Chapter 15 - Geosynthetic Design

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15.1 Introduction

This chapter provides an overview of geosynthetic types, materials, functions, and design for use in highway construction projects. Although geosynthetic materials have been used in highway construction for decades, design standards continue to evolve for existing and new applications. Geosynthetic technology continues to improve materials and their performance while research continues to improve design methods through the use of index properties.

15.1.1 Geosynthetic Products

Geosynthetic is defined in ASTM D4439 - Standard Terminology for Geosynthetics as a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system.

Geosynthetic product types discussed in this chapter are listed below. See also ASTM D4439 Standard Terminology for Geosynthetics for additional definitions.

- Geotextile - a permeable geosynthetic comprised solely of textiles.
- Geogrid - a geosynthetic formed by a regular network of integrally connected elements with apertures greater than 6.35 mm (1/4 in.) to allow interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as reinforcement.
- Geostrip - polymeric material in the form of a strip of width not more than 8 in., used in contact with soil or other materials.
- Geocomposite - a product composed of two or more materials, at least one of which is a geosynthetic.
- Geomembrane - an essentially impermeable geosynthetic composed of one or more synthetic sheets.
- Geocell - a three-dimensional comb-like structure, filled with soil, aggregate or concrete.
- Geonet - a geosynthetic consisting of integrally connected parallel sets of ribs overlying similar sets at various angles for planar drainage of liquids or gases.

15.1.2 Materials In Manufacture Of Geosynthetics

Geosynthetics are manufactured from synthetic polymers (for example polyethylenes, polypropylenes, polyester, etc.). A primary polymer resin may be combined with other resins, fillers and additives (for example UV absorbers, stabilizers, plasticisers, fibers, etc.) The formulation of polymers and additives, methods of manufacture, fiber type, fabric structure, and coating (if used)provides variability of geosynthetic product types, material properties, and performance properties, necessary to engineer solutions for construction applications.

15.1.3 Geosynthetic Functions

Geosynthetic functions presented in this chapter include:

- Filtration – To provide adequate water flow and limit soil clogging and migration through the Geosynthetic.
- Drainage – To provide capacity and conveyance for water flow through or along the plane of the geosynthetic. In typical geocomposite drains the flow is along the plane of the geosynthetic material combination.
- Separation – To provide isolation, maintain integrity and prevent intermixing between subsurface layers: preventing base aggregate from penetrating into soft subgrade, preventing pumping of fine grained soils into base aggregate.
- Reinforcement – To add tensile element to a soil or soil mass, creating a soil mass and geosynthetic reinforcement matrix which improves strength and stability. Examples for uses of reinforcement include MSE walls, reinforced soil slopes, subgrade stabilization and base/subbase courses of pavement structures.
- Fluid barrier -To impede the flow of a liquid or gas across the plane of the geosynthetic. Examples of fluid barriers include controlling moisture seepage into subgrade, stormwater ponds, prefabricated vertical drains, and bridge decks.
- Protection - Providing a layer to minimize damage: geosynthetic mat for erosion control, stress relief: addition of geotextile as puncture protection for geomembrane, geomembrane placement for protection of metallic reinforcements from infiltration of de-icing salts runoff into MSE backfill

15.1.4 Geosynthetic Material Selection And Specification

ASTM Committee D35 on Geosynthetics formulates test methods, specifications, guides, practices, and terminology regarding Geosynthetics materials testing. AASHTO Committee on Materials and Pavement (COMP), Technical Subcommittee 4e (TS4e) develops standards and guides, material specifications for bearings, joints and geosynthetics. TS4e has developed AASHTO M 288 Standard Specification for Geosynthetic Specification for Highway Applications. This specification is a materials specification for geosynthetics used in subsurface drainage, separation, stabilization, erosion control, temporary silt fence, paving, and soil (walls and slopes). The testing methods and criteria are organized by function with reference to ASTM test methods. The materials tables in ODOT Specifications 02320 Geosynthetics are produced from AASHTO M 288. National Transportation Product Evaluation Program (NTPEP) is a technical service program of AASHTO, resourced by State DOTs, AASHTO and contracted product materials testing and manufacturing auditors to evaluate materials, products, and devices of common interest for use in highway and bridge construction with a goal of eliminating duplication of testing and auditing by the states and duplication of effort by the manufacturers that provide products for evaluation. Technical committees within NTPEP serve as liaison to AASHTO COMP. The NTPEP Geosynthetics technical committee has two product evaluation plans, but is expected to continue expansion to include more applications of Geosynthetics. The geosynthetic product material evaluation plans are as follows:

- Geotextiles (GTX)

This includes geotextiles used in subsurface drainage, erosion control, temporary silt fence and paving.

- Reinforcement Geosynthetics (REGEO)
  This includes geosynthetic reinforcement for reinforced soil walls, reinforced slopes, and reinforced fills over soft ground.

Annual independent sampling, testing and auditing of these products under NTPEP program provide data for states to evaluate geosynthetics included in the program.

Common separation, filtration, drainage, erosion control, reinforcement geosynthetics applications often refer to Standard Specifications for Geosynthetic properties. ODOT Standard Specifications with geosynthetic application include:

- Section 00280 Erosion and Sediment Control
- Section 00331 Subgrade Stabilization
- Section 00350 Geosynthetic Installation
- Section 00390 Riprap Protection
- Section 00435 Prefabricated Vertical Drains
- Section 00596A Mechanically Stabilized Earth Retaining Walls
- Section 00596B Prefabricated Modular Retaining Walls
- Section 00596C Cast-in-Place Concrete Retaining Walls
- Section 00748 Asphalt Concrete Pavement Repair
- Section 02320 Geosynthetics

There are Geosynthetics applications in highway construction not covered by ODOT, ASTM or AASHTO specifications. Geocells and composite wall drains are examples of common products without established ASTM or AASHTO standards. In some cases manufacturers have developed a specification for an innovative product. In the absence of developed standards, use diligence to ensure the design and specification are adequately substantiated by laboratory and field data, and cannot be substituted with existing established materials and standards of practice.

15.2 Geosynthetic Types, Characteristics And Highway Applications

15.2.1 Geotextiles

Geotextiles are made from one or more synthetic polymers. The most common: polypropylene (PP), polyester (PET), and polyethylene (PE), all generally have good resistance to common biological and chemical degradation. The seaming thread used for sewn geotextiles should be material of equal or greater durability as the fabric. Nylon (polyamide (PA)) is not durable in soil so nylon thread should not be used. Geotextiles require protection from ultra violet (UV) light degradation. This is achieved by limiting UV exposure time, addition of stabilizing additives to the formula, and use of protective wrapping of the product rolls for shipping. ODOT Standard Specifications for Construction Section 02320 Geosynthetics include geotextile property requirements by ASTM D4355.

The polymers used in the manufacture of geotextiles are formed into one of the three basic fiber types: filaments (long polymer yarns), staple fibers (cut polymer yarns), and slit films (yarns cut from polymer sheet). Specification Section 02320 does not allow slit film geotextiles for use in Drainage Geotextile or Riprap Geotextile. Geotextile fabric types are woven or nonwoven. Woven geotextiles are made by weaving yarns. Nonwoven geotextiles are made with polymer yarns that are massed together and needlepunched (mechanically bonded), wet laid resin bonded (chemical bonded), or spunbonded (heat bonded). The long-term performance of a geotextile is a function of the durability and creep characteristics of the polymer structure and fabric style.

Geotextiles are available in a variety of geometric and polymeric composition to serve various applications. Geotextiles are used for separation, reinforcement, filtration, drainage, and hydraulic barrier.

Woven geotextiles exhibit high tensile strength, high modulus, and low strain. Woven geotextiles are commonly used for reinforcement.

Non-woven geotextiles typically have high permeability and high strain characteristics. Thermal treatment can add strength. Non-woven geotextiles are commonly used for filtration, drainage, separation and protection,

15.2.2 Geogrids

Geogrids are fabricated several ways: from extrusion of perforated polymer sheets that are stretched in one or more directions under controlled temperature to form the desired size and proportion of grid openings; from weaving: yarns are woven and coated to form polymer grid sheets; another manufacture process involves bonding or welding polymer strips. Geogrids as well as coating materials for geogrids are made from one or more polymers.

The chief qualities of geogrids are their high tensile strength with low deformation and ample apertures between tensile elements to interlock with surrounding compacted aggregates. The principal strength orientation can be one direction (machine direction, uniaxial), two directions (machine and cross-machine direction, biaxial), and triaxial (proprietary product). Therefore, their primary function is in reinforcement applications such as MSE walls, reinforced steepened slopes, and subgrade stabilization.

15.2.3 Geocomposite

Geocomposites are made from two or more geosynthetics. Geosynthetic combinations include geotextile-geonets, geotextile-geogrids, geotextile-geomembranes, geomembrane-geonets, geotextile-polymeric cores, and three-dimensional polymeric cell structures. Drainage geocomposites are presented in this manual. Prefabricated vertical drains, also known as PVDs or wick drains are constructed of a stiff plastic core, surfaced to promote drainage and jacketed in a nonwoven geotextile. The PVD is pushed into place in a grid pattern in soft, compressible soils to remove excess pore pressure and increase the rate of consolidation. Wick drain design considerations, example designs, guideline specifications, and installation considerations are provided by reference in Chapter 12. Section 00435 of the ODOT Standard Specifications addresses installation of wick drains.

Prefabricated wall drains have a drainage core (dimpled or fluted plastic sheets, geonets, or other) sandwiched with filtration and separation geotextile facing. They are commonly used behind the facing of soil nail and soldier pile retaining walls to drain the retained soil. The geotextile facing wrap keeps the core clean of fines so water can flow through the drainage core.

15.2.4 Geomembrane

Three main manufacturing methods of geomembrane are by extrusion, calendaring (rolled through a series of high pressure rollers), and spread coating. Each of these start with the polymer resin and various additives that make up the formulation to be processed into the geomembrane sheet. Some geomembranes are processed creating a roughened surface, some are multiple plies and may include a layer of geotextile or bituminous permeated geotextile. Geomembrane use covers a wide range of applications: as fluid barriers and liners to prevent leakage and inhibit infiltration of fluid as well as protection from contaminants in the fluid; they are also used for containment. Geomembranes are used for waterproofing tunnels and other structures, for controlling moisture infiltration into a subgrade of expansive soil, for lining stormwater detention ponds, for protection steel reinforced MSE wall backfill from infiltration of deicing salts, for lining polystyrene geofoam lightweight embankment fill as protection from petrochemical spills that destabilize and dissolve the material, etc.

15.2.5 Geocell

Geocells are commonly made from high and low density polyethylene (HDPE, LLDPE) panels that expand to form three-dimensional cellular structures. Interconnected, expanded panels provide confinement and reinforcement for infill material. Geocells have been used as plantable facing on reinforced steepened embankment slopes adjacent to wetlands, and as base support on weak subgrade. Standards are presently lacking for Geocells, however ASTM D35 Geosynthetics Committee work item ATSM WK61159 is scoped to develop guidance on design principles, properties and methods for geocells in slope stability, erosion control, retaining walls, channel protection, pavement load support, and subgrade improvement.

15.3 Geosynthetic Functional And Application Design

Geosynthetic properties needed for design depend on their function and application. (Primary functions repeated from 14.1.3: filtration, drainage, separation, reinforcement, fluid barrier, and protection). With each type of application of geosynthetics (for example: inlet protection, reinforcement beneath asphalt overlay, subsurface drainage filter, subgrade stabilization, etc.), a primary function as well as secondary function(s) distinguish the criteria and properties important for design, construction and longevity. ASTM test methods and material properties listed for geotextiles and geogrids by function and application (Drainage Geotextile, Riprap Geotextile, Sediment Fence, Subgrade Geotextile – Separation, and Pavement Overlay Geotextile) in ODOT Standard Specifications Section 02320 – Geosynthetics. In most situations where a geosynthetic is specified for these applications, the material from the Standard Specifications can be used.

Design and applications of Geosynthetics are also discussed in other chapters of this manual and in other ODOT manuals:

- GDM Chapter 15- Retaining Walls for Mechanically stabilized earth walls and reinforced slopes.
- GDM Chapter 9- Embankments for embankment base reinforcement.
- GDM Chapter 9- Embankments as well as GDM Chapter 12 for wick drains.
- ODOT Erosion Control Manual for erosion and sediment control Geosynthetic applications.
- ODOT Pavement Design Guide for subgrade stabilization and Geosynthetics in roadbed prism functions

Table 15-1 lists types of geosynthetics along with functions. Table 15-2 provides specific applications and the associated primary and secondary functions.

Table 15-1 Geosynthetic and Associated Functions

Type of Geosynthetic	Function					
	Filtration	Drainage	Separation	Reinforcement	Fluid Barrier	Protection
Geotextile	√	√	√	√		√
Geogrid				√		
Geonet		√				
Geomembrane					√	√
Geosynthetic Clay Liner					√	√
Geocomposite	√	√	√	√	√	√
Geocell						√

Table 15-2 Geosynthetic Applications and Functional Properties for Evaluation (Modified from FHWA-NHI-07-092)

PRIMARY FUNCTION	APPLICATION EXAMPLES	SECONDARY FUNCTION(S)
Filtration	1. Trench drain and base drain lining	1. Separation, drainage
	2. Perforated pipe and subsurface drain wrapping	2. Separation, drainage, protection
	3. Silt fence	3. Separation, drainage
	4. MSE facing panel joint cover	4. Drainage
	5. Filter layer between backfill and gabion wall or other modular walls	5. Separation, drainage
	6. Welded wire wall facing filter	6. Separation, drainage
Drainage	1. Prefabricated vertical drains (PVD, wick drains)	1. Separation, filtration
	2. Geocomposite wall drains	2. Filtration

PRIMARY FUNCTION	APPLICATION EXAMPLES	SECONDARY FUNCTION(S)
Separation	1. Subgrade separation	1. Filtration, drainage
	2. Subgrade stabilization	2. Filtration, reinforcement
	3. Temporary construction access	3. Filtration, drainage, reinforcement
Reinforcement	1. MSE retaining walls, reinforced slopes	1. Drainage
	2. Subbase reinforcement, load distribution pad	2. Separation
	3. Embankment over soft subgrade	3. Filtration, drainage, separation
Fluid barrier	1. Ditch liner	1. ---
	2. Stormwater pond lining	2. ---
	3. Structure waterproofing	3. ---
	4. Control of moisture infiltration into expansive soil or from wet soils	4. ---
Protection	1. As Cushion for geomembrane puncture protection	1. ---
	2. Protection of MSE backfill from road deicing salts	2. Fluid barrier
	3. Protection of geofoam fill from effect of petrochemicals	3. Fluid barrier

Design approach from Holtz et. al. 2008:

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 the geosynthetic's performance. Critical projects with severe conditions or consequences warrant thorough engineering.
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 the design if necessary.
7. Prepare detailed plans and specifications including: a) specific property requirements for the geosynthetic; and 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

Table 15-3 Guidelines for Evaluating Critical Nature or Severity of Drainage and Erosion Control Applications

A. Critical Nature of Project		
Item	**Critical**	**Less Critical**
1. Risk of loss of life and/or structural damage due to drain failure:	High	None
2. Repair costs versus installation costs of drain:	Significantly greater	Less than or equal
3. Evidence of drain clogging before potential catastrophic failure:	None	Yes
B. Severity of the Conditions		
Item	**Severe**	**Less Severe**
1. Soil to be drained:	Gap-graded, pipable or dispersible	Well-graded or uniform
2. Hydraulic gradient:	High	Low
3. Flow conditions:	Dynamic, cyclic, or Pulsating	Steady state

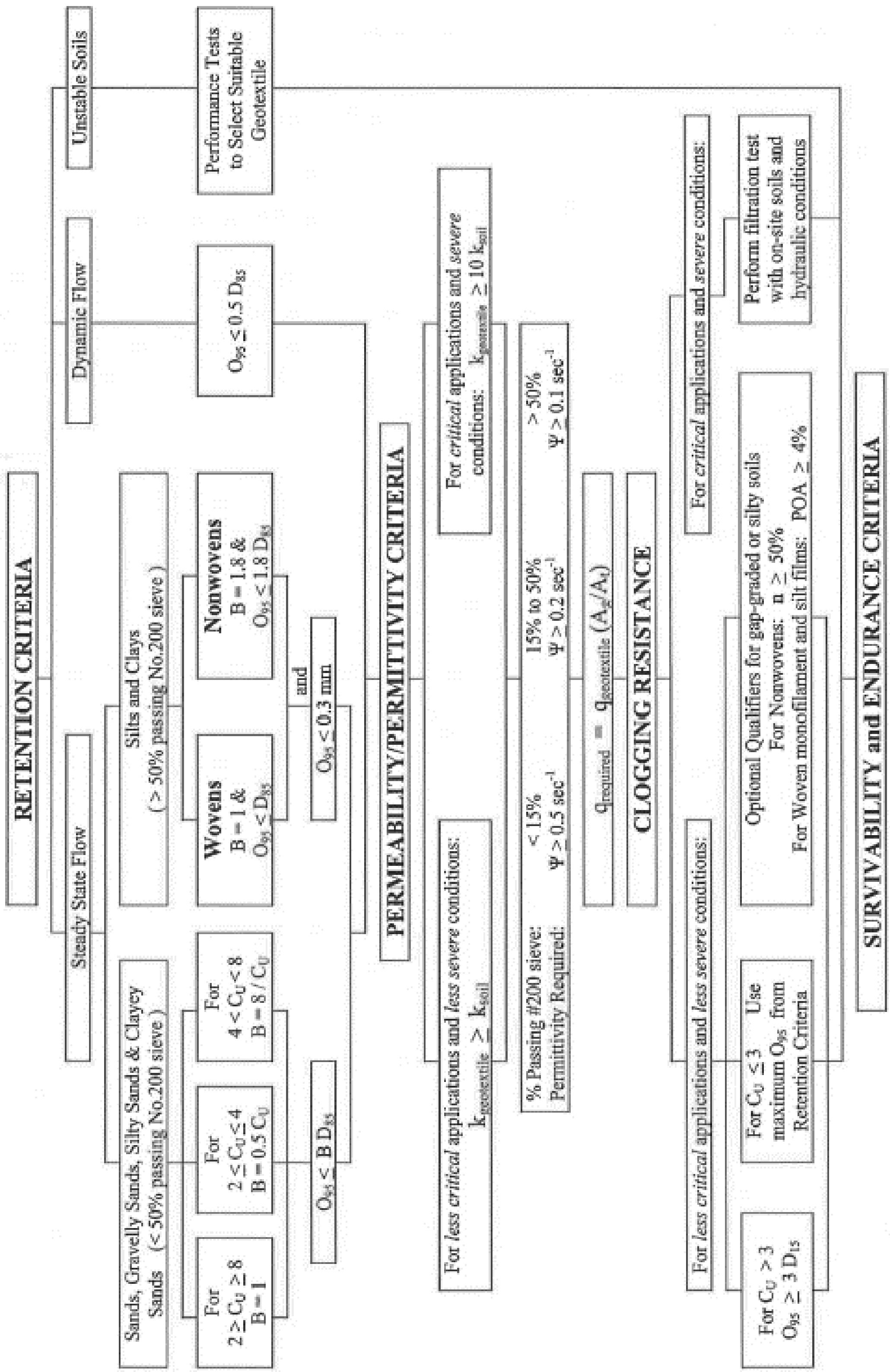

Figure 15-1 FHWA Filter Design Procedure Flow Chart

15.3.1 Drainage Geotextile - Subsurface Drainage Filter Design

Drainage and filter geotextiles often are misnamed and/or misidentified. Even in the ODOT Standard Specifications Section 00350, the definition of drainage geotextile is defined as a filter. With that in mind, drainage geotextile is often referred to as filter fabric for the purposes of this manual, the definitions, and recommended primary function of the geotextile. Geotextiles used for wrapping subsurface drain aggregate have the primary function of filtration and secondary functions separation, drainage, and protection. Geotextile filtration design procedure is given in Holtz et. al. 2008. The flow chart is shown above in Figure 15-1. Filtration geotextiles are most commonly nonwoven. As with graded granular filter design criteria, a geotextile filter also needs to satisfy criteria for retention, permeability, and resist clogging. Standard Specification 02320 for Drainage Geotextile lists geotextile strength requirements for installation and survivability, apparent opening size, permittivity and UV stability for Type 1 and Type 2 Drainage Geotextile. Distinct minimum property values are given for woven and nonwoven type 1 (lower strength) and type 2 (higher strength) drainage geotextiles. Type 1 Drainage Geotextile is used in applications with low contact stress subsurface drainage applications: rounded drainage aggregate, low confining stress, low compaction stress. Type 1 Drainage Geotextile is specified for use in Section 00596A, 00596B, and 00596C (geotextile filter for subsurface drainage, concrete panel facing joint cover, modular block drainage fill filter, welded wire facing filter, filter between backfill and gabion wall). Type 2 Drainage Geotextile is used in high contact stress subsurface drainage applications such as: angular drainage aggregate, heavy compaction, high confining stress. Standard Specification 00350 should be used for installation, placement and construction.

15.3.2 Riprap Geotextile

Riprap geotextiles function as separation, filtration and protection/erosion control of the slope beneath riprap. Standard Specification 02320 for Riprap Geotextile lists geotextile strength requirements for installation and survivability, apparent opening size, permittivity and UV stability for Type 1 and Type 2 Riprap Geotextile. Distinct minimum property values are given for woven and nonwoven type 1 (lower strength) and type 2 (higher strength) riprap geotextiles. Standard Specification 00350 Geosynthetic Installation addresses the placement and construction requirements. Design Guidelines and examples of geotextiles in permanent erosion control systems as well as installation procedures for specific applications and aleternate riprap designs are provided in Holtz et. al 2008.

15.3.3 Sediment Fence

Geotextiles used for sediment fence have the primary function of filtration and secondary functions separation, drainage, and protection. Design of sediment fence is presented in the ODOT Erosion Control Manual. Standard Specification 02320 for Sediment Fence lists geotextile strength requirements for installation and survivability, apparent opening size, permittivity and

UV stability for geotextile used in sediment fence. Section 00350 Geosynthetic Installation addresses the placement and construction requirements.

15.3.4 Subgrade Geotextile (Separation)

In subgrade separation, the geosynthetic is placed at the interface between subgrade and aggregate (or in general between dissimilar materials) to prevent intermixing of either material upward or downward. By protecting against fines migrating upwards, a secondary function is filtration. There is also drainage to some extent. Separation geotextile can be either woven or nonwoven – generally a woven is stiffer (<50% strain) so it has less elongation but requires a smooth surface for good contact, while a nonwoven is more flexible (>50% strain) and will conform better to surface irregularities, nonwovens also provide better drainage properties. Standard Specification 02320 for Subgrade Geotextile (Separation) lists geotextile strength requirements for installation and survivability, apparent opening size, permittivity and UV stability.

15.3.5 Embankment Geotextile

Embankment geotextile is used as separation and reinforcement in the lower portion of embankment to strengthen the foundation and in layered embankment construction. Embankment geotextile can be either woven or nonwoven. Standard Specification 02320 for Embankment Geotextile lists geotextile strength requirements for installation and survivability, apparent opening size, permittivity and UV stability. Section 00350 Geosynthetic Installation addresses the placement and construction requirements.

Failure mechanisms for reinforced embankments on soft foundations include:

- Bearing failure
- Rotational failure (shear slip surface)
- Lateral spreading (sliding wedge)

Layers of embankment geotextile or geogrid can be designed to reinforce Design steps for reinforced embankments on soft foundations condensed from FHWA NHI-07-092 Geosynthetic Engineering, Chapter 8 Reinforced Embankments:

1. Establish embankment dimensions and loading.
2. Determine engineering properties and soil profile of the foundation.
3. Determine engineering properties of the embankment.
4. Evaluate bearing resistance.
5. Perform rotational stability analysis without base reinforcement; establish limits of failure zone.
6. Perform lateral spreading stability analysis
7. Establish tolerable geosynthetic deformation, required reinforcement modulus, tensile strength, soil-reinforcement friction, anchorage length beyond failure zone to resist pullout. Check transverse direction and longitudinal direction.
8. Estimate anticipated settlement, anticipated rate of settlement

9. Specify subgrade preparation, geosynthetic and fill placement sequence and compaction, and construction monitoring recommendations

See GDM Chapter 15 and FHWA manual "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design & Construction Guidelines" by Berg, et al for design of reinforced soil slopes.

15.3.6 Pavement Overlay Geotextile

Pavement overlay geotextile provides reinforcement, stress relief and separation beneath asphalt concrete overlay. See ODOT Pavement Design Manual for geosynthetic placement subgrade and pavement structure. Specification 02320 for Pavement Overlay Geotextile lists geotextile strength and strain requirements, asphalt retention and melting point minimum property values. Section 00350 Geosynthetic Installation addresses the placement and construction requirements.

15.3.7 Subsurface Drainage Design

In most drainage applications involving geosynthetics, the geosynthetic's primary role is filtration, for example geotextile wrap encasing drainage aggregate (discussed above). Geosynthetics for the primary function as drainage applications (flow along the plane of geosynthetic) include composite prefabricated vertical drains (see Chapter 12), horizontal drains with geotextile wrap (see Chapter 10), nonwoven needlepunched geotextile drainage blanket over steep slopes in seepage areas (see Chapter 10), composite prefabricated wall drains behind soldier pile, soil nail retaining walls (see Chapter 15).

Drainage design steps and a trench drain design example as well as prefabricated geocomposite drain design example are provided in Holtz et. al. 2008.

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D4751, Standard Test Method for Determining Apparent Opening Size of a Geotextile

D5141, Standard Test Method to Determine Filtering Efficiency and Flow Rate of a Geotextile for Silt Fence Application Using Site Specific Soil

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D5262, Standard Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics

D5321, Standard Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids

D5818, Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics

D6637, Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method

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