Chapter 20

GEOSYNTHETIC DESIGN

GEOTECHNICAL DESIGN MANUAL

January 2022

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CHAPTER 20

GEOSYNTHETIC DESIGN

20.1 INTRODUCTION

According to Holtz, Christopher, and Berg (2008),

> ASTM (2006) D4439 defines a geosynthetic as a planar product manufactured from a polymeric material used with soil, rock, earth or other geotechnical-related material as an integral part of a civil engineering project, structure, or system.

Geosynthetic materials are comprised of 4 basic groups: geotextiles, geogrids, geomembranes, and geocomposites. Each of these basic groups is discussed in greater detail below. The materials making up the geosynthetics may be either man-made or natural. The most common man-made materials consist of synthetic polymers such as polypropylene (PP), polyester (PET) and high density polyethylene (HDPE). It should be noted that these polymers are highly resistant to biological and chemical degradation. Other man-made polymers used less frequently are polyamides, polyvinyl chloride (PVC) and glass fibers. The polyamides (e.g., nylon) are not very durable in the soil since they tend to soften in the presence of water. Natural materials consist of cotton, jute, etc.; however, natural materials are biodegradable and, therefore, should be used for temporary ($\leq$ 1 year) applications only. Figure 20-1 provides a classification scheme for geosynthetics. Chapter 2 provides a glossary of selected geosynthetic terms which are based on ASTM (2006) D4439 *Standard Terminology for Geosynthetics*.

SCDOT has prepared STSs for various geosynthetic materials depending on the use of the material. Geosynthetic materials used for separation and stabilization shall conform to the requirements of SC-M-203-1 (latest version) for *Geosynthetic Materials for Separation and Stabilization.* Two STSs have been developed for soil reinforcement, SC-M-203-2 and SC-M-203-3 (latest version) for *Geogrid Soil Reinforcement* and *Geotextile Soil Reinforcement*, respectively. Either geosynthetic group (i.e. geogrids or geotextiles) can be used for reinforced embankments or RSSs as defined in Chapter 17. Reinforcement geosynthetics should not be used for stabilization or separation even though the materials may be the same. The difference in use is that geosynthetics used in slope stability analysis are reinforcement. If the geosynthetic is not used in slope stability analysis then it is a separation and stabilization material. The latest version of the STSs is available on the SCDOT website:

> https://www.scdot.org/business/business-landing.aspx.

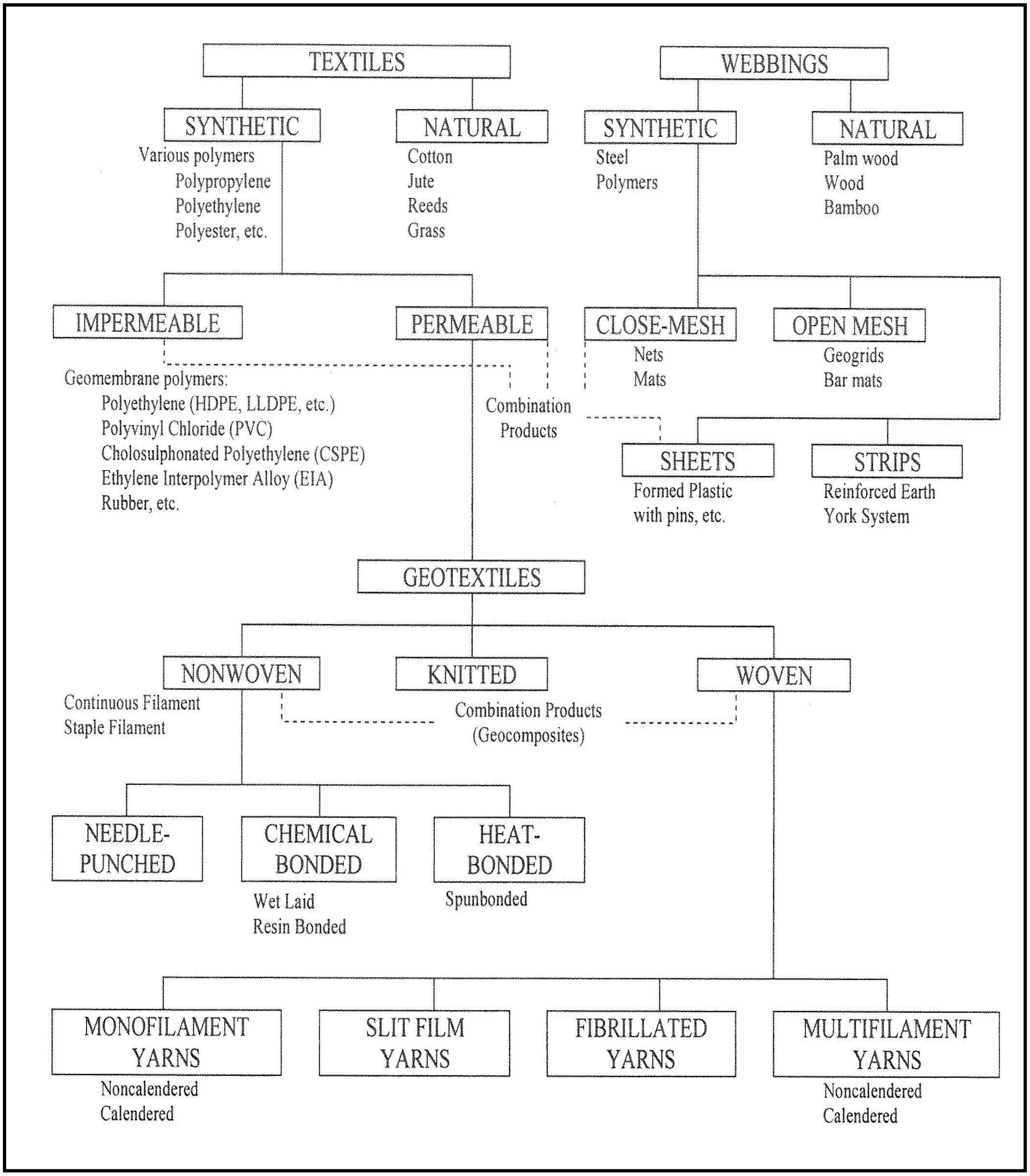

Figure 20-1, Geosynthetic Classification Scheme (Holtz, et al. (2008))

Geosynthetics are identified using the information contained in Table 20-1.

Table 20-1, Geosynthetic Generic Identifiers (adopted from Holtz, et al. (2008))

Identifier	Descriptive Term	Example
Polymer	High density, low density, etc.	**High density polyethylene** geomembrane
Type of Element	Filament, yarn, type, strand, rib, coated rib, etc.	Polypropylene staple **filament** needlepunched nonwoven geotextile, 10 oz/yd^2
Manufacturing Process	Woven, needlepunched nonwoven, heatbonded nonwoven, stitchbonded, extruded, knitted, welded, uniaxial, biaxial, roughened sheet, smooth sheet, etc.	Polypropylene staple filament **needlepunched nonwoven** geotextile, 10 oz/yd^2
Primary Geosynthetic Type	Geotextile, geogrid, geomembrane, etc.	High density polyethylene **geomembrane**
Mass per Unit Area or Thickness[1]	Mass per unit area – geotextiles Thickness – geomembranes	Polypropylene staple filament needlepunched nonwoven geotextile, **10 oz/yd^2**
Additional Information	As required	Polypropylene extruded biaxial geogrid, **with 1 in x 1 in openings**

[1]As appropriate

20.2 GEOTEXTILES

Geotextiles are subdivided into 2 categories: woven and nonwoven. Both categories are comprised of fibers or yarns that are combined into a planar textile structure. The fibers can be either continuous filaments or staple fibers. The continuous filaments are very long thin polymeric strands, whereas, the staple fibers are short (3/4 to 6 inches) filaments. Both filament types can be manufactured from an extruded plastic sheet that is slit to form thin, flat tapes. The extrusion or drawing process elongates the polymers in the direction of the draw causing an increase in the strength of the filament. After the drawing process, filaments may also be fibrillated, a process in which the filaments are split into finer filaments by crimping, twisting, cutting, or nipping with a pinned roller. Fibrillation provides pliable, multifilament yarns with a more open structure that are easier to weave.

Woven geotextiles are made of monofilament, multifilament, or fibrillated yarns or of slit film tapes. This category of geotextiles is manufactured similarly to cloth or other textiles, using traditional weaving techniques. In nonwoven geotextile manufacturing, the polymeric fibers or filaments are continuously extruded and spun, blown or otherwise, placed onto a moving conveyor belt. The mass of fibers or filaments are then either needlepunched or heat bonded. Needlepunch is the process of mechanically entangling the fibers or filaments using a series of small needles. Heat bonding is the process in which individual fibers or filaments are welded together by heat and pressure at contact points to create a nonwoven mass.

Overlapping of the geotextiles in the strong axis direction is not permitted. The use of sewn seams may be permitted in the strong axis direction; however, the strength of the geotextile will be reduced to the strength of the sewn seam. The sewn seam strength (whether field or factory sewn) shall be at least 25 percent of T_{ult} (ASTM D4884 – *Standard Test Method for Strength of Sewn or Bonded Seams of Geotextiles*). Prior to using sewn seams obtain written permission from the OES/GDS. For sewn seams use thread that consists of either polypropylene or polyester polymers and which has a strength matching the strength of the geotextile being seamed. Do not use nylon thread. Use thread that is of contrasting color to that of the geotextile itself. Use a double row of double-thread chain stitch, Type 401 as defined by ASTM D6193 – *Standard Practice for Stitches and Seams* (see Figure 20-2). Use 150 to 400 stitches per yard depending on the weight of the geotextile. The GEOR should consult with a geotextile manufacturer or supplier to determine the appropriate stitch density. Use either a "butterfly" seam (Type SSd) or "J" seam (Type SSn) as defined in ASTM D6193 (see Figure 20-3). Geotextiles may be overlapped in the weak axis direction. The minimum overlap shall be 12 inches. If a sewn seam is allowed in the strong axis direction, the GEOR is reminded that the location of the sewn seam, the type of thread, the color contrast of the thread, the type and density of stitching, and the seam type shall be shown on the plans. In addition, the sewn seam should be easily visible during construction (see Figure 20-4) and the placement of the seam should be indicated on the plans. The seam should not be placed as indicated in Figure 20-5. Further, the plans should also include a requirement for the Contractor to provide the results of sewn seam testing.

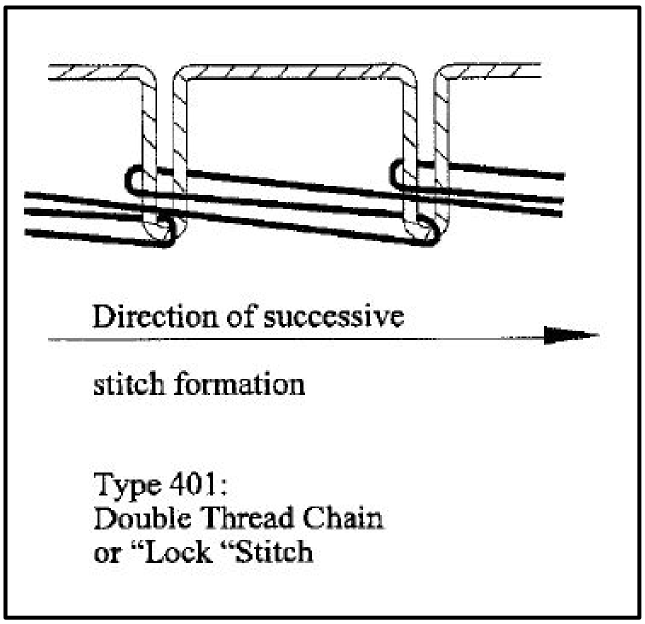

Figure 20-2, Stitch Type
(Holtz, et al. (2008))

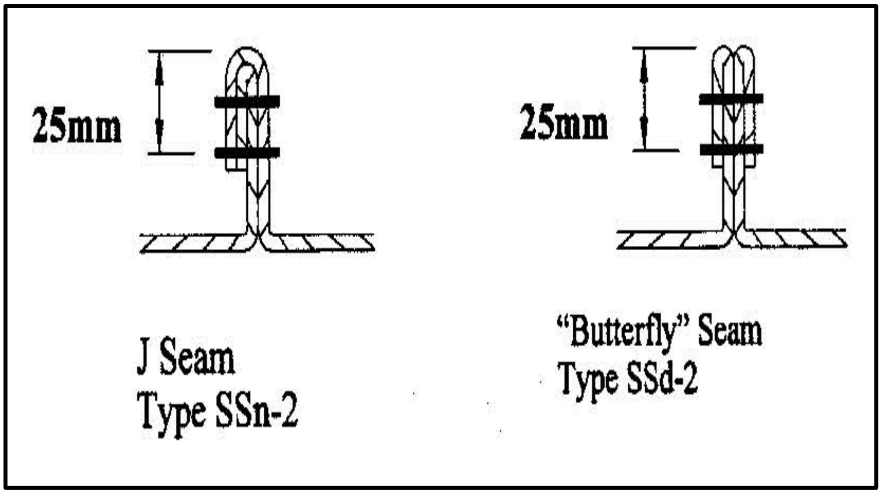

Figure 20-3, Seam Type
(Holtz, et al. (2008))

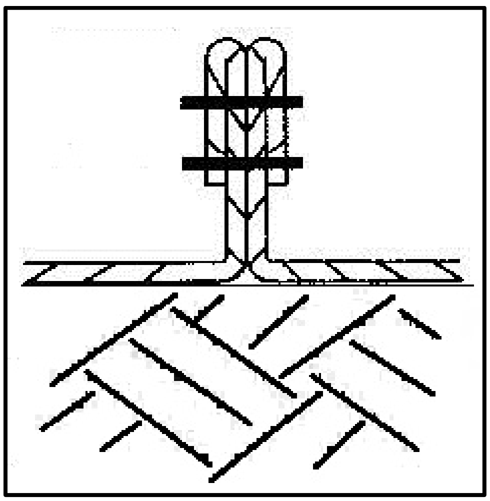

Figure 20-4, Proper Seam Placement
(Holtz, et al. (2008))

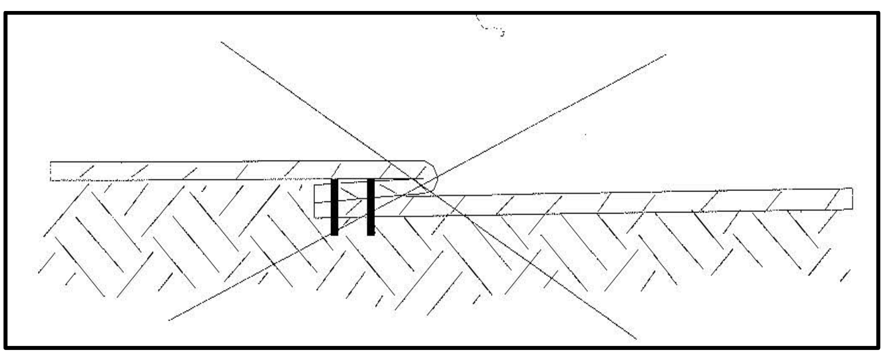

Figure 20-5, Improper Seam Placement
(Holtz, et al. (2008))

20.3 GEOGRIDS

Geogrids are formed by a regular network of tensile elements with openings of sufficient size to allow interlock with the surrounding fill materials. The primary purpose of geogrids is reinforcement. Geogrids can be manufactured in 3 ways: extrusion, knitting or weaving, and welding. Extruded geogrids, also called integral geogrids, are manufactured with integral junctions by extruding and orienting polymeric (polyethylene or polypropylene) materials. Geogrids may also be manufactured of multifilament polyester yarns, joined at the crossover points by knitting or weaving processes and then encased with a polymer-based, plasticized coating. Welded geogrids are manufactured by welding polymeric strips together at the cross over points. All of these manufacturing techniques allow geogrids to be oriented such that the principal strength is in a single direction (uniaxial geogrids) or in both directions (biaxial geogrids). In biaxial geogrids, the strength is typically not the same in both directions.

Overlapping of geogrids in the strong axis direction is not permitted. The use of a mechanical connection (i.e., a bodkin connector (see Figure 20-6)) will be permitted, provided the strength of the connection is equal to the required geogrid strength or if reduced geogrid strength equal to the connection is used. Prior to using a mechanical connection obtain written permission from the OES/GDS. Geogrids may be overlapped in the transverse (i.e., perpendicular to the slope face) direction. The minimum overlap shall be 12 inches. If a mechanical connection is allowed in the strong axis direction, the GEOR is reminded that the location, type and material for the connection, shall be shown on the plans. In addition, the plans should also include a requirement for the Contractor to provide the results of testing of the mechanical connection.

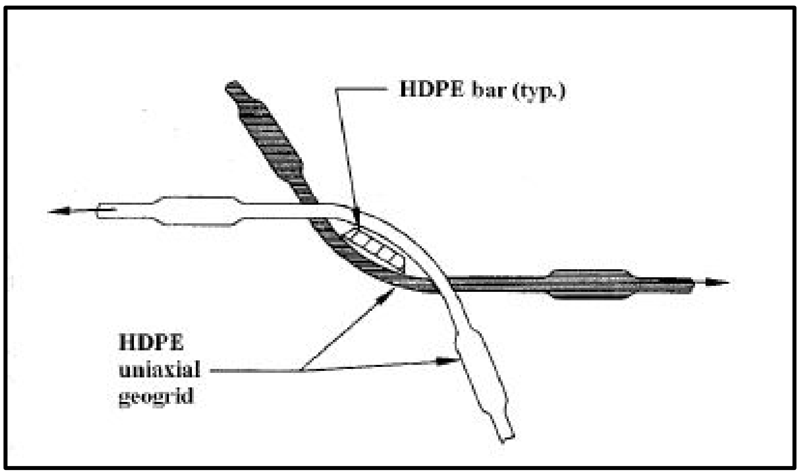

Figure 20-6, Geogrid Mechanical Connection
(Holtz, et al. (2008))

20.4 GEOMEMBRANES

Geomembranes, unlike geotextiles and geogrids, are manufactured with a single, solid sheet of geosynthetic material. Geomembranes are used as either a low-permeability or impermeable boundary to prevent the movement of fluids (either liquid or gas). The primary use of geomembranes is in the design and construction of landfills; however, geomembranes have selected uses on transportation projects, such as being used as an impermeable barrier above structural backfill behind an ERS or above lightweight EPS materials (see Figure 20-7). Because there are limited requirements for the use of geomembranes in transportation projects, geomembranes will not be discussed in the remainder of this Chapter.

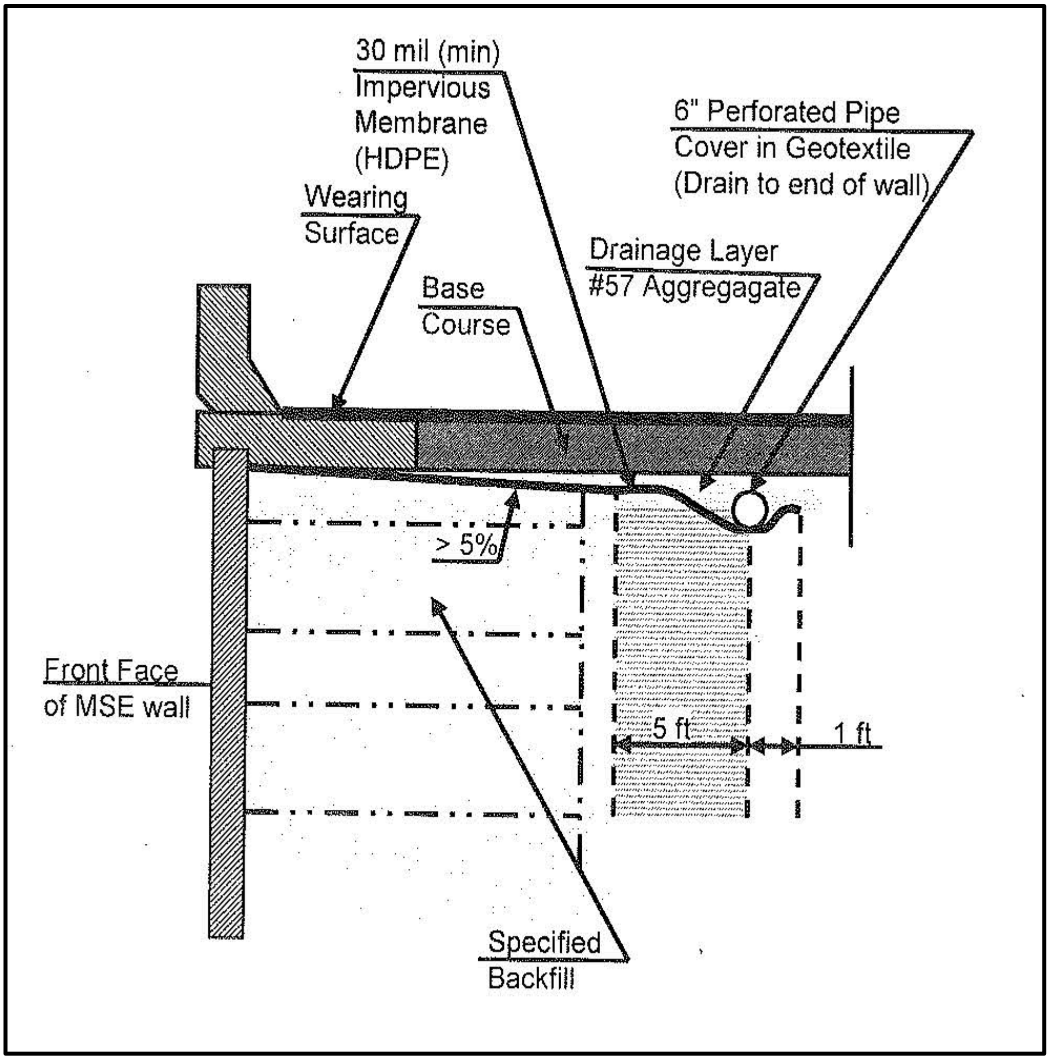

Figure 20-7, Geomembrane Use Above ERS
(Tanyu, Sabatini, and Berg (2008))

20.5 GEOCOMPOSITES

Geocomposites are the combination of 2 or more geosynthetic materials combined together, such as geotextiles and geogrids. Most geocomposites are used in either drainage applications or waste-containment. Prefabricated vertical drains (PVDs) are an example of geocomposites. Included in geocomposites are the 3-dimensional polymeric cell structures.

20.6 FUNCTIONS AND APPLICATIONS

Geosynthetics have 6 primary functions as listed below:

- Filtration
- Drainage
- Separation
- Reinforcement
- Fluid Barrier
- Protection

20.6.1 Filtration

Geotextiles (woven and nonwoven) are used as filters to prevent soils from migrating into drainage aggregate or pipes, while maintaining water flow through the system. These materials are also used below riprap and other armor materials to prevent erosion of the soils from the stream bank. For a geotextile to function as a filter, the Apparent Opening Size (AOS) must be smaller than the smallest size particle to be retained and still allow for the flow of water through the geotextile material. To provide good filtration, a geotextile should meet the criteria provided in the following equation.

$$\boldsymbol{AOS \leq B * D_{85(soil)}}$$ **Equation 20-1**

Where,

AOS = Apparent Opening Size (see Chapter 2), millimeter (mm)
$D_{85(soil)}$ = Diameter of soil particle for which 85 percent are smaller, mm
B = Dimensionless coefficient related to C_u

For Sand-Like soils B, for both woven and nonwoven geotextiles, is determined from the following equations.

For $C_u \leq 2$ or $C_u \geq 8$, then

$$\boldsymbol{B = 1.0}$$ **Equation 20-2**

For $2 \leq C_u \leq 4$, then

$$\boldsymbol{B = 0.5C_u}$$ **Equation 20-3**

For $4 \leq C_u \leq 8$, then

$$\boldsymbol{B = \frac{8}{C_u}}$$ **Equation 20-4**

For Clay-Like soils, B is a function of the type of geotextile.

Woven geotextiles

$$\boldsymbol{B = 1.0}$$ **Equation 20-5**

Nonwoven geotextiles

$$\boldsymbol{B = 1.8}$$ **Equation 20-6**

In addition to the AOS, the permeability and permittivity of the geotextile requires consideration. The selection of the correct filter is based on the critical/severe nature of the project. The criteria for critical/severe projects are provided in the following table.

Table 20-2, Guidelines for Evaluating Critical/Severe Nature (adopted from Holtz, et al. (2008))

A. Critical Nature of Project		
Item	**Critical**	**Less Critical**
Risk of loss of life and/or structural damage due to drain failure	High	None
Repair cost versus installation costs of drain	>>>	= or <
Evidence of drain clogging before potential catastrophic failure	None	Yes
B. Severity of Conditions		
Item	**Severe**	**Less Severe**
Soil to be drained	Gap-graded, pipable, or dispersible	Well-graded or uniform
Hydraulic gradient	High	Low
Flow conditions	Dynamic, cyclic, or pulsating	Steady state

For less critical applications and less severe conditions,

$$k_{geotextile} \geq k_{soil}$$ **Equation 20-7**

For critical applications and severe conditions,

$$k_{geotextile} \geq 10k_{soil}$$ **Equation 20-8**

Where,

$k_{geotextile}$ = Coefficient of permeability of geotextile
k_{soil} = Coefficient of permeability of soil

Permittivity is the coefficient of permeability normal to the plane of the geotextile divided by the thickness of the geotextile material (see Figure 20-8)

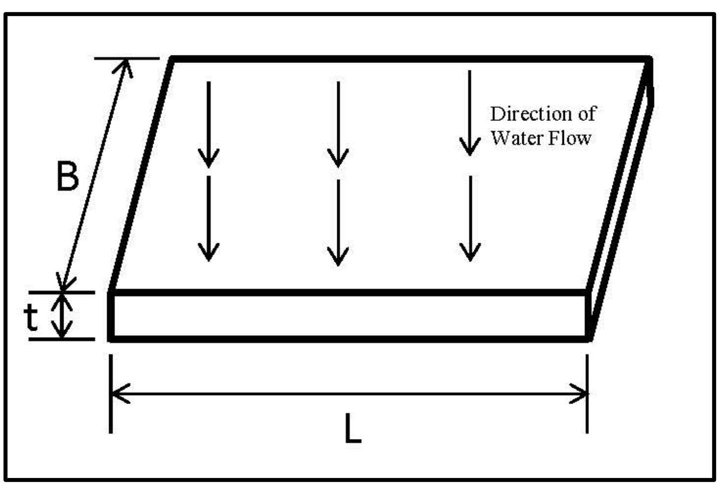

Figure 20-8, Permittivity

$$Q_n = \Psi * \Delta h * A_n \qquad \textbf{Equation 20-9}$$

$$\Psi = \frac{k_n}{t} \qquad \textbf{Equation 20-10}$$

$$A_n = L * B \qquad \textbf{Equation 20-11}$$

Where,

Q_n = Normal volumetric flow
Δh = Head causing flow
k_n= Coefficient of permeability normal to geotextile
t = Thickness of geotextile
Ψ = Permittivity of geotextile
L = Length of geotextile
B = Width of geotextile

The permittivity requirements depend on the fines content of the soil to be filtered. The more fines in the soil, the greater the permittivity required. The following table contains approximate fines content and recommended permittivity requirements based on previous experience.

Table 20-3, Permittivity Requirements (adopted from Holtz, et al. (2008))

Percent Passing No. 200 Sieve	Ψ (sec^{-1})
< 15	$\geq$ 0.5
15 – 50	$\geq$ 0.2
> 50	$\geq$ 0.1

20.6.2 Drainage

Nonwoven needlepunched geotextiles and geocomposites can also provide drainage by allowing water to drain from or through low permeability soils. The primary application of the use of geotextiles for drainage is in dissipation of excess pore pressures. In some cases, the nonwoven geotextile is thick and will allow the flow of water through geotextile material itself. This flow of water through (within) the geotextile material is called transmissivity. Transmissivity is the product of the permeability of the geotextile for in plane water flow and the thickness of the geotextile (see figure below).

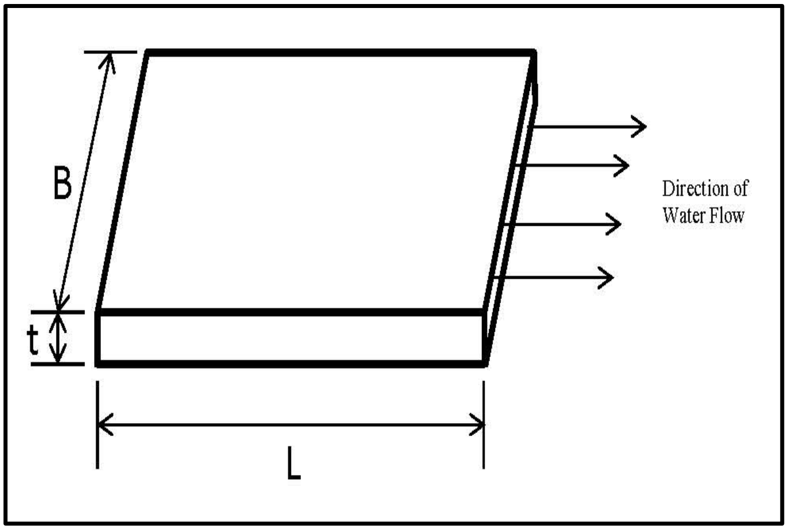

Figure 20-9, Transmissivity

$$Q_p = \Theta * i * B$$ **Equation 20-12**

$$\Theta = k_p * t$$ **Equation 20-13**

$$i = \frac{\Delta h}{L}$$ **Equation 20-14**

Where,

Q_p = In-plane volumetric flow
Δh = Head causing flow
i = Hydraulic gradient
k_p= Coefficient of permeability in plane to geotextile
t = Thickness of geotextile
Θ = Transmissivity of geotextile
L = Length of geotextile
B = Width of geotextile

20.6.3 Separators

Geosynthetic materials, primarily geotextiles, are used to prevent the migration of fines from subgrade soils into granular bases. The AOS of the geotextile should be sized to prevent the migration of fines. In addition, geogrids may also be used as a separator to prevent the migration of granular materials (aggregate) into fine-grained, soft subgrade soils (see Figure 20-10). However, this application will not prevent the migration of fines from the subgrade soil into the aggregate. The separator materials to be used shall meet the criteria provided in the latest version of the STS for *Geosynthetic Materials for Separation and Stabilization*, SC-M-203-1.

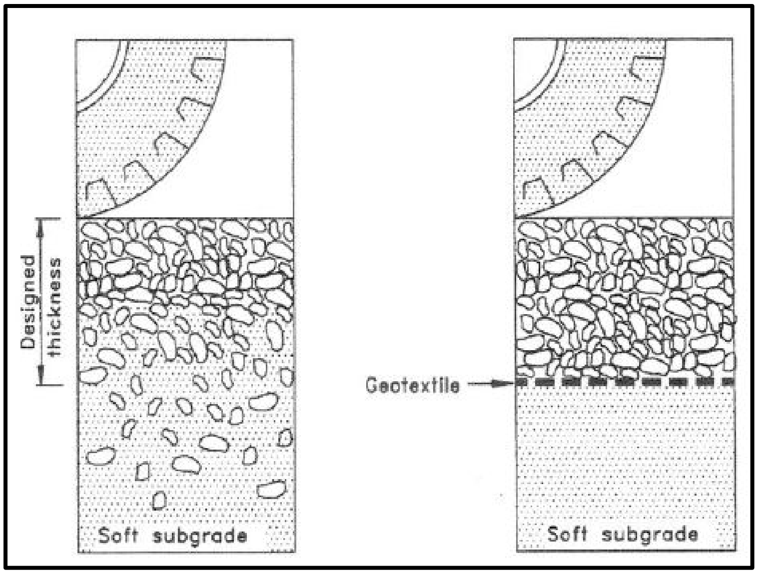

Figure 20-10, Geogrid Soil Separator (Holtz, et al. (2008))

20.6.4 Reinforcement

Both geotextiles and geogrids are used as reinforcement. These materials add tensile strength to a soil matrix, thus providing a more competent and stable material. Reinforcement enables embankments to be constructed over very soft foundation soils (see Chapter 17) and permits the construction of steep slopes and ERSs (see Chapters 17 and 18 and Appendices C and D). The reinforcement materials to be used shall meet the criteria provided in the latest version of the STSs for *Geogrid Soil Reinforcement*, SC-M-203-2 or *Geotextile Soil Reinforcement*, SC-M-203-3.

Geosynthetic materials used for stabilization shall meet the criteria provided in the latest version of the STS for *Geosynthetic Materials for Separation and Stabilization*, SC-M-203-1. Geosynthetic stabilization is a subset of reinforcement and is used to stabilize a subgrade to allow construction to proceed. The geosynthetic stabilization materials are not included in slope stability analysis; however, geosynthetic reinforcement materials are included in slope stability analysis.

20.6.5 Fluid Barriers

Geomembranes, geotextile composites, and geosynthetic clay liners are used as fluid barriers to impede the flow of a liquid or a gas from one location to another. As indicated previously, fluid barriers (geomembranes) are used in lightweight (EPS) fill applications for transportation projects. Fluid barriers have limited applications in transportation projects; therefore, there will be no detailed discussion of fluid barriers. If a fluid barrier is required, please refer to Holtz, et al. (2008) for additional details.

20.6.6 Protection

Geosynthetics provide protection by providing a stress relief layer. Temporary geosynthetic blankets and permanent geosynthetic mats are placed over the soil to reduce erosion caused by rainfall impact and water flow shear stress. Geosynthetics are also used to retard the development of reflection cracks in pavement overlays.

20.6.7 Secondary Applications

The previous Sections indicated the various primary functions of geosynthetics; however, geosynthetics can provide several secondary functions while providing the primary function. Provided in Table 20-4 are the primary function and some of the secondary functions. According to Holtz, et al. (2008),

> Design for the compaction improvement applications is simple. Place a *geosynthetic reinforcement* that will survive construction at every lift or every other lift in a continuous plane along the edge of the slopes. Only narrow strips, about 4 to 6 *feet* in width, at 2 to 20 *inches* vertical spacing are required. No reinforcement design is required if the overall slope is found to be safe without reinforcement.

Table 20-4, Primary and Secondary Functions (adopted from Holtz, et al. (2008))

Primary Function	Secondary Function	Selected Applications[1]
Filtration	Separation, drainage, protection, reinforcement, stabilization	Trench drains, pipe wrapping, base course drains
Drainage	Separation, filtration	Retaining walls, vertical and horizontal drains
Separation	Filtration, drainage, reinforcement	Working platforms, embankment construction
Reinforcement	Filtration, drainage, separation, stabilization	Base reinforcement, fill reinforcement, load redistribution
Fluid Barrier	Protection	Asphalt overlays[2]
Protection	Reinforcement, fluid barrier	Permanent and temporary erosion control

[1]More applications are possible; this is not a complete list

[2]Not currently allowed by SCDOT, presented here only for information

20.7 DESIGN APPROACH

Holtz, et al. (2008) recommends the following design procedure for geosynthetics:

1. Define the purpose and establish the scope of the project.
2. Investigate and establish the geotechnical conditions at the site (geology, subsurface exploration, laboratory and field testing, etc.)
3. Establish application criticality, severity, and performance criteria. Determine external factors that may influence geosynthetic performance.
4. Formulate trial designs and compare several alternatives.
5. Establish the models to be analyzed, determine the parameters, and carry out the analysis.
6. Compare results and select the most appropriate design; consider alternatives versus cost, construction feasibility, etc. Modify design if necessary.
7. Prepare detailed plans and specifications including:
    a) specific property requirements for the geosynthetic;

b) detailed installation procedures.

8. Hold preconstruction meeting with contractor and inspectors.
9. Approve geosynthetic on the basis of specimens' laboratory test results and/or manufacturer's certification.
10. Monitor construction.
11. Inspect after major events (e.g., 100-year rainfall or an earthquake) that may compromise system performance.

20.8 EVALUATION OF PROPERTIES

The required geosynthetic design properties depend on the specific application and associated function the geosynthetic is to provide. Table 20-5 provides a list of properties that cover the range of important criteria that are required to evaluate a geosynthetic for most applications. It should be noted that not all of the listed requirements will be necessary for all applications. Typically 6 to 8 properties are required for a specific application. The properties required for mechanical or hydraulic design are different from those required for constructability (survivability) and durability. Table 20-6 provides typical SCDOT applications along with the associated function. Tables 20-4, 20-5 and 20-6 should be used in conjunction to determine the appropriate properties for each application. All geosynthetic material properties can be placed into 3 basic categories: general, index, and performance. General properties are usually provided by the manufacturer or distributor or from publically available literature. Index properties were originally developed by manufacturers for quality control purposes and only provide an indication or qualitative assessment of the property of interest. Performance tests are an attempt to model the soil-geosynthetic interaction and, therefore, require the geosynthetic to be tested together with on-site soils. This type of testing provides a direct measure of specific properties of interest.

Table 20-5, Important Criteria and Principal Properties (adopted from Holtz, et al. (2008))

Criteria and Parameter	Property[1]	Function					
		Filtration	Drainage	Separation	Reinforcement	Fluid Barrier	Protection
Design Requirements:							
Mechanical Strength							
Tensile Strength	Wide Width Strength	-	-	-	✓	✓	-
Tensile Modulus	Wide Width Modulus	-	-	-	✓	✓	-
Seam Strength	Wide Width Strength	-	-	-	✓	✓	-
Tension Creep	Creep Resistance	-	-	-	✓	✓	-
Compression Creep	Creep Resistance	-	✓[2]	-	-	-	-
Soil-Geosynthetic Friction	Shear Strength	-	-	-	✓	✓	✓
Hydraulic							
Flow Capacity	Permeability	✓	✓	✓	✓	✓	-
	Transmissivity	-	✓	-	-	-	✓
Piping Resistance	AOS	✓	-	✓	✓	-	✓
	Porimetry	✓	-	-	-	-	✓
Clogging Resistance	Gradient Ratio or Long-Term Flow	✓	-	-	-	-	✓
Constructability Requirements:							
Tensile Strength	Grab Strength	✓	✓	✓	✓	✓	✓
Seam Strength	Grab Strength	✓	✓	✓	-	✓	-
Bursting Resistance	Burst Strength	✓	✓	✓	✓	✓	✓
Puncture Resistance	Rod or Pyramid Puncture	✓	✓	✓	✓	✓	✓
Tear Resistance	Trapezoidal Tear	✓	✓	✓	✓	✓	✓
Durability:							
Abrasion Resistance[3]	Reciprocating Block Abrasion	✓	-	-	-	-	-
UV Stability[4]	UV Resistance	✓	-	-	✓	✓	✓
Soil Environment[5]	Chemical	✓	✓	?	✓	✓	?
	Biological	✓	✓	?	✓	✓	?
	Wet-Dry	✓	✓	-	-	-	✓
	Freeze-Thaw	✓	✓	-	-	✓	-

Notes:
1. See Table 1-4 of Holtz, et al. (2008) for specific procedures.
2. Compression creep is applicable to some geocomposites.
3. Erosion control applications where armor stone may move.
4. Exposed geosynthetics only.
5. Where required.

Table 20-6, Evaluation of Geosynthetic Property Requirements (adopted from Holtz, et al. (2008))

Application	Function			
	Filtration	Drainage	Separation	Reinforcement
Subsurface Drainage	☑		✓	
Prefabricated Drains	✓	☑	✓	
Hard Armor Erosion Control			✓	
Silt Fence			✓	
Subgrade Separation	✓		☑	
Subgrade Stabilization	☑	✓	☑	✓
Base/Subbase Reinforcement			✓	☑
Embankments over Soft Subgrade	☑	✓	✓	☑
Reinforced Slopes		✓		☑
Reinforced Soil Walls	☑			
✓ indicates Primary Function ☑ indicates Secondary Function				

20.9 REFERENCES

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Holtz, R. D., Christopher, B. R., and Berg, R.R., (2008), Geosynthetic Design and Construction Guidelines, (FHWA NHI-07-092), U.S. Department of Transportation, National Highway Institute, Federal Highway Administration, Washington D.C.

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