Geosynthetic Engineering: *Introduction*

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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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1.0 INTRODUCTION, IDENTIFICATION, AND EVALUATION

1.1 BACKGROUND

This manual was prepared to assist design engineers, specification writers, estimators, construction inspectors, and maintenance personnel with the design, selection, and installation of geosynthetics. In addition to providing a general overview of these materials and their applications, step-by-step procedures are given for the cost-effective use of geosynthetics in drainage and erosion control systems, roadways, and reinforcement, and in containment applications. Although the title refers to the general term *geosynthetic*, specific applications address the appropriate use of subfamilies of geotextiles, geogrids, geocomposites, and geomembranes.

The basis for much of this manual is the FHWA *Geotextile Engineering Manual* (Christopher and Holtz, 1985). Other sources of information include the books by Koerner (1994), John (1987), and Veldhuijzen van Zanten (1986). If you are not already familiar with geosynthetics, you are encouraged to read Richardson and Koerner (1990) and Ingold and Miller (1988), especially if you are attempting to use geosynthetics for the first time. A listing of other geosynthetics literature can be found in Cazzuffi and Anzani (1992) and Holtz and Paulson (1988), both of which are reproduced in Appendix A. Comprehensive geosynthetic bibliographies have recently been prepared by Giroud (1993, 1994). If you are unfamiliar with geosynthetics terminology, see ASTM (1997) D 4439 Standard Terminology for Geosynthetics. Basic terms are defined in Appendix B. The authors assume that you are already familiar with the engineering basics of geotechnical, highway, hydraulic, retaining wall, and pavement design. Common notation and symbols are used throughout this manual, and a list is provided in Appendix C for easy reference. These notations and symbols are generally consistent with the International Geosynthetic Society's (IGS) Recommended Mathematical and Graphical Symbols (1993).

Sample specifications included in this manual were developed in several cases by Task Force 25 Subcommittee of the American Association of State Highway and Transportation Officials (AASHTO, 1990), the Association General Contractors (AGC), and the American Road and Transportation Builders Associations (ARTBA) Joint Committee, along with representatives from the geosynthetic industry. Important input has also been obtained from the AASHTO-AGC-ARTBA Task Force 27 Subcommittee (1990). Specifications from the FHWA Guidelines for Design, Specification, and Contracting of Geosynthetic Mechanically Stabilized Earth Slopes on Firm Foundations (Berg, 1993) are also used with this manual. Finally, sample specifications were obtained from some state Departments of Transportation. **These specifications are meant to serve only as guidelines and should be modified as required by engineering judgment and experience, based upon project specific design and performance criteria.**

Chapter 1 introduces you to the functions and applications of geosynthetics, to the identification of the materials, and to the methods used to evaluate their properties. The remaining nine chapters give specific details about important application categories of geosynthetics, such as drainage and roadways. Each chapter provides a systematic approach to applying geosynthetics so that successful cost-effective designs and installations can be achieved.

1.2 DESIGN APPROACH

We recommend the following approach to designing with 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 the geosynthetic's 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 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 events (*e.g.*, 100 year rainfall) that may tax structure performance.

By following this systematic approach to designing with geosynthetics, cost-effective designs can be achieved, along with improved performance, increased service life, and reduced maintenance costs. Good communication and interaction between all concerned parties is imperative throughout the design and selection process.

1.3 DEFINITIONS, MANUFACTURING PROCESSES, AND IDENTIFICATION

ASTM (1997) has defined 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. A *geotextile* is a permeable geosynthetic made of textile materials. There are a number of other materials available today that technically are not textiles -- including webs, grids, nets, meshes, and composites -- that are used in combination with or in place of geotextiles. These are sometimes referred to as geotextile-related materials. Geotextiles and related materials all fall under the principal category of geosynthetics. *Geogrids*, geosynthetics primarily used for reinforcement, are formed by a regular network of tensile elements with apertures of sufficient size to interlock with surrounding fill material. *Geomembranes* are low-permeability geosynthetics used as fluid barriers. Geotextiles and related products, such as nets and grids, can be combined with geomembranes and other synthetics to complement the best attributes of each material. These products are called *geocomposites*, and they may be geotextile-geonets, geotextile-geogrids, geotextile-geomembranes, geomembrane-geonets, geotextile-polymeric cores, and even three-dimensional polymeric cell structures. There is almost no limit to the combinations of geocomposites.

A convenient classification scheme for geosynthetics is provided in Figure 1-1. For details on the composition, materials, and manufacturing processes, see Koerner (1994), Ingold and Miller (1988), Veldhuijzen van Zanten (1986), Christopher and Holtz (1985), Giroud and Carroll (1983), Rankilor (1981), and Koerner and Welsh (1980). Most geosynthetics are made from synthetic polymers of polypropylene, polyester, or polyethylene. These polymer materials are highly resistant to biological and chemical degradation. Less-frequently-used polymers include polyamides (*nylon*) and glass fibers. Natural fibers, such as cotton, jute, etc., could also be used as geotextiles, especially for temporary applications, but they have not been researched or utilized in the U.S. as widely as polymeric geotextiles.

In manufacturing geotextiles, elements such as fibers or yarns are combined into planar textile structures. The fibers can be continuous *filaments*, which are very long thin strands of a polymer, or *staple fibers,* which are short filaments, typically 20 to 150 mm long. The fibers may also be produced by slitting an extruded plastic sheet or film to form thin flat tapes. In both filaments and slit films, the extrusion or drawing process elongates the polymers in the direction of the draw and increases in the filament strength.

Geotextile type is determined by the method used to combine the filaments or tapes into the planar structure. The vast majority of geotextiles are either *woven* or *nonwoven.* Woven geotextiles are made of *monofilament*, *multifilament*, or *fibrillated* yarns, or of slit films and tapes. The weaving process is as old as Homo sapiens' textile cloth-making. Nonwoven textile manufacture is a modern development, a *high-tech* process industry, in which synthetic polymer fibers or filaments are continuously extruded and spun, blown or otherwise laid onto a moving belt. Then the mass of filaments or fibers are either *needlepunched*, in which the filaments are mechanically entangled by a series of small needles, or *heat bonded,* in which the fibers are *welded* together by heat and/or pressure at their points of contact in the nonwoven mass.

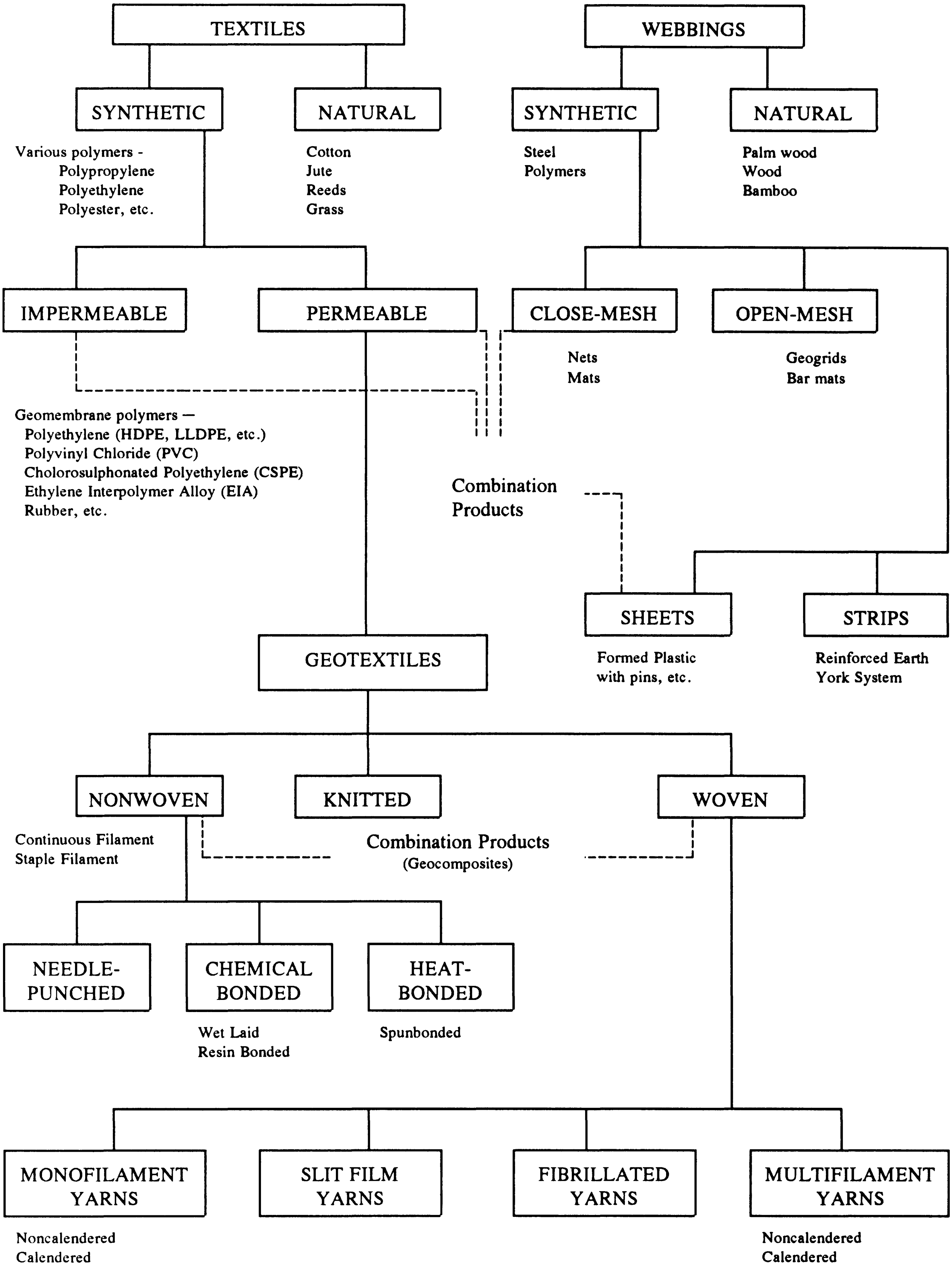


Figure 1-1 Classification of geosynthetics and other soil inclusions (after Rankilor, 1981).

The manufacture of geotextile-related products is as varied as the products themselves. Geonets, geosynthetic erosion mats, geogrids, etc., can be made from large and often rather stiff filaments formed into a mesh with integral junctions or which are welded or glued at the crossover points. Geogrids with integral junctions are manufactured by extruding and orienting sheets of polyolefins. These types of geogrids are usually called *stiff* geogrids. Geogrids are also manufactured of polyester yarns, joined at the crossover points by a knitting or weaving process, and encased with a polymer-based, plasticized coating. These types of geogrids are generally called *flexible* geogrids. Manufacture of geomembranes and other geosynthetic barriers is discussed in Chapter 10.

Geocomposites result when two or more materials are combined in the geosynthetic manufacturing process. Most are used in highway drainage applications and waste containment. A common example of a geocomposite is a prefabricated drain formed by wrapping a fluted or dimpled polymeric sheet, which acts as a conduit for water, with a geotextile which acts as a filter.

Geosynthetics are generically identified by:

1. polymer (descriptive terms, *e.g.*, high density, low density, etc. should be included);
2. type of element (*e.g.*, filament, yarn, strand, rib, coated rib), if appropriate;
3. distinctive manufacturing process (*e.g.*, woven, needlepunched nonwoven, heatbonded nonwoven, stitchbonded, extruded, knitted, roughened sheet, smooth sheet), if appropriate;
4. primary type of geosynthetic (*e.g.*, geotextile, geogrid, geomembrane, etc.);
5. mass per unit area, if appropriate (*e.g.*, for geotextiles, geogrids, GCLs, erosion control blankets,) and/or thickness, if appropriate (*e.g.*, for geomembranes); and
6. any additional information or physical properties necessary to describe the material in relation to specific applications.

Four examples are:

- polypropylene staple filament needlepunched nonwoven geotextile, 350 g/m^2;
- polyethylene geonet, 440 g/m^2 with 8 mm openings;
- polypropylene extruded biaxial geogrid, with 25 mm x 25 mm openings; and
- high-density polyethylene roughened sheet geomembrane, 1.5 mm thick.

1.4 FUNCTIONS AND APPLICATIONS

Geosynthetics have six primary functions:

1. filtration
2. drainage

3. separation
4. reinforcement
5. fluid barrier, and
6. protection

Geosynthetic applications are usually defined by their primary, or principal, function. For example, geotextiles are used as *filters* to prevent soils from migrating into drainage aggregate or pipes, while maintaining water flow through the system. They are similarly used below riprap and other armor materials in coastal and stream bank protection systems to prevent soil erosion.

Geotextiles and geocomposites can also be used as *drainage*, or lateral transmission media, by allowing water to drain from or through soils of lower permeability. Geotextile applications include dissipation of pore water pressures at the base of roadway embankments. For situations with higher flow requirements, geocomposite drains have been developed. These materials are used as pavement edge drains, slope interceptor drains, and abutments and retaining wall drains. Filtration and drainage are addressed in Chapter 2 - Geosynthetics in Subsurface Drainage Systems.

Geotextiles are often used as *separators* to prevent road base materials from penetrating into the underlying soft subgrade, thus maintaining the design thickness and roadway integrity. Separators also prevent fine-grained subgrade soils from being pumped into permeable, granular road bases. Separators are discussed in Chapter 5 - Geosynthetics in Roadways and Pavements.

Geogrids and geotextiles can also be used as *reinforcement* to add tensile strength to a soil matrix, thereby providing a more competent structural material. Reinforcement enables embankments to be constructed over very soft foundations and permits the construction of steep slopes and retaining walls. Reinforcement applications are presented in Chapter 7 - Reinforced Embankments on Soft Foundations; Chapter 8 - Reinforced Slopes; and Chapter 9 - Mechanically Stabilized Earth Retaining Walls and Abutments.

Geomembranes, thin-film geotextile composites, geosynthetic clay liners, and field-coated geotextiles are used as *fluid barriers* to impede the flow of a liquid or gas from one location to another. This geosynthetic function has wide application in asphalt pavement overlays, encapsulation of swelling soils, and waste containment. Barrier applications are summarized in Chapters 6 - Pavement Overlays, and 10 - Geomembranes and Other Geosynthetic Barriers.

In the sixth function, *protection*, the geosynthetic acts as 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. A protective cushion of nonwoven geotextiles is often used to prevent puncture of geomembranes (by reducing point stresses) from stones in the adjacent soil or drainage aggregate during installation and while in service. Erosion control is presented in Chapter 3 - Geotextiles in Riprap Revetments and Other Permanent Erosion Control Systems; and Chapter 4 - Temporary Runoff and Sediment Control.

In addition to the primary function, geosynthetics usually perform one or more *secondary* functions. The primary and secondary functions make up the total contribution of the geosynthetic to a particular application. A listing of common applications according to primary and secondary functions is presented in Table 1-1. It is important to consider both the primary and secondary functions in the design computations and specifications.

1.5 EVALUATION OF PROPERTIES

Today, there are more than 600 different geosynthetic products available in North America. Because of the wide variety of products available, with their different polymers, filaments, weaving (or nonwoven) patterns, bonding mechanisms, thicknesses, masses, etc., they have a considerable range of physical and mechanical properties. Thus, the process of comparison and selection of geosynthetics is not easy. Geosynthetic testing has progressed significantly since the first Geotextile Engineering Manual (Christopher and Holtz, 1985) was published. Specific test procedures are given in AASHTO (1997), ASTM (1997), and GRI (1997). The AASHTO Standard Specification for Geotextiles, designated M 288, is specifically for highway applications and addresses subsurface drainage, sediment control, erosion control, separation, and pavement overlay applications. The AASHTO M 288 specification can be found in Appendix D. Testing procedures developed by the Geosynthetics Research Institute of Drexel University are considered only interim standards until an equivalent ASTM standard is adopted. ASTM and GRI standards are listed in Appendix E.

The particular, required design properties of the geosynthetic will depend on the specific application and the associated function(s) the geosynthetic is to provide. The properties listed in Table 1-2 cover the range of important criteria and properties required to evaluate geosynthetic suitability for most applications. It should be noted that not all of the listed requirements will be necessary for all applications. For a specific application requirements, refer to the subsequent chapter covering that application.

All geosynthetic properties and parameters to be considered for specific projects are listed in Table 1-3. Again, see AASHTO (1997), ASTM (1997), and GRI (1997) for test procedures for each specific property. Manufacturers can provide information on general properties. The December issue of *Geotechnical Fabrics Report* magazine, published by the Industrial Fabrics Association

TABLE 1-1
REPRESENTATIVE APPLICATIONS AND CONTROLLING FUNCTIONS OF GEOSYNTHETICS

PRIMARY FUNCTION	APPLICATION	SECONDARY FUNCTION(S)
Separation	Unpaved Roads (temporary & permanent) Paved Roads (secondary & primary) Construction Access Roads Working Platforms Railroads (new construction) Railroads (rehabilitation) Landfill Covers Preloading (stabilization) Marine Causeways General Fill Areas Paved & Unpaved Parking Facilities Cattle Corrals Coastal & River Protection Sports Fields	Filter, drains, reinforcement Filter, drains Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, reinforcement Reinforcement, drains, protection Reinforcement, drains Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, reinforcement Filter, drains, protection
Filter	Trench Drains Pipe Wrapping Base Course Drains Frost Protection Structural Drains Toe Drains in Dams High Embankments Filter Below Fabric-Form Silt Fences Silt Screens Culvert Outlets Reverse Filters for Erosion Control: Seeding and Mulching Beneath Gabions Ditch Armoring Embankment Protection, Coastal Embankment Protection, Rivers & Streams Embankment Protection, Lakes Vertical Drains (wicks)	Separation, drains Separation, drains, protection Separation, drains Separation, drainage, reinforcement Separation, drains Separation, drains Drains Separation, drains Separation, drains Separation Separation Separation
Drainage-Transmission	Retaining Walls Vertical Drains Horizontal Drains Below Membranes (drainage of gas & water) Earth Dams Below Concrete (decking & slabs)	Separation, filter Separation, filter Reinforcement Reinforcement, protection Filter Protection

TABLE 1-1
REPRESENTATIVE APPLICATIONS AND CONTROLLING FUNCTIONS OF GEOSYNTHETICS

(continued)

PRIMARY FUNCTION	APPLICATION	SECONDARY FUNCTION(S)
Reinforcement	Pavement Overlays	----------
	Subbase Reinforcement in Roadways & Railways	Filter
	Retaining Structures	Drains
	Membrane Support	Separation, drains, filter, protection
	Embankment Reinforcement	Drains
	Fill Reinforcement	Drains
	Foundation Support	Drains
	Soil Encapsulation	Drains, filter, separation
	Net Against Rockfalls	Drains
	Fabric Retention Systems	Drains
	Sand Bags	----------
	Reinforcement of Membranes	Protection
	Load Redistribution	Separation
	Bridging Nonuniformity Soft Soil Areas	Separation
	Encapsulated Hydraulic Fills	Separation
	Bridge Piles for Fill Placement	----------
Fluid Barrier	Asphalt Pavement Overlays	----------
	Liners for Canals and Reservoirs	----------
	Liners for Landfills and Waste	----------
	Repositories	----------
	Covers for Landfill and Waste	----------
	Repositories	----------
	Cutoff Walls for Seepage Control	----------
	Waterproofing Tunnels	----------
	Facing for Dams	----------
	Membrane Encapsulated Soil Layers	----------
	Expansive Soils	----------
	Flexible Formwork	----------
Protection	Geomembrane cushion	Drains
	Temporary erosion control	Fluid barrier
	Permanent erosion control	Reinforcement, fluid barrier

TABLE 1-2
IMPORTANT CRITERIA AND PRINCIPAL PROPERTIES REQUIRED FOR GEOSYNTHETIC EVALUATION

CRITERIA AND PARAMETER	PROPERTY[1]	FUNCTION					
		Filtration	Drainage	Separation	Reinforcement	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	Apparent Opening Size	✓	—	✓	✓	—	✓
Clogging Resistance	Porimetry	✓	—	—	—	—	✓
	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	✓	✓	✓	✓	✓	✓
Longevity (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 1-3 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 1-3
GEOSYNTHETIC PROPERTIES AND PARAMETERS

PROPERTY	TEST METHOD	UNITS OF MEASUREMENT
I. GENERAL PROPERTIES (from manufacturers)		
Type and Construction	N/A	-----
Polymer	N/A	-----
Mass per Unit Area	ASTM D 5261	g/m^2
Thickness (geotextiles & geomembranes)	ASTM D 5199	mm
Roll Length	Measure	m
Roll Widths	Measure	m
Roll Weight	Measure	kg
Roll Diameter	Measure	m
Specific Gravity & Density	ASTM D 792 and D 1505	g/m^3
Surface Characteristics	N/A	-----
II. INDEX PROPERTIES		
MECHANICAL STRENGTH - UNIAXIAL LOADING		
a) Tensile Strength (Quality Control)		
1) Grab Strength (geotextiles & CSPE reinforced geomembranes)	ASTM D 4632	N
2) Single Rib Strength (geogrids)	GRI:GG1	N
3) Narrow Strip (geomembranes)		
- EDPM, CO, IR, CR	ASTM D 412	N
- HDPE	ASTM D 638	N
- PVC, VLDPE	ASTM D 882	N
b) Tensile Strength (Load-Strain Characteristics)		
1) Wide Strip (geotextiles)	ASTM D 4595	N
2) Wide Strip (geogrid)	no standard	N
3) Wide Strip Strength (geomembranes)	ASTM D 4885	N
4) 2% Secant Modulus (PE geomembranes)	ASTM D 882	N
c) Junction Strength (geogrids)	GRI:GG2	%
d) Dynamic Loading	no standard	
e) Creep Resistance	ASTM D 5262 (Note: interpretation required)	creep strain: %ϵ/hr creep rupture: kN/m
f) Index Friction	GRI:GS7	dimensionless
g) Seam Strength		
1) Sewn (geotextiles)	ASTM D 4884	% efficiency
2) Factory Peel and Shear (geomembranes)	ASTM D 4545	kg/mm
3) Field Peel and Shear (geomembranes)	ASTM D 4437	kg/mm
h) Tear Strength		
1) Trapezoid Tearing (geotextile)	ASTM D 4533	N
2) Tear Resistance (geomembranes)	ASTM D 1004	N
MECHANICAL STRENGTH - RUPTURE RESISTANCE		
a) Burst Strength		
1) Mullen Burst (geotextiles)	ASTM D 3786	Pa
2) CBR (geotextiles, geonets, geomembranes)	GRI:GS1	Pa or N
3) Large Scale Hydrostatic (geomembranes and geotextiles)	ASTM D 5514	Pa
b) Puncture Resistance		
1) Index (geotextiles and geomembranes)	ASTM D 4833	N
2) Pyramid Puncture (geomembranes)	ASTM D 5494	N
3) CBR (geotextile, geonets, and geomembranes)	GRI:GS1	N
c) Penetration Resistance (Dimensional Stability)	no standard	

TABLE 1-3 GEOSYNTHETIC PROPERTIES AND PARAMETERS (continued)

PROPERTY	TEST METHOD	UNITS
II. INDEX PROPERTIES (continued)		
MECHANICAL STRENGTH - RUPTURE RESISTANCE (cont.)		
d) Geosynthetic Cutting Resistance	no standard	
e) Flexibility (Stiffness)	ASTM D 1388	mg/cm^2
ENDURANCE PROPERTIES		
a) Abrasion Resistance (geotextile)	ASTM D 4886	%
b) Ultraviolet (UV) Radiation Stability		
1) Xenon-Arc Apparatus (geotextile)	ASTM D 4355	%
2) Outdoor Exposure	ASTM D 5970	%
c) Chemical Resistance		
1) Chemical Immersion	ASTM D 5322	N/A
2) Oxidative Induction Time	ASTM D 5885	minutes
3) Environmental Exposure	EPA 9090	% change
d) Biological Resistance		
1) Biological Clogging (geotextile)	ASTM D 1987	m^3/s
2) Biological Degradation	ASTM G 21 and G 22	
3) Soil Burial	ASTM D 3083	% change
e) Wet and Dry Stability	no standard	
f) Temperature Stability		
1) Temperature Stability (geotextile)	ASTM D 4594	% change
2) Dimensional Stability (geomembrane)	ASTM D 1204	% change
HYDRAULIC		
a) Opening Characteristics (geotextiles)		
1) Apparent Opening Size (AOS)	ASTM D 4751	mm
2) Porimetry (pore size distribution)	Use AOS for O_{95}, O_{85}, O_{50}, O_{15}, and O_5	mm
3) Percent Open Area (POA)	(see Christopher & Holtz, 1985)	%
4) Porosity (n)	(V_{voids}/V_{total}) 100	%
b) Permeability (k) and Permittivity (Ψ)	ASTM D 4491	m/s and s^{-1}
c) Soil Retention Ability	Empirically Related to Opening Characteristics	
d) Clogging Resistance	ASTM D 5101 and GRI:GT8	
e) In-Plane Flow Capacity (Transmissivity, θ)	ASTM D 4716	m^2/s
III. PERFORMANCE PROPERTIES		
Stress-Strain Characteristics:		kN/m and % strain
a) Tension Test in Soil	(see McGown, et al., 1982)	
b) Triaxial Test Method	(see Holtz, et al., 1982)	
c) CBR on Soil Fabric System	(see Christopher & Holtz, 1985)	
d) Tension Test in Shear Box	(see Christopher & Holtz, 1985)	
Creep Tests:		kN/m and % strain
a) Extension Test in Soil	(see McGown, et al., 1982)	
b) Triaxial Test Method	(see Holtz, et al., 1982)	
c) Extension Test in Shear Box	(see Christopher & Holtz, 1985)	
d) Pullout Method	(see Christopher, et al., 1990)	

TABLE 1-3 GEOSYNTHETIC PROPERTIES AND PARAMETERS (continued)

PROPERTY	TEST METHOD	UNITS
III. PERFORMANCE PROPERTIES (cont.)		
Friction/Adhesion:		
a) Direct Shear (soil-geosynthetic)	ASTM D 5321	degrees (°)
b) Direct Shear (geosynthetic-geosynthetic)	ASTM D 5321	degrees (°)
c) Pullout (geogrids)	GRI:GG5	dimensionless
d) Pullout (geotextiles)	GRI:GT6	dimensionless
e) Anchorage Embedment (geomembranes)	GRI:GM2	kN/m
Dynamic and Cyclic Loading Resistance:	no standard procedures	N/A
Puncture		
a) Gravel, truncated cone or pyramid	ASTM D 5494	kPa
Chemical Resistance:		
a) In Situ Immersion Testing	ASTM D 5496	N/A
Soil Retention and Filtration Properties:		
a) Gradient Ration Method - for noncohesive sand and silt type soils	ASTM D 5101	dimensionless
b) Hydraulic Conductivity Ratio (HCR) - for fine-grained soils	ASTM D 5567	dimensionless
c) Slurry Method - for silt fence applications	ASTM D 5141	%

International (IFAI), is formatted as a Specifier's Guide. General and some index properties are listed according to product type and manufacturer. The Specifier's Guide also contains a directory of product manufacturers, product distributors, geosynthetic installers, design engineers and testing laboratories, with contact person, address, telephone and facsimile numbers noted.

The tests listed in Table 1-3 include *index* tests and *performance* tests. Index tests do not produce an actual design property in most cases, but they do provide a general value from which the property of interest can be qualitatively assessed. Index tests are primarily used by manufacturers for quality control purposes. When determined using identical test procedures, index tests can be used for product comparison, specifications, and quality control evaluation.

On the other hand, performance tests require testing of geosynthetic with its companion material (*e.g.*, soil) to obtain a direct assessment of the property of interest. **Since performance tests should be performed under specific design conditions with soils from the site, manufacturers should no be expected to have the capability or the responsibility to perform such tests.** These tests should be performed under the direction of the design engineer. Performance tests are not normally used in specifications; rather, geosynthetics should be preselected for performance testing based on index values, or performance test results should be correlated to index values for use in specifications.

Brief descriptions of some of the basic properties of geosynthetics (after Christopher and Dahlstrand, 1989) are presented below.

Mass per Unit Area: The unit weight of a geosynthetic is measured in terms of area as opposed to volume due to variations in thickness under normal stress. This property is mainly used to identify materials.

Thickness: Thickness is not usually required information for geotextiles except in permeability-flow calculations. It is used as a primary identifier for geomembranes. When needed, it can be simply obtained using the procedure in Table 1-3, but it must be measured under a specified normal stress. The nominal thickness used for product comparison is measured under a normal stress of 2 kPa for geotextiles and 20 kPa for geogrids and geomembranes.

Tensile Strength: To understand the load-strain characteristics, it is important to consider the complete load-strain curve. It is also important to consider the nature of the test and the testing environment. With most materials, it is usual to use stress in strength and modulus determination. However, because of the thin, two-dimensional nature of geosynthetics, it is awkward to use stress. Therefore, it is conventional with geosynthetics to use force per unit length along the edge of the material. Then, strength and modulus have units of FL^{-1} (*i.e.*, kN/m).

There are several types of tensile strength tests. Specific geosynthetic specimen shapes and loadings are indicated by the referenced procedures in Table 1-3. These tests all give different results.

The plane-strain test represents the loading for many applications, but because it is complicated to perform, it is not a practical test for many routine applications. Therefore, it is approximated by a strip tensile test. Since many narrow strip geosynthetic specimens neck when strained, most applications use wide, short specimens. This is called a wide strip tensile test.

Geosynthetics may have different strengths in different directions. Therefore, tests should be conducted in both principal directions.

The *grab tensile test* is typically used in the specification of geotextiles and is an unusual test. It is widely used and almost universally misused. The grab test may be useful in some applications, but it is difficult, if not impossible, to relate to actual strength without direct correlation tests. The grab tensile test normally uses 25 mm jaws to grip a 100 mm specimen. The strength is reported as the total force needed to cause failure -- not the force per unit width. It is not clear how the force is distributed across the sample. The effects of the specimen being wider than the grips depend on the geotextile filament interaction. In nonwoven geotextiles, these effects are large. In woven geotextiles, they are small.

The *burst test* is performed by applying a normal pressure (usually by air pressure) against a geosynthetic specimen clamped in a ring. The burst strength is given in pascals. This is not the stress in the specimen - it is the normal stress against the geosynthetic at failure. The burst strength depends on the strength in all directions and is controlled by the minimum value. Burst strength is a function of the diameter of the test specimen; therefore, care must be used in comparing tests.

Creep is a time-dependent mechanical property. It is strain at constant load. Creep tests can be run for any of the tensile test types, but are most frequently performed on a wide strip specimen by applying a constant load for a sustained period. Creep tests are influenced by the same factors as tensile load-strain tests - specimen length to width ratio, temperature, moisture, lateral restraint, and confinement.

Short-term creep strain is strongly influenced by the geosynthetic structure. Geogrids and woven geotextiles have the least; heat-bonded geotextiles have intermediate; and needled geotextiles have the most. Longer-term creep rates are controlled by structure and polymer type. Of the most common polymers, polyester has lower creep rates than polypropylene. The creep limit is the most important creep characteristic. It is the load per unit width above which the geosynthetic will creep to rupture. The creep limit is controlled by the polymer and ranges from 20% to 60% of the material's ultimate strength.

Friction: Soil-geosynthetic and geosynthetic-geosynthetic friction are important properties. It is common to assume a soil-geotextile friction value between ⅔ and 1 of the soil angle of friction. For geogrid materials, the value approaches the full friction angle. Caution is advised for geomembranes where soil-geosynthetic friction angle may be much lower than the soil angle of friction. For important applications, tests are justified.

The direct friction test is simple in principle, but numerous details must be considered for accurate results. Recent procedures proposed by ASTM indicate a minimum shear box size of 300 mm by 300 mm to reduce boundary effects. For many geosynthetics, the friction angle is a function of the soils on each side of the geosynthetic and the normal stress; therefore, test conditions must model the actual field conditions.

Durability Properties: Other properties that require consideration are related to durability and longevity. Exposure to ultraviolet light can degrade some geosynthetic properties. The geosynthetic polymer must be compatible with the environment chemistry. The environment should be checked for such items as high and low pH, chlorides, organics and oxidation agents such as ferroginous soils which contain Fe_2SO_3, calcareous soils, and acid sulfate soils that may deteriorate of the geosynthetic in time. Other possible detrimental environmental factors include chemical solvents, diesel, and other fuels. Each geosynthetic is different in its resistance to aging and attack by chemical and biological agents. Therefore, each product must be investigated individually to determine the effects of these durability factors. The geosynthetic manufacturer should supply the results of product exposure studies, including, but not limited to, strength reduction due to aging, deterioration in ultraviolet light, chemical attack, microbiological attack, environmental stress cracking, hydrolysis, and any possible synergism between individual factors.

Guidelines on soil environments and on geosynthetics properties are presented in the FHWA Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes (Elias, 1997). This research has been summarized and numeric recommendations for selecting aging reduction factors for reinforcement applications is presented in an FHWA Geotechnology Technical Note (1997); attached in Appendix F. A durability reduction factor as low as 1.1 is recommended with supporting data.

Hydraulic Properties: Hydraulic properties relate to the pore size distribution of the geosynthetic and correspondingly its ability to retain soil particles over the life of the project while allowing water to pass. Hydraulic properties may also be affected by chemical and biological agents. Ionic deposits as well as slime growth have been known to clog filter systems (granular filters as well as geotextiles).

The ability of a geotextile to retain soil particles is directly related to its apparent opening size (AOS) which is the apparent largest hole in the geotextile. The AOS value is equal to the size of the largest particle that can effectively pass through the geotextile in a dry sieving test.

The ability of water to pass through a geotextile is determined from its hydraulic conductivity (coefficient of permeability, k), as measured in a permeability test. The flow capacity of the material can then be determined from Darcy's law. Due to the compressibility of geotextiles, the permittivity, ψ (permeability divided by thickness), is often determined from the test and used to directly evaluate flow capacity.

The ability of water to pass through a geotextile over the life of the project is dependent on its filtration potential or its ability not to clog with soil particles. Essentially, if the finer particles of soil can pass through the geotextile, it should not clog. Effective filtration can be evaluated through relations between the geotextile's pore size distribution and the soil's grain size distribution; however, such formulations are still in the development phase. For a precise evaluation, laboratory performance testing of the proposed soil and candidate geotextile should be conducted.

One popular filtration test is the gradient ratio test (ASTM D 5101). This test is primarily suitable for sandy and silty soils ($k \leq 10^{-7}$ m/s). In this test, a rigid wall permeameter, with strategically located piezometer ports, is used to obtain a ratio of the head loss in the soil to the head loss at the soil-geotextile interface under different hydraulic gradients. Although the procedure indicates that the test may be terminated after 24 hours, to obtain meaningful results, the test should be continued until stabilization of the flow has clearly occurred. This may occur within 24 hours, but could require several weeks. A gradient ratio of 1 or less is preferred. Less than 1 is an indication that a more open *filter bridge* has developed in the soil adjacent to the geotextile. However, a continued decrease in the gradient ratio indicates piping, and an alternate geotextile should be evaluated. A high gradient ratio indicates a flow reduction at the geotextile. If the gradient ratio approaches 3 (the recommended maximum by the U.S. Army Corps of Engineers, 1977), the flow rate through the system should be carefully evaluated with respect to design requirements. A continued increase in the gradient ratio indicates clogging, and the geotextile is unacceptable.

For fine-grained soils, the hydraulic conductivity ratio (HCR) test (ASTM D 5567) should be considered. This test uses a flexible wall permeameter and evaluates the long-term permeability under increasing gradients with respect to the short-term permeability of the system at the lowest hydraulic gradient. A decrease in HCR indicates a flow reduction in the system. Since measurements are not taken near the geotextile-soil interface and soil permeability is not measured, it is questionable whether an HCR decrease is the result of flow reduction at the geotextile or blinding within the soil matrix itself. An improvement to this method would be to include piezometer or transducers within these zones (after the gradient ratio method) to aid in interpretation of the results.

Other filtration tests for clogging potential include the Caltrans slurry filtration test (Hoover, 1982), which was developed by Legge (1990) into the Fine Fraction filtration (F^3) test (Sansone and Koerner, 1992), and the Long-Term Flow (LTF) test (Koerner and Ko, 1982; GRI Test Method GT1). According to Fischer (1994), all of these tests have serious disadvantages that make them less suitable than the Gradient Ratio (GR) test for determining the filtration behavior of the soil-geotextile system. The GR test must be run longer than the ASTM-specified 24 hours, and proper attention must be paid to the test details (Maré, 1994) to get reproducible results.

Some additional hydraulic properties often required in filtration design are the Percent Open Area (POA) and the porosity. As noted in Table 1-3, there are no standard tests for these properties, although there is a suggested procedure for POA given by Christopher and Holtz (1985), which follows Corps of Engineers procedures. Basically, POA is determined on a light table or by projection enlargement. Porosity is readily calculated just as it is with soils; that is, porosity is the volume of the voids divided by the total volume. The total volume is, for example, 1 m^2, times the nominal thickness of the geotextile. The volume of voids is the total volume minus the volume of the fibers and filaments (*solids*), or the mass of 1 m^2 divided by the specific gravity of the polymer.

1.6 SPECIFICATIONS

Specifications should be based on the specific geosynthetic properties required for design and installation. *Standard* geosynthetics may result in uneconomical or unsafe designs. To specify a particular type of geosynthetic or its *equivalent* can also be very misleading. As a result, the contractor may select a product that has completely different properties than intended by the designer. In almost every chapter of this manual, guide specifications are given for the particular application discussed in the chapter. See Richardson and Koerner (1990) and Koerner and Wayne (1989) for additional guide specifications.

All geosynthetic specifications should include:

- general requirements
- specific geosynthetic properties
- seams and overlaps
- placement procedures
- repairs, and
- acceptance and rejection criteria

General requirements include the types of geosynthetics, acceptable polymeric materials, and comments related to the stability of the material. Geosynthetic manufacturers and representatives are good sources of information on these characteristics. Other items that should be specified in this section are instructions on storage and handling so products can be protected from ultraviolet exposure, dust, mud, or any other elements that may affect performance. Guidelines concerning on-site storage and handling of geotextiles are contained in ASTM D 4873, Standard Guide for Identification, Storage, and Handling of Geotextiles. If pertinent, roll weight and dimensions may also be specified. Finally, certification requirements should be included in this section.

Specific geosynthetic physical, index, and performance properties as required by the design must be listed. Properties should be given in terms of *minimum (or maximum) average roll values* (MARVs), along with the required test methods. MARVs are simply the smallest (or largest) anticipated *average* value that would be obtained for any roll tested (Koerner, 1994). This *average* property value must exceed the minimum (or be less than the maximum) value specified for that property based on a particular test. Ordinarily it is possible to obtain a manufacturer's certification for MARVs.

If performance tests have been conducted as part of the design, a list of approved products could be provided. **The language *or equal* and *or equivalent* should be avoided within the specification, unless equivalency is spelled out in terms of the index properties and the performance criteria that were required to be included on the approved list.** Approved lists can also be developed based on experience with recurring application conditions. Once an approved list has been established, new geosynthetics can be added as they are approved. Manufacturer's samples should be periodically obtained so they can be examined alongside the original tested specimens to verify whether the manufacturing process has changed since the product was approved. Development of an approved list program will take considerable initial effort, but once established, it provides a simple, convenient method of specifying geosynthetics with confidence.

Seam and overlap requirements should be specified along with the design properties for both factory and field seams, as applicable. A minimum overlap of 0.3 m is recommended for all geotextile applications, but overlaps may be increased due to specific site and construction requirements. Sewing of seams, discussed in Section 1.8, may be required for special conditions. Also, certain geotextiles may have factory seams. The seam strengths specified should equal the required strength of the geosynthetic, in the direction perpendicular to the seam length, using the same test procedures. For designs where wide width tests are used (*e.g.*, reinforced embankments on soft foundations), the required seam strength is a calculated design value. Therefore, seam strengths should not be specified as a percent of the geosynthetic strength.

Geogrids and geonets may be connected by mechanical fasteners, though the connection may be either structural or a construction aid (*i.e.*, strength perpendicular to the seam length is not required by design). Geomembranes are normally thermally bonded and specified in terms of peel and shear seam strengths, as discussed in Chapter 10.

For sewn geotextiles, geomembranes, and structurally connected geogrids, the seaming material (thread, extrudate, or fastener) should consist of polymeric materials that have the same or greater durability as the geosynthetic being seamed. For example, nylon thread, unless treated, which is often used for geotextile seams may weaken in time as it absorbs water.

Placement procedures should be given in detail within the specification and on the construction drawings. These procedures should include grading and ground-clearing requirements, aggregate specifications, aggregate lift thickness, and equipment requirements. These requirements are especially important if the geosynthetic was selected on the basis of survivability. Detailed placement procedures are presented in each application chapter.

Repair procedures for damaged sections of geosynthetics (*i.e.*, rips and tears) should be detailed. Such repairs should include requirements for overlaps, sewn seams, fused seams, or replacement requirements. For overlap repairs, the geosynthetic should extend the minimum of the overlap length requirement from all edges of the tear or rip (*i.e.*, if a 0.3 m overlap is required, the patch should extend at least 0.3 m from all edges of the tear).

Acceptance and rejection criteria for the geosynthetic materials should be clearly and concisely stated in the specifications. It is very important that all installations be observed by a designer representative who is knowledgeable in geotextile placement procedures and who is aware of design requirements. Sampling (*e.g.*, ASTM D 4354, Standard Practice for Sampling of Geosynthetics for Testing) and testing requirements be required during construction should also be specified. Guidelines for acceptance and rejection of geosynthetic shipments are contained in ASTM D 4759, Standard Practice for Determining the Specification Conformance of Geosynthetics.

For small projects, the cost of ASTM acceptance/rejection criterion testing is often a significant portion of the total project cost and may even exceed the cost of the geosynthetic itself. In such cases, a manufacturer's product certification specification requirement or an approved product list type specification may be satisfactory.

1.7 SPECIFICATION CONFORMANCE EXAMPLE

DEFINITION OF EXAMPLE

- Project Description: a geotextile separator will be used in construction of a roadway

GIVEN DATA

- a Class 2 (AASHTO M 288) geotextile was specified for survivability
- 110 rolls of geotextile are required for the project, and have arrived on site in one shipment
- geotextile is a nonwoven, with an elongation at failure (per ASTM D 4632) of greater than 50%
- test results for the samples are presented in the table below
- the coefficient of variation for the test laboratory is undefined

DETERMINE

- whether the geotextile meets the required grab tensile strength of 700 N

SOLUTION

A. What is the lot size?

The lot size is 110, the number of rolls shipped to this project.

B. How many units, or number of rolls, should be selected for as samples for conformance testing?

The total number of units, or rolls, in this lot is 110. The number of rolls to take lot samples from is 5, per ASTM D 4354, Standard Practice for Sampling of Geosynthetics for Testing.

C. How many sampling units should be take from each roll?

One laboratory sampling unit should be taken from each roll (lot sampling unit), per ASTM D 4632, Standard Test Method for Grab Breaking Load and Elongation of Geotextiles.

D. How many test specimens per laboratory sampling unit, in each direction, are required?

Since the coefficient of variation is undefined for the test laboratory (in this example), specify the fixed number of 10 specimens per roll, in both the machine and cross-machine directions, are required. This is based upon an assumed $v = 9.5\%$, which is somewhat larger than usually found in practice.

The number of tests may be reduced, with the following equation, when the laboratory's coefficient of variation is defined. Test Method D 4632 defines the following number of test specimens per laboratory sampling unit in each direction:

$$n = (tv/A)^2$$

where:

n = number of test specimens per laboratory sampling unit (rounded upward to the next whole number);
v = reliable estimate of the coefficient of variation for individual observations based on similar materials in the user's laboratory under conditions of single-operator precision, %;
t = the value of Student's t for one-sided limits, a 95% probability level, and the degrees of freedom associated with the estimate of v; and
A = 5.0% of the average, the value of allowable variation.

Per Test Method D 4632 if there is no reliable estimate of v for the user's laboratory, the equation above should not be used directly. Instead, specify the fixed number of 10 specimens for the machine direction tests and 10 specimens for the cross-machine direction test.

Test Results — Machine Direction

	Roll Number				
Specimen	1	2	3	4	5
1	720	733	687	702	693
2	713	715	715	689	701
3	715	721	717	707	698
4	708	719	706	716	711
5	707	707	724	730	707
6	700	713	699	724	720
7	699	720	705	717	725
8	711	703	712	712	720
9	717	700	717	707	718
10	703	712	722	716	715
Average	709.3	714.3	710.4	712.0	710.8

Test Results — Cross-Machine Direction

	Roll Number				
Specimen	1	2	3	4	5
1	715	723	683	699	690
2	708	710	710	687	700
3	710	711	707	701	691
4	703	717	707	706	701
5	709	709	713	723	706
6	703	715	688	719	718
7	689	710	701	707	721
8	701	708	700	702	719
9	707	707	693	707	713
10	700	710	701	710	711
Average	704.5	712.0	700.3	706.1	707.0

All roll averages exceed the specification value of 700 N. Therefore, the grab strength of this lot is acceptable.

1.8 FIELD INSPECTION

Problems with geosynthetic applications are often attributed to poor product acceptance and construction monitoring procedures on the part of the owner, and/or inappropriate installation methods on the part of the contractor. A checklist for field personnel responsible for observing a geosynthetic installation is presented in Table 1-4. Recommended installation methods are presented in the application chapters.

1.9 FIELD SEAMING

Some form of geosynthetic seaming will be utilized in those applications that require continuity between adjacent rolls. Seaming techniques include overlapping, sewing, stapling, tying, heat bonding, welding and gluing. Some of these techniques are more suitable for certain types of geosynthetics than others. For example, the most efficient and widely used methods for geotextiles are overlapping and sewing, and these techniques are discussed first.

The first technique, the *simple overlap*, will be suitable for most geotextile and biaxial geogrid projects. The minimum overlap is 0.3 m. Greater overlaps are required for specific applications. If stress transfer is required between adjacent rolls, the only strength provided by an overlap is the friction between adjacent sheets of geotextiles, and by friction and fill *strike-through* of substantial apertures of biaxial geogrids. Unless overburden pressures are large and the overlap substantial, very little stress can actually be transferred through the overlap.

The second technique, *sewing*, offers a practical and economical alternative for geotextiles when overlaps become excessive or stress transfer is required between two adjacent rolls of fabric. For typical projects and conditions, sewing is generally more economical when overlaps of 1 m or greater are required. To obtain good-quality, effective seams, the user should be aware of the following sewing variables (Koerner, 1994; Diaz and Myles, 1990; Ko, 1987):

- Thread type: Kevlar aramid, polyethylene, polyester, or polypropylene (in approximate order of decreasing strength and cost). Thread durability must be consistent with project requirements.
- Thread tension: Usually adjusted in the field to be sufficiently tight; but not cut the geotextile.
- Stitch density: Typically, 200 to 400 stitches per meter are used for lighter-weight geotextiles, while heavier geotextiles usually allow only 150 to 200 stitches per meter.
- Stitch type: Single- or double-thread chainstitch, Types 101 or 401; with double-thread chain- or *lock*-stitch preferred because it is less likely to unravel (Figure 1-2(a)).
- Number of rows: Usually two or more parallel rows are preferred for increased safety.
- Seam type: Flat or *prayer* seams, J- or Double J-type seams, or *butterfly* seams are the most widely used (Figure 1-2(b)).

TABLE 1-4
GEOSYNTHETIC FIELD INSPECTION CHECKLIST

☐ 1. Read the specifications; determine if geosynthetic is specified by (a) specific properties or (b) an approved products list.

☐ 2. Review the construction plans.

☐ 3. (a) For specification by specific properties, check listed material properties of supplied geosynthetic, from published literature, against the specific property values specified.

OR

(b) Obtain the geosynthetic name(s), type, and style, along with a small sample(s) of approved material(s) from the design engineer. Check supplied geosynthetic type and style for conformance to approved material(s). If the geosynthetic is not listed, contact the designer with a description of the material and request evaluation and approval or rejection.

☐ 4. On site, check the rolls of geosynthetics to see that they are properly stored; check for any damage.

☐ 5. Check roll and lot numbers to verify whether they match certification documents.

☐ 6. Cut two samples 100 mm to 150 mm square from a roll. Staple one to your copy of the specifications for comparison with future shipments and send one to the design engineer for approval or information.

☐ 7. Observe materials in each roll to make sure they are the same. Observe rolls for flaws and nonuniformity.

☐ 8. Obtain test samples according to specification requirements from randomly selected rolls. Mark the machine direction on each sample and note the roll number.

☐ 9. Observe construction to see that the contractor complies with specification requirements for installation.

☐ 10. Check all seams, both factory and field, for any flaws (*e.g.*, missed stitches in geotextile). If necessary, either reseam or reject materials.

☐ 11. If possible, check geosynthetic after aggregate or riprap placement for possible damage. This can be done either by constructing a trial installation, or by removing a small section of aggregate or riprap and observing the geosynthetic after placement and compaction of the aggregate, at the beginning of the project. If perforations, tears, or other damage has occurred, contact the design engineer.

☐ 12. Check future shipments against the initial approved shipment and collect additional test samples. Collect samples of seams, both factory and field, for testing. For field seams, have the contractor sew several meters of a *dummy* seam(s) for testing and evaluation.

When constructed correctly, sewn seams can provide reliable stress transfer between adjacent sheets of geotextile. However, there are several points with regard to seam strength that should be understood, as follows.

1. Due to needle damage and stress concentrations at the stitch, sewn seams are weaker than the geotextile (good, high-quality seams have only about 50% to 80% of the intact geotextile strength based on wide width tests).
2. Grab strength results are influenced by the stitches, so the test yields artificially high seam strengths. Grab test should only be used for quality control and not to determine strength.
3. The maximum seam strengths achievable at this time are on the order of 200 kN/m under factory conditions, using 330 kN/m geotextiles.
4. Field seam strengths will most likely be lower than laboratory or factory seam strengths.
5. All stitches can unravel, although lock-type stitches are less likely to.
6. Unraveling can be avoided by utilizing high-quality equipment and proper selection of needles, thread, seam and stitch type, and by using two or more rows of stitches.
7. Careful inspection of all stitches is essential.

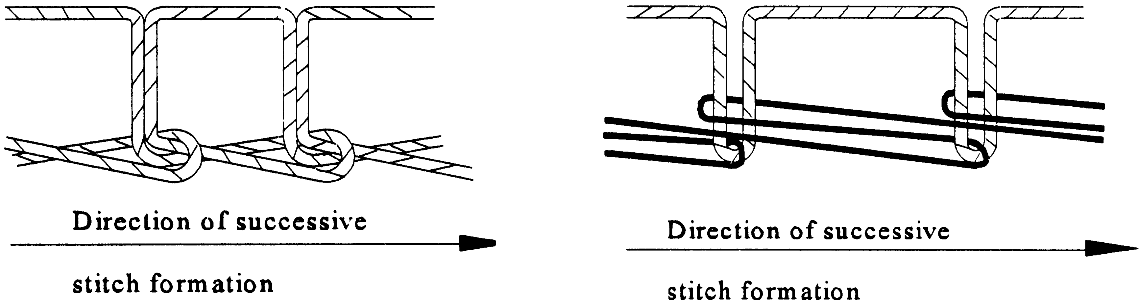
Field sewing is relatively simple and usually requires two or three laborers, depending on the geotextile, seam type, and sewing machine. Good seams require careful control of the operation, cleanliness, and protection from the elements. However, adverse field conditions can easily complicate sewing operations. Although most portable sewing machines are electric, pneumatic equipment is available for operating in wet environments.

Since the seam is the weakest link in the geotextile, all seams, including factory seams, should be carefully inspected. To facilitate inspection and repair, the geotextile should be placed (or at least inspected prior to placement) with all seams up (Figure. 1-2(c)). Using a contrasting thread color can facilitate inspection. Procedures for testing sewn seams are given in ASTM D 4884, Standard Test Method for Seam Strength of Sewn Geotextiles.

Seaming of biaxial geogrids and geocomposites is most commonly achieved by overlaps, and the remarks above on overlap of geotextiles are generally appropriate to these products. Uniaxial geogrids are normally butted in the along-the-roll direction. Seams in the roll direction of uniaxial geogrids are made with a *bodkin* joint for HDPE geogrids, as illustrated in Figure 1-3, and may be made with overlaps for coated PET geogrids.

Seaming of geomembranes and other geosynthetic barriers is much more varied. The method of seaming is dependent upon the geosynthetic material being used and the project design. Overlaps of a designated length are typically used for thin-film geotextile composites and geosynthetic clay liners. Geomembranes are seamed with thermal methods or with solvents.

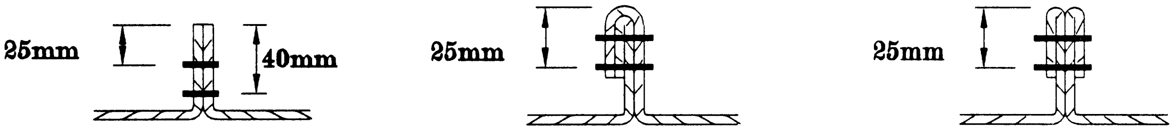
(a) Type of stitches



Type 101:
Single Thread Chain Stitch

Type 401:
Double Thread Chain
or "Lock "Stitch

(b) Type of seams

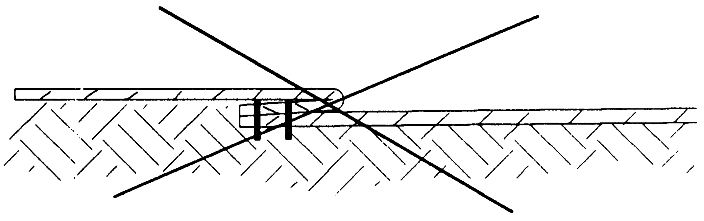


Flat or "prayer Seam
Type SSa-2

J Seam
Type SSn-2

"Butterfly" Seam
Type SSd-2

(c) Improper placement



Cannot Inspect or Repair

Figure 1-2 Types of (a) stitches and (b) seams, according to Federal Standard No. 751a (1965); and (c) improper seam placement.

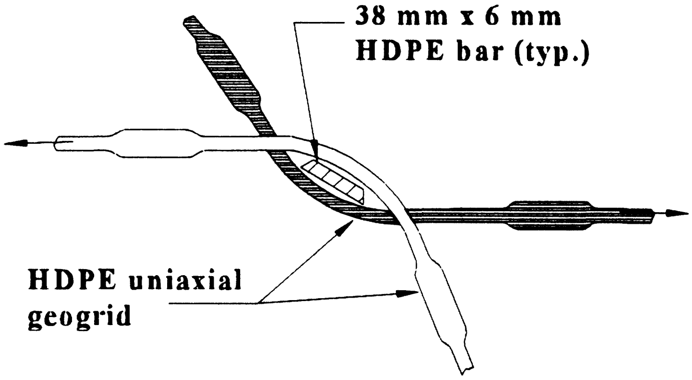


Figure 1-3 Bodkin connection of HDPE uniaxial geogrid.

1.10 REFERENCES

References quoted within this section are listed below. The Holtz and Paulson and the Cazzuffi and Anazani lists of geosynthetic literature are attached as Appendix A. Detailed lists of specific ASTM and GRI test procedures are presented in Appendix E. The Koerner (1994) is a recent, comprehensive textbook on geosynthetics and is a *key* reference for design. The bibliographies by Giroud (1993, 1994) comprehensively contain references of publications on geosynthetics before January 1, 1993. These and other *key* references are noted in bold type.

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