RECLAMATION

Managing Water in the West

Design Standards No. 13

Embankment Dams

Chapter 19: Geotextiles
Phase 4 Final

U.S. Department of Interior
Bureau of Reclamation

June 2014

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 13

Embankment Dams

DS-13(19)-1: Phase 4 Final
June 2014

Chapter 19: Geotextiles

Foreword

Purpose

The Bureau of Reclamation (Reclamation) design standards present technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Reclamation facilities in a way that protects the public's health, safety, and welfare; recognizes needs of all stakeholders; and achieves lasting value and functionality necessary for Reclamation facilities. Responsible designers accomplish this goal through compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholders' vision and values, that are then reflected in the constructed facilities.

Application of Design Standards

Reclamation design activities, whether performed by Reclamation or by a non-Reclamation entity, must be performed in accordance with established Reclamation design criteria and standards, and approved national design standards, if applicable. Exceptions to this requirement shall be in accordance with provisions of *Reclamation Manual Policy*, Performing Design and Construction Activities, FAC P03.

In addition to these design standards, designers shall integrate sound engineering judgment, applicable national codes and design standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs are produced that protect the public's investment and safety. Designers shall use the most current edition of national codes and design standards consistent with Reclamation design standards. Reclamation design standards may include exceptions to requirements of national codes and design standards.

Proposed Revisions

Reclamation designers should inform the Technical Service Center, via Reclamation's Design Standards Web site notification procedure, of any recommended updates or changes to Reclamation design standards to meet current and/or improved design practices.

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 13

Embankment Dams

Chapter 19: Geotextiles

DS-13(19)-1:[1] **Phase 4 Final**
June 2014

Chapter 19 – Geotextiles is an existing chapter within Design Standards No. 13 and was revised to include:

- Detailed descriptions and photographs of geotextile materials
- Expanded discussions of geotextile functions
- Updated design criteria for filtration and drainage
- Discussions of slope stability concerns for riprap placed on geotextiles
- Geotextile embankment reinforcement design methods
- Detailed discussions of geotextile storage and handling
- Recommended methods for installation and covering geotextiles
- An appendix with examples of projects using geotextiles

[1] DS-13(19)-1 refers to Design Standards No. 13, chapter 19, revision 1.

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Chapter 19

Geotextiles

19.1 Introduction

Geotextiles were first used in an embankment dam in 1970 at Valcros Dam in France. A geotextile was used as a filter to wrap the gravel drain materials in the downstream slope, and another geotextile was placed on the upstream slope between the embankment and the riprap. In the 1980s, the use of geotextiles grew dramatically, including applications in water retention dams, tailings dams, coal refuse dams, and waste impoundments. Although there are no documented performance problems associated with geotextile installations at dams, there have been some instances of poor performance on roadway, landfill, canal, and general civil projects. The designer should always consider the critical nature of the application and the consequences should the geotextile fail to perform as intended. Geotextiles are vulnerable to installation damage, they have a finite useful life (typically 50 to 150 years), and they may lose their permeability due to excessive clogging. They should not be used in locations that are critical to the safety of the dam should they fail to perform as intended. Also, because of their finite service life, they should not be used in deeply buried locations or other places that would result in difficult and costly measures to gain access for replacement.

19.1.1 Purpose

This standard provides guidelines for the design and installation of geotextiles and geocomposite drains in embankment dams. The standard does not apply to geomembranes or geomembrane composites (comprised of a geomembrane attached to a geotextile cushion), which are covered in chapter 20 of these design standards.

19.1.2 Scope

This standard is intended to provide an understanding of geotextile materials, their functions in embankment dams, and to present design principles. This standard discusses geotextile design by function, which includes filtration, drainage, separation, protection, reinforcement, and erosion control. Criteria are presented regarding the selection of key geotextile design properties, including apparent opening size (AOS) (particle retention), drainage characteristics (permittivity and transmissivity), interface friction, mass per unit area, and tensile strength. Because geotextiles are vulnerable to installation damage, guidance on proper handling and installation is also included.

19.1.3 Deviations from Standard

Geotextile design and specification should conform to this design standard. If deviations from the standard are required, the rationale for not using the standard should be presented in the technical documentation for the geotextile design and be peer reviewed and approved.

19.1.4 Revisions of Standard

This chapter will be revised as its use indicates. Comments or suggested revisions should be forwarded to the Chief, Geotechnical Services Division (86-68300), Bureau of Reclamation, Denver, Colorado 80225; they will be comprehensively reviewed and incorporated as needed.

19.1.5 Applicability

These standards for the design and installation of geotextiles are applicable to their use in embankment dams.

19.2 Geotextile Materials

Geotextiles are fabrics used in earthwork projects. Although fabrics made from natural fibers are used to manufacture many erosion control products, most geotextiles are made with fibers derived from synthetic polymers. At present, over 95 percent of all geotextiles are made from polypropylene due to its inert nature, low cost, and ease of use in the manufacturing process (Koerner, 2012). The remaining 5 percent of geotextiles are manufactured from polyester, polyethylene, and polyamide. The design and specification of a geotextile requires an understanding of the properties of the polymer and of the type and configuration of the fibers used to manufacture the material. For example, all of the polymers degrade (lose strength) by exposure to ultraviolet light. Therefore, carbon black and other substances are added to the polymer to enhance its resistance to degradation by exposure to sunlight. Even with the additives, the geotextile should be promptly covered with soil or other suitable covers after installation to limit the extent of strength loss. Table 19.2-1 presents a brief comparison of the different synthetic polymers used to manufacture geotextiles.

Table 19.2-1. General comments on polymers used in geotextile manufacture (Koerner, 2012)

Type of polymer alternate names	Approximate specific gravity (varies due to additives)	Coefficient of thermal expansion X 10^{-5} per 1 ºC	Degradation
Polyester (PET)	1.22 to 1.38 Sinks in water	4 to 5	Some resistance to ultraviolet exposure. Cover within 30 days. Can be affected by high pH water. Avoid fresh concrete.
Polypropylene (PP)	0.91 Floats in water	6	Requires carbon black for sunlight resistance. Cover within 14 days. Good chemical resistance.
Polyethylene –High Density and Linear Low Density Polyethylene (HDPE, LLDPE)	0.90 to 0.96 Floats in water	13	Requires carbon black for sunlight resistance. Cover within 14 days. Good chemical resistance.
Polyamide (PA) (nylon)	1.05 to 1.14 Sinks in water	5.5	May be degraded by low pH waters and acids.

19.2.1 Glossary

Adhesion strength – The force required to separate two materials that are bonded together.

Anchor trench – An excavation used to hold the edge of a flexible geosynthetic material to maintain its position.

Apparent opening size (AOS) – Also referred to as O_{95}, it is the approximate size of the largest particle that can pass through a geotextile. AOS is usually reported as US standard sieve size, while O_{95} is reported in millimeters. For example, an AOS of 100 is the same as an O_{95} of 0.15 millimeters (mm). The test is performed according to a dry sieving method using glass beads (Test Method for Determining Apparent Opening Size of a Geotextile ASTM D4751-04).

Blinding – Plugging of a geotextile filter by partial penetration of particles into surface openings and/or formation of a surface coating or crust, thereby reducing the hydraulic conductivity of the geotextile.

Clogging – The plugging of a fabric by deposition of particles (soil particles, chemical or biological precipitates) within the fabric pores. The condition in which particles are retained in the openings of the geotextile, thereby reducing the hydraulic conductivity of the geotextile.

Creep – Increasing strain (stretching) while a material is under constant stress.

Degradation – The reduction or loss of desirable physical properties by a material as a result of some process or physical/chemical phenomenon.

Direct shear test – A test using a shear box to determine the interface friction behavior between a soil and a geosynthetic material (ASTM D5321).

Dispersive clays – Dispersive clays differ from “normal” clays because of their electrochemical properties. Dispersive clays usually have a preponderance of sodium cations on the clay particles compared to a preponderance of calcium and magnesium cations on “normal” clays. The imbalance of electrical charges that result from this makeup causes dispersive clays to deflocculate (disperse) in the presence of water. This deflocculation occurs because the interparticle forces of repulsion exceed the attractive forces. The clay particles go into suspension even in slowly moving or standing water. This means that dispersive clays are extremely erosive. Water flow through cracks in dispersive clays can quickly erode the soil and lead to rapid enlargement of the cracks. Dispersive clays are not detectable with normal soil tests, such as mechanical analyses and Atterberg limit tests, and special tests such as the crumb test, double hydrometer, and pinhole test, are required to detect the presence of dispersive clays.

Drain – A structure, pipe, or porous material that collects and conveys water flow.

Fiber – The basic element of fabrics characterized by a flexible material having a length at least 100 times its width and which can be spun into a yarn or otherwise made into a fabric.

Filter – A zone of material designed to provide drainage while preventing the movement of soil particles due to flowing water.

Geocomposite – A geosynthetic product consisting of two or more materials. There are many different types of geocomposites. Some examples are:

> Geocomposite drain – A combination of a geotextile for filtration and a structured material such as a geonet, geopipe, or other material to function as a drain.
>
> Geomembrane composite – A combination of a geomembrane with a geotextile. The geotextile provides added strength and puncture resistance to the geomembrane.
>
> Geosynthetic clay liner – A combination of a layer of processed clay placed between two geotextiles. Hydration of the clay results in establishment of a hydraulic barrier, which impedes the passage of fluids.

Geogrid – A synthetic product used for soil reinforcement formed with a regular network of openings that are large enough for coarse particles of soil to pass through. Most geogrids are made by perforating a sheet of polymer material and then drawing it under controlled temperatures to form the shape and openings desired. The stretching tempers the polymer, increasing its tensile strength. Geogrids are used for soil reinforcement imparting tensile strength.

Geomembrane – A synthetic material formed into thin and impermeable sheets that are intended to block the transmission of fluids. A common application is as a water retaining liner to establish a pond in a pervious soil.

Geonet – A synthetic product manufactured using parallel strands of polyethylene to form an open pattern resembling a fisherman's net. The strands are stacked in a manner to allow for in-plane drainage through the material. Bi-planar and tri-planar geonets are made that consist of either two or three sets of parallel strands of material. Geonets are normally used by placing them between two geotextiles, geomembranes, or between a geomembrane and a geotextile to exclude soil while allowing fluid to flow.

Geosynthetic – A manmade material used in earthwork projects. It is a general term for a large group of synthetic products including geotextiles, geomembranes, geonets, geogrids, geofoam, and geocomposites.

Geotextile – A permeable fabric used in earthwork projects. The fabrics are usually comprised of synthetic polymer fibers that are in woven, nonwoven, or knitted form.

Hydraulic conductivity ratio test – A test method used to evaluate the filtration of a soil by a geotextile (ASTM D5567). The test method applies to the filtration behavior of soils with conductivities of 5×10^{-2} centimeters per second (cm/s); otherwise, a gradient ratio test (ASTM D5101) is performed.

Internal erosion – A general term that describes an undesirable transport of soil particles by the flow of water. Former geotechnical practice referred to this as "piping," which is now recognized as one of several different erosional processes such as scour, suffusion, concentrated leak piping, and internal migration. In the case of a geotextile filter, the term refers to the failure of the filter to prevent the migration of soil particles through the plane of the filter.

Minimum average roll value (MARV) – This is the minimum value as determined by representative sampling and testing of the manufactured rolls of fabric. It is a value that is 2 standard deviations below the average (mean) value of the test results. As such 2.5 percent of the samples will have values that are lower than the MARV. When specifying geotextile properties, it is meant to be the MARV. When one is specifying a property that should not be larger than the value being specified (such as opening size in the case of soil retention), the maximum value is a more appropriate specification value than MARV.

Percent open area (POA) – A measure of open space in the plane of a fabric where there are no fibers. It provides an indication of the permeability of a woven geotextile.

Slit film – A type of fiber made by cutting an extruded film or sheet of synthetic material to form ribbon-like fibers. Slit film fibers are used in the manufacture of woven geotextiles as individual fibers or can be twisted together to form yarns. When the individual ribbons have additional short cuts in them to add porosity, they are said to be fibrillated.

Staple fiber – Short length fibers made by cutting long filaments. Staple fibers are usually cut in the range of 1 to 4 inches in length and are used in the manufacture of nonwoven geotextiles. Staple fibers can also be twisted together to form yarns for weaving.

Synthetic fibers – Manmade material produced in a long and narrow form similar to thread. Fibers for geotextiles are produced by melting and stretching synthetic polymers to produce fibers or by extruding thin sheets, which are then cut into long strips (slit film). The fibers may be further processed into other forms, such as multifilament yarns, or have chemical coatings applied prior to manufacturing into fabrics.

19.2.2 Geotextile Fabrics

A wide variety of geotextiles are available depending upon the combination of form and types of fibers used in the manufacturing. Forms include woven, nonwoven, and knitted fabrics. Fibers are made by pulling melted polymers to form long filaments or by extruding thin sheets that are cut into ribbon-shaped fibers. Prior to preparing the fabric, geotextile fibers can be further processed to form multifilament yarns, cut into short lengths (called “staple” fibers), or cut and twisted together to form staple fiber yarns. For further discussion of manufacturing methods, see Designing with Geosynthetics, Volume 1 (Koerner, 2012). Some common types of geotextiles include woven monofilament, woven multifilament, woven slit-film, nonwoven needle-punched staple-fiber, nonwoven spun-bonded (heat-bonded) continuous-filament, and knitted multifilament geotextiles. The selection of the type of geotextile is largely dependent upon the functions to be performed by the material and its required engineering properties.

19.2.2.1 Woven Geotextiles

Woven geotextiles are manufactured by interlacing two sets (warp and filling) of synthetic fibers or yarns to form a fabric. The weaving methods are similar to that used in the textile industry to produce cloth fabrics. The weaving is normally configured in a simple rectangular pattern. Woven geotextiles are made using different types of fibers: monofilament (single fiber), multifilament (many parallel fibers), slit film (ribbon shaped fibers), and fibrillated (slit film ribbons containing many shorter parallel cuts). As a further variation, the different types of fibers can be twisted together to form multifilament yarns, which may also be used for weaving. Woven geotextiles tend to have a higher cost than other types of geotextiles. They have the highest strength and modulus of any type of geotextile, and the strength may vary with direction depending on the fibers used and the weave. They have the least elongation before rupture. They are principally used where the high tensile strength of the fabric is needed. Common applications include reinforcement in earth embankments to strengthen steep slopes, under road embankments to improve bearing capacity and prevent soil intrusion into the free-draining aggregates, and as silt fence to temporarily retain and filter muddy water. Many previous drainage and filtration applications of woven geotextiles have shifted to nonwoven geotextiles, which are usually better suited to such applications. Woven geotextiles made from monofilament and slit film fibers have a simple pore structure because the holes through the geotextile are located at the junctions between the fibers. Woven geotextiles made from multifiber and fibrillated slit film fibers have secondary pores in the fibers themselves. Some examples of woven geotextiles are shown on figures 19.2.2.1-1 and 19.2.2.1-2.

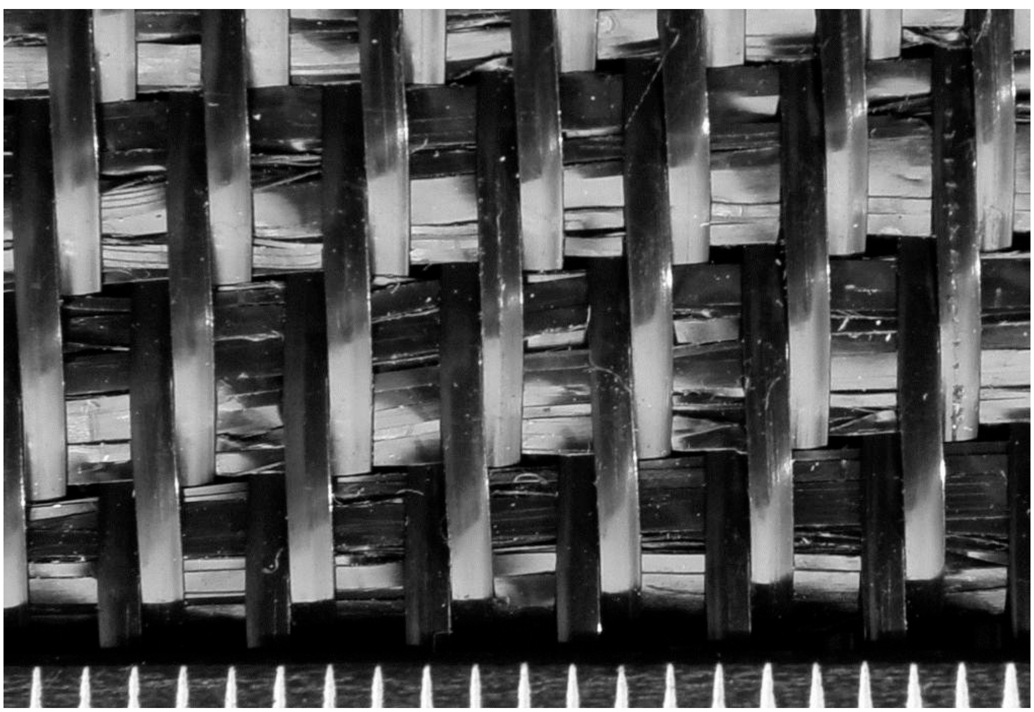


Figure 19.2.2.1-1. Woven monofilament (vertical fibers) and fibrillated slit film (horizontal fibers) geotextile; magnified view, a scale with 1-mm gradations is shown along the bottom of the photograph. There are pore spaces at the junctions between the vertical and the horizontal fibers. The horizontal fibers also have a secondary porosity due to the secondary cuts (fibrillation) in the horizontal fibers, which can be seen in the photograph.

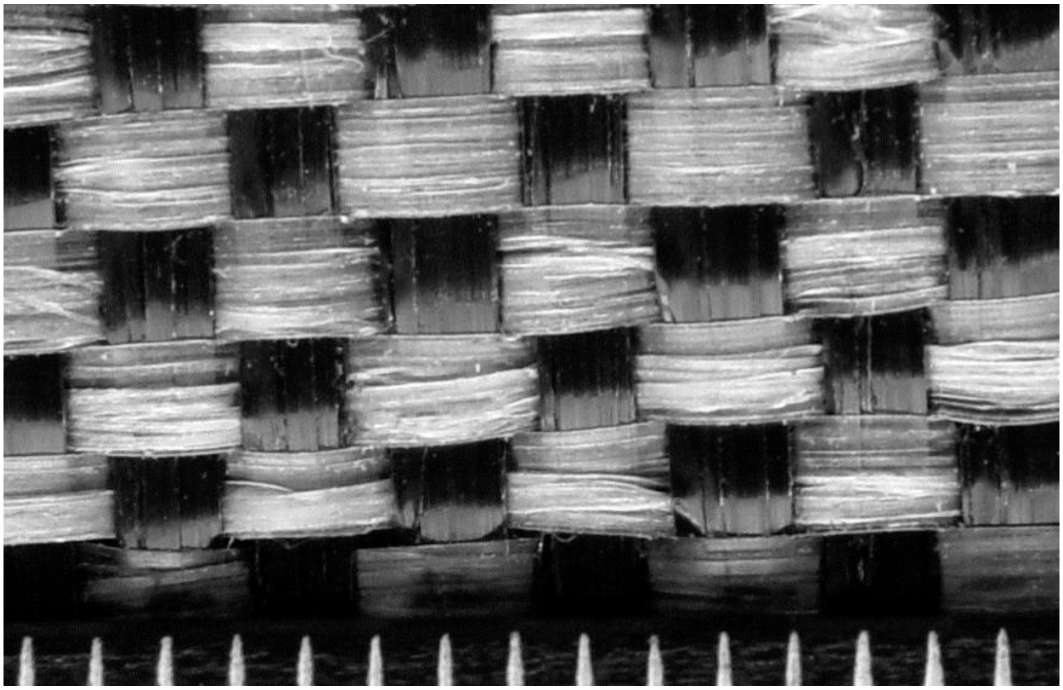


Figure 19.1.2.1-2. Woven fibrillated slit film geotextile, magnified view (1-mm scale). This geotextile has a greater porosity and is therefore more permeable than that shown on figure 19.2.2.1-1.

19.2.2.2 Nonwoven Geotextiles

Nonwoven geotextiles have fibers with a random orientation. The fabric is manufactured by one of three methods: needle punching, spun bonding, or resin bonding. Needle punching uses barbed needles to puncture and entangle a mass of synthetic fibers to form a fabric. Staple (cut) fibers are commonly used to make needle-punched fabrics. Spun bonding is a process that extrudes fibers and then lays them down onto a conveyer belt to form a web or mat of fibers. The layer of fibers is tangled together with random orientation. Spun bonding is a general term; the geotextile can either be mechanically bonded by needle punching (less common) or heat bonded (also called “heat set”), the fabric made by melting the fibers together. Resin bonding is less commonly used in manufacturing nonwoven geotextiles. Resin bonding introduces the issue of chemical compatibility and durability of the resin, which can further limit the service life of the geotextile. Heat bonding is commonly used to produce lightweight geotextiles used as filters for wick drains.

Nonwoven geotextiles are available in various weights. Because they are compressible, they are specified by their mass per unit area (ounces per square yard [oz/yd^2]), not by their thickness, which is the practice for a geomembrane. Common values used in construction are 8, 10, 12, 16, and 32 oz/yd^2 geotextiles. Because a 4 oz/yd^2 geotextile is easily torn, an 8oz/yd^2 or heavier fabric is normally used.

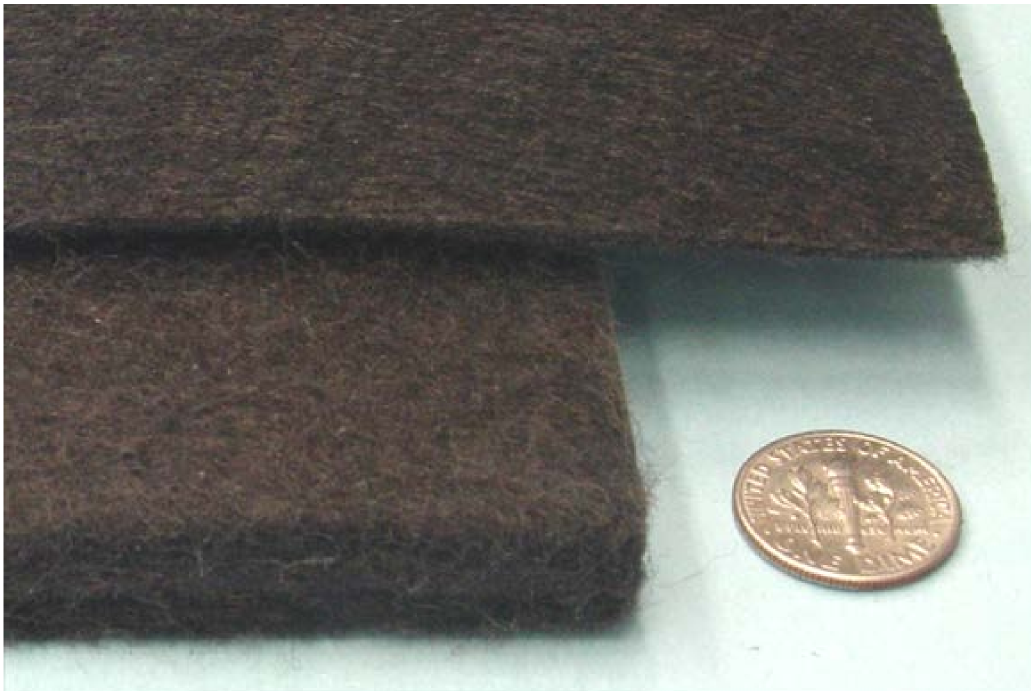


Figure 19.2.2.2-1. Examples of nonwoven needle-punched geotextiles showing variation in thickness with mass. At top, a 4 oz/yd^2 geotextile, and at lower left, a 32 oz/yd^2 geotextile.

Nonwoven geotextiles are preferred for most soil filtration applications and have supplanted woven geotextiles in most applications where filtration (soil retention) is required. Thick nonwoven geotextiles (16 and 32 oz/yd^2) are mainly used for protection, for example between a geomembrane and angular gravel, as they can provide some puncture resistance. They also have the ability to transmit flow in the plane of the fabric and are sometimes used for drainage applications. Geonet composite drains consisting of a geonet sandwiched between two geotextiles is a more common means of transmitting flow in the plane of the geosynthetic. A 64 oz/yd^2 nonwoven geotextile can be obtained on special order. It is the heaviest geotextile available and is produced by needle punching two 32 oz/yd^2 fabrics together. Typically, the thicker fabrics are made by joining two 8 oz/yd^2 fabrics together to make a 16 oz/yd^2 fabric, then joining two 16 oz/yd^2 fabrics to make a 32 oz/yd^2 fabric, etc. Composite geotextiles can also be produced by combining two or more layers of geotextiles having different properties (e.g., different drainage characteristics). Figure 19.2.2.2-1 shows nonwoven needle-punched geotextiles, and figure 19.2.2.2-2 shows a nonwoven needle-punched staple-fiber geotextile.

Although needle-punched geotextiles are the most prevalent form, heat-bonded geotextiles are used in applications such as wick drains to filter very fine-grained soils such as clays. Heat bonding provides more dimensional stability to the opening sizes in a geotextile, and it results in a stronger fabric. Heat bonding also results in a smoother fabric surface that reduces the interface friction angle, which is a benefit when trying to insert wick drains deep into the ground. Although they can be used in separation and other applications, the lower interface friction strength of heat-bonded geotextiles means that they are not favored for installation on sloped surfaces. Lower interface friction can lead to slope instability. Heat bonding allows the manufacture of lightweight geotextiles, which are relatively thin (20 to 40 mils), while needle punching usually results in fabrics of considerable thickness (40 to over 200 mils). There are nonwoven needle-punched fabrics that have been lightly heat bonded on one side, creating two different textures – a smooth side and a rough side.

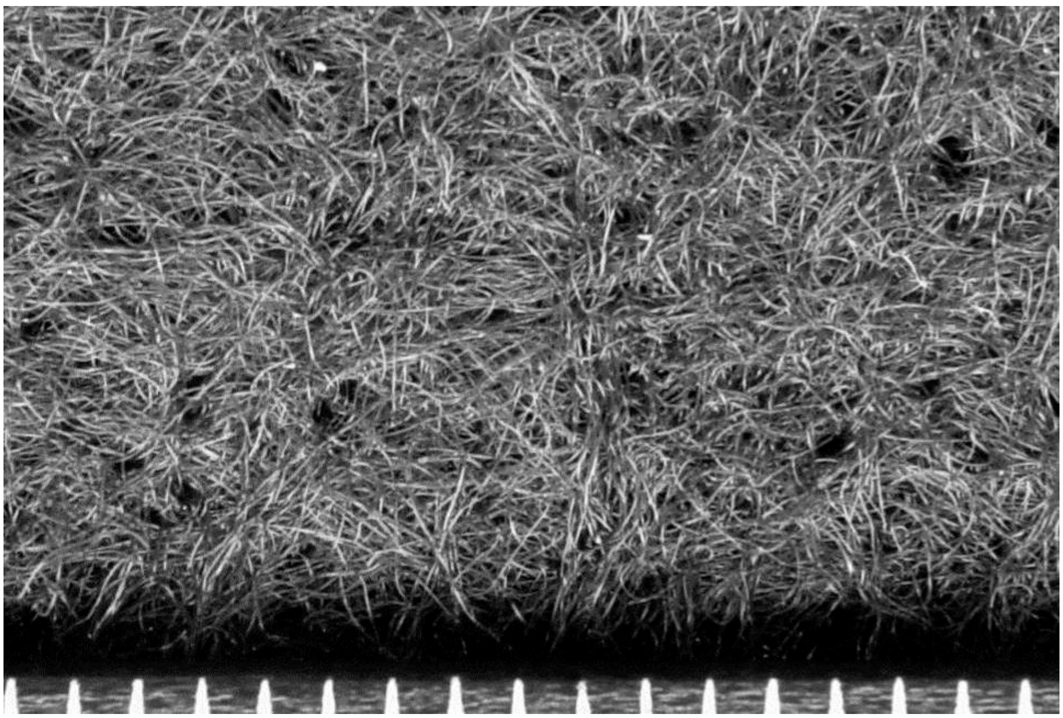


Figure 19.2.2.2-2. Photograph of a nonwoven needle-punched staple-fiber geotextile, magnified view (1-mm scale). The needle holes are visible in the photograph. The entanglement of the fibers holds the fabric together.

The smooth surface created by heat bonding tends to be hydrophobic. A driving head of water is typically needed for water to flow into and through a heat-bonded nonwoven geotextile. A needle-punched nonwoven is usually a better choice for drainage and filtration applications when the geotextile is placed at shallow depths. Figure 19.2.2.2-3 shows a nonwoven continuous-filament needle-punched spun-bond geotextile, and figure 19.2.2.2-4 shows a nonwoven continuous-filament spun-bond and heat-bonded geotextile.

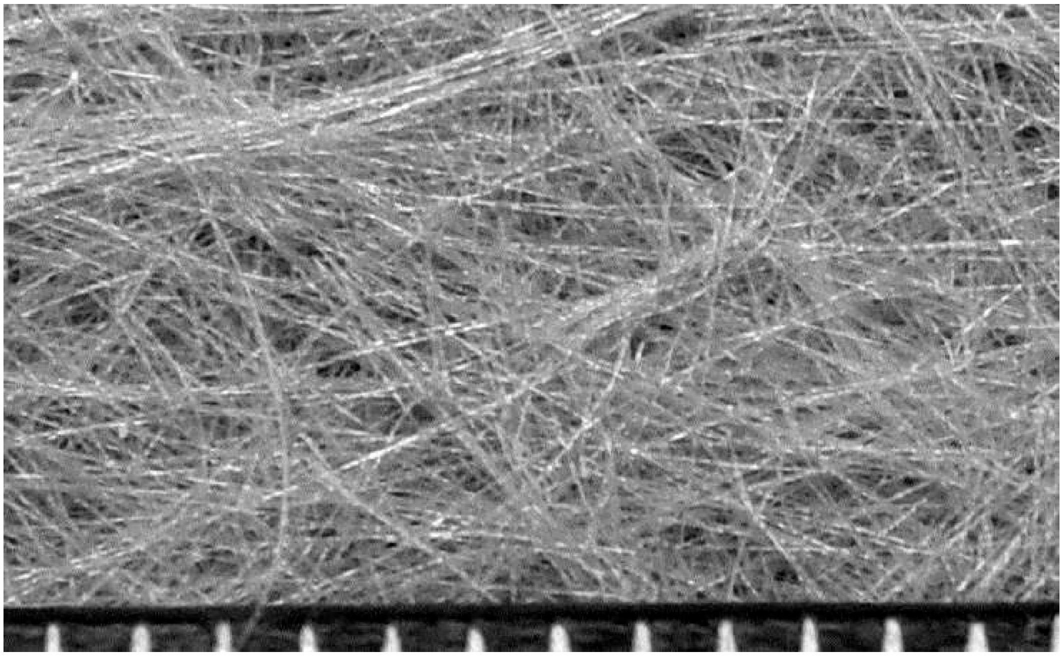


Figure 19.2.2.2-3. Photograph of a nonwoven continuous-filament needle-punched spun-bond geotextile, magnified view (1-mm scale). This geotextile is only lightly "heat set" (lightly fused together).

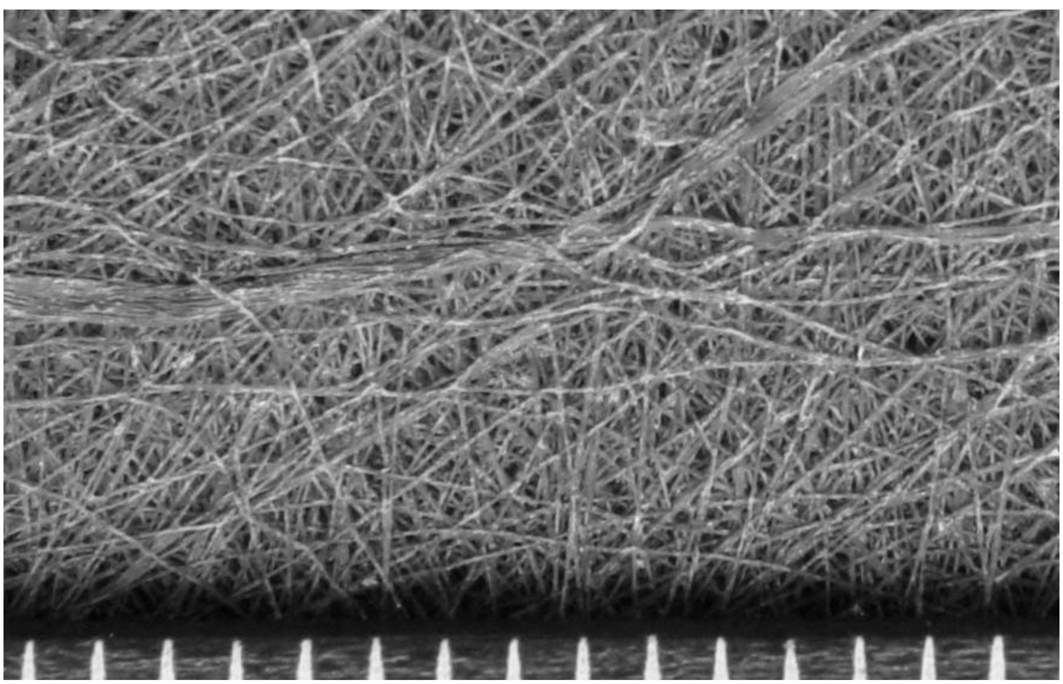


Figure 19.2.2.2-4. Photograph of a nonwoven continuous-filament spun-bond and heat-bonded geotextile, magnified view (1-mm scale). The fibers in this geotextile have a heavy "heat set." The fibers are more thoroughly melted to fuse them together than the example on figure 19.2.2.2-3. This geotextile is used as a filter wrapping for wick drains.

19.2.2.3 Knitted Geotextiles

Knitted geotextiles are formed by interlocking a series of loops of one or more yarns to form a fabric. Monofilament, multifilament, and fibrillated yarns are used in knitted geotextiles. Knitted geotextiles are easily stretched and distorted out of shape, changing their opening size; therefore, their transport, storage, handling, and installation require a great deal of care to avoid distortion of the geotextile, which could result in erosion of soil through the fabric (failure to retain filtered soil particles). Figure 19.2.2.3-1 shows a knitted multifilament geotextile.

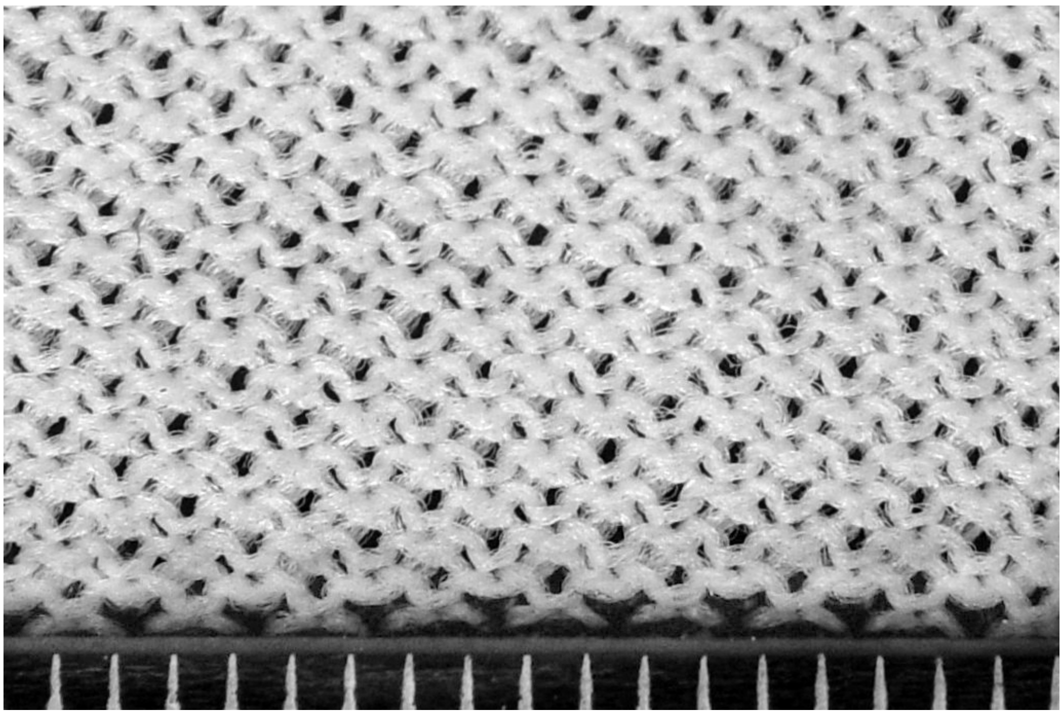


Figure 19.2.2.3-1. Knitted multifilament geotextile, magnified view (1-mm scale). This geotextile is used as a filter placed around perforated pipe.

Several manufacturers of polyethylene drainage pipe supply a knitted polyester geotextile as a filter wrapping around a slotted (perforated) pipe. This product is sometimes referred to as a "filter sock" (knitted geotextile) placed around the "drainage tubing" (pipe) and is usually supplied with the geotextile already installed on the pipe. Drainage pipes with geotextile filters may be prone to clogging. Use of a knitted geotextile in direct contact with a natural soil may perform poorly. The Bureau of Reclamation (Reclamation) recommends limiting the use of knitted geotextiles placed around drainage pipes to installations where they are placed in contact with an envelope of engineered filter sand.

19.2.2.4 Geotextile Roll Dimensions

Geotextiles are commonly supplied in rolls that are 12.5 or 15 feet wide (some wider rolls are made). Typical lengths are 150 feet, 300 feet, and 360 feet, with the heavy geotextiles being available only in the shorter (150 and 300 feet) lengths. For greater area coverage, geotextile panels are joined in the field.

Geotextile panels can be joined by sewing, stapling, heat welding, tying, gluing, and overlapping. Each method has its advantages and disadvantages. Seams are not as strong as the geotextile. High quality sewn seams can only achieve tensile strengths that are 50 to 70 percent of that of the geotextile. Seaming methods are discussed in more detail in section 19.6.3.

19.3 Functions of Geotextiles

Geotextiles are used for filtration, drainage, separation, protection, reinforcement, and soil erosion control functions (figure 19.3-1). They are a commonplace component of civil engineering construction projects such as roads and highways, which account for the majority of geotextile use. Prior to the development of geotextiles, thick layers of natural materials such as sand, gravel, and rock were used in earthwork projects to perform many of the functions now assumed by geotextiles. Lightweight and strong, geotextiles often offer an economic advantage in performing a necessary function without the bulk tonnage required of a natural soil or rock. The lightweight nature of geotextiles, which gives them an economic advantage in materials handling, also makes them vulnerable to damage. Because they behave differently than natural materials, their design and specification is more complicated and requires specialized knowledge and experience. The significant economic and technical advantages of geotextiles cannot be realized if performance is compromised by improper design or installation. Geotextile service life and replacement requirements need to be evaluated during design.

Although geotextiles are typically designed by function, there are often several functions involved with a given application. Typically, a primary function, such as filtration, also relies on a secondary function, such as drainage, for the application to be successful. Successful design often requires evaluation of several functions for a geotextile application. Table 19.3-1 presents functions of geotextiles in different locations within an earth dam, and figure 19.3-1 presents some graphical representations of geotextile functions in earth dams.

Natural materials (such as sands and gravels) are usually preferred over synthetic materials in embankment dams. Synthetic materials can be less expensive than natural materials, but the cost factor is often not as important for a dam as the greater assurance of the long-term successful performance achieved by natural materials. Synthetics become increasingly attractive when natural materials are in short supply near the construction site.

Table 19.3-1. Functions of geotextiles in different locations in an earth dam

Location	Purpose	Type of flow or loading	Significance of failure	Access for repair
Downstream slope protection	Control of erosion by rainfall	Occasional surface flow	Noncritical	Easy
Downstream surface drains	Removal of surface seepage	Continuous local seepage	Noncritical, local wet areas may reappear	Easy
Upstream slope protection	Control of erosion by wave action and by outward flow during drawdown	Cyclic flow during wave action, small flow during drawdown	Usually noncatastrophic	Possible
Temporary internal drainage	Dissipation of excess pore pressure during construction of wet fills	Temporary flow. Limited quantity, some migration of fines allowable if drains not blocked.	Noncatastrophic. Failure may lead to instability during construction or delays	None
Upstream internal fill boundary	Prevention of unacceptable migration of fines in upstream direction	Transient and small flows during drawdown	Noncatastrophic. Only significant if migration is large and continuous.	None
Downstream internal interface, no continuous flow from reservoir	Prevention of unacceptable migration of fines	Flow only due to infiltration of rainfall	Limited and noncatastrophic	May be possible to excavate with reservoir drawn down for safety.
Downstream internal interface, continuous flow from reservoir	Prevention of internal erosion, including effects of concentrated flow in cracks, etc.	Continuous flow from reservoir, potentially large and increasing	Potentially catastrophic and rapid. General seepage from downstream slope may involve only slow deterioration	Generally none. Downstream fill/inverted filter may need to be removed and repaired with reservoir drawn down for safety.
Between embankment zones	Prevention of cross contamination between zones	Continuous seepage	Clogging may cause pore pressure buildup and slope stability failure, which may be catastrophic if it releases the reservoir.	None. Likely to require extensive excavation and reservoir drawdown for repair.

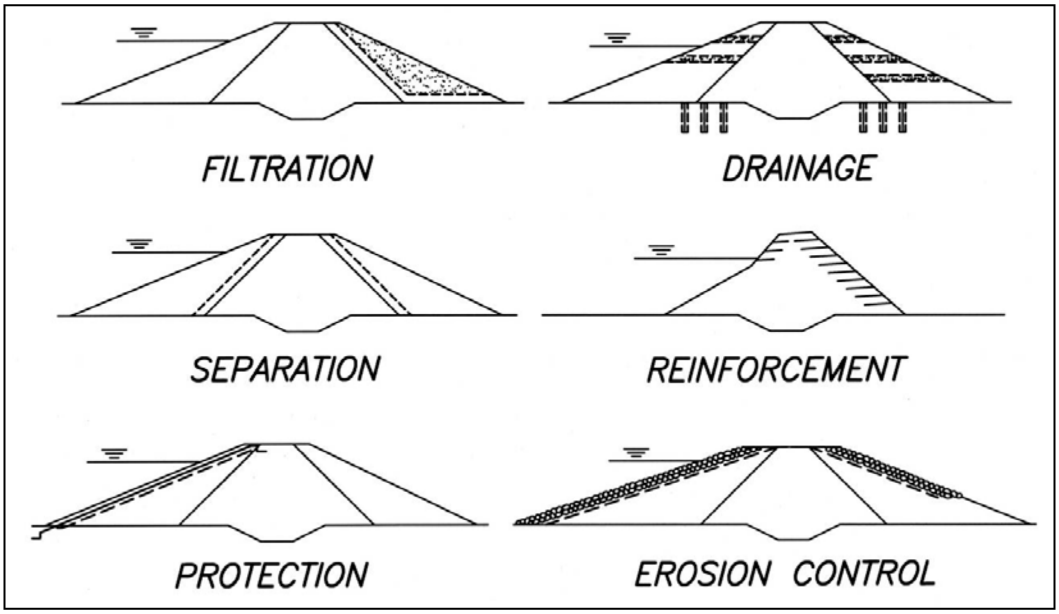


Figure 19.3-1. A graphical representation of various geotextile functions in earthen dams.

19.3.1 Filtration

The filtration function allows fluid flow across the plane of the geotextile while retaining the soil particles on the upstream side of the geotextile. Because geotextile integrity can be compromised by tearing, puncture, and seam separation during installation, and by clogging after installation, they are not favored for use as a primary filter or drain in an earthen dam. Although it is often possible to achieve considerable cost savings by substituting a geotextile for a filter made from a natural material such as sand, such a substitution has risk. Use of a geotextile as the primary protective filter buried within an embankment dam would be considered a deviation from this standard. This has been done only in rare circumstances and is typically associated with a toe drain or in the upper (dry) portion of a dam embankment where access for replacement would be a reasonably feasible undertaking. One emerging trend is the use of geotextile filters to repair cracked dams in arid environments (Doerge et al., 2011).

Design for filtration requires consideration of the nature of the seepage flow, evaluation of the soil to be filtered, and consideration of the behavior of the geotextile in its environment. Two opposing criteria must be satisfied by a geotextile filter. The geotextile must have small enough openings to adequately retain the filtered soil, and yet it must have sufficient permeability so it does not restrict the flow of liquid out of the soil and across the plane of the geotextile. The first criterion is soil retention, and it is dependent upon the particle sizes (gradation) of the soil to be filtered in comparison to the openings in the geotextile. The second criterion is permeability, and it is dependent upon an evaluation of the potential of the geotextile to clog over the course of time.

The nature of the liquid flow through the soil is also a factor that is to be considered during design. Differences in water chemistry between seepage flow and the soil can lead to formation of precipitates, causing clogging. Organic-rich water or soil can lead to biological clogging. Also, the movement of soil particles against and into a geotextile can lead to particulate clogging. Some level of clogging is expected in a geotextile filter application. When clogging is so extensive that the geotextile cannot properly function to transmit seepage flows, it is considered to be subject to excessive clogging, which is to be avoided. There are several situations in which the use of geotextiles as filters are not recommended (Koerner, 2005a):

- Narrowly graded soils such as loess, rock flower, or crusher fines – It is difficult to build up a filter cake of various soil particle gradations on or in the geotextile when the base soil is made of particles of a fairly uniform size.
- Dispersive clays – These cohesive soils tend to flocculate into fine particles that are easily transported through a geotextile.
- Gap-graded cohesionless soils – It may be difficult to build a filter cake unless the finer fraction shows a range of particle sizes.
- Turbid water – Such as water that is affected by dredging operations. Muddy water can quickly lead to excessive clogging.
- Microorganism laden water – Water from agricultural runoff can be problematic in causing excessive clogging of the filter.

19.3.1.1 Seepage Flow

The designer must evaluate the nature of the seepage flow to be filtered. This requires an understanding of the expected water chemistry, flow variation, and gradients. Water chemistry is typically more of a concern with waste impoundments than with water reservoirs. Where water is expected to be very alkaline (pH greater than 10), it is likely to degrade geotextiles made from polyester resins (Koerner, 2012). Acidic water (pH less than 3) can degrade some polyester and polyamide (nylon) geotextiles. In cases of extreme pH, a geotextile material such as polypropylene or polyethylene should be considered.

Variation in flow is another factor to consider. A geotextile placed in the downstream portion of an embankment such as in a toe drain may have a relatively steady seepage flow, which varies gradually with changes in reservoir height. Such a geotextile is usually placed in contact with a downstream layer of gravel or sand into which the flow migrates and is quickly carried away. The flow is in one direction. A geotextile placed beneath the upstream face of embankment slope protection material such as riprap can experience flow that is unsteady and dynamic. The flow can vary rapidly, and the flow direction can reverse due to wave action and reservoir filling and drawdown.

When a geotextile is placed between two different soils and flow reversal is possible, then filtration behavior to prevent particle movement in either direction across the fabric should be considered.

There have been some failures in which a blocky revetment material was placed directly against a geotextile. The revetment covered too great an area of the geotextile, leaving little surface area exposed for drainage. Wave action during storm events caused the phreatic surface in the embankment soils to become elevated, causing a flow reversal situation as each wave receded. Rapid drainage was not possible, and the elevated phreatic surface led to sliding of the revetment.

A high seepage gradient with large flow rates, and/or the action of a dynamic gradient, may also affect the filtration properties of a geotextile. Consideration should be given to geotextile performance where high gradients are anticipated. High seepage forces can distort a geotextile, changing its soil retention characteristics. Laboratory testing using the proposed geotextile and soils under conditions similar to the proposed installation should be considered (Koerner, 2012).

19.3.1.2 Soil Retention

Filter design for soil retention involves principals similar to those used in the design of granular filters (see Design Standards No. 13 Chapter 5, Protective Filters). Key performance properties of a geotextile used as a filter are the size of its openings that governs the retention of solid particles and its permeability to water. Refer to section 19.4.1 of this design standard for geotextile filter design.

19.3.1.3 Geotextile Permeability

In many applications, it is important that a geotextile be able to transmit flow through the fabric. In filter applications, the ability to transmit flow is essential. Most geotextile installations show a significant decrease in permeability sometime after installation due to clogging. Clogging occurs when soil particles fill the void space of a geotextile and reduce its ability to transmit flow. A reduction in permeability occurs in proportion to the amount of void space that becomes clogged with foreign material. The clogging can be caused by filling the voids with soil, with biological microorganisms and their byproducts, or with inorganic chemical precipitates. Some degree of clogging always occurs when establishing a geotextile filter. If a large amount of the pores within the geotextile become clogged, the geotextile is likely to fail to adequately perform its intended filtration and drainage functions and is therefore described as being excessively clogged. Excessive clogging must not be allowed to occur. Excessive clogging of a drainage system could raise groundwater levels in a dam embankment to such an extent that an embankment slope failure might occur.

Chemical clogging involves the precipitation of minerals onto the fibers of a geotextile without the influence of a biological microorganism. Water can dissolve and hold minerals in solution. Precipitates form as a result of a reduction in a water's mineral solubility. This solubility reduction can arise from several causes. It is principally affected by changes in water temperature, pH, or salinity. Changes from reducing to oxidizing conditions, or evaporation of mineral saturated water, are other mechanisms that lead to formation of precipitates. Change in water pH is the most significant cause for formation of large amounts of mineral precipitates.

Water pH may change due to mixing of two different water sources, chemical reaction of groundwater seepage with minerals in soils, changes in oxidation state, or by dissolving or releasing dissolved gas such as carbon dioxide. The problem of mineral precipitation typically arises in geotextiles where there is highly alkaline groundwater flowing through the material. Calcium, sodium, or magnesium precipitates may form depending upon the water chemistry.

Biological clogging occurs when microorganisms and/or their byproducts coat the fibers and fill the void spaces in a geotextile. The resulting substances causing the clogging are often referred to as "biofilms" or "bioslimes" and are typically composed of a mixture of living and dead organisms and mineral precipitates. Microorganisms require nutrients as an energy source for metabolism and thrive where the nutrients are available in conjunction with a growth substrate. The growth substrate is a material having a large surface area (such as a geotextile) that the organisms can attach onto. Excessive biological clogging is not limited to geotextiles. Gravel drains, sand filters, and slotted well screens are also examples of substrates that have a large amount of surface area that can be affected by biofilm deposition. Biological clogging can occur in both aerobic and anaerobic environments. There are many types of water chemistries and microorganism combinations that can lead to this type of biological activity. Experience has shown that processes involving either iron oxidation or sulfate reduction can be problematic at dams.

The formation of "ochre biofilm," a yellowish-brown to red-colored substance containing iron oxides and organic matter (living and dead bacteria), is the most prevalent cause of excessive biological clogging in embankment dam drainage systems, and it also is known to affect geotextile filters. When seepage water containing dissolved iron reaches an oxygen-rich environment such as a filter or drainpipe, the ochre deposits are observed to form. The mechanism involves oxidation of the iron from Fe^{+2} to Fe^{+3} and subsequent precipitation of Fe_2O_3. This mechanism can occur naturally through inorganic processes but at a very slow rate. Research has shown that microorganisms are able to greatly accelerate this geochemical process (Mendonca et al., 2003). It has been speculated that it may be possible to limit the ochre clogging problem (Mendonca et al., 2006) by constructing drains so they remain submerged. At the Ergo tailings dam in South Africa, a "p" trap was used to vary the drain conditions from aerobic to anaerobic on a regular basis to control biological clogging (Legge, 2004).
An example of an anaerobic biological clogging mechanism involves acidic waters containing iron and sulfate. In this case, sulfate-reducing bacteria can act in an oxygen depleted environment to form brown to black-colored bioslimes composed of organic matter mixed with iron sulfides. It has been problematic for

geotextiles installed in some tailings dams, although it is believed that sand filters would experience similar problems with clogging (Scheurenberg, 1982). This phenomena is the subject of considerable investigation and research in the mining industry. Attempts to use sulfate reducing bacteria to remove acid and metals from contaminated mine drainage has been hampered by bioslimes clogging flow paths in water treatment and drainage systems.

19.3.2 Drainage

Geotextiles not only allow the passage of fluids in a direction that is perpendicular to the plane of the geotextile layer (like a filter), they can also function to provide planar drainage (flow parallel to the geotextile layer). This property is governed by transmissivity (volumetric flow rate of water per unit width of geotextile per unit gradient in a direction parallel to the plane of the geotextile), which is defined by ASTM D-4439. Woven geotextiles have almost no transmissivity and cannot be used as drains. Planar drainage can be provided by a thick nonwoven geotextile, a geonet composite (geotextile bonded to a geonet), or structured geodrains. Examples of some geocomposite drainage products are shown on figures 19.3.2-1 through 19.3.2-3.

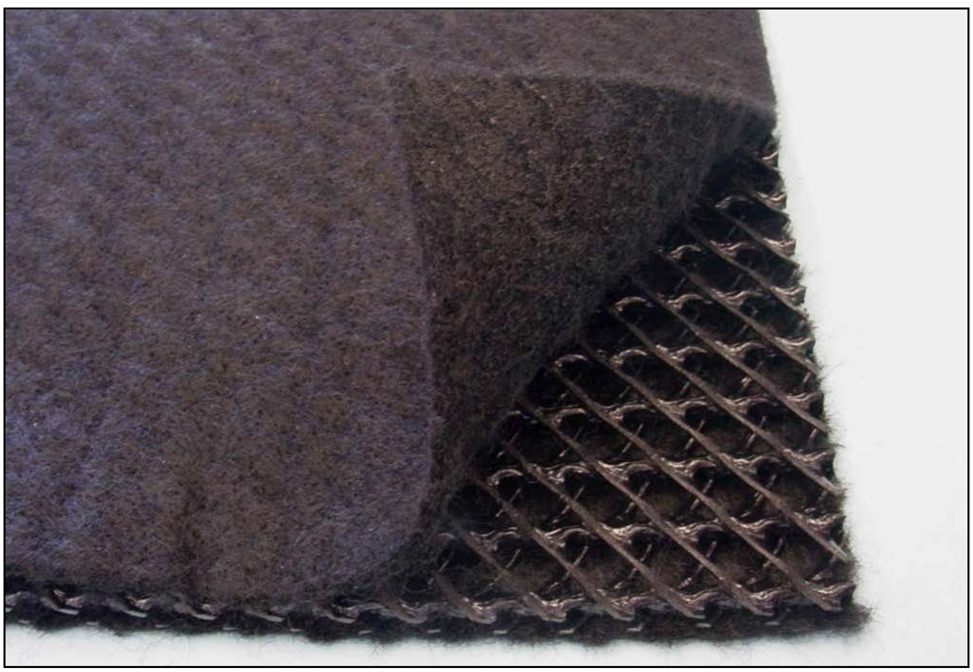


Figure 19.3.2-1. Photograph of a geonet composite drain made by bonding nonwoven geotextiles to each side of a tri-planar geonet. One corner of the upper geotextile layer has been peeled back to show the underlying geonet core.

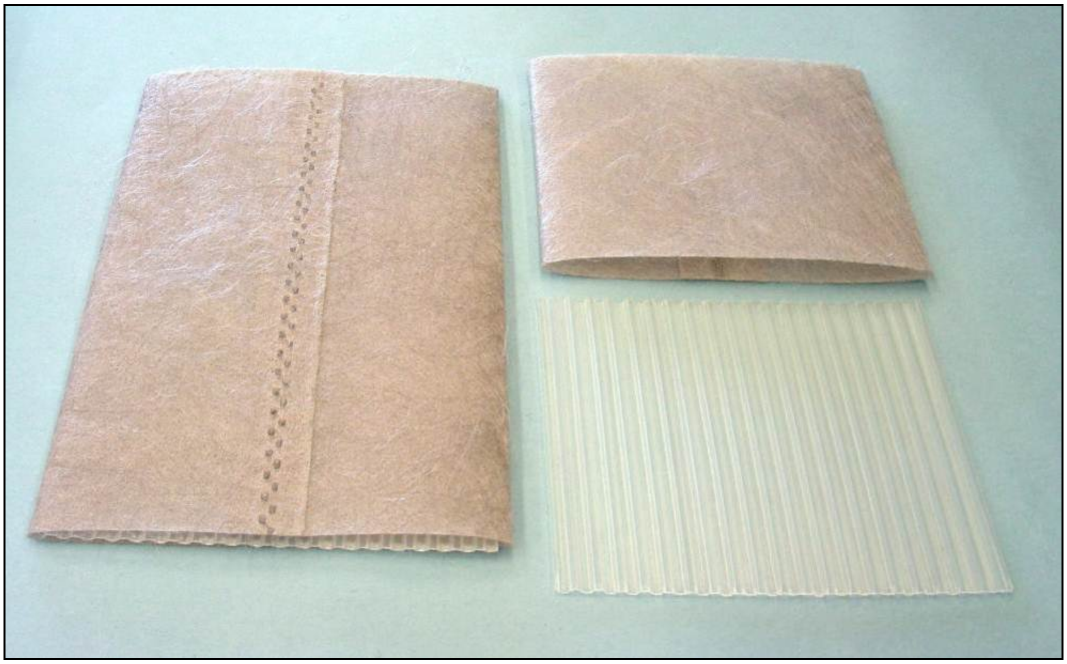


Figure 19.3.2.-2. Photograph of a wick drain composed of a polymeric corrugated core and outer heat set nonwoven geotextile. The assembled drain is on the left, and the components are shown on the right.

Figure 19.3.2-3. Photograph of a geocomposite edge drain formed by enclosing a row of perforated geopipes inside a nonwoven geotextile filter fabric.

There are many other types of geocomposite drainage products besides those shown in the photographs. Important aspects of design for the drainage function are considerations for flow capacity and compressive strength. Some typical values for geotextiles and related products are:

- Needle-punched nonwoven geotextile – Typical values are 3 to 10 mm thick, 10^{-4} to 10^{-3} meters per second (m/s) for the permeability, and 10^{-7} to 10^{-6} m^2/s for the transmissivity.
- Geonet composites – 10 to 20 mm thick, 10^{-1} to 1 m/s for the permeability, and 10^{-3} to 10^{-2} m^2/s for the transmissivity.

The values for thickness, permeability, and transmissivity decrease when subjected to compressive stress. The compression due to burial can compress geotextile and geocomposite drains to the extent that their ability to accept and transmit fluid flow is greatly restricted. For nonwoven geotextiles, the reduction in transmissivity (about 20 to 30 percent of the uncompressed value) reaches a constant value around 100 kiloPascals (kPa) of compressive stress, beyond which the yarn structure is dense enough to hold the load and still convey fluid (Koerner, 2012).

19.3.3 Separation

The separation function uses a geotextile placed between two soils that would have a tendency to mix when squeezed together under applied loads. This typically occurs with soils that are filter incompatible, resulting in the migration of the fine soil particles into the coarser soil. Although separation is inherent in most geotextile applications, it is considered the primary function when the need to transmit fluid flow through the geotextile is of minor importance. A typical example of separation is the placement of a geotextile over a fine-grained soil subgrade prior to laying down a layer of gravel for a road base course. The geotextile serves to prevent the fine soil from infilling the coarser gravel, which would compromise the drainage and shear strength properties of the gravel. In these applications, particle retention is the primary function. The geotextile also must have sufficient strength to resist bursting, tearing, and puncturing (Koerner, 2012). Reclamation has used this function in embankment dams by placing a geotextile over a downstream gravel drain zone to prevent fine soil from an overlying shell material from filling the voids in the gravel and reducing its permeability. In other cases, it has been used beneath grouted riprap in high velocity flow situations (10 to 25 feet per second) to prevent the grout from penetrating into an underlying permeable subgrade such as gravel, which needs to remain free draining to avoid formation of uplift pressures. Nonwoven, woven, and geocomposite products have been used in separation applications at dams. When the geotextile is placed on a slope, it introduces a potential weak layer that must be evaluated for slope stability. Note that the interface friction angle between a geotextile and a layer of soil may be considerably less than the frictional strength of the soil mass without a geotextile. For example, a sand with a 36-degree internal friction angle may only have an interface friction angle of 23 to 26 degrees when placed against a geotextile. This is a significant reduction in strength with respect to slope stability. An even more critical application is the use of a geotextile against a smooth geomembrane where interface friction angles can be very low (6 to 24 degrees). A textured geomembrane is usually a better choice for placement against a geotextile. Typical interface friction angles are in the range of 11 to 32 degrees for geotextiles placed against textured geomembranes.

19.3.4 Reinforcement

Geotextiles can reinforce soils by being sandwiched in layers (horizontal reinforcement), by supporting the soil at an exposed face (vertical reinforcement), or by completely encapsulating the soil. Soils typically can resist compression but not tension. Soil reinforcement can be achieved by introducing structural elements into a soil mass to impart tensile and shear strength. This function can be performed by woven and nonwoven geotextiles. Reinforcement is also achieved using other products such as geogrids (figure 19.3.4-1), by mixing loose polymer fibers into a soil, or by injecting steel or fiberglass rods (soil nails) into a soil mass. Geotextiles are often a consideration for use in reinforcement of low-strength silt and clay soils. The geotextile is sandwiched between layers of compacted soil. Reinforcement is a function of the tensile strength of the geotextile and of the interface friction between the geotextile and the soil. While woven geotextiles have superior tensile strength, they typically generate lower interface friction than that achieved by nonwoven geotextiles. The selection of the reinforcement material requires evaluation with respect to the specific soil under consideration. Geogrids were developed for their high tensile strength application to soil reinforcement and are often used with coarse granular soils. For fine-grained soils, a geotextile has more surface area in contact with the soil than a geogrid. Geotextiles are more commonly chosen for fine-grained soil reinforcement. Both woven geotextiles and geogrids are able to develop high strength at small strains.

Geotextiles have been used in reinforcement of road embankments and on other projects to achieve steeper slopes than would be possible in the same soils without reinforcement. For embankment dams, they have been used to provide stable over-steepened slopes, which would not be possible in unreinforced soil. As the strength is mobilized, elongation and creep deformation under sustained loading becomes important. It is advisable that a geosynthetic reinforced structure be made flexible and capable of self-adjusting to the internal movement under stress. The geosynthetic may strain several percent before it reaches its designed working load. The behavior is also affected by elevated temperatures, which may be a consideration in some installations.

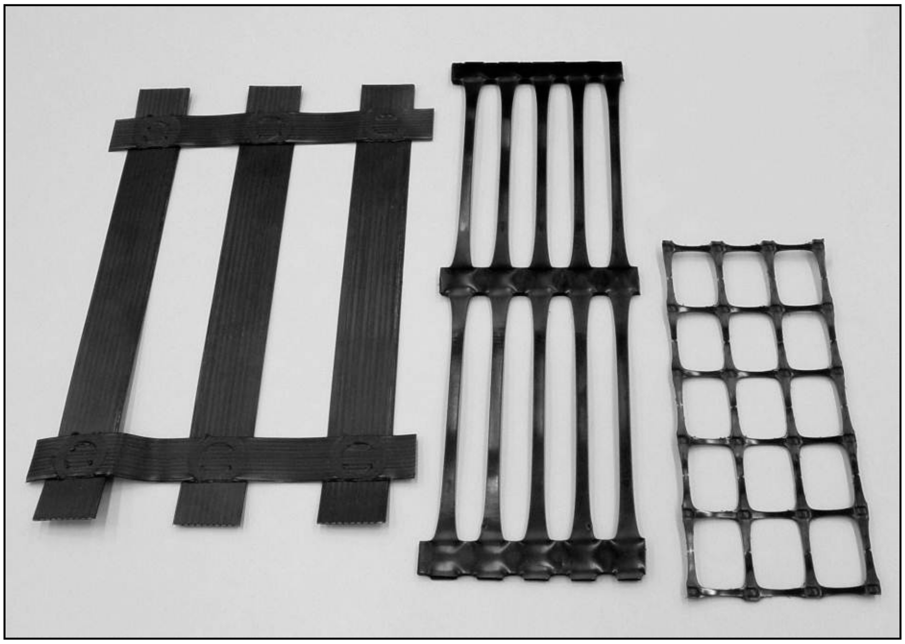


Figure 19.3.4-1. Photograph showing examples of geogrids. Geogrids have supplanted geotextiles in many reinforcement applications where high-strength reinforcement of granular soils is required.

19.3.5 Protection

Although formerly considered a separate function, protection is now considered to be included in the separation function. The typical use of a geotextile in protection is the placement of a geotextile between a geomembrane and a layer of gravel or other rocky soil that might puncture the geomembrane and compromise its fluid containment property. To achieve the desired protection, consideration of bursting, tearing, and/or puncturing of the geotextile may be necessary. In addition to performing calculations, laboratory testing and field demonstrations are sometimes used to verify protection of a critical layer. Laboratory testing has been used in the mining industry to simulate the effects of deep burial of geosynthetics. The field demonstration process involves construction of a test section by placing the various design components in the field, subjecting them to expected loading conditions, and then carefully exhuming the materials to visually inspect the level of protection achieved. Reclamation has used the field demonstration method where a geomembrane is protected by a geotextile.

19.3.6 Erosion Control

Erosion is the removal of soil particles caused by the flow of water across a soil surface. Erosion control was formerly considered a separate geotextile function, but it is now considered to involve the separation, filtration, and drainage functions. Geotextiles have been used on dams for erosion control for the following applications:

- Geotextiles have been placed between riprap and soil on the upstream slope of a dam embankment to prevent erosion of the fine soil particles by wave action. Granular bedding is preferred in such an application, but a geotextile may be used where riprap size is small and embankment soils are not highly erosive.
- Geotextiles can be placed under a bedding layer to protect the fabric during riprap installation.
- Geotextiles are used beneath riprap in surface water conveyance channels as a substitute for a granular bedding layer to provide protection against erosion of the underlying soil.
- Woven geotextiles have been used as a temporary cover to protect soil surfaces that have been seeded until vegetation can become established. This type of geotextile is often referred to as an "erosion control blanket." It is a superior form of erosion protection to that of straw mulch and is often used on steep slopes (2H:1V or steeper) in areas subject to intense rainfall. Erosion control blankets have been used on the downstream slopes of some embankment dams to facilitate vegetation establishment. Geotextiles made from natural, synthetic, and combined natural and synthetic materials have been used. Synthetic materials that will degrade when exposed to the elements are usually preferred for this application. The blankets are used in semi-arid areas to retard moisture loss from the seed bed.
- Woven geotextiles called "silt fence" are commonly used as temporary barriers in dam construction projects to capture suspended particles from sediment-laden storm water runoff.
- Geotextiles have been used as a "silt curtain" placed within a stream or reservoir to retain suspended particles generated by underwater excavation and soil placement activities.
- Geotextiles have been placed under the gravel surfacing on the crest of embankment dams to protect against rutting from vehicle travel and to protect the underlying embankment soil from desiccation cracking.

The use of geotextiles for erosion control has spawned the development of many different products. In addition to geotextiles, geocells filled with gravel have been used in dams as an alternative to a vegetated slope. Gravel-filled geocells can be an effective erosion control method in arid areas where it is difficult to establish and maintain vegetation. Only the first two applications listed above, where a geotextile is substituted for a granular bedding layer, are discussed further in this design standard.

19.4 Design Procedures

Geotextiles offer a potentially large savings in cost and can reduce the time of construction as compared to the use of natural materials such as sand and gravel for filters and drains. In these applications a natural material, which is two or more feet in thickness, is being eliminated by substitution of a synthetic material that is only a fraction of an inch in thickness. The significant economic and technical advantages of geotextiles cannot be realized if performance is compromised. There are numerous factors that can lead to performance problems with geotextile installations. The performance problems are related to one of the following general mechanisms:

- Excessive clogging of filters and drains
- Internal erosion of soil particles through filters and drains
- Stress-induced distortion
- Environmental degradation
- Slope instability
- Rupture
- Constructability requirements

The performance problems can result from improper design, poor installation, post installation damage, or degradation. Because geotextiles are vulnerable to installation damage and they have a finite useful life, they should not be used in locations that are critical to the safety of the dam should they fail to perform as intended. All synthetic polymers oxidize and lose strength with the passage of time. For properly designed and installed geotextiles, the useful service life is believed to be in the range of 50 to 150 years. Because of their finite service life, Reclamation policy does not allow the use of geotextiles in deeply buried locations or other places in an embankment dam that would result in difficult and costly measures to gain access for repair or replacement. Reclamation has designed and specified the use of geotextiles in the following applications at embankment dams:

- As a filter in toe drains with shallow depth of burial

- As a separation/filter layer between a downstream gravel drain and the overlying downstream embankment shell

- As a filter/bedding layer beneath riprap placed for upstream slope protection from waves

- As a filter/bedding layer placed beneath riprap in storm water conveyance ditches

- As soil reinforcement to increase the crest height of a dam using steepened slopes

- As reinforcement/separation over soft soils
- As a protective barrier placed beneath gravel road surfacing in the embankment crest
- As a protective layer to prevent puncture of an upstream waterproofing geomembrane by an adjacent soil layer
- As a temporary erosion control material to protect seeded slopes to establish vegetation

A systematic approach should be followed to design, select, and specify a geotextile. It is recommended that several alternatives be considered for a particular design and the reasons for the chosen alternative be documented. The design and specification of geotextiles requires specialized knowledge and experience. Assuming a geotextile is the best alternative, or that it will work because it has been used previously on a similar project without a full engineering evaluation and comparison, is not considered sound engineering. A systematic approach to design for geotextiles has been adapted from Perloff and Baron (1976) and is presented in the following table.

Table 19.4-1. Systematic approach to geotextile design (adapted from Perloff and Baron, 1976)

Sequence number	Design activity
1.	Define the purpose and establish the scope of the problem (functions and boundary conditions).
2.	Investigate and document the relevant geotechnical conditions at the site (geology, soils, hydrology, water chemistry, etc.).
3.	Formulate design concepts; include several feasible alternatives.
4.	Establish the models to be analyzed; determine the parameters of each model.
5.	Carry out and document the analyses.
6.	Compare results and select most appropriate design. Consider alternatives versus cost, construction feasibility, reliability, durability, etc.; modify the design if necessary.
7.	Prepare a detailed design of the selected alternative, including plans and specifications.
8.	Observe and document construction.
9.	Monitor performance, document, and report lessons learned.

Appropriate selection of the optimum geotextile characteristics for a particular application depends on meeting the functional requirements, constructability requirements, and endurance requirements. Tables 19.4.1-1 and 19.4.1-2 list the specific properties for the various functional applications of geotextiles and indicate the relationship between the functions and properties of geotextiles. Those properties, which are relevant to the site-specific application, should be considered, and all may not be important in every application.

Geotextile design has traditionally followed two paths:

- Design by specification of a material based upon experience in various service conditions: This method is used by the American Association of State Highway and Transportation Officials (AASHTO) in their M288 geotextile specification for many road and highway applications. Also, although there are calculation procedures (Koerner, 2012) for silt fencepost spacing, fence height, fabric strength etc., they are rarely used in practice. It is more common to specify an available product, and the design places emphasis on the placement details, which are based upon past experience with similar applications (Carpenter, 2006).
- Design by function based on calculation of a required material property value with an added factor of safety (FS) (Koerner, 2012): Except for silt fence, this is the preferred method for the design of geotextiles as applied to embankment dams in this design standard.

19.4.1   Geotextile Filter Design

Characteristics of geotextile filters in different locations in an earth dam are listed in table 19.3-1, and important criteria and properties associated with filtration applications are listed in table 19.4.1-1. Filtration involves the formation of a stable interface between a fine soil (base soil) and a coarse soil or geotextile (filter) when fluid flows from the base soil to the filter (one directional flow condition). A properly designed geotextile filter must satisfy the following criteria as do granular filters:

- Retention
- Permeability
- Nonclogging

Filter criteria for granular filters were developed by a combination of practical experience, laboratory tests, and theoretical considerations. Granular filter design initially was only concerned with average soil grain sizes, but evolved over time to consider other factors such as the internal stability of a soil, the presence of dispersive soil, construction considerations, and other factors (Kleiner, 2005). Current design procedures, as presented in Design Standards No. 13 Chapter 5,

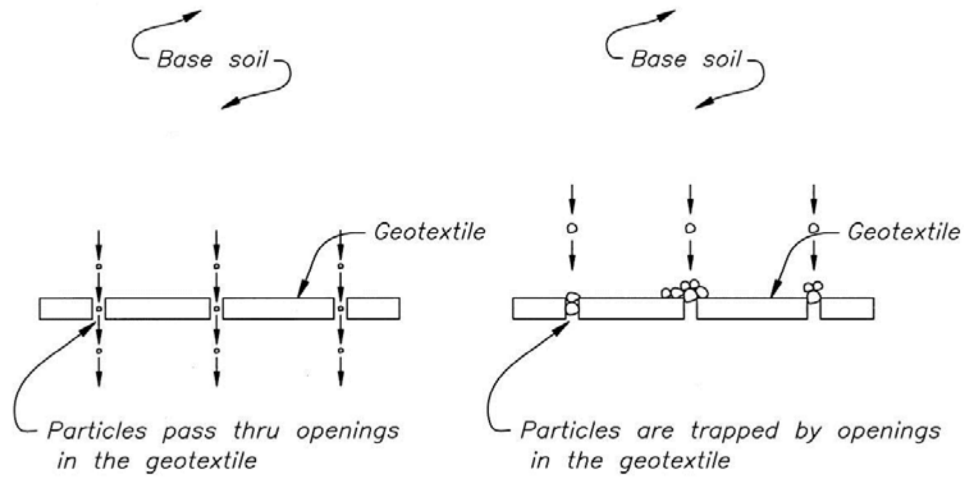
Table 19.4.1-1. Important criteria and properties – filtration and drainage applications

Criteria	Properties
Constructability	Thickness Weight Absorption (wet weight) Flexibility Tensile strength Puncture resistance Cutting resistance Seam strength Flammability Tear strength Ultraviolet stability
Durability	Chemical stability Biological stability Thermal stability
Hydraulic	Soil Retention Thickness Permeability Clogging resistance

Protective Filters (Reclamation, 2011) result in granular filters that are robust and have been proven with many years of successful operation. In a similar manner, the initial geotextile filter design criteria were based largely on average soil grain size considerations. There was a history of poor performance due to several causes, including (1) excessive clogging of the geotextile when attempting to filter internally unstable base soils due to buildup of a low permeability layer of fine-grained soil particles against and/or inside the geotextile; (2) growth of bacteria on the geotextile fibers in organic-rich environments leading to excessive clogging; (3) internal erosion of fines through the geotextile due to improper filter retention criteria, which failed to consider the seepage behavior of dispersive clay base soils; and (4) internal erosion of fines through the geotextile due to tears and punctures caused during installation and covering of the fabric.

Similar to the design of granular filters, geotextile filter design has evolved over several decades to incorporate lessons learned from experiences with poor performance, from laboratory research, and theoretical considerations (Christopher and Fischer, 1991; Giroud, 2010). Past problems with clogging largely result from a poor understanding of geotextile filtration behavior and inadequate design criteria.

In filtration, liquid flows across the plane of the geotextile while soil is retained. Similar to the design of a granular filter, the design of a geotextile filter requires balancing opposing criteria. The filter openings must be small enough to prevent loss of significant amounts of the base soil (meet particle retention criteria), and the openings must be large enough to effectively transmit seepage flows without clogging (meet permeability and clogging criteria) (figure 19.4.1-1).



INTERNAL EROSION – Geotextile openings are too large, allowing small particles to erode through the fabric.

EXCESSIVE CLOGGING – Geotextile openings are too small, preventing seepage flow through the geotextile.

Figure 19.4.1-1. Illustration of a geotextile filter showing the concepts of soil internal erosion and excessive clogging. In each case, a permeable "filter cake" fails to form; thus, the geotextile is not suitable as a filter.

The design of a geotextile filter involves the identification of a fabric that is able to facilitate the establishment of a soil "filter cake" or "bridging network" against the geotextile (Watson and John, 1999; Aydilek, 2006). A soil "filter cake" comprised of a mixture of grain sizes builds up between the base soil and the filter (figures 19.4.1-2 and 19.4.1-3). Once this filter cake is established, it is able to trap the smallest soil grains while allowing seepage flows to continue.

The filter cake is a transition zone formed by modification of the base soil being protected by the filter. Upon initiation of seepage flow, the particles in the base soil adjacent to the geotextile are mobilized. The smallest-sized particles are removed and pass through the geotextile, and the medium and larger-sized particles are retained on and within the geotextile. A granular soil filter cake or

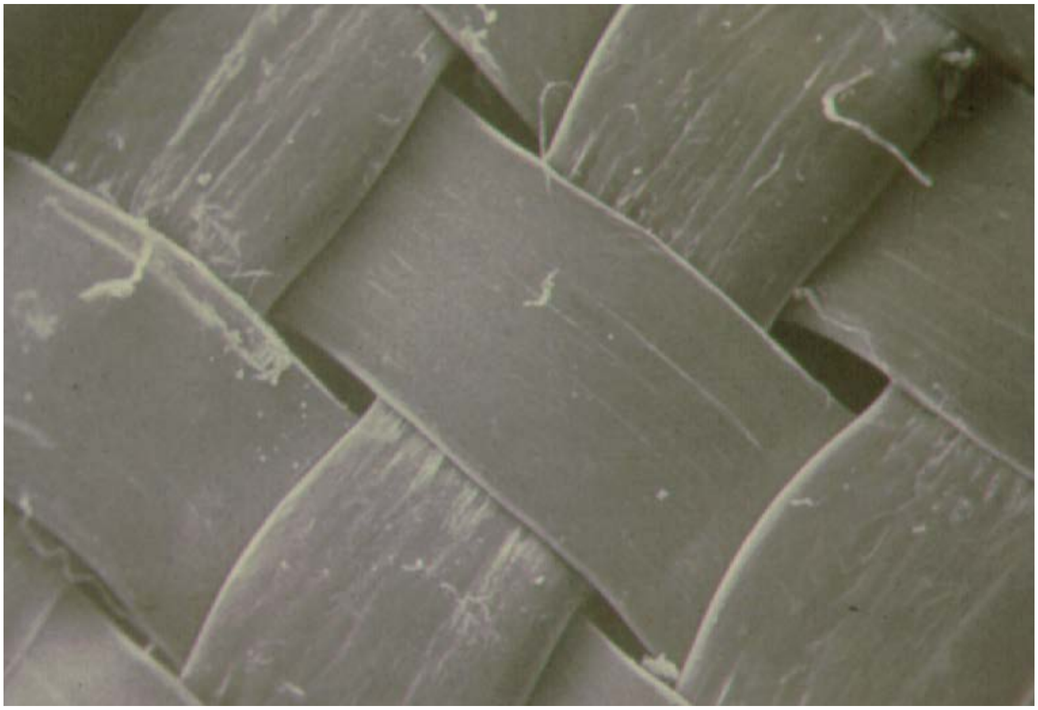


Figure 19.4.1-2. Photograph (magnified view) of a woven geotextile showing openings between the woven fibers. Photograph courtesy of Dr. George Koerner.

Figure 19.4.1-3. Photograph (magnified view) of soil filter cake built up on the geotextile and bridging across the openings between the fibers. Photograph courtesy of Dr. George Koerner.

soil filter zone is built up between the base soil and geotextile and it acts to retain the remaining layers of base soil while allowing seepage flow to pass. In this ideal condition, neither excessive internal erosion nor excessive clogging occurs. Since a variety of soil particle sizes are required for the filter cake to form, geotextiles may have difficulty in forming an effective filter for some soils. Highly dispersive clays, gap-graded, and narrowly graded cohesionless soils have a tendency toward excessive clogging rather than forming a filter cake. Such soils may be filtered by a geotextile, but the design requires careful selection, and laboratory testing may be necessary. A better choice under such conditions may be to use a granular sand filter rather than a geotextile.

In both granular filters and geotextile filters, there is a rearrangement of soil particles at the interface between the base soil and the filter. The smaller soil particles from the base soil are mobilized by the seepage flow. Initially, a certain amount of the smallest soil grains will pass through the filter while those that are too large to pass through the filter begin to deposit in and on the filter material.

There are differences in the behavior of a geotextile filter as compared to a granular filter. A granular filter is much thicker than a geotextile, so there are opportunities for a filter cake to form on or deep within a granular filter. A properly designed granular filter results in a filter cake becoming rapidly established at or near the base soil seepage face.

Unlike a granular filter, which conforms tightly to and places pressure against the irregular base soil seepage face, it is difficult to apply a geotextile filter firmly against an irregular base soil surface without gaps and wrinkles. Also, the geotextile is unable to apply a positive pressure to the surface against which it is placed. Since the geotextile is a flexible fabric, it must have a material placed on the downstream side of the fabric to hold it against the discharge face. If a coarse gravel aggregate drain is used against the downstream side of the geotextile, it will allow the fabric to bulge out away from the base soil discharge face (figure 19.4.1-4) once seepage flow commences. The flow mobilizes soil particles in the base soil, which move to fill the gaps between the base soil and the geotextile. Rather than establishment of a filter cake, the gaps fill with fine soil particles, creating a thick, low permeability zone, thus “blinding” (excessively clogging) the filter.

Excessive clogging of a filter in an embankment dam can lead to formation of an elevated phreatic surface that can potentially result in safety problems such as uplift, blowout, and slope instability.

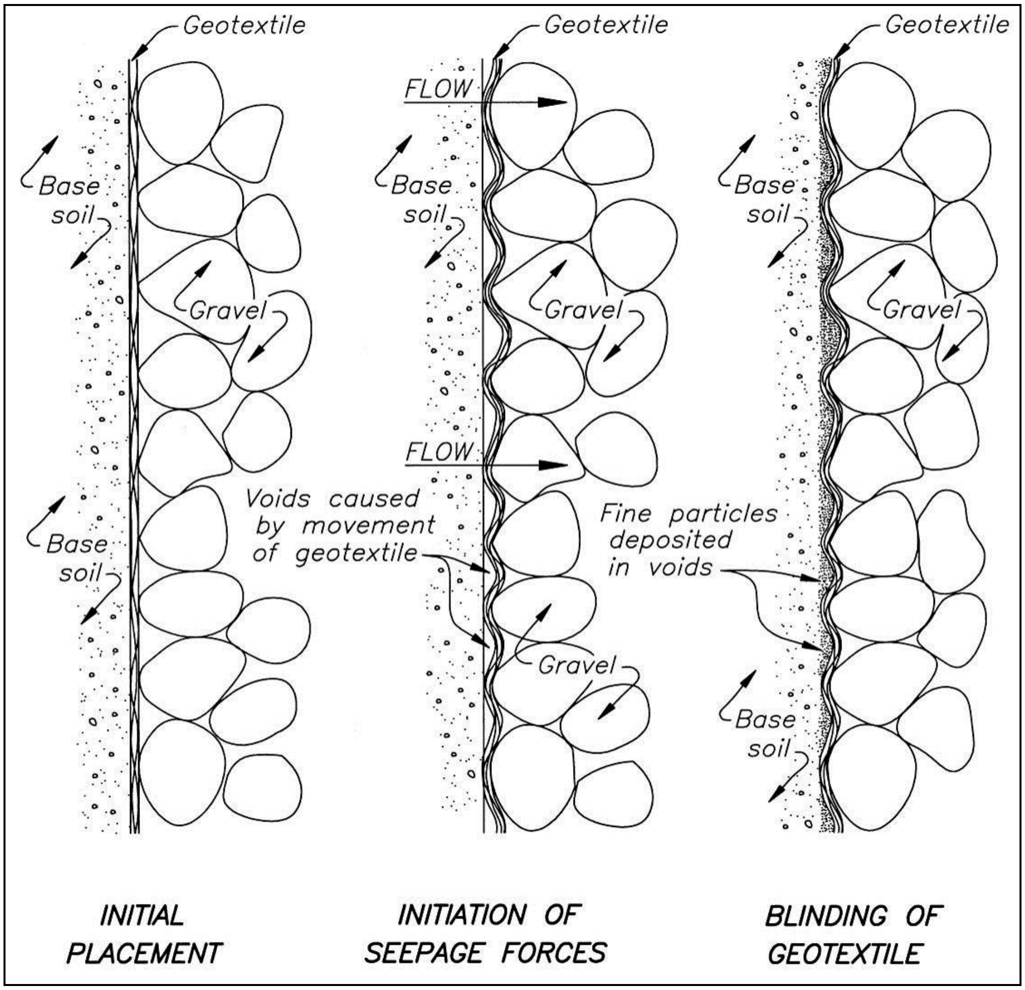


Figure 19.4.1-4. Illustration showing the progressive steps leading to blinding of a geotextile, which is a type of excessive clogging that deposits a layer of fine soil particles on the geotextile. It can be caused by using drainage aggregate that is too large in size.

Some base soils may not have enough variation in soil particle size for a sufficiently permeable filter cake to form on the geotextile. If all of the mobilized particles are of similar size, they can form a relatively low permeability layer. This problem with forming a permeable filter cake is less pronounced when using a granular sand filter because the fine particles from the base soil intrude into the sand, and the filter cake can form using a mixture of the various sand particle sizes acting in conjunction with the fine particles from the base soil. For this reason, for a dispersive soil containing 20 percent or more fines, current geotextile filter criteria recommend a layer of filter sand be placed between the base soil and the geotextile or that a granular sand filter be used instead of a geotextile.

For a geotextile to effectively perform as a filter, it must remain free draining by having opening characteristics compatible with the surrounding soil. The problem of blinding can also occur if there are open voids in the base soil or if the base soil surface is irregular and thus prevents good contact with the geotextile from being established and maintained. This problem becomes more evident for geotextile placements against vertical or steeply inclined slopes. Precautions are needed to eliminate the tendency toward blinding:

- Ensure the base soil surface is smooth and regular and place the geotextile in close contact with the base soil with a minimum of wrinkles.
- Use fine gravel, around 1-inch maximum size (or sand), rather than a coarse rock on the downstream side of the geotextile for the drainage layer.

By limiting the size of the gravel placed in contact with the geotextile, the geotextile will be held tightly against the base soil (Giroud, 1997). Regarding the maximum gravel size to use against the geotextile, published recommendations vary from 0.75 inch (Giroud, 1997) to 1.5 inches (Van Zyl and Robertson, 1980). It is best to use a well-graded gravel containing a mix of different size particles. For example, a well-graded gravel with a minimum size of 0.25 inch and a maximum size of 1 inch would be an appropriate choice for a drainage material placed against a geotextile filter.

Current geotextile filter design is a multistep process (Luettich et al., 1992) which involves:

- Definition of the filtration and drainage requirements – Each dam has unique geology, geometry, and hydrologic conditions.
- Definition of the soil boundary conditions – The properties of the upstream base soil to be filtered and the downstream material placed against the geotextile must be determined.
- Determination of the soil retention requirements – Use the flowcharts resulting from the research of Luettich et al. (1992).
- Determination of the geotextile permeability requirements – To not impede seepage flow, a geotextile filter must remain at least 10 times more permeable than the base soil after partial clogging due to formation of a filter cake. Specify a geotextile that is much more permeable (40 to 100 times more) than the base soil.
- Determine the anticlogging requirements – Select a high porosity geotextile and do not use a geotextile filter in environments known to lead to excessive clogging.
- Determine the strength and durability requirements – The geotextile must resist tearing and puncturing during and after installation.

- Select a geotextile filter – Select available products from manufacturer's published geotextile property data and check factors of safety by comparing the properties of the selected geotextile to the required properties of the filter.
- When warranted, verify performance by conducting laboratory tests with site soils and the proposed geotextile – Use the hydraulic conductivity ratio test ASTM D5567-94 to evaluate filter performance and shear box testing to evaluate interface shear strength for slope stability concerns.

19.4.1.1 Filtration and Drainage Requirements

The overall filter and drainage requirements of the geotextile application must be defined. Each site has unique geology, geometry, and hydrologic conditions. Preparation of plan view and cross-section drawings will facilitate compilation of the anticipated site geometry and geology conditions for the proposed geotextile installation. Geometry is important and may reveal issues with construction sequencing and slope stability concerns. The hydraulic conditions anticipated in the soil must also be determined, including the seepage pathways, anticipated gradients, flow quantities, and nature of the flow. If varying, or reversing flow conditions are anticipated, they should be carefully evaluated.

19.4.1.2 Soil Boundary Conditions

The nature of the soils to be placed in contact with the geotextile must be defined. For flow in one direction, more information is required about the base soil on the upstream side of the geotextile than the soil on the downstream side. If flow reversal is possible, the material on both sides of the geotextile must be evaluated for filtration. The gradation, plasticity index (PI), density, coefficient of uniformity, and hydraulic conductivity (usually estimated based on soil gradation) of the base soil to be filtered must be determined. Except for shallow burial, the confining pressures acting on the geotextile should be evaluated with respect to how it can alter the geotextile properties such as AOS and permeability. The base soil should be evaluated to verify that it is not a dispersive clay or a gap-graded or broadly graded (internally unstable) noncohesive soil. Such soils are prone to internal erosion, and only a small range of geotextile products may work as effective filters for these soils. Internally stable base soils and plastic clays are more easily filtered by geotextiles, and there may be a wider range of geotextiles that can filter these types of base soils.

The base soil can be naturally occurring deposits (in situ), such as a toe drain in contact with the foundation of a dam, or earthfill placed during construction. Base soil selection can be complicated by soil variability that becomes evident when reviewing gradation and index property test results from numerous samples. The discussions and procedures presented in Section 5.4.1, Base Soil Selection found in Design Standards No. 13 Chapter 5, Protective Filters (Reclamation, 2011) are to be followed in evaluating base soil variability and are considered a part of this design standard. For example, base soils that contain particles larger than the #4 sieve are regraded to represent only the particles smaller than the #4 sieve.

19.4.1.3 Retention Criterion

A geotextile in a uni-directional flow filter application does not actually filter the water from the soil, but acts as a catalyst in the formation of a stable soil filter zone (filter cake) derived from the base soil. The soil filter zone is, in effect, a granular filter derived solely from the in situ base soil particles. A properly designed filter will avoid internal erosion and clogging. The theory of geotextile soil retention is best explained in a paper written by Giroud (2010).

Important filter design parameters for soil retention are defined as follows:

C_c = Soil coefficient of curvature: $(D_{30})^2/(D_{60} \times D_{10})$.

C_u = Soil coefficient of uniformity: D_{60}/D_{10}.

C'_u = Soil linear coefficient of uniformity: $D'_{60}/D'_{10} = \sqrt{(D'_{100}/D'_{0})}$ where d'_{100} and d'_{0} are defined by the ends of a straight line drawn through the middle part of the gradation plot (the straight line approximates the base soil gradation curve).

D_x = Soil particle size, where x is the percent of soil particles smaller than the stated size.

D'_x = Soil particle size, where x percent is smaller and obtained from a straight-line approximation of the soil particle size distribution (linear particle size).

DHR = Double hydrometer ratio of the soil (ASTM D4221-11) Standard Test Methods for Dispersive Characteristics of Clay Soil by the Double Hydrometer.

I_d = Soil relative density: $(e_{max} - e) / (e_{max} - e_{min})$, where e is the soil void ratio.

PI = Soil plasticity index.

O_x = Geotextile opening size, where x percent of openings are smaller than the stated size (usually stated as the O_{95}, in which 95 percent of the openings are smaller than the designated size). Note that O_{95} is usually in mm, while the AOS reported in product literature is often the U.S. standard sieve size (check the units).

POA = The percent open area for a woven geotextile.

Terzaghi developed the well-known and accepted retention criterion for granular filters:

$$D_{15} \text{ filter } < 4 \text{ x } D_{85} \text{ base soil}$$

While this formula worked well for many base soils, it fails to provide filtration of the finer fraction of broadly graded soils with a high coefficient of uniformity (Giroud, 2010). Granular filter design evolved to take into account the variable behavior of different soils and considers other properties besides grain size (see Design Standard No. 13 Chapter 5, Protective Filters). In a similar manner, various early retention criteria for geotextiles failed to perform for all soils for similar reasons and are now considered obsolete.

Current geotextile filter particle retention criterion for soils considers not only the base soil grain size but also the coefficient of uniformity, fines content, plasticity index, and dispersive nature of the base soil. This design standard requires the use of the retention criteria developed by Luettich et al. (1992), which is reproduced in the widely available textbook, *Designing with Geosynthetics* (Koerner, 2012). These criteria are briefly summarized in table 19.4.1.3-1, but for design use, the actual flowcharts are found in the cited reference:

Table 19.4.1-3-1. Geotextile particle retention criteria for dense soil and steady seepage

Retention criterion by soil type	Reference	Comments
For soil with D_{20} < 0.002 mm: O_{95} < 0.21 mm For soil D_{20} > 0.002 mm, C'_u > 3: $O_{95} < 18\ d'_{50}/C'_u$ For soil D_{20} > 0.002 mm, C'_u <3: $O_{95} < 2C'_u\ D'_{50}$	(Luettich et al., 1992)	For steady flow conditions, the method utilizes a flowchart for determining geotextile opening size. Criteria are given in the chart for loose, medium, and dense (I_d > 65%) soils. Only the dense criteria, which would apply to a well-compacted embankment, are shown here. For dispersive clays, a fine sand layer (finer than C33 sand) is to be placed between the base soil and the geotextile, and the geotextile is designed to filter the fine sand.

Large factors of safety should not be applied to the calculated O_{95} value for retention because this may reduce the opening size of the specified geotextile to the point that it tends to clog. While a geotextile with an opening size equal to or smaller than the calculated value is needed to satisfy the retention requirement, the smaller the opening size, the less permeable and the more likely the geotextile may clog. The lower bounds of the allowable O_{95} will be determined by the permeability and nonclogging requirements. For important applications, filtration testing, such as the hydraulic conductivity ratio test (ASTM D5567), will confirm soil retention for a candidate geotextile filter.

A large variety of geotextiles, including nonwoven needle-punched, nonwoven heat-bonded, woven (usually monofilament), and knitted geotextiles have been successfully used for filtration in embankment dams. Each type of geotextile has its place in filtration applications. Although nonwoven geotextiles are most commonly employed as filters, they are not automatically the best choice for a given application. For example, woven geotextiles have been successfully used as filters under seashore slope revetment linings where flow reversal from severe wave action or rapid drawdown can lead to pore pressure buildup underneath the geotextile. Knitted geotextiles should only be used in shallow burial with an upstream sand filter. The key filtration properties of geotextiles with respect to their commercial availability are presented in table 19.4.1-3-2.

Table 19.4.1.3-2. Geotextile filtration properties

Geotextile type	Opening size (O_{95}) ASTM D4751 (mm)	Permittivity ASTM D4491 (sec^{-1})	Comments
Woven monofilament	Common range: 0.15 to 0.85 Can be as low as 0.05 (Ramsey and Narejo, 2005)	Common range: 0.05 to 1.5 Can range from 0.01 to 4.0 (Ramsey and Narejo, 2005)	Does not transmit flow in the plane of the geotextile. Stiff, direct soil contact is more difficult to achieve. Has lower interface friction strength than nonwovens. Heat-bonding (the fibers are fused together at the weave intersections) provides excellent dimensional stability (maintains AOS). POA is used for permeability design.
Woven slit film	0.35 to 0.6 (see comments)	0.05 to 0.6	Large variation in AOS; not recommended for filtration function. Has lower interface friction strength than nonwovens.
Nonwoven needle-punched	Common range: 0.15 to 0.5 Can be as low as 0.074 (Hwang et al. 1998)	Common range: 0.7 to 2.5 Can be as low as 0.5 (Ramsey and Narejo, 2005) and as high as 4.5 (Hwang et al., 1998)	Flexible and conforms well to soil surfaces and has higher interface friction than woven or heat-bonded geotextiles. Provides higher flow rates than heat-bonded geotextiles and also transmits flow in the plane of the fabric. Increasing depth of burial reduces permeability and AOS, which can cause clogging. Thicker fabrics have greater strength, but may clog.
Nonwoven heat-bonded	0.1 to 0.3	0.2 to 0.8	Thin and stiffer than needle-punched nonwovens, hydrophobic and may require a driving head for flow to occur. Heat-fused fibers have excellent dimensional stability to retain AOS. Wick drains use this geotextile to filter and dewater fine clay and silt.
Knitted	0.6		Principal application is a polyester "sock" wrapping a corrugated perforated drainage pipe. Tensile stress causes changes in AOS. Only for shallow burial in a sand filter.

19.4.1.4 Permeability Criteria

The seepage flows must pass from the base soil through the filter and into the drain without significant flow restriction. Excess pore pressure buildup in the base soil is to be avoided. This condition can be met if the downstream components receiving seepage flows (filter cake, geotextile, and drain) are progressively more permeable than the base soil. The term hydraulic conductivity is more commonly used to describe the hydraulic property of soils. In this document, the term permeability is applied to both geotextiles and the surrounding soils to simplify the discussion. Another term, permittivity, is often used to describe the perpendicular flow through a geotextile. Because nonwoven geotextiles are compressible, the permeability varies with thickness. Permittivity, which is the permeability divided by the geotextile thickness, is used to specify geotextile cross plane flow behavior.

Also, when designing a geotextile filter, the downstream drainage features must have adequate flow capacity to convey the seepage away from the filter. There should not be a constriction or low permeability zone downstream from the filter that could retard the flow. It is recommended that drainage features on the downstream side of the filter, such as gravel drains, toe drain pipes, geonet drains, etc., be sized to have more flow capacity than anticipated. This standard requires the design to provide at least two times the flow capacity that seepage estimates would indicate is required. However, it is preferable to provide 4 times or more flow capacity (10 to 20 times would not be unreasonable in many cases) than required in order to compensate for uncertainty in estimating seepage amounts and to allow for future changes in seepage behavior.

Terzaghi proposed the following permeability criterion for sizing the particle gradation of granular filters:

$$D_{15} \text{ filter} > 4 \times D_{15} \text{ base}$$

Subsequently, current design requirements require a more permeable granular filter (approximately 25 times more permeable than the base soil). In Design Standards No. 13 Chapter 5, Protective Filters (Reclamation, 2011) the updated permeability criteria for a granular filter is:

D_{15} filter > 5 x D_{15} base; but D_{15} filter not less than 0.1 mm,
and the granular filter must not contain more than
5 percent minus no. 200 sieve size fines

Geotextile filters also need to have a much higher hydraulic conductivity than the base soil. When the filter cake forms on the face of the geotextile, the permeability must not be so reduced that it restricts seepage flow out of the base soil. Because a geotextile filter is thinner than a granular filter, the theoretical permeability requirement is less demanding. It has been shown that if the geotextile filter after formation of the filter cake is at least 10 times more permeable than the base soil, then the seepage flow out of the base soil will not be significantly restricted (Giroud, 2010). The following formula is used to determine the permeability requirement for a geotextile:

$$k_g > FS\ k_s$$

where:

- k_g = The permeability of the geotextile across the plane of the fabric
- FS = A factor of safety for geotextile permeability
- k_s = Permeability (hydraulic conductivity) of the base soil

Formerly, several authors (Loudiere et al., 1983), (Christopher and Fischer, 1991) recommended that the FS value be between 10 and 100. The previous version of this design standard allowed a permeability FS as low as 10 for noncritical low-hazard structures and required a value much greater than 10 for critical, high-hazard structures. French practice for dams recommends a minimum value of 100 (Degoutte and Fry, 2002). Many geotextile design guides still recommend a minimum value of 10; however, 10 is actually too low for any installation, including noncritical structures. Formation of the filter cake will reduce permeability. Also, compression of nonwoven geotextiles by the weight of the overlying soil will further reduce the permeability of the system. Although woven geotextiles show little change in permeability under load, the permeability of nonwoven geotextiles can reduce by a factor of between 2 to 8 for burial under 150 feet of dense soil (Carroll, 1987). Considering that compression and filter cake formation will reduce the filter system permeability, the design value needs to be more than 10 if it is expected to be no less than 10 after the installation. This design standard requires the permeability FS have a minimum value of 40 and, for critical locations, a minimum value of 100. For designs that do not include laboratory testing of the geotextile and soil filter combination, or where clogging may occur, a factor of 100 or more is recommended even for shallow burial. For deep burial, the effects of compression need to be considered.

Most nonwoven geotextiles and some woven geotextiles have a high permeability. The permeability criterion is usually easily met by many geotextiles in most practical applications. It is possible for two geotextiles to have the same permeability yet have different cross plane flow rates for a given head. According to Darcy' law for laminar flow:

$$q = kiA$$

where:

- q = Flow rate
- k = Permeability
- i = Hydraulic gradient: change in head divided by the length of the flow path ($\Delta h/L$)
- A = Cross-sectional area

Since the gradient is proportional to the length of the flow path, a thicker geotextile allows less flow than a thin one of similar permeability. To overcome the issue of thickness, the concept of permittivity is used to allow direct comparison of flow capability between different fabrics. Geotextile product literature presents both the permittivity and the uncompressed thickness of a geotextile. The permeability of candidate geotextiles can be obtained from the permittivity and thickness information using the following formula:

$$k_g = \psi_g t_g$$

where:

k_g = Geotextile permeability normal to the plane of the fabric
ψ_g = Geotextile permittivity, provided by manufacturers or from testing (ASTM D 4491), defined at the volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile
t_g = Geotextile thickness

Table 19.4.1-5. Typical values for permittivity and permeability of geotextiles

Geotextile type	Permittivity (1/s)	Permeability (k_g) (cm/s)
Woven monofilament	1.5 – 0.05	10 – 0.001
Woven slit film	1 – 0.01	0.01 – 0.001
Nonwoven needle-punched	2.5 – 0.7	1 – 0.01
Nonwoven heat-bonded	0.8 – 0.2	0.1 – 0.005

The permeability of candidate geotextiles is evaluated and then checked against that of the minimum allowable value to determine the FS provided – this should be a high value (40 or more). In the method proposed by the Geosynthetic Institute (Koerner, 2005b, 2012) the minimum allowable permittivity is calculated, and then various reduction factors are applied to determine the allowable permittivity for the geotextile. Design involves first determining the soil permeability by laboratory testing such as ASTM D 5084. For less critical applications, the soil permeability can be estimated based upon soil gradation d_{10} size (see Luettich et al., [1992]). The minimum allowable geotextile permeability is then determined.

19.4.1.5 Nonclogging Criteria

Nonclogging criteria ensures that the geotextile filter has enough openings so that blocking of some of them will not inhibit long-term seepage flow. Prediction of clogging is difficult to quantify. Some clogging will occur when the geotextile is put into service. The geotextile must remain sufficiently open so that accumulation of particles and chemical and biological precipitates will not reduce the permeability to the point where the filter cake/geotextile system becomes less permeable than the base soil. The designer should seek to provide as permeable and porous of a geotextile as possible while maintaining retention criteria. This will allow for a substantial reduction in the installed geotextile filter permeability due to compression, partial clogging due to filter cake formation, and other factors, and yet maintain an overall installation that is much more permeable than the base soil. One of the other factors to consider is flow concentration. If the porosity of the geotextile (n_g) is less than that of the base soil, there will be flow concentrations for water seeking a limited number of entrance sites in the geotextile. Flow concentration at the filter boundary is undesirable because it tends to mobilize soil particles that can lead to excessive clogging. Flow concentration can be avoided by providing a geotextile with a large amount of porosity. The following criteria should be met:

- Use the largest opening size that satisfies the retention criterion.
- For nonwoven geotextiles, use one with the largest porosity available that meets other design requirements, but not less than 55 percent (ng > 55 percent or 0.55).
- For woven geotextiles, use the largest POA available, but not less than 10 percent.
- Do not use geotextile filters in environments where precipitates are likely to form. Avoid high alkalinity groundwater, which can form calcium, sodium, or magnesium precipitates. Also avoid acidic seepage, which can form iron and aluminum hydroxide precipitates.
- Avoid use of geotextiles with internally unstable (Cu > 20) or dispersive soils.
- Avoid organic-rich environments such as agricultural runoff, landfill leachates, and sites known to form iron bacteria.
- Do not wrap perforated pipes with geotextile; wrap the gravel envelope with the geotextile.
- Make sure that the geotextile filter makes intimate contact with the soil.
- Do not place geotextile filters against cohesive soils containing voids.

For nonwoven geotextiles, porosity is not normally given by product literature, but it can be calculated with the formula:

$$n_g = 1 – (u_g / \rho_g \times t_g)$$

where:

- n_g = The geotextile porosity (dimensionless) expressed as a decimal percent (55 percent = 0.5)
- u_g = The geotextile mass per unit area
- ρ_g = The polymer density
- t_g = The thickness of the geotextile

Nonwoven geotextiles are specified for most filter applications. The previous version of this design standard required a minimum porosity of 30 percent. This is similar to the porosity of natural soils and granular filters which are in the 20–30 percent range. Giroud (2010) states that the porosity of a nonwoven geotextile filter should be 55 percent or higher. Fortunately, the typical porosity values for most nonwoven needle-punched geotextile products are in the range of 60 to 95 percent.

For woven geotextile filters, the former version of this design standard required a minimum POA of 4 percent, which is now considered to be obsolete. The 4 percent came from historic practice before the advent of nonwoven geotextiles when there was a limited variety of woven geotextile products available (Giroud, 2003). Giroud provides theoretical reasoning for a higher POA in order to avoid flow concentration at the filter interface. There is currently no good agreement on the minimum value of POA in practice, and many authors rely on the old 4-percent criterion. Although Giroud (2003) argued for a POA of 30 percent, his latest analysis (Giroud, 2010) is for a POA of 10 percent. Given a past history of problems of excessive clogging of woven geotextile filters, a value higher than 4 percent is indicated by experience. Some geotextile manufacturers are now producing woven geotextile products with POA values in the range of 6 to 8 percent in recognition that the old 4-percent value was too low. Some products with values as high as 30 to 50 percent also exist**. This standard requires woven geotextile filters to have a minimum POA of 6 percent.** When possible, meeting the 10-percent POA suggested by Giroud should be considered.

In addition to the above criteria, problems have developed in applications involving dispersive clays, broadly graded soils with Cu > 20, and in gap-graded sandy soils where the base soil contains less than 20 percent silty fines and the fines are 10 times smaller than the fine sand in the soil. Even with current filter criteria, such soils tend to form a relatively low permeability layer against the geotextile rather than a pervious filter cake (Fluet and Luettich, 1993). Such soils require careful consideration regarding their filtration behavior. A sand filter is likely a better choice than a geotextile. If a sand filter is used, care is needed to select a proper gradation for the filter.

In the case of dispersive clays, current retention criterion requires the use of a layer of sand between the dispersive soil and the geotextile filter. Typical C-33 concrete sand may not be an adequate filter in this instance. It is likely that a C-33 sand gradation will need to be modified by the addition of small sand particles (around 60 to 100 sieve size) to make an effective filter for retention of the small dispersive clay particles. Cohesive clay soils do not have this problem because seepage forces tend to break off the soil in clumps of particles with filtration behavior being similar to that of a soil composed of larger-sized particles. The design procedures found in Design Standards No. 13 Chapter 5, Protective Filters (Reclamation, 2011) should be followed for determining the gradation of a sand filter to be used with a geotextile for a dispersive clay soil.

Where nonclogging is essential, laboratory performance testing is recommended. Tests include hydraulic conductivity ratio, gradient ratio, and biological clogging tests. The gradient ratio test (ASTM D5101) developed by the U.S. Army Corps of Engineers has some problems, including internal erosion of soil along the walls of the test cylinder, and it may take months to complete. It has been supplanted by the hydraulic conductivity ratio test (ASTM D5567), which uses a flexible wall permeameter and is relatively rapid (Koerner, 2012).

A nonwoven geotextile is made up of a random arrangement of geotextile fibers. The overlapping fibers form void spaces of varying sizes. While conventional filter design looks only at a characteristic opening size such as O_{95}, a soil particle passing through a nonwoven geotextile will encounter voids of various sizes. Larger voids may allow particles to pass through that are meant to be retained, and smaller voids are constrictions that may trap and retain the soil particles. Just as a geotextile has a range of opening sizes, it also has a range of pathways with differing minimum constrictions (Giroud, 1997). As a geotextile of the same material is made thicker for increased strength, the variation in these minimum constriction sizes will be less. All flow pathways will tend to have similar-sized small constrictions. If a nonwoven geotextile is too thin, it will have a highly variable range of opening sizes, which may not be reliable for soil retention. As it becomes thicker, a more uniform product is provided. By providing a geotextile with a minimum of 25 constrictions, the risk of internal erosion through the geotextile is minimized. It is also possible for the geotextile filter to be too thick. A thicker layer reduces the variability of opening sizes through the geotextile and can lead to clogging. Limiting the maximum number of constrictions to approximately 40 helps to avoid clogging in a thick geotextile. A method to calculate the number of constrictions has been devised (Giroud, 2010):

$$N_{constrictions} = u_g /(\rho_g \times d_f \ \times \sqrt{1-n_g})$$

where:

$N_{constrictions}$ = Number of constrictions (minimum 25 to maximum 40) for a nonwoven geotextile filter

u_g = The geotextile mass per unit area
ρ_g = The polymer density
d_f = Nonwoven geotextile fiber diameter
n_g = The geotextile porosity (dimensionless) expressed as a decimal percent (55 percent = 0.55) as determined from a previously presented formula: $n_g = 1 - (u_g / \rho_g \times t_g)$

The above calculation regarding constrictions has not yet been adopted in design practice. It is offered here as an additional factor to consider.

19.4.1.6 Durability and Strength Requirements

The geotextile must have sufficient durability and strength to survive the installation process and the post installation stresses without significant damage. Durability relates to the environmental conditions the geotextile will be exposed to. It must resist degradation from ultraviolet (UV) light, oxidation, and chemical exposure. Once buried, geotextile exposure to UV light and oxidation are of minor concern. Also, the geotextile must be strong enough to resist stretching, tearing, abrasion, and puncture during transport, storage, installation, and covering.

Previous concerns regarding the resistance of geotextiles to degradation have largely been addressed (Koerner, 2012), and a design life of 100 years or more can be expected for most applications involving burial of the geotextile. Except for extremely high or low pH environments, or applications involving other strong chemicals, geotextiles will remain inert to chemical attack. The principal concerns are resistance to UV light (sunlight) exposure and resistance to oxidation. Geotextiles should be covered within 2 weeks of installation to minimize the strength reduction that results from exposure to sunlight. However, deviations from this cover requirement can be made if it can be demonstrated that the geotextile will not be compromised by longer exposure. This requires site-specific testing accomplished by placing test sections exposed to sunlight for the proposed extended time period followed by laboratory strength testing of exposed samples to evaluate the resulting degradation. Designers should consider the constructability of the proposed installation with regard to providing cover within the required time period. Temporary covers to block UV exposure or a thin soil cover may be feasible.

Oxidation is a much slower process in reducing geotextile strength than UV exposure. Covering the geotextile with soil also slows the oxidation process. Immersion below the water table slows oxidation by a factor of 10,000 or more because of the lower oxygen content of water as compared to air.

Providing a geotextile with the proper strength to survive the construction process is a major concern. A study of 100 geotextile installations (Koerner and Koerner, 1990) showed that geotextiles less than 8 oz/yd^2 are likely to be damaged during the construction process. Fabrics lighter than 8 oz/yd^2 should not be specified unless special precautions against installation damage, such as sand cushioning layers and use of low-ground pressure equipment, are included in the design and construction specifications.

There are two approaches used to select a geotextile to meet strength requirements: selection based on past experience and selection based upon calculation of expected stresses. Historically, strength requirements were developed for road and highway applications and are based upon experience with constructed projects and by constructing test sections that were later exhumed and evaluated. Geotextile strength requirements have been published for geotextiles based on the severity of the application after AASHTO (1996). Current geotextile design in the United States continues to rely on the values derived from road construction. For drainage applications, the following strength requirements can be used as a guide:

Table 19.4.1.5.1. Suggested geotextile strength requirements (AASHTO 1996)

Application	Contact stress	Grab strength (pounds) ASTM D4632	Elonga-tion (%)	Sewn seam strength (pounds)	Puncture strength (pounds) ASTM D4833	Burst strength (pounds)	Trapezoid tear (pounds) ASTM D4533
Subsurface drainage	High stress – angular drainage media, heavy compaction, high confining stress	180	–	160	80	290	50
Subsurface drainage	Low stress – rounded drainage media, light compaction, low confining stress	80	–	70	25	130	25
Armored erosion control	Direct stone placement	200	15	180	80	320	50
Armored erosion control	Sand cushion, low drop height	90	15	80	40	140	30

For deep burial and harsh conditions, the designer should evaluate the stresses expected and may need to consider a stronger geotextile than the requirements shown in the table. Procedures for calculation of geotextile strength requirements based upon stress have been developed only for limited cases like puncture strength (see section 19.4.3 of this standard). In cases of thin cover layers, and operation of heavy equipment, dynamic loads from construction activities may also need to be considered and will likely require a stronger fabric than that indicated in the table for shallow burial conditions.

19.4.2 Geotextile Drainage Design

Drainage implies that water will be transported in the plane of the geotextile or geocomposite material. In contrast, filtration considers flow perpendicular to the plane of the geotextile. The geotextile must function properly as a filter if it is also intended to function as a drain. In such instances, the geotextile drain must meet all of the filtration requirements discussed in section 19.4.1 (particle retention, permeability, nonclogging, durability and strength criteria), and it also must have adequate in-plane flow capacity to convey the drainage as desired. Flow capacity is evaluated using the transmissivity of the geotextile. There are three principal types of geotextile products used for in-plane drainage applications: (1) thick nonwoven needle-punched geotextiles, (2) multilayered nonwoven needle-punched geotextiles (a nonwoven geotextile with high transmissivity is sandwiched between nonwoven geotextiles having lower transmissivity but better particle retention characteristics), and (3) geocomposite drains that consist of a geonet or other structural synthetic material bonded to one or two layers of geotextile or prefabricated vertical drains where a drainage core is inserted into a heat-bonded geotextile wrapping. Woven and heat-bonded nonwoven geotextiles by themselves are thin and can only transmit minimal amounts of flow in the plane of the fabric; therefore, they are not normally considered for this type of application.

Geotextile and geocomposite drains are commonly used in shallow burial applications such as drainage for roadway base courses and as building foundation drains. The drainage function plays an important role in the design of landfill leachate collection systems and landfill caps. This industry has experienced numerous failures related to flow reduction due to compression, creep, and excessive clogging by mineral precipitates and biological organisms. There have also been problems with slope instability in which reductions in drainage capacity have led to pore pressure buildup above the drainage synthetic. Considerable research and forensic investigation has led to a better understanding of drainage behavior of geotextiles and geocomposites under actual service conditions in landfills. Factors of safety regarding flow capacity in the range of 10 to 20 are now applied to landfill caps and leachate collection systems to ensure proper long-term drainage performance.

19.4.2.1 Geotextile Transmissivity

Characteristics of geotextile in-plane drainage are measured in terms of transmissivity, which is defined as:

$$\Theta = k_p t$$

where:

Θ = Geotextile transmissivity in units of square meters per minute (m^2/min) or square feet per minute (ft^2/min)
k_p = Geotextile permeability in the plane of the fabric
t = Geotextile thickness at a specified normal pressure

In-plane flow can be determined using the relationship:

$$q = k_p iA = k_p i(Wt)$$

where:

q	=	Flow rate in the plane of the geotextile
k_p	=	Hydraulic conductivity along the plane of the geotextile
i	=	Hydraulic gradient
A	=	Cross-sectional area
W	=	Width of the geotextile
t	=	Thickness of the geotextile

Since the transmissivity is proportional to thickness, the transmissivity of a geotextile and of a geocomposite is reduced by compressive forces resulting from burial. For a nonwoven geotextile the transmissivity is greatly reduced up to normal stress on the order of 500 pounds per square foot (lb/ft^2) (24 kPa). For normal stresses greater than 500 lb/ft^2 (about 4.5 feet of soil cover), most fabrics reach a constant but small value of transmissivity. The fiber structure is sufficiently tight and dense enough to support increasing loads while still transmitting some water (in the range of 1×10^{-6} to 5×10^{-4} m^2/min) depending upon geotextile thickness. Geocomposites, on the other hand, exhibit high transmissivity (greater than 1 gallon per min-ft (2×10^4 m^2/s), approximately equal to 6 inches of free-flowing sand at a gradient of 1.0) and ordinarily function as designed at stresses well over 1,000 lb/ft^2 (48 kPa). The manufacturing of geocomposites is quite varied such that no generalization can be made of their performance. Geonets, in combination with geomembranes and or geotextiles, are one of the most effective and relatively cost-efficient materials to convey water under a wide range of normal stress conditions (Koerner, 1986).

Transmissivity is evaluated by testing at a given normal compressive stress using various gradients (ASTM D-4716). This test includes index tests, in which the geotextile is tested between two stainless steel plates, and design tests in which the test is run with site soils and expected normal loads. The test requires a seating time of 100 hours, which contributes to significant cost and time to run. The hydraulic gradient should be selected based on expected field conditions. There are differences in the results obtained from index tests and design tests. The rigid steel plates used in the index test typically do not cause the same degree of compression that a soil boundary will cause. As a result, the index transmissivity values will be different from a design test formulated to simulate actual site conditions. The differences are most significant for a geocomposite where intrusion of the geotextile and soil into the void space of the geocomposite causes a larger reduction in transmissivity than the steel plates cause in the index test. Where the adjacent soils are soft (as in a landfill), the intrusion and resulting reduction in transmissivity can be substantially less than the index test would indicate. Also, flow calculations use Darcy's law ($q = kiA$), which assumes laminar flow conditions. With high gradients, turbulent flow conditions result, and transmissivity is reduced. A minimum FS of 5 to 10 is recommended for transmissivity (Koerner, 2012).

Due to the low flow rates possible using a geotextile, a geocomposite geonet drain is more often specified than a geotextile for drainage applications. Design procedures for geonet drains can be found in Koerner (2012).

19.4.3 Geotextile Design for Separation Applications

In water-retaining embankment dams, geotextiles are used to prevent penetration of a finer-grained soil into a coarser soil. The coarser soil does not meet filter requirements for the fine-grained soil, and movement of fine-grained soil into the voids of the coarse-grained soil could be initiated unless the geotextile was present. Geotextiles must perform as a separator for other functions such as filtration and drainage to be effective.

Table 19.4.1-1 lists some applications of geotextiles used for separation of materials. If granular material having the appropriate gradation to prevent contamination from an adjacent zone is not available, it may be possible to use a geotextile to keep the adjacent zones separated. A geotextile can be used at the boundary of a sand drain to keep the sand free from contamination and maintain its ability to drain. During construction, geotextiles can be used for many temporary or permanent installations. They can be used during fill placement to help avoid cross contamination of zones, for the installation of instruments or other structures, for the construction of roads or the improvement of foundation conditions for heavy structures or equipment, and many more applications. It is important to consider that maintenance of a geotextile within an embankment dam is likely to be very difficult or impossible, and that the geotextile will have a finite service life.

19.4.3.1 Design Criteria

The retention properties are generally the same as those required for filtration and drainage. Therefore, for geotextiles used as separators even when drainage is not of primary consideration, retention criteria should be specified. Also, the permeability criteria should be followed, and the geotextile should have a permeability that is at least equal to or more permeable than the permeability of the finer-grained soil. When separation involves placing material on slopes, the geotextile introduces a potential plane of weakness, which must be evaluated for slope stability. The interface friction strength of the geotextile becomes a key parameter that is needed for the stability analysis.

A common geotextile separation application is the placement of a fabric between a fine-grained soil and an aggregate layer to establish a roadway. Procedures for determination of required burst resistance, tensile strength, puncture resistance, and impact resistance have been formulated (Koerner, 2012). The calculations utilize truck tire inflation pressure as well as information about aggregate size. For impact resistance, the calculations determine the energy imparted by dropping rock onto the geotextile. Reclamation does not have experience using these calculation procedures in design; however, they may have merit in addition to the existing procedure of selecting a geotextile based on past experience (AASHTO, 1996). Two geotextile separation applications are frequently used by Reclamation in dam rehabilitation projects: (1) as a substitute for granular bedding placed underneath riprap used for erosion protection on the upstream face of a dam and (2) in the downstream side of an embankment dam as a substitute for a granular filter placed between a gravel drain and the earthfill for the downstream embankment shell.

19.4.3.2 Geotextile as Separation Between Embankment and Riprap

The conventional method of protecting a dam embankment slope from erosion due to wave action is to place a granular bedding and cover it with appropriately sized riprap. This type of design is covered by Design Standards No. 13, Embankment Dams, Chapter 7, Riprap Slope Protection. Where the riprap is large in diameter, it is often necessary to use two bedding layers (one of cobble size and one of gravel size material) to achieve filter compatibility between the embankment soil and the riprap. The substitution of a geotextile for one or both of the granular bedding layers can seem to be a more economical alternative to one or two layers of granular bedding. Such a substitution should be made with great care. A geotextile can be substituted for granular bedding; however, it will have a finite service life due to oxidation of the polymer. The fabric will eventually require replacement, which is more likely to be in the 50- to 100-year range due to the shallow burial of the fabric. For a long dam, with a large area to cover, a geotextile may not be a good choice due to the substantial future earthmoving effort that would be required to remove and replace the geotextile and riprap. Reclamation has typically selected a geotextile in lieu of granular bedding for small dams where the area of coverage is not great and where availability of aggregate for bedding is limited and costly. When a geotextile is proposed as the underlayment for riprap or other revetment material, the designer should document why granular bedding, or the use of soil cement slope protection are less favorable options to protect against wave action. Soil cement is discussed in Design Standards No. 13 Embankment Dams Chapter 17: Soil-Cement Slope Protection.

It is essential to reduce the drop height to a few inches and avoid rolling or sliding when placing large riprap onto a geotextile. Alternatively, providing a sand or gravel cushion over the geotextile may be necessary to avoid punctures due to impact. Reclamation specifications typically limit drop height of riprap onto a geotextile to 1 foot to avoid puncture from impact and requires use of an excavator bucket with a “thumb” attachment so the placement of individual rocks can be controlled. Reclamation uses a field demonstration of the placement method to address the potential for impact-related damage. A trial section of geotextile and riprap cover is installed, then the riprap is carefully removed, and the geotextile is examined for damage. If damage is found, either the placement method is modified to further reduce the drop height (down to an inch or less), or a sand and gravel cushion is added to the project requirements. Impact resistance calculations (Koerner, 2012, pp. 186–189) may be useful in the design of geotextiles where no granular bedding is used between the geotextile and riprap. This calculation procedure is new and has not been used on Reclamation projects.

To ensure slope stability for riprap placed onto a geotextile, attention to drainage, interface friction strength, and placement geometry is required. A geotextile and riprap were applied to halt erosion of the upstream slope of an existing small dam in Arizona. The upstream embankment had eroded to a variable slope ranging from 2H:1V near the abutments to about a 1.5H:1V slope near the maximum section of the dam. Working from the dam crest, the operator installed a nonwoven geotextile and then placed riprap from several feet below the reservoir surface up to the dam crest (figure 19.4.3.2-1). As the riprap placement progressed from the right abutment toward the maximum section, and the slope became progressively steeper, the riprap experienced a sliding failure on the steeper slope (approximately 1.7H:1V slope) and tore the fabric.

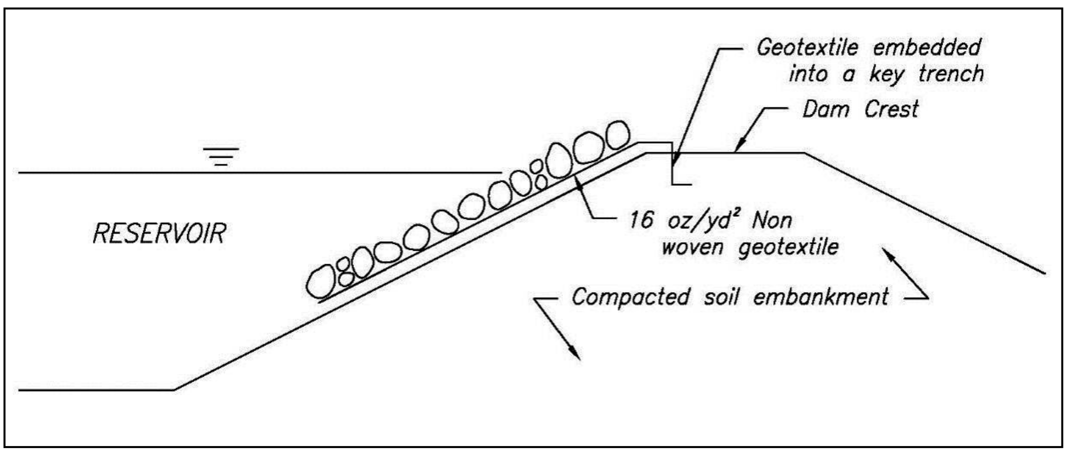


Figure 19.4.3.2-1. Illustration of riprap on geotextile bedding at a small dam in Arizona. This installation experienced a slope failure. The riprap slid along the interface between the riprap and the underlying geotextile.

Reclamation was asked to evaluate the situation. It was determined that a bench, or key, was not provided at the bottom of the slope, and the riprap was hanging on the geotextile with no support from underneath. The slide occurred because the available interface friction strength between the geotextile and the riprap was exceeded. The basic forces at work are shown in figure 19.4.3.2-2.

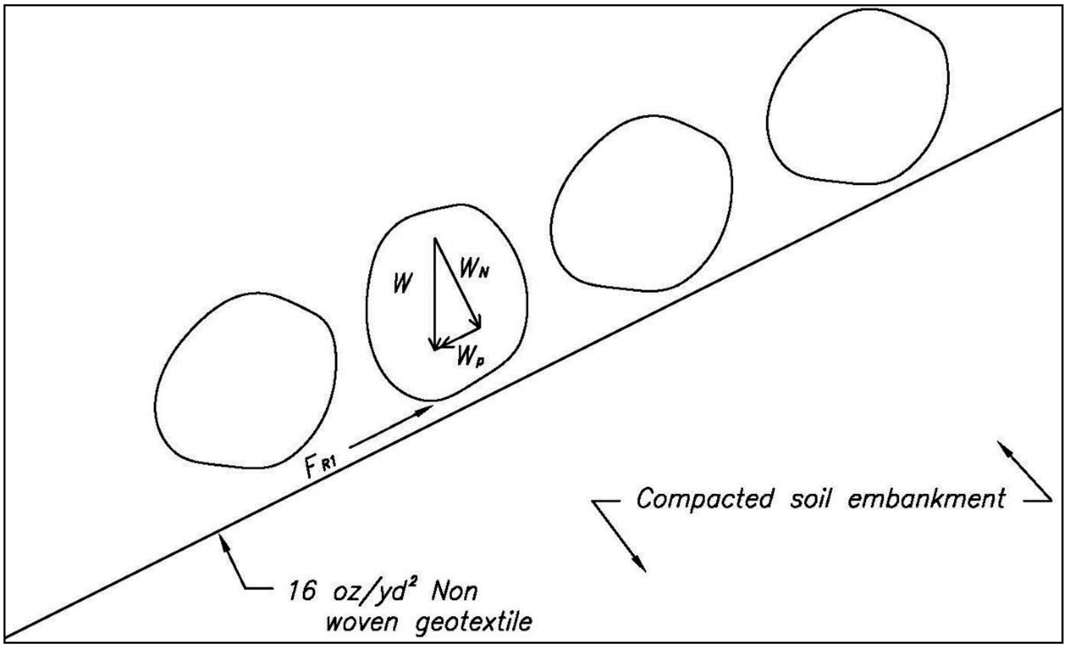


Figure 19.4.3.2-2. Illustration of static forces involved with riprap placed onto a geotextile. The driving force is the component vector of the weight of the riprap (W) acting parallel to the slope (W_P). The resisting force (F_{R1}) is the interface friction generated between the riprap and the geotextile surface. This frictional force is equal to the component vector of the weight of the riprap (Wn) acting normal (perpendicular) to the slope times the tangent of the interface friction angle between the riprap and geotextile ($F_{r1} = W_N \tan \Phi_{interface}$). If Wp is greater than Fr1, the riprap is unstable and will slide.

It was concluded that the placement on the portion of the slope that was at a 2H:1V slope was only marginally stable and might also slide in the future due to the added forces of wave action acting on the riprap. Wave action could have the added effects of placing a drag force on the riprap as the wave recedes, and it could result in elevated pore pressures acting to lift the geotextile and riprap if the phreatic surface in the soil embankment is temporarily elevated by the waves. The recommended remedy was to remove all of the riprap and geotextile, restore the entire upstream slope to 2H:1V, and to either key in the placement by cutting a bench into the embankment slope (figure 19.4.3.2-3.) or to place riprap starting at the toe of the slope so there is physical support by stacking the riprap in addition to the support gained from the friction at the geotextile interface. Note that the bench can either be inclined, as shown in the illustration, or it can be horizontal.

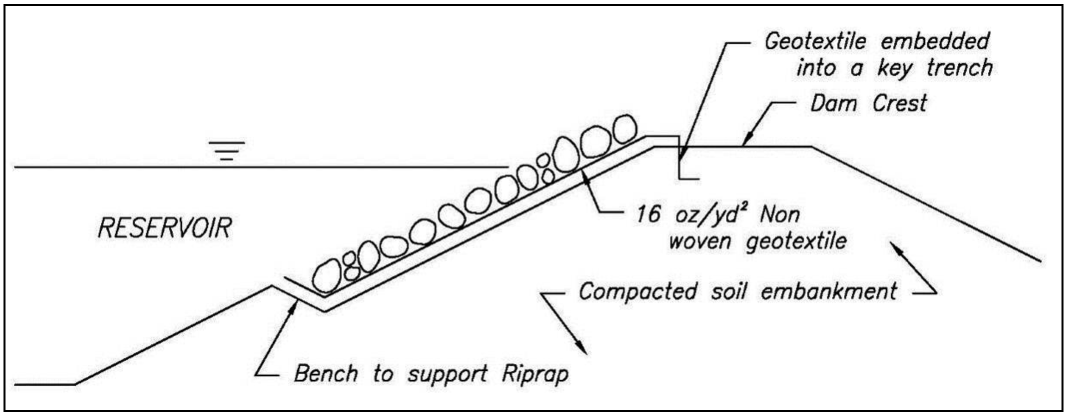


Figure 19.4.3.2-3. Illustration showing the use of a bench to support the placement of riprap on a geotextile bedding to improve slope stability performance. In addition to the frictional resistance along the riprap/geotextile interface, the bench adds physical support, which is transmitted up the slope from one piece of riprap to the next one above it to resist sliding.

The previous discussion is simplified. There is also the interface friction between the geotextile and underlying soil to consider, the effects of buoyancy for the submerged portions of the placement, and possible pore pressure (uplift) effects to consider for rapid drawdown and wave action. Also, if geotextile panel seams are made by overlapping rather than sewing, the reduced interface strength of one geotextile resting on another should be considered.

A slope stability analysis should be prepared to evaluate the design. When using a geotextile on a slope, all of the interfaces should be evaluated. Figure 19.4.3.2-4 shows a case of riprap placed upon a granular bedding, which in turn is placed on a geotextile that is placed on a fine-grained compacted embankment soil. In this case, there are three interface surfaces to evaluate for sliding: (1) riprap on granular bedding, (2) granular bedding on geotextile, and (3) geotextile on fine-grained compacted embankment soil. Note that evaluation of the second interface requires the weight of the granular bedding be added to the weight of the riprap to determine the total driving and resisting forces acting at the interface. Again, this is a simplification of the forces. With consideration of reservoir level and wave action, there are buoyant forces due to part of the slope being submerged. There are also drag forces and uplift forces to consider for waves acting against the slope. This is likely to be the worst case, but a similar evaluation should also be made to consider the effects of rapid drawdown conditions. If a support bench is used, there are both circular failure and sliding failure geometries associated with the bench to be considered in the evaluation. Although an anchor trench provides extra stability to a geotextile, it should be regarded as a temporary tool to facilitate construction, not a part of a long-term static stability analysis.

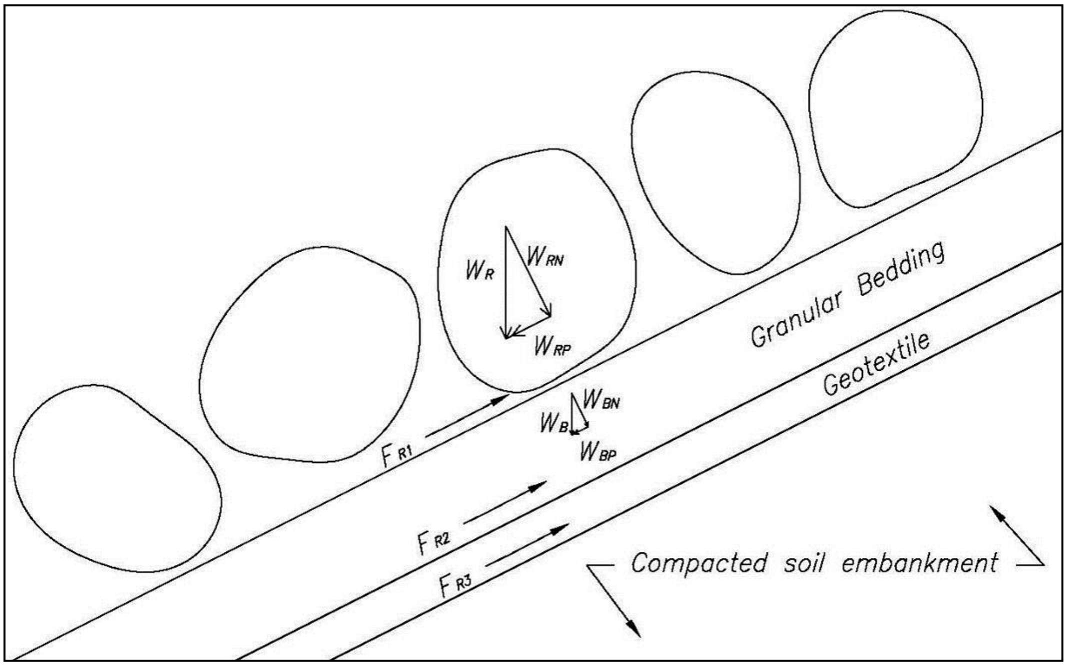


Figure 19.4.3.2-4. Illustration of static forces showing three frictional interfaces to be evaluated: F_{R1} riprap on a granular bedding, F_{R2} granular bedding on geotextile, and F_{R3} geotextile on compacted soil embankment.

Published values for interface friction (Koerner and Narejo, 2005) can be used for preliminary design. Shear box testing (ASTM D5321) to determine interface friction between the geotextile and the proposed adjacent site soils is strongly recommended. It is not possible to test large riprap in a shear box, but one could use a coarse gravel (without fines) and test it in a shear box or build a large table that can be tilted and used to test at what angle small riprap will slide along the geotextile interface. Nonwoven needle-punched geotextiles are preferred due to their higher interface friction strengths as compared to other geotextiles such as heat-bonded nonwovens or woven geotextiles that typically have lower interface friction strengths.

Koerner (2012, p. 274) depicts a slope failure where flat rectangular paving blocks were placed over a geotextile with only narrow gaps between the blocks and very little open area through which the geotextile could drain. The failure occurred when large waves caused a temporary rise in the phreatic surface in the fine-grained soil under the geotextile. The elevated water could not drain rapidly through the geotextile during the low cycle of the waves. The resulting elevated pore pressures caused uplift and sliding of the revetment blocks. Such revetments must be rapidly draining and not subject to excessive clogging if stability is to be maintained. A comprehensive design includes evaluation of filtration, permeability, drainage, and strength requirements, including slope stability considerations. The installation must maintain adequate permeability and drainage characteristics to assure long-term slope stability (Abromeit, 2002).

19.4.3.3 Geotextile Separation Between Gravel Drain and Downstream Embankment Shell

Soil retention, puncture resistance, and slope stability are the primary design considerations for this type of application (figure 19.4.3.3-1). Depending upon the site, the need for the geotextile to act as a fully functional filter may be less critical in this application. Water from precipitation will enter the permeable backfill. If the geotextile were to clog, it is possible that pore pressure could build up. The potential for a sliding failure along the geotextile interface should be evaluated with a stability analysis.

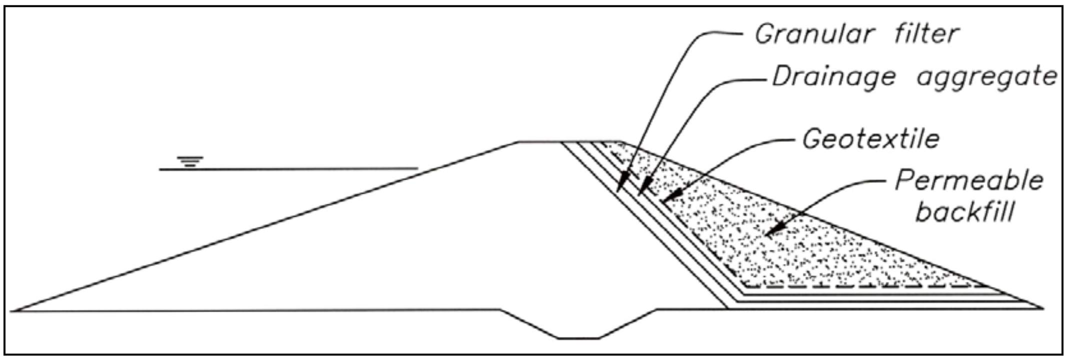


Figure 19.4.3.3-1. Illustration showing a geotextile being used to separate a downstream aggregate drain from the overlying backfill (shell material).

19.4.3.4 Design for Separation – Protective Layer

Using a thick nonwoven geotextile as a protective cushion placed against a waterproofing geomembrane installed on or in the upstream slope of an embankment dam is an accepted engineering practice. This type of application requires slope stability considerations along with determination about the adequacy of the cushioning. Typically, a pea gravel-sized layer would be of no concern with a thick (16 oz/yd^2) geotextile. If the stone layer has larger size material, Reclamation typically has used the field demonstration of a test section to verify that the cushioning is adequate.

19.4.3.5 Design for Separation – Toe Drains

Geotextiles can be used to prevent drainage material from entering perforated drainage pipes. Conventional construction of a toe drain typically consists of a sand filter surrounding a gravel aggregate drain that contains a perforated drainpipe as shown on figure 19.4.3.5-1. Alternate configurations using a geotextile are possible. A reduction in the cost of the installation can be realized by substituting a geotextile for one or more of the granular materials.

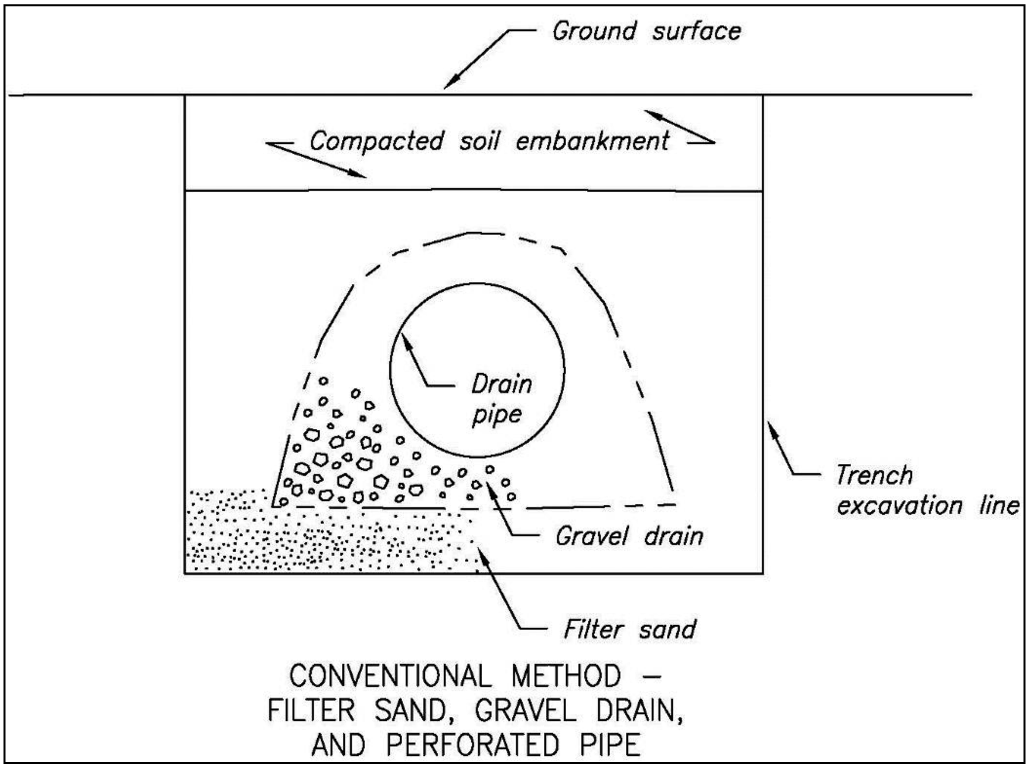


Figure 19.4.3.5-1. Conventional toe drain construction without a geotextile is formed by placing a sand filter around a gravel aggregate drain containing a perforated drainpipe.

Although a geotextile can be placed directly around a drainage pipe, it is rarely recommended due to the numerous instances of such installations failing due to excessive clogging of the geotextile. Geotextile "socks" wrapped around perforated drainage pipes are normally supplied as knitted polyester with an opening size of 0.6 mm (#30 sieve). Heat-bonded nonwoven geotextiles can also be obtained as pipe wrappings; however, some lead time may be required for ordering. Although perforated pipe can also be wrapped in the field by a construction crew by cutting appropriate widths of a nonwoven geotextile and placing it around perforated pipe, this method is not preferred because it is prone to excessive clogging.

Placing a geotextile-wrapped pipe into a soil-filled trench is not recommended unless the soil is a free-draining sand. When fine-grained soils are used against the geotextile wrapped pipe, the geotextile is likely to clog. With the geotextile placed directly against the pipe, only a small surface area of the geotextile is available to transmit flow into the pipe. This configuration causes flow concentration adjacent to the pipe openings and often rapidly causes excessive clogging of the fabric. Once the geotextile adjacent to the pipe perforations clogs, the drain will cease to function. Alternatives to wrapped pipes are well screens, which, although more costly per foot, can provide drainage and filtration but with much less concern for clogging and poor long-term performance.

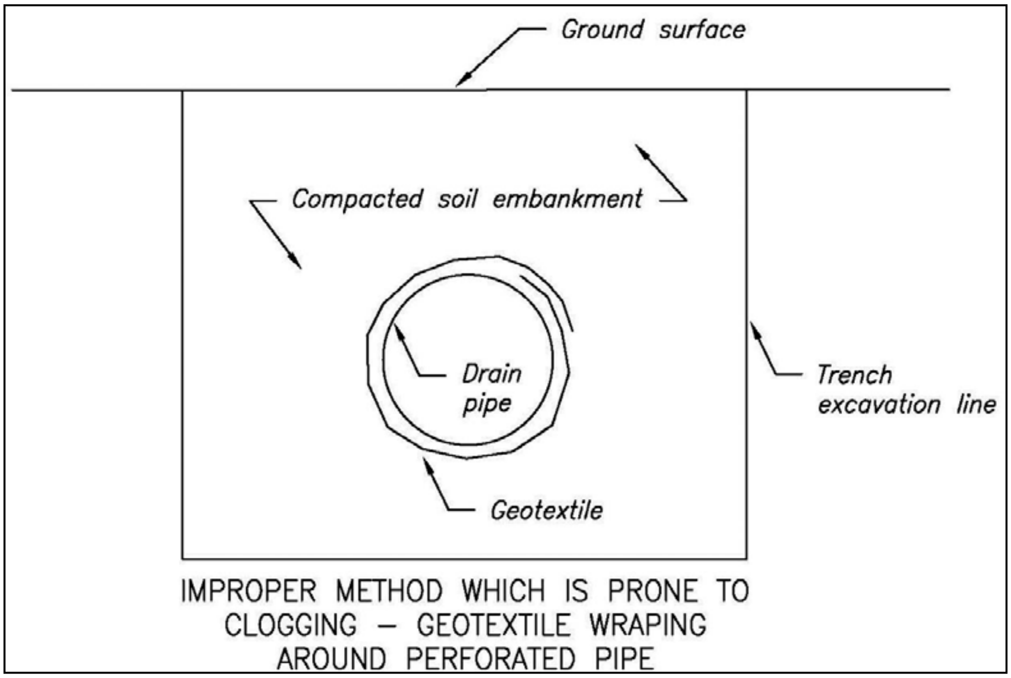


Figure 19.4.3.5-2. Toe drain formed by placing a geotextile filter around a perforated drainpipe. Although this method eliminates the need for sand and gravel, there are many cases of excessive clogging of the geotextile.

The configuration shown on figure 19.4.3.5-3 is also prone to excessive clogging and not recommended. In this example, excessive clogging of the drain will take longer because both the gravel drain material and the geotextile will need to clog before the drain becomes nonfunctional. Although it will operate for a longer period of time than the configuration shown on figure 19.4.3.3-2, the configuration shown in 19.4.3.3-3 is also likely to eventually stop functioning and should not be used.

A more appropriate design is to embed the perforated pipe in gravel drainage aggregate and wrap the outside perimeter of the gravel with a geotextile as shown in figure 19.4.3.5-4. A much larger surface area of geotextile is provided, and flow concentration is avoided at the soil-geotextile interface. This reduces the likelihood that the geotextile will clog. The other acceptable configuration, embedding a perforated pipe with a geotextile wrapping in filter sand, is shown on figure 19.4.3.5-5. The filter sand is designed to filter the surrounding base soil in accordance with the methods presented in Design Standards No. 13, Chapter 5, Protective Filters.

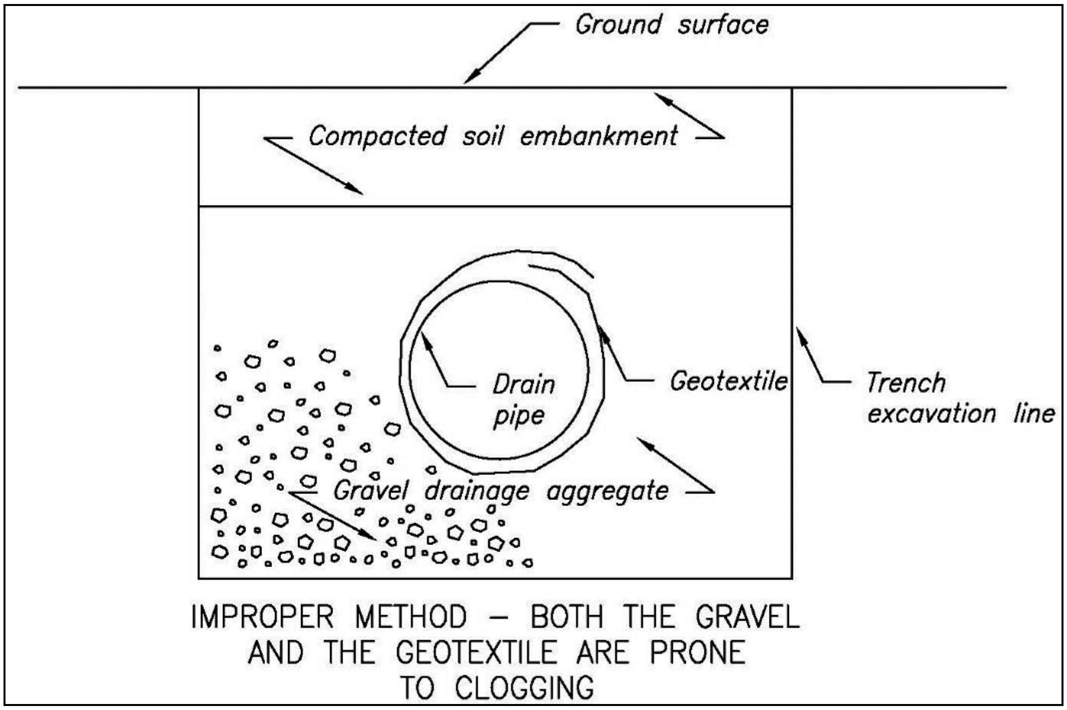


Figure 19.4.3.5-3. Toe drain formed by placing a geotextile filter around a perforated drainpipe surrounded by a gravel aggregate drain. This method is prone to clogging if the gravel does not filter the surrounding soil embankment.

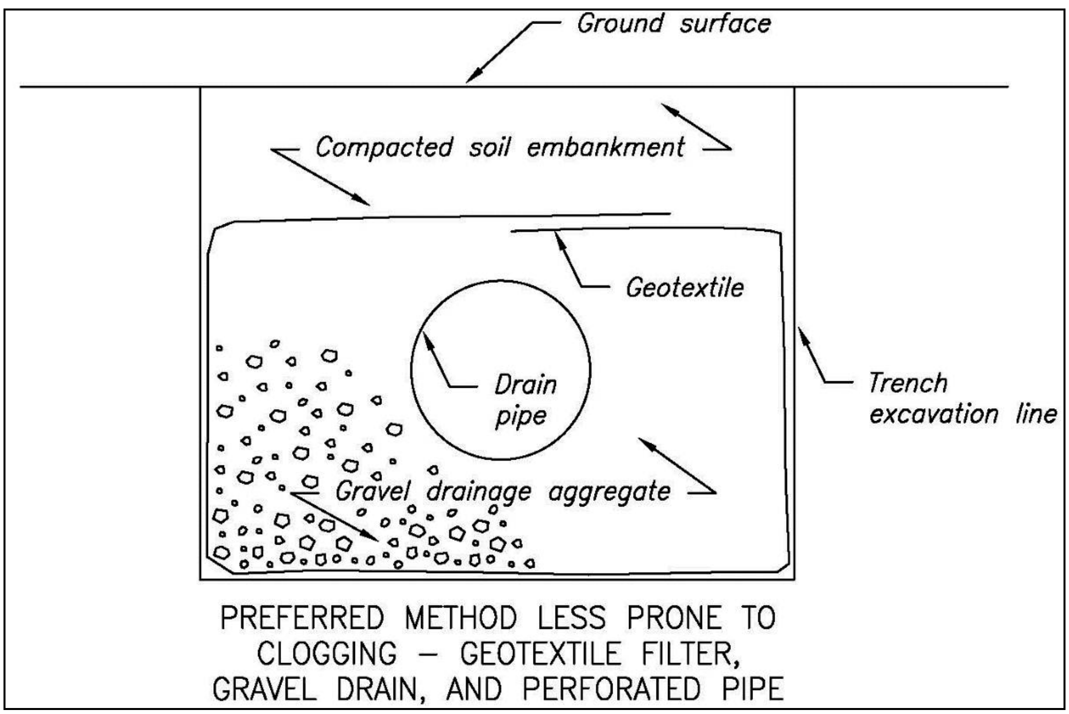


Figure 19.4.3.5-4. Toe drain formed by placing a geotextile filter around a gravel aggregate drain.

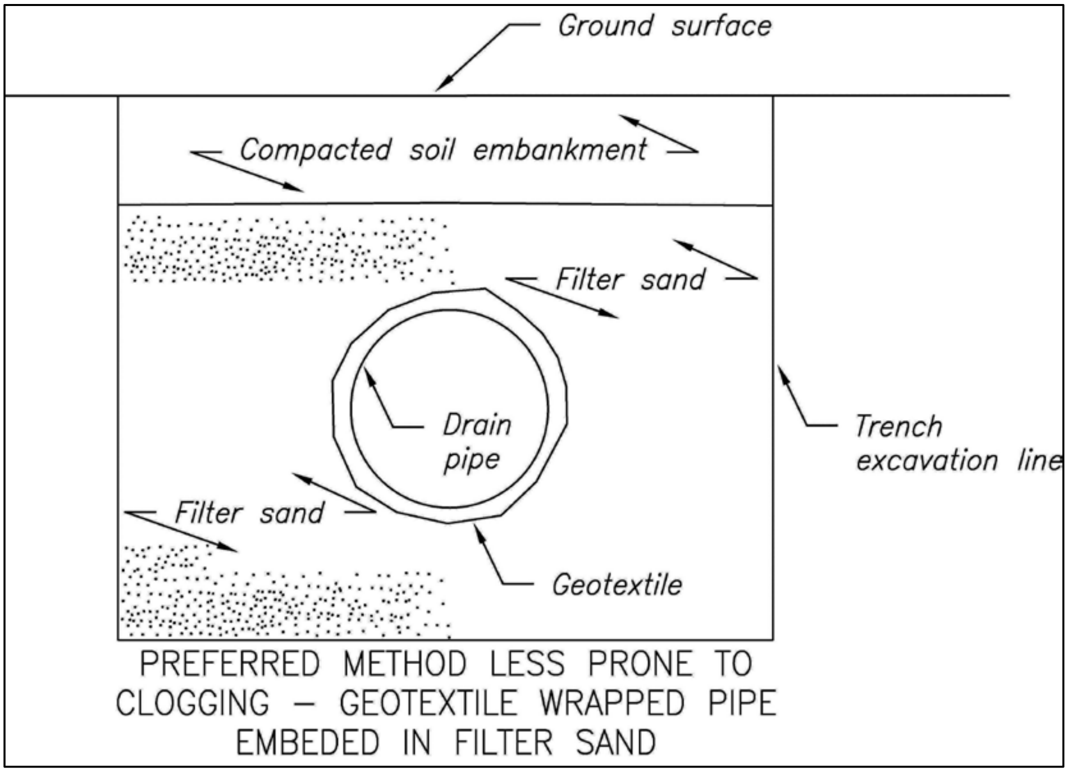


Figure 19.4.3.5-5. Toe drain formed by placing a geotextile filter around a perforated drainpipe, which is embedded in filter sand.

19.4.4 Geotextile Reinforcement Design

Geosynthetic reinforcement systems consist of geotextiles and or geogrid materials arranged in layers within a soil backfill to resist tensile forces. Geosynthetic reinforced soil is ductile and flexible, making the soil mass able to resist deformation and cracking that typically results from static, live, and seismic loading. Reclamation has used geosynthetic reinforced soils in embankment crest raises that require oversteepened slopes or vertical walls. The three general categories of geosynthetic soil reinforcement are:

- Embankment foundation – to distribute loading and improve bearing capacity
- Earth slopes – to enhance stability and allow steeper slopes to be constructed
- Earth retaining walls – to provide tensile strength for soil backfill for near vertical walls

Current design methods include reinforcement as tensile-resisting elements. However, research continues to investigate the concept that multiple closely spaced interbedded layers of geosynthetic within soils result in improved soil properties (Adams et al., 2012). This concept has been endorsed by the Federal Highway Administration (FHWA) for design of vertical bridge abutment walls, but has yet to gain acceptance for embankment foundation design methods. This design standard will focus on methods that consider the geosynthetic reinforcement as tensile-resisting elements (Elias et al, 2001; Koerner, 2012).

The methods described in this portion are intended to provide general guidance of accepted practice at the time that this design standard was completed. Detailed design methods can be found in the references by Koerner (2012) and in Elias et al. (2001). The FHWA and AASHTO regularly publish updated methods of design for structures using geosynthetics as reinforcement.

19.4.4.1 Geosynthetic Reinforcement Strength

Determination of geosynthetic allowable tensile strength uses a partial FS approach. Reduction factors are used to consider the effects of environmental conditions for a specific application such as installation damage, effects of creep deformation of the polymer, and other issues. The design technique employing reduction factors involves reducing the ultimate material property such as tensile strength cited for the material by various reduction factors, which are multiplied together to obtain a long-term design capacity. The symbol $RF_{subscript}$ is used to designate any of the appropriate reduction factors compromising the ultimate capacity of the geotextile. The total reduction factor is found by multiplying the various factors together. Judgment must be used regarding the specific application and the severity of the proposed environment to determine the values for the reduction factors used for a particular material property being evaluated (Koerner, 2012).

In the case of reinforcement, the tensile strength is the property of interest. The long-term tensile strength (T_i) is defined as:

$$T_i = \frac{T_{ult}}{RF}$$

where:

T_i = Long-term tensile strength (design strength)
T_{ult} = Ultimate geosynthetic tensile strength based on laboratory tests (reported by manufacturer)
RF = Product of all reduction factors (i.e., $RF = RF_{CR} \times RF_{ID} \times RF_{CD}$)
RF_{CR} = Creep reduction factor
RF_{ID} = Installation damage reduction factor
RF_{CD} = Chemical degradation reduction factor

Typical RF values range from 1.5 to 4.0, and when multiplied together, the total RF factor can vary from 3 to 7. The long-term strength is determined by dividing the ultimate strength by the total RF. This consideration does not include factors of safety accounting for variation from design assumptions. Factors of safety are additionally applied during design (e.g., FS = 1.5 for static slope stability), resulting in conservative geosynthetics design strengths.

19.4.4.2 Embankment Foundation Reinforcement

Geosynthetic reinforcement can be installed in lower portions of embankments to strengthen the foundation against potential failure modes as depicted on figure 19.4.4.2-1. A reinforced foundation increases the stability against bearing capacity failure (figure 19.4.4.2-1 a), embankment slope failure (figure 19.4.4.2-1 b), and lateral spreading (figure 19.4.4.2-1 c).

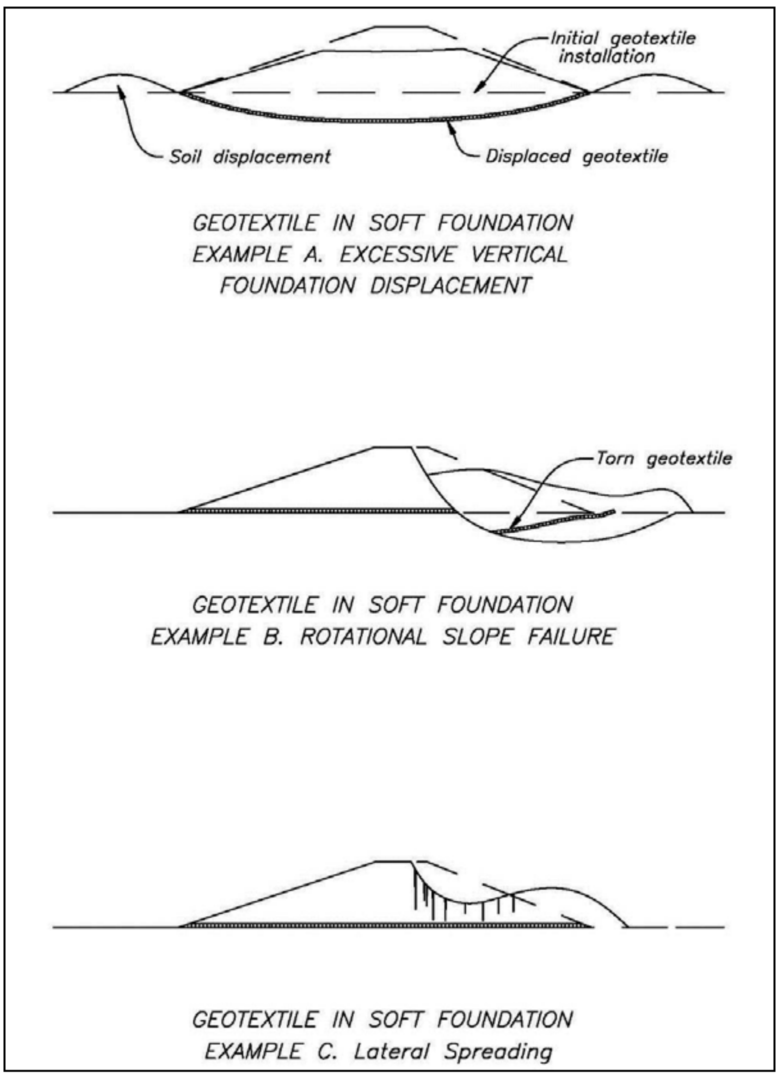


Figure 19.4.4.2-1. Illustration showing types of foundation failures.

Reclamation has used geotextiles on a limited basis to reinforce soft foundations when replacing the outlet works for small dams and in downstream excavations exposing soft foundation conditions. Geosynthetic reinforcement could potentially provide a concentrated and preferential seepage path, which would require appropriate defensive measures (such as filters and/or seepage cutoffs) to protect against internal erosion of the foundation or embankment soils. Both cutoffs and downstream filters were used in the case of placing geotextiles underneath outlet works on soft soils. Also, evaluations should be made to determine if failure of the geotextile could lead to dam failure, an unacceptable risk.

Geotextiles have been used in reinforcement of soils to steepen the slopes of soil added to the top of an embankment for a dam crest raise. This is typically performed to provide extra temporary (flood) storage capacity for a dam. This section of the report is intended to provide an outline of the design of reinforced embankments that will not function to impound water for any prolonged amount of time. Due to the limited applicability to Reclamation embankment dams, a general outline of steps used in embankment foundation reinforcement are presented herein. Specific design information can be found in Koerner (2012).

The calculations required to analyze stability and settlement utilize conventional geotechnical design procedures modified for the presence of reinforcement. The stability of the embankments over soft soils are usually determined using an undrained strength analysis. It is possible to calculate stability using a drained strength method; however, accurate pore pressure measurements in the design and construction phases should be included. Consider including multiple layers of geosynthetic reinforcement interbedded with fill soils in closely spaced lifts to achieve tensile reinforcement needed for stability. The following is a generalized outline of design procedures used for reinforced embankment foundations:

1. Define embankment dimensions and loading conditions.

2. Establish the soil profile and determine the engineering properties of the foundation soil.

3. Obtain engineering properties of the embankment fill materials.

4. Establish minimum appropriate factors of safety and operational settlement criteria for the embankment.

5. Check bearing capacity.

6. Perform a rotational slip surface analysis on the unreinforced embankment and foundation to determine the critical failure surface and the FS against local shear instability. If the minimum factor of safety is met, the reinforcement against rotational failure is not needed. If the minimum FS is not met, then determine the required reinforcement strength to achieve an adequate factor of safety.

7. Perform a lateral spreading or sliding wedge stability analysis. If the minimum FS is met, then reinforcement is not needed for failure against spreading. If the minimum FS is not met, then determine the reinforcement tensile strength required.

8. Establish tolerable geosynthetics deformation requirements and calculate the required reinforcement modulus.

9. Determine anchorage or pullout requirements for the soil to ensure reinforcement beyond the failure zone.

10. Establish geosynthetic properties, including tensile strength in the longitudinal direction and transverse directions; the soil-geosynthetic interface friction angle; drainage requirements; environmental conditions; and constructability requirements. Creep potential should be considered when selecting a geosynthetic, although creep will only be a factor if the creep rate in the reinforcement is greater than the strength gain in the foundation soil as a result of consolidation.

The selection of appropriate fill materials is also an important design consideration. Granular fill is preferred, especially for the first few lifts above the highest layer of geosynthetic.

19.4.4.3 Slope Reinforcement

Geosynthetic reinforced soil slopes can be constructed significantly steeper than nonreinforced slopes. Reclamation has applied steep geosynthetic reinforced slopes in the design of embankment dam crest raise modification alternatives. For example, reinforcement was used to steepen a crest raise for Pactola Dam. Care must be taken to ensure that prolonged water impoundment, hydrostatic pressures, or seepage conditions do not negatively impact the reinforced slope or the dam performance. Designers should be aware of the potential for internal erosion because the geosynthetic reinforcement may create a preferential seepage path and concentrated seepage pressures. Hydrostatic pressures could also create global stability issues that should be checked.

The overall design methods for reinforced slopes are similar to those for unreinforced slopes in that stability must be adequate for both short-and long-term conditions and for internal and global failure modes. Reinforced slopes are currently analyzed using modified versions of the classical limit equilibrium slope stability methods. A circular or wedge-type potential failure surface is assumed, and the driving and resisting forces or moments are compared to obtain a FS. Reinforcement layers are then included in a variety of orientations into the design, intersecting the failure surface and improving the tensile or moment resistance. For ease of construction, geosynthetic reinforcement layers are usually placed in a horizontal orientation. The tensile resistance of the reinforcement is a function of the pullout resistance behind or within the sliding mass. A wide variety of potential failure surfaces must be considered, including deep-seated surfaces through or behind the reinforced zone. Failure modes of reinforced slopes include the following:

1. The failure plane passes through the reinforcing elements
2. The failure plane passes behind and underneath the reinforced soil mass
3. The failure plane passes behind and through the reinforced soil mass
4. Pullout failure of reinforcement
5. Tensile failure of reinforcement
6. Sliding failure at interface of reinforcement and soil

Detailed design of reinforced slopes is an iterative process of determining an adequate FS with various reinforcement arrangements. The general steps for design of reinforced slopes are:

1. Establish the geometric, loading, and performance requirements for design
2. Determine the subsurface stratigraphy and engineering properties of the subsurface soils
3. Determine the engineering properties of the available fill soils
4. Evaluate design parameters for the reinforcement
5. Determine the FS of the unreinforced slope
6. Design reinforcement to achieve slope stability requirements
7. Check global stability
8. Check for pullout of embedment length
9. Evaluate requirements for seepage, hydrostatic, and surface water control

The method of slices is used for slopes utilizing fill soils with cohesion and friction angle. The resulting equations for total and effective stress circular arc failure conditions, respectively, and corresponding to figure 19.4.4.3-1 are:

$$\mathrm{FS} = \frac{\sum_{i=1}^{n}(N_i \tan\phi + c\Delta l_i)R + \sum_{i=1}^{m} T_i Y_i}{\sum_{i=1}^{n}(W_i \sin\theta_i)R}$$

$$FS = \frac{\sum_{i=1}^{n}(N'_i \tan\phi' + c'\Delta l_i)R + \sum_{i=1}^{m} T_i Y_i}{\sum_{i=1}^{n}(W'_i \sin\theta_i)R}$$

where:

- F = Factor of safety
- N_i = W Cos θ_i
- W_i = Total weight of each slice
- W'_i = Effective weight of each slice
- θ_i = Angle of intersection of horizontal to tangent at center of each slice
- Δl_i = Arch length of each slice
- R = Radius of failure circle
- ϕ, ϕ' = Total and effective stress angles of shearing resistance respectively,
- c, c' = Total and effective cohesion respectively
- T_i = Allowable geotextile tensile strength
- Y_i = Moment arm for geotextiles
- n = Number of slices
- m = Number of geotextile layers
- N'_i = N_i-$u_i\Delta x_i$, where:
  - u_i = Pore water pressure
  - Δx_i = Width of slices

The method for fine-grained cohesive soils defined by the undrained condition is considerably simpler. Slices are not necessary because the soil strength does not depend on the frictional forces on the shear plane. Figure 19.4.4.3-2 indicates a fine-grained soil condition. The slope stability equations can therefore be reduced to:

$$FS = \frac{cL_{arc}R + \sum_{i=1}^{m} T_i Y_i}{WX}$$

where:

- FS = Factor of safety
- c = Cohesion
- L_{arc} = Arch length of each slice
- R = Radius of failure circle
- T_i = Allowable geotextile tensile strength
- Y_i = Moment arm for geotextiles
- W = Weight of the failure zone
- X = Moment arm to center of gravity of the failure zone

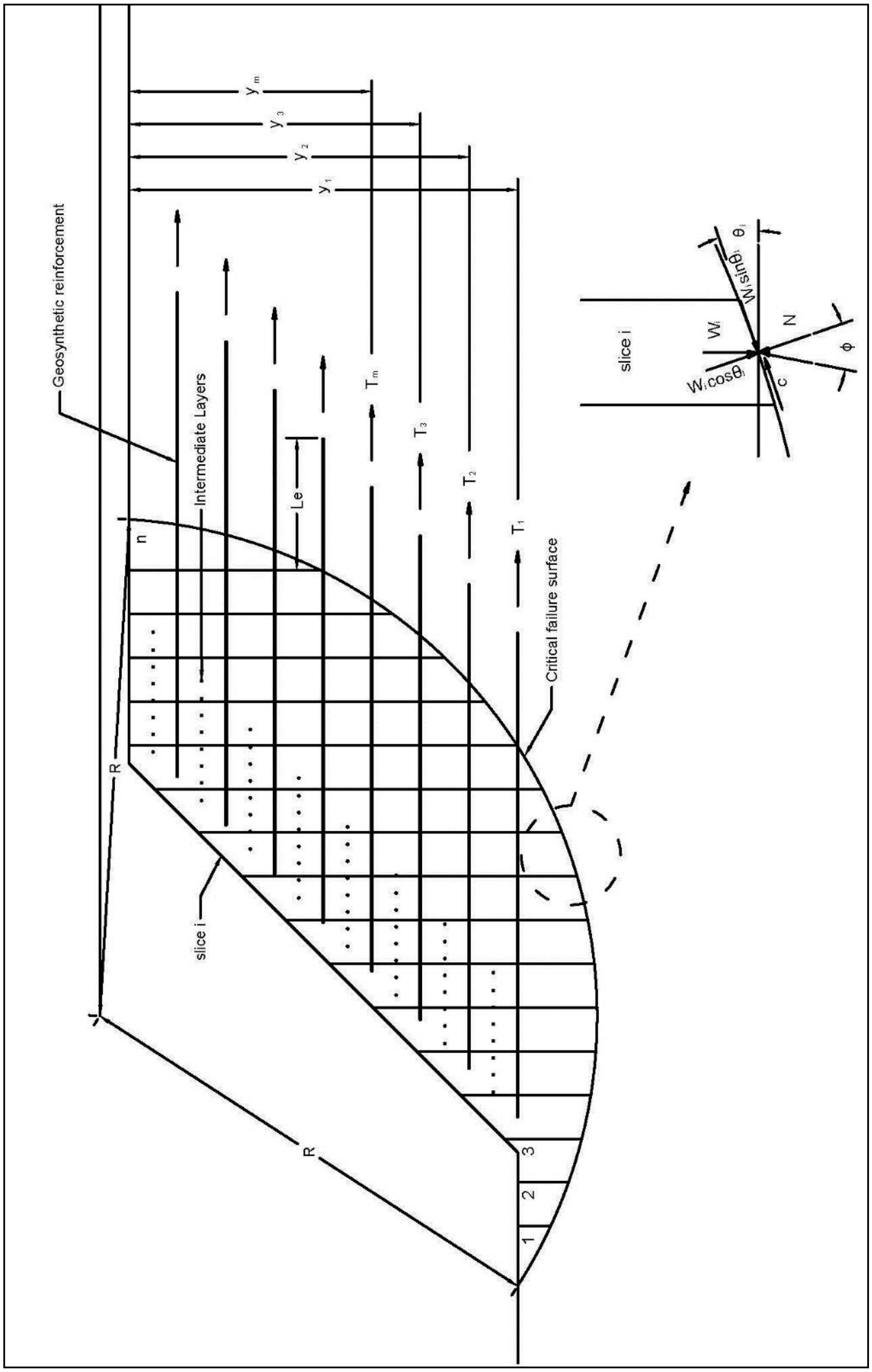


Figure 19.4.4.3-1. Circular slope stability analyses for soils that have c and ϕ (after Koerner, 2012).

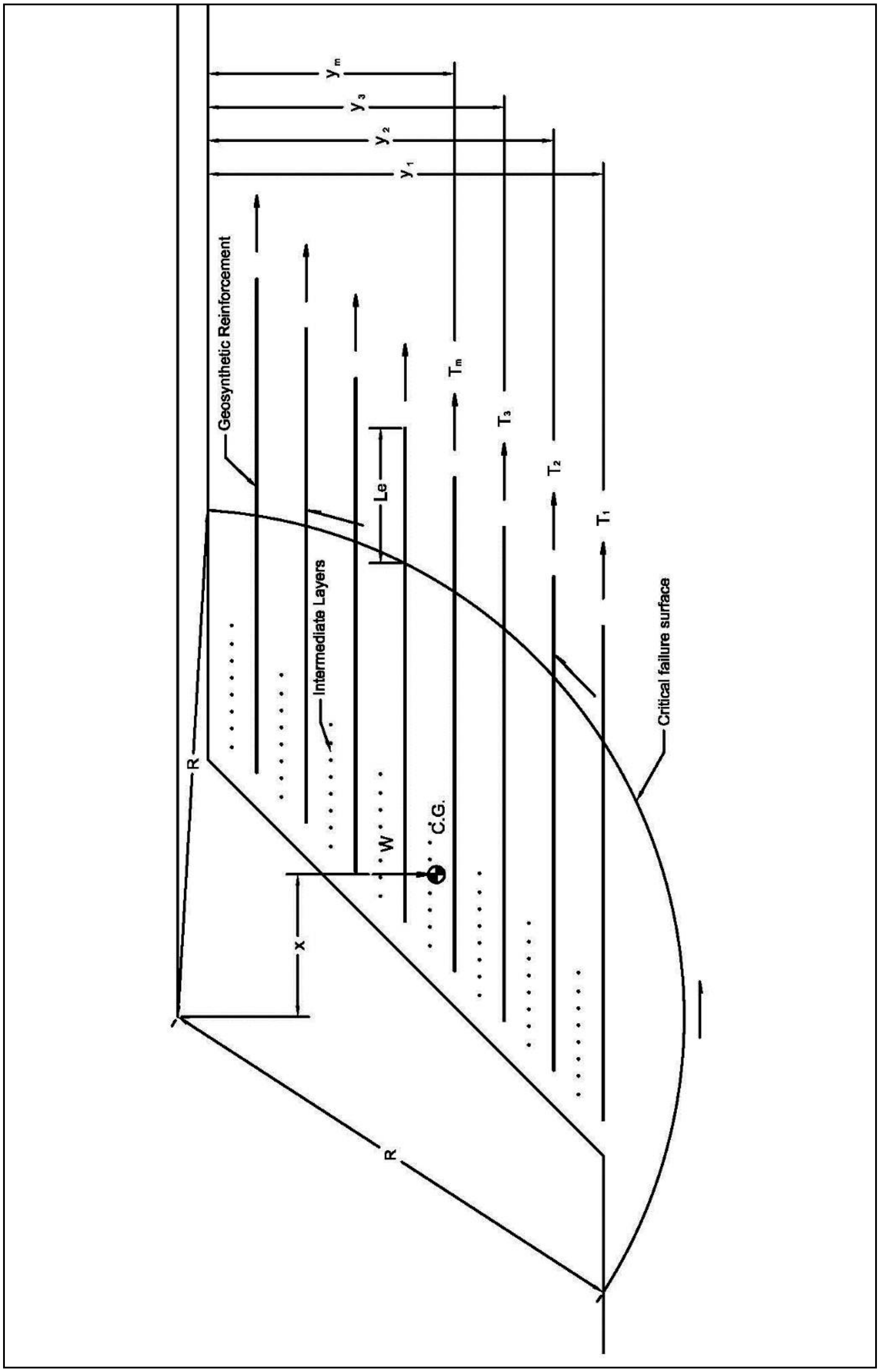


Figure 19.4.4.3-2. Circular slope stability analyses for c only soils (after Koerner, 2012).

The embedment length L_e, of each reinforcement layer is the length of the geosynthetic that extends beyond the failure surface into the slope. L_e is a function of the pullout resistance and is added to the length of the geosynthetic from the failure surface to the slope to get the total geosynthetic length. L_e should be a minimum of 3 feet and can be found using the relationship:

$$L_e = \frac{T_i FS}{2E(c + \sigma_v(\tan\delta))} \geq 3 \text{ ft}$$

where:

- Le = Embedment length
- T_i = Allowable geosynthetic tensile strength
- FS = Factor of safety
- E = Frictional resistance transfer efficiency (typically 0.8–1.2 for geotextiles)
- σ_v = Overburden stress above the geosynthetic layer
- δ = Interface friction angle between the geosynthetic and soil

E and δ are best determined through laboratory or field testing; however, presumptive values can be found in published text such as Koerner (2012). Reinforcement lengths are expected to be longer within the failure mass than behind the critical failure surface because overburden stresses are less toward the slope face. Short lengths of reinforcement layers can be used between the primary tensile resisting layers to minimize surficial erosion of the slope face, improve compaction quality, and minimize slough failures.

Analytical slope stability calculations can be tedious and time consuming. Computer aided slope stability modeling programs have gained in popularity as a design tool. Several commercial slope stability programs are available that include options for reinforcement inclusion. It is good practice to verify that numerical modeling agrees with accepted analytical methods.

19.4.4.4 Geosynthetic Reinforced Walls

Geosynthetic reinforced walls may utilize geotextiles as soil reinforced elements. Reclamation has utilized geosynthetic reinforced walls for crest raise alternatives where dam slopes could not be significantly modified. A number of approaches to design have been proposed; however, the most commonly used method is based on the classical Rankine earth pressure theory combined with tensile-resisting geosynthetic layers extending beyond an assumed failure plain acting as a “tie back”. The angle where a slope is considered a wall and analyzed using the Rankine earth pressure theory instead of limiting equilibrium slope stability methods is widely debated. The FHWA currently assumes slopes greater than 70 degrees from the horizontal are analyzed using Rankine earth pressure theory. As with conventional retaining structures, overall external stability and wall settlement must also be considered. The general steps for analyzing a geosynthetic wall are as follows:

1. Establish design limits, scope of the project, and external loads

2. Determine the engineering properties of the foundation soil

3. Determine properties of both the reinforced fill (preferably granular) and retained backfill soils

4. Establish design factors of safety and performance criteria

5. Determine preliminary wall dimensions

6. Develop the internal and external lateral earth pressure diagrams for the reinforced section

7. Check the external stability of the wall

8. Estimate the settlement of the reinforced section using traditional methods

9. Calculate the maximum horizontal stress at each level of reinforcement

10. Check internal stability and determine reinforcement requirements

11. Check the reinforcement length required to develop pullout resistance beyond the Rankine failure wedge

Several internal stability methods have been proposed, but the method developed by the U.S. Department of Agriculture, Forest Service, illustrated on figure 19.4.4.4-1 has been widely accepted and has been historically successful. As shown in Figure 19.4.4.1-1, the total internal lateral soil pressure (σ_h) is the sum of lateral stresses developed by soil pressure (σ_{hs}), surcharge pressure (σ_{hq}), and live loads (σ_{hl}). Lateral stress can be determined at any depth (Z) from the top of the wall where:

$$\sigma_{hs} = K_a \gamma$$

$$\sigma_{hq} = K_a q$$

$$\sigma_{hl} = P \frac{x^2 Z}{R^5}$$

$$\sigma_h = \sigma_{hs} + \sigma_{hq} + \sigma_{hl}$$

where:

K_a = Coefficient of active earth pressure ($\tan^2 (45 - \Phi/2)$)
Φ = Angle of shearing resistance

Υ = Unit weight of soil
q = $\Upsilon_d D$
D = Depth of the surcharge soil
Υ_d = Unit weight of the surcharge Soil
P = Concentrated live load on backfill surface
x = Horizontal distance load is away from the wall
R = Radial distance from load point on the wall where pressure is being calculated

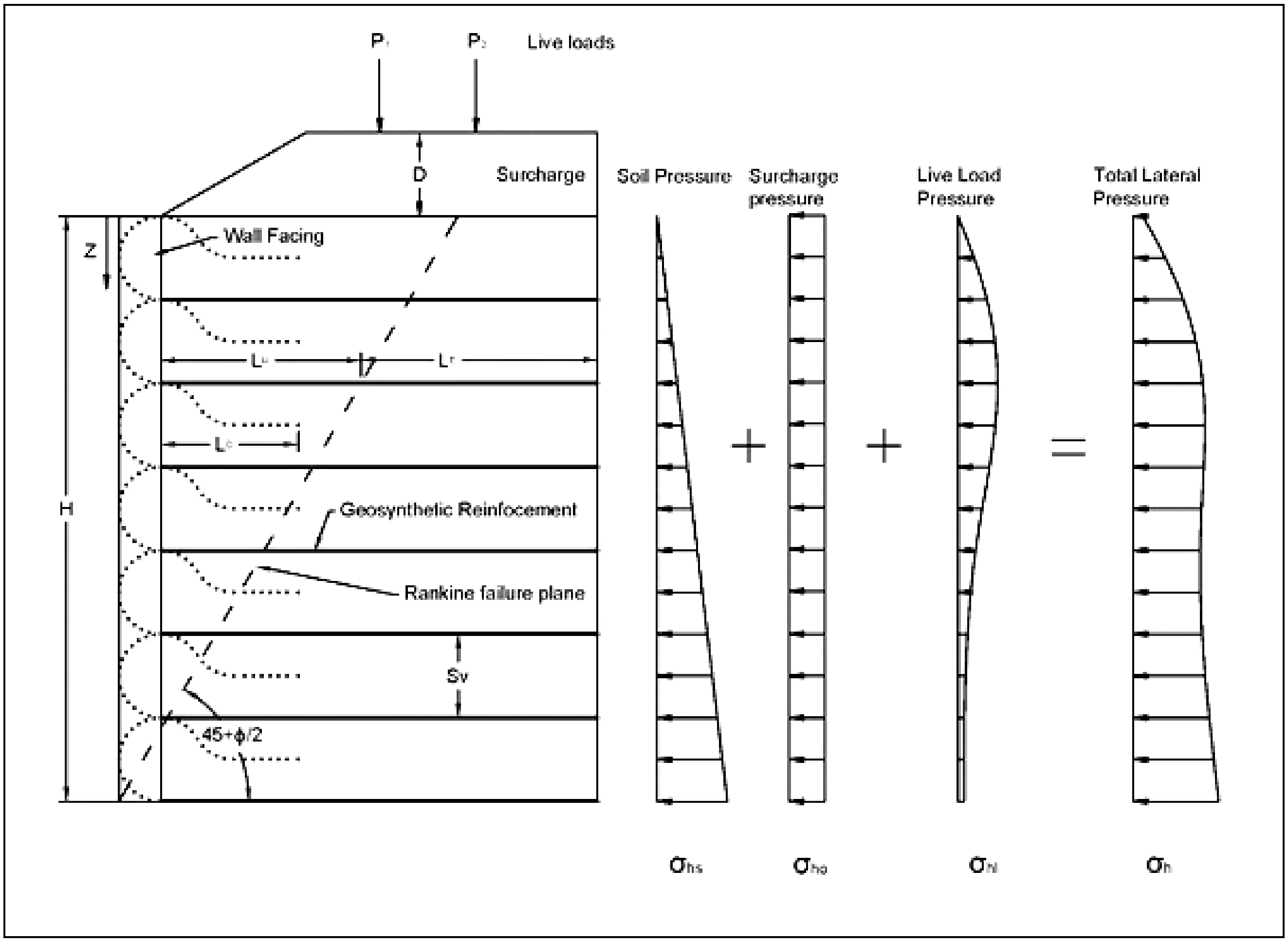


Figure 19.4.4.4-1. Rankine earth pressure concepts for geosynthetic reinforced soil wall design (after Koerner, 2012).

Reference NFAC (1986) provides a convenient aid and guidance in determining the lateral pressure resulting from a point load.

Vertical spacing between reinforcement layers (S_v) can be obtained using the following relationship:

$$S_v = \frac{T_i}{\sigma_h FS}$$

where:

T_i = Allowable geotextile tensile strength
σ_h = Total lateral earth pressure at depth
FS = Factor of safety

The length of the reinforcement layers is defined as:

$$L = L_R + L_E$$

where:

L = The length of reinforcement layers
L_R = The sum of length within the failure zone, determined as:

$$L_R = (H - z)\mathrm{Tan}\left(\frac{45 - \phi}{2}\right)$$

L_E = Length of anchorage, determined as:

$$L_E = \frac{S_v \sigma_h FS}{2(C_a + \gamma z \tan\delta)}$$

where:

C_a = Adhesion between the soil and the geotextile (assumed to be zero for a granular soil)
δ = Angle of internal friction between the geosynthetic and the soil

For wrapped faced walls, an overlap length (L_O) can be found using the following relationship:

$$L_O = \frac{S_v \sigma_h FS}{4(C_a + \gamma z \tan\delta)}$$

A high occurrence of geosynthetic reinforced wall failures can be attributed to poorly designed drainage conditions and low quality fill soils. Care should be taken to avoid the development of internal hydrostatic and seepage pressures, and fill soils should be of high quality adhering to the following minimum soil gradation requirement listed in table 19.4.4.4-1.

Table 19.4.4.4-1. Minimum suggested fill soil requirements for walls

Sieve size	Percent passing
19 mm	100
4.75 mm	20–100
0.425 mm	0–60
0.075 mm	0–15
Plastic index ≤ 6	
Magnesium sulfate soundness loss 30 percent after four cycles.	

From: Elias et al. (2001).

A significant advantage of geosynthetic reinforced walls over conventional earth retaining structures is their lower cost per square foot of exposed surface over conventional gravity wall systems and the variety of facings that can be used and the resulting construction benefits and aesthetic options that can be selected. Some examples of wall facings are modular block wall units, wraparound facings, segmental precast concrete panels, timber, and gabion units. Each facing unit has design considerations that must be evaluated such as geosynthetic attachment, seismic behavior, maintenance, and constructability.

19.5 Storage and Handling

Care in storage and handling is necessary to prevent damage to the geosynthetic material before it is installed. Damage can occur anywhere in their journey from the factory to the completed installation. Typical damage resulting from poor loading, shipping, and offloading procedures includes tears and punctures caused by tiedown restraints, shifting of loads during transport, improper removal of restraints, and abrasion from dragging materials.

An inspection of delivered materials should be performed. The material should be inspected visually on the truck before the restraints are removed (figure 19.5-1), during the process of removing the restraints, and unloading the product and transporting it to temporary storage should be monitored.

Careful unloading and movement about the site is best performed using canvas slings (figure 19.5-2) or spreader bars and a probe such as a steel pipe that can be inserted into the center of the roll to prevent tearing or puncturing the geotextile. These methods allow the rolls to be relocated without dragging them across the ground or using other improper methods such as lifting the rolls with the forks of a forklift or with an excavator bucket.

Figure 19.5-1. Photograph showing delivery of geosynthetic rolls to a construction site. The tiedown straps at the front of the truck are intruding into and have distorted the shape of the top roll, which must be examined to verify that it has not been damaged.

Figure 19.5-2. Photograph showing proper offloading of geotextile product rolls. Cloth slings, rather than the forks of the lift, are used to properly unload this delivery.

Contamination of the geotextile can originate from storage on bare ground, accidental spills of chemicals, and storage and transport in dusty environments. Particulate contamination can reduce filtration and drainage performance due to clogging. Chemical contamination may degrade the polymer compounds, resulting in severe loss of strength.

Geotextile materials are usually covered with UV-resistant packaging at the factory before being shipped to the site. Since geosynthetics are shipped with a protective outer wrapper, the problem of light exposure typically originates when the protective wrapper is damaged (figure 19.5-3) or when rolls of goods have been unwrapped and then delays in installation are encountered.

Standard guidance is available for proper geotextile storage and handling procedures (ASTM 2002). Rolls should be marked and/or tagged with the following information: (1) product identification, including manufacturer and type; (2) lot number and roll number, and (3) roll length, width, and weight. This information should be provided in at least three locations: outer cover, roll, and inside roll cover.

Figure 19.5-3. Photograph of geotextile storage. A layer of fine-grained soil was placed in the storage area to avoid placing the rolls directly on the rocky soil, which is visible on the left side of the photograph. Damage to the ends of the protective wrappers is evident; the inspector required these rolls to be covered by a tarp to prevent contamination by dust and to avoid degradation from prolonged UV exposure.

At the factory, geotextiles are typically rolled onto strong and durable cardboard tubes that allow for storage and easy movement and loading onto trucks for shipping to the site. Storage areas at the site should be prepared prior to delivery. If stored on the ground, a smooth surface free of rocks and vegetation should be prepared. Other storage methods include placing geotextile rolls on pallets, on sheets of plywood, or on asphalt or concrete pads.

The manufacturer usually specifies the maximum height of stacking for the rolls to ensure that the product is not crushed by the weight of the storage pile. The problem of degradation by UV light can originate from extended outside storage of geosynthetics where the protective covers have been damaged or removed. Because UV degradation is an invisible process, inspectors must be aware of the issue and be diligent in frequently reviewing the condition of storage piles to ensure that protective covers remain intact.

19.6 Installation

The performance of a geotextile can be significantly affected by the quality of the installation. It is critical that the mechanical and hydraulic properties of the geotextile are not compromised by construction activities. Prolonged UV exposure, contamination, abrasion, puncture, tearing, and misalignment of geotextiles during construction must be avoided. To achieve a successful installation, the design must be feasible to construct, the geotextile must be able to accommodate the anticipated construction stresses, specifications must clearly provide proper installation requirements, and quality control and quality assurance procedures must be strictly enforced.

19.6.1 Subgrade Preparation and Approval

Preparation of the foundation surface (subgrade) against which the geotextile will be placed is the initial step in the installation process. Subgrade preparation requirements are an important aspect of project requirements. For most applications, the subgrade is required to be smooth and firm, free of voids and protruding rocks. For highway and road applications, a three-tiered classification system of subgrades has been developed (AASHTO, 1996). Based on the quality of the subgrade, different strength requirements for the geotextile are specified. For use in dams, no such classification system has been adopted. Reclamation has adopted a two-tiered classification of either Class A or Class B defined as follows:

> Class A – Applications in which installation stresses are considered more severe than Class B, very sharp angular aggregate is utilized/or is present in significant percentages, or where cover materials will be subjected to compaction greater than 95 percent.

Class B – Applications in which the foundation/subgrade is smooth, having no sharp angular projections; no sharp angular aggregate is used; and compaction requirements are less than 95 percent.

Regardless of the exact nature of the subgrade, geotextiles must be placed in intimate contact with the soil that they are being used in or on. For a stiff woven geotextile, the soil surface should be as smooth as possible. Nonwoven geotextiles are more flexible and will better conform to an irregular surface, but the goal should be to provide as smooth of a surface as possible for nonwovens geotextiles as well. Typically, the subgrade will be compacted with a smooth drum roller (figure 19.6.1-1), bladed smooth with a motor patrol (if the slope is 3H:1V or flatter), and then re-compacted with a smooth drum roller. For slopes steeper than 3H:1V, the roller will have to be secured in a safe manner to allow it to traverse up and down the slope. Depending on the material, vibration may be utilized. The goal is to have a smooth subgrade surface with no rock protruding. It is recommended that laborers walk the subgrade and remove rocks and protrusions and fill holes (figure 19.6.1-2). Pockets of coarse fragments should be filled with sand to provide a smooth surface. The intent is to remove any sharp rock fragments that could puncture and/or tear the geotextile and to fill voids in the subgrade. Rounded rocks are less likely to damage the geotextile.

Figure 19.6.1-1. Photograph showing compaction equipment preparing a suitably smooth and firm subgrade surface for geotextile placement.

Figure 19.6.1-2. Photograph showing a defect in a prepared subgrade surface for which the contractor wanted approval. This portion of the subgrade was rejected by the inspector and had to be filled and smoothed.

When geotextiles are placed in vertical or steeply sloped trenches, it is often not possible to create a completely smooth surface. The sides of the trench can be lightly trimmed as needed, and the trench bottom can be smoothed using a smooth excavator bucket (without teeth) just prior to geotextile installation to eliminate gross irregularities.

19.6.2 Deployment

Once the subgrade has been approved, deployment of the geotextile can commence. For efficient installation, it is best to verify that all the necessary equipment and supplies (such as sandbags) are ready prior to bringing the geotextile to the installation area. The geotextile must be transported from the onsite storage area to the installation site with care. Onsite transport activities can damage geosynthetics. Common problems include improper lifting of rolls. Methods such as using an excavator bucket or a forklift to lift the rolls creates a stress concentration that can stretch or tear the geotextile. In some cases, forklifts have been observed to impale the roll, resulting in severe puncture damage. During transfer to the deployment area, ensure that the product does not strike any other objects that could abrade, puncture, or tear the geosynthetic material (figure 19.6.2-1).

Figure 19.6.2-1. Photograph showing how a geosynthetic roll is moved with a pipe, spreader bar, and a spotter. The spotter (person walking in front of the equipment) is needed to ensure that the geosynthetic product does not strike any other objects that could damage the material.

Panel layout and tailoring the geotextile to the site is generally the responsibility of the installer, subject to approval by the engineer. The geotextile should be unrolled with the length of the roll in the direction of anticipated water flow or movement. Successive geotextile rolls are overlapped (shingled) such that the upslope panel is placed over the downslope panel. Some geocomposite materials, such as a tri-planar geonet composite, have a flow direction that must be aligned for the material to function properly. In reinforcement applications, geotextiles should be laid in strips transverse (perpendicular) to the centerline of the embankment. The object is to avoid (or minimize) seams along the direction of stress (flow or reinforcement).

Anchor trenches (figure 19.6.2-2) are typically used at the top of slopes to anchor the geotextile. They are generally excavated a minimum 3 feet deep and 2 feet wide to allow hand tampers to be used to compact the backfill. The geotextile should extend down the side and across the bottom of the anchor trench. In certain applications, if there is adequate space, swales or benches are excavated into long slopes to serve as intermediate anchor locations without the need for a trench (figure 19.6.2-3). The use of a wide bench facilitates geotextile installation

Figure 19.6.2-2. Photograph of an anchor trench at a dam for a geonet composite.

Figure 19.6.2-3. Photograph showing a bench used to divide a long slope and provide an intermediate anchor location. Note the presence of proper equipment, sufficient labor, and adequate supplies.

and allows the use of rubber-tired loaders and other larger equipment to place and compact the anchor trench fill. Runout can be used in lieu of an anchor trench.

The process of the unrolling and positioning the geotextile panel may loosen the subgrade surface or cause rock fragments to become exposed. Therefore, it is important to monitor the activity and walk the geotextile after it has been placed to make sure that there are no protruding rock fragments that could puncture and/or tear the geotextile or that could cause the geotextile to move away from close contact with the subgrade.

As deployment progresses, it is possible that adjacent areas of subgrade can become damaged by construction activities. Additional inspection of the subgrade surface immediately prior to placing the geotextile is essential. Any areas that become rutted or disturbed must be corrected prior to proceeding with additional geotextile placement. If the subgrade becomes wet and muddy, stop the installation. Unless the design calls for building a road on soft, wet ground, geotextiles should not be placed on muddy ground that can clog the fabric. Dry, dusty conditions should also be avoided to prevent the geotextile from being clogged with dust particles.

19.6.3 Seaming

Seaming methods include overlapping, sewing, heat bonding, stapling, tying, welding, and gluing. Thermal seaming methods are the most efficient when joining of panels is required. Overlapping has a low labor cost, but requires more geotextile product. Sewing provides the most reliable seams in terms of strength, but has higher labor costs. Depending upon the cost of the geotextile and overlap distance, sewing often pays for itself (Koerner, 2012) as compared to overlapping.

The previous practice of using overlaps in the range of 6 inches to 1 foot has led to failures (caused by gaps in coverage) due to the geotextile shifting when loaded with cover soil. For overlapped seams, it is recommended that an overlap distance of 1 to 3 feet be used, with wider overlaps being used for softer soil conditions. This standard recommends a minimum overlap distance of 1 foot when used adjacent to firm, compacted materials on both sides of the geotextile.

When proper overlap requirements are followed, laps can result in a significant additional cost of materials. An analysis by Koerner (2012) suggests that only on relatively strong subgrades with light geotextiles does sewing not pay for itself in saved costs. Sewing should always be considered for placement of geotextiles on soft soils.

Also, in addition to the risk of gaps in coverage, there can be a risk of slope failure in using the overlapping method for seaming. Research indicates that the frictional resistance between overlapped fabric sections is considerably less than that between fabric and soil (Koerner and Narejo, 2005).

By sewing, seam strengths of about 50 to 90 percent of the geotextile strength can be achieved. The lower percentage for seam strengths is associated with the higher strength geotextiles. Sewing, in the past, used Kevlar thread. The use of thread stronger than the geotextile, or of a different material, is no longer favored. Thread made from the same polymer as the geotextile material is the preferred material for sewing panels together. Field sewn seams are likely to have a lower strength than factory sewn seams.

There are three basic types of seams produced by sewing geotextiles (Koerner, 2012): flat or prayer type, J or Double J, and butterfly. Figure 19.6.3-1 shows typical types of sewn seams.

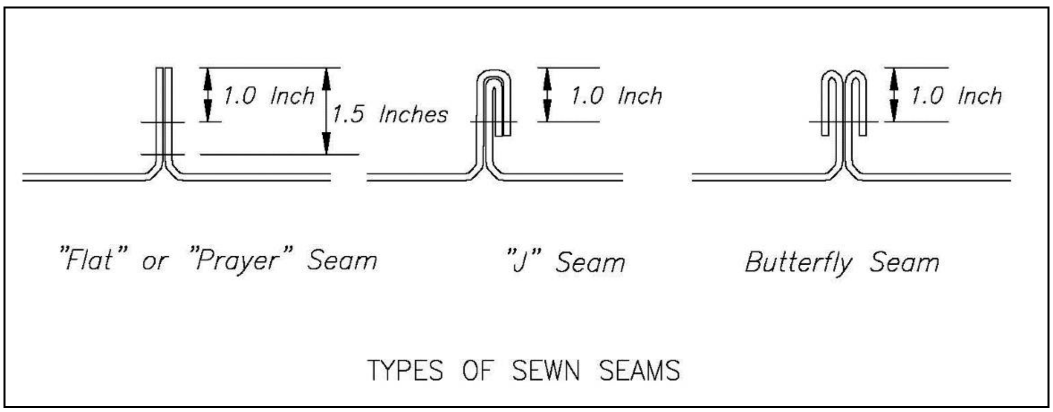


Figure 19.6.3-1. Illustration showing types of sewn seams used to join geotextile panels.

The seams normally have between one to three rows of stitching. A stitch density of about 400 stitches per 3 feet should be used for lighter weight geotextiles. About 200 stitches per 3 feet should be utilized for heavier weight geotextiles. A lock type stitch should be utilized because it is less likely to unravel. Single- or double-thread chain stitch is also utilized. When constructed correctly, sewn seams can provide reliable stress transfer between adjacent geotextile panels.

Fabric seams should be evaluated for their potential to open up under load, possibly creating unprotected areas where soils could pipe under hydrostatic pressure or flow. Overlapping "J" type seams are preferable. It is recommended that double sewing be utilized. The past practice of using high-strength polyester, polypropylene, or Kevlar thread is no longer recommended. It is now preferred to use thread made from the same polymer material as the geotextile, and it should be obtained from the same manufacturer that supplies the geotextile for the installation.

Tying is a method used for some geocomposite products such as geonets. Stapling is used for erosion control blankets; however, it should not be used for geotextiles placed as filters or separators where soil retention is essential.

Geonet composite drains are seamed by butt joining or lapping. Butt joining is difficult because it requires good alignment (uniform surfaces) and placement of strips of geotextile over the seams to prevent soil infiltration into the drain. Nylon ties are used to hold seams together for geonet composite drains. The geonet is joined with nylon ties, and the surrounding geotextile portions are thermally bonded.

Heat-bonding equipment includes a wedge welder, hot air, and a propane torch. Heat bonding/welding is becoming more common as new lightweight type field welders are developed. These types of machines require operators that are trained, and the equipment must be maintained. Temperature control and uniformity of the heating elements are critical to ensure that the geotextiles are not burned or damaged.

19.6.4 Covering

Once installed in the field, geotextile materials should be covered with the specified materials as soon as practicable. On many projects, the contractor wants to delay cover placement until all of the geotextile is placed. UV susceptible geotextiles should be covered within 3–5 days of exposure and within 14 days for UV treated and low UV susceptible polymer geotextiles. The recommended time limits for covering geotextiles can be extended in some cases up to 30 days, but some degradation is likely to occur. Site-specific exposure tests must demonstrate that additional UV exposure will not adversely affect the required geotextile strength properties.

In addition, geotextiles (especially needle-punched nonwovens) exposed to rain absorb a considerable amount of water and become heavy and difficult to handle should repositioning be required. All geotextiles used as filters or transmissive media must be protected to prevent contamination by dust, dirt, and mud. In underwater applications, it is recommended that cover soils be placed the same day.

The covering operation must be carefully controlled to avoid damage to the geotextile. Immediately prior to covering, the installed geotextile should be inspected to ensure that it is still in proper position and that the subgrade has not been compromised. The cover soil must meet the specification requirements. On slopes, cover soil placement should begin at the toe and proceed up the slope. A geotextile can be damaged by equipment operating on too thin of a cover or by pushing cover fill down slope. For heavy equipment hauling, cover layers should be increased (figure 19.6.4-1). The maximum allowable slope on which soil cover can be placed is equal to the lowest soil-geotextile friction angle. After the fill material is dumped, small low-ground-pressure (LGP) bulldozers and/or front-end loaders may be used to spread the fill.

The use of LGP dozers typically eliminates excessive puncture stresses on the geotextile. However, of equal or greater importance is the shear stresses that are developed along the subgrade soil/geotextile (lower interface) and soil cover/geotextile (upper interface) interfaces during the action of pushing the cover soil over the geotextile. The potential for large interface shear stresses exist when an equipment operator tries to push too much material at any one time. Signs of improper operation are the bulldozer blade pushing a load of soil that is taller than the top of the blade. Also, if the bulldozer dozer is spinning its tracks while trying to push soil, it is being severely overloaded. The creation of wrinkles or waves in the uncovered geotextile ahead of the bulldozer is another sign of improper operation. If the resulting shear stresses below the geotextile exceed the interface shear strength, localized slipping will result, causing stretching of the geotextile. This may tear the geotextile. Many construction-quality assurance inspectors are unlikely to recognize this situation. Usually, inspectors focus on the minimum required cover soil thickness and look for evidence of damage below the dozer's blade and tracks if they accidentally contact the geotextile. Inspectors need to be aware of the need to avoid pushing thick layers of cover soil. An excavator can be used to safely reduce the height of high dump truck loads of cover soil such as that seen on figure 19.6.4-2. The trucks should not be allowed to dump directly onto the geotextile. It is preferred that the trucks dump onto a previously placed layer of cover material.

Typically, no additional compaction of the initial lifts is necessary, as sufficient compaction can be achieved by the static weight of the equipment. If compaction of the cover soil is required, the use of heavy equipment on the first lift should be avoided. A minimum cover thickness of 12 inches should be maintained for low pressure equipment operation. The maximum depth of soil placed in any one layer should not exceed 18 inches. The gradation and angularity of the cover soil is an important variable. Coarse gravel covers should be placed no greater than 12 inches thick. Cover soils that have higher percentages of sand/clay or "pea gravel" such as that shown on figure 19.6.4-3, can be spread in up to 18-inch thick lifts.

Conveyors have been used to provide the initial cover over a geotextile or geonet composite to avoid potential damage from equipment travel. Figure 19.6.4-4 shows the use of a telescoping conveyor that was used for a Reclamation dam to cover a geonet composite with a C-33 filter sand to rapidly provide the required protection from UV degradation until the chimney zone could be constructed.

Figure 19.6.4-1. Photograph showing a haul road where the cover layer thickness has been temporally increased to 5 feet to protect the geotextile from heavy equipment loading.

Figure 19.6.4-2. Photograph of an excavator removing the tops of thick piles of cover material. Attempting to move such thick piles with a bulldozer is likely to damage the geotextile because of the high traction forces required to push a thick layer of material.

Figure 19.6.4-3. Photograph of a low-ground-pressure bulldozer grading cover material to a uniform thickness of 1.5 feet. Note that material is pushed upslope and the presence of an inspector monitoring the work.

Figure 19.6.4-4. Photograph showing initial placement of sand cover onto a geonet composite using a telescoping conveyor at Red Willow Dam in 2012. Note that placing cover from upslope to downslope is usually not allowed; use of other types of equipment in a downslope manner would damage the geotextile.

When a geotextile is installed as a filter in a trench drain, the aggregate fill should be carefully placed to ensure intimate contact of the geotextile with the trench bottom and walls (Ingold and Miller, 1988). An effective procedure for trench drains is to:

- Observe the trench surfaces and remove sharp stones and projections.
- Lay the geotextile into the trench with extra material extending beyond both sides.
- Place small stones or gravel piles at intervals along the top edge of the trench to lightly hold the fabric in place. It is important that the fabric not be firmly restrained.
- Gently pull or reposition portions of the geotextile as needed to remove wrinkles.
- Use fine aggregate (0.75- to 1-inch maximum size) for filling so that the geotextile will be supported against the trench soil in many places.
- Use clean drainage aggregate material without fines that might clog the drain.
- Slowly place clean drainage aggregate to form an initial bedding layer in the bottom of the trench. Avoid large drop heights.
- Place the drainpipe in the bedding.
- Slowly place additional thin layers of clean drainage aggregate. Allow the geotextile to partially slip into the trench as needed so it conforms to the variations in the sidewalls.
- Close the top of the filled trench by folding over the remaining geotextile flaps.

The placement of erosion protection materials over a geotextile depends on the type of armoring to be used (riprap, articulating concrete mattresses, etc.). Small riprap is often directly placed onto a geotextile (figure 19.6.4-5). A protective soil cover (cushion layer) is normally used when large riprap is installed such as that seen on figure 19.6.4-6. The following considerations are used by Reclamation when placing riprap for slope erosion protection:

- For slope surfaces, placement should always start from the base of the slope, moving upslope, and preferably from the center outward.
- For geotextiles placed on well-prepared subgrade (AASHTO Class B) with no cushion layer, the height of drop for stones weighing less than 250 pounds should be less than 12 inches, and stones weighing more than 250 pounds should be placed without free fall.

Figure 19.6.4-5. Photograph showing riprap placement on a geotextile. The slope height that can be covered by this method is limited by the equipment reach.

- For geotextiles placed on well-prepared subgrade (AASHTO Class B) with a cushion layer over the geotextile, the height of drop for stones weighing less than 250 pounds should be less than 36 inches, and stones weighing more than 250 pounds should be placed with no free fall.
- For geotextiles placed on poorly prepared subgrade (AASHTO Class A) with no cushion layer, the height of drop for stones weighing less than 250 pounds should be less than 12 inches, and stones weighing more than 250 pounds should be placed with no free fall.
- For geotextiles placed on poorly prepared subgrade (AASHTO Class A) with a cushion layer, the height of drop for stones weighing less than 250 pounds should be less than 24 inches, and stones weighing more than 250 pounds should be placed with no free fall.

Figure 19.6.4-6. Photograph showing placement of large riprap as slope protection. Note that a layer of bedding soil has been placed as a cushion under each piece of riprap prior to gently placing the large rock into position.

19.7 Quality Control and Quality Assurance

Problems with geotextile applications/installations are often attributed to poor product acceptance and construction monitoring procedures on the part of the owner and/or installation methods on the part of the contractor. Acceptance and rejection criteria should be clearly stated in the specifications. It is very important that all installations be observed by an experienced and qualified inspector. There are ASTM standards for acceptance and rejection of geotextile shipments. In addition, there are standard sampling and testing requirements during construction (ASTM, 2002).

Specifications typically require the contractor to develop, submit, and follow a quality control plan with the frequencies for sampling and testing of samples required to match those required in the specifications. Also, the design engineer usually develops a quality assurance plan to guide the inspection and independent sampling and testing by Reclamation. A field inspection checklist is presented as follows:

- Review the construction plans and specifications.
- Verify and document listed material properties of supplied geotextile and compare against the specified property values.
- Inspect loads prior to unloading.
- Check to see that the rolls are offloaded and properly stored onsite. Check for any damage.
- Document roll and lot numbers to verify that they match certification documents.
- Inspect and document that the subgrade and anchor trenches (if specified) are constructed in accordance with the specifications.
- Observe that the geotextiles are unrolled and placed over the subgrade without damaging them.
- Observe materials in each roll to ensure that they are the same. Observe rolls for flaws and nonuniformity.
- Obtain test samples according to the specifications.
- Monitor seaming operations.
- Inspect all seams, both factory and field, for any flaws. Note any seams that need repair.
- Collect samples of seams, both factory and field, for testing.
- Observe all operations associated with placement of cover materials to ensure that the geotextile is not damaged.
- Repair all damaged areas that are observed.

All construction activities shall be recorded by photographs and in detailed daily reports.

19.8 Laboratory Testing of Geotextiles

19.8.1 ASTM Test Standards

D 1987-02 Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters

D 4354-04 Practice for Sampling of Geosynthetics for Testing

D 4355-05 Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)

D 4439-04 Terminology for Geosynthetics

D 4491-04 Test Methods for Water Permeability of Geotextiles by Permittivity

D 4533-04 Test Method for Index Trapezoid Tearing Strength of Geotextiles

D 4594-03 Test Method for Effects of Temperature on Stability of Geotextiles

D 4595-01 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method

D 4632-03 Test Method for Grab Breaking Load and Elongation of Geotextiles

D 4716-04 Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products

D 4751-04 Test Method for Determining Apparent Opening Size of a Geotextile

D 4759-02 Practice for Determining the Specification Conformance of Geosynthetics

D 4833-00 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products

D 4873-02 Guide for Identification, Storage, and Handling of Geotextiles

D 4884-03 Test Method for Seam Strength of Sewn Geotextiles

D 4886-02 Test Method for Abrasion Resistance of Geotextiles (Sand Paper/Sliding Block Method)

D 5101-01 Test Method for Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio

D 5141-04 Test Method for Determining Filtering Efficiency and Flow Rate of a Geotextile for Silt Fence Application Using Site-Specific Soil

D 5199-01 Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes

D 5261-03 Test Method for Measuring Mass per Unit Area of Geotextiles

D 5321-02 Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method

D 5322-03	Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids
D 5493-03	Test Method for the Permittivity of Geotextiles Under Load
D 5494-99	Test Method for the Determination of Pyramid Puncture Resistance of Unprotected and Protected Geomembranes
D 5496-98	Practice for In-Field Immersion Testing of Geosynthetics
D 5514-01	Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics
D 5567-01	Test Method for Hydraulic Conductivity Ratio (HCR) Testing of Soil/Geotextile Systems
D 5617-04	Test Method for Multi-Axial Tension Test for Geosynthetics
D 5819-05	Guide for Selecting Test Methods for Experimental Evaluation of Geosynthetic Durability
D 6364-04	Test Method for Determining the Short-Term Compression Behavior of Geosynthetics
D 6389-99	Practice for Tests to Evaluate the Chemical Resistance of Geotextiles to Liquids
D 6461-99	Specification for Silt Fence Materials
D 6685-01	Guide for the Selection of Test Methods for Fabrics Used in Fabric Formed Concrete
D 6707-05	Specification for Circular-knit Geotextile for Use in Subsurface Drainage Applications
D 6917-03	Guide for Selection of Test methods for Prefabricated Vertical Drains (PVD)
D 6992-03	Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition using the Stepped Isothermal Method
D 7005-03	Test Method for Determining the Bond Strength (Ply Adhesion) of Geocomposites

19.8.2 Geosynthetics Research Institute Test Methods

GT1	Geotextile Filter Performance via Long Term Flow (LTF) Tests
GT2	Superseded by ASTM D1987
GT3	Superseded by ASTM D5970
GT4	Discontinued - superseded by ASTM D5493
GT5	Superseded by ASTM D5262
GT6	Superseded by ASTM D6706
GT7	Determination of Long-Term Design Strength of Geotextiles
GT8	Fine Fraction Filtration Using Geotextile Filters

GT9	Grip Types for Use in Wide Width Testing of Geotextiles and Geogrids
GT10	Test Methods, Properties and Frequencies for High Strength Geotextile Tubes used as Coastal and Riverine Structures
GT11	Installation of Geotextile Tubes used as Coastal and Riverine Structures
GT12(a)	Test Methods and Properties for Nonwoven Geotextiles Used as Protection (or Cushioning) Materials – ASTM Version
GT12(b)	Test Methods and Properties for Nonwoven Geotextiles Used as Protection (or Cushioning) Materials – ISO Version
GT13	Test Methods and Properties for Geotextiles Used as Separation Between Subgrade Soil and Aggregate
GT14	Hanging Bag Test for Field Assessment of Fabrics Used for Geotextile Tubes and Containers

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Appendix A

Projects Examples Using Geotextiles

Appendix A

Project Examples Using Geotextiles

Asaayi Dam	Geotextile separator between gravel drain and downstream embankment shell, and geotextile as bedding/filter underneath riprap
Many Farms Dam	Geotextile sock around toe drain pipe
Heart Butte Dam	Geotextile filter over seep inside an outlet works conduit
Red Willow Dam	Geonet composite filter and drain
Summitville Mine	Geotextile filter underneath grouted riprap diversion channel

Project: Asaayi Dam

Location: McKinley County, New Mexico, USA

Geosynthetic Materials Installed: Separation layer: nonwoven needle-punched geotextile with an apparent opening size of a #70 sieve (0.212 millimeter [mm]) and a mass of 8 ounces per square yard (oz/yd^2).

Installation Date: April 2008

Summary: Geotextile was placed between a gravel drain layer and the downstream embankment fill to prevent migration of fine soil into the gravel. The remote site was subject to high costs for import of granular materials such as filter sand and granular bedding material. A total of 5,000 square yards of nonwoven geotextile was substituted for 2,500 cubic yards of imported filter sand, resulting in a project savings of $200,000.

Project Details: Four trees had become established on the downstream embankment of Asaayi Dam about 6 feet above the toe of the slope. Removal of the trees led to the occurrence of muddy seepage flowing from the former tree stump locations about 1 year later. The dam was a homogeneous embankment without filters or drains. A reservoir restriction was imposed to stop the seepage. Evaluation indicated the dam was vulnerable to internal erosion, and it was decided that a downstream filter and drain would be installed.

The toe of the existing dam was excavated to bedrock, and a sand filter and gravel drain were installed (figures A1, A2, and A3). The dam also required an embankment raise and a new spillway to increase the ability to pass large flood events. Borrow material for the embankment raise was fine-grained sandy silt, which is not filter compatible with the gravel drain. Placing this material onto the gravel drain would likely cause contamination of the drain with fine sand and silt. Rather than incur the expense of an imported filter-compatible granular material, a geotextile was selected to provide separation between the gravel drain and the overlying embankment soil. Neither the gravel nor the fine-grained cover soil presented a significant risk of puncturing the geotextile; therefore, an 8 oz/yd^2 fabric was selected. With the dam raise a decision had already been made to flatten the downstream slope from 2H:1v to 2.5H:1V. Slope stability was a concern because the geotextile would be placed on the pre-existing embankment slope of 2H:1V. A slope stability analysis was prepared to verify the safety of the installation.

Performance: The dam has operated satisfactorily since refilling the reservoir in 2009. The existing dam had piezometers drilled through the embankment crest. These instruments were preserved by extending the standpipes through the raised embankment surface. Since refilling the reservoir, the piezometers have shown piezometric levels similar to those experienced prior to the seepage incident.

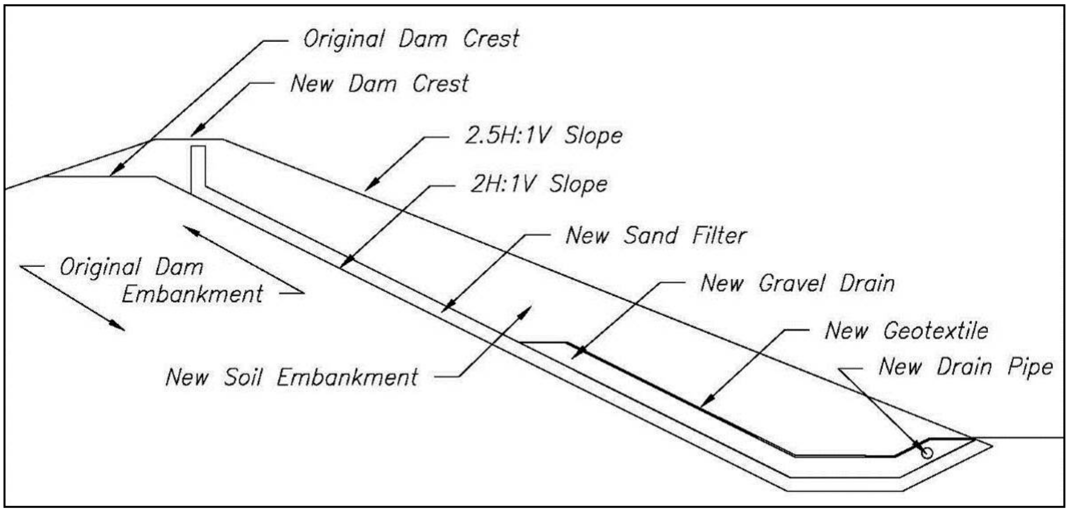

Figure A1. Cross section showing geotextile separator to prevent migration of fine soil from new embankment fill into gravel drain.

Figure A2. Photograph showing placement of sand filter (underneath excavator and partially up embankment slope), gravel drain (light-colored material), geotextile (black-colored material), and new embankment fill.

Figure A3. Photograph showing compaction of embankment fill placed over a geotextile separation layer. View is looking down from the embankment crest.

Project: Many Farms Dam

Location: Navajo Indian Reservation, Apache County, Arizona, USA

Geosynthetic Materials Installed: Geotextile-wrapped perforated high-density polyethylene (HDPE) drainage pipe. The geotextile functions as a filter around the toe drain pipe, which is a single-wall corrugated pipe with 1/16-inch wide slotted perforations. A knitted polyester geotextile sock with an apparent opening size (AOS) of a #30 sieve (0.6 mm) covers the pipe.

Installation Date: July, 2000

Summary: Geotextile wrapping around a toe drain pipe eliminated the need for a second-stage gravel filter between the filter sand and the toe drain. This design approach allowed excavation and installation of the filter sand and toe drain pipe using a shielded-wheel trenching machine in a vertical trench, which did not need to be dewatered.

Project Details: Many Farms Dam has an impermeable core constructed from local silty soils that contain highly dispersive clays. The dam embankment and its foundation suffered from internal erosion of the dispersive soil material. Rehabilitation of the dam included installation of a filter and drainage system, including a downstream toe drain.

The highly dispersive clay soils at the site required the specification of a sand filter with a fine gradation. Design of the toe drain pipe indicated that the sand was too fine and would be liable to erode through the slots in the drainage pipe. A secondary filter comprised of fine gravel would normally be placed between the drainpipe and the filter sand.

The dam is 2,700 feet long and at a remote location where filter sand and clean gravel must be imported at considerable expense. There was a strong desire to economize on the required amounts of filter sand and gravel and to use a trenching machine to minimize the size of the excavation and gain the high productivity of a machine installation. Trenching machines can install backfill and a pipe at the same time; however; they are limited to installing only one type of backfill material. Because a two-stage granular filter could not be efficiently placed by machine, a geotextile-wrapped drainage pipe was substituted for gravel in the re-designed toe drain as shown on figure MF1.

The design change lowered costs by reducing the size of excavation and required amounts of costly filter material used as backfill. A comparison of the required excavation for three different toe drain configurations is illustrated on figure MF2.

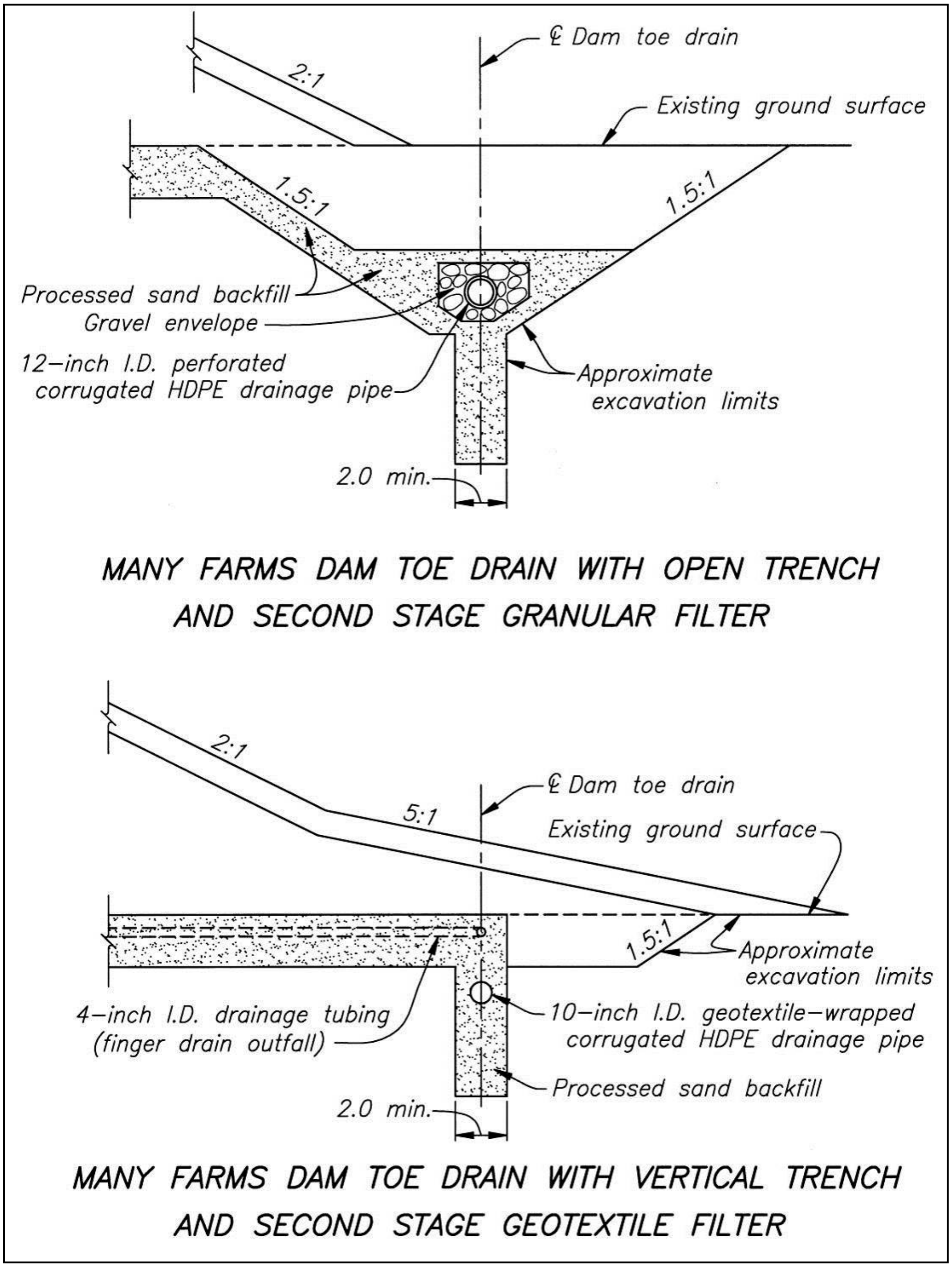

Figure MF1. Illustration showing the original Many Farms Dam toe drain design with a two-stage granular filter (at top) and the re-designed toe drain with a single granular filter containing a geotextile-wrapped pipe.

The unconventional design raised concerns at the Bureau of Reclamation regarding the loss of fines or the potential for clogging of the geotextile over time. The geotextile/corrugated pipe combination would need to retain the primary stage filter (fine sand) material without significant loss of fines through the geotextile and into the drainage pipe. The geotextile would also need to transmit significant seepage flows without becoming clogged, which could reduce the flow capacity of the toe drain system.

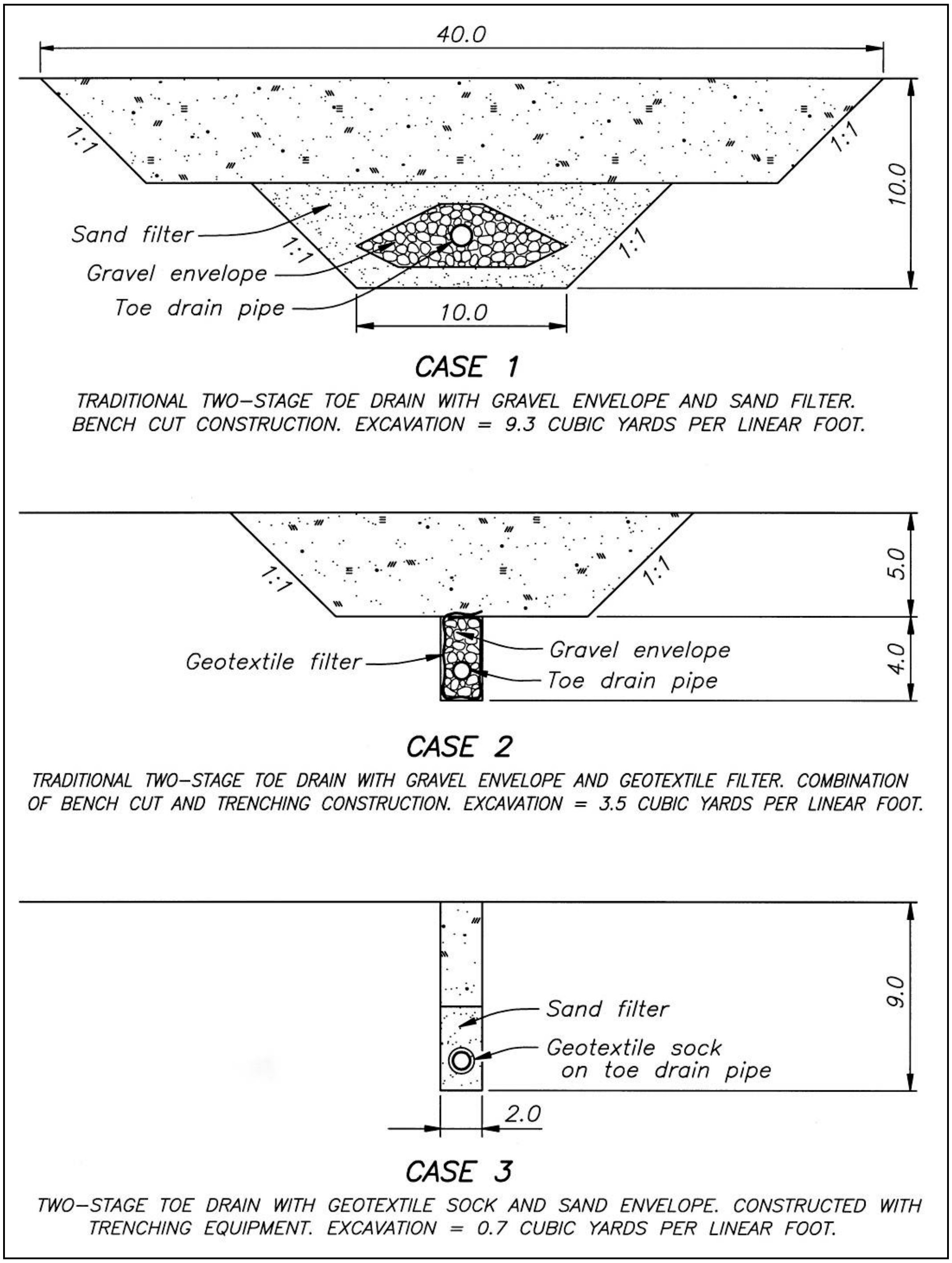

Figure MF2. Illustration showing the required amounts of excavation for three different toe drain configurations.

The concerns about loss of fines and geotextile clogging were addressed by conducting a full-scale laboratory test using the specified filter sand and a sample of the proposed geotextile-wrapped pipe (Swihart, 1999). A watertight test box was constructed to simulate the toe drain system. The box was sealed in a manner such that all flow had to exit one end of the drainage pipe. Water was pumped into the box, causing flow to move through the filter sand, across the geotextile, and into the slots in the corrugated drainpipe. The initial flow rate was increased until the test box began to overflow. The flow rate was reduced slightly, and the system was found to accommodate a maximum steady flow rate of 7.3 gpm/ft of pipe length. This flow rate is almost 100 times the design seepage rate of 0.08 gpm/ft predicted for the actual installation.

The test was run at the maximum flow rate for 13 days. Water exiting the pipe was directed into a reservoir where sand removed by flow through the system was captured. The lost filter material was periodically removed, dried and weighed, and plotted in relation to time. The test showed a loss of 1,000 grams of filter material per foot of pipe length after which a stable filter formed with no further loss of material. This loss of material equates to a thickness of 0.087 inch of material around the circumference of the pipe.

The box was opened after the test, and the filter sand was carefully excavated to expose the area around the geotextile. A graded sand filter was seen to have built up around the outside of the geotextile-wrapped pipe. The filter was about 1-inch thick below the pipe invert and thinner (less than ½ inch thick) around the remainder of the pipe perimeter. Because the amount of material loss was higher than anticipated, the design was revised to provide a slightly coarser filter sand gradation as shown in the following table:

Sieve size	Original filter specification (% finer)	Revised filter specification (% finer)
0.75	100	100
0.375	100	85–100
#4	95–100	70–90
#8	90–100	60–80
#16	70–100	50–70
#30	40–85	35–60
#50	20–55	20–45
#100	10–30	10–30
#200	0–3	0–5

Performance: The quarry supplying filter sand to the site could not keep up with the demands of the highly productive trenching machine installation (figures MF3 and MF4).

Figure MF3. Photograph of a trenching machine excavating a trench and backfilling it with a geotextile-wrapped pipe surrounded by a sand backfill.

Figure MF4. Photograph of the toe drain trench showing geotextile-wrapped pipe without sand backfill. The trenching machine was so efficient that sand deliveries to the site could not keep up with pipe installation rates.

For future projects, the specifications will require that sufficient sand stockpiles be placed at the site prior to initiation of the trenching and pipe installation operation. An extended drought at the site occurred after rehabilitation of the dam. First filling of the reservoir occurred in 2005. Flow in the toe drains has not yet been observed.

Figure MF5. Photograph of a geotextile-wrapped pipe emerging from a completed segment of the Many Farms Dam toe drain trench.

References: Swihart, J. (1999). Full scale laboratory testing of a toe drain with a geotextile sock. Bureau of Reclamation, Materials and Engineering Research Laboratory, DSO-98-014, Denver, Colorado.

Project: Heart Butte Dam

Location: Grant County, North Dakota, USA

Geosynthetic Materials Installed: Nonwoven needle-punched staple fiber geotextile with an AOS of a #100 sieve (0.15 mm) and a mass of 16 oz/yd^2.

Installation Date: March 6, 2013.

Summary: A geotextile was placed in an outlet works conduit to act as a filter to stop the migration of silt and fine sand, which was being carried by seepage through a joint in the concrete pipe.

Project Details: The outlet works conduit has been monitored for seepage through cracks and joints since construction of the dam. In January 2013, sand deposits were found in the conduit (figure HB1). A sample of the sand was analyzed for gradation. It was determined that fine sand and silt were being carried by seepage flow through a construction joint in the conduit. This form of internal erosion was determined to be a threat to the dam.

Figure HB1. Photograph showing sand deposits found inside the outlet works conduit.

It was decided to place a geotextile filter over the joint. The conduit does not experienced pressurized flow when it is in operation, so placing a filter inside the pipe was a viable option. This would allow seepage to continue, but would filter the flow and prevent further migration of fine soil particles into the conduit. The other option considered was to seal the joint by injecting a sealing compound, but it was deemed to be less desirable because it would stop seepage flow, and the seepage might find another pathway such as along the outside of the conduit. The dam was constructed without the benefit of an engineered filter, so seepage migration to the downstream toe might result in another location for internal erosion to develop.

A nonwoven geotextile with an AOS of a #100 sieve (0.15 mm) and a mass of 16 oz/yd^2 was selected for the application. The small AOS was selected so the filter would retain the silt and fine sand that was being transported by the seepage flow. A stainless steel cover plate made of 3/6-inch thick stainless steel with dimensions of 28 by 52 inches in size was fabricated to match the curved interior shape of the conduit. The plate (figure HB 2) was made to be bolted onto the inside of the conduit and hold the geotextile in place when the conduit was in operation.

Figure HB2. Photograph showing the fabricated stainless steel plate that will be used to attach a geotextile to the outlet works conduit. Note the slots down the middle to allow seepage though the plate. Slots around the perimeter are for the anchor bolts.

Although a thick geotextile was used, it was found that two layers were necessary to account for irregularities in the conduit surface. Anchor bolts were installed, and the nuts were tightened enough to provide a snug fit to hold down the geotextile. The desire was to provide a fit tight enough to make a seal against the concrete conduit but not compress the geotextile so much that it would severely restrict seepage flow. The installation was made on March 6, 2013, by Bureau of Reclamation (Reclamation) Dakotas Area Office personnel and proved successful (figures HB3, HB4, and HB5). Seepage continued, but no further sand deposition was experienced.

Performance: Seepage through the joint continued to flow with seepage observed coming through the slots in the plate and through the bolt holes in the plate. Some restriction of the flow was observed. When the nuts were tightened, the seepage limits expanded. Seepage from the joint was observed as much as 6 inches above the outside limits of the steel plate. Fortunately, the flow from the portions of the joint outside of the filter are not transporting soil particles. The installation was verified by placing a sand-filled inner tube about 10 feet downstream from the seepage area to form a shallow pond inside the conduit to trap sediment (figure HB6). No sediment has been observed.

Figure HB3. Photograph showing two layers of geotextile having been placed over the conduit joint and anchor bolts.

Figure HB4. Photograph showing workers lowering the cover plate into place.

Figure HB5. Photograph showing the nuts have been tightened down to complete the installation of the cover plate and underlying geotextile filter.

Figure HB6. Photograph showing a sand-filled inner tube that was used to form a temporary sediment trap within the conduit about 10 feet downstream from the geotextile filter installation.

Project: Red Willow Dam

Location: Red Willow County, Nebraska, USA

Geosynthetic Materials Installed: Geonet composite filter and drain. A 5-mm (200 mil) thick bi-planer geonet with nonwoven needle-punched geotextiles bonded to each side. One geotextile is a 16 oz/yd^2 fabric with an AOS of a #100 sieve (0.15 mm), and the other is a 6 oz/yd^2 fabric with an AOS of a #70 sieve (0.6 mm).

Installation Date: July, 2012 through December, 2012

Summary: Differential settlement and cracking within the embankment required the dam be modified to protect the embankment from seepage-induced internal erosion. A two-stage chimney zone (primary) and a geonet composite (secondary) were installed. The geonet composite was installed between the excavated downstream slope of the embankment and the chimney zone to span across open cracks that existed in the embankment, preventing propagation of this cracking across the new chimney filter/drain, as well as providing a boundary where the chimney sand filter cannot be lost into the open cracks during placement. Additionally, the geonet composite acts as a secondary filter and drain system within the embankment in combination with the primary chimney zone. The geonet composite is intended to be the primary filter/drain protection above the top of the chimney zone; however, it was determined that this application is not critical to the safety of the dam as determined in a risk-based framework.

Project Details: The modified homogeneous dam was originally constructed without designed filters in 1962. In response to the high risk of internal erosion failure through the embankment, dam safety modifications were implemented in 2011 to reduce the risks to acceptable levels based on Reclamation's Public Protection Guidelines.

As shown in on figure RW1, the chimney filter and drain consists of a geonet with geotextiles bonded to each side, a modified ASTM C33 fine aggregate sand filter (zone 2), a C33 coarse aggregate No. 57 gravel drain (zone 2A), and a geotextile separator on top of the Zone 2A to protect the gravel from contamination by the overlying zone 1 embankment berm material. The geonet portion of the geonet composite is specified to have a maximum thickness of 200 mil (5 mm). The geotextile on the upstream side of the geonet composite (the side in contact with the excavated embankment surface) is specified as a heavy weight, 16 oz/yd, nonwoven, needle-punched geotextile. Design calculations used for retention assumes that the AOS of the geotextile should be less than two to three times the D_{85} of the base (silty embankment) materials. This was considered to be satisfactory retention criteria by the design team. The AOS

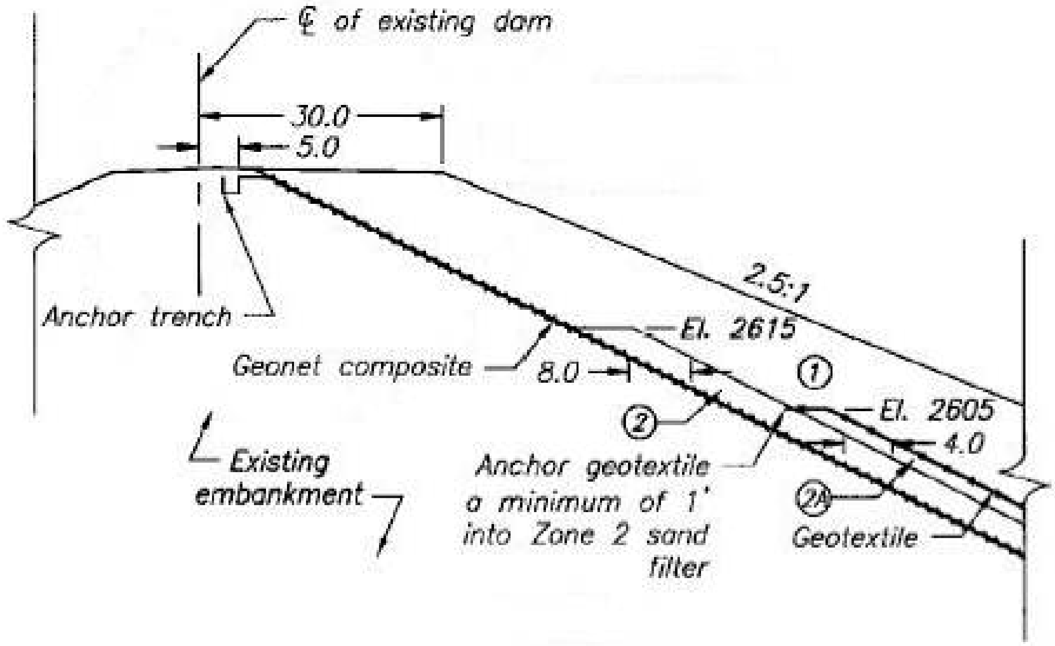

Figure RW1. Cross-section view of Red Willow chimney filter and drain incorporating a geonet composite.

of the upstream geotextile should be approximately 0.15 mm (#100 sieve), which is approximately 2.5 times the average D_{85} of the embankment material at Red Willow Dam. The geotextile on the downstream side of the geonet composite is specified as a 6 oz/yd fabric, which will be adequate to retain the sand from the chimney filter.

Due to the steep excavation slopes, 2H:1V up to 1-1/2H:1V in some places, preparation of the subgrade required care. The excavated surface required backdragging with a bulldozer and hand labor raking and removing loose earth materials. The subgrade requirement was a firm and relatively even and smooth surface free of offsets, abrupt indentations, and/or surface protrusions greater than 1-1/2 inches. Figure RW2 shows the prepared surface and initial installation of geonet composite panels.

The geonet composite, placed on the downstream excavated embankment surface, was installed in panels (one width of geonet composite roll) starting from the dam crest down to the top of the existing sand blanket. Seaming of the panels was accomplished by overlapping adjacent panels a minimum of 6 inches. Both top and bottom geotextile components of the composite were seamed by heat welding (figures RW3 and RW4). The geonet composite was fastened with nylon cable ties on 5-foot spacings as shown on figures RW5 and RW6.

Figure RW2. Photograph showing a view of the prepared downstream surface and initial installation of geonet composite panels at Red Willow Dam.

Figure RW3. Photograph showing heat bonding a seam in the lower 16 oz/yd^2 geotextile in the geonet composite.

Figure RW4. Photograph showing a closeup view of the heat bonding of a seam in the lower 16 oz/yd^2 geotextile in the geonet composite.

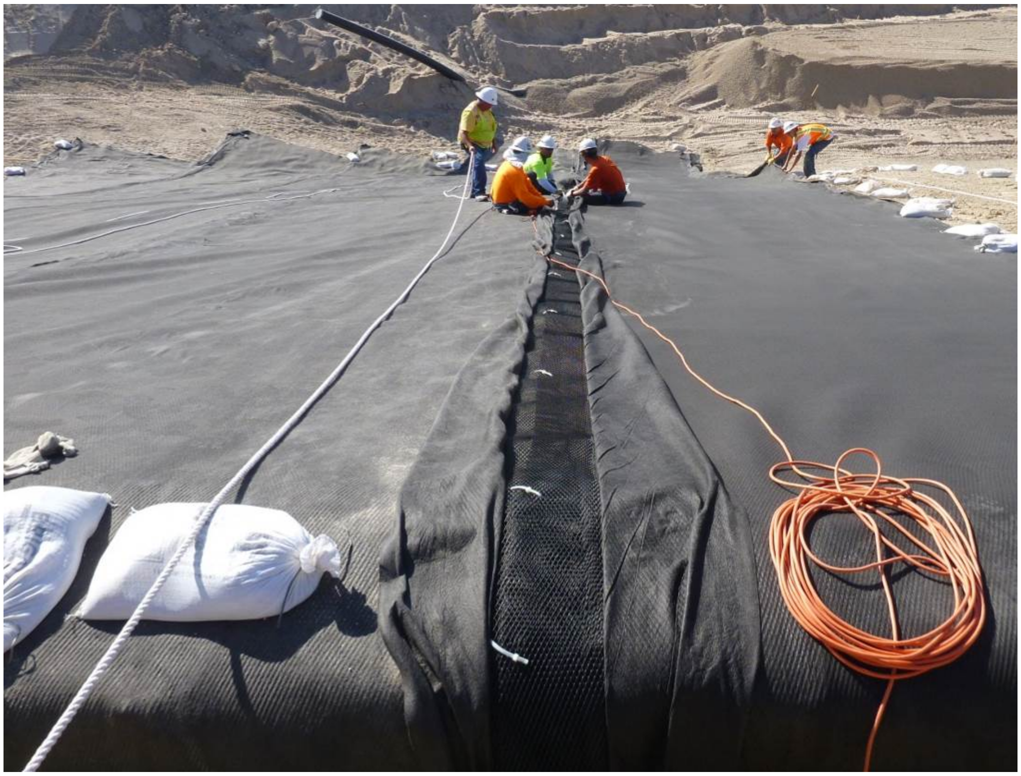

Figure RW5. Photograph showing the use of nylon ties to join the geonet layer of the composite.

Figure RW6. Photograph showing a closeup view of nylon ties joining the geonet layer of the geonet composite.

A layer of sand a minimum of 3 inches thick was placed on top of the geonet composite in order to protect the exposed top geotextile layer from ultraviolet (UV) degradation. Although the specification required covering the geonet composite within 14 days of installation (based on manufactures guidelines), this requirement was changed to allow a maximum of 30 days of exposure based on some field trials and laboratory testing of the top component geotextile (6 oz/yd^2) as shown on figure RW7. Field testing indicated that the tensile strength of the geotextile did not fall below the required 70-percent limit until exposure beyond 30 days.

The sand cover was placed by the contractor as shown on figure RW8. A "telebelt" telescoping conveyor was used to cover the geonet composite with an initial layer of C33 sand. This cover was required to prevent UV degradation due to exposure to sunlight until the chimney zone could be constructed. Note that placing cover soil on a geotextile from upslope to downslope is normally not allowed because the combined forces from the cover soil and equipment travel have been shown to damage the geotextile. In this case, the telescoping conveyor placing equipment does not travel upon the cover soil.

The chimney zone terminates at the existing blanket drain. This blanket was was modified to incorporate a new toe drain pipe placed within a gravel envelope. Addtional use of geotextile for this modification included the use of a 16 oz/yard nonwoven needle-punched geotextile placed over the gravel envelope to protect it from contamination by the zone 1 material. The toe drain consisted of a 12-inch-diameter, perforated HDPE pipe surrounded by a 1-foot-thick gravel envelope as shown on figure RW9. A photograph of the geotextile installed over the gravel and initial placements of the fine-grained berm materials is shown on figure RW10.

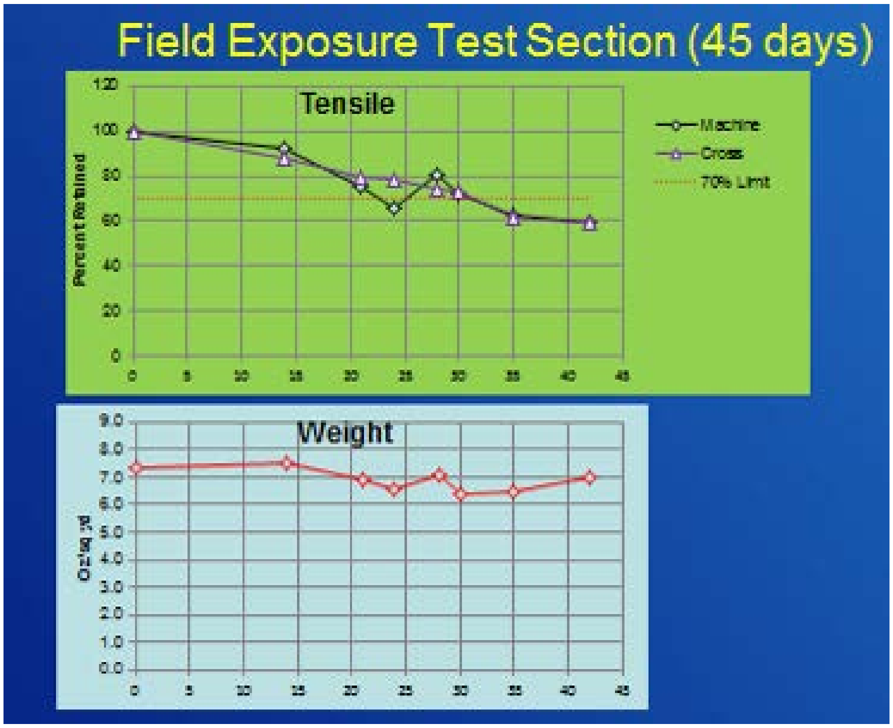

Figure RW7. Field exposure test section results for the Red Willow Dam geotextile. The horizontal axis is exposure time in days. The vertical axis for the upper graph is percent tensile strength retained. The vertical axis for the lower graph is fabric weight in oz/yd^2.

Figure RW8. Photograph showing a telescoping conveyor placing sand cover onto the geonet composite at Red Willow Dam.

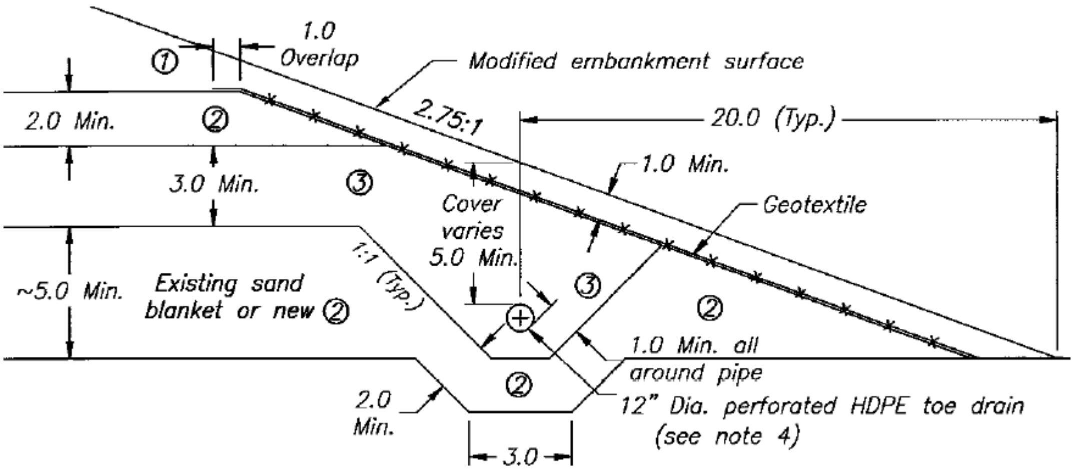

Figure RW9. Cross section showing toe drain detail with geotextile separating zone 1 from the zone 2 sand and the zone 3 gravel.

Figure RW10. Photograph showing installation of geotextile and zone 1 over the toe drain.

One risk with placing the geonet composite upstream of the two-stage chimney filter and drain is clogging of the geotextile. Excessive clogging could prevent seepage from reaching the downstream layers of sand filter and gravel drain. This risk was considered and found to be minimal for this particular site. Most of the embankment is dry, and if clogging of the geonet were to occur, it would be very localized and would not affect the overall performance of the system.

Performance: The dam safety modifications were completed in December 2013. However, due to release requirements identified in the Republican River Compact Agreement, filling of the reservoir has not yet begun.

Project: Summitville Mine

Location: Rio Grande County, Colorado, USA

Geosynthetic Materials Installed: A 16 oz/yd^2 nonwoven geotextile with AOS of a #100 sieve.

Installation Date: November 2012

Summary: Geotextile was placed as a filter/bedding underneath grouted riprap on a 3H:1V slope to replace a failed stream channel lining consisting of loose riprap on geotextile on a 2H:1V slope.

Project Details: Acid water is temporally stored behind the Summitville Dam Impoundment at the Summitville Mine while it awaits water treatment. The project required a diversion of Wightman Fork Creek to convey uncontaminated creek flow around the dam. An outfall structure called the "Rundown" at the end of the diversion conveys flow from two culverts down a steep 2H:1V slope, returning the water to the original creek alignment. The "Rundown" channel was designed by a private consultant with a riprap lining placed loose onto a geotextile bedding. The channel experienced an erosion failure in 2010 after experiencing flows that were a fraction of the design flood event.

The erosion damage shown on figure SM1 was temporarily repaired by placing additional geotextile and riprap over the erosion hole. In 2012, the United States Environmental Protection Agency requested technical assistance from Reclamation to determine the cause of the erosion failure and to formulate a solution to provide a stable channel capable of passing a 100-year flood event of 3,900 cubic feet per second (ft^3/s). Reclamation reviewed the design documents and examined the structure as seen on figure SM2.

The original design combined very aggressive channel hydraulics with a marginally stable riprap placement. The plan was to take 3,900 ft^3/s of flow down a 40-foot-wide channel at a slope of approximately 2H:1V. The channel was lined with a geotextile filter and covered with riprap armor with a design average diameter (D_{50}) of 2.5 feet. The selection of a channel with a slope of 2H:1V and a width of only 40 feet for a design flow of 3,900 ft^3/s resulted in deep and fast flow conditions. Velocities would be about 36 feet per second and the flow would overtop the riprap by nearly 2 feet, creating buoyant effects. The unit discharge of 97.5 ft^3/s per foot of channel width would be challenging even for a concrete spillway. Furthermore, the riprap size was selected using a method meant for channels having not more than 2-perccent slopes – this slope was 50 percent. In addition to the high velocity flow, there would be impact forces due to the jet of water flowing out of the culvert and striking the riprap. The partial failure seen

Figure SM1. Photograph showing damage to the riprap armor and underlying geotextile after a small flood event in 2010 at the Summitville Mine.

Figure SM2. Photograph showing an overview of the "Rundown" as it appeared in the summer of 2012 after some repair and addition of riprap. This is the 2H:1V channel that Reclamation was asked to evaluate.

in 2010 was at a location where the flow from the culvert struck the riprap channel. Had a proper sizing method been used, an average riprap diameter of over 5 feet would have been calculated (an impractical size), indicating the channel design was not realistic.

Compounding the hydraulic design errors was a lack of a slope stability analysis. Placing riprap onto a geotextile on a steep slope raises slope stability concerns. A geotextile typically has lower interface friction strength than granular bedding. At a 2H:1V slope, the riprap was placed on a surface where most of the frictional resistance to sliding was already mobilized by the steep slope. The addition of flow-related forces would further reduce any remaining frictional strength available for sliding resistance. As a result, small flows were able to push the riprap off the geotextile, resulting in the damage experienced in 2010 (see figure SM1).

It was decided to modify the channel characteristics by flattening and widening. The 2H:1V slope was reduced to 3H:1V. The concrete apron and one of the wing walls at the top of the slope was extended. A sill at the end of the apron created a 2-foot-deep pool of water for the culvert outflow to impinge upon.

Figure SM3. Photograph showing the flattened 3H:1V slope and initial placement of geotextile, blasted rock, geotextile, and riprap in the left channel berm on October 16, 2012.

Extending the apron resulted in a widening of the start of the riprap channel to 60 feet. The channel was shaped to progressively increase in width, reaching 100 feet at the base of the slope where a wide flat bench was placed 10 feet above the stream channel. A wider channel was desired but not possible due to the presence of the dam on one side and a turbine house on the other side of the channel.

A grouted riprap structure was selected as the best option to address the flow erosion problem. Reclamation recommended a grouted riprap design concept using large boulders (3 to 5 feet in diameter) with an average size D_{50} = 4.0 feet. Also, to further reduce flow velocity, the grout was placed so the upper 2-feet of the riprap boulders would project up above the grout surface to produce a very rough channel surface. The roughened channel helps slow the flow and introduces air into the flow. Although there was a desire to use a geotextile filter, this would have an adverse effect upon slope stability, which had to be addressed. Slope stability would be enhanced by the flattened slope, the introduction of a 2-foot-thick layer of blasted rock for underdrainage to prevent pore pressure buildup underneath the grouted riprap layer, and the use of two deep cutoff trenches that would act as shear keys to provide additional support to the slope. One cutoff trench was placed at the base of the slope and one at midslope. These deep trenches were filled with 4- to 5-foot diameter boulders, which were grouted in place. The underdrainage is also essential to prevent buildup of uplift pressures. The grout is expected to crack around the rocks, but the grouted riprap will still function properly (U.S. Army Corps of Engineers, 1992). A 4,000-pound-per-square-inch concrete with 1/4-inch aggregate and polypropylene fibers was used for the grout.

Geotextile was placed below the blasted rock drainage layer to protect the underlying soil from erosion. Geotextile placed on top of the blasted rock layer was added to protect the layer from infilling with grout. Since the geotextile layers introduce potential planes of weakness regarding sliding, the drainage layer and the deep cutoff trenches are essential to maintain slope stability. The midslope cutoff trench interrupts the plane of the geotextile filter layer and provides a massive midslope anchor. The cutoff trench at the base of the slope provides an anchor at the base of the grouted riprap layer. On the flat bench, where a hydraulic jump is expected, drainage pipes were incorporated into the blasted rock layer to further enhance drainage underneath the grouted riprap layer.

Performance: The slope has been reduced from 50 percent to a slope of 33 percent, which has reduced flow velocities from a maximum of 34 ft/s to around 27 ft/s for the 100-year flood event. For most runoff events, the velocities will be around 20 to 24 ft/s, which is a reasonable value for grouted riprap. The facility has only seen one spring runoff event to date, but performed well.

Figure SM4. Photograph showing excavation of the lower cutoff trench at the toe of the grouted riprap slope. The blasted rock underdrain is visible underneath the geotextile fabric in the lower right portion of the photograph.

Figure SM5. Photograph showing flow in the reconstructed structure on May 22, 2013.

References: Corps of Engineers (1992) Design and Construction of Grouted Riprap, Technical Letter No. 1110-2-334. Department of the Army, U.S. Army Corps of Engineers, Washington, D.C.

Appendix B

Sample Specifications

Appendix B

Sample Specifications

USBR Standard Specification for Geotextile Materials and Installation

SECTION 02342 GEOTEXTILE	
GUIDE SPECIFICATION DEPARTMENT OF THE INTERIOR – BUREAU OF RECLAMATION	
REVISIONS Reference Standards Checked/Updated: 11/12/07	
Content Revisions:	
8/12/04	Added RSN to submittals. Added burst strength to material requirements. Minor revisions.
7/8/03	Revised values in table for 16 oz fabric. Changed subgrade imperfections to 1-1/2 inch and added vibratory roller. Added LGP equipment. Updated name of ASTM. Minor revisions.
6/15/01	Added and revised footnotes for seaming.
2/9/01	Changed "bid" to "offered".
7/21/00	Added tables for two more geotextile weights and corrected table values.
8/14/98	First CSI95 draft
Editorial/Format Revisions:	
11/12/07	Changed template and added blank page code at end.
7/1/02	First MS Word version
Template: CSI_02a.dot	
NOTES	
Please provide comments on guide specifications to LAN address: TalkToGuideSpecs (talktoguidespecs@do.usbr.gov)	

SECTION 02342 - GEOTEXTILE

PART 1 GENERAL

1.01 MEASUREMENT AND PAYMENT

A. Geotextile:

1. Measurement: Surface area required to be covered [1][including geotextile placed in anchor trench], except no allowance will be made for seam overlap, repairs, or waste.
2. Payment: Square yard price offered in the schedule.

1.02 REFERENCES

A. ASTM International (ASTM)

1.	ASTM D 3786-06	Hydraulic Bursting Strength of Textile Fabrics – Diaphragm Bursting Strength Tester Method
2.	ASTM D 4355-07	Deterioration of Geotextiles by Exposure to Light, Moisture, and Heat in a Xenon-Arc Type Apparatus
3.	ASTM D 4491-99a(2004)	Water Permeability of Geotextiles by Permittivity
4.	ASTM D 4533-04	Trapezoid Tearing Strength of Geotextiles
5.	ASTM D 4632-91(2003)	Grab Breaking Load and Elongation of Geotextiles
6.	ASTM D 4751-04	Determining Apparent Opening Size of a Geotextile
7.	ASTM D 4833-00	Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
8.	ASTM D 5261-92(2003)	Measuring Mass per Unit Area of Geotextiles

1.03 SUBMITTALS

A. Submit the following in accordance with Section 01330 – Submittals

B. RSN 02342-1, Manufacturer's certification:

1. Geotextile furnished meets specified chemical, physical, and manufacturing requirements.

[1] Include if anchor trench required.

C. [2]RSN 02342-2, Samples:

1. Include manufacturer's certified test results covering properties listed in Table 02342B – Geotextile Physical Properties.
2. Samples: One yard in length from entire roll width.
3. Mark samples:
   a. Project name and contract number.
   b. Product identification.
   c. Lot number.
   d. Roll number.
   e. Machine direction.
   f. Quantity represented.
4. [3] [Number of samples: {1} {Table 02342A – Geotextile Sampling Requirements. Frequency of sampling may be increased if a geotextile sample does not meet specification requirements.

[4] [Table 02342A. Geotextile sampling requirements

Number of rolls to be furnished	Number of rolls to be sampled
1 - 2	1
3 - 8	2
9 - 27	3
28 - 64	4
65 -125	5
126 - 216	6
217 - 343	7
344 - 512	8
513 - 729	9
730 - 1000	10

D. [5] RSN 02342-3, Protection method:

1. Method to protect exposed geotextile, when covering is not possible within 14 days.

[2] Recommended submittal time: At least [45] days before delivery to job site. When TSC responsible for submittal review, submit to 86-68180.
[3] For most jobs, one sample should be sufficient. Include table only for larger jobs.
[4] Edit table to reasonably correspond with number of rolls expected to be furnished. Number of samples is cube root of top number in range.
[5] Recommended submittal time: At least [45] days before delivery to job site. When TSC responsible for submittal review, submit to 86-68180.

E. [6] Sewn seams, if used:

1. Certification stating that polymeric threads to be used for sewing have chemical resistance properties equal to or exceeding those of geotextile.
2. Include data showing that sewn seams have tensile strength of not less than specified percent of parent geotextile material.

1.04 DELIVERY, STORAGE, AND HANDLING

A. Wrap geotextile rolls in relatively impermeable and opaque protective covers.

B. Mark or tag geotextile rolls with manufacturer's name, product identification, lot number, roll number, and roll dimensions.

C. Mark geomembrane with special handling requirements such as "This Side Up" or "This Side Against Soil to be Retained".

D. Protect geotextile from ultraviolet light exposure, temperatures greater than 140 degrees F (60 degrees C), precipitation or other inundation, mud, dirt, dust, puncture, cutting, or other damaging or deleterious conditions.

E. Elevate and cover material stored outside with waterproof membrane.

PART 2 PRODUCTS

2.01 GEOTEXTILES

A. Needle-punched, nonwoven geotextile comprised of long-chain polymeric filaments composed of at least 85 percent, by weight, polyolefins or polyesters.

B. Orient filaments into stable network which retains its structure during handling, placement, and long-term service.

C. Stabilizers or inhibitors added to filament base material: Resist deterioration due to ultraviolet or heat exposure.

D. Geotextile edges: Selvaged or otherwise finished to prevent outer material from pulling away.

E. Conform to roll values listed in Table 02342B – Geotextile Physical Properties.

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[6] Recommended submittal time: At least [45] days before delivery to job site. When TSC responsible for submittal review, submit to 86-68180.

1. Values listed are minimum average roll values (MARVs) unless otherwise noted.
2. Test results for weaker principal direction shall meet or exceed minimum values listed in the table.
3. Mass per unit area is a nominal value and is provided for information purposes only.

F. Direct exposure to sunlight: Withstand 14 days with no measurable deterioration.

[7] [Table 02342B. Geotextile physical properties

Property	Test method	Required values
Mass per unit area, nominal	ASTM D 5261	4 oz/yd^2
Grab tensile	ASTM D 4632	90 lb
Elongation at break	ASTM D 4632	50 percent
Trapezoidal tear	ASTM D 4533	40 lb
Puncture strength	ASTM D 4833	50 lb
Burst strength	ASTM D 3786	140 lb/in^2
Permittivity	ASTM D 4491	1.5 sec^{-1}
Apparent opening size (minimum U.S. sieve No. / maximum opening size)	ASTM D 4751	70 U.S. sieve
UV resistance – Tensile strength retained at 500 hours, minimum	ASTM D 4355	70 percent

Table 02342B. Geotextile physical properties

Property	Test method	Required values
Mass per unit area, nominal	ASTM D 5261	8 oz/yd^2
Grab tensile	ASTM D 4632	200 lb
Elongation at break	ASTM D 4632	50 percent
Trapezoidal tear	ASTM D 4533	70 lb
Puncture strength	ASTM D 4833	90 lb
Burst strength	ASTM D 3786	300 lb/in^2
Permittivity	ASTM D 4491	1.0 sec^{-1}
Apparent opening size (minimum U.S. sieve No. / maximum opening size)	ASTM D 4751	70 U.S. sieve
UV resistance – Tensile strength retained at 500 hours, minimum	ASTM D 4355	70 percent

[7] Select table(s) based on design and construction requirements. Delete table(s) not required. Renumber table(s) if more than one weight of textile required.

Table 02342B. Geotextile physical properties

Property	Test method	Required values
Mass per unit area, nominal	ASTM D 5261	16 oz/yd^2
Grab tensile	ASTM D 4632	380 lb
Elongation at break	ASTM D 4632	50 percent
Trapezoidal tear	ASTM D 4533	140 lb
Puncture strength	ASTM D 4833	230 lb
Burst strength	ASTM D 3786	700 lb/in^2
Permittivity	ASTM D 4491	0.5 sec^{-1}
Apparent opening size (minimum U.S. sieve No. / maximum opening size)	ASTM D 4751	100 U.S. sieve
UV resistance – Tensile strength retained at 500 hours, minimum	ASTM D 4355	70 percent

2.02 PINS

A. Pins: 3/16-inch-diameter, 18-inches long steel pins, pointed at one end, and fitted with 1-1/2 inch-diameter washer at other end.

2.03 CRUSHED GRAVEL

A. In accordance with section [8] [02_] - Gravel.

PART 3 EXECUTION

3.01 SUBGRADE PREPARATION

A. Prepare surface upon which geotextile is to be placed to a firm surface, reasonably even and smooth, and free of offsets, abrupt indentations, and protruding materials greater than 1-1/2 inches.

B. [9][Roll with vibratory roller.]

C. Fill low spots with crushed gravel or compacted native material.

D. Obtain COR approval of subgrade before installing geotextile.

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[8] Complete section number.

[9] Include when very smooth surface required and subgrade is coarse, especially angular, material.

3.02 INSTALLATION

A. Place geotextile in the manner and at locations shown on drawings.

B. Lay geotextile smoothly, free of tension, stress, folds, wrinkles, or creases so far as is practical and except where required in these specifications.

C. Shingle overlaps on slopes with upstream roll placed over downstream roll.

   1. [10][On slopes steeper than _H:_V, roll out geotextile up or down slope.]

D. Pin, staple, or weight to hold geotextile in position. [11][Do not puncture underlying geomembrane with anchors.]

E. Anchor terminal ends of geotextile with key trenches or aprons at crest and toe of slopes.

F. In the presence of wind, weight geotextiles with sandbags or equivalent until cover material placed.

G. Do not entrap stones, soil, excessive dust, or moisture in geotextile that could damage geotextile or hamper subsequent seaming.

H. Do not drive or operate equipment directly on geotextile.

   1. Cover material depth required for equipment travel over geotextile, minimum: [12][__] inches.

I. [13][Place cover material with a low-ground-pressure (LGP) wide track crawler type dozer.

   1. Ground pressure, maximum: 5 lb /in^2.
   2. Maintain 1.5 feet of cover material under LGP tracks during placement.
   3. Maintain maximum of 1.5 feet of push height on dozer blade when spreading material on slope areas.
   4. Push cover material upslope.]

J. Drop height of cover material on to geotextile, maximum: [14][ ].

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[10] Include when geotextile required to be placed on relatively steep slope. Insert definition for steep slope.

[11] Delete if geomembrane not used on job.

[12] Insert depth of cover material required

[13] Include when equipment travel required over geotextile to place cover material.

[14] Specify drop height depending on construction conditions. Typical values are 1 foot, 2 feet, or 3 feet.

K. Cover geotextile within 14 days after geotextile placement.

1. If covering geotextile with specified material is not possible within 14 days, protect exposed geotextile with suitable cover approved by the Government.

2. Replace geotextile not protected.

L. [15][Compact fill against geotextile in accordance with Section 02302 - Compacting Earth Materials.]

3.03 SEAMING

A. Join adjacent sheets of geotextile by [16][overlapping, sewing, or thermal welding].

B. Overlapped seams:

1. Overlap minimum: [17][ ].

2. Upstream/upslope roll placed over the downstream/downslope roll.

3. Weight or pin on 3-foot centers to secure the overlap during placement of cover material.

   a. Do not use pins when installed over geomembrane.

C. [18][Sewn seams:

1. Interlocking or sewn twice.

2. Thread:

   a. Contrasting color.

   b. Chemical resistance: Equal to geotextile.

3. Sew geotextiles continuously. Spot sewing is not allowed.

4. Sewn seam strength: Not less than 70 percent of parent material strength.]

3.04 [19][RIPRAP INSTALLATION

A. Place riprap or backfill material so as not to damage geotextile.

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[15] Include when cover material is required to be compacted. Minimum density for geotextile cover material is often not required.

[16] Select type of seaming to be allowed.

[17] Specify overlap depending on subgrade firmness. Typical values are 12, 24, or 36 inches.

[18] Delete if sewn seams not allowed or required.

[19] Delete if riprap not used on job. Modify as appropriate for other materials. If riprap is used, delete redundancies between this section and Section 02375 – Riprap.

1. Smaller than 6-inch-diameter riprap: Place directly on 8 oz geotextile with drop height not exceeding 3 feet.
2. 6-inch to 12-inch-diameter riprap: Place directly on 16 oz geotextile with drop height not exceeding 1 foot.
3. Greater than 12-inch-diameter riprap: Use with 4-inch gravel cushion over 16 oz. geotextile. Place with drop height not exceeding 1 foot.

B. Before placing riprap, demonstrate that placing technique will not damage geotextile or underlying geomembrane. If the demonstration does not show that riprap can be installed without damaging geotextile, modify riprap placing technique (such as reducing drop height, installing additional layer of sacrificial geotextile, or installing additional gravel cushion).

C. Begin riprap placement at toe and proceed up slope.]

3.05 REPAIRS

A. At placement, geotextile will be rejected if it has defects, rips, holes, flaws, deterioration, contamination, or damage.

B. Replace or repair geotextile damaged during installation or placement of cover in the following manner:

1. Remove cover from damaged area of geotextile.
2. Remove any soil or other material which may have penetrated torn geotextile.
3. Repair damaged geotextile by placing additional layer of geotextile to cover damaged area and [20][either sew the patch to undamaged geotextile according to sewing requirements stated above or] overlap undamaged geotextile by at least 3 feet on all sides.

3.06 [21][SAFETY

A. If white colored geotextile is used, take precautions against “snowblindness” of personnel.]

3.07 FIELD QUALITY CONTROL

A. After installation, examine entire geotextile surface to ensure that potentially harmful foreign objects (such as needles) are not present.

B. Remove foreign objects or replace geotextile.

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[20] Delete if sewn seams are not included.
[21] Include only for large jobs. Delete for most jobs.