Overview of Geosynthetic Materials, Their Characteristics, Applications, and Design Considerations

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The University of Kansas
Outline of Presentation

- Introduction
- Geosynthetic Products
- Primary Functions
- Material Characteristics
- Applications
- Design Considerations
Geosynthetics

- Geo: Earth - soil or rock
- Synthetics: Man-made products, mainly polymers
# Textural Soil Classification

<table>
<thead>
<tr>
<th>Soil Name</th>
<th>Particle Size (in.)</th>
<th>U.S. Sieve No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulders</td>
<td>&gt; 12</td>
<td></td>
</tr>
<tr>
<td>Cobbleles</td>
<td>12 - 3</td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine</td>
<td>3/4 – 0.19</td>
<td>3/4 in. to No. 4</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse</td>
<td>0.19 – 0.079</td>
<td>No. 4 to No. 10</td>
</tr>
<tr>
<td>Medium</td>
<td>0.079 - 0.017</td>
<td>No. 10 to No. 40</td>
</tr>
<tr>
<td>Fine</td>
<td>0.017 - 0.003</td>
<td>No. 40 to No. 200</td>
</tr>
<tr>
<td>Clays and silts</td>
<td>&lt; 0.003</td>
<td></td>
</tr>
</tbody>
</table>
State of Soil

- Dry
- Unsaturated
- Saturated
Particle Sizes

Percent of Passing (Finer)

Particle Size (in.) – log Scale

D_{85} D_{60} D_{50} D_{30} D_{15} D_{10}
Soil Gradation

Coefficient of uniformity

\[ C_u = \frac{D_{60}}{D_{10}} \]

Coefficient of curvature

\[ C_c = \frac{D_{30}}{D_{60}D_{10}} \]

Cu > 4 (gravel) or 6 (sand) \quad \text{Well-graded (W)}

1 < Cc < 3

Others \quad \text{Poorly-graded (P)}

% fines

\( D_{60} \quad D_{30} \quad D_{10} \)
### Surface Erosion Potential and Plant Growth Capability

<table>
<thead>
<tr>
<th>USDA Soil Texture*</th>
<th>USCS group symbol</th>
<th>USCS Soil Description</th>
<th>Surface Erosion Potential (rill/interrill/wind)</th>
<th>Support of Vegetation Establishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>GW</td>
<td>Well-graded gravel</td>
<td>Low to medium</td>
<td>Poor</td>
</tr>
<tr>
<td>Gravel</td>
<td>GP</td>
<td>Poorly-graded gravel</td>
<td>Low</td>
<td>Very poor</td>
</tr>
<tr>
<td>Gravel/silt</td>
<td>GM</td>
<td>Silty gravel</td>
<td>Low to medium</td>
<td>Poor to fair</td>
</tr>
<tr>
<td>Gravel/clay</td>
<td>GC</td>
<td>Clayey gravel</td>
<td>Low</td>
<td>Poor to fair</td>
</tr>
<tr>
<td>Sand</td>
<td>SW</td>
<td>Well-graded sand</td>
<td>Medium to high</td>
<td>Poor to fair</td>
</tr>
<tr>
<td>Sand</td>
<td>SP</td>
<td>Poorly-graded sand</td>
<td>Medium to high Wind erosion-high</td>
<td>Very poor</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>SM</td>
<td>Silty sand</td>
<td>Medium to high</td>
<td>Good to very good</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>SC</td>
<td>Clayey sand</td>
<td>Medium to high</td>
<td>Good to very good</td>
</tr>
<tr>
<td>Silt</td>
<td>ML</td>
<td>Silt</td>
<td>High Wind erosion-high to very high</td>
<td>Good to very good</td>
</tr>
<tr>
<td>Clay</td>
<td>CL</td>
<td>Clay</td>
<td>Low to medium</td>
<td>Fair to good</td>
</tr>
<tr>
<td>Silt</td>
<td>MH</td>
<td>Silt, high plasticity</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>Clay</td>
<td>CH</td>
<td>Clay, high plasticity</td>
<td>Low to medium</td>
<td>Fair to good</td>
</tr>
<tr>
<td>PT, OL/OH</td>
<td></td>
<td>Peat/Organic silts/clays</td>
<td>Low to high</td>
<td>Very good</td>
</tr>
</tbody>
</table>

* The USDA soil texture system does not correlate well with some aspects of the USCS, especially for gravelly and organic soils.

Rivas (2006)
Soil Permeability

Permeability

\[ k = \frac{QL}{Ah} \]
Basics of Physics

Frictional coefficient

\[ f = \frac{F}{W} = \tan \phi \]

\( \phi \) = frictional angle

Factor of Safety

\[ FoS = \frac{F}{T} = \frac{\tan \phi}{\tan \alpha} \]
**Soil Strength**

Shear strength

\[ \tau_f = c + \frac{W}{A} \tan \phi \]

- **c** = cohesion
- **\( \phi \)** = frictonal angle

**Short term**
- \( c = 0 \) for uncemented sand (air dry or saturated)
- \( c > 0 \) for clay (air dry or saturated)

**Long term**
- \( c = 0 \) for uncemented sand
- \( c = 0 \) for clay (saturated)
Apparent Cohesion

Shear strength

\[ \tau_f = c_a + \frac{W}{A} \tan \phi \]

- \( c_a \) = apparent cohesion
- \( \phi \) = frictional angle

Apparent cohesion

- Exist when soil is unsaturated due to capillary action (i.e., suction), but disappear when soil is saturated or dry
- Rooted soil has apparent cohesion
Long-term Stability of Natural Slope

\[ FS = \frac{\tan \phi}{\tan \alpha} \geq 1.0 \]

\[ FS \approx 0.5 \frac{\tan \phi}{\tan \alpha} \geq 1.0 \]

For typical soil, \( \phi = 30^\circ \)

2(H):1(V) slope (27°) \( \text{Stable} \) 4(H):1(V) slope (14°)
Products of Geosynthetics
Geosynthetic Products

- Geotextile (GT)
- Geogrid (GG)
- Geonet (GN)
- Geomembrane (GM)
- Geosynthetic Clay Liner (GCL)
- Geocell/geoweb (GW)
- Geocomposite (GC)
- Geotube (GTB)
- Erosion mat (EM)
- Others
Types of Geosynthetics Used

Gabr et al. (2006)
Type of Polymer

- Polypropylene (PP)
- Polyester (PET)
- Polyethylene (PE)
- Polyamide (nylon)
- Others
Geotextiles

- Nonwoven Geotextiles: bonded or needle-punched
- Woven Geotextiles
Geogrids

- Consist of apertures with ribs
- UX, BX, or TX geogrid
- Punched and drawn, coated woven or welded
Geonets

- Grid-like materials, made of polyethylene (PE)
- Have thickness difference in ribs
- Used for in-plane drainage
Geomembranes

- PE dominates, sometimes PP or PVC
- Manufactured by extrusion
- Smooth or rough (textured) surfaces
- Impermeable materials, mainly used as barriers
Geosynthetic Clay Liners

- Bentonite clay bonded between two geotextiles
- Used as replacement for compacted clay liners or geomembranes
Geocomposites

- Combine two or more geosynthetic products to one product
- Geotextile-geonet composites
- Geotextile-geogrid composites
**Geocell or Geoweb**

- An expandable three-dimensional honeycomb-like structure
- Used for soil confinement
Geotubes

- Sediment-filled sleeves of geotextile with an oval cross section

- Mainly used for erosion protection along shores and waterfronts
Erosion Blanket or Mats

- Protect ground surfaces (especially slopes) from loss of soil due to water

- Temporary erosion mats are used for flatter slopes (<45°) and degraded after development of vegetation (i.e., Erosion-control blanket)

- Permanent erosion mats are used for steep slopes (>45°) (i.e., Turf Reinforcement Mat)
Functions of Geosynthetics
Primary Functions of Geosynthetics

- Separation
- Filtration
- Drainage
- Reinforcement
- Containment (barrier)
- Erosion protection
Separation Function

- Keep the integrity and functioning of two dissimilar materials intact
- Prevent stone aggregate intruding into fine soil
- Prevent soil fines pumping into aggregate
Filtration Function

- Allow for adequate liquid flow
- Limit soil loss across the interface plane

GRADUALLY INCREASE PARTICLE SIZES

Natural filter

Geotextile filter
Drainage Function

- Large porosity or open space to allow water quickly flow through

![Diagram of drainage function](image)

- Fabric
- Voids
- Nonwoven geotextile
- Core
- Geocomposite
- Geopipe
Reinforcement Function

- Provide (tensile) strength necessary for soil
- Increase shear (interlocking) resistance
- Increase stiffness & minimize deformation (confinement)
Containment Function

- Low permeable materials minimize liquid flow

Geomembrane or GCL
Erosion Protection Function

- Avoid water drops directly hitting on soil surface
- Reduce rate of water flow
- Contain and retain soil particles
### Summary of Primary Functions of Geosynthetics

<table>
<thead>
<tr>
<th>Type</th>
<th>SP</th>
<th>RF</th>
<th>FT</th>
<th>DN</th>
<th>CT</th>
<th>EP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWV GT</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>WV GT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>GG</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>GN</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>GM</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GCL</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GW</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GP</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>GC</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>GTB</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
</tbody>
</table>

SP=Separation
RF=Reinf.
FT=Filtration
DN=Drainage
CT=Containment
EP=Erosion Protection
Properties of Geosynthetics
Properties of Geosynthetics

Physical properties
- Mainly for quality control and assurance

Hydraulic properties
- Important for separation, filtration, drainage, and containment applications

Mechanical properties
- Important for reinforcement applications and constructability

Durability properties
- Important for long-term performance
Physical Properties

• Polymer (PE, PP, PET, etc.)
• Mass per unit area (oz/yd² or g/m²)
• Thickness (mil = 1/1000 inch, mm)
• Roll length
• Roll width
• Roll diameter
• Specific gravity and density
• Surface characteristics
Hydraulic Properties

• Opening characteristic (geotextile)
  - Apparent Opening Size (AOS)
  - Percent Open Area (POA)
  - Porosity (n)

• Permeability and permittivity

• In-plane flow capacity (transmissivity)
Apparent Opening Size (AOS)

Test procedures

- Place geotextile sample into the sieve frame
- Start with the smallest diameter beads
- Place 50g of one size glass beads on the center of geotextile
- Shake the sieve for 10 min.
- Weigh the glass beads that pass through the specimen
- Repeat the test using larger bead size fractions until the weight of beads passing through the specimen to be 5% or less

AOS or $O_{95}$ = the size of the beads of which 5% or less pass
Test for AOS
Permittivity

Water flow

\[ \psi = \frac{k_n}{t} \]

\( \psi \) = Permittivity
\( k_n \) = Cross-plane permeability coefficient
\( t \) = Thickness at a specified normal pressure
Transmissivity

Water flow

Normal pressure

\[ \theta = k \cdot t \]

\[ \theta = \text{Transmissivity} \]

\[ k = \text{In-plane permeability coefficient} \]
Allowable Flow Rate of Geosynthetic Filter or Drainage

\[ q_a = q_{\text{ult}} \times \frac{1}{RF_{\text{SCB}} \times RF_{\text{CR}} \times RF_{\text{IN}} \times RF_{\text{CC}} \times RF_{\text{BC}}} = q_{\text{ult}} \times \frac{1}{RF} \]

- \( q_a \) = allowable flow rate
- \( q_{\text{ult}} \) = ultimate flow rate
- \( RF \) = overall reduction factor
- \( RF_{\text{SCB}} \) = RF for soil clogging and blinding (2 – 10)
- \( RF_{\text{CR}} \) = RF for creep reduction of void space (1 – 2)
- \( RF_{\text{IN}} \) = RF for adjacent materials intruding into void space of geosynthetics (1 – 1.2)
- \( RF_{\text{CC}} \) = RF for chemical clogging (1 – 1.5)
- \( RF_{\text{BC}} \) = RF for biological clogging (1 – 4)
Geotextile Clogging and Blinding

Richardson

Bell and Hicks (1980)
Mechanical Properties

• Tensile strength
  ➢ Grab strength (geotextile or geomembrane)
  ➢ Single rib strength (geogrid)
  ➢ Narrow strip strength (geomembrane)
  ➢ Wide-width strength (geotextile or geogrid)
• Junction strength (geogrid)
• Creep resistance
• Seam strength (geotextile or geomembrane)
• Tear strength (geotextile or geomembrane)
• Burst strength (geotextile or geomembrane)
• Puncture strength (geotextile or geomembrane)
• Penetration Resistance
Tensile Strength Test
Creep Test

Courtesy of Leshchinsky

Yuan
# Creep Reduction Factors

<table>
<thead>
<tr>
<th>Polymer Type</th>
<th>Creep reduction factor, $RF_{CR}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester (PET)</td>
<td>1.6 to 2.5</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>4.0 to 5.0</td>
</tr>
<tr>
<td>High Density Polyethylene (HDPE)</td>
<td>2.6 to 5.0</td>
</tr>
</tbody>
</table>

(FHWA NHI-00-043)
Resistance Tests
Durability Properties

- Abrasion resistance
- UV resistance
- Chemical resistance
- Biological resistance
- Temperature stability
Sunlight (UV) Degradation

Laboratory exposure test

- Xenon-arc exposure test (ASTM D4355)
- Ultraviolet Fluorescent light test (ASTM G53 and D5208)
# Resistance of Polymers to Specific Environment

<table>
<thead>
<tr>
<th>Soil Environment</th>
<th>Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PET</td>
</tr>
<tr>
<td>Acid Sulphate Soils</td>
<td>NE</td>
</tr>
<tr>
<td>Organic Soils</td>
<td>NE</td>
</tr>
<tr>
<td>Saline Soils pH &lt; 9</td>
<td>NE</td>
</tr>
<tr>
<td>Calcareous Soils</td>
<td>?</td>
</tr>
<tr>
<td>Modified Soils/Lime, Cement</td>
<td>?</td>
</tr>
<tr>
<td>Sodic Soils, pH &gt; 9</td>
<td>?</td>
</tr>
<tr>
<td>Soils with Transition Metals</td>
<td>NE</td>
</tr>
</tbody>
</table>

**NE** = No Effect  **?** = Questionable, exposure test required

(FHWA NHI-00-043)
Allowable Tensile Strength of Geosynthetic

\[ T_a = T_{\text{ult}} \frac{1}{RF_{\text{ID}} \times RF_{\text{CR}} \times RF_{\text{CD}} \times RF_{\text{BD}}} = T_{\text{ult}} \frac{1}{RF} \]

- \( T_a \) = allowable tensile strength
- \( T_{\text{ult}} \) = ultimate tensile strength in lab
- \( RF_{\text{ID}} \) = reduction factor for installation damage
- \( RF_{\text{CR}} \) = reduction factor for creep
- \( RF_{\text{CD}} \) = reduction factor for chemical degradation
- \( RF_{\text{BD}} \) = reduction factor for biological degradation
- \( RF \) = overall reduction factor
Installation Damage Test

Step 1: Place geosynthetic and backfill

Step 2: Compaction

Step 3: Exhume geosynthetic sample

Step 4: Test for tensile strength

Step 5: Determine reduction factor

\[ RF = \frac{T_{\text{control}}}{T_{\text{damaged}}} \]
# Installation Damage Reduction Factors

<table>
<thead>
<tr>
<th>Geosynthetic</th>
<th>Type 1 Backfill</th>
<th>Type 2 Backfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE UX geogrid</td>
<td>1.20 - 1.45</td>
<td>1.10 - 1.20</td>
</tr>
<tr>
<td>PP BX geogrid</td>
<td>1.20 - 1.45</td>
<td>1.10 - 1.20</td>
</tr>
<tr>
<td>PVC coated PET geogrid</td>
<td>1.30 - 1.85</td>
<td>1.10 - 1.30</td>
</tr>
<tr>
<td>Acrylic coated PET geogrid</td>
<td>1.30 - 2.05</td>
<td>1.20 - 1.40</td>
</tr>
<tr>
<td>Woven geotextiles (PP&amp;PET)</td>
<td>1.40 - 2.20</td>
<td>1.10 - 1.40</td>
</tr>
<tr>
<td>Nonwoven geotextiles (PP&amp;PET)</td>
<td>1.40 - 2.50</td>
<td>1.10 - 1.40</td>
</tr>
<tr>
<td>Slit filmwoven geotextiles (PP)</td>
<td>1.60 - 3.00</td>
<td>1.10 - 2.00</td>
</tr>
</tbody>
</table>

**Type I backfill:** Max. particle size of 102mm & $D_{50}$ of 30mm

**Type II backfill:** Max. particle size of 20mm & $D_{50}$ of 0.7mm

(FHWA NHI-00-043)
Interface Shear Test

ASTM D5321

Interaction coefficient:

\[ C_i = \frac{\text{Interface strength}}{\text{Soil strength}} \]
## Geotextile/Soil Friction Angles

<table>
<thead>
<tr>
<th>Getextile</th>
<th>Concrete sand ($\phi=30^0$)</th>
<th>Ottawa sand ($\phi=30^0$)</th>
<th>Mica schist sand ($\phi=26^0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonwoven needle-punched</td>
<td>$30^0$</td>
<td>$26^0$</td>
<td>$25^0$</td>
</tr>
<tr>
<td>Nonwoven heat-bonded</td>
<td>$26^0$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Woven monofilament</td>
<td>$26^0$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Woven slit-film</td>
<td>$24^0$</td>
<td>$24^0$</td>
<td>$23^0$</td>
</tr>
</tbody>
</table>

\[
C_i = \frac{\text{Interface strength}}{\text{Soil strength}} = \frac{\tan (24^0)}{\tan (30^0)} = 0.8
\]

Martin et al. (1984)
Geosynthetic Applications
Soft Soil Stabilization
Erosion Control

- Erosion Mat or Blanket
- Enhance seed germination and erosion resistance
- UV protected

Village at Westlake - Austin, TX
Stream/River Bank Protection

FHWA NHI-07-092
Geocell for Low-water Crossing

Clarkin et al. (2006)
Geocell for Channel Protection
Geotubes for Erosion Control

Soil

Fill entry

Geotubes

Wave

Water
Geotube Applications
Marine Mattress for Coastal Revetment
Rubber Dam by Geotube
Canal Liner

- Canal Liner
- Soil
- Geomembrane or GCL
- Anchor trench
- Concrete or soil
- Water

Diagram showing a cross-section of a canal with layers of soil, geomembrane or GCL, and concrete or soil, with water in the middle and anchor trenches on the sides.
Geosynthetic-Reinforced Slope

- Reinforced fill
- Geosynthetics
- Geopipe
- Foundation soil
- Retained soil
- Drainage composites

FACE WRAP FOR ANGLES > 40° TO 50°

USE LIGHTWEIGHT COMPACTION EQUIPMENT

USE ORDINARY COMPACTION EQUIPMENT
Mechanically Stabilized Earth (MSE) Wall

- Geosynthetics
- Reinforced fill
- Block
- Geopipe
- Retained soil
- Drainage composite
- Foundation soil
- Gabion
Design Considerations
Channel Design Criteria

- Based on peak flow capacity
- Consider site conditions
- Design channel lining to ensure the stability
  - Vegetation
  - Riprap
  - Geosynthetic liner
Design Methods

• Maximum permissible velocity method
  ➢ Predicted mean velocity < maximum permissible velocity

• Tractive force (shear stress) method
  ➢ Predicted shear stress < maximum allowable shear stress
<table>
<thead>
<tr>
<th>Channel Material</th>
<th>Permissible Mean Channel Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sand</td>
<td>1.5</td>
</tr>
<tr>
<td>Silt loam</td>
<td>2.0</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>2.0</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>2.5</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>3.0</td>
</tr>
<tr>
<td>Cobbles and gravel (to 3 in.)</td>
<td>4.0</td>
</tr>
<tr>
<td>Earth</td>
<td></td>
</tr>
<tr>
<td>Silty sand</td>
<td>2.0</td>
</tr>
<tr>
<td>Silty clay</td>
<td>3.5</td>
</tr>
<tr>
<td>Clay</td>
<td>4.0</td>
</tr>
<tr>
<td>Cobbles and small rock (to 6 in.)</td>
<td>7.0</td>
</tr>
<tr>
<td>Small boulders (to 10 in.)</td>
<td>10.0</td>
</tr>
<tr>
<td>Medium boulders (to 25 in.)</td>
<td>15.0</td>
</tr>
<tr>
<td>Large boulders (to 50 in.)</td>
<td>20.0</td>
</tr>
<tr>
<td>Grass lined earth channel (slopes&lt; 5%)</td>
<td></td>
</tr>
<tr>
<td>(for 5-10%, reduce velocity by 1 ft/s, for &gt;10%, reduce velocity by 2 ft/s)</td>
<td></td>
</tr>
<tr>
<td>Bermuda grass</td>
<td></td>
</tr>
<tr>
<td>Sandy silt</td>
<td>6.0</td>
</tr>
<tr>
<td>Silt clay</td>
<td>8.0</td>
</tr>
<tr>
<td>Kentucky blue grass</td>
<td></td>
</tr>
<tr>
<td>Sandy silt</td>
<td>5.0</td>
</tr>
<tr>
<td>Silt clay</td>
<td>7.0</td>
</tr>
<tr>
<td>Poor in-place rock—usually sedimentary</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Soft sandstone bedrock</td>
<td>8.0</td>
</tr>
<tr>
<td>Volcanic ash</td>
<td>3.0</td>
</tr>
<tr>
<td>Soft shale</td>
<td>3.5</td>
</tr>
<tr>
<td>Good rock (usually igneous or hard metamorphic bedrock)</td>
<td>20.0+</td>
</tr>
</tbody>
</table>
Max. Design Velocity and Flow Duration for Erosion Resistance

NOTES:
1. Hard Armor - includes Concrete, Riprap, Gabions, Concrete Blocks, etc.
2. Soft Armor - includes Turf Reinforcement Mats (TRM), Erosion Control Revegetation Mats (ECRM), Vegetated Geocells, and many Biotechnical Treatments.
3. Available data shows considerable variability in the Allowable Velocity Limits.

Hewlett et al. (1987)
Theisen (1992),
Clarkin et al. (2006)
Required Size of Riprap Stone

FHWA (1967)
Predicted and Maximum Allowable Shear Stresses

\[ \tau = \gamma_w \cdot d \cdot s \]

\( \gamma_w \) = unit weight of water, \( d \) = depth of flow
\( s \) = channel slope

General Guide for Maximum Allowable Shear Stress (psf)

- Vegetation (unreinforced) 3
- Erosion control blanket 3
- Rip-rap (18” stone) 6
- Rip-rap (24” stone) 8
- Typical turf reinforcement mat 8
- Articulating concrete block 15
- Fabric-formed concrete 20
Bio-stabilization

\[ FS \approx \frac{2c}{\gamma H \sin 2\alpha} + 0.5 \frac{\tan \phi}{\tan \alpha} \]

Example:

\[ c_a = 50 \text{ psf, } H = 2 \text{ ft, } \gamma = 120 \text{ pcf, } \phi = 30^\circ \]

\[ FS = 1.0 \]

\[ \alpha = 40^\circ \text{ (1:1 slope, no-seepage condition)} \]

\[ \alpha = 27^\circ \text{ (2:1 slope, seepage condition)} \]
Toe Protection or Support

Passive wedge

Active wedge

$W_P$

$W_A$

$\alpha$
Anchorage Requirements in Erosion Control Applications

# Pin Spacing Requirements in Erosion Control Applications

<table>
<thead>
<tr>
<th>Slope</th>
<th>Pin Spacing (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steeper than 3(H) : 1(V)</td>
<td>2</td>
</tr>
<tr>
<td>3(H) : 1(V) to 4(H) : 1(V)</td>
<td>3</td>
</tr>
<tr>
<td>Flatter than 4(H) : 1(V)</td>
<td>5</td>
</tr>
</tbody>
</table>

Steel securing pins: 8/16 in. (diameter), 18 in. (long), fitted with a 1.5-inch metal washer

Longer pins are advisable for use in loose soils

Why is Anchorage Needed Sometimes?

\[ FoS = \frac{\tan \delta}{\tan \alpha} = \frac{C_i \tan \phi}{\tan \alpha} \]

Typical \( C_i = 0.6 \) to 0.8
Typical Geosynthetic Layout for Reinforced Slope

- PRIMARY REINFORCEMENT
- INTERMEDIATE REINFORCEMENT

- S = 16 INCHES MAX.
- s = 32 INCHES MAX.

- STONE ARMOR FACING (BY OTHERS)
  - 6-INCH (MAX) TO 4-INCH (MIN.)
  - AGGREGATE SIZE - SURGE STONE (TYP.)

- AASHTO M288 Class 2 Geotextile Filter

- OFFSET VARIES SEE TABLE

- PRIMARY REINFORCEMENT

- USE LIGHTWEIGHT COMPACTION EQUIPMENT
  - USE ORDINARY COMPACTION EQUIPMENT

FHWA NHI-07-092
## Face Options for Reinforced Slopes

<table>
<thead>
<tr>
<th>Slope Face Angle and Soil Type</th>
<th>Type of Facing</th>
<th>Type of Facing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Face not wrapped with geosynthetic</td>
<td>Face wrapped with geosynthetic</td>
</tr>
<tr>
<td></td>
<td>Vegetated Face</td>
<td>Vegetated Face</td>
</tr>
<tr>
<td></td>
<td>Hard Facing</td>
<td>Hard Facing</td>
</tr>
<tr>
<td>&gt;50° All Soil Types</td>
<td>Not Recommended</td>
<td>Gabions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sod Permanent Erosion Blanket w/ seed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wire baskets Stone Shotcrete</td>
</tr>
<tr>
<td>35° to 50° Clean Sands Rounded Gravel</td>
<td>Not Recommended</td>
<td>Gabions Soil-Cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sod Permanent Erosion Blanket w/ seed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wire baskets Stone Shotcrete</td>
</tr>
<tr>
<td>35° to 50° Silts Sandy Silts</td>
<td>Bioreinforcement</td>
<td>Gabions Soil-Cement Stone veneer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sod Permanent Erosion Blanket w/ seed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wire baskets Stone Shotcrete</td>
</tr>
<tr>
<td>35° to 50° Silty Sands Clayey Sands</td>
<td>Temporary or Permanent Erosion Blanket w/ seed or sod</td>
<td>Hard Facing not needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geosynthetic wrap not needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geosynthetic wrap not needed</td>
</tr>
<tr>
<td>25° to 35° All Soil Types</td>
<td>Temporary or Permanent Erosion Blanket w/ seed or sod</td>
<td>Hard Facing not needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geosynthetic wrap not needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geosynthetic wrap not needed</td>
</tr>
</tbody>
</table>

Collin (1996)
Long-term design strength, $T_{ltds} = 23$ kN/m
Length of reinforcement, $L = 12.0$ m

Trace of critical circle = $ab$

$Fs = 1.31$

From ReSSA Software

Courtesy of Leshchinsky
MSE Wall vs. Reinforced Slope

- **Slope: Face inclination ≤ 70°**
- **Solution driven by many factors**
  - Space
  - Cost
  - Vegetation
  - Backfill

![Graph showing estimated construction cost vs. vertical height for different wall types: Cast-in-Place Wall, Precast Concrete MSE Wall, Reinforced Slope System.](image)
MSE Wall Design

(a) Sliding

(b) Overturning

(c) Bearing

(d) Global failure

(e) Pullout

(f) Rupture
<table>
<thead>
<tr>
<th>Sieve size</th>
<th>% passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 in.</td>
<td>100 – 75</td>
</tr>
<tr>
<td>No. 4</td>
<td>100 – 20</td>
</tr>
<tr>
<td>No. 40</td>
<td>0 – 60</td>
</tr>
<tr>
<td>No. 200</td>
<td>0 – 35</td>
</tr>
</tbody>
</table>

Plasticity Index (PI) of fine fraction < 20

National Concrete Masonry Association
MSE Wall Drainage Design

Low permeable soil

Drainage material
Design Procedure for Geotextile Filter beneath Hard Armor

Step 1: Evaluate critical nature of site conditions
Step 2: Obtain soil samples from site and test
Step 3: Evaluate armor material and placement
Step 4: Determine anticipated reversing flow through system
Step 5: Determine geotextile requirements
  - A. Retention (i.e., AOS)
  - B. Permeability/permittivity ($k_{\text{geotextile}} > k_{\text{soil}}$ or $10 k_{\text{soil}}$)
  - C. Clogging (i.e., $O_{95}$, porosity, POA)
  - D. Survivability (i.e., geotextile class)
Step 6: Estimate costs
Step 7: Prepare specification
Step 8: Obtain samples of geotextile before acceptance
Step 9: Monitor installation and performance
FHWA Filter Design Procedure

**RETENTION CRITERIA**

- **Steady State Flow**
  - Sands, Gravelly sand, Silty Sands & Clayey Sands (< 50% passing No.200 sieve)
    - For \( C_U \leq 2 \) or \( C_U \geq 8 \) \( B = 1 \)
    - \( D_{95} \leq B D_{85} \)
  - Silts and Clays (> 50% passing No.200 sieve)
    - For \( 2 \leq C_U < 4 \) \( B = 0.5 C_U \)
    - \( D_{95} \leq B D_{85} \)
    - For \( 4 < C_U < 8 \) \( B = 8 / C_U \)
    - \( O_{95} \leq 0.3 \text{ mm} \)

- **Dynamic Flow**
  - For \( 4 < C_U < 8 \) \( B = 8 / C_U \)
  - \( O_{95} \leq 0.3 \text{ mm} \)

- **Unstable Soils**
  - \( O_{95} \leq 0.5 D_{85} \)

**PERMEABILITY/PERMITTIVITY**

- For less critical applications and less severe conditions: \( k_{\text{geotextile}} \geq k_{\text{soil}} \)
- For critical applications and severe conditions: \( k_{\text{geotextile}} \geq 10 k_{\text{soil}} \)
  - % Passing #200 sieve: < 15% 15% to 50% >50%
  - Permittivity Required: \( \Psi \geq 0.5 \text{ sec}^{-1} \) \( \Psi \geq 0.2 \text{ sec}^{-1} \) \( \Psi \geq 0.1 \text{ sec}^{-1} \)
  - \( q_{\text{required}} = q_{\text{geotextile}} (A_g/A_t) \)

**CLOGGING RESISTANCE**

- For less critical applications and less severe conditions:
  - For \( C_U > 3 \) \( O_{95} \geq 3D_{15} \)
  - \( O_{95} \) from Retention Criteria
- For critical applications and severe conditions:
  - Optional Qualifiers for gap-graded or silty soils
  - For Nonwovens: \( n \geq 50\% \)
  - For woven monofilament and silt films: \( \text{POA} \geq 4\% \)
  - Perform filtration test with on-site soils and hydraulic conditions

**SURVIVABILITY and ENDURANCE CRITERIA**

- For less critical applications and less severe conditions:
  - For \( C_U < 3 \) \( O_{95} \geq 3D_{15} \)
- For critical applications and severe conditions:
  - \( O_{95} \) from Retention Criteria
  - Perform filtration test with on-site soils and hydraulic conditions
Classifications of Geotextiles in AASHTO M288-96 Specifications

Class 1:
For severe or harsh survivability conditions where there is a greater potential for geotextile damage

Class 2:
For typical survivability conditions; this is the default classification to be used in the absence of site specific information

Class 3:
For mild survivability conditions
## Geotextile Strength Property Requirements for Permanent Erosion Control

<table>
<thead>
<tr>
<th>Units</th>
<th>Grab strength</th>
<th>Sewn seam strength</th>
<th>Tear strength</th>
<th>Puncture strength</th>
<th>Ultraviolet stability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
<td>50% retained strength after 500 hours of exposure</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>&lt; 50</td>
<td>≥ 50</td>
<td>&lt;50</td>
<td>≥50</td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>315</td>
<td>200</td>
<td>250</td>
<td>157</td>
<td></td>
</tr>
<tr>
<td>Class 2</td>
<td>280</td>
<td>180</td>
<td>220</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Class 3</td>
<td>110</td>
<td>80</td>
<td>90</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Class 4</td>
<td>620</td>
<td>433</td>
<td>495</td>
<td>309</td>
<td></td>
</tr>
</tbody>
</table>
Design of Geotube

Input:
- Pressure head, $b_1$
- Circumference, $S$

Output:
- Tube heights, $H$, $H'$
- Tube width, $B$, $B'$
- Geotextile strength, $T$
Next Presentation: Case Studies

- Simple Slope with Temporary Toe Protection
- Reinforced Vegetation with Temp. Toe Protection
- Reinforced Slope with Permanent Toe Protection
- Hard Armor Structures
- Retaining Structures
Questions?