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Chapter 20
GEOSYNTHETICS

Geosynthetics include a variety of manufactured products that are used in drainage, earthwork, erosion control and soil reinforcement applications. Geosynthetics are defined in ASTM D 4439 as a planar product manufactured from a polymeric material that is used with soil, rock, earth or other geotechnical-related material as an integral part of a civil engineering project, structure or system. The source material used to produce geosynthetics typically includes one or more of the following polymers:

- polypropylene,
- polyester,
- polyethylene,
- polyamide (nylon), and
- PVC.

20.1 GENERAL

20.1.1 Specifications

Sections 622 and 716 of the *MDT Standard Specifications* address the use of geosynthetics in construction. The AASHTO Specification M288, "Standard Specifications for Geotextiles," provides additional subgrade preparation and geosynthetic installation guidelines.

AASHTO and ASTM provide specifications that address numerous properties of geosynthetics and the test methods that are used to define the properties. Most of the primary properties and test methods for transportation projects fall under one of the following three categories:

- physical properties,
- mechanical properties, and
- hydraulic properties.

As a quick reference guide, specific properties and associated specifications are listed in Figure 20.1-A. Additional categories not listed in Figure 20.1-A include endurance properties and degradation properties. Note that the *MDT Standard Specifications* only address the ultraviolet light degradation test (ASTM D 4355).

20.1.2 Geotechnical Report

The majority of MDT projects that require geotechnical involvement usually require at least some minimal use of geosynthetics, and select projects may require extensive use possibly consisting of various types of geosynthetics. Besides recommending the use of a geosynthetic for a particular application, the geotechnical report will also need to provide the type of geosynthetic(s) to be utilized and specific locations within the project to use the geosynthetic.

When a geosynthetic is referenced to the *MDT Standard Specifications*, it is also necessary to provide the following information in both the report and the project plans:

- type of geotextile (e.g., separation, stabilization, erosion control);
- survivability (high or moderate); and
- class for permanent erosion control and subsurface drainage geotextiles (A, B or C).

The recommended use of a particular geosynthetic that is not currently addressed by the *Standard Specifications* will require a Special Provision as part of the report and project plans.

20.1.3 References

For further guidance on geosynthetics, review the following documents:

- *Montana Standard Specifications for Road and Bridge Construction*, Sections 622 and 716;
- AASHTO M 288, "Standard Specifications for Geotextiles";
- ASTM D 4439, "Standard Terminology for Geosynthetics";
- *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, FHWA-NHI-00-043;
- *Geosynthetic Design and Construction Guidelines Reference Manual*, FHWA HI-95-038;
- *Geocomposite Drains*, Volumes 1 and 2, FHWA RD-86-171 and FHWA RD 86-172;
- *Designing with Geosynthetics*, Prentice Hall, Inc., New Jersey;
- *Geotechnical Aspects of Landfill Design and Construction*, Qian, X., Koerner, R. and Gray, D., Prentice Hall, Inc., New Jersey, 2002; and
- *Waste Containment Systems, Waste Stabilization and Landfills: Design and Evaluation*, Sharma, H. and Lewis, S., Wiley Publishing, 1994.

Physical Properties	Specification	Mechanical Properties	Specification	Hydraulic Properties	Specification
Specific Gravity	ASTM D 792, D 1505	Tensile Tests	ASTM D 4595, D 6637	Apparent Opening Size	ASTM D 4751
Mass Per Unit Area	ASTM D 5261	Grab Tensile Strength	ASTM D 4632	Permittivity	ASTM D 4491
Aperture Size	DM	Trapezoidal Tear Test	ASTM D 4533	Transmissivity	ASTM D 4716
Rib Size	DM	Puncture Test	ASTM D 4833	Soil Retention	ASTM D 5141
Thickness	ASTM D 5199	Burst Strength	ASTM D 3786		
Melting Point	ASTM D 276	Compressibility	ASTM D 6364, D 6454, D 6244		
Stiffness	ASTM D 1388	Direct Shear	ASTM D 5321		
		Pullout	ASTM D 6706		

Note: DM indicates this property is obtained using direct measurement techniques.

Figure 20.1-A — GEOSYNTHETIC PROPERIES AND ASSOCIATED STANDARD SPECIFICATIONS

20.2 TYPES OF GEOSYNTHETICS FOR HIGHWAY APPLICATIONS

Geosynthetics used in transportation applications in Montana generally fall into one of the following categories:

1. Geotextile. Geotextiles are permeable materials comprised of fibers or yarns combined into planar textile structures. *Specifications* for geotextiles are provided in AASHTO M 288 and *MDT Standard Specifications* Sections 622 and 716. The vast majority of geotextiles are either woven or nonwoven, described as:

   a. Woven. Woven geotextiles are typically made of monofilament, multifilament or fibrillated yarns. Occasionally, manufacturers will use slit films or tapes.

   b. Non-Woven. Nonwoven geotextile is manufactured using a process in which synthetic polymer fibers or filaments are continuously extruded and spun. The fibers or filaments are then connected using needle punching or heat bonding techniques.

   Geotextiles are used for strength, separation, drainage and filter purposes. Properties of the geotextile will change depending on the type of application.

2. Geogrid. Geogrids consist of polymer mats constructed either of coated yarns or punched and stretched polymer sheets. They are commonly used for soil reinforcement. Geogrids are formed using a regular network of integrally connected elements with apertures greater than ¼ in (6 mm) to allow interlocking with surrounding geomaterials. Standard specifications for geogrids are provided in ASTM D 5262.

   Geogrid types can be divided into the following:

   a. Junctions. This geogrid design is determined according to the method used to form junctions between the ribs of the grid. Geogrids based on junction type include extruded geogrid, bonded geogrid and woven geogrid.

   b. Direction. This design is based on the number of directions in which the geogrid is designed to carry loads. Geogrids based on load carrying direction include uniaxial geogrid and biaxial geogrid.

3. Geonets. Geonets are a netlike polymeric material manufactured of integrally connected parallel sets of ribs overlying similar sets of ribs. They are used for planar drainage of liquids or gases.

4. Geocomposites. Geocomposites generally consist of a geonet or a cuspated or dimpled polyethylene drainage core wrapped in a geotextile. These are often used as edge drains, wall drains, vertical drains (wick drains) and sheet drains. The drainage net/core acts as a conduit for water and the geotextile wrap acts as a filter keeping the net/core clean of soil particles.

5. Geomembranes. Geomembranes consist of impervious polymer sheets that are typically used to line ponds or landfills or, in some cases, encapsulate moisture sensitive swelling clays to control moisture. Various types of materials are used for

geomembranes (e.g., polyvinyl chloride (PVC), high density polyethylene (HDPE), polypropylene (PP), polyester (PET)). The thickness of these materials can range from 20 mils to 100 mils (0.5 mm to 2.5 mm) or more. Various seaming methods are used to seal multiple membrane panels together.

6. Geosynthetic Clay Liners (GCL). Geosynthetic clay liners are manufactured hydraulic barriers consisting of sodium bentonite clay sandwiched and bonded between two geotextiles or attached with an adhesive to a geomembrane. GCL are manufactured in continuous sheets and are installed by unrolling and overlapping the edges and ends of the panels. Overlaps self-seal when the sodium bentonite hydrates. Some transportation applications of GCLs include:

   - control of vertical or horizontal infiltration of moisture into a subgrade of expansive soil,
   - maintenance of moisture content of frost-sensitive soils,
   - sealing of berms for wetland mitigation,
   - waterproofing walls and bridge abutments, and
   - lining rest area waste water treatment lagoons.

20.3 TYPICAL APPLICATIONS AND DESIGN CONCEPTS

The type of a geosynthetic varies with the intended application. Geosynthetics have six primary applications: filtration, separation/stabilization, subsurface drainage, erosion protection, fluid barrier and reinforcement. In addition to these primary functions, geosynthetics often perform one or more secondary functions. The required design properties of the geosynthetic depend on the application and the associated function(s) that the geosynthetic is to provide. The *Geosynthetic Design and Construction Guidelines Reference Manual* (*Geosynthetic Reference Manual*) provides:

- a list of criteria and principal properties for use in evaluating the suitability of geosynthetics,
- detailed descriptions of geosynthetic design properties, and
- index and performance tests.

A listing of currently available geosynthetic products can be found in the annual *Specifier's Guide* published by the Industrial Fabrics Association International in Geosynthetics.

20.3.1 <u>Filtration</u>

Geotextiles are used as filters in drainage applications (e.g., trench and interception drains, blanket drains, pavement edge drains, structure drains, beneath permeable roadway bases). The filter restricts movement of soil particles as water flows into the drain structure and is collected and/or transported downstream. Geotextiles, like graded granular filters, require proper engineering design or they may not perform as desired. Unless flow requirements, piping resistance, clogging resistance and survivability requirements are properly specified, the geotextile/soil filtration system may not perform properly. Properly designed geotextiles can be used as a replacement for or, in conjunction with, conventional graded granular filters in almost any drainage application.

The *Geosynthetic Reference Manual* presents detailed guidelines for geotextile filter design. The design process is based on consideration of the following criteria:

1. <u>Retention</u>. The geotextile must retain the soil.
2. <u>Permeability/Permittivity</u>. The geotextile must allow water to pass.
3. <u>Clogging Resistance</u>. The geotextile must not bind or clog as a result of movement of smaller particles of soil.
4. <u>Survivability and Endurance</u>. The geotextile must survive the construction process. Minimum strength and endurance properties for filtration and drainage applications are provided in the *Geosynthetic Reference Manual*.

As part of the filtration design process, the project geotechnical specialist will need to identify the grain-size distribution of the material that will be retained, and the material into which particle migration is being restricted.

20.3.2 Separation

Separation is defined as the prevention of the mixing of two dissimilar materials. Separation geotextiles are commonly used to separate unsaturated subgrade soil from the overlying granular base course. Separators prevent road base materials from penetrating into the underlying soft subgrade and prevent fine-grained subgrade soils from contaminating permeable, granular road bases. Either of these cases can result in loss of the supporting characteristics of the roadway subgrade, resulting in cracking and rutting of the pavement surface. Appropriate use of separators in roadway design may significantly save in the cost of maintenance and repair of roadway surfaces.

Separation geotextile should normally be used where the subgrade is workable so that it can be compacted and prepared with typical earthwork equipment. Separation geotextiles typically have low strengths and should not be used with the expectation that they will improve the bearing capacity for a soft subgrade condition. If a soft subgrade is encountered, then select a stabilization geotextile or geogrid as discussed in Section 20.3.3. The feasibility of separation geotextile may be dependent on weather conditions expected when the geotextile is to be installed.

Separation geotextile placed beneath the roadway surfacing should be limited to locations where the undrained shear strength is greater than 1900 psf (90 kPa) or the R-value is greater than 7 (CBR > 3), and where saturated fine sandy, silty or clayey subgrades are not present. In general, separation geotextile is not necessary if:

- the subgrade is dense and predominately granular and not saturated,
- the subgrade resilient modulus is greater than 15,000 psi (103 mN/m^2), or
- poor subgrade soil will be removed and replaced with granular material.

Separation geotextiles are manufactured with varying properties (e.g., strength, permeability). If a separation geotextile is used, select the properties to meet the desired function. In cases where the subgrade may be saturated during the design life of the section, design the geotextile to meet filtering criteria. Filtering criteria should be used to confirm that fine-grained soil particles will not migrate through the geotextile during water flow or stress application.

Non-woven and woven geotextiles are acceptable for separation applications provided that they meet the material requirements specified in *MDT Standard Specifications.* The plans and/or special provision should:

- specify the geotextile strength requirements for the level of survivability;
- summarize the separation geotextile property requirements including permittivity, apparent opening size and ultraviolet stability; and
- provide detailed construction installation requirements. Additional installation guidelines are provided in AASHTO Specification M 288.

20.3.3 Stabilization

Stabilization geosynthetics are used for soft, very moist to wet subgrade conditions. Geosynthetics for this application must function as a separator, a filtration layer and, to a minor extent, as a reinforcement layer. This application is similar to a separation application, except that the subgrade is anticipated to be softer and wetter than in the separation application. The need for a soil stabilization geosynthetic should be anticipated where the subgrade undrained shear strength is less than 1900 psf (90 kPa), where the R-value is less than 7 (CBR < 3), or where a saturated fine sandy, silty or clayey subgrade is likely to be present.

Do not use woven, slit-film geotextiles (i.e., geotextiles made from yarns of a flat, tape-like character) for stabilization. The *MDT Standard Specifications* identifies:

- specific geotextile strength requirements for the level of survivability specified on the plans or in the special provisions;
- separation geotextile property requirements including permittivity, apparent opening size and ultraviolet stability; and
- detailed construction installation guidelines.

Select stabilization geosynthetics based on the desired performance function; considering both strength and filtration properties. Design procedures for filtration are discussed in Section 20.3.1. Consider the amount and distribution of load from wheel loads for strength-based design. The *Geosynthetics Reference Manual* can be used for this design.

20.3.4 Subsurface Drainage

Geosynthetics can be used below grade to facilitate long-term transmission of water into a subsurface drain system while retaining the in-situ soil. Geotextiles, geocomposites and geonets can be used in this application as lateral transmission media, in which water is removed (drained) from, or through, soils of lower permeability. In many applications, geosynthetics can be used in place of graded granular filters. The geosynthetic functions as both filter and drain, by:

- retaining soil particles in place and preventing their migration (piping) through the filtering component, and
- collecting and transporting water down-gradient in a controlled manner.

Drainage applications include pavement edge drains, slope interceptor drains, abutment and retaining wall drains, and sheet drains for dissipating porewater pressures at the base of roadway embankments. Higher flow requirements in many of these applications generally necessitate the use of geocomposites or geonets, or the use of a pipe or other drainage medium in combination with a geotextile.

Detailed step-by-step guidelines for designing a complete drainage system, including an example design, are presented in the *Geosynthetic Reference Manual*. These design guidelines incorporate an open-graded, free-draining aggregate as the drain with a geotextile functioning as the filter.

In some applications, flow can occur both perpendicular and transverse to the plane of the geo-drain. Geotextile products are generally inadequate in high-flow situations because the seepage quantities transmitted by in-plane flow through the geotextile under a pressure equivalent to 2 ft (0.6 m) of soil are relatively small when compared to the seepage capacity of geocomposites, geonets, or 6 in to 12 in (150 mm to 300 m) of coarse sand or drain rock.

The procedure for designing a geocomposite drainage system involves consideration of the same criteria described for geotextile filtration and drainage design. Additional details specific to geocomposite design and construction are provided in the *Geosynthetic Reference Manual*.

Proper installation of the drainage system, whether it is a geotextile or geocomposite drainage system, is necessary to ensure the intended construction performance.

20.3.5 <u>Erosion Protection</u>

The primary function of geotextiles used for permanent erosion control is to protect the soil beneath it from erosion caused by surface water flow, runoff, or piping. Examples of permanent erosion control geotextile applications used in combination with riprap include:

- runoff and erosion protection along drainage channels and high-velocity diversion ditches;
- scour protection around bridge piers;
- erosion protection for hydraulic structures (e.g., culverts, drop inlets); and
- erosion protection for highway cuts or fill slopes.

Geotextile design for hard-armor erosion control systems is nearly the same as geotextile design for filters in subsurface drainage systems. The *Geosynthetic Reference Manual* summarizes the geotextile design and selection criteria for hard-armor erosion control applications. The design process is divided into the following categories:

- soil retention (piping resistance criteria),
- permeability/permittivity criteria,
- clogging criteria, and
- survivability.

Geosynthetic erosion control mats are used to retain soil, moisture and vegetative seed to promote plant growth on slopes and in ditches.

Account for the following items when designing an erosion control mat:

- type and magnitude of water flow over the surficial soil that is being considered for protection,

- erodibility of the soil, and
- amount of vegetative cover present.

The source of flowing water could be a stream, man-made channel (ditch), wave action or runoff. Water may also flow from the soil behind (or underneath) the mat, depending on the ground water level. If ground water cannot escape through the mat, an erosion control system failure termed ballooning (water pressure buildup behind the geotextile) or soil piping could occur. Therefore, the mat must have good filtration and water flow characteristics.

20.3.6 Fluid Barriers (Cutoffs and Liners)

Geosynthetic fluid barriers are used in highway projects to:

- control vertical or horizontal infiltration of moisture into a subgrade consisting of expansive or highly moisture-sensitive soil,
- maintain the moisture content of frost-sensitive soils,
- waterproof walls and bridge abutments,
- prevent moisture changes beneath roadways, and
- contain water and wastes in storm drainage systems.

These types of synthetic barriers are used to either prevent damage to highway pavements and structures, or as part of a water quality enhancement system. Barriers must be engineered to perform their intended function for the particular application and project conditions.

20.3.6.1 Barrier Characteristics and Importance of QA/QC

Geosynthetic barrier materials are categorically classified as geomembranes, thin-film geotextile composites, geosynthetic clay liners (GCL) or field-impregnated geotextiles. Geomembranes are relatively impermeable compared to natural materials (e.g., compacted clay). Leakage is the primary concern when designing geomembrane containment structures, not necessarily permeability. For example, the as-constructed permeability of geomembranes is estimated as approximately 1×10^{-8} cm/sec if the liner is installed with excellent workmanship and quality control during installation. Excellent construction is defined by Qian, Koerner and Gray (2002) as a liner that has one small hole (0.015 in^2) per acre ((24 mm^2) per hectare).

Leakage can occur because of poor field seams, poor factory seams, pinholes from the manufacturing process and puncture holes from handling, placement or in-service loads. Leakage of geomembrane liner systems is minimized by paying close attention to design, specifications, testing, quality control (QC) and quality assurance (QA) of manufacture, and QC and QA of construction. The project geotechnical specialist may be requested to provide oversight during installation of barrier materials, particularly at locations where the function of the barrier system could impact a slope or bridge foundation.

20.3.6.2 Moisture Barriers in Roadway Construction

Moisture barriers are not frequently used in highway construction by MDT. In other States, thin-film geotextile composites are reportedly the most popular selection when a moisture barrier is necessary for roadway construction. These composites are used to prevent or minimize moisture changes in pavement subgrades and are typically installed above the subgrade and below the base course.

Geotextile composites are available in a variety of configurations. Two typical arrangements used to construct thin-film geotextile composites consist of a very lightweight polypropylene nonwoven geotextile sandwiched between two layers of polypropylene film or a polyethylene film sandwiched between two layers of nonwoven polypropylene geotextiles. Similar products are available with PVC, chlorosulfonated polyethylene (CSPE) and polypropylene geomembranes as the core.

20.3.6.3 Fluid Barriers for Stormwater Ponds

In urban areas, geosynthetic fluid barriers are used to line stormwater drainage ponds. This design is not commonly used by MDT; however, it may be used more frequently in the future. Lined ponds are used to:

- Collect and store stormwater from roadways before it is discharged to wastewater treatment facilities. This approach is used in areas where water collected from the roadway is contaminated with hydrocarbons, lead and other contaminants associated with roadway use.

- Reduce the rate of runoff of turbid surface water to allow coarse particles to settle into the bottom of the drainage structure before the surface water drains into stream, rivers and lakes. This approach is used to enhance water quality within waterways adjacent to roadways.

Common types of fluid barriers for these applications include geosynthetic clay liners (GCLs) and polyvinyl chloride (PVC) liners. Design considerations for these fluid barriers include the type of seams to minimize infiltration, protection of the membrane from damage caused by maintenance work after the pond is constructed (e.g., when equipment is used to remove accumulated sediment) and stability of soil above the liner for the side slopes of the drainage pond.

The frictional resistance between soil and geosynthetic liner can be very low (i.e., less than 15 degrees), which can lead to soil sliding on the side slope of the drainage pond if appropriate design provisions are not used or if inappropriate geosynthetic types are selected. The interface friction between soil and the geosynthetic liner will depend on the particular liner material (e.g., textured versus smooth surface, PVC versus HDPE). Published values of interface friction are available and, where critical conditions exist, interface friction tests can be conducted in large-size direct shear equipment.

To fulfill its barrier function, the geosynthetic system must remain leak-proof and relatively impermeable during transportation and installation, and must be durable enough to maintain its integrity throughout the design life of the project. The following steps outline the basic design process for geosynthetic barrier systems:

- define performance requirements,
- identify in-service conditions,
- design for durability,
- determine the anticipated installation conditions, and
- conduct peer review and economic analyses.

Guidance for performing these steps is provided in the *Geosynthetics Reference Manual* and *Designing with Geosynthetics*. Various documents describing the construction of fluid barrier systems are also available. For example, vendors of barrier products usually have specific guidelines on how their products should be installed. The US Environmental Protection Agency also has guidance documents for construction and inspection of lining systems.

20.3.7 <u>Reinforcement</u>

One of the most common use of geosynthetics is for reinforcing the soil. This type of application includes reinforcing the base of embankments being constructed over soft foundation soils, using geosynthetics to increase the slope steepness and constructing mechanically stabilized (MSE) earth walls.

20.3.7.1 Reinforced Embankments on Soft Foundations

Embankments constructed on soft foundation soils have a tendency to spread laterally because of horizontal earth pressures acting within the embankment. These earth pressures cause horizontal shear stresses at the base of the embankment, which must be resisted by the foundation soil. If the foundation soil does not have adequate shear resistance, bearing failure can result. Properly designed horizontal layers of high-strength geotextiles or geogrids can provide reinforcement that can increase stability and thereby reduce differential settlements associated with bearing failures.

Three possible modes of failure should be analyzed — bearing failure, rotational failure and lateral spreading. In addition, settlement of the embankment and potential creep of the reinforcement should be considered; although, creep is only a factor if the creep rate in the reinforcement is greater than the strength gain occurring in the foundation due to consolidation. Because the most critical condition for stability of an embankment when constructed over a soft fine-grained soil is at the end of construction, the reinforcement is primarily relied upon to prevent failure until the foundation soils gain sufficient strength to support the embankment.

The *Geosynthetics Reference Manual* provides a detailed procedure for design of reinforced embankments. Several of the computer software packages used for assessing slope stability allow either a geotextile or a geogrid to be included in the stability model; see Chapter 13. Using limit equilibrium slope stability methods, the designer determines the minimum geosynthetic strength required to meet stability requirements.

Various documents describing the construction of base reinforcement systems are available. After the product is selected, the vendor's suggested construction guidelines should be obtained and reviewed before preparing special provisions.

20.3.7.2 Reinforced Soil Slopes

Multiple layers of geogrids or geotextiles may be placed in an earthfill slope during construction or reconstruction to reinforce the soil and provide increased slope stability for a given slope angle. Reinforced soil slopes (RSS) are a form of mechanically stabilized earth that incorporates planar reinforcing elements in constructed earth-sloped structures that have face inclinations less than 70^{o}. Structures with face inclinations of 70^{o} to 90^{o} are classified as walls (i.e., mechanically stabilized earth walls).

Steeper slopes can be constructed when reinforcement is properly incorporated into the earth mass, which can result in substantial right-of-way savings, especially for road-widening projects in urban areas. In some cases, RSS can be constructed at about one-half the cost of MSE structures. Vegetated-faced reinforced soil slopes can be landscaped to blend with natural environments and may provide an aesthetic advantage over retaining wall-type structures.

Slope facing requirements depend on soil type, slope angle and reinforcement spacing. If slope facing is required to prevent sloughing or erosion, several options are available for wrapped and non-wrapped face construction. Review the FHWA *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines* for detailed information and options regarding available treatment methods for the outward face of wrapped and non-wrapped RSS. Slopes steeper than approximately 1:1 require facing support during construction. Removable facing support (e.g., wood forms) or left-in-place welded wire mesh forms are typically used. Facing support may also serve as permanent or temporary erosion protection, depending on the requirements of the slope.

For wrapped or non-wrapped construction, the reinforcement should be maintained at close spacing; i.e., every lift or every other lift but no greater than 16 in (400 mm). For armored hard-faced systems, the maximum spacing should be no greater than 32 in (800 mm). A positive frictional or mechanical connection should be provided between the reinforcement and armored-type facing systems.

Design requirements for RSS are similar to those for unreinforced slopes; i.e., the factor of safety for all possible modes of failure must be adequate for both short-term and long-term conditions. Failure modes for RSS include:

- internal, where the failure plane passes through reinforcing elements;
- external, where the failure plane passes behind and underneath the reinforced mass; and
- compound, where the failure surface passes behind and through the reinforced soil mass.

RSS are analyzed using classical equilibrium slope stability methods modified to account for the stabilizing effect of reinforcement. A number of commercial slope stability computer programs are available for analyzing RSS; see Chapter 13.

The construction of RSS involves special procedures, which should be documented in a special provision. The FHWA *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines* provides guidelines that can be used to develop this special provision.

20.3.7.3 MSE Walls

Mechanically stabilized earth (MSE) walls are constructed using layers of a suitable soil that are reinforced using strips, sheets or grids made of extensible (geosynthetics) or inextensible (mild steel or aluminum) materials. Chapter 17 provides additional discussion on MSE walls using inextensible materials.

The soil fill is traditionally sand gravel mixes with less than about 15% fines. In some cases, higher percentages of fines have been used, particularly for projects where the geosynthetic wall is temporary. Typically, the geosynthetic material is placed between lifts of compacted soil. The lift thickness ranges from 1 ft to 2 ft (0.3 m to 0.6 m) depending on the specific design characteristics. The length of geosynthetic reinforcing will be approximately 0.7 times the wall height for level-ground conditions. Longer reinforcing lengths could be required where slopes occur above the wall, large seismic-induced ground shaking occurs or live loads are high.

Geosynthetic MSE walls have been constructed using woven geotextiles or uniaxial geogrids as soil reinforcing elements. However, the prevalent material used in highway geosynthetic walls is geogrid reinforcement. The most important property of geogrids and geotextiles that must be considered, in the context of soil reinforcement, is the long-term tensile strength (T_{al}), usually expressed in units of force per unit width. T_{al} is equal to the ultimate tensile strength divided by the product of all applicable reduction factors including creep, construction damage and durability.

MSE wall systems are more flexible than conventional earth retaining walls (e.g., reinforced concrete cantilever walls, gravity walls). Therefore, they are very suitable for sites with poor foundations and for seismically active areas. MSE walls are generally cost effective, especially for walls in fill embankment cross sections. These walls are commonly used to heights of 30 ft (9 m); although, walls in excess of 70 ft (21 m) have been constructed.

A wide range of finishes and colors are available for MSE facing elements. In addition to aesthetics, the facing provides:

- protection against backfill sloughing and erosion,
- drainage pathways in certain cases, and
- protection against ultraviolet (UV) radiation deterioration.

Major facing types include segmental precast concrete panels, dry cast modular block wall units, metallic facings, welded wire grids, gabion facing, geosynthetic facing and post-construction facing. Precast elements are available in several shapes and facing textures to match environmental requirements and to blend aesthetically into the environment. Retaining structures using precast concrete elements as the facings can have surface finishes similar to any reinforced concrete structure. Retaining structures with metal facings have the disadvantage of shorter life because of corrosion, unless compensating provisions are incorporated into the design.

MSE walls have many advantages compared with conventional reinforced concrete and concrete gravity retaining walls. The relatively small quantities of manufactured materials required, rapid construction and competition among the developers of different proprietary systems has resulted in a cost reduction relative to traditional types of retaining walls. MSE walls are likely to be more economical than other wall systems for walls higher than about 10 ft (3 m) or where special foundations would be required for a conventional wall. MSE walls are flexible and can absorb deformations caused by poor subsoil foundation conditions. These structures have demonstrated a higher resistance to seismic loading than have rigid concrete structures.

The following general disadvantages may be associated with all soil-reinforced structures:

- RSS and MSE structures require relatively large space in the reinforced zone to obtain enough width for internal and external stability.
- MSE walls often require select granular fill, which could be expensive at some sites. Requirements for RSS are typically less restrictive.
- Suitable design criteria are required to address deterioration of certain types of exposed facing elements by ultraviolet rays and potential degradation of polymer reinforcement in the ground.
- Specifications and contracting practices have not been fully standardized because design and construction practices are still evolving, especially for RSS.

For additional MSE wall details and design methodologies, see Chapter 17 of the *Montana Geotechnical Manual* and the FHWA *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*.

20.4 FRICTIONAL BEHAVIOR OF GEOSYNTHETICS

The friction or interface shear strength between soils and geosynthetics and between two geosynthetics must be assessed when evaluating the stability of geosynthetic systems placed on or in a slope. Thorough evaluation of interface strength parameters is important because a preferential sliding or failure plane will develop on the weakest surface, which often occurs on the soil/geosynthetic or the geosynthetic/geosynthetic interface. These preferential sliding or failure planes can result because of the very low interface friction that occurs between geosynthetics and other materials.

20.4.1 Methods of Determining Interface Strength

Use large-displacement (residual) strength parameters when assessing the shear strength of these interfaces. Residual strengths are always less than or equal to peak strengths. The differences are material-specific and site-specific; hence, no general guidelines for quantifying the relationship between peak and residual strengths are available.

Direct shear tests are typically used for assessing the shear strength of geosynthetic interfaces as described in ASTM D 5321 and ASTM D 6243. Typically, use large shear boxes for these tests, with plan dimensions of at least 12 in by 12 in (300 mm by 300 mm). Shear tests are conducted to relatively large displacements to assess residual (or, at least large displacement) strengths and to capture the strain-softening behavior that occurs on geosynthetic interfaces. The use of conventional direct shear testing with a soil testing system is usually not desirable because of the small size (i.e., 2.5 in (64 mm)) of the test sample.

Interface friction angles of soil-to-geosynthetic will always be less than soil-to-soil friction angles. Values of interface friction values for different soil types and geosynthetics are available in the technical literature. However, it is difficult to compare the data because of varying test procedures and protocols. Much of the published information was based on tests conducted prior to the development of standardized procedures (e.g., ASTM D 5321). In addition, geosynthetic types, tensile strengths, moduli and surface roughness values significantly affect the results. *Geotechnical Aspects of Landfill Design and Construction* (Qian et al., 2002) and *Waste Containment Systems, Waste Stabilization and Landfills: Design and Evaluation* (Sharma and Lewis, 1994) provide tables of typical interface strength values and cite additional reference sources for more specific data.

20.4.2 Interface Strength for Geomembranes

In general, smooth hard geomembranes (e.g., HDPE) have the lowest friction angles of all geosynthetics. For example, the interface strength between smooth HDPE and clay can be less than 10°. This low interface strength can lead to stability problems. In addition, if the interface between the clay and geomembrane is wetted (i.e., due to condensation of water under the geomembrane, clay swelling, excess moisture during construction), the interface strength can be further reduced. Likewise, the interface friction of GCL can also be very low (e.g., less than 10°) if the bentonite making up the GCL hydrates.

Rough softer geomembranes (e.g., EPDM-R, PVC, CSPE-R), textured geomembranes and needle punched GCL have relatively higher friction angles. It is critical that interface friction tests accurately model the geosynthetic, the soil and the potential field conditions.

20.4.3 Interface Strength for Geotextiles

Geomembrane-to-geotextile interface friction angles vary over a wide range. For example, the interface friction angle between rough PVC and woven, slit film geotextile can be as high as 28°, while the interface between HDPE and woven monofilament geotextile may have a friction angle as low as 6°. Other site-specific factors can further reduce the interface strength, for example: polishing of geomembrane surfaces by geotextiles and strand orientation with respect to slope angle.

Soil-to-geotextile interface friction angles are less than soil-to-soil friction angles. In general, nonwoven geotextiles have higher interface friction angles than woven geotextiles, especially the slit film variety. The references cited in this Section present typical soil-geotextile interface friction values ranging from 15° to 30°. The lower end of the range is for clay-geosynthetic interfaces, while the higher end of the range is generally associated with sand-geosynthetic interfaces.