Geosynthetic Engineering: Geosynthetic Protectors

Course No: G06-003
Credit: 6 PDH

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16. ABSTRACT  
This manual is an updated version of the Geotextile Design & Construction Guidelines, used for the FHWA training course Geosynthetic Engineering Workshop. The update was performed to reflect current practices and codes for geotextile design, and has been expanded to address geogrid and geomembrane materials. The manual was prepared to enable the Highway Engineer to correctly identify and evaluate potential applications of geosynthetics as an alternative to other construction methods and as a means to solve construction problems. With the aid of this text, the Highway Engineer should be able to properly design, select, test, specify, and construct with geotextiles, geocomposite drains, geogrids and related materials in drainage, sediment control, erosion control, roadway, and embankment on soft soils applications. Steepened slope and retaining wall applications also are addressed, but designers are referred to the FHWA Demonstration Project No. 82 references on mechanically stabilized earth structures for details on design. Application of geomembranes and other barrier materials to highway works are summarized within. This manual is directed toward geotechnical, hydraulic, roadway, bridge and structures, and route layout highway engineers.  
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3.0 GEOTEXTILES IN RIPRAP REVETMENTS AND OTHER PERMANENT EROSION CONTROL SYSTEMS

3.1 BACKGROUND

As in drainage systems, geotextiles can effectively replace graded granular filters typically used beneath riprap or other hard armor materials in revetments and other erosion control systems designed to keep soil in place. This was one of the first applications of woven monofilament geotextiles in the United States; rather extensive use started in the early 1960s. Numerous case histories have shown geotextiles to be very effective compared to riprap-only systems and equally effective as conventional graded granular filters in preventing fines from migrating through the armor system, while providing a cost savings.

Since the early developments in coastal and lake shoreline erosion control, the same design concepts and construction procedures have subsequently been applied to stream bank protection (see HEC 11, FHWA, 1989), cut and fill slope protection, protection of various small drainage structures (see HEC 14, FHWA, 1983) and ditches (see HEC 15, FHWA, 1988), wave protection for causeway and shoreline roadway embankments, and scour protection for structures such as bridge piers and abutments (see HEC 18, FHWA, 1995, and HEC 23, FHWA, 1997). Design guidelines and construction procedures for these and other similar permanent erosion control applications are presented in sections 3.3 through 3.10. Hydraulic design considerations can be found in the AASHTO Model Drainage Manual (1991) and the above FHWA Hydraulic Engineering Circulars. Also note that, at the time of printing of this manual, a new FHWA course and text entitled Identifying and Controlling Erosion and Sedimentation was under development.

Erosion control mats are another type of geosynthetic used in permanent erosion control systems. They are also referred to as a Rolled Erosion Control Product (RECP). These three-dimensional mats retain soil and moisture, thus promoting vegetation growth. Vegetation roots grow through and are reinforced by the mat. The reinforced grass system is capable of withstanding short-term (e.g., 2 hours), high velocity (e.g., 6 m/s) flows with minimal erosion. Erosion control mats are addressed in section 3.11. Sediment control and temporary erosion control designed to keep soil within a prescribed boundary, including the use of geotextiles as silt fences, erosion control blankets, and other geosynthetics, are covered in Chapter 4.
3.2 APPLICATIONS

- Riprap-geotextile systems have found successful application in protecting precipitation runoff collection and high-velocity diversion ditches.

- Geotextiles may be used in slope protection to prevent or reduce erosion from precipitation, surface runoff, and internal seepage or piping. In this instance, the geotextile may replace one or more layers of granular filter materials which would be placed on the slope in conventional applications.

- Erosion control systems with geotextiles may also be required along streambanks to prevent encroachment of roadways or appurtenant facilities.

- Similarly, they may be used for scour protection around structures.
• A riprap-geotextile system can also be effective in reducing erosion caused by wave attack or tidal variations when facilities are constructed across or adjacent to large bodies of water.

• Finally, hydraulic structures such as culverts, drop inlets, and artificial stream channels may require protection from erosion. In such applications, if vegetation cannot be established or the natural soil is highly erodible, a geotextile can be used beneath armor materials to increase erosion resistance.

In several of the above applications, placement of the filter layer may be required below water. In these cases, in comparison with conventional granular filter layers, geotextiles provide easier placement and continuity of the filter medium is assured.

• Geosynthetic erosion control *mats* are made of synthetic meshes and webbings and reinforce the vegetation root mass to provide tractive resistance to high water velocity on slopes and in ditches. These three-dimensional mats retain soil, moisture, and seed, and thus promote vegetative growth.
3.3 DESIGN OF GEOTEXTILES BENEATH HARD ARMOR

Geotextile design for hard armor erosion control systems is essentially the same as geotextile design for filters in subsurface drainage systems discussed in Section 2.3. Table 3-1 reiterates the design criteria and highlights special considerations for geotextiles beneath hard armor erosion control systems. The following is a discussion of these special considerations.

3.3-1 Retention Criteria for Cyclic or Dynamic Flow

In cyclic or dynamic flow conditions, soil particles may be able to move behind the geotextile if it is not properly weighted down. Thus, the coefficient $B = 1$ may not be conservative, as the bridging network (Figure 2-2) may not develop and the geotextile may be required to retain even the finer particles of soil. If there is a risk that uplift of the armor system can occur, it is recommended that the $B$ value be reduced to 0.5 or less; that is, the largest hole in the geotextile should be small enough to retain the smaller particles of soil.

In absence of detailed design, the AASHTO M 288 Standard Specification for Geotextiles (1997) provides the following recommended maximum AOS values in relation to percent of situ soil passing the 0.075 mm sieve: (i) 0.43 mm for less than 15% passing; (ii) 0.25 mm for 15 to 50% passing; and (iii) 0.22 mm for more than 50% passing. However, for cohesive soils with a plasticity index greater than 7, the maximum AOS size is 0.30 mm. These default AOS values are based upon the predominant particle sizes of the in situ soil. The engineer may require performance testing based on engineering design for erosion control systems in problematic soil environments. Site specific testing should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as non-cohesive silts; gap graded soils; alternating sand/silt laminated soils; dispersive clays; and/or rock flour.

In many erosion control applications it is common to have high hydraulic stresses induced by wave or tidal action. The geotextile may be loose when it spans between large armor stone or large joints in block-type armor systems. For these conditions, it is recommended that an intermediate layer of finer stone or gravel be placed over the geotextile and that riprap of sufficient weight be placed to prevent wave action from moving either stone or geotextile. For all applications where the geotextile can move, and when it is used as sandbags, it is recommended that samples of the site soils be washed through the geotextile to determine its particle-retention capabilities.

3.3-2 Permeability and Effective Flow Capacity Requirements for Erosion Control

In certain erosion control systems, portions of the geotextile may be covered by the armor stone or concrete block revetment systems, or the geotextile may be used to span joints in sheet pile bulkheads. For such systems, it is especially important to evaluate the flow rate required through...
TABLE 3-1
SUMMARY OF GEOTEXTILE DESIGN AND SELECTION CRITERIA FOR HARD ARMOR EROSION CONTROL APPLICATIONS

I. SOIL RETENTION (PIPING RESISTANCE CRITERIA)\(^1\)

<table>
<thead>
<tr>
<th>Soils</th>
<th>Steady State Flow</th>
<th>Dynamic, Pulsating and Cyclic Flow (if geotextile can move)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50% Passing(^2) 0.075 mm</td>
<td>AOS or (0_{95} \leq B D_{85})</td>
<td></td>
</tr>
<tr>
<td>(C_a \leq 2) or (\geq 8):</td>
<td>(B = 1)</td>
<td></td>
</tr>
<tr>
<td>(2 \leq C_a \leq 4):</td>
<td>(B = 0.5 C_a)</td>
<td>(0_{95} \leq 0.5 D_{85})</td>
</tr>
<tr>
<td>(4 \leq C_a \leq 8):</td>
<td>(B = 8/C_a)</td>
<td></td>
</tr>
<tr>
<td>(\geq 50%) Passing 0.075 mm</td>
<td>Woven: (0_{95} \leq D_{85})</td>
<td>(0_{95} \leq 0.5 D_{85})</td>
</tr>
<tr>
<td>Nonwoven: (0_{95} \leq 1.8 D_{85})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For cohesive soils (PI > 7) \(0_{95}\) (geotextile) \(\leq 0.3\) mm

II. PERMEABILITY/PERMITTIVITY CRITERIA\(^3\)

A. Critical/Severe Applications
   \(k_{\text{geotextile}} \geq 10 k_{\text{soil}}\)

B. Less Critical/Less Severe Applications (with Clean Medium to Coarse Sands and Gravels)
   \(k_{\text{geotextile}} \geq k_{\text{soil}}\)

C. Permittivity Requirement
   \(\psi \geq 0.7\) sec\(^{-1}\) for \(< 15\%\) passing 0.075 mm
   \(\psi \geq 0.2\) sec\(^{-1}\) for 15 to 50\% passing 0.075 mm
   \(\psi \geq 0.1\) sec\(^{-1}\) for \(> 50\%\) passing 0.075 mm

III. CLOGGING CRITERIA

A. Critical/Severe Applications\(^4\)

B. Less Critical/Less Severe Applications
   1. Perform soil/geotextile filtration tests.
   2. Alternative: \(0_{95} > 3 D_{15}\) for \(C_a > 3\)
   3. For \(C_a \leq 3\), specify geotextile with maximum opening size possible from retention criteria
   4. Apparent Open Area Qualifiers
      For soils with % passing 0.075 mm
      \[
      \begin{array}{c|c|c}
      \hline
      \% & > 5\% & < 5\% \\
      \hline
      \text{Woven monofilament geotextiles: Percent Open Area} & 4\% & 10\% \\
      \text{Nonwoven geotextiles: Porosity} & 50\% & 70\% \\
      \hline
      \end{array}
      \]

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IV. SURVIVABILITY REQUIREMENTS

GEOTEXTILE STRENGTH PROPERTY REQUIREMENTS\(^1,2,3,4\)
FOR PERMANENT EROSION CONTROL GEOTEXTILES
(after AASHTO, 1997)

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Test Method</th>
<th>Units</th>
<th>Geotextile Class 1(^5,6)</th>
<th>Geotextile Class 2(^5,6,7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elongation(^b) (&lt; 50%)</td>
<td>Elongation(^b) (\geq 50%)</td>
</tr>
<tr>
<td>Grab Strength</td>
<td>D 4632</td>
<td>N</td>
<td>1400</td>
<td>900</td>
</tr>
<tr>
<td>Sewn Seam Strength(^6)</td>
<td>D 4632</td>
<td>N</td>
<td>1260</td>
<td>810</td>
</tr>
<tr>
<td>Tear Strength</td>
<td>D 4533</td>
<td>N</td>
<td>500</td>
<td>350</td>
</tr>
<tr>
<td>Puncture Strength</td>
<td>D 4833</td>
<td>N</td>
<td>500</td>
<td>350</td>
</tr>
<tr>
<td>Burst Strength</td>
<td>D 3786</td>
<td>kPa</td>
<td>3500</td>
<td>1700</td>
</tr>
<tr>
<td>Ultraviolet Stability</td>
<td>D 4355</td>
<td>%</td>
<td>50% strength retained after 500 hours of exposure</td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer’s certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. Minimum; use value in weaker principal direction. All numerical values represent minimum average roll value (i.e., test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Woven slit film geotextiles will not be allowed.
5. Use Class 2 for woven monofilament geotextiles, and Class 1 for all other geotextiles.
6. As a general guideline, the default geotextile selection is appropriate for conditions of equal or less severity than either of the following:
   a) Armor layer stone weights do not exceed 100 kg, stone drop is less than 1 m, and no aggregate bedding layer is required.
   b) Armor layer stone weights exceed 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150 mm thick aggregate bedding layer designed to be compatible with the armor layer. More severe applications require an assessment of geotextile survivability based on a field trial section and may require a geotextile with higher strength properties.
7. The engineer may specify a Class 2 geotextile based on one or more of the following:
   a) The engineer has found Class 2 geotextiles to have sufficient survivability based on field experience.
   b) The engineer has found Class 2 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
   c) Armor layer stone weighs less than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150 mm thick aggregate bedding layer designed to be compatible with the armor layer.
   d) Armor layer stone weights do not exceed 100 kg, stone is placed with a zero drop height.
8. As measured in accordance with ASTM D 4632.
9. When seams are required. Values apply to both field and manufactured seams.
10. The required MARV tear strength for woven monofilament geotextiles is 250 N.
the open portion of the system and select a geotextile that meets those flow requirements. Again, since flow is restricted through the geotextile, the required flow capacity is based on the flow capacity of the area available for flow; or

\[ q_{\text{required}} = q_{\text{geotextile}} \left( \frac{A_g}{A_t} \right) \quad \text{(Eq. 2 - 9)} \]

where: \( A_g \) = geotextile area available for flow, and \( A_t \) = total geotextile area.

The AASHTO M 288 Standard Specification for Geotextiles (1997) presents recommended minimum permittivity values in relation to percent of situ soil passing the 0.075 mm sieve. The values are the same as presented in Table 3-1. The default permittivity values are based upon the predominant particle sizes of the in situ soil. Again, the engineer may require performance testing based on engineering design for drainage systems in problematic soil environments.

### 3.3-3 Clogging Resistance for Cyclic or Dynamic Flow

Since erosion control systems are often used on highly erodible soils with reversing and cyclic flow conditions, severe hydraulic conditions often exist. Accordingly, designs should reflect these conditions, and soil-geotextile filtration tests should always be conducted. Since these tests are performance-type tests and require project site soil samples, they must be conducted by the owner or an owner representative and not by the geotextile manufacturers or suppliers. For sandy and silty soils (\( k \geq 10^{-7} \) m/s) the long-term, gradient ratio test (ASTM D 5101) is recommended as described in Chapter 1. For fine-grained soils, the hydraulic conductivity ratio (HCR) test (ASTM D 5567) should be considered with the modifications and caveats recommended in Chapter 1. Other filtration tests, some of which are appropriate for finer soils, are described by Christopher and Holtz (1985) and Koerner (1990), among others.

### 3.3-4 Survivability Criteria for Erosion Control

Because the construction procedures for erosion control systems are different than those for drainage systems, the geotextile property requirements for survivability in Table 3-1 differ somewhat from those discussed in Section 2.3-4. As placement of armor stone is generally more severe than placement of drainage aggregate, required property values are higher for each category of geotextile.

Riprap or armor stone should be large enough to withstand wave action and thus not abrade the geotextile. The specific site conditions should be reviewed, and if such movement cannot be avoided, then an abrasion requirement based on ASTM D 4886 (modified flex stoll) should be included in the specifications. Allowable physical property reduction due to abrasion should be specified. No reduction in piping resistance, permeability, or clogging resistance should be allowed after exposure to abrasion.
It is important to realize that these minimum survivability values are not based on any systematic research but on the properties of existing geotextiles which are known to have performed satisfactorily in hard armor erosion control applications. The values are meant to serve as guidelines for inexperienced users in selecting geotextiles for routine projects. They are not intended to replace site-specific evaluation, testing, and design.

3.4 GEOTEXTILE DESIGN GUIDELINES

STEP 1. Application evaluation.

A. Critical/less critical
   1. If the erosion control system fails, will there be a risk of loss of life?
   2. Does the erosion control system protect a significant structure, and will failure lead to significant structural damage?
   3. If the geotextile clogs, will failure occur with no warning? Will failure be catastrophic?
   4. If the erosion control system fails, will the repair costs greatly exceed installation costs?

B. Severe/less severe
   1. Are soils to be protected gap-graded, pipable, or dispersive?
   2. Are soils present which consist primarily of silts and uniform sands with 85% passing the 0.15 mm sieve?
   3. Will the erosion control system be subjected to reversing or cyclic flow conditions such as wave action or tidal variations?
   4. Will high hydraulic gradients exist in the soils to be protected? Will rapid drawdown conditions or seeps or weeps in the soil exist? Will blockage of seeps and weeps produce high hydraulic pressures?
   5. Will high-velocity conditions exist, such as in stream channels?

NOTE: If the answer is yes to any of the above questions, the design should proceed under the critical/severe requirements; otherwise use the less critical/less severe design approach.

STEP 2. Obtain soil samples from the site.

A. Perform grain size analyses
   1. Determine percent passing the 0.075 mm sieve.
2. Determine the plastic index (PI).
3. Calculate $C_u = D_{60}/D_{10}$.

NOTE: When the protected soil contains particles passing the 0.075 mm sieve, use only the gradation of soil passing the 4.75 mm sieve in selecting the geotextile (i.e., scalp off the +4.75 mm material).

4. Obtain $D_{85}$ for each soil and select the worst case soil (i.e., soil with smallest $B \times D_{85}$) for retention.

B. Perform field or laboratory permeability tests
1. Select worse case soil (i.e., soil with highest coefficient of permeability $k$).

NOTE: The permeability of clean sands (<5% passing 0.075 mm sieve) with $D_{10} < 3$ mm and $C_u < 5$ can be estimated by Hazen's formula, $k = (D_{10})^2 (k$ in cm/s; $D_{10}$ in mm). This formula should not be used for finer-grained soils.

STEP 3. Evaluate armor material and placement.

A. Size armor stone or riprap
Where minimum size of stone exceeds 100 mm, or greater than a 100 mm gap exists between blocks, an intermediate gravel layer 150 mm thick should be used between the armor stone and geotextile. Gravel should be sized such that it will not wash through the armor stone (i.e., $D_{85}$ gravel $\geq D_{15}$ riprap/5).

B. Determine armor stone placement technique (i.e., maximum height of drop).

STEP 4. Calculate anticipated reverse flow through erosion control system.
Here we need to estimate the maximum flow from seeps and weeps, maximum flow from wave runout, or maximum flow from rapid drawdown.

A. General case -- use Darcy's law
$$q = kiA$$  
(Eq. 2 - 15)
where:
- $q$ = outflow rate ($L^3/T$)
- $k$ = effective permeability of soil (from Step 2B above) ($L/T$)
- $i$ = average hydraulic gradient in soil (e.g., tangent of slope angle for wave runoff)(dimensionless)
A = area of soil and drain material normal to the direction of flow ($L^2$). Can be evaluated using a unit area.

Use a conventional flow net analysis (Cedergren, 1977) for seepage through dikes and dams or from a rapid drawdown analysis.

B. Specific erosion control systems -- Hydraulic characteristics depend on expected precipitation, runoff volumes and flow rates, stream flow volumes and water level fluctuations, normal and maximum wave heights anticipated, direction of waves and tidal variations. Detailed information on determination of these parameters is available in the FHWA (1989) Hydraulic Engineering Circular No. 11.

STEP 5. Determine geotextile requirements.

A. Retention Criteria

From Step 2A, obtain $D_{s5}$ and $C_u$; then determine largest pore size allowed.

$$AOS \text{ or } O_{95(geotextile)} < B \cdot D_{s5(soil)}$$  \hspace{1cm} (Eq. 2 - 1)

where: $B = 1$ for a conservative design.

For a less-conservative design and for $\leq 50\%$ passing 0.075 mm sieve:

- $B = 1$ \hspace{1cm} for \hspace{0.5cm} $C_u \leq 2 \text{ or } \geq 8$  \hspace{1cm} (Eq. 2 - 2a)
- $B = 0.5 \cdot C_u$ \hspace{1cm} for \hspace{0.5cm} $2 \leq C_u \leq 4$  \hspace{1cm} (Eq. 2 - 2b)
- $B = 8/C_u$ \hspace{1cm} for \hspace{0.5cm} $4 < C_u < 8$  \hspace{1cm} (Eq. 2 - 2c)

For $\geq 50\%$ passing 0.075 mm sieve:

- $B = 1$ \hspace{1cm} for wovens
- $B = 1.8$ \hspace{1cm} for nonwovens

and $AOS \text{ or } O_{95(geotextile)} \leq 0.3 \text{ mm}$  \hspace{1cm} (Eq. 2 - 5)

For nondispersive cohesive soils ($PI > 7$) use:

$AOS \text{ or } O_{95} \leq 0.3 \text{ mm}$

If geotextile and soil retained by it can move:

$B = 0.5$

B. Permeability/Permittivity Criteria

1. Less Critical/Less Severe

$$k_{geotextile} \geq k_{soil}$$ \hspace{1cm} (Eq. 2 - 7a)
2. Critical/Severe
\[ k_{\text{geotextile}} \geq 10 k_{\text{soil}} \] (Eq. 2 - 8a)

3. Permittivity \( \psi \) Requirement
\[ \psi \geq 0.7 \text{ sec}^{-1} \quad \text{for } < 15\% \text{ passing } 0.075 \text{ mm} \] [3 - 1a]
\[ \psi \geq 0.2 \text{ sec}^{-1} \quad \text{for } 15 \text{ to } 50\% \text{ passing } 0.075 \text{ mm} \] [3 - 1b]
\[ \psi \geq 0.1 \text{ sec}^{-1} \quad \text{for } > 50\% \text{ passing } 0.075 \text{ mm} \] [3 - 1c]

4. Flow Capacity Requirement
\[ q_{\text{geotextile}} \geq (A_g/A_t) \cdot q_{\text{required}} \] (from Eq. 2 - 9)
or
\[ (k_{\text{geotextile}}/t) \cdot h \cdot A_g \geq q_{\text{required}} \]

where: \( q_{\text{required}} \) is obtained from Step 4 (Eq. 15) above.
\[ k_{\text{geotextile}}/t = \psi = \text{permittivity} \]
\[ h = \text{average head in field} \]
\[ A_g = \text{area of fabric available for flow (e.g., if 50\% of geotextile}
\[ \text{covered by flat rocks or riprap, } A_g = 0.5 \text{ total area)} \]
\[ A_t = \text{total area of geotextile} \]

C. Clogging Criteria
1. Less critical/less severe
   a. Perform soil-geotextile filtration tests.
   b. Alternative: From Step 2A obtain \( D_{15} \); then determine minimum pore size requirement, for soils with \( C_u > 3 \), from
\[ O_{95} \geq 3 \cdot D_{15} \] (Eq. 2 - 10)
c. Other qualifiers
   For soils with \% passing 0.075 mm
   \[ > 5\% \quad < 5\% \]
   Woven monofilament geotextiles: Percent Open Area \[ \geq 4\% \quad 10\% \]
   Nonwoven geotextiles: Porosity \[ \geq 50\% \quad 70\% \]

2. Critical/severe
Select geotextiles that meet retention, permeability, and survivability criteria; as well as the criteria in Step 5C.1 above; perform a filtration test.

Suggested filtration test for sandy and silty soils \((i.e., k > 10^{-7} \text{ m/s})\) is the gradient ratio test as described in Chapter 1. The hydraulic conductivity ratio test (see Chapter 1) is recommended for fine-grained soils \((i.e., k < 10^{-7} \text{ m/s})\), if appropriately modified.
D. Survivability
Select geotextile properties required for survivability from Table 3-1. Add durability requirements if applicable. Don’t forget to check for abrasion and check drop height. Evaluate worst case scenario for drop height.

STEP 6. Estimate costs.
Calculate the volume of armor stone, the volume of aggregate and the area of the geotextile. Apply appropriate unit cost values.

Grading and site preparation (LS) ________________
Geotextile (/m²) ________________
Geotextile placement (/m²) ________________
In-place aggregate bedding layer (/m²) ________________
Armor stone (/kg) ________________
Armor stone placement (/kg) ________________
Total cost ________________

STEP 7. Prepare specifications.
Include for the geotextile:
A. General requirements
B. Specific geotextile properties
C. Seams and overlaps
D. Placement procedures
E. Repairs
F. Testing and placement observation requirements
   See Sections 1.6 and 3.7 for specification details.

STEP 8. Obtain samples of the geotextile before acceptance.

STEP 9. Monitor installation during construction, and control drop height. Observe erosion control systems during and after significant storm events.
3.5 GEOTEXTILE DESIGN EXAMPLE

DEFINITION OF DESIGN EXAMPLE

- Project Description: Riprap on slope is required to permit groundwater seepage out of slope face, without erosion of slope. See figure for project cross section.
- Type of Structure: small stone riprap slope protection
- Type of Application: geotextile filter beneath riprap
- Alternatives: i) graded soil filter; or ii) geotextile filter between embankment and riprap

GIVEN DATA

- see cross section
- riprap is to allow unimpeded seepage out of slope
- riprap will consist of small stone (50 to 300 mm)
- stone will be placed by dropping from a backhoe
- seeps have been observed in the existing slope
- soil beneath the proposed riprap is a fine silty sand
- gradations of two representative soil samples

---

![Project Cross Section](image_url)

*Erosion Control Systems*
### Sieve Size Distribution

<table>
<thead>
<tr>
<th>SIEVE SIZE (mm)</th>
<th>PERCENT PASSING, BY WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample A</td>
</tr>
<tr>
<td>4.75</td>
<td>100</td>
</tr>
<tr>
<td>1.68</td>
<td>96</td>
</tr>
<tr>
<td>0.84</td>
<td>92</td>
</tr>
<tr>
<td>0.42</td>
<td>85</td>
</tr>
<tr>
<td>0.15</td>
<td>43</td>
</tr>
<tr>
<td>0.075</td>
<td>25</td>
</tr>
<tr>
<td>0.037</td>
<td>3</td>
</tr>
</tbody>
</table>

### Grain Size Distribution Curve

**Grain Size Distribution Curve**

DEFINITE

A. Geotextile function(s)

B. Geotextile properties required

C. Geotextile specification
SOLUTION

A. Geotextile function(s):
   Primary  - filtration
   Secondary - separation

B. Geotextile properties required:
   apparent opening size (AOS)
   permittivity
   survivability

DESIGN

STEP 1. EVALUATE CRITICAL NATURE AND SITE CONDITIONS.

From given data, this is a critical application due to potential for loss of life and potential for significant structural damage.
Soils are well-graded, hydraulic gradient is low for this type of application, and flow conditions are steady state.

STEP 2. OBTAIN SOIL SAMPLES.

A. GRAIN SIZE ANALYSES
   Plot gradations of representative soils. The $D_{40}$, $D_{10}$, and $D_{85}$ sizes from the gradation plot are noted in the table below for Samples A and B.

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>$D_{40} + D_{10} = C_u$</th>
<th>$B = \frac{8}{C_u} = \frac{8 + 4.4}{4.4} = 1.82$</th>
<th>$B \times D_{85} &gt; AOS$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.20 + 0.045 = 4.4</td>
<td>1.82 x 0.44 = 0.8</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.30 + 0.06 = 5</td>
<td>1.6 x 0.54 = 0.86</td>
<td></td>
</tr>
</tbody>
</table>

Worst case soil for retention is Soil A, with $D_{85}$ equal to 0.44 mm.

B. PERMEABILITY TESTS
   This is a critical application and soil permeability tests should be conducted. An estimated permeability will be used for preliminary design purposes.

STEP 3. EVALUATE ARMOR MATERIAL AND PLACEMENT.

A. Small stone (50 to 300 mm) riprap will be used.

B. A placement drop of less than 1 m will be specified.

STEP 4. CALCULATE ANTICIPATED FLOW THROUGH SYSTEM.
   Flow computations are not included within this example. The entire height of the slope face will be protected, to add to conservatism of design.
STEP 5. DETERMINE GEOTEXTILE REQUIREMENTS.

A. RETENTION

\[ AOS < B D_{50} \]  \hspace{1cm} (Eq. 2 - 1)

Determine uniformity coefficient, \( C_u \), coefficient \( B \), and the maximum AOS. Sample A controls (see table above), therefore, \[ AOS \leq 0.8 \text{ mm} \]

B. PERMEABILITY/PERMITTIVITY

This is a critical application, therefore, \[ k_{\text{geotextile}} \geq 10 \times k_{\text{soil}} \]

Estimate permeability (after Hazen’s formula, which is for clean sands), for preliminary design, \[ k = (D_{10})^2 \]

where: \( k \) = approximate soil permeability (cm/sec); and \( D_{10} \) is in mm.

\[ k_{\text{soil}} = 2.0 \times 10^{-3} \text{ cm/sec for Sample A} \]
\[ 3.6 \times 10^{-3} \text{ cm/sec for Sample B} \]

Therefore (with rounding the number), \[ k_{\text{geotextile}} \geq 4 \times 10^{-2} \text{ cm/sec} \]

Since 15\% to 25\% of the soil to be protected is finer than 0.075 mm, from Table 3-1: \[ \Psi_{\text{geotextile}} \geq 0.2 \text{ sec}^{-1} \]

C. CLOGGING

As the project is critical, a filtration test is recommended to evaluate clogging potential. Select geotextile(s) meeting retention, permeability, survivability criteria, and the following qualifiers. Run filtration test (e.g., gradient ratio) and prequalify materials or test representative materials to confirm compatibility.

Minimum Opening Size Qualifier (for \( C_u > 3 \)): \[ O_{95} \geq 3 \times D_{15} \]

\[ O_{95} \geq 3 \times 0.057 = 0.17 \text{ mm for Sample A} \]
\[ 3 \times 0.079 = 0.24 \text{ mm for Sample B} \]

Sample A controls, therefore, \[ O_{95} \geq 0.17 \text{ mm} \]

Other Qualifiers, since greater than 5\% of the soil to be protected is finer than 0.075 mm, from Table 3-1:

<table>
<thead>
<tr>
<th>Qualifier</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>POA (Percent Open Area)</td>
<td>&gt; 4%</td>
</tr>
</tbody>
</table>

D. SURVIVABILITY

A Class 1 geotextile will be specified because this a critical application. Effect on project cost is minor. Therefore, from Table 3-1, the following minimum values will be specified:

<table>
<thead>
<tr>
<th>Property</th>
<th>&lt;50% Elongation</th>
<th>&gt;50% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grab Strength</td>
<td>1400 N</td>
<td>900 N</td>
</tr>
<tr>
<td>Sewn Seam Strength</td>
<td>1260 N</td>
<td>810 N</td>
</tr>
<tr>
<td>Tear Strength</td>
<td>500 N</td>
<td>350 N</td>
</tr>
<tr>
<td>Puncture Strength</td>
<td>500 N</td>
<td>350 N</td>
</tr>
<tr>
<td>Burst Strength</td>
<td>3500 N</td>
<td>1700 N</td>
</tr>
<tr>
<td>Ultraviolet Degradation</td>
<td>50 % strength retained at 500 hours</td>
<td></td>
</tr>
</tbody>
</table>
Complete Steps 6 through 9 to finish design.

STEP 6. ESTIMATE COSTS.

STEP 7. PREPARE SPECIFICATIONS.

STEP 8. COLLECT SAMPLES.

STEP 9. MONITOR INSTALLATION, AND DURING & AFTER STORM EVENTS.

3.6 GEOTEXTILE COST CONSIDERATIONS

The total cost of a riprap-geotextile revetment system will depend on the actual application and type of revetment selected. The following items should be considered:

1. grading and site preparation;
2. cost of geotextile, including cost of overlapping and pins versus cost of sewn seams;
3. cost of placing geotextile, including special considerations for below-water placement;
4. bedding materials, if required, including placement;
5. armor stone, concrete blocks, sand bags, etc.; and
6. placement of armor stone (dropped versus hand- or machine-placed).

For Item No. 2, cost of overlapping includes the extra material required for the overlap, cost of pins, and labor considerations versus the cost of field and/or factory seaming, plus the additional cost of laboratory seam testing. These costs can be obtained from manufacturers, but typical costs of a sewn seam are equivalent to 1 to 1.5 m² of geotextile. Alternatively, the contractor can be required to supply the cost on an area covered or in-place basis. For example, current U.S. Army Corps of Engineers Specifications CW-02215 (1977) require measurement for payment for geotextiles in streambank and slope protection to be on an in-place basis without allowance for any material in laps and seams. Further, the unit price includes furnishing all plant, labor, material, equipment, securing pins, etc., and performing all operations in connection with placement of the geotextile, including prior preparation of banks and slopes. Of course, field performance should also be considered, and sewn seams are generally preferred to overlaps.

Items 2, 4, and 6 can be compared with respect to using Moderate Survivability versus High Survivability (Table 3-1, Section IV) geotextiles based on the cost of bedding materials and placement of armor stone.

To determine cost effectiveness, benefit-cost ratios should be compared for the riprap-geotextile system versus conventional riprap-granular filter systems or other available alternatives of equal
technical feasibility and operational practicality. Average cost of geotextile protection systems placed above the water level, including slope preparation, geotextile cost of seaming or securing pins, and placement is approximately $3.00-6.00 per square meter, excluding the armor stone. Cost of placement below water level can vary considerably depending on the site conditions and the contractor's experience. For below-water placement, it is recommended that prebid meetings be held with potential contractors to explore ideas for placement and discuss anticipated costs.

3.7 GEOTEXTILE SPECIFICATIONS

In addition to the general recommendations concerning specifications in Chapter 1, erosion control specifications must include construction details (see Section 3.8), as the appropriate geotextile will depend on the placement technique. In addition, the specifications should require the contractor to demonstrate through trial sections that the proposed riprap placement technique will not damage the geotextile.

Many erosion control projects may be better-served by performance-type filtration tests that provide an indication of long-term performance. Thus, in many cases, approved list-type specifications, as discussed in Section 1.6, may be appropriate. To develop the list of approved geotextiles, filtration studies (as suggested in Section 3.4, Step 4) should be performed using problem soils and conditions that exist in the localities where geotextiles will be used. An approved list for each condition should be established. In addition, geotextiles should be classified as High or Moderate Survivability geotextiles, in accordance with the index properties listed in Table 3-1 and construction conditions.

The following example specification is a combination of the AASHTO M288 (1997) geotextile material specification and its accompanying construction/installation guidelines. It includes the requirements discussed in Section 1.6 for a good specification. As with the specification presented in Chapter 2, site-specific hydraulic and physical properties must be appropriately selected and included.

EROSION CONTROL GEOTEXTILE SPECIFICATION
(after AASHTO M288, 1997)

1. SCOPE

1.1 Description. This specification is applicable to the use of a geotextile between energy absorbing armor systems and the in situ soil to prevent soil loss resulting in excessive scour and to prevent hydraulic uplift pressure causing instability of the permanent erosion control system. This specification does not apply to other types of geosynthetic soil erosion control materials such as turf reinforcement mats.
2. REFERENCED DOCUMENTS

2.1 AASHTO Standards

T88  Particle Size Analysis of Soils
T90  Determining the Plastic Limit and Plasticity Index of Soils
T99  The Moisture-Density Relationships of Soils Using a 2.5 kg Rammer and a 305 mm Drop

2.2 ASTM Standards

D 123  Standard Terminology Relating to Textiles
D 276  Test Methods for Identification of Fibers in Textiles
D 3786 Test Method for Hydraulic Burst Strength of Knitted Goods and Nonwoven Fabrics, Diaphragm Bursting Strength Tester Method
D 4354 Practice for Sampling of Geosynthetics for Testing
D 4355 Test Method for Determination of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon Arc Type Apparatus)
D 4439 Terminology for Geosynthetics
D 4491 Test Methods for Water Permeability of Geotextiles by Permittivity
D 4632 Test Method for Grab Breaking Load and Elongation of Geotextiles
D 4751 Test Method for Determining Apparent Opening Size of a Geotextile
D 4759 Practice for Determining the Specification Conformance of Geosynthetics
D 4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 4873 Guide for Identification, Storage, and Handling of Geotextiles
D 5141 Test Method to Determine Filtering Efficiency and Flow Rate for Silt Fence Applications Using Site Specific Soil

3. PHYSICAL AND CHEMICAL REQUIREMENTS

3.1 Fibers used in the manufacture of geotextiles and the threads used in joining geotextiles by sewing, shall consist of long chain synthetic polymers, composed of at least 95% by weight polyolefins or polyesters. They shall be formed into a stable network such that the filaments or yarns retain their dimensional stability relative to each other, including selvages.

3.2 Geotextile Requirements. The geotextile shall meet the requirements of following Table. Woven slit film geotextiles (i.e., geotextiles made from yarns of a flat, tape-like character) will not be allowed. All numeric values in the following table, except AOS, represent minimum average roll values (MARV) in the weakest principal direction (i.e., average test results of any roll in a lot sampled for conformance or quality assurance testing shall meet or exceed the minimum values). Values for AOS represent maximum average roll values.

NOTE: The property values in the following table represent default values which provide for sufficient geotextile survivability under most conditions. Minimum property requirements may be reduced when sufficient survivability information is available [see Note 5 of Table 2-2 and Appendix D]. The Engineer may also specify properties different from those listed in the following Table based on engineering design and experience.

4. CERTIFICATION

4.1 The Contractor shall provide to the Engineer a certificate stating the name of the manufacturer, product name, style number, chemical composition of the filaments or yarns and other pertinent information to fully describe the geotextile.

4.2 The Manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of the specification. Documentation describing the quality control program shall be made available upon request.

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4.3 The Manufacturer’s certificate shall state that the furnished geotextile meets MARV requirements of the specification as evaluated under the Manufacturer’s quality control program. The certificate shall be attested to be a person having legal authority to bind the Manufacturer.

4.4 Either mislabeling or misrepresentation of materials shall be reason to reject those geotextile products.

5. SAMPLING, TESTING, AND ACCEPTANCE

5.1 Geotextiles shall be subject to sampling and testing to verify conformance with this specification. Sampling for testing shall be in accordance with ASTM D 4354. Acceptance shall be based on testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer’s certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354. A lot size for conformance or quality assurance sampling shall be considered to be the shipment quantity of the given product or a truckload of the given product, whichever is smaller.

5.2 Testing shall be performed in accordance with the methods referenced in this specification for the indicated application. The number of specimens to test per sample is specified by each test method. Geotextile product acceptance shall be based on ASTM D 4759. Product acceptance is determined by comparing the average test results of all specimens within a given sample to the specification MARV. Refer to ASTM D 4759 for more details regarding geotextile acceptance procedures.
6. **SHIPMENT AND STORAGE**

6.1 Geotextile labeling, shipment, and storage shall follow ASTM D 4873. Product labels shall clearly show the manufacturer or supplier name, style number, and roll number. Each shipping document shall include a notation certifying that the material is in accordance with the manufacturer's certificate.

6.2 Each geotextile roll shall be wrapped with a material that will protect the geotextile from damage due to shipment, water, sunlight, and contaminants. The protective wrapping shall be maintained during periods of shipment and storage.

6.3 During storage, geotextile rolls shall be elevated off the ground and adequately covered to protect them from the following: site construction damage, precipitation, extended ultraviolet radiation including sunlight, chemicals that are strong acids or strong bases, flames including welding sparks, temperatures in excess of 71°C (160°F), and any other environmental condition that may damage the physical property values of the geotextile.

7. **CONSTRUCTION**

7.1 **General.** Atmospheric exposure of geotextiles to the elements following lay down shall be a maximum of 14 days to minimize damage potential.

7.2 **Seaming.**

    a. If a sewn seam is to be used for the seaming of the geotextile, the thread used shall consist of high strength polypropylene, or polyester. Nylon thread shall not be used. For erosion control applications, the thread shall also be resistant to ultraviolet radiation. The thread shall be of contrasting color to that of the geotextile itself.

    b. For seams which are sewn in the field, the Contractor shall provide at least a 2 m length of sewn seam for sampling by the Engineer before the geotextile is installed. For seams which are sewn in the factory, the Engineer shall obtain samples of the factory seams at random from any roll of geotextile which is to be used on the project.

    b.1 For seams that are field sewn, the seams sewn for sampling shall be sewn using the same equipment and procedures as will be used for the production of seams. If seams are to be sewn in both the machine and cross machine directions, samples of seams from both directions shall be provided.

    b.2 The seam assembly description shall be submitted by the Contractor along with the sample of the seam. The description shall include the seam type, stitch type, sewing thread, and stitch density.

7.3 **Geotextile Placement.**

    a. The geotextile shall be placed in intimate contact with the soils without wrinkles or folds and anchored on a smooth graded surface approved by the Engineer. The geotextile shall be placed in such a manner that placement of the overlying materials will not excessively stretch so as to tear the geotextile. Anchoring of the terminal ends of the geotextile shall be accomplished through the use of key trenches or aprons at the crest and toe of slope. See Figures 3-2 and 3-3 [this manual].

    NOTE 1: In certain applications to expedite construction, 450 mm anchoring pins placed on 600 to 1800 mm centers, depending on the slope of the covered area, have been used successfully.

    a.2 Care shall be taken during installation so as to avoid damage occurring to the geotextile as a result of the installation process. Should the geotextile be damaged during installation, a geotextile patch shall be placed over the damaged area extending 1 m beyond the perimeter of the damage.
b. Armor. The armor system placement shall begin at the toe and proceed up the slope. Placement shall take place so as to avoid stretching resulting in tearing of the geotextile. Riprap and heavy stone filling shall not be dropped from a height of more than 300 mm. Stone weighing more than 450 N shall not be allowed to roll down the slope.

b.1 Slope protection and smaller sizes of stone filling shall not be dropped from a height exceeding 1 m, or a demonstration provided showing that the placement procedures will not damage the geotextile. In underwater applications, the geotextile and backfill material shall be placed the same day. All void spaces in the armor stone shall be backfilled with small stone to ensure full coverage.

b.2 Following placement of the armor stone, grading of the slope shall not be permitted if the grading results in movement of the stone directly above the geotextile.

c. Damage. Field monitoring shall be performed to verify that the armor system placement does not damage the geotextile.

c.1 Any geotextile damaged during backfill placement shall be replaced as directed by the Engineer, at the Contractor's expense.

8. METHOD OF MEASUREMENT

8.1 The geotextile shall be measured by the number of square meters computed from the payment lines shown on the plans or from payment lines established in writing by the Engineer. This excludes seam overlaps, but shall include geotextiles used in crest and toe of slope treatments.

8.2 Slope preparation, excavation and backfill, bedding, and cover material are separate pay items.

9. BASIS OF PAYMENT

9.1 The accepted quantities of geotextile shall be paid for per square meter in place.

9.2 Payment will be made under:

<table>
<thead>
<tr>
<th>Pay Item</th>
<th>Pay Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion Control Geotextile</td>
<td>Square Meter</td>
</tr>
</tbody>
</table>

3.8 GEOTEXTILE INSTALLATION PROCEDURES

Construction requirements will depend on specific application and site conditions. Photographs of several installations are shown in Figure 3-1. The following general construction considerations apply for most riprap-geotextile erosion protection systems. Special considerations related to specific applications and alternate riprap designs will follow.
Figure 3-1  Erosion control installations: a) installation in wave protection revetment; b) shoreline application; and c) drainage ditch application.
3.8-1 General Construction Considerations

1. Grade area and remove debris to provide smooth, fairly even surface.
   a. Depressions or holes in the slope should be filled to avoid geotextile bridging and possible tearing when cover materials are placed.
   b. Large stones, limbs, and other debris should be removed prior to placement to prevent fabric damage from tearing or puncturing during stone placement.

2. Place geotextile loosely, laid with machine direction in the direction of anticipated water flow or movement.

3. Seam or overlap the geotextile as required.
   a. For overlaps, adjacent rolls of geotextile should be overlapped a minimum of 0.3 m. Overlaps should be in the direction of water flow and stapled or pinned to hold the overlap in place during placement of stone. Steel pins are normally 5 mm diameter, 0.5 m long, pointed at one end, and fitted with 40 mm diameter washers at the other end. Pins should be spaced along all overlap alignments at a distance of approximately 1 m center to center.
   b. The geotextile should be pinned loosely so it can easily conform to the ground surface and give when stone is placed.
   c. If seamed, seam strength should equal or exceed the minimum seam requirements indicated in the specification section of Chapter 1.

4. The maximum allowable slope on which a riprap-geotextile system can be placed is equal to the lowest soil-geotextile friction angle for the natural ground or stone-geotextile friction angle for cover (armor) materials. Additional reductions in slope may be necessary due to hydraulic considerations and possible long-term stability conditions. For slopes greater than 2.5 to 1, special construction procedures will be required, including toe berms to provide a buttress against slippage, loose placement of geotextile sufficient to allow for downslope movement, elimination of pins at overlaps, increase in overlap requirements, and possible benching of the slope. Care should be taken not to put irregular wrinkles in the geotextile because erosion channels can form beneath the geotextile.

5. For streambank and wave action applications, the geotextile must be keyed in at the bottom of the slope. If the riprap-geotextile system cannot be extended a few meters above the anticipated maximum high water level, the geotextile should also be keyed in at the crest of the slope. Alternative key details are shown in Figure 3-2.
Figure 3-2  Construction of hard armor erosion control systems (a., b. after Keown and Dardeau, 1980; c. after Dunham and Barrett, 1974)
6. Place revetment (cushion layer and/or riprap) over the geotextile width, while avoiding puncturing or tearing it.
   a. Revetment should be placed on the geotextile within 14 days.
   b. Placement of armor cover will depend on the type of riprap, whether quarry stone, sandbags (which may be constructed of geotextiles), interlocked or articulating concrete blocks, soil-cement filled bags, or other suitable slope protection is used.
   c. For sloped surfaces, placement should always start from the base of the slope, moving up slope and, preferably, from the center outward.
   d. In no case should stone weighing more than 400 N be allowed to roll downslope on the geotextile.
   e. Field trials should be performed to determine if placement techniques will damage the geotextile and to determine the maximum height of safe drop. As a general guideline, for Moderate Survivability geotextiles (Table 3-1) with no cushion layer, height of drop for stones less than 100 kg should be less than 300 mm. For High Survivability geotextiles (Table 3-1) or Moderate Survivability geotextiles with a cushion layer, height of drop for stones less than 100 kg should be less than 0.9 m. Stones greater than 100 kg should be placed with no free fall unless field trials demonstrate they can be dropped without damaging the geotextile.
   f. Grading of slopes should be performed during placement of riprap. Grading should not be allowed after placement if it results in stone movement directly on the geotextile.

As previously indicated, construction requirements will depend on specific application and site conditions. In some cases, geotextile selection is affected by construction procedures. For example, if the system will be placed below water, a geotextile that facilitates such placement must be chosen. The geotextile may also affect the construction procedures. For example, the geotextile must be completely covered with riprap for protection from long-term exposure to ultraviolet radiation. Sufficient anchorage must also be provided by the riprap for weighting the geotextile in below-water applications. Other requirements related to specific applications are depicted in Figure 3-3 and are reviewed in the following subsections (from Christopher and Holtz, 1985).

3.8-2 Cut and Fill Slope Protection
Cut and fill slopes are generally protected using an armor stone over a geotextile-type system. Special consideration must be given to the steepness of the slope. After grading, clearing, and leveling a slope, the geotextile should be placed directly on the slope. When possible, geotextile placement should be placed parallel to the slope direction. A minimum overlap of 0.3 m between adjacent roll ends and a minimum 0.3 m overlap of adjacent strips is recommended. It is also important to place the up-slope geotextile over the down-slope geotextile to prevent overlap.
Figure 3-3  Special construction requirements related to specific hard armor erosion control applications.
Figure 3-3 Special construction requirements related to specific hard armor erosion control applications (cont.).
separation during aggregate placement. When placing the aggregate, do not push the aggregate up the slope against the overlap. Generally, cut and fill slopes are protected with armor stone, and the recommended placement procedures in Section 3.8-1 should be followed.

3.8-3 Streambank Protection

For streambank protection, selecting a geotextile with appropriate clogging resistance to protect the natural soil and meet the expected hydraulic conditions is extremely important. Should clogging occur, excess hydrostatic pressures in the streambank could result in slope stability problems. Do not solve a surface erosion problem by causing a slope stability problem!

Detailed data on geotextile installation procedures and relevant case histories for streambank protection applications are given by Keown and Dardeau (1980). Construction procedures essentially follow the procedures listed in Section 3.8-1. The geotextile should be placed on the prepared streambank with the machine direction placed parallel to the bank (and parallel to the direction of stream flow). Adjacent rolls of geotextile should be seamed, sewed, or overlapped; if overlapped, secure the overlap with pins or staples. A 0.3 m overlap is recommended for adjacent roll edges, with the upstream roll edge placed over the downstream roll edge. Roll ends should be overlapped 1 m and offset as shown in Figure 3-3a. The upslope roll should overlap the downslope roll.

The geotextile should be placed along the bank to an elevation determined to be below mean low water level based on anticipated flow velocities in the stream. Existing agency design criteria for conventional nongeotextile streambank protection could be utilized to locate the toe of the erosion protection system. In the absence of other specifications, placement to a vertical distance of 1 m below mean water level, or to the bottom of the streambed for streams shallower than 1 m, is recommended. Geotextiles should either be placed to the top of the bank or at a given distance up the slope above expected high water level from the appropriate design storm event, including whatever requirements are normally used for conventional (nongeotextile) streambank protection systems. In the absence of other specifications, the geotextile should extend vertically a minimum of 0.5 m above the expected maximum water stage, or at least 1 m beyond the top of the embankment if less than 0.5 m above expected water level.

If strong water movements are expected, the geotextile must be toed in at the top and bottom of the embankment, or the riprap extended beyond the geotextile 0.5 m or more at the toe and the crest of the slope. If scour occurs at the toe and the rocks beyond the geotextile are undermined, they will in effect toe into the geotextile. The whole unit thus drops, until the toed-in section is stabilized. However, if the geotextile extends beyond the stone and scour occurs, the geotextile will flap in the water action, causing accelerated formation of a scour pit at the toe. Alternative toe treatments are shown in Figure 3-2. The trench methods in Figures 3-2a and 3-2b require

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excavating a trench at the toe of the slope. This may be a good alternative for new construction; however, it should be evaluated with respect to slope stability when a trench will be excavated at the toe of a potentially saturated slope below the water level. Keying in at the top can consist of burying the top bank edge of the geotextile in a shallow trench. This will provide resistance to undermining from infiltration of over-the-bank precipitation runoff, and also provide stability should a storm greater than anticipated occur. However, unless excessive quantities of runoff are expected and stream flows are relatively small, this step is usually omitted.

The armoring material (e.g., riprap, sandbags, blocks) must be placed to avoid tearing or puncturing the geotextile, as indicated in Section 3.8-1.

3.8-4 Precipitation Runoff Collection and Diversion Ditches

Runoff drainage from cut slopes along the sides of roads and in the median of divided highways is normally controlled with one or more gravity flow ditches. Runoff from the pavement surface and shoulder slopes are collected and conveyed to drop inlets, stream channels, or other highway drainage structures. If a rock protection-geotextile system is used to control localized ditch erosion problems, select and specify the geotextile using the properties indicated in Table 3-1. Geotextile requirements for ditch linings are less critical than for other types of erosion protection, and minimum requirements for noncritical, nonsevere applications can generally be followed. If care is taken during construction, the protected strength requirements appear reasonable. The geotextile should be sized with AOS to prevent scour and piping erosion of the underlying natural soil and to be strong enough to survive stone placement.

The ditch alignment should be graded fairly smooth, with depressions and gullies filled and large stones and other debris moved from the ditch alignment. The geotextile should be placed with the machine direction parallel to the ditch alignment. Most geotextiles are available in widths of 2 m or more, and, thus, a single roll width of geotextile may provide satisfactory coverage on the entire ditch. If more than one roll width of geotextile is required, sew adjacent rolls together. This can be done by the manufacturer or on site. Again, for seams, the required strength of the seam should meet the minimum seam requirements in Table 3-1. The longitudinal seam produced by roll joining will run parallel with the ditch alignment. Geotextile widths should be ordered to avoid overlaps at the bottom of the ditch, since this is where maximum water velocity occurs. Roll ends should also be sewn or overlapped and pinned or stapled. If overlap is used, then an overlap of at least 1 m is recommended. The upslope roll end should be lapped over the downslope roll end, to retard in-service undermining. Pins or staples should be spaced so slippage will not occur during stone placement or after the ditch is placed in service.

Cover stone, sandbags, or other material intended to dissipate precipitation runoff energy should be placed directly on the geotextile, from downslope to upslope. Cover stone should have
sufficient depth and gradation to protect the geotextile from ultraviolet radiation exposure. Again, the stone should be placed with care, especially if the geotextile strength criteria have been reduced to a less critical in-service application. A cross section of the proper placement is shown in Figure 3-3c. Vegetative cover can be established through the geotextile and stone cover if openings in the geotextile are sufficient to support growth. If a vegetative cover is desirable, geotextiles should be selected on the basis of the largest opening possible.

3.8-5 Wave Protection Revetments
Because of cyclic flow conditions, geotextiles used for wave protection systems should be selected on the basis of severe criteria, in most cases. Geotextile should be placed in accordance with the procedures listed in Section 3.8-1.

If a geotextile will be placed where existing riprap, rubble, or other materials placed on natural soil have been unsuccessful in retarding wave erosion, site preparation could consist of covering the existing riprap with a filter sand. The geotextile could then be designed with less rigorous requirements as a filter for the sand than if the geotextile is required to filter finer soils.

The geotextile is unrolled and loosely laid on the smooth graded slope. The machine direction of the geotextile should be placed parallel to the slope direction, rather than perpendicular to the slope, as was recommended in streambank protection. Thus, the long axis of the geotextile strips will be parallel to anticipated wave action. Sewing of adjacent rolls or overlapping rolls and roll ends should follow the steps described in Section 3.8-1, except that a 1 m overlap distance is recommended by the Corps of Engineers for underwater placement (Figure 3-2). Again, securing pins (requirements per Section 3.8-1) should be used to hold the geotextile in place.

If a large percentage of geotextile is to be placed below the existing tidal level, special fabrication and placement techniques may be required. It may be advantageous to pre-sew the geotextile into relatively large panels and pull the prefabricated panels downslope, anchoring them below the waterline. Depending upon the placement scheme used, selection of a floating or nonfloating geotextile may be advantageous.

Because of potential wave action undermining, the geotextile must be securely toed-in using one of the schemes shown in Figure 3-2. Also, a key trench should be placed at the top of the bank, as shown in Figure 3-2a, to prevent revetment stripping should the embankment be overtopped by wave action during high-level storm events.

Riprap or cover stone should be placed on the geotextile from downslope to upslope, and stone placement techniques should be designed to prevent puncturing or tearing of the geotextile. Drop heights should follow the recommendations stated in the general construction criteria (see 3.8-1).
3.8-6 Scour Protection

Scour, because of high stream flow around or adjacent to structures, generally requires scour protection for structures. Scour protection systems generally fall under the critical and/or severe design criteria for geotextile selection.

An extremely wide variety of transportation-associated structures are possible and, thus, numerous ways exist to protect such structures with riprap geotextile systems. A typical application is shown in Figure 3-3d. In all instances, the geotextile is placed on a smoothly graded surface as stated in the general construction requirements. Such site preparation may be difficult if the geotextile will be placed underwater, but normal stream action may provide a fairly smooth stream bed. In bridge pier protection or culvert approach and discharge channel protection applications, previous high-velocity stream flow may have scoured a depression around the structure. Depressions should be filled with granular cohesionless material. It is usually desirable to place the geotextile and riprap in a shallow depression around bridge piers to prevent unnecessary constriction of the stream channel.

The geotextile should normally be placed with the machine direction parallel to the anticipated water flow direction. Seaming and/or overlapping of adjacent rolls should be performed as recommended in general construction requirements (Section 3.8-1). When roll ends are overlapped, the upstream ends should be placed over the downstream end. As necessary and appropriate, the geotextile may be secured in place with steel pins, as previously described. Securing the geotextile in the proper position may be of extreme importance in bridge pier scour protection. However, under high-flow velocities or under deep water, it will be difficult, if not impossible, to secure the geotextile with steel pins alone. Underwater securing methods must then be developed, and they will be unique for each project. Alternative methods include floating the geotextile into place, then filling from the center outward with stones, building a frame to which the geotextile can be sewn; using a heavy frame to submerge and anchor the geotextile; or constructing a light frame, then floating the geotextile and sinking it with riprap. In any case, it may be desirable to specify a geotextile which will either float or sink, depending upon the construction methods chosen. This can be based on a bulk density criteria for the geotextiles \( (i.e., \text{bulk density greater than } 1 \text{ g/cm}^3 \text{ will sink and less than } 1 \text{ g/cm}^3 \text{ will float}). \)

Riprap and/or bedding material, precast concrete blocks, or other elements to be placed on the geotextile should be placed without puncturing or tearing the geotextile. Drop heights should be selected on the basis of geotextile strength criteria, as discussed in the general construction requirements (Section 8.3-1).
3.9 GEOTEXTILE FIELD INSPECTION

In addition to the general field inspection checklist presented in Table 1-4, the field inspector should pay close attention to construction procedures. If significant movement (greater than 0.15 m) of stone riprap occurs during or after placement, stone should be removed to inspect overlaps and ensure they are still intact. As indicated in Section 3.8, field trials should be performed to demonstrate that placement procedures will not damage the geotextile. If damage is observed, the engineer should be contacted, and the contractor should be required to change the placement procedure.

For below-water placement or placement adjacent to structures requiring special installation procedures, the inspector should discuss placement details with the engineer, and inspection requirements and procedures should be worked out in advance of construction.

3.10 GEOTEXTILE SELECTION CONSIDERATIONS

To enhance system performance, special consideration should be given to the type of geotextile chosen for certain soil and hydraulic conditions. The considerations listed in Section 2.10 also apply to erosion control systems. Special attention should be given to gap-graded soils, silts with sand seams, and dispersive clays. In certain situations, multiple filter layers may be appropriate. These consist of a sand layer over the soil, with the geotextile designed as a sand filter only and with sufficient size and number of openings to allow any fines that reach the geotextile to pass through it. Another special consideration for erosion control applications relates to preference toward felted versus slick geotextiles on steep slope sections. In any case, for steep slopes, the potential for riprap to slide on the geotextile must be assessed either through field trials or laboratory tests.

3.11 EROSION CONTROL MATS

In unlined areas where water can flow, the earth surface is susceptible to erosion by high-velocity flow. Where flow is intermittent, a grass cover will provide protection against erosion. By reinforcing the grass cover, the resulting composite armor layer will enhance the erosion resistance. Geosynthetic erosion control mats are made of synthetic meshes and webbings that reinforce the vegetation root mass to provide tractive resistance to high water velocities (e.g., 6 m/s). Mats are used within this manual to describe geosynthetics for permanent erosion control applications, and blankets (see Chapter 4) are used to describe geosynthetics used in temporary applications (i.e., until vegetation is established).
The three-dimensional erosion control mats retain soil, moisture, and seed, and thus promote vegetative growth. The principal applications of reinforced grass are in highway stormwater runoff ditches, steep waterways such as auxiliary spillways on dams, and protection of embankments against erosion by heavy precipitation or flooding events. Reinforced grass is used for temporary (e.g., 2 hours), high-velocity flow areas, and not for permanent or long-term flow applications suited for hard armor systems. These systems have been found very effective in preventing erosion of the steep face of reinforced slopes (Chapter 8).

This section provides the general design and construction procedures and principles for grass systems reinforced with erosion control mats. The information contained in this section along with additional details pertaining to planning, design, specifications, construction, on-going management, and support research, are contained in Hewlett, Boorman and Bramley (1988).

The performance of reinforced grass is determined by a complex interaction of the constituent elements. At present, these physical processes, and the engineering properties of geotextiles and grass, cannot be fully described in quantitative terms. Thus, the design approach is largely empirical and involves a systematic consideration of each constituent element's behavior under service conditions, and how engineering properties can be effectively, yet safely, utilized. Specific products have been tested in laboratory flume tests to empirically quantify the tractive shear forces and velocities they can withstand as a function of flow time.

3.11-1 Planning
The planning stage involves assessing the feasibility of constructing a reinforced grass system in a particular situation and establishing the basic design parameters. The following points should be considered at this stage:

- overall concept of the waterway, and frequency and duration of flow;
- risk (acceptability of failure);
- design discharge and hydraulic loading;
- properties of subsoil;
- *dry* usage in normal no-flow conditions (*e.g.*, agricultural or amenity use, risk of vandalism);
- maintenance ability and requirements of the owner;
- appearance;
- capital and maintenance costs;
- access to site and method of construction;
- climate; and
- strategy for design, specification, construction, and future maintenance.
Any reinforced grass waterway will require an inspection and maintenance strategy different from that for conventionally lined waterways. Grass requires management, and some of the materials involved are more readily susceptible to damage, particularly by vandalism. If it is apparent at this stage that these considerations cannot be accommodated, then reinforced grass should not be used. However, the aesthetic advantages of a soft armor lining of reinforced grass usually outweighs potential disadvantages.

3.11-2 Design Procedure

Once the feasibility of constructing a reinforced grass waterway has been established, the detailed design can proceed. This will involve consideration of the hydraulic, geotechnical, and botanical aspects of the project. See by Hewlett, et. al. 1988, for other details.

**Hydraulic Design:** The main hydraulic design parameters are the velocity and duration of flow, as well as the erosion resistance of various armor layers.

The recommended hydraulic design procedure is as follows:

1. Choose the design hydrograph or overtopping condition. The consequences of waterway failure should be considered. Generally, grassed slopes can be considered where the overtopping discharge intensity is less than $0.005 \text{ m}^3/\text{s}/\text{m}$. Hardened protection should be used for greater discharge intensities.

2. Consider various engineering options for the proposed waterway, with particular reference to topography of the site. A site survey may be required if sufficient topographical information is not available. These options may relate to either general overtopping or construction of a purpose-made channel. Channel widths, slopes downstream of the crest, and, where appropriate, alternative weir lengths and crest levels may be considered.

3. If a reservoir is involved, carry out a flood routing calculation for each option. If a spillway is involved, check that the freeboard is adequate (including any allowance for waves). The operation frequency of the waterway should then be apparent. Modify the layout accordingly if occurrence of flow is more or less frequent than desired. The effect of waves and spray on areas adjacent to the waterway, along with the potential effect of the works on the area downstream, should be considered.

4. A variety of engineering options may be suitable at the site. The detailed hydraulics of each option should be investigated using the following procedure:
(i) Select an armor layer and a hydraulic roughness "n" value from Figure 3-4.

(ii) Solve Manning's equation by trial and error for design flow or discharge intensity, using different depths of flow to determine the velocity. (Manning's equation is commonly used in civil engineering applications to estimate the velocity and depth of flow in open channels.)

\[
v = \frac{R^{2/3} S^{1/2}}{n}
\]

where:
- \( V \) = mean velocity of flow (m/s)
- \( R \) = hydraulic radius (m) which equals cross-sectional area of flow divided by wetted perimeter
- \( S \) = slope of the energy line
- \( n \) = Manning's roughness coefficient (Figure 3-4)

Alternative forms of the equation for discharge and discharge intensity in a wide channel, respectively, are:

\[
Q = \frac{A R^{2/3} S^{1/2}}{n}
\]

\[
q = \frac{d^{5/3} S^{1/2}}{n}
\]

where:
- \( Q \) = discharge (m³/s)
- \( A \) = area of flow (m²)
- \( q \) = discharge per unit width of channel (m³/s/m)
- \( d \) = depth of flow (m)

A channel may be considered to be hydraulically wide when velocity in the center of the channel is not affected by friction at the sides. In supercritical flow, this may require a channel width of up to 10 times the depth of flow.
Grass Retardance Categories

<table>
<thead>
<tr>
<th>Average grass length</th>
<th>Retardance</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 mm to 250mm</td>
<td>C</td>
</tr>
<tr>
<td>50mm to 150mm</td>
<td>D</td>
</tr>
<tr>
<td>less than 50mm</td>
<td>E</td>
</tr>
</tbody>
</table>

Flow parameter, \( VR(m/s)^2 \)

(a) HYDRAULIC ROUGHNESS OF GRASSES FOR SLOPES FLATTER THAN 1 IN 10

(b) RECOMMENDED RETARDANCE COEFFICIENTS FOR GRASSED SLOPES STEEPER THAN 1 ON 10

Figure 3-4 Roughness and retardance coefficients \( n \) for grassed slopes (Hewlett et al., 1987).

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When uniform flow conditions have developed (i.e., terminal velocity is reached), the energy slope, $S_1$ equals the slope of the channel bed. Depth of uniform flow conditions is referred to as *normal depth*.

On steep slopes, the terminal velocity and normal *blackwater* depth calculated using Manning's equation will normally be achieved. The normal *blackwater* depth may be converted to *whitewater* using the air voids ratio. For water flow with a relatively small head loss between upstream and downstream energy levels, normal depth may not be reached; a step-by-step method should be used to determine the depth of flow and maximum velocity (Hewlett et al., 1987).

(iii) Compare this velocity with the recommended velocity for the armor layer from Figure 3-5. If the recommended velocity is exceeded, it may be possible to decrease the discharge intensity or select a more erosion-resistant armor layer. If the velocity is less than that recommended, it may be possible to reduce the base width or select a less erosion-resistant armor layer.

5. Determine the tailwater conditions over a range of discharges and consider ways to dissipate energy at the toe of the waterway.

If the tailwater conditions cause a hydraulic jump to form on the slope (Figure 3-6, Case (a)), it may be advisable to provide heavier armor, stronger restraint, discharge, or anchorage than normally used to protect the waterway from erosion by high-velocity flow. The decision will depend on the energy loss and frequency of occurrence. The critical zone of potential erosion is at the front of the jump. Experience from field trials and embankment overtopping under high tailwater conditions has shown that high-velocity flow zones within the jump generally occur only at the front of the jump and that erosion is consequently restricted.

If Cases (b), (c), or (d) in Figure 3-6 apply, provided the slope reinforcement is terminated in a safe manner, limited erosion may be acceptable. Note that in all cases, the flow velocity decreases downstream of the toe. Erosion protection may be provided -- either by continuing the slope reinforcement or by other means (*e.g.*, gabion mattress, rock armor).

If it is necessary to stabilize and contain the hydraulic jump -- for example, to accommodate the short-term design discharge -- then a control and/or armored stilling basin may be adopted.
Concrete systems, good interlocking restraint

Other concrete block systems

Open mats

Filled mats, fabrics

Meshes

Plain grass - good cover

Plain grass - average cover

Plain cover - poor cover

Erosion Resistance

Figure 3-5 Recommended limiting values for erosion resistance of plain and reinforced grass (Hewlett et al., 1987).

Notes:
1. Minimum superficial mass 135 kg/m².
2. Minimum nominal thickness 20 mm.
3. Installed within 20 mm of soil surface, or in conjunction with surface mesh.
4. See text for other criteria for geosynthetic reinforcement.
5. These graphs should only be used for erosion resistance to unidirectional flow.
6. Values are based on available experience and information as of 1987.
7. Other criteria (such as short term protection, ease of installation and management, susceptibility to vandalism, etc) must be considered in choice of reinforcement.
Figure 3-6  Possible flow conditions at base of steep waterway (Hewlett et al., 1987).
**Geotechnical Considerations:** The principal geotechnical consideration is the effect that water entering the embankment (or excavation) will have on the subsoil. The procedure normally followed is listed below. Consider the following principal points: (1) investigate the stability of the slope during normal dry conditions, as well as during and immediately following flow; (2) consider whether any localized drainage should be provided to provide relief of pore pressures for increased stability; and (3) consider whether there is likely to be any settlement of the subsoil and whether the armor layer is flexible enough to accommodate movement.

**Botanical Considerations:** Botanical considerations include the choice of grass mixture, and its establishment and management. Consider the following principal points.

1. Obtain samples of soil that will support the grass and carry out physical and chemical tests to determine its suitability.
2. Choose a grass mixture. The principal factors affecting this choice are soil conditions, climate, and management requirements.
3. Decide on the method of sowing and establishment of grass.

**Detailing and Specification:** A number of detailed points should be considered which combine the hydraulic, geotechnical, and botanical aspects, to complete the design process. These should be included on the drawings or in the specification and are listed below.

1. Anchorage: Anchorage details of geosynthetic erosion control mats should be developed, by the design engineer, on a project specific basis. Details include type and length of anchorage pins or stakes, spacing of anchors across and along the edges the mat, roll end anchorage, downslope shingling or anchorage of adjacent rolls, and anchorage at the top of slope or embankment.
2. Crest Details: Complete a detailed design of the waterway or slope crest. The upstream end of the reinforcement system must be designed to avoid the risk of waterway erosion from the upstream area.
3. Channel Details: Cross-sections of the channel should be drawn. Estimate freeboard based on bulked depth of flow. Careful detailing is required at any transition between two or more plane surfaces.
4. Toe Details: Complete a detailed design of the toe of the waterway or slope.
5. Construction Details: Foundation preparation, transition to adjacent structures, placement requirements, etc.

Details for each of these requirements are in Hewlett, et al. (1988). Remember to:

- check that the waterway will perform satisfactorily;
- produce the construction drawings;
- prepare a specification, including material and acceptance tests; and
- set up a framework for future construction, maintenance, and inspection.
It is important that adequate design and site supervision be exercised at all stages by the client or its representative to ensure that the work is constructed in accordance with good practice.

3.11-3 Specification

The following example specification for erosion control mats is after the Texas Department of Transportation specification for RECPs. This agency tests candidate erosion control materials and categorizes them into classes and types in an approved materials list.

SOIL EROSION CONTROL MATS

(after Texas Department of Transportation, Special Specification, Item 1225 February 1993)

1. DESCRIPTION.

This item shall govern for providing and placing wood, straw, or coconut fiber mat, synthetic mat, jute mesh or other material as a soil erosion control mat on slopes or ditches or for long-term protection of seeded areas as shown on the plans or as specified by the Engineer.

2. MATERIALS.

(1) Soil Erosion Control Mats. All soil erosion control mats must be prequalified by the Director of Maintenance and Operations prior to use.

Prequalification procedures and a current list of prequalified materials may be obtained by writing to the Director of Maintenance and Operations. A 0.3 m x 0.3 m sample of the material may be required by the Engineer in order to verify prequalification. Samples taken, accompanied by the manufacturer’s literature, will be sent, properly wrapped and identified, to the Division of Maintenance and Operations for verification.

The soil erosion control mat shall be a Class 2 material and be one (1) of the following types as shown on the plans:

Class 2. “Erosion Control Mat”

(i) Type E. Short-term duration (Up to 2 Years)
Shear Stress ($t_d$) < 50 Pa

Prequalified Type E products are:

________________________
________________________
________________________

(ii) Type F. Short-term duration (Up to 2 Years)
Shear Stress ($t_d$) 50 to 95 Pa
Prequalified Type F products are:

(iii) Type G. Long-term duration (Longer than 2 Years)
Shear Stress ($t_d$) > 95 to < 240 Pa

Prequalified Type G products are:

(iv) Type H. Long-term duration (Longer than 2 Years)
Shear Stress ($t_d$) greater than or equal to 240 Pa

Prequalified Type H products are:

(2) **Staples.** Staples for anchoring the soil erosion control mat shall be U-shaped, made of 3 mm or large diameter steel wire, or other approved material, have a width of 25 to 50 mm, and a length of not less than 150 mm for firm soils and not less than 300 mm for loose soils. [Longer staples, and closer spacings, should be considered for steep reinforced soil slope applications.]

3. **CONSTRUCTION METHODS.**

(1) **General.** The soil erosion control mat shall conform to the class and type shown on the plans. The Contractor has the option of selecting an approved soil erosion control mat conforming to the class and type shown on the plans, and according to the current approved material list.

(2) **Installation.** The soil erosion control mat, whether installed as slope protection or as flexible channel liner in accordance with the approved materials list, shall be placed within 24 hours after seeding or sodding operations have been completed, or as approved by the Engineer. Prior to placing the mat, the area to be covered shall be relatively free of all rocks or clods over 1-1/2 inches in maximum dimension and all sticks or other foreign material which will prevent the close contact of the mat with the soil. The area shall be smooth and free of ruts or depressions exist for any reason, the Contractor shall be required to rework the soil until it is smooth and to reseed or resod the area at the Contractor’s expense.

Installation and anchorage of the soil erosion control mat shall be in accordance with the project construction drawings unless otherwise specified in the contract or directed by the Engineer.

(3) **Literature.** The Contractor shall submit one (1) full set of manufacturer’s literature and manufacturer’s installation recommendations for the soil erosion control mat selected in accordance with the approved material list.
4. **MEASUREMENT.**

This Item will be measured by the square meter of surface area covered.

5. **PAYMENT.**

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Soil Erosion Control Mat" of the class and type shown on the plans. This price shall be full compensation for furnishing all materials, labor, tools, equipment and incidentals necessary to complete the work. Anchors, checks, terminals or junction slots, and wire staples or wood stakes will not be paid for directly but will be considered subsidiary to this Item.

### 3.12 REFERENCES


ASTM Test Methods - *see Appendix E.*


Keown, M.P. and Dardeau, E.A., Jr. (1980), *Utilization of Filter Fabric for Streambank Protection Applications*, TR HL-80-12, Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.


4.0 TEMPORARY RUNOFF AND SEDIMENT CONTROL

4.1 INTRODUCTION

Geotextiles, geosynthetic erosion control blankets, and other geosynthetic products can be used to temporarily control and minimize erosion and sediment transport during construction. Four specific application areas have been identified:

- Geotextile silt fences can be used as a substitute for hay bales or brush piles to remove suspended particles from sediment-laden runoff water.

- Geotextiles can be used as a turbidity curtain placed within a stream, lake, or other body of water to retain suspended particles and allow sedimentation to occur.

- Special soil retention blankets, made of both natural and synthetic grids, meshes, nets, fibers, and webbings, can be used to provide tractive resistance and resist water velocity on slopes. These products retain seeds and add a mulch effect to promote the establishment of a vegetative cover.
Geotextiles held in place by pins or riprap can be used to temporarily control erosion in diversion ditches, culvert outfalls, embankment slopes, etc. Alternatively, soil retention blankets can be used for temporary erosion control until vegetation can be established in the ditch.

The main advantages of using geosynthetics over conventional techniques in sediment control applications include the following.

- In the case of a silt fence, the geotextile can be designed for the specific application, while conventional techniques are basically designed by trial-and-error.
- Geotextile silt fences in particular often prove to be very cost-effective, especially in comparison to hay bales, considering ease of installation and material costs.
- Control by material specifications is easier.

For runoff control, geosynthetic products are designed to help mitigate immediate erosion problems and provide long-term stabilization by promoting the establishment and sustainment of vegetative cover. The main advantages of using geosynthetics for erosion control applications include the following.

- Vegetative systems have desirable aesthetics.
- Products are lightweight and easy to handle.
- Temporary, degradable products improve establishment of vegetation.
- Continuity of protection is generally better over the entire protected area.
- Empirically predictable performance; traditional techniques such as seeding, mulch covers, and brush or hay bale barriers, are often less reliable.

The following sections review the function, selection specifications, and installation procedures for geosynthetics used as silt fences, turbidity curtains, and erosion control blankets. Design of geotextiles in temporary riprap-geotextile systems to control ditch erosion follows Chapter 3 design guidelines. Additional information on erosion and sediment control will be available in the FHWA course and text entitled Identifying and Controlling Sedimentation and Erosion currently being developed.
4.2 FUNCTION OF SILT FENCES

In most applications, a geotextile silt fence is placed downslope from a construction site or newly graded area to reduce sediment being transported by runoff to the surrounding environment. Sometimes silt fences are used in permanent or temporary diversion ditches for the same purpose.

A silt fence primarily functions as a temporary dam (Mallard and Bell, 1981). It retains water long enough for suspended fine sand and coarse silt particles in the runoff to settle out before they reach the fence. Generally, a retention time of 20 to 25 minutes is sufficient, so flow through the geotextile after the first charge must provide this retention time. Although smaller geotextile pore opening sizes and low permittivity can be selected to allow finer particles to settle out, some water must be able to pass through the fence to prevent possible overtopping of the fence. A silt fence is intended for drainage areas experiencing sheet flow. Appropriate applications of silt fences are: along the site perimeter; below disturbed areas subject to sheet and rill erosion and sheet flow; and below the toe of exposed and erodible slopes.

Because not all the silt and clay in suspension will settle out before reaching the fence, water flowing through the fence will still contain some fines in suspension. Removal of fines by the geotextile creates a difficult filtration condition. If the openings in the geotextile (i.e., AOS) are small enough to retain most of the suspended fines, the geotextile will blind and its permeability will be reduced so that bursting or overtopping of the fence could occur. Therefore, it is better to have some geotextile openings large enough to allow silt-sized particles to easily pass through. Even if some silt passes through the fence, the flow velocity will be small, and some fines may settle out. If the application is critical, e.g., when the site is immediately adjacent to environmentally sensitive wetlands or streams, multiple silt fences could be used. A second fence with a smaller AOS is placed a short distance downslope of the first fence to capture silt that passed through the first fence.

In the past, the AOS and permittivity, \( \psi \), have been used to design and specify the filtration requirements of the geotextile. However, Wyant (1980) and Allen (1994) indicate that these geotextile index properties are not directly related to silt fence performance. Experience indicates that, in general, most geotextiles have hydraulic characteristics that provide acceptable silt fence performance for even the most erodible silts (Wyant, 1980; Allen, 1994). Thus, geotextile selection and specification can be based on typical properties of silt fence geotextiles known to have performed satisfactorily in the past, or through the use of performance type tests such as ASTM D 5141, Determining Filtering Efficiency and Flow Rate of a Geotextile for Silt Fence Applications Using Site-Specific Soil. Past experience is the basis for the AOS and permittivity values presented later in this chapter.
Most silt fence applications are temporary; the fence only must work until the site can be revegetated or otherwise protected from rainfall and erosion. According to Richardson and Middlebrooks (1991), silt fences are best limited to applications where sheet erosion occurs and where flow is not concentrated, though silt fences can be used in both ditch or swale applications by special design (with varying success). Flow velocity should be less than about 0.3 m/s. Recommendations for allowable slope length versus slope angle to limit runoff velocity are presented in Table 4-1. Furthermore, the limiting slope angle and velocity requirements suggest that the drainage areas for overland flow to a fence should be less than about 1 ha per 30 m of fence.

Silt fence ends should be turned uphill to ensure they capture runoff water and prevent flow around the ends. The groundline at the fence ends should be at or above the elevation of the lowest portion of the fence top. Measures should be taken to prevent erosion along the fence backs that run downhill for a significant distance. Gravel check dams at approximately 2 to 3 m intervals along the back of the fence can be used.

<table>
<thead>
<tr>
<th>Slope Steepness (%)</th>
<th>Maximum Slope Length (m)</th>
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<tbody>
<tr>
<td>&lt; 2</td>
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<tr>
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<td>25</td>
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<td>10 - 20</td>
<td>10</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>5</td>
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</tbody>
</table>

4.3 DESIGN OF SILT FENCES

4.3-1 Simplified Design Method

This section follows the simplified design method of Richardson and Middlebrooks (1991), except the Revised Universal Soil Loss Equation (RUSLE) is used in Step 2 in lieu of the Universal Soil Loss Equation (USLE). See their paper for additional details on this design procedure. See the FHWA Identifying and Controlling Erosion and Sedimentation course text (Hydrodynamics, 1997) for a summary discussion on advantages and disadvantages of USLE and RUSLE equations.
STEP 1. Estimate runoff volume.

Use the Rational Method (small watershed areas):

\[ Q = 2.8 \times 10^{-3} C i A \] [4 - 1]

where:
- \( Q \) = runoff (m\(^3\)/s)
- \( C \) = surface runoff coefficient
- \( i \) = rainfall intensity (mm/hr)
- \( A \) = area (ha)

Use \( C = 0.2 \) for rough surfaces, and \( C = 0.6 \) for smooth surfaces. A 10-year storm event is typically used for designing silt fences.

Use the appropriate rainfall intensity factor, \( i \), for the locality. Assume a 10-year design storm, or use local design regulations. Neglect any concentration times (worst case). This calculation gives the total storage volume required of the silt fence.

STEP 2. Estimate sediment volume.

Use the Revised Universal Soil Loss Equation (RUSLE)

\[ A = 2.2 \ R \ K \ (L S) \ C \ P \] [4 - 2]

where:
- \( A \) = annual soil loss due to erosion (metric tons/ha/yr)
- \( R \) = rainfall factor
- \( K \) = soil erodibility factor
- \( L S \) = slope length and steepness factor
- \( C \) = vegetative cover factor \( C^* = 1 \) for no cover
- \( P \) = erosion control practice factor \( P = 1 \) for minimal practice

Obtain rainfall erosion index from Figure 4-1; note that the factors are based upon a 2-year, 6-hour storm event. Use Figure 4-2 to obtain the values of KLS (limited slope lengths and steepness factors are applicable to most silt fence applications).
(a) annual R-factors for the eastern U.S.

Figure 4-1 Rainfall erosion factors, R (Renard et al., 1997).
(b) annual R-factors for the western U.S.

Figure 4-1 Rainfall erosion factors, R (Renard et al., 1997) (cont.).
(c) annual R-factors for Oregon and Washington

Figure 4-1  Rainfall erosion factors, R (Renard et al., 1997) (cont.).
Figure 4-1 Rainfall erosion factors, R (Renard et al., 1997) (cont.).
Equation 4-2 predicts an erosion rate per year. This rate may be used to provide an estimate of predicted tons of sediment produced per hectare for a 6-month (typical) silt fence design (Richardson and Middlebrooks, 1991). This should provide a reasonable estimate for sizing the storage volume behind the silt fence. A density of about 800 kg/m³ may be assumed for converting the soil loss in metric tons to a volume. Sediment behind a silt fence should be removed when accumulation reaches approximately one-third to one-half fence height.

**STEP 3.** Select geotextile.

**A. Hydraulic properties**

Because site specific designs for retention and permittivity are not necessary for most soils (at least in a practical sense), use nominal AOS and permittivity values for geotextiles known to perform satisfactorily as silt fences. Suggested values (Richardson and Middlebrooks, 1991) are:

- 0.15 mm < AOS < 0.60 mm for woven silt films
- 0.15 mm < AOS < 0.30 mm for all other geotextiles
- Permittivity, $\psi > 0.02$ s$^{-1}$
B. Physical and mechanical properties

The geotextile must be strong enough to support the pooled water and the sediments collected behind the fence. Minimum strength depends on height of impoundment and spacing between fence posts.

Use Figure 4-3 to determine required tensile strength for a range of impoundment heights and post spacings. For geotextiles without wire or plastic mesh backing, limit impoundment heights to 0.6 m and post spacing to 2 m; for greater heights and spacings, use steel or plastic grid/mesh reinforcement to prevent burst failure of geotextile. Unsupported geotextiles must not collapse or deform, allowing silt-laden water to overtop the fence. Use Figure 4-4 to design the fence posts.

**Figure 4-3** Geotextile strength versus post spacing (Richardson and Koerner, 1990).

**Figure 4-4** Post requirements vs post spacing (Richardson and Koerner, 1990).
4.3-2 Alternate Hydraulic Design Using Performance Tests

An alternate design approach for silt fences uses model studies to estimate filtration efficiency for specific site conditions. This method was developed by Wyant (1980) for the Virginia Highway and Transportation Research Council (VHTRC) and is based on observed field performance and laboratory testing. The procedures for this method are described in ASTM D 5141. The laboratory model consists of a flume with an outflow opening similar to the size of a hay bale and positioned at a fixed slope of 8%. The geotextile is strapped across the end of the flume. A representative soil sample from the site is then suspended in water to a concentration of about 3000 ppm (equivalent water content is 0.3 percent) and poured through the flume. Based on the performance of the geotextile, appropriate geotextiles can be selected to provide filtering efficiencies approximating of 75% or more and flow rates on the order of 0.1 L/min/m² after three test repetitions.

The model study approach provides a system performance evaluation by utilizing actual soils from the local area of interest. Thus, it cannot be performed by manufacturers. The approach lends itself to an approved list-type specification for silt fences. In this case, the agency or its representatives perform the flume test using their particular problem soils and prequalifies the geotextiles that meet filtering efficiency and flow criteria requirements. Qualifying geotextiles can be placed on an approved list that is then provided to contractors. Geotextiles on any approved list should be periodically retested because manufacturing changes often occur.

4.3-3 Constructability Requirements

The geotextile used as a silt fence must be strong enough to enable it to be properly installed. AASHTO M288 property recommendations are indicated in Table 4-2. Realize that these specifications are not based on research but on properties of existing geotextiles which have performed satisfactorily in silt fence applications. Also given are requirements for resistance to ultraviolet degradation. Although the applications are temporary (e.g., 6 to 36 months), the geotextile must have sufficient UV resistance to function throughout its anticipated design life.
<table>
<thead>
<tr>
<th>Requirement</th>
<th>ASTM Test Method</th>
<th>Units</th>
<th>Supported Silt Fence</th>
<th>Unsupported Silt Fence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Geotextile Elongation</td>
<td>Geotextile Elongation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 50%</td>
<td>&lt; 50%</td>
</tr>
<tr>
<td>Maximum Post Spacing</td>
<td></td>
<td>1.2 m</td>
<td>1.2 m</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Grab Strength Machine Direction</td>
<td>D 4632</td>
<td>N</td>
<td>400</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>400</td>
<td>450</td>
</tr>
<tr>
<td>X-Machine Direction</td>
<td></td>
<td></td>
<td>400</td>
<td>450</td>
</tr>
<tr>
<td>Permittivity</td>
<td>D 4491</td>
<td>sec&quot;</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Apparent Opening Size</td>
<td>D 4751</td>
<td>mm</td>
<td>0.60 max.</td>
<td>0.60 max.</td>
</tr>
<tr>
<td>Ultraviolet Stability</td>
<td>D 4355</td>
<td>%</td>
<td>70% after 500 hours of exposure</td>
<td>70% after 500 hours of exposure</td>
</tr>
</tbody>
</table>

NOTES:
1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. All numeric values except AOS represent minimum average roll value (i.e., test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Silt fence support shall consist of 14 gage steel wire mesh spacing of 150 mm by 150 mm or prefabricated polymeric mesh of equivalent strength.
5. As measured in accordance with ASTM D 4632.
6. These default filtration property values are based on empirical evidence with a variety of sediments. For environmentally sensitive areas, a review of previous experience and/or site or regionally specific geotextile tests should be performed by the agency to confirm suitability of these requirements.

### 4.4 SPECIFICATIONS

The following specifications were developed by the Washington State Department of Transportation in 1994 and are included herein for your reference. They are meant to serve as guidelines for selecting and installing of geotextiles for routine (less critical) projects. They are not intended to replace site-specific evaluation, testing, and design.
Description
The Contractor shall furnish and place construction geotextile for silt fence in accordance with the details shown in the Plans.

Materials

Geotextile and Thread for Sewing
The material shall be a geotextile consisting only of long chain polymeric fibers or yarns formed into a stable network such that the fibers or yarns retain their position relative to each other during handling, placement, and design service life. At least 85 percent by weight of the material shall be polyolefins or polyesters. The material shall be free from defects or tears. The geotextile shall also be free of any treatment or coating which might adversely alter its hydraulic or physical properties after installation. The geotextile shall conform to the properties as indicated in Table 1.

Thread used for sewing shall consist of high strength polypropylene, polyester, or polyamide. Nylon threads will not be allowed. The thread used to sew permanent erosion control geotextiles must also be resistant to ultraviolet radiation.

<table>
<thead>
<tr>
<th>Geotextile Property</th>
<th>ASTM Test Method(^2)</th>
<th>Unsupported Between Posts</th>
<th>Supported Between Posts with Wire or Polymeric Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOS</td>
<td>D 4751</td>
<td>0.15 mm min.; 0.30 mm max. for other geotextiles; 0.60 mm max. for slit film wovens</td>
<td>0.15 mm min.; 0.30 mm max. for other geotextiles; 0.60 mm max. for slit film wovens</td>
</tr>
<tr>
<td>Water Permittivity</td>
<td>D 4491</td>
<td>0.02 sec(^{-1}) min.</td>
<td>0.02 sec(^{-1}) min.</td>
</tr>
<tr>
<td>Grab Tensile Strength, min. in MD</td>
<td>D 4632</td>
<td>800 N min. in MD</td>
<td>450 N min.</td>
</tr>
<tr>
<td>and CMD</td>
<td></td>
<td>450 N min.</td>
<td></td>
</tr>
<tr>
<td>Grab Failure Strain, min. in MD</td>
<td>D 4632</td>
<td>30% max. at 800 N or more</td>
<td>---</td>
</tr>
<tr>
<td>only</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultraviolet (UV) Radiation Stability</td>
<td>D 4355</td>
<td>70% Strength Retained min., after 500 hr in weatherometer</td>
<td>70% Strength Retained min., after 500 hr in weatherometer</td>
</tr>
</tbody>
</table>

NOTES:
1. All geotextile properties in Table 1 are minimum average roll values \((i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table).\)
2. The test procedures used are essentially in conformance with the most recently approved ASTM geotextile test procedures, except for geotextile sampling and specimen conditioning, which are in accordance with WSDOT Test Methods 914 and 915, respectively. Copies of these test methods are available at the Headquarters Materials Laboratory in Tumwater.
Geotextile Approval and Acceptance

Source Approval

The Contractor shall submit to the Engineer the following information regarding each geotextile proposed for use:

- Manufacturer’s name and current address,
- Full product name,
- Geotextile structure, including fiber/yarn type, and
- Proposed geotextile use(s).

If the geotextile source has not been previously evaluated, a sample of each proposed geotextile shall be submitted to the Headquarters Materials Laboratory in Tumwater for evaluation. After the sample and required information for each geotextile type have arrived at the Headquarters Materials Laboratory in Tumwater, a maximum of 14 calendar days will be required for this testing. Source approval will be based on conformance to the applicable values from Tables 1 through 6. Source approval shall not be the basis of acceptance of specific lots of material unless the lot sampled can be clearly identified and the number of samples tested and approved meet the requirements of WSDOT Test Method 914.

Geotextile Samples for Source Approval

Each sample shall have minimum dimensions of 1.5 meters by the full roll width of the geotextile. A minimum of 6 square meters of geotextile shall be submitted to the Engineer for testing. The geotextile machine direction shall be marked clearly on each sample submitted for testing. The machine direction is defined as the direction perpendicular to the axis of the geotextile roll. Source approval for temporary silt fences will be by manufacturer’s certificate of compliance as described under "Acceptance Samples."

The geotextile samples shall be cut from the geotextile roll with scissors, sharp knife, or other suitable method which produces a smooth geotextile edge and does not cause geotextile ripping or tearing. The samples shall not be taken from the outer wrap of the geotextile roll nor the inner wrap of the core.

Acceptance Samples

Samples will be randomly taken by the Engineer at the job site to confirm that the geotextile meets the property values specified.

Approval will be based on testing of samples from each lot. A "lot" shall be defined for the purposes of this specification as all geotextile rolls within the consignment (i.e., all rolls sent to the project site) which were produced by the same manufacturer during a continuous period of production at the same manufacturing plant and have the same product name. After the samples and manufacturer’s certificate of compliance have arrived at the Headquarters Materials Laboratory in Tumwater, a maximum of 14 calendar days will be required for this testing. If the results of the testing show that a geotextile lot, as defined, does not meet the properties required for the specified use as indicated in Tables 1 through 6 the roll or rolls which were sampled will be rejected. Two additional rolls for each roll tested which failed from the lot previously tested will then be selected at random by the Engineer for sampling and retesting. If the retesting shows that any of the additional rolls tested do not meet the required properties, the entire lot will be rejected. If the test results from all the rolls retested meet the required properties, the entire lot minus the roll(s) which failed will be accepted. All geotextile which has defects, deterioration, or damage, as determined by the Engineer, will also be rejected. All rejected geotextile shall be replaced at no cost to the State.

Acceptance by Certificate of Compliance

When the quantities of geotextile proposed for use in each geotextile application are less than or equal to the following amounts, acceptance shall be by Manufacturer’s Certificate of Compliance:

| Application: Temporary Silt Fence | Geotextile Quantities: All quantities |

The manufacturer’s certificate of compliance shall include the following information about each geotextile roll to be used:

- Manufacturer’s name and current address,
- Full product name,
- Geotextile structure, including fiber/yarn type
- Geotextile roll number,

Temporary Runoff and Sediment Control 135
Proposed geotextile use(s), and
Certified test results.

Approval of Seams
If the geotextile seams are to be sewn in the field, the Contractor shall provide a section of sewn seam before the geotextile is installed which can be sampled by the Engineer.

The seam sewn for sampling shall be sewn using the same equipment and procedures as will be used to sew the production seams. If production seams will be sewn in both the machine and cross-machine directions, the Contractor must provide sewn seams for sampling which are oriented in both the machine and cross-machine directions. The seams sewn for sampling must be at least 2 meters in length in each geotextile direction. If the seams are sewn in the factory, the Engineer will obtain samples of the factory seam at random from any of the rolls to be used. The seam assembly description shall be submitted by the Contractor to the Engineer and will be included with the seam sample obtained for testing. This description shall include the seam type, stitch type, sewing thread type(s), and stitch density.

Construction Geotextile (Installation Requirements)

Description
The Contractor shall furnish and place construction geotextile in accordance with the details shown in the Plans.

Identification, Shipment and Storage
Geotextile roll identification, storage, and handling shall be in conformance to ASTM D 4873. During periods of shipment and storage, the geotextile shall be kept dry at all times and shall be stored off the ground. Under no circumstances, either during shipment or storage, shall the material be exposed to sunlight, or other form of light which contains ultraviolet rays, for more than five calendar days.

Installation
The Contractor shall be fully responsible to install and maintain temporary silt fences at the locations shown in the Plans. A silt fence shall not be considered temporary if the silt fence must function beyond the life of the contract. The silt fence shall minimize soil carried by runoff water from going beneath, through, or over the top of the silt fence, but shall allow the water to pass through the fence. The minimum height of the top of the silt fence shall be 600 mm and the maximum height shall be 750 mm above the original ground surface. Damaged or otherwise improperly functioning portions of silt fences shall be repaired or replaced by the Contractor at no expense to the Contracting Agency, as determined by the Engineer.

The geotextile shall be attached on the up-slope side of the posts and support system with staples, wire, or in accordance with the manufacturer's recommendations. The staples or wire shall be installed through or around a 13 mm thick wood lath placed against the geotextile at the fence posts, or other method approved by the Engineer, to reduce potential for geotextile tearing at the staples or wire. Silt fence back-up support for the geotextile in the form of a wire or plastic mesh is optional, depending on the properties of the geotextile selected for use in Table 1. If wire or plastic back-up mesh is used, the mesh shall be fastened securely to the up-slope of the posts with the geotextile being up-slope of the mesh back-up support.

The geotextile shall be sewn together at all edges at the point of manufacture, or at an approved location as determined by the Engineer, to form geotextile lengths and widths as required. Alternatively, a geotextile seam may be formed by folding the geotextile from each geotextile section over on itself several times and firmly attaching the folded seam to the fence post, provided that the Contractor can demonstrate, to the satisfaction of the Engineer, that the folded geotextile seam can withstand the expected sediment loading.

The geotextile at the bottom of the fence shall be buried in a trench to a minimum depth of 150 mm below the ground surface. The trench shall be backfilled and the soil tamped in place over the buried portion of the geotextile as shown in the Plans such that no flow can pass beneath the fence nor scour occur. When wire or polymeric back-up support mesh is used, the wire or polymeric mesh shall extend into the trench a minimum of 80 mm. The fence posts shall be placed or driven a minimum of 600 mm into the ground. A minimum depth of 300 mm will be allowed if topsoil
or other soft subgrade soil is not present, and the minimum depth of 600 mm cannot be reached. Fence post depths shall be increased by 150 mm if the fence is located on slopes of 3:1 or steeper and the slope is perpendicular to the fence. If the required post depths cannot be obtained, the posts shall be adequately secured by bracing or guying to prevent overturning of the fence due to sediment loading, as approved by the Engineer.

Silt fences shall be located on contour as much as possible, except at the ends of the fence, where the fence shall be turned uphill such that the silt fence captures the runoff water and prevents water from flowing around the end of the fence as shown in the Plans. If the fence must cross contours, with the exception of the ends of the fence, gravel check dams placed perpendicular to the back of the fence shall be used to minimize concentrated flow and erosion along the back of the fence. The gravel check dams shall be approximately 0.3 m deep at the back of the fence and be continued perpendicular to the fence at the same elevation until the top of the check dam intercepts the ground surface behind the fence as shown in the Plans. The gravel check dams shall consist of Crushed Surfacing Base Course (Section 9-03.9(3)), Gravel Backfill for Walls (Section 9-03.12(2)), or Shoulder Ballast (Section 9-03.9(2)).

The gravel check dams shall be located every 3 m along the fence where the fence must cross contours. The slope of the fence line where contours must be crossed shall not be steeper than 3:1.

Either wood or steel posts shall be used. Wood posts shall have minimum dimensions of 40 mm by 40 mm by the minimum length shown in the Plans, and shall be free of defects such as knots, splits, or gouges. Steel posts shall consist of either size No. 8 rebar or larger, or shall consist of ASTM A 120 steel pipe with a minimum diameter of 25 mm. The spacing of the support posts shall be a maximum of 2.0 m as shown in the plans.

Fence backup support, if used, shall consist of steel wire with maximum a mesh spacing of 50 mm, or a prefabricated polymeric mesh. The strength of the wire or polymeric mesh shall be equivalent to or greater than that required in Table 1 for the geotextile (i.e., 800 N grab tensile strength) if it is unsupported between posts. The polymeric mesh must be as resistant to ultraviolet radiation as the geotextile it supports.

Sediment deposits shall either be removed when the deposit reaches approximately one-third the height of the silt fence, or a second silt fence shall be installed, as determined by the Engineer.

Measurement
Construction geotextile, with the exception of temporary silt fence geotextile and underground drainage geotextile used in trench drains, will be measured by the square meter for the ground surface area actually covered. Temporary silt fence geotextile will be measured by the linear meter of silt fence installed. Underground drainage geotextile used in trench drains will be measured by the square meter for the perimeter of drain actually covered.

Payment
Payment will be made in accordance with Section 1-04.1, for each of the following bid items that are included in the "Construction Geotextile For Temporary Silt Fence", per linear meter.

Sediment removal behind silt fences will be paid by force account under temporary water pollution/erosion control. If a new silt fence is installed in lieu of sediment removal, as determined by the Engineer, the silt fence will be paid for at the unit contract price per linear meter for "Construction Geotextile For Silt Fence".

4.5 INSTALLATION PROCEDURES

Silt fences are quite simple to construct; the normal construction sequence is shown in Figure 4-5. Installation of a prefabricated silt fence is shown in Figure 4-6.

1. Install wooden or steel fence posts or large wooden stakes in a row, with normal spacing between 0.5 to 3 m, center to center, and to a depth of 0.4 to 0.6 m. Most prefabricated fences have posts spaced approximately 2 to 3 m apart, which is usually adequate (Step 1).
2. Construct a small (minimum \(0.15\) m deep and \(0.1\) m wide) trench on the upstream side of the silt fence (Step 2).
3. Attach reinforcing wire, if required, to the posts (Step 3).
4. If a prefabricated silt fence is not being used, the geotextile must be attached to the posts using staples, reinforcing wire, or other attachments provided by the manufacturer. Geotextile should be extended at least \(150\) mm below the ground surface (Step 4 & 5).
5. Bury the lower end of the geotextile in the upstream trench and backfill with natural material, tamping the backfill to provide good anchorage (Step 6).

The field inspector should review the field inspection guidelines in Section 1.7.

### 4.6 INSPECTION AND MAINTENANCE

Silt fences should be checked periodically, especially after a rainfall or storm event. Excessive buildup of sediment must be removed so the silt fence can function properly. Generally, sediment buildup behind the fence should be removed when it reaches \(\frac{1}{3}\) to \(\frac{1}{2}\) of the fence height. Repair or replace any split, torn slumping or weathered geotextile. The toe trench should also be checked to ensure that runoff is not piping under the fence.

### 4.7 SILT AND TURBIDITY CURTAINS

Silt and turbidity curtains perform essentially the same function as silt fences; that is, the geotextile intercepts sediment-laden water while allowing clear water to pass. Thus, for maximum efficiency, a silt or turbidity curtain should pass a maximum amount of water while retaining a maximum amount of sediment. Unfortunately, such optimum performance is normally not possible because sediments will eventually blind or clog (Figure 2-3) the geotextile. To maximize the geotextile's efficiency, the following soil, site, and environmental conditions should be established, and the geotextile selected should provide a specific filtering efficiency while maintaining the required flow rate (Bell and Hicks, 1980).

1. Grain size distribution of soil to be filtered.
2. Estimate of the soil volume to be filtered during construction.
3. Flow conditions, anticipated runoff, and water level fluctuations.
4. Expected environmental conditions, including temperature and duration of sunlight exposure.
5. Velocity, direction, and quantity of discharge water.
6. Water depth and levels of turbidity.
7. Survey of the bottom sediments and vegetation at the site.
8. Wind conditions.
Figure 4-5  Typical silt fence installation.
Figure 4-6 Installation of a prefabricated silt fence.

On the basis of these considerations, the geotextile can then be selected either according to the properties required to maximize particle retention and flow capacity while resisting clogging, or by performing filtration model studies such as ASTM D 5141. The first approach follows the criteria developed in Chapter 2 for drainage systems. Silt and turbidity curtains are generally concerned with fine-grained soils, therefore, the following criteria could be considered when selecting the geotextile.

A. Retention Criteria

\[
AOS = D_{85} \text{ for woven geotextiles.}
\]

\[
AOS = 1.8 \times D_{85} \text{ for nonwovens.}
\]

NOTE: The \( D_{85} \) is a characteristic large-grain size appropriate to the suspended sediment grain size distribution. It will be strongly influenced by items Nos. 1, 3, 5, 6, and 7 above.

B. Flow Capacity Criteria

\[
\psi = \left( 10 q \right) / A
\]

where:

\[
\psi = \text{permittivity of geotextile (T}^{-1}\text{)}
\]

\[
q = \text{flow rate (L}^3/\text{T)}
\]
A = cross-sectional area silt curtain (L²)
10 = factor of safety

C. Clogging Resistance

Maximize AOS requirements using largest opening possible from criterion A above.

For silt and turbidity curtain construction, the geotextile forming the curtain is held vertical by flotation segments at the top and a ballast along the bottom (Bell and Hicks, 1980). A tension cable is often built into the curtain immediately above or below the flotation segments to absorb stress imposed by currents, wave action, and wind. Barrier sections are usually about 30 m long and of any required width. Curtains can also be constructed within shallow bodies of water using silt fence-type construction methods. Geotextiles have also been attached to soldier piles and draped across riprap barriers as semipermanent curtains.

The U.S. Army Corps of Engineers (1977) indicates that silt and turbidity curtains are not appropriate for certain conditions, such as:
- operations in open ocean;
- operations in currents exceeding 0.5 m/s;
- in areas frequently exposed to high winds and large breaking waves; and
- near hopper or cutter head dredges where frequent curtain movement would be necessary.

4.8 EROSION CONTROL BLANKETS

In freshly graded areas, the soil is susceptible to erosion by rainfall and runoff. Temporary, degradable blankets are used to enhance the establishment of vegetation. These products are used where vegetation alone provides sufficient site protection after the temporary products degrade. Such products are usually evaluated by field trial sections, and, therefore, are empirically designed. There are very few published records of comparative use, so the user must decide on the preferable system, usually based on local experience. You should be aware that a variety of products and systems exist. As an aid to selecting the best system, consult manufacturers and other agencies about their experiences.

Erosion protection must be provided for three distinct phases, namely:
1. prior to vegetation growth;
2. during vegetation growth; and
3. after vegetation is fully established.
Erosion control blankets provide protection during the first two phases. After vegetation is established protection can be provided by erosion control mats that reinforce the vegetation root mass, as discussed in Chapter 3.

Geosynthetic erosion control blankets are manufactured of light-weight polymer net(s) and a bedding of polymer webbing or organic materials such as straw or coconut. The bedding material protects the soil against erosion and helps retain moisture, seeds, and soil to promote growth. These polymer materials are typically not stabilized against ultraviolet light, and are designed to degrade over time. Erosion control blankets have design lives that vary between approximately 6 months to 5 years. Some blankets are provided with seeds encased in paper.

Erosion control blankets provide protection against moderate-flow velocities for short periods of time. They are typically used on moderate slopes and low velocity intermittent flow channels. Flows up to 1.5 m/s and durations of ½ to approximately 5 hours can be withstood, as illustrated in Figure 4-7. Again, design is empirical, and blanket product manufacturers should have actual flume test data and design recommendations available for their specific products. Duration of flume tests should be noted.

Figure 4-7  Recommended maximum design velocities and flow durations for various classes of erosion control materials (after Theisen, 1992).
Since the design of erosion control blankets is empirical, specification by index properties is not easily accomplished. Also, relatively few test methods have been standardized for erosion control blankets. Therefore, it is recommended that specifications use an approved products list.

Construction plans and specifications should detail and note installation requirements. Details such as anchoring in trenches, use of pins, pin length, pin spacing, roll overlap requirements, and roll termination should be addressed.

The following example specification for erosion control blankets is after the Texas Department of Transportation specification for RECP (rolled erosion control products). This agency tests candidate erosion control materials and categorizes them into classes and types in an approved materials list.

SOIL EROSION CONTROL BLANKETS
(after Texas Department of Transportation, Special Specification, Item 1225, February 1993)

1. DESCRIPTION.

This item shall govern for providing and placing wood, straw, or coconut fiber mat, synthetic mat, jute mesh or other material as a soil erosion control blankets on slopes or ditches or for short-term or long-term protection of seeded areas as shown on the plans or as specified by the Engineer.

2. MATERIALS.

(1) Soil Erosion Control Blankets. All soil erosion control blankets must be prequalified by the Director of Maintenance and Operations prior to use.

Prequalification procedures and a current list of prequalified materials may be obtained by writing to the Director of Maintenance and Operations. A 0.3 m x 0.3 m sample of the material may be required by the Engineer in order to verify prequalification. Samples taken, accompanied by the manufacturer’s literature, will be sent, properly wrapped and identified, to the Division of Maintenance and Operations for verification.

The soil erosion control blanket shall be one (1) of the following classes and types as shown on the plans:

(a) Class 1. "Slope Protection"

(i) Type A. Slopes of 3:1 or flatter — Clay soils

Prequalified Type A products are:

__________________________________________
__________________________________________
__________________________________________
__________________________________________
__________________________________________

Temporary Runoff and Sediment Control
(ii) Type B. Slopes of 3:1 or flatter — Sandy soils

Prequalified Type B products are:

(iii) Type C. Slopes steeper than 3:1 — Clay soils

Prequalified Type C products are:

(iv) Type D. Slopes steeper than 3:1 — Sandy soils

Prequalified Type D products are:

(b) Class 2. “Flexible Channel Liner”

(i) Type E. Short-term duration (Up to 2 Years)
Shear Stress ($t_d$) < 50 Pa

Prequalified Type E products are:

(ii) Type F. Short-term duration (Up to 2 Years)
Shear Stress ($t_d$) 50 to 95 Pa

Prequalified Type F products are:

(2) Staples. Staples for anchoring the soil erosion control mat shall be U-shaped, made of 3 mm or large diameter steel wire, or other approved material, have a width of 25 to 50 mm, and a length of not less than 150 mm for firm soils and not less than 300 mm for loose soils.

3. CONSTRUCTION METHODS.

(1) General. The soil erosion control blanket shall conform to the class and type shown on the plans. The Contractor has the option of selecting an approved soil erosion control blanket conforming to the class and type shown on the plans, and according to the current approved material list.
(2) **Installation.** The soil erosion control blanket, whether installed as slope protection or as flexible channel liner in accordance with the approved materials list, shall be placed within 24 hours after seeding or sodding operations have been completed, or as approved by the Engineer. Prior to placing the blanket, the area to be covered shall be relatively free of all rocks or clods over 38 mm in maximum dimension and all sticks or other foreign material which will prevent the close contact of the blanket with the soil. The area shall be smooth and free of ruts or depressions exist for any reason, the Contractor shall be required to rework the soil until it is smooth and to reseed or resod the area at the Contractor's expense.

Installation and anchorage of the soil erosion control mat shall be in accordance with the project construction drawings unless otherwise specified in the contract or directed by the Engineer.

(3) **Literature.** The Contractor shall submit one (1) full set of manufacturer's literature and manufacturer's installation recommendations for the soil erosion control blanket selected in accordance with the approved material list.

4. **MEASUREMENT.**

This Item will be measured by the square meter of surface area covered.

5. **PAYMENT.**

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Soil Erosion Control Blanket" of the class and type shown on the plans. This price shall be full compensation for furnishing all materials, labor, tools, equipment and incidentals necessary to complete the work. Anchors, checks, terminals or junction slots, and wire staples or wood stakes will not be paid for directly but will be considered subsidiary to this Item.

4.9 **REFERENCES**


ASTM Test Methods - see Appendix E.


