Geosynthetics Successes
Hidden in the Details

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Director - Geosynthetic Institute
www.geosynthetic-institute.org
Robert (Bob) M. Koerner Ph.D., P.E. & NAE

- Born and raised in Philadelphia of immigrant parents
- BSCE/MSCE at Drexel University
- Married Paula Feuerer in 1959 (58 years and going strong)
- Work Experience: Dames and Moore, Standard Dredging, Conduit and Foundations and James J. Skelly Co.
- Ph.D. Geotechnical Engr. from Duke
- Drexel faculty member since 1968
Geosynthetics!

- several small polymer projects in 1978-79
- co-authored first GS textbook in 1980
- “phone never stopped ringing” since
- formed Geosynthetic Research Institute within Drexel in 1986 which included an industry consortium
- wrote DwGS textbook in 1986
Accomplishments-to-Date

- Prolific writer, impressive communicator & teacher
- Graduated 36 MS and 14 Ph.D. students
- 105 Koerner Family Fellows
- 133 students are GSI Fellows
- Inducted into National Academy of Engineering in 1998
- Has run 26 Marathons
- morphed into “Webinar Bob”

Sponsored Research
- Geotech = $1.2M
- NDT = $1.6M
- GS = $16M

Books
Journal Articles
Conference Papers
Articles
Report
Congrats Dad!
OUTLINE

1. Commentary on Robert M. Koerner Ph.D., P.E. & NAE
2. The Awesomeness of Geosynthetics
3. Geotextile Details
4. Geogrid Details
5. Geonet/Geospaceer Composite Details
6. Geomembrane Details
7. Geosynthetic Clay Liner Details
8. Erosion Control Product Details
9. Concluding Remarks
GT in roads and on water
GM for landfill liners and covers
GG, GT & GC in walls
EC for slopes and channel
As Geo-Professionals

“We are **entrusted** with the development of systems and infrastructure that drive economic prosperity, enhance quality of life, and sustain the natural environment.”
What a fantastic ride!!

![Graph showing the Geosynthetic Market from 1970 to 2020 with GM, GT, and Total growth over the years.](image-url)
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Various Geotextile Details

Installation damage appears to be generally underestimated hence, reduction factors should be conservatively selected.

GRBA

FHWA Exhuming Project
Installation damage RF should have been ~ 1.7!
Geotextile Installation Damage Cases
Equipment and site condition
GSI’s NCHRP Project Exhuming 100 Drainage Sites
Turbid water thru GT led to core clogging with fine silt and clay soils

Remedy
Low Permeability Filter Cake Inside Geotextile Tube Fabrics is Troublesome
Various additives for dewatering & decontamination

1. Lime (calcium oxide)
2. Alum (aluminum sulfate)
3. Ferric Chloride (iron salts)
4. Polymers

Effect of cationic flocculent on silty clay (CL) dredged soil. (left side with ZETA Lyte 55; right side original clay slurry)
Biological and participate clogging can also be extreme conditions

GT in red and black are the same 450g/m² needle punched nonwoven
Exhuming of a Biological Clogged GT Socked Pipe

a) 5m of hydraulic head not draining

b) Excavate sump

c) Cut open geotextile socking perforated pipe
Geotextile filter turbidity clogging can be troublesome; the balance between high and low AOS is a major design compromise.
Ochre deposits are particularly troublesome

Ochre deposition on geotextile filters (Palmeria, 2007)  Deposits in a highway underdrain pipe (Gourc, 1998)
Use Drain Correction Factor (DCF); recommended less than 100

(a) Entire cell filter (DCF = 1)
(b) GT wrapped drain (DCF = 10-40)
(c) Socked corrugated pipe (DCF = 60-260)
(d) Socked smooth perforated pipe (DCF = 7,500-24,000)
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Of 301 MSE wall failures, “0” were improper geogrid manufacturing and 99% of the failures were due to improper design or construction...
Construction-installation issues

Need to know principle direction of stress in reinforcement and design
Geogrid connection issues

Photo compl. of D. Sandri
Construction-installation issues
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A major concern is the lack of back drains when using fine-grained backfill soils in MSE walls.

(comp. TenCate Geosynthetics)
Leading causes of 301 MSE wall failures (from GSI data base)

<table>
<thead>
<tr>
<th>Internal Instability (22%)</th>
<th>External Instability (14%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- low soil friction</td>
<td>- high surcharge</td>
</tr>
<tr>
<td>- low interface friction</td>
<td>- low soil strength</td>
</tr>
<tr>
<td>- wide GS spacing</td>
<td>- low bearing capacity</td>
</tr>
<tr>
<td>- short GS length</td>
<td>- steep exit angle</td>
</tr>
<tr>
<td>- wrong GS orientation</td>
<td>- seismic forces</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Internal Water (37%)</th>
<th>External Water (27%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- drainage pipe leakage</td>
<td>- retained soil seepage</td>
</tr>
<tr>
<td>- catch basin leakage</td>
<td>- tension crack pressure</td>
</tr>
<tr>
<td>- pressure pipe breakage</td>
<td>- surface infiltration</td>
</tr>
<tr>
<td>- perched water</td>
<td>- elev. phreatic surface</td>
</tr>
<tr>
<td>- saturated backfill</td>
<td>- soil erosion at wall toe</td>
</tr>
</tbody>
</table>

Note: All of the above are readily avoided.
Various Types of Drainage Geocomposites
Use of continuous and intermittent geocomposite back drains when using fine grained soils in the reinforced soil zone (compl., TenCate Geosynthetics, Inc.)
Joining or Overlapping Geocomposites

Field bond

Electrical tie

No bond necessary
Recommended geonet core to drainage pipe connection.
(compl. COE)
Root intrusion into drainage core outlets resulting in blockages; hence, the core becomes a “reservoir” for vegetation growth
<table>
<thead>
<tr>
<th>Case</th>
<th>Drainage Core</th>
<th>Outlet</th>
<th>Blockage Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD-1995</td>
<td>geonet</td>
<td>road swale</td>
<td>road maintenance</td>
</tr>
<tr>
<td>DE-2011</td>
<td>geonet</td>
<td>collapse outlet pipe</td>
<td>errant construction vehicle</td>
</tr>
<tr>
<td>CA-2012</td>
<td>geonet</td>
<td>clogged pipe</td>
<td>vegetation growth</td>
</tr>
<tr>
<td>PA-2013</td>
<td>geospcer</td>
<td>French drain</td>
<td>soil intrusion</td>
</tr>
</tbody>
</table>

Obviously, the outlet maintenance is necessary for the life of the drainage system...
Lamination GT’s to GN forming GC
Peel Strength of GT-to-GN

- GT laminated onto GN (1 or 2 sides)
- MQC test is “peel strength”
- Bonding should be continuous except for edges
- Typical Spec ≥ 180 N/m (1.0 ppi)
- Balance not to compromise transmissivity
Different Nonbonding Patterns

(called “blisters” by Thiel and Narejo in GFR, May, 2005)
GT to GN of Geocomposite
Peel vs Shear Strength

PP GT on GC, Saturated, 44,114 & 228 psf Normal Pressure

Peel Strength (ppi)

Peak Friction Angle (degrees)

\[ y = 0.0028x^2 - 0.05x + 0.01 \]
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Various Geomembrane Details

Puncture by stones is a major concern
Geomembrane Punctures Caused by Stones in Subgrade or by Stones in Cover Soil
LIS Data from 300 Sites and Over 3M m² of GM Provides a Reference Base

Notes:
1 = flat floor
2 = corners and edges
3 = under drainage pipes
4 = pipe penetrations
5 = other (access roads, temporary storage, concrete structures)

Ref. Noski and Touze-Foltz
EuroGeo II, Italy, 2000
Table 1. Location of Holes

<table>
<thead>
<tr>
<th>No. of Holes</th>
<th>Flat Floor (1)</th>
<th>Corners and Edges (2)</th>
<th>Under Drainage Pipes (3)</th>
<th>Pipe Penetrations (4)</th>
<th>Other (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4194</td>
<td>3261</td>
<td>395</td>
<td>165</td>
<td>84</td>
<td>289</td>
</tr>
<tr>
<td>100%</td>
<td>77.8%</td>
<td>9.4%</td>
<td>3.9%</td>
<td>2.0%</td>
<td>6.9%</td>
</tr>
</tbody>
</table>

Table 2. Cause of Holes vs. Size of Holes

<table>
<thead>
<tr>
<th>Size of Holes (cm²)</th>
<th>Stones</th>
<th>%</th>
<th>Heavy Equip.</th>
<th>%</th>
<th>Welds</th>
<th>%</th>
<th>Cuts</th>
<th>%</th>
<th>Worker Directly</th>
<th>%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td>332</td>
<td>11.1</td>
<td>-</td>
<td>-</td>
<td>115</td>
<td>43.4</td>
<td>5</td>
<td>8.5</td>
<td>195</td>
<td>-</td>
<td>452</td>
</tr>
<tr>
<td>0.5-2.0</td>
<td>1720</td>
<td>57.6</td>
<td>41</td>
<td>6.3</td>
<td>105</td>
<td>39.6</td>
<td>36</td>
<td>61.0</td>
<td>105</td>
<td>84.4</td>
<td>2097</td>
</tr>
<tr>
<td>2.0-10</td>
<td>843</td>
<td>28.2</td>
<td>117</td>
<td>17.9</td>
<td>30</td>
<td>11.3</td>
<td>18</td>
<td>30.5</td>
<td>36</td>
<td>15.6</td>
<td>1044</td>
</tr>
<tr>
<td>&gt;10</td>
<td>90</td>
<td>3.0</td>
<td>496</td>
<td>75.8</td>
<td>15</td>
<td>5.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>601</td>
</tr>
<tr>
<td>Amount</td>
<td>2985</td>
<td></td>
<td>654</td>
<td></td>
<td>265</td>
<td></td>
<td>59</td>
<td></td>
<td>231</td>
<td></td>
<td>4194</td>
</tr>
<tr>
<td>Total</td>
<td>71.17%</td>
<td></td>
<td>15.59%</td>
<td></td>
<td>6.32%</td>
<td></td>
<td>1.41%</td>
<td></td>
<td>5.51%</td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Comment: The above data suggests our inspection emphasis might be redirected to stone concerns!
Truncated Cone Puncture Resistance of Different Geomembranes

Cone height (mm) vs. Failure pressure (kPa)

HDPE
fPP-R
PVC
LLDPE
Truncated Cone Puncture Test Setup

Pressure gage
Air bleed valve
Water control valve
Truncated cones
Ottawa sand
Truncated Cone Results

HDPE alone
w/ 135 g/m² GT
w/ 270 g/m² GT
w/ 550 g/m² GT

Failure pressure (kPa)

Cone height (mm)
Options of Selecting a Proper GT Cushion’s Mass/Unit Area

- perform a simulated test as above
- perform a simulated test per BAM method in Germany
- do a theoretical design per DwG
- critical decision: Is the design to prevent actual puncture or prevent long-term stress concentration
Concerns over Entombed Waves or Wrinkles

- All GMs expand with increasing temperature
- They create waves or wrinkles depending on their stiffness and thickness
- These waves do not disappear upon backfilling
- They are fixed in position by friction of the flat geomembrane on either side of the wave
- Their shape actually squashes under increasing load from backfill soil
Large Squashed Wave Being Entombed
Various Concerns over Entombed Waves

- stress concentrations & durability concerns
- mini-dams inhibiting leachate flow
- damage while backfilling
- enlarged leakage area if punctured
- regulations usually do not allow waves
- concern over lack of intimate contact, residual stresses, and shortened lifetime
## Possible Methods to Achieve “Intimate Contact”

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>push/accumulate/cut/seam</td>
<td>quick and cheap</td>
<td>extrusion welds; CQA inspection</td>
</tr>
<tr>
<td>fixing berms</td>
<td>helps greatly</td>
<td>slow and expensive</td>
</tr>
<tr>
<td>white GM or white GT</td>
<td>quick</td>
<td>doesn’t completely avoid issue</td>
</tr>
<tr>
<td>Textured geomembrane</td>
<td>easy</td>
<td>only minimizes effect</td>
</tr>
<tr>
<td>Scrim reinforced geomembranes</td>
<td>helps somewhat</td>
<td>Cost and longevity sacrifice</td>
</tr>
<tr>
<td>temporary tent</td>
<td>HVAC</td>
<td>limits productivity;</td>
</tr>
<tr>
<td>controlled backfilling, morning or night</td>
<td>working with nature</td>
<td>Safety and slower backfilling</td>
</tr>
</tbody>
</table>
New Study on Long-Term Crease Behavior

- laboratory study began February 10, 2017
- GMs folded into S-shape configuration
- placed in UV-fluorescent incubators at 25, 55, 65 and 80°C per ASTM D7238
- 7-GM types (same as previous lifetime study)
  - 1.65 mm thick black HDPE
  - 1.11 mm thick black LLDPE
  - 1.02 mm thick black fPP
  - 1.20 mm thick black EPDM
  - 0.78 mm grey PVC
  - 1.15 mm thick tan fPP-R
  - 1.18 mm thick black LLDPE-R
New GSI Study – Example of Individual Incubation Specimens
(there are 28 similar setups; 7 GMs at four temperatures)

objective → observe craze and crack behavior over time
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Needle Punched GCL

Stitch Bonded GCL

Needlepunching (left) and Stitch Bonding (right)

Broken Needle
Preventative Measures: magnet, metal detector, tag & visual inspect
Increased permeability due to ion exchange

- this issue has been “brewing” for some time; greatly heightened by Benson’s publications
- main concern is for final covers
- clearly the “GCL-alone” design is being challenged
- three very different options are available:
  - protective film
  - greatly decrease k of upper GT
  - use some type of modified bentonite
Available products used to greatly decrease “k” of upper geotextile covering

PE Film on or under Upper GT
(Bentomat® products)

Polymer infill in Upper GT
(Bentofix® products)

Organoclay – Bentonite treated with organic molecules
Multiswell – Bentonite modified with polyethylene carbonate
Trisoplate – Sand, bentonite and polymer mixture
Cationic Polymers – Cationic polymers adsorbed onto bentonite
Anionic Polymer – Anionic polymers adsorbed onto bentonite
Prehydrated – Bentonite prehydrated with polymeric solution
Salt Resistant – Proprietary treated bentonite for salt resistance
Nanocomposite – Bentonite-polymer nanocomposite
GCL panel separation

Separation of GCL panels ~ 300 mm (12 in.)
(Thiel and Richardson, 2005)

Separation of GCL panels ~ 200 mm (8 in.)
(California, 2004)
GCL Panel Separation

- first observed in 1993 by Daniel & Koerner
- since 2000, four more cases appeared
- separation from nil-to-300 mm
- one case in 2004, separation was over 1.0 m; necessitated major repairs (using cap strips over separated GCL areas and major repair of geomembranes)
Various methods used for bonding GCL panel overlaps

- Wood glue
- Liquid nail
- Application of urethane
- Seam produced by gluing GCL's
- Product-A
- Product-B
- Seam produced by taping GCL overlap
- Hand held hot air gun
- GCL seams produced with hot air gun
- Automated hot air device
- Automated hot air seaming in the field
- Hand held hot iron
- Hand held propane torch seaming of GCLs
- Sewing geotextiles in a prayer seam
- Close-up of prayer seam being sewn
- Photo of sewn GCL prayer seam
Destructive testing of a GCL seam specimen
Various steps in nondestructive GCL seam testing
Recommendations Regarding GCL Panel Separation

- cover GM - ASAP
- use white (or light) GM reduce thermal cycling extremes
- increase overlap distance
- use woven GT or scrim in double nonwoven
- thermal seam, tape, glue or sew overlaps
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Various Erosion Control materials used for channel or slope protection

Categories/Types Suggested by ECTC, 1995

<table>
<thead>
<tr>
<th>TERMS</th>
<th>PERMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary Biodegradable</td>
<td>Long-Term Geosynthetic</td>
</tr>
<tr>
<td>Straw, hay and hydraulic mulches</td>
<td>UV stabilize fiber roving systems (FRSs)</td>
</tr>
<tr>
<td>Tackifiers and soil stabilizers</td>
<td>Erosion control revegetation mats (ECRM)</td>
</tr>
<tr>
<td>Hydraulic mulch geofibers</td>
<td>Turf reinforcement mats (TRM)</td>
</tr>
<tr>
<td>Erosion control meshes and nets (ECMN)</td>
<td>Discrete length geofibers</td>
</tr>
<tr>
<td>Erosion control blankets (ECB)</td>
<td>Vegetated Geocellular containment systems (GCS)</td>
</tr>
<tr>
<td>Fiber roving systems (FRS)</td>
<td></td>
</tr>
</tbody>
</table>
Know the limits of the various EC products and job specific performance expectations
Performance & functional longevity

After M. Theisen 1992
Lack of intimate contact, poor backfilling and overall impossible installations
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Recommendations

- Good performance requires a quality system approach
  - Adequate design
  - Quality materials which are tested for conformance to a specification
  - Best Available Installation which is Quality Assured
  - Performance checked or monitored, and
  - Careful operations and maintenance
# Summary GS Report Card

<table>
<thead>
<tr>
<th>Topic</th>
<th>Grade</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>A</td>
<td>Problems are immediately corrected</td>
</tr>
<tr>
<td>Design</td>
<td>A to D</td>
<td>Specialty firms from excellent to entering consultants which are poor</td>
</tr>
<tr>
<td>Index Test Methods</td>
<td>B</td>
<td>Must have harmonization between ASTM and ISO/EN methods</td>
</tr>
<tr>
<td>Performance Test Methods</td>
<td>D</td>
<td>Lack of engineering input</td>
</tr>
<tr>
<td>Generic Specifications</td>
<td>C</td>
<td>Needed for consultants... but do they stifle innovation?</td>
</tr>
<tr>
<td>Installation</td>
<td>B to D</td>
<td>Specialty firms are good; newbie's need help</td>
</tr>
<tr>
<td>Earth Work Contractors</td>
<td>C to F</td>
<td>Equipment too large... insight is lacking</td>
</tr>
<tr>
<td>Inspectors</td>
<td>A to C</td>
<td>Specialty firms good... others are dicey</td>
</tr>
<tr>
<td>Monitoring</td>
<td>D to F</td>
<td>There are few operation and monitoring budgets</td>
</tr>
<tr>
<td>Regulatory Reviews</td>
<td>A to D</td>
<td>Varies enormously</td>
</tr>
</tbody>
</table>
Conclusions

- traditional GS applications are nicely positioned
- new GS applications are appearing regularly
- signals excellent health and continued industry growth
- infers reasonable overall design, testing and performance
- other than environmental applications, CQA lacking
- overall acceptance of GSs continues to be good but requires constant care and outreach
- sincere congratulations to all involved....
- I am very proud to me a member of the GS community
Thanks for Attending and I am honored by the award

GSI Website
www.geosynthetic-institute.org
E-mail: gsigeokoerner@gmail.com
Worldwide Answering Service is also Available
<gmatechline@ifai.com>
Let’s Discuss

Questions Please!