

Geosynthetics

1.1 Overview

Geosynthetics are man-made polymeric materials used for geotechnical application. They are used in lieu of conventional materials and often are more cost effective with equal or improved engineering performance. The intent of this module is to provide general guidance to the practicing geotechnical designer on the proper use of geosynthetics for both design and construction. The key assumptions of this module are that the user has sufficient overall geotechnical experience and is already familiar with general civil engineering and construction practices and uses professional judgment in the decision to use and specification of geosynthetic materials. This module closely follows the design and construction procedures provided in the FHWA Publication No. FHWA-NHI-07-092 “Geosynthetic Design and Construction Guidelines” (Holtz, et al., 2008) hereafter referred to as the FHWA manual with other references cited as needed within appropriate sections of this module with a complete list given in Section 4.

The following subsections in Section 1 establish a systematic design approach, develop uniform nomenclature, and define the concept of primary geosynthetic function with associated applications. Section 2 explains design criteria and procedures and construction considerations including specifications. Section 3 explains quality control (QC), quality assurance (QA), conformance test, and construction inspection.

1.2 Design Approach

The selection of an appropriate geosynthetic is a complex undertaking that depends upon integration of available knowledge and experience and involves a number of project specific and site-specific factors. In general, the geotechnical investigation conducted for a project without geosynthetics will be adequate which is logical as most products replace conventional materials. However, specific geotechnical data such as site-specific test of subsurface/geosynthetic interaction may be needed during the investigation depending on the product function and critical nature of the application.

A systematic approach to design is needed due to the potentially large variety of geotechnical uses and available geosynthetic products. The FHWA manual recommends the following systematic approach to designing with geosynthetics:

1. Define purpose and scope of project;
2. Investigate and establish geotechnical site conditions;
3. Establish application criticality, severity, and performance criteria and identify external influences on performance;
4. Formulate trial designs and compare alternatives;
5. Create design models and parameters and perform analyses;
6. Select most effective design based on analyses and considering cost, construction feasibility, etc.;

7. Prepare detailed geosynthetic specifications and plan/details including key property requirements and installation procedures;
8. Hold preconstruction and construction follow-up meetings with Caltrans field inspectors and contractor(s);
9. Review and comment on acceptance of proposed geosynthetic materials based on manufacturer's certification and/or laboratory testing;
10. Carefully monitor construction paying particular attention to potential damage to geosynthetics caused by field operations; and
11. Inspect finished application after any significant events which could affect performance.

A systematic approach will allow a geosynthetics design which is technically robust, cost effective, constructible, and meets long term performance requirements.

1.3 Nomenclature

Due to the multitude of geosynthetic products available it is imperative to use a consistent terminology to allow a comprehensive comparison of alternatives. The FHWA manual should be consulted for more thorough definitions and detailed descriptions of geosynthetic manufacturing processes and identifying terms. For clarity some commonly used terms are defined here as follows.

Geosynthetic – A planar product manufactured from polymeric material used with soil, aggregate, or other geotechnical engineering materials as an integral part of a civil engineering project.

Geotextile – a permeable geosynthetic comprised solely of textile materials (nonwoven or woven comprised of various synthetic polymers and manufactured by numerous processes).

Geogrid – a geosynthetic formed by a regular network of tensile elements and apertures typically used for reinforcement functions (may be uniaxial or biaxial in reinforcement direction).

Geomembranes – an impermeable geosynthetic, typically used to control fluid migration (composed of various polymer compositions, surface textures, and welding/overlap methods).

Geocomposite – a geosynthetic material manufactured of two or more geosynthetic materials (e.g., a drainage geocomposite formed by heat bonding a filter geotextile and a drainage geonet together).

A good source of geosynthetic product data using the above commonly used terms is the annual December issue of the Geotechnical Fabrics Report (GFR) magazine published by the Industrial Fabrics Association International (IFAI) which is formatted as a specifier's guide and is available at www.geosyntheticsmagazine.com.

1.4 Functions and Applications

A key concept for geosynthetics design is to define the primary function of the product as this determines the necessary properties to be specified. The FHWA manual defines the six primary geosynthetic functions as follows (along with common geosynthetics used for each one):

1. Filtration (geotextile typically nonwoven but some specially manufactured wovens).
2. Drainage (geonets, drainage geocomposites (geonet-geotextile), sheet/wall drains and prefabricated vertical drains (wicks)).
3. Separation (geotextile – typically woven for less elongation and nonwoven for better drainage properties).
4. Reinforcement (geogrids, geotextiles – typically woven but some high strength nonwovens if more elongation is allowable).
5. Fluid Barrier (geomembranes, geosynthetic clay liners (GCLs)).
6. Protection (non-degradable and degradable rolled erosion control products (RECPs) such as mats and blankets, geocells, geotextiles both woven and nonwoven).

Any geosynthetic may also have secondary functions but it is usually the primary function that controls the design property requirements as outlined in tables in section 1.0 of the FHWA manual. It is important to note that the design for geosynthetic applications rely on both index and engineering properties of the geosynthetics. Index properties are not the properties that directly satisfy design demands but provide indirect measurements from which the geosynthetics can be evaluated, mostly for survivability. Engineering properties are the material properties that must satisfy the engineering demand under anticipated design conditions, such as tensile strength.

Specifications for geosynthetics commonly used for geotechnical projects can be found in 2015 Standard Specifications (Section 96) and SSPs, or NSSPs sponsored by Geotechnical Services (GS). These should be used if meeting the FHWA manual design and construction requirements for the intended use but should be checked for construction survivability which is often critical to geosynthetics long term performance.

Section 2 of this module provides a comprehensive review of the various geosynthetic use categories and associated functions that can help in deciding essential design properties of the product.

Geosynthetic Design Criteria and Procedures

2.1 Overview

The intent of this section is to identify the general design criteria and procedures by examining the main geotechnical use categories and required functions outlined in the FHWA manual (sections 2.0 through 10.0 with pavement overlay (section 6.0) omitted as subject covered by Caltrans Materials). The organization of this section closely

follows the FHWA manual so the user of this module can quickly find the key parameters needed for geosynthetics and refer to more detailed design information as needed.

It should be mentioned that geosynthetics design is often an iterative approach where various properties are selected and checked against the primary function and then modified to optimize the overall performance. Another element of design common to all products is that the final geosynthetics properties specified should be checked that they are commercially currently available from at least three sources (a useful reference is the GFR annual specifier's guide available at www.geosyntheticsmagazine.com).

It should be also noted that a critical element of all geosynthetic use is the ability to survive construction (survivability) which is much more an issue than with conventional geotechnical materials. For this reason, Section 3 of this module addresses the construction considerations that must be covered with the related subjects of specifications, conformance testing, and perhaps most importantly, installation monitoring and inspection.

2.2 Subsurface Drainage

This category covers one of the major geosynthetic uses related to subsurface drainage applications including retaining walls, prefabricated vertical drains (wick drains), blanket drains, trench/french drains, interceptor/toe drains, and seepage control. These applications use the primary functions of filtration and flow capacity (both perpendicular as measured by geotextile permittivity and in-plane as measured by geonet or sheet/wall drain transmissivity) and these two primary functions basically replace granular filters or granular drainage materials respectively.

The filtration function replaces a granular filter and as such must allow water to flow through the geotextile (typically nonwoven unless specially manufactured woven) while retaining soil particles to prevent piping and protect the drainage media. The filter must also perform for the life of the drainage system by resisting clogging. The design procedures are given in detail in the FHWA manual but key considerations are the tradeoffs between flow through the geotextile (as measured by geotextile permittivity) and retention ability of the geotextile (as measured by Apparent Opening Size (AOS)) which must be weighted depending on the actual applications (e.g., retaining wall application with drain pipe would favor flow capacity over retention criteria while a geocomposite blanket use would favor retention over flow capacity). Clogging resistance is enhanced by the largest porosity for nonwoven geotextiles or percent open area for woven geotextiles. In general, nonwoven geotextiles are most effective at filtration while woven geotextiles should only be used when specially manufactured for that function.

AASHTO provides drainage geotextile strength requirements based on severity of installation anticipated with Class 1 for severe, Class 2 (ASAHTO default selection) for less severe and Class 3 for light trench applications. Generally, the Caltrans Filter

Fabric standard nonwoven geotextile may be used (similar to AASHTO Class 2) if checked versus filter design criteria with soils to be filtered and applies for construction survivability under most conditions.

The drainage function of in-plane flow capacity replaces a granular drainage media and the key geosynthetic property is therefore in-plane transmissivity. The products commonly used are geonets, sheet/wall drains, or geocomposites (nonwoven filter geotextile heat bonded to one or both sides of a drainage geonet). A key consideration is that although the geosynthetics may have equal flow capacity its resistance to fines blocking its flow path is far less than a comparable gravel layer so the retention part of the attached filter may favor retention over permissivity. Therefore, the complete drainage system operation must be looked at during geosynthetics design. Geocomposite wall drain Standard Specifications is available and should be used if it meets all design requirements including construction survivability.

Detailed procedures and examples of filter and drain design are provided in section 2.0 of the FHWA manual. Another good source of information is to contact geosynthetic manufacturers (available in GFR annual specifier's guide) directly for case study and often even software to assist in design.

Prefabricated vertical drains (commonly known as wick drains) are used during surcharge preloading of soft foundation soils to accelerate settlement during construction and prevent bearing type failure (to allow stable embankment placement) and efficiently replace sand drains. For wick drain design, FHWA manual No. FHWA/RD-86/168 "Prefabricated Vertical Drains-A design and Construction Guidelines Manual" (Rixner, et al., 1986) should be used.

2.3 Rock Slope Protection (RSP) and Permanent Erosion Control

This category covers many important geosynthetic uses related to erosion/scour/rock slope protection applications, including shoreline or cut/fill slope protection beneath riprap or other hard armor, structure scour, and other permanent erosion control systems for ditches/streams/slopes. These applications use the primary function of protection against erosive forces under static and dynamic flow conditions.

The same criteria used for filtration design apply with generally more severe survivability and durability requirements due to the harsh and critical nature of the applications. The need for permanent erosion protection requires higher survivability and products should be selected that are permanent in nature as they must perform for the life of the protection system. Detailed procedures and examples are provided in section 3.0 of the FHWA manual.

Typical products include geotextiles (both woven and nonwoven), geocells, non-degradable rolled erosion control products (RECP) such as mats or blankets. Design may be under the direction of the landscape architect or hydraulics but it is important to

understand the design procedures and construction specifications. Improper selection of these permanent measures can severely affect overall project performance.

Standard Specifications is provided under RSP fabric which can generally be used after checked versus design requirements and evaluating the critical nature of application and meeting the extreme survivability needs anticipated.

2.4 Temporary Erosion and Sediment Control

This category covers many temporary or construction period geosynthetic uses related to sediment and erosion control/slope protection applications including silt fences, turbidity curtains, soil retention blankets, geotextile on ditches/culvert outfalls/slopes, and other non-permanent erosion control systems. These applications use the primary function of protection against erosive forces under static and dynamic flow conditions. The products selected must function for a limited period of time before permanent vegetation or other permanent erosion control measures are established.

The key consideration is the ability of the selected product to withstand maximum anticipated run-off velocities which may be under the design direction of the landscape architect and/or hydraulics. The application is included in this module for completeness and since improper selection can adversely affect other geotechnical parameters by undermining walls or cut slopes/embankments. Detailed procedures and examples of design are provided in section 4.0 of the FHWA manual. Typical products include geotextiles (both woven and nonwoven), and degradable rolled erosion control products (RECPs) such as mats or blankets.

Specifications are provided under silt fence fabric, sediment filter bag, and temporary cover in Standard Specifications Section 96, which can be used for most temporary applications.

2.5 Roadway Separation and Subgrade Enhancement

This category covers probably some of the most common geotechnical geosynthetic uses related to roadway applications including weak subgrade stabilization and protection of aggregate materials from subgrade intrusion. Due to the fact that Caltrans Materials designs permanent roadway structural section, the discussion here is limited to temporary roads such as detours, haul/access roads, working platforms, as well as placement and compaction of fill over weak subgrades. These applications use the primary function of separation by keeping weak subgrade soils from pumping through overlying fill or preventing contamination of select fill by intrusion into the subgrade. This may allow stable construction over soils that may otherwise require expensive ground improvement technologies.

The key criteria used for separation design is survivability and durability requirements due to the nature of the applications. Typical products include geotextiles (both woven and nonwoven), geogrids, or geocomposites such as a combination of geogrid and

geotextile. Detailed procedures and examples of filter and drain design are provided in section 5.0 of the FHWA manual.

Specifications is provided under subgrade enhancement geotextile, in Standard Specifications Section 96, which can generally be used after checked versus design procedures and meeting the survivability needs anticipated.

2.6 Reinforced Embankments on Soft Foundation

This category covers another significant group of geosynthetic uses related to reinforced embankments over soft foundations. These applications use the primary functions of reinforcement to allow stable construction over otherwise unsuitable conditions by preventing bearing failure in soft foundation cases. The nature of the application requires that all applications are critical even temporary slopes or embankments during construction with only reduced factors of safety used versus permanent long term stability analyses. Generally, conventional geotechnical analyses of bearing capacity, slope stability, and settlement must be performed to determine the optimal selection of primary geosynthetic reinforcing elements including vertical spacing and secondary facing reinforcement if needed for construction and long term performance. Many commercial software packages are available for these analyses which allow modeling of geosynthetic elements.

Embankments over soft foundations utilize horizontal geosynthetic reinforcing layers over the entire area of the embankment in single or multiple layers with key parameters being the Long Term Design Strength (LTDS) based on the ultimate tensile strength as measured by the wide width tensile strength test for geotextile or geogrids with a reduction factor applied (based on design life creep, backfill materials installation damage, and long term durability). Other important geosynthetic properties for reinforced embankments are the sewn seam strength, soil-geosynthetic friction (for sliding resistance). The ability of the geosynthetic to withstand severe installation conditions is also important and is well summarized in tables in section 7.0 of the FHWA manual. Also, the soils to be used for the embankment should be carefully specified to allow specified compaction even under challenging site conditions. Construction monitoring as discussed in Section 3 of this module is also very important to overall system performance. The FHWA manual section 7.0 should be utilized for full design procedures and example calculations along with typical specifications.

Key design considerations are the internal and external slope stability (using conventional geotechnical analyses methodology with the addition of tensile reinforcing elements) and ability to handle anticipated settlements and overall durability over the life of project. In general, woven geotextiles are most effective at reinforcing functions while nonwoven geotextiles may be used if secondary functions of drainage/filtration are required and/or additional elongation of reinforcing material is not a concern (i.e., typically secondary facing reinforcement use). Generally, the specifications for Geotechnical Subsurface Reinforcement described in Standard Specifications Section

96-1.02D may be used if checked versus design criteria and applies for construction survivability under most conditions.

The products commonly used are geogrids (uniaxial and biaxial) or geotextiles (typically woven but nonwoven may be used for secondary facing reinforcing uses) and reinforcing geocomposites (woven geotextile used with a geogrid over very soft foundations spoils to prevent subgrade intrusion). A key consideration is that the geosynthetic material chosen must have sufficient construction survivability which includes strength of sewn seams or sufficient overlap if sewn seams are not required.

Another good source of information is to contact geosynthetic manufacturers (available in GFR annual specifier's guide) directly for case study and often even software to assist in design. Many commercially available slope stability software programs can be used which allow modeling of geosynthetic reinforcement materials.

2.7 Reinforced Slope and Mechanically Stabilized Embankment Wall

This category covers another significant geosynthetic use related to reinforced soil slopes (RSS) and mechanically stabilized embankment (MSE) retaining walls. Reinforced soil slopes are defined as those up to 70 degrees in slope angle. MSE walls are defined as those geosynthetic reinforced structures with facing slope angles from 70 to 90 degrees. These applications use the primary functions of reinforcement to allow stable construction at steeper face angles than possible without reinforcement. A brief discussion is provided below but the user should carefully follow the FHWA manual sections 8.0 and 9.0 for full design procedures. The nature of the application requires that all applications are critical even temporary RSS and MSE walls during construction with only reduced factors of safety used versus permanent long term stability analyses. Generally, conventional geotechnical analyses of bearing capacity, slope stability, and settlement must be performed to determine the optimal selection of primary geosynthetic reinforcing elements including vertical spacing and secondary facing reinforcement if needed for construction and long term performance. A key feature of RSS and MSE walls is that permanent structures usually have some type of facing to protect the exposed elements. Many commercial software packages are available for these analyses which allow modeling of geosynthetic elements.

RSS and MSE walls utilize horizontal geosynthetic reinforcing layers from the face of the wall for a minimum required reinforcement length with key parameters being the Long Term Design Strength (LTDS) based on the ultimate tensile strength as measured by the wide width tensile strength for either geotextile or geogrids. Other important geosynthetic properties are soil-reinforcement interaction (for pullout resistance and interface friction), and overall system creep resistance. These are discussed briefly here but the FHWA manual should be used for full design procedures and example calculations along with specifications. Additional references for MSE and RSS applications are included in the Section 4.

The design procedures are given in detail in the referenced FHWA manual but key considerations are the internal and external slope stability (using conventional geotechnical analyses methodology with the addition of tensile reinforcing elements) and ability to handle anticipated settlements and overall durability over life of project. The specifications for Geotechnical Subsurface Reinforcement in Standard Specifications Section 96-1.02D may be used if checked versus design criteria and applies for construction survivability under most conditions.

The products commonly used are geogrids (uniaxial and biaxial) or geotextiles (typically woven but nonwoven may be used for secondary facing reinforcing uses) and reinforcing geocomposites (geotextile used with a geogrid). A key consideration is that the geosynthetic material chosen must have sufficient construction survivability which includes sufficient overlap or connection methods.

Detailed procedures and examples of RSS and MSE wall design are provided in sections 8.0 and 9.0 of the FHWA manual and in the FHWA Demonstration Project 82 (FHWA publication No FHWA-SA-96-071). Another good source of information is to contact geosynthetic manufacturers (available in GFR annual specifier's guide) directly for case study and often can provide software to assist in design. Generic programs are also available from FHWA which can allow rapid checks of various geometries and material properties for fine tuning of design.

2.8 Geomembrane and Fluid Barrier

This category covers a wide variety of potential uses related to roadway applications including fluid barrier around lightweight geofam (to prevent hydrocarbon damage), cut-off walls, tunnel linings, control of moisture in expansive subgrade soils, waterproofing of walls/bridge abutments, and detention/retention basin liners. Because this application is very specialized, the discussion is limited and the FHWA manual should be consulted for more design and specification information.

The key criteria used for barrier design is leakage prevention as well as survivability and durability requirements due to the nature of the applications as well as friction between subgrade and material selected (textured surfaced products are available for increased friction). Typical products include geomembranes (comprised of various polymeric compounds including polyethylene (High Density Polyethylene (HDPE) and non-HDPE, polypropylene, and Polyvinyl (PVC) being the most common) and Geosynthetic Clay Liners (GCLs) (composed of bentonite clay bonded to a geomembrane or sandwiched between geotextiles commonly used in environmental containment applications). Each material has specific methods of welding/overlapping sheets together for water tightness and highly developed QC/QA protocols. Detailed procedures and examples of fluid barrier design are provided in section 10.0 of the FHWA manual.

CONSTRUCTION CONSIDERATIONS

3.1 Specifications

Although this Section covers the specifications which are prepared during design and could therefore be discussed in Section 2, it is during construction that their effectiveness is tested. This is particularly important for geosynthetic materials as their overall function is heavily influenced by how they are installed and their susceptibility to damage during construction. It is probably the one true disadvantage of geosynthetics use in that improper installation is the weakest link in their performance and therefore must be mitigated by well prepared specifications and construction monitoring covering all aspects of installation. The FHWA manual provides an excellent discussion of the six elements that should be included in all geosynthetic specifications as follows.

1. General Requirements (such as storage and handling requirements including ultraviolet resistance).
2. Specific Geosynthetic Properties (both specified index and performance tests if needed).
3. Seams and Overlaps (as applicable for design function and product selected).
4. Placement Procedures (including minimum cover and maximum equipment ground pressures if required).
5. Repair Procedures (if damaged during placement).
6. Product Acceptance and Rejection Criteria.

These are discussed at length in section 1.0 of the FHWA manual and guide specification examples for each category are provided in appropriate design sections. Standard Specifications Section 96 should be used for most applications but must be checked to ensure that they have the key elements of geosynthetic specifications outlined above and meet design requirements. The following section discusses an additional element that must be included in the specifications for larger projects and critical uses and involves procedures to accept or reject geosynthetic materials proposed for use.

3.2 Quality Control, Quality Assurance, and Product Conformance Test

For large projects and critical applications special Quality Control (QC), Quality Assurance (QA), and product conformance test requirements may be needed.. For these critical use projects, acceptance criteria should be clearly and concisely stated in the specifications. For smaller projects, a manufacturer's certification letter may be satisfactory for non-critical applications and this should be clearly stated in the specifications. The FHWA manual provides an example of geosynthetic specification conformance example per ASTM 4759. The following section covers the most critical consideration for use of geosynthetics in geotechnical practice which is the need for vigilant construction inspection.

3.3 Construction Inspection

This section covers what is perhaps the most critical element of successful geosynthetics use. Many problems with geosynthetics use are directly attributable to improper installation or damage caused by contractor operations. The FHWA manual provides a field inspection checklist (table in section 1.0) which is a good starting point but it is most important to actually observe the installation and placement procedures used by the contractor in the field. In this regard, it is very important to educate Caltrans construction personnel on what to look for during placement of geosynthetics and backfill as it must be performed continuously which will require full-time knowledgeable inspectors with regular visits by the geotechnical designer.

The key criterion is construction survivability which varies depending on the geosynthetics, foundation and backfill materials, applications, construction equipment, and construction methods. In any case, geosynthetics must survive construction and provide primary and secondary (if needed) functions through the design life of the project. The more critical the nature of the application warrants more careful construction inspection. Detailed procedures and examples of proper construction for various products are provided in the appropriate sections of the FHWA manual.

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