1. Ingenuity in earth dam design
2. Ingenuity in the design of resistive barriers
3. Ingenuity in unsaturated soil cover design
4. Ingenuity in veneer design
5. Ingenuity in the design of coastal protection systems
6. Ingenuity in foundation design
7. Ingenuity in bridge abutment design
8. Ingenuity in the design of retaining walls
9. Ingenuity in reinforced embankment design
10. Ingenuity in pavement design
Case 1: Ingenuity in Earth Dam Design

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

How?
By using geotextiles as filters in order to satisfy permeability and retention criteria

Where?
Valcros dam, France

Valcros Dam

- 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
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:

\[ D_{15} < 5 \cdot d_{85} \]
Retention Requirement (Cont.)

- Granular filters have been designed using criteria that do not account for aspects of the internal stability of the retained soil.
- The geotextile filter in Valcros dam was selected without using a design method.
- Filter criteria were recently refined taking into account the internal stability 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.

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

- Use of the retention criterion developed for geotextile filters improves the design of granular filters (relevant for soils having 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: Ingenuity in the Design of Resistive Barriers

What?
Promoting the generation of alternative energy in the closure of MSW landfills

How?
By using exposed geomembrane covers for waste containment

Where?
Tessman Road Landfill, San Antonio, Texas, USA

Solar EGCs
Tessman Road Landfill

- Operated by Republic Services, Inc.
- Cover developed by CPS Energy, Greater San Antonio’s electric and natural gas provider
- Project designed by HDR
- Construction by AEG Environmental
- One of the largest MSW landfills in Texas: 2,500 – 5,000 ton/day
- 844 Acre Permit Boundary

- GM with good mechanical properties (design against wind uplift)
- Installed in 2 months (2009)
- Good GM properties allowed mounting an array of flexible solar laminate panels
- First solar energy cover
- Now generates 120 kW
GM is a green 60-mil, fiber-reinforced flexible polypropylene
Initial phase involves a total of 30 solar panels
Expanded solar generation capacity planned
Capacity Recovery Using Exposed Geomembrane And “Bioreactor” Technologies

STEP 1: FILLING AND COVER PLACEMENT
- Waste Disposal Capacity
- Long-term Exposed Geomembrane Cap

STEP 2: VOLUME REDUCTION
- Active Landfill Gas Extraction System
- Leachate Recirculation System

STEP 3: CAPACITY RECOVERY
- Originally Placed Waste
- Additional Disposal Capacity (Apx. 15% of Original Volume)

STEP 4: FINAL CLOSURE
- Final Cover System

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: Ingenuity in Unsaturated Soil Cover Design

What?
Minimizing infiltration of liquids into waste containment facilities in semi-arid locations

How?
Using geotextiles to develop a capillary barrier

Where?
Rocky Mountain Arsenal, Denver, Colorado, USA

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 Landfills (34 ha) that include both double and triple liners, multi-layer covers, and leachate collection/leak-detection systems
- In-situ consolidation of lesser-contaminated soils and demolished structures below “unsaturated soil” covers (183 ha) – no liners
The thickness of an ET cover is designed to minimize downward flux of water beyond a certain depth.

In an engineered cover, we would like to measure the drainage that would occur beyond the cover depth.
The cover was redesigned by incorporating a permanent capillary barrier.
A capillary barrier develops at the interface between geotextiles and overlying fine-grained soils.

In addition to adding water storage capacity, geotextiles also offer the benefits of separation and filtration.

The geotextile capillary barrier at the Rocky Mountain Arsenal was recognized as an essential component of the cover system.

What is the Significance of the Ingenious Design at the Rocky Mountain Arsenal?

- A capillary barrier develops at the interface between geotextiles and overlying fine-grained soils.
- In addition to adding water storage capacity, geotextiles also offer the benefits of separation and filtration.
- The geotextile capillary barrier at the Rocky Mountain Arsenal was recognized as an essential component of the cover system.
Case 4: Ingenuity in Veneer Design

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

How?
Use of geosynthetic reinforcements anchored into solid waste

Where?
OII Superfund site, near Los Angeles, California

OII Superfund Landfill

- Old, unlined landfill
- Stability a major concern
- 1.5:1 (H:V), 65 m-high slopes
- Landfill located in area of high seismicity
- Semi-arid climate
- Construction completed in 2000
• Difficulty in satisfying stability using a cover with GM
• Alternative exposed geomembrane: Stable but not accepted by neighbors
• Conventional cover reinforcement (parallel to slope) not suitable because of long, steep slopes.

Source: Zornberg et al. (2001)
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: Ingenuity in Coastal Protection System Design

What?
Design of multiple anti-tsunami structures

How?
Use of reinforced soil structures to optimize land use

Where?
Japanese Pacific Coast (Proposed by JGS)

- Japan experienced a devastating Tsunami on 11 March 2011
- Most tsunami defense facilities functioned adequately until they were overtopped
- Failure of gravity type seawall during tsunami
- Well performing geosynthetic-reinforced soil retaining wall with staged-constructed full-height rigid facing (facing the ocean!)

Destroyed seawall at Takata-mastubara

Courtesy: Prof. Tatsuoka
About 12 m

Tsunami height

About 12 m
Multiple Anti-tsunami System

Conventional:

Proposed:

What is the Significance of the Ingenious (proposed) Design of Anti-Tsunami Structures?

- Geosynthetic-reinforced soil structures had already become the system of choice in Japan’s transportation infrastructure.

- Following on some 1,600 site investigations after the 2011 Tohoku EQ, it was concluded that geosynthetic RSW performed excellently (less than 1% of RSW were seriously damaged; over 90% did not show any damage) (Tatsuoka 2015).

- Geosynthetic RSW structures have now become the system of choice in Japan’s coastal protection infrastructure.
Case 6: Ingenuity in Foundation Design

**What?**
A cost-effective approach for foundation of embankments on very soft soils

**How?**
Use of geotextile encased columns (GECs)

**Where?**
Airbus land reclamation project, Hamburg, Germany

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**Airbus Dockyards Extension**

- Area extension of 140 ha
- Achieved by constructing a 2.4 km-long dike

- Main problem: Very low undrained shear strength (0.4 to 10 kPa)
- For such low strength, even stone columns were inadequate

Photo Courtesy: Dimiter Alexiew
Geotextile Encased Columns (GECs) can serve as foundation elements for VERY soft clays
High strength geotextile provides radial support

Ultimately, a dike was constructed with a foundation involving 60,000 GECs
Depth ranging between 4 and 14 m below the base of the dike
Project successfully implemented between 2001 and 2004

Photo Courtesy: Dimiter Alexiew
What is the Significance of the Ingenious Design at the Airbus Land Reclamation Project?

- The project illustrates the ability of using geosynthetics in foundation projects involving extremely soft soils
- Comprehensive instrumentation at the site allowed verification of stability and deformability design criteria
- Settlements are smaller than initially predicted, confirming the soundness of the design involving GECs

Case 7: Ingenuity in Bridge Abutment Design

What?
Bridge abutments that minimize the “bump at the end of the bridge”

How?
Use an integral geosynthetic-reinforcement wall rather than deep foundations to support bridge loads

Where?
Founders-Meadows bridge abutment, Denver, Colorado, USA
Objective is to minimize differential settlement induced by the use of different foundation types (e.g. deep foundation for the bridge, foundation on grade for approaching road)
Founders-Meadows Bridge Abutment

- Construction initiated in 1998, completed in 1 year
- Decreased construction costs by avoiding the use of two different types of foundation
- Accommodated six traffic lanes and sidewalks on both sides of the bridge
- Structure was heavily instrumented and monitoring during and after construction
What is the Significance of the Ingenious Design at the Founders-Meadow Project?

- The project constitutes the first major bridge in the US built on footings supported by the GRS system
- Monitoring results show an 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: Ingenuity in the Design of Retaining Walls

What?
Design and construct a 81 m-high (!) MSE structure in seismically active area

How?
By using geosynthetic reinforcements to provide adequate internal and external stability

Where?
Sikkim Airport, India
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

MSE Structure at Sikkim Airport

Courtesy: Edoardo Zannoni
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: Ingenuity in Reinforcement Embankment Design

**What?**
Steep slopes constructed using backfill with a significant fraction of fines

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

**Where?**
Idaho National Forest, Idaho, USA
Slope at Idaho National Forest

- 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

- 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
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: Ingenuity in Pavement Design

What?
Minimize the detrimental effect on pavements of expansive clay subgrades

How?
Use of geosynthetics to reinforce the pavement base

Where?
Bryan County, Texas, USA

Expansive Clays

- Unit contains abundant clay having high swelling potential
- Part of unit (generally less than 50%) consists of clay having high swelling potential
Pavements on Expansive Clays

Effect of Geosynthetic Reinforcement on Expansive Clay Subgrades

Lesson: Geosynthetic reinforcement prevented development of longitudinal cracks

Source: Zornberg et al. (2008)
What is the Significance of the Ingenious Design of the Pavement at Bryant County?

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

Final Remarks

- This presentation illustrates 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. geosynthetic reinforcements in critical coastal protection projects,
  6. geotextile encased columns (GECs) as foundations in extremely soft soils,
  7. integral 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 pavements.
Final Remarks (Cont.)

• Although geosynthetics are now a well-established technology in our portfolio of geotechnical engineering solutions, ingenuity continues to be significant in geotechnical projects that involve their use.

• 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.