Geosynthetics in Forestry Application

By

Donald Lindsay, CEG, PE
Engineering Geologist/Civil Engineer
California Geological Survey
Presentation Outline

- Background information on Geosynthetics.
- Look at examples of geosynthetics in Forestry Applications.
- Review currently accepted design standards.
- Where applicable, identify simplified design procedures to promote the use of geosynthetics.
GOAL

GEOSYNTHETICS
KNOWLEDGE
DESIGN STANDARDS

PRACTITIONERS
RPFs
LTOs

REVIEW TEAM AGENCIES
CDF
DFG
RWQCB
CGS
Geosynthetics Defined

“Planar, polymeric material used with soil, rock, earth, or other geotechnical-related material as an integral part of an engineered project, structure, or system.”
Common Geosynthetics in Forest Applications

- Geotextiles
- Geogrids
- Geocomposites
- Geocells
Common Geosynthetic functions in Forest Applications

► Separation
► Filtration
► In-plane Drainage
► Reinforcement
► Protection/Cushion
► Fluid Barrier
Separation

- Tensar
- Geotextile Separator
- Rock Fill
- CMP
- Road surface
- Geotextile
- Armoured Slope
Filtration

Wrapped aggregate drains

Filter fabric

Geocomposites
In-Plane Drainage

Geocomposite

Nonwoven
Reinforcement

Geosynthetics increase soil shear resistance by increasing tensional and passive resistant forces.
# Mechanics of Reinforcement

<table>
<thead>
<tr>
<th>Friction between geosynthetic and soil</th>
<th>GEOGRID</th>
<th>GEOTEXTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIGH</td>
<td>LOW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Confinement (Dilation)</th>
<th>GEOGRID</th>
<th>GEOTEXTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIGH</td>
<td>LOW to NA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extensibility of geosynthetic</th>
<th>GEOGRID</th>
<th>GEOTEXTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOW</td>
<td>HIGH</td>
</tr>
</tbody>
</table>
Confinement:
GEOSYNTHETICS
Geogrids
Geocells
Geotextiles
Geocomposites

FUNCTIONS
Separation
Filtration
In-Plane Drainage
Reinforcement

FOREST APPLICATIONS
Forest Applications

► Erosion Control Systems
► Soft Subgrade Reinforcement and Separation
► Subsurface Drainage
► Reinforced Slopes
Erosion Control Systems

- Used instead of graded granular materials in hard armor structures such as:
  - Beneath rock slope protection along stream channels and bridge abutments (separation, filtration)
  - Beneath armor stone on cut and fill slopes (separation, filtration)
Erosion Control Systems

- Used as scour protection in low-water stream crossings (separation, reinforcement)

Clarkin K. et. al., 2006 (USFS)

Geocell
Erosion Control Systems

- Used to temporarily control and minimize erosion and sediment transport until vegetation can be established. Examples include:
  - Erosion control blankets and mats.

Ed Rose, USFS
Erosion Control Systems

Advantages:

► Reduce the use of costly granular aggregate material.
► Expedite construction.
► Provide protection while promoting vegetation growth.
Erosion Control Systems

Disadvantages:

► Additional time to place and workaround.
► Use of improper geosynthetic for the given function and site conditions (oversight).
► Improper installation (oversight).
Forest Applications

- Erosion Control Systems
- Soft Subgrade Reinforcement and Separation
- Subsurface Drainage
- Reinforced Slopes
Soft Subgrade Reinforcement and Separation

- The cost to rock roads can be substantially lower when the road has a soft, yielding subgrade.

- Achieved by providing three functions:
  - Reinforcement
  - Separation
  - Filtration (less common)
Soft Subgrade Reinforcement

(a) Lateral Restraint

(b) Bearing Capacity Increase

(c) Membrane Tension Support
Soft Subgrade Reinforcement

Tensar BX1200 supports continued traffic of fully loaded trucks. This section is immediately behind failed section on previous photo that did not have BX1200 reinforcement.
Soft Subgrade Separation
Aggregate lost to weak subgrades
Soft Subgrade Reinforcement and Separation

Advantages:

► Reduces stresses in subgrade (reinforcement).
► Prevents contamination of surface rock (separation, filtration).
► Reduces excavation of unsuitable subgrade materials (separation, reinforcement).
► Reduces the thickness of aggregate required to stabilize the subgrade (separation, reinforcement).
► Aids in compaction of surface rock (separation, reinforcement, drainage).
► Reduces maintenance and extends the life of the road surface (filtration, separation, drainage, reinforcement).
Soft Subgrade Reinforcement and Separation

Disadvantages:

- Price of geosynthetics? (about $3/ft. road).
- Use of improper geosynthetic for the given function and site conditions (specifications and/or oversight).
Forest Applications

- Erosion Control Systems
- Soft Subgrade Reinforcement and Separation
- Subsurface Drainage
- Reinforced Slopes
Subsurface Drainage

► Geosynthetics can be used as a replacement for, or in conjunction with, conventional graded granular filters.

► Examples:
  - Geocomposite drains
  - Wrapped aggregate drains (burrito drains, wrapped underdrains)
Geocomposite Drain

Ed Rose, USFS
Geocomposite Drain

Ed Rose, USFS
Precautions to prevent damage from construction:
Precautions to prevent clogging:

Need to choose appropriate fabric for the soil conditions.

AOS = apparent opening size

Filter bridge forms

Too large an AOS can cause soil piping.

AOS ≤ D_{85}

AOS ≥ 3D_{15}

Too small an AOS can cause clogging.

AOS ≥ 3D_{15}

No Filter bridge

Too large an AOS can cause soil piping.

AOS ≤ D_{85}

Too small an AOS can cause clogging.

AOS ≥ 3D_{15}

No Filter bridge

No Filter bridge
Subsurface Drainage

Advantages:

► Prevents fines from contaminating the drain rock while allowing water to pass (filtration).

► Allows for the use of less-costly drainage aggregate (separation, filtration).

► Expedites construction.
Subsurface Drainage

Disadvantages:

► Use of improper geosynthetic for the given function and site conditions (specifications and oversight).

► Poor installation.
Accepted Design Procedure

1. Evaluate the critical nature of the application.
2. Obtain soil samples and perform necessary tests (gradation, hydrometer, Atterberg limits).
3. Determine the dimensions of the drain system.
4. Determine geotextile hydraulic requirements (retention, flow, clogging).
5. Determine geotextile survivability requirements.
7. Monitor Installation.

Adapted from FHWA HI-95-038
Chart 1. Soil Retention Criteria of Steady-State Flow Conditions

Notes:

- $d_s = \text{particle diameter of which size x percent is smaller}$
- $C'_{ia} = \sqrt{\frac{d_{10}}{d_{50}}} \text{ where } d_{10} \text{ and } d_{50} \text{ are the extremities of a straight line drawn through the particle-size distribution, as directed above and } \overline{d_{10}} \text{ is the midpoint of this line}$
- $C_c = \frac{(\overline{d_{10}})^2}{d_{50} \times d_{10}}$
- $I_d = \text{relative density of the soil}$
- $P_I = \text{plasticity index of the soil}$
- $DHR = \text{double-hydrometer ratio of the soil}$
- $d_{50} = \text{geocell opening size}$

geotextile filter design, application, and product selection guide
Table 3-1. Geotextile Filter Design Criteria.

<table>
<thead>
<tr>
<th>Protected Soil (Percent Passing No. 200 Sieve)</th>
<th>Permeability Woven Nonwoven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5%</td>
<td>AOS (mm) &lt; 0.6</td>
</tr>
<tr>
<td>(Greater than #30 US Standard Sieve)</td>
<td>POA &gt; 5% k_g &gt; 5k_s</td>
</tr>
<tr>
<td>5 to 50%</td>
<td>AOS (mm) &lt; 0.6</td>
</tr>
<tr>
<td>(Greater than #30 US Standard Sieve)</td>
<td>POA &gt; 4% k_g &gt; 5k_s</td>
</tr>
<tr>
<td>50 to 85%</td>
<td>AOS (mm) &lt; 0.297</td>
</tr>
<tr>
<td>(Greater than #50 US Standard Sieve)</td>
<td>POA &gt; 4% k_g &gt; 5k_s</td>
</tr>
<tr>
<td>Greater than 85%</td>
<td>AOS (mm) &lt; 0.297</td>
</tr>
<tr>
<td>(Greater than #50 US Standard Sieve)</td>
<td>k_g &gt; 5k_s</td>
</tr>
</tbody>
</table>

1 When the protected soil contains appreciable quantities of material retained on the No. 4 sieve use only the soil passing the No. 4 sieve in selecting the AOS of the geotextile.
2 k, is the permeability of the nonwoven geotextile and k_s is the permeability of the protected soil.
3 POA = Percent Open Area.
<table>
<thead>
<tr>
<th>NONWOVEN</th>
<th>WOVEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>High porosity + High permeability</td>
<td>High permeability but Percent open area (POS) is more prone to clogging.</td>
</tr>
<tr>
<td>= High flow for longer.</td>
<td></td>
</tr>
</tbody>
</table>
Forest Applications

- Erosion Control Systems
- Soft Subgrade Reinforcement and Separation
- Subsurface Drainage
- Reinforced Slopes.....Finally the good stuff!
Reinforced Slopes

► Geosynthetic-reinforced slopes allow the ability to construct slopes steeper than those constructed using more traditional means.

► Two common types of reinforcement:
  - Geogrid
  - Geotextile
Ed Rose, USFS
Ed Rose, USFS
Reinforced Slopes

Advantages:

- Allows for the use of on-site, native material rather than importing select material (reinforcement).
- Can eliminate the need for buttress elements such as rip-rap, k-rails, etc. (reinforcement).
- Reduces the area and volume of fills (reinforcement).
- Aids in compaction during construction (separation, reinforcement, drainage).
- Can stabilize large landslides by unloading the head, reinforcing the toe, and providing internal drainage (separation, reinforcement, drainage).
Reinforced Slopes

Disadvantages:

► Consultant fees for design.

► Use of improper geosynthetic for the given function and site conditions.

► Requires more complex construction techniques (keying, benching) and more stringent construction specifications (moisture conditioning, compaction).
Accepted Design Procedure

1. Address cause of original failure.
2. Establish the geometric, loading, and performance requirements for design.
3. Determine the subsurface stratigraphy and the engineering properties of the natural soils.
4. Determine the engineering properties of the available fill soils.
5. Establish design parameters for the reinforcement (design reinforcement strength, durability criteria, soil-reinforcement interaction).
6. Determine the factor of safety of the unreinforced slope.
7. Design reinforcement to provide stable slope.
8. Check external stability.
9. Evaluate requirements for subsurface and surface water control.

FHWA HI-95-038
CHART PROCEDURE:

1) Determine force coefficient $K$ from figure above, where $\phi_r = \text{friction angle of reinforced fill}$:

$$\phi_r = \tan^{-1}\left(\frac{\tan \theta}{FS_r}\right)$$

2) Determine:

$$T_{S\text{MAX}} = 0.5 K \gamma' (H')^2$$

where:
- $H' = H + q'$
- $q = \text{a uniform load}$

3) Determine the required reinforcement length at the top $L_T$ and bottom $L_B$ of the slope from the figure above.

LIMITING ASSUMPTIONS

- Extensible reinforcement.
- Slopes constructed with uniform, cohesionless soil, $c = 0$.
- No pore pressures within slope.
- Competent, level foundation soils.
- No seismic forces.
- Uniform surcharge nor greater than 0.2 $\gamma$, $H$.
- Relatively high soil/reinforcement interface friction angle, $\phi_{ir} = 0.9 \phi_r$ (may not be appropriate for some geotextiles).

*Figure 8-6* Sliding wedge approach to determine the coefficient of earth pressure $K$ (after Schmertmann, et al., 1987).

NOTE: Charts © The Tenser Corporation.
Figure 3—Cross section of typical deep patch road embankment repair.

Figure 4—Deep patch depth vs. slope distance.

Figure 5—Required force vs. slope distance.
REINFORCED SOIL SLOPES

CASE 1a - 45° Maximum Slope Angle, Granular Borrow Reinforced Soil Fill

<table>
<thead>
<tr>
<th>Max. Slope Angle (degrees)</th>
<th>Reinforced Soil Fill Friction Angle (degrees)</th>
<th>Minimum Reinforcement Length, L (m)</th>
<th>Primary Soil Reinforcement</th>
<th>Maximum Slope Height (m)</th>
<th>Zone 1</th>
<th>Zone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>30</td>
<td>1.1 H</td>
<td>Type I 10</td>
<td>8.0</td>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type II 15</td>
<td>8.0</td>
<td>6.5</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type III 20</td>
<td>8.0</td>
<td>5.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

CASE 1b - 45° Maximum Slope Angle, Modified Select Granular Borrow Reinforced Soil Fill

<table>
<thead>
<tr>
<th>Max. Slope Angle (degrees)</th>
<th>Reinforced Soil Fill Friction Angle (degrees)</th>
<th>Minimum Reinforcement Length, L (m)</th>
<th>Primary Soil Reinforcement</th>
<th>Maximum Slope Height (m)</th>
<th>Zone 1</th>
<th>Zone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>35</td>
<td>0.8 H</td>
<td>Type I 10</td>
<td>8.0</td>
<td>8.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type II 15</td>
<td>8.0</td>
<td>5.4</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type III 20</td>
<td>8.0</td>
<td>8.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

NOTE: SECONDARY REINFORCEMENT SHALL HAVE A MINIMUM LONG TERM STRENGTH OF 6 kN/m².
Challenges of Simplified Design

- Assessment of on-site materials.
- Assessment of Global Stability.
- Accountability that the work was performed as designed. Needs oversight by designer or designee.
- Evaluating the appropriateness of the proposed repairs.
Developing Soil Strengths

**Table 5.5—Reported values of \( \phi \), \( C'_v \), and \( \gamma_s \) for silts, sands, and gravels**

<table>
<thead>
<tr>
<th>USC</th>
<th>% Dc</th>
<th>( \gamma_s ), psi</th>
<th>( C'_v ), psi</th>
<th>( \phi ), deg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW loose</td>
<td>0–35</td>
<td>*</td>
<td>0</td>
<td>35–38</td>
</tr>
<tr>
<td></td>
<td>118–128</td>
<td>0</td>
<td>28–33.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>99–111</td>
<td>0</td>
<td>36.3–39.3</td>
<td></td>
</tr>
<tr>
<td>GW medium-dense</td>
<td>35–65</td>
<td>*</td>
<td>0</td>
<td>38–41</td>
</tr>
<tr>
<td></td>
<td>128–135</td>
<td>0</td>
<td>33.5–38.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>127</td>
<td>0</td>
<td>38.4–39</td>
<td></td>
</tr>
<tr>
<td>GW dense to very dense</td>
<td>65–100</td>
<td>*</td>
<td>0</td>
<td>41–45</td>
</tr>
<tr>
<td></td>
<td>135–145</td>
<td>0</td>
<td>38.5–45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>125–135</td>
<td>0</td>
<td>&gt; 38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>119.5–137</td>
<td>0</td>
<td>39–46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>123–125.4</td>
<td>790–1140</td>
<td>38.0–41.4</td>
</tr>
<tr>
<td>GP loose</td>
<td>0–35</td>
<td>*</td>
<td>0</td>
<td>33–36</td>
</tr>
<tr>
<td></td>
<td>108–118</td>
<td>0</td>
<td>27.5–32.5</td>
<td></td>
</tr>
<tr>
<td>GP medium-dense</td>
<td>35–65</td>
<td>*</td>
<td>0</td>
<td>36–39</td>
</tr>
<tr>
<td></td>
<td>118–124</td>
<td>0</td>
<td>32.6–37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>117–122</td>
<td>288–432</td>
<td>38.7–40.4</td>
<td></td>
</tr>
<tr>
<td>GP dense to very dense</td>
<td>65–100</td>
<td>*</td>
<td>0</td>
<td>39–43</td>
</tr>
<tr>
<td></td>
<td>124–134</td>
<td>0</td>
<td>37–42.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>115–125</td>
<td>0</td>
<td>&gt; 37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>111–124</td>
<td>0</td>
<td>38–42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>126.5</td>
<td>432</td>
<td>40.4</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>129.1</td>
<td>432</td>
<td>44.4</td>
</tr>
<tr>
<td>GM loose</td>
<td>0–35</td>
<td>*</td>
<td>0</td>
<td>33–36</td>
</tr>
<tr>
<td></td>
<td>114</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>51.5–91</td>
<td>104–200</td>
<td>33.6–43</td>
</tr>
<tr>
<td>Soil Type</td>
<td>USCS Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>SW-SP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>SC-SM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loam</td>
<td>SC-SM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt loam</td>
<td>ML</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay loam</td>
<td>CL-ML</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>CL-CH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Global Stability Issues

A) SLIDING INSTABILITY  

B) DEEP SEATED OVERALL INSTABILITY

C) LOCAL BEARING CAPACITY (LATERAL SQUEEZE) FAILURE

D) EXCESSIVE SETTLEMENT
Summary

► Erosion Control Systems
  - Training.
  - Easy access to available information.

► Soft Subgrade Reinforcement and Separation
  - Training.
  - Easy access to available information.
Summary

► Subsurface Drainage
  ▪ Training.
  ▪ Easy access to available information.
  ▪ Simplified design guidelines.

► Reinforced Slopes
  ▪ Training.
  ▪ Easy access to available information.
  ▪ Simplified design guidelines.
QUESTIONS?