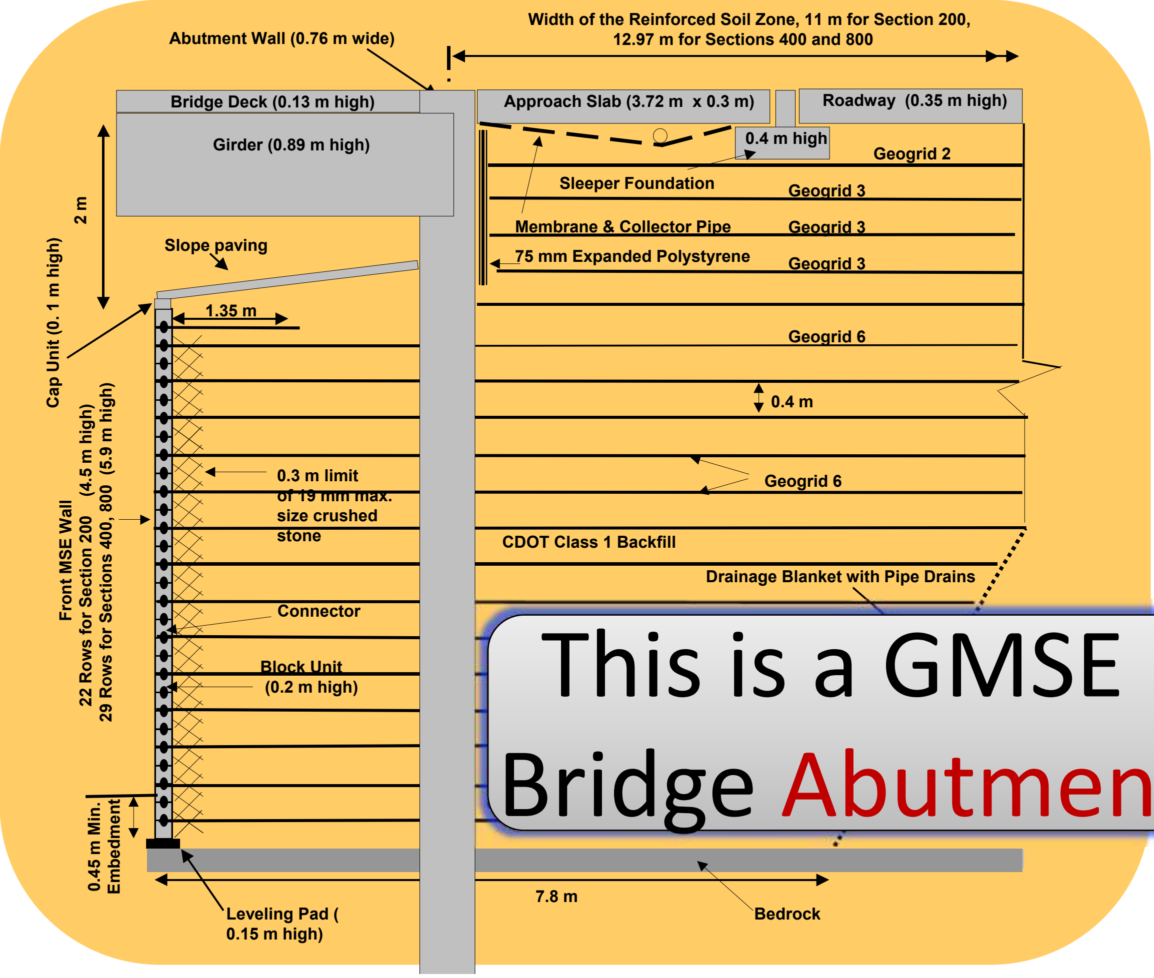
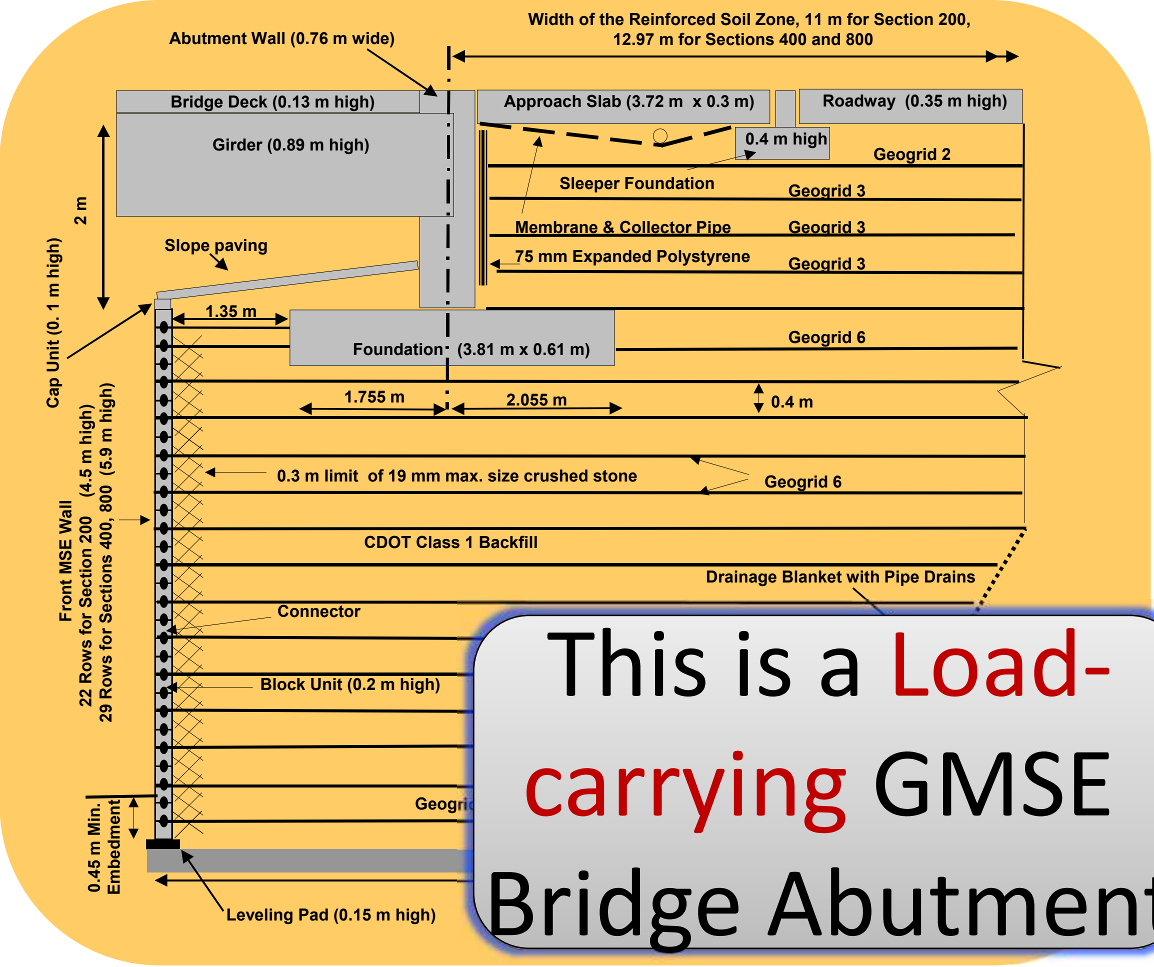
9. Embankments
10. Roadways



This is a GMSE Bridge Abutment



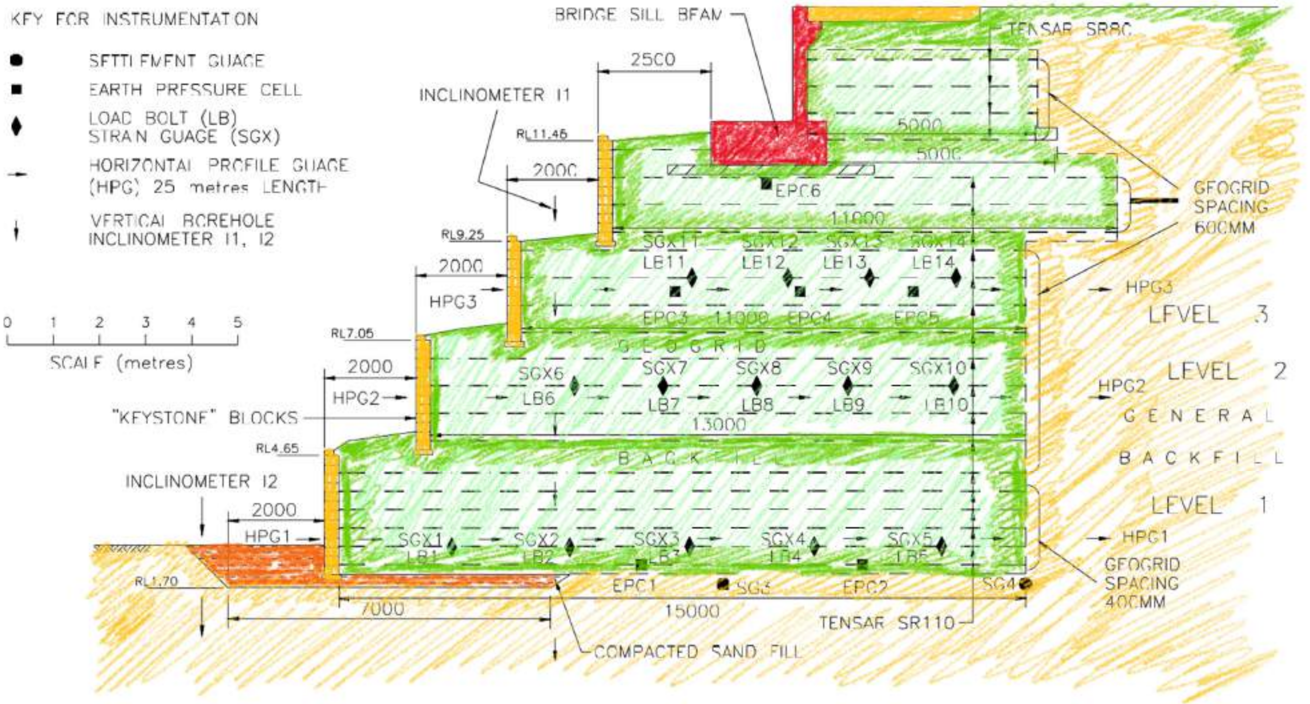
This is a Load-carrying GMSE Bridge Abutment

Barney's Point Bridge Abutment

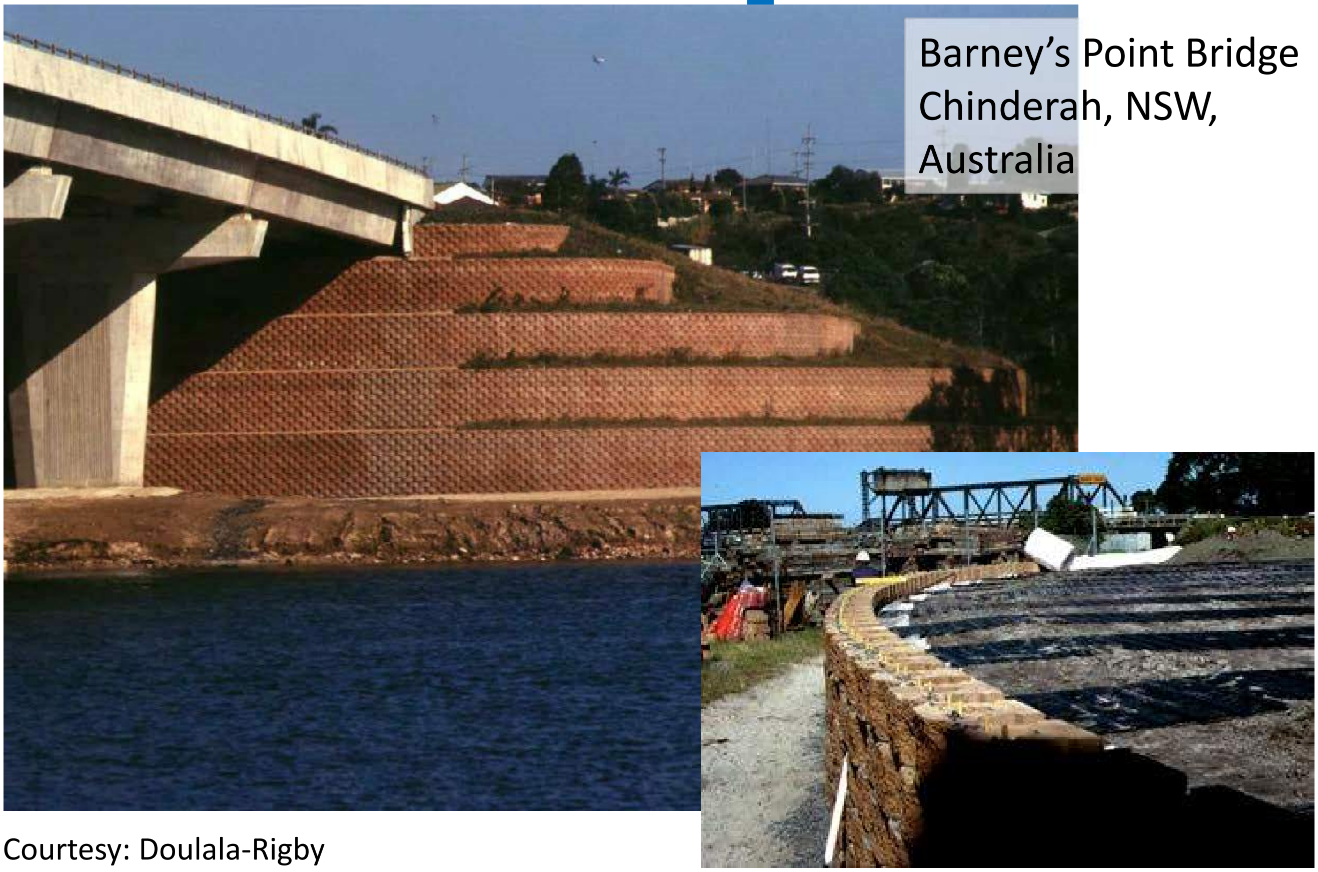
Courtesy: Mike Dobie

A key consideration in selecting a load-carrying GMSE alternative was to minimize differential settlements expected if different foundation types are adopted (e.g. deep foundations for bridge girders, foundation on grade for approaching road)

Barney's Point Bridge Abutment



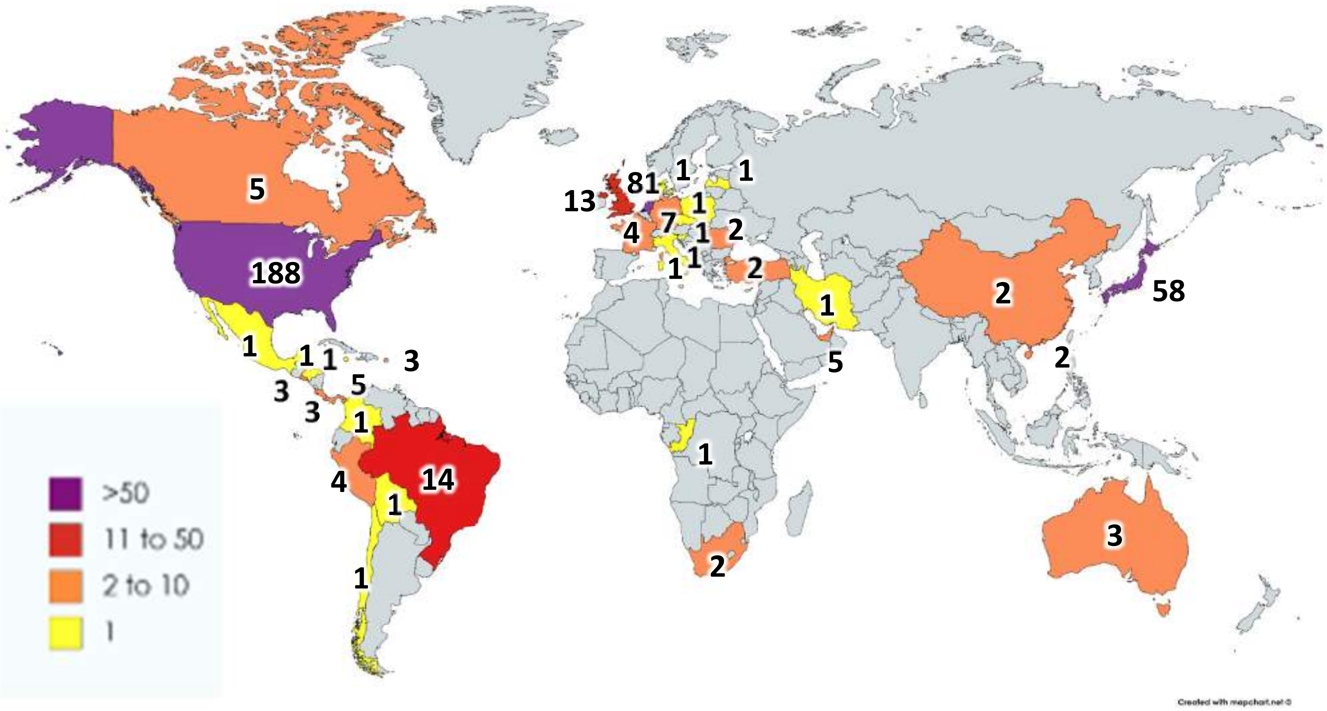
Australian Experience



Barney's Point Bridge
Chinderah, NSW,
Australia

Courtesy: Doulala-Rigby

Where in the World are the LC-GMSE Bridge Abutments?



Zornberg et al. (2018)

What is the Significance of the Ingenious Design at the Barney's Point Bridge Project?

- The project constitutes one of the world's first major bridges built on footings supported by the GRS system
- Monitoring results have shown excellent short- and long-term performance of the bridge abutment
- There are no signs of development of the "bump at the end of the bridge"

Case 8: Resourcefulness in the Design of Retaining Walls

Case 8: Resourcefulness in the Design of Retaining Walls

Where?

Sikkim Airport, India

What?

Design and construct a 74 m-high (!) MSE structure in a seismically active area

How?

By using geosynthetic reinforcements to provide adequate internal and external stability

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

MSE Wall at Sikkim Airport

- Hybrid wall/slope system constructed in a very hilly terrain (Himalayas)
- Reinforcements with 800 kN/m tensile strength
- Seismic considerations were crucial in the selection of the system
- Locally available backfill material used throughout the project

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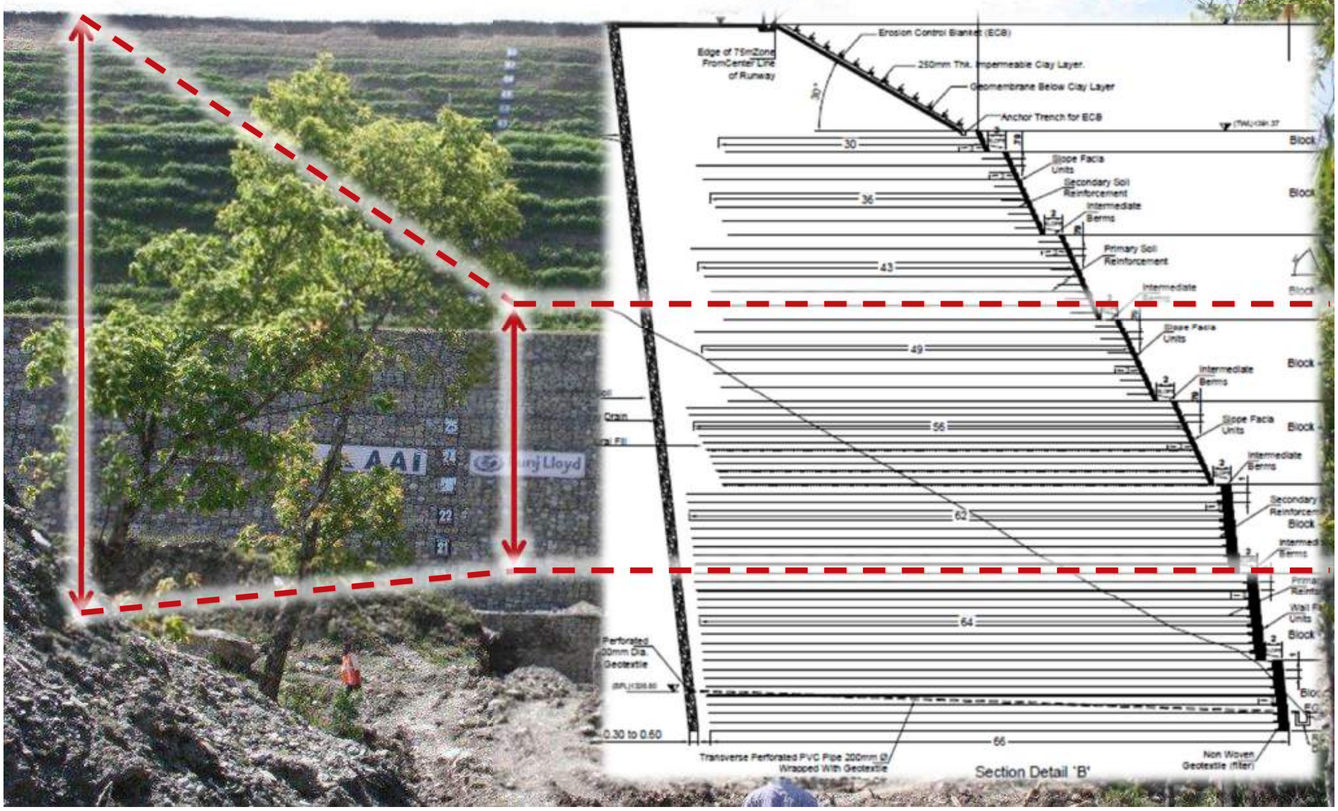
MSE Structure at Sikkim Airport



Courtesy: Edoardo Zannoni

Courtesy: Petrucio dos Santos

What is the Significance of the Ingenious Design at the Sikkim Airport?

- The structure possibly constitutes the highest geosynthetic-reinforced soil structure in the world
- Experienced a magnitude 6.8 earthquake during construction, with no signs of distress

Case 9: Resourcefulness in Reinforcement Embankment Design

Case 9: Resourcefulness in Reinforcement Embankment Design

Where?

Idaho National Forest, Idaho, USA

What?

Steep slopes constructed using backfill with significant fines fraction

How?

Use dual-function geosynthetic inclusions that provide not only reinforcement but also in-plane drainage

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
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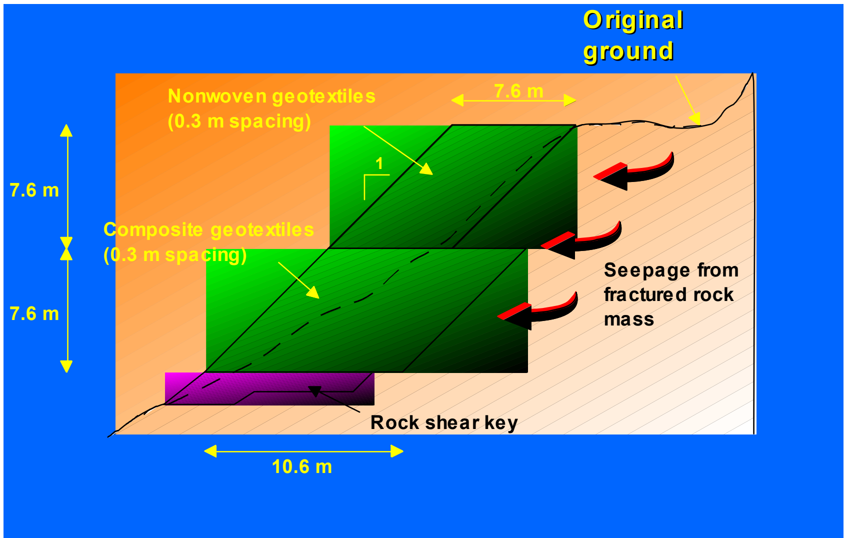
Slope at Idaho National Forest



Cross section of the geotextile-reinforced slope

- Project involved widening of a 2H:1V slope into a 1H:1V slope
- Constructed in 1993 and re-evaluated in 2010
- Decomposed granite available as backfill material
- Seepage from fractured rock mass is significant during spring thaw

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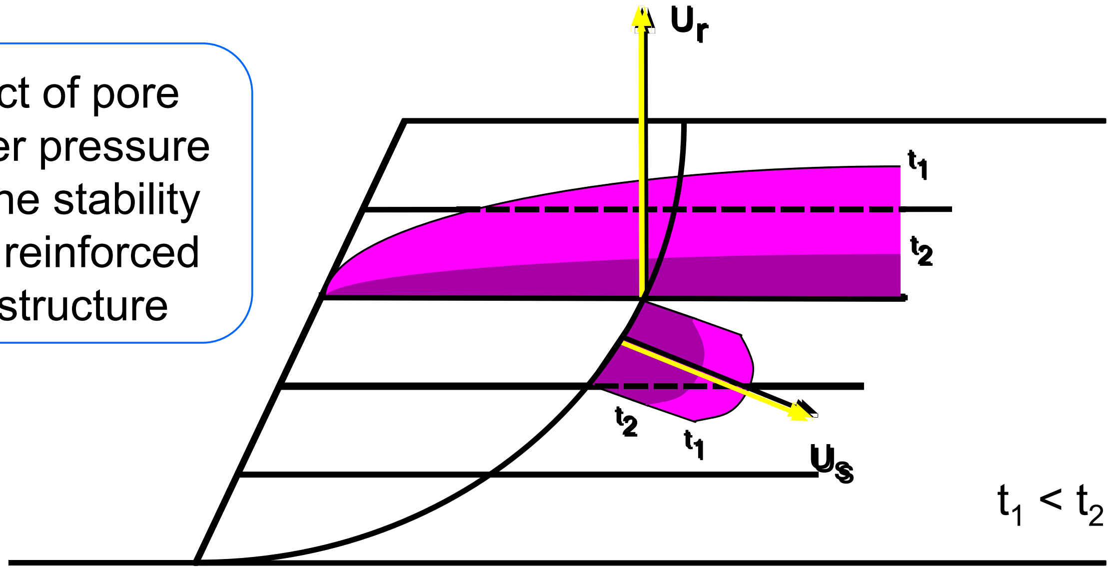
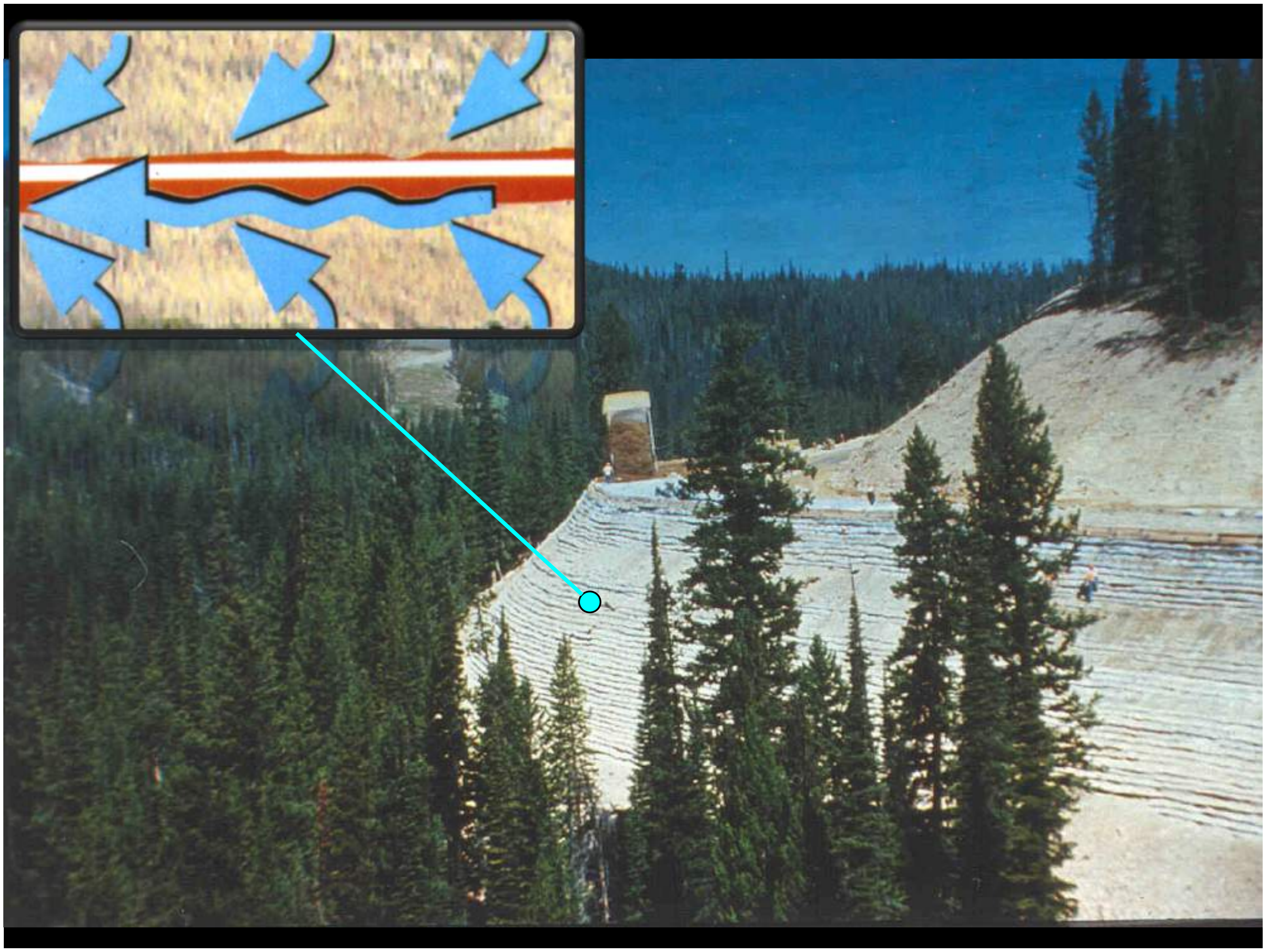
- Permeable geosynthetic reinforcements were used to stabilize poorly draining backfills
- Accordingly, geosynthetic layers were designed to work not only as reinforcements but also as lateral drains

Effect of pore water pressure on the stability of a reinforced soil structure





What is the Significance of the Ingenious Design at the Idaho National Forest?

- Small deformations reflected by maximum strain in the reinforcement on the order of 0.2% (eight weeks after construction in 1993)
- Good long-term performance based on reevaluation in 2010, which indicated a maximum strain of only 0.4%
- Good in-plane drainage, as evidenced by seeps observed in the facing at the reinforcement locations

Case 10: Resourcefulness in Roadway Design

Case 10: Resourcefulness in Roadway Design

1. Earth dams
2. Resistive barriers
3. Unsaturated covers
4. Veneers
5. Hydraulic protection
6. Foundations
7. Bridge abutments
8. Retaining walls
9. Embankments
10. Roadways

Where?

Milam County, Texas, USA

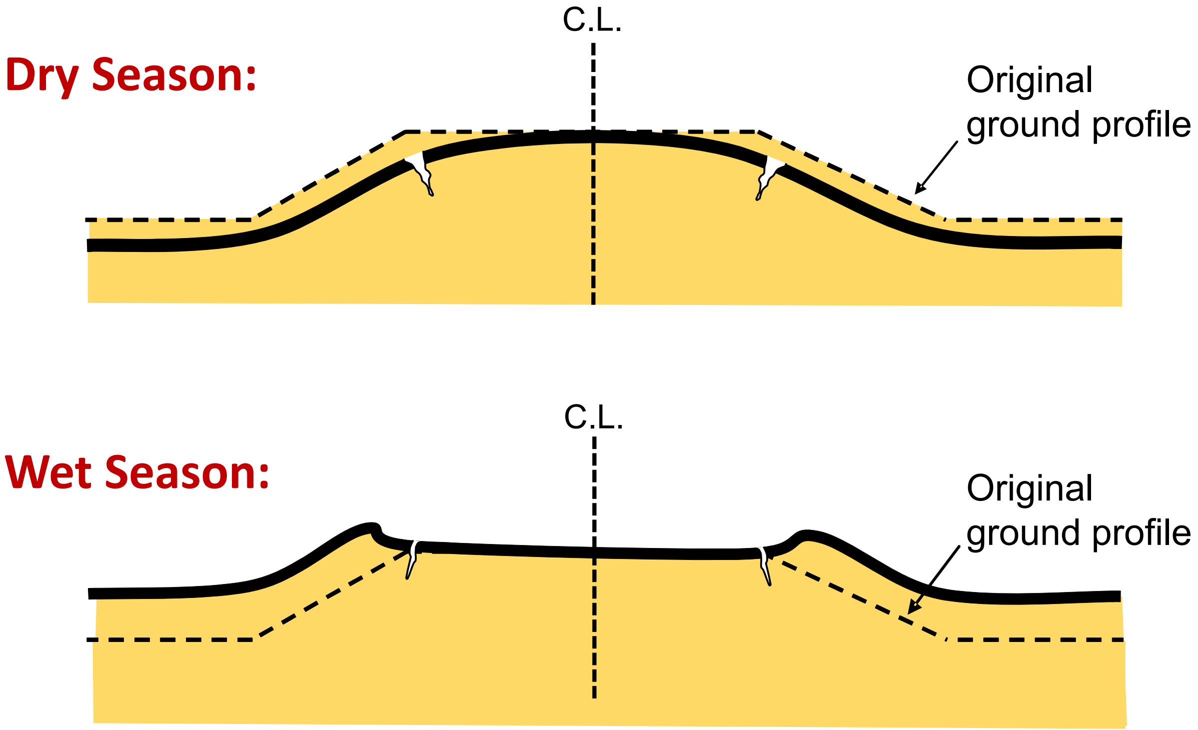
What?

Minimize the detrimental effect on roadways of expansive clay subgrades

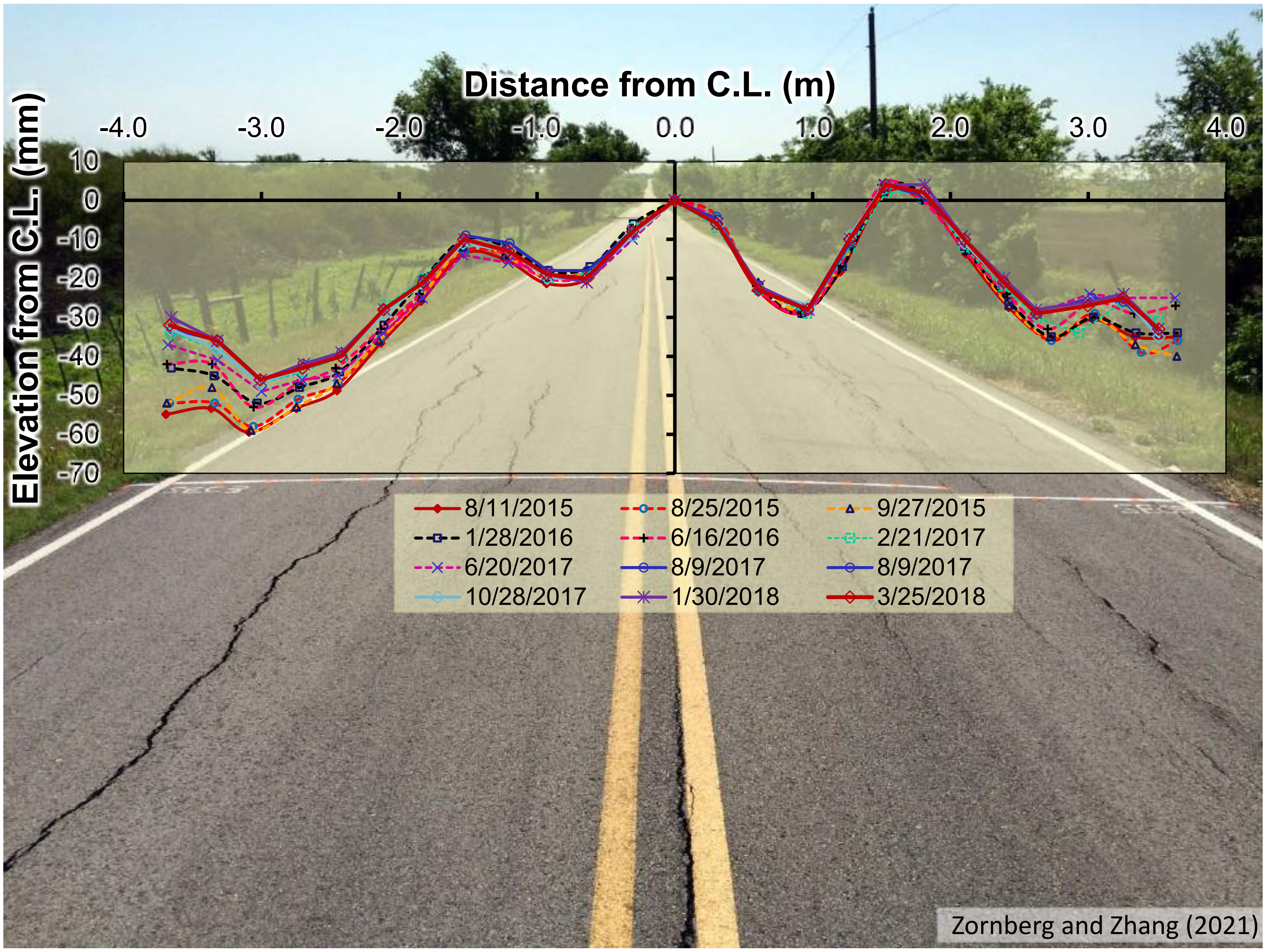
How?

Use of geosynthetics to stabilize the roadway base

Roadways on Expansive Clays



Zornberg and Roodi (2021)

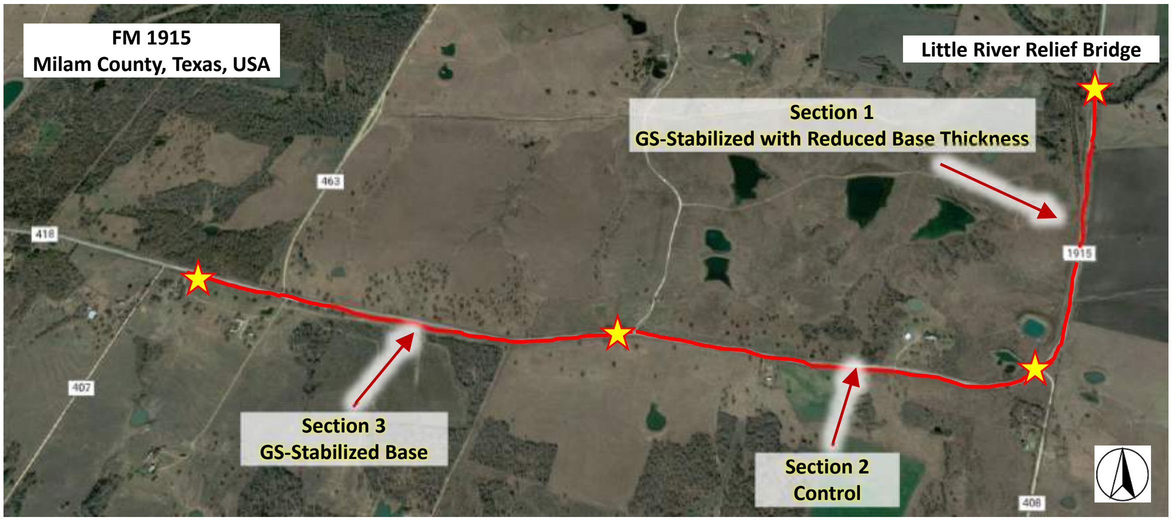


Zornberg and Zhang (2021)

Challenge: Expansive Clay Subgrade

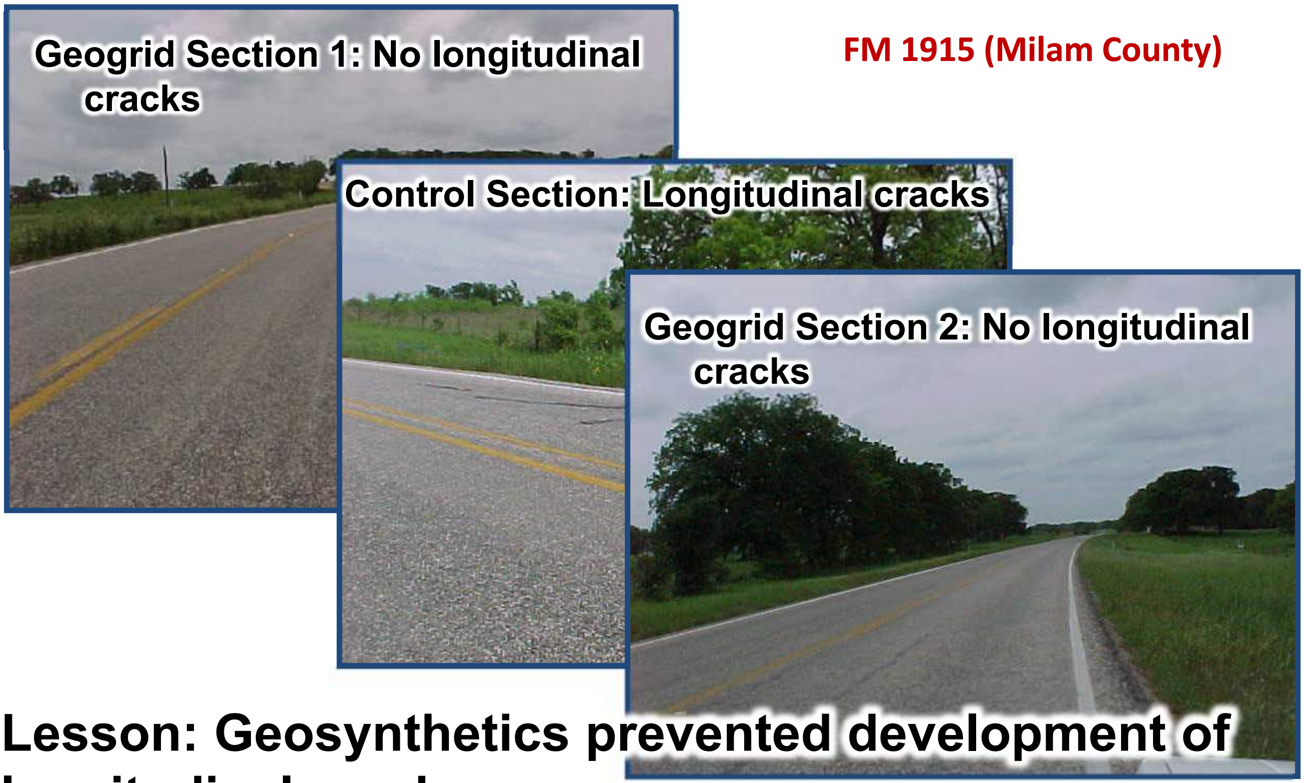
FM 1915, Milam County, Texas

- Founded on expansive clay subgrade with **PI ranging from 30 to 56**
- Severe longitudinal cracks reported on an extension of **4 km south of Little River Relief Bridge**
- Reconstructed **in 1997**
- **3 Test Sections** Constructed including: **Control**, **Geosynthetic-Stabilized Base**, and **Geosynthetic-Stabilized Base** with **Reduced Thickness**
- Length of each test section **approximately 1.3 km**



Effect of Geosynthetic Stiffening

FM 1915 (Milam County)



Lesson: Geosynthetics prevented development of longitudinal cracks

Zornberg and Roodi (2021)

Seeing is Believing…

FM 2 (Grimes County)

Geosynthetic-stabilized Section

Control Section

What is the Significance of the Ingenious Design of the Roadway in Milam County?

- Field evidence has shown that basal stabilization precluded the development of cracks associated with expansive clays
- This important benefit adds to the traditionally reported benefits of basal stabilization of roadways (e.g. decreased base thickness, increased design life)

Final Remarks

This presentation illustrated the merits of using:

1. geotextiles as filters in earth dams,
2. exposed geomembranes as a promising approach for resistive covers,
3. geotextiles as capillary barriers in unsaturated soil covers,
4. anchored geosynthetic reinforcements in stabilization of steep veneer slopes,
5. geocells with concrete infill in hydraulic protection systems,
6. geotextile encased columns (GECs) as foundations in extremely soft soils,
7. load-carrying GRS bridge abutments to minimize the “bump at the end of the bridge,”
8. geogrids in the design of the highest MSE wall,
9. reinforcements with in-plane drainage capabilities in the design of embankments, and
10. geosynthetic reinforcements to mitigate the detrimental effect of expansive clays on roadways.

Final Remarks (Cont.)

- Although geosynthetics are now a well-established technology in our portfolio of geotechnical engineering solutions, they offe continued resourcefulness towards innovation in design
- This is probably because of the ability to tailor their mechanical and hydraulic properties in order to satisfy specific needs in the multiple areas of geotechnical engineering

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Thank You!

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