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An Introduction to Geotextiles in Pavement and Drainage Applications (Video Course)

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AN INTRODUCTION TO GEOTEXTILES IN ENGINEERING APPLICATIONS

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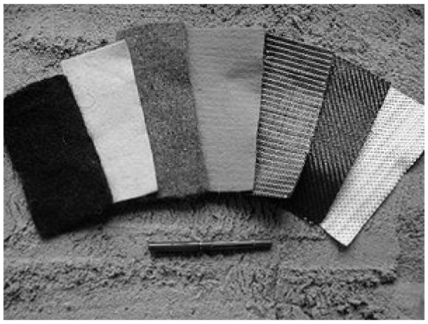
1. GEOTEXTILES IN GENERAL

1.1 Scope

This course covers physical properties, functions, design methods, design details and construction procedures for geotextiles as used in certain engineering applications. Geotextile functions described include primarily pavements, filtration and drainage, and reinforced embankments. Other applications, not discussed here, include railroad right-of-way engineering, erosion and sediment control, and soil wall reinforcement applications. This course does not cover the use of other geosynthetics such as geogrids, geonets, geomembranes, plastic strip drains, composite products and products made from natural cellulose fibers.



Examples of geotextiles.

GEOTEXTILES IN GENERAL.

1.2 Geotextile Types and Construction

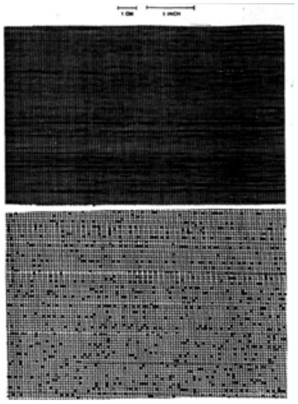
1.2.1 Materials. Geotextiles are made from polypropylene, polyester, polyethylene, polyamide (nylon), polyvinylidene chloride, and fiberglass. Polypropylene and polyester are the most used. Sewing thread for geotextiles is made from Kevlar or any of the above polymers. The physical properties of these materials can be varied by the use of additives in the composition and by changing the processing methods used to form the molten material into filaments. Yarns are formed from fibers which have been bundled and twisted together, a process also referred to as spinning. (This reference is different from the term spinning as used to denote the process of extruding filaments from a molten material.) Yarns may be composed of very long fibers (filaments) or relatively short pieces cut from filaments (staple fibers).

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction

1.2.2 Geotextile Manufacture.

1.2.2.1 In woven construction, the warp yarns, which run parallel with the length of the panel (machine direction), are interlaced with yarns called fill or filling yarns, which run perpendicular to the length of the panel. Woven construction produces geotextiles with high strengths and moduli in the warp and fill directions and low elongations at rupture. The modulus varies depending on the rate and the direction in which the geotextile is loaded. When woven geotextiles are pulled on a bias, the modulus decreases, although the ultimate breaking strength may increase. The construction can be varied so that the finished geotextile has equal or different strengths in the warp and fill directions. Woven construction produces geotextiles with a simple pore structure and narrow range of pore sizes or openings between fibers.

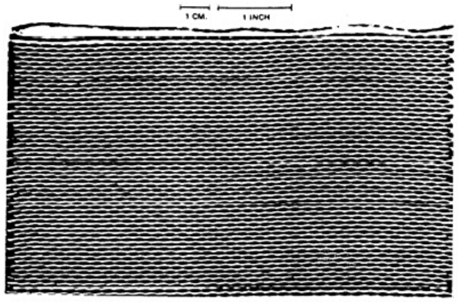
Woven Monofilament Geotextiles Having Low Percent Open Area (Top), and High Percent Open Area (Bottom)



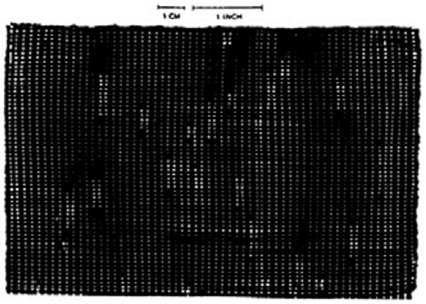
GEOTEXTILES IN GENERAL.
Geotextile Types and Construction

Woven geotextiles are commonly plain woven, but are sometimes made by twill weave or leno weave (a very open type of weave). Woven geotextiles can be composed of monofilaments or multifilament yarns. Multifilament woven construction produces the highest strength and modulus of all the constructions but are also the highest cost.

A monofilament variant is the slit-film or ribbon filament woven geotextile. The fibers are thin and flat and made by cutting sheets of plastic into narrow strips. This type of woven geotextile is relatively inexpensive and is used for separation, i.e., the prevention of intermixing of two materials such as aggregate and fine-grained soil. These fabrics are the cheapest wovens and are typically used in road stabilization/separation applications.



Woven Multifilament Geotextile.



Woven Slit-Film Geotextile.

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction

1.2.2.2 Manufacturers literature and textbooks should be consulted for greater description of woven and knitted geotextile manufacturing processes which continue to be expanded

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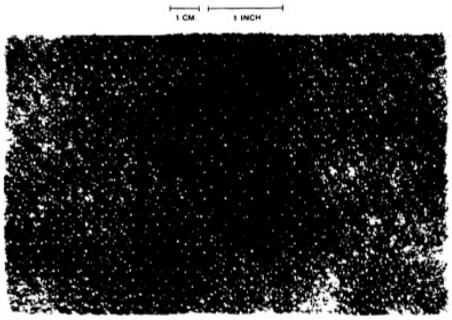
1.2.2.3 Nonwoven geotextiles are formed by a process other than weaving or knitting, and they are generally thicker than woven products. These geotextiles may be made either from continuous filaments or from staple fibers. The fibers are generally oriented randomly within the plane of the geotextile but can be given preferential orientation.
In the spun-bonding process, filaments are extruded, and laid directly on a moving belt to form the mat, which is then bonded by one of the processes described below. Nonwoven fabrics can range in thickness from a thin, lightweight material (4 oz./s.y.) to a fairly thick felt-type material (over 16 oz./s.y.). They are typically used for drainage purposes, such as in gravel underdrains.

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction
Nonwoven Geotextiles

1.2.2.4 Needle punching. Bonding by needle punching involves pushing many barbed needles through one or several layers of a fiber mat normal to the plane of the geotextile. The process causes the fibers to be mechanically entangled. The resulting geotextile has the appearance of a felt mat.



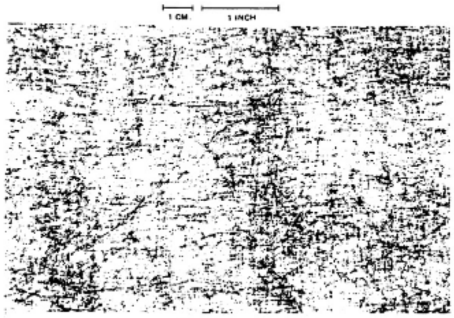
Needle-Punched Nonwoven Geotextile.

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction

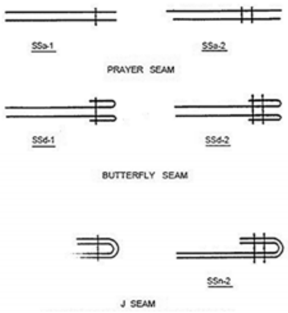
- **Heat bonding.** This is done by incorporating fibers of the same polymer type but having different melting points in the mat, or by using heterofilaments, that is, fibers composed of one type of polymer on the inside and covered or sheathed with a polymer having a lower melting point.

- **Resin bonding.** Resin is introduced into the fiber mat, coating the fibers and bonding the contacts between fibers.

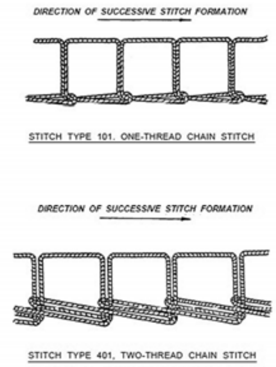
- **Combination bonding.** Sometimes a combination of bonding techniques is used to facilitate manufacturing or obtain desired properties.



Heat-Bonded Nonwoven Geotextile.

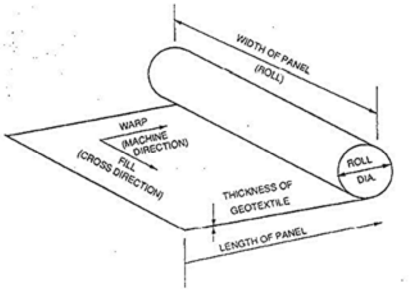


Seam Types Used in Field Seaming of Geotextiles.



Stitch Types Used in Field Seaming of Geotextiles.

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction



Dimensions and Directions for Woven Geotextiles
Figure 1-1

GEOTEXTILES IN GENERAL.
Geotextile Types and Construction

1.2.2.5 Composite geotextiles are materials which combine two or more of the fabrication techniques. The most common composite geotextile is a nonwoven mat that has been bonded by needle punching to one or both sides of a woven scrim.

GEOTEXTILES IN GENERAL.

1.3 Geotextile Durability

Exposure to sunlight degrades the physical properties of polymers. The rate of degradation is reduced by the addition of carbon black but not eliminated. Hot asphalt can approach the melting point of some polymers. Polymer materials become brittle in very cold temperatures. Chemicals in the groundwater can react with polymers. All polymers gain water with time if water is present. High pH water can be harsh on polyesters while low pH water can be harsh on polyamides. Where a chemically unusual environment exists, laboratory test data on effects of exposure of the geotextile to this environment should be sought. Experience with geotextiles in place spans only about 30 years. All of these factors should be considered in selecting or specifying acceptable geotextile materials. Where long duration integrity of the material is critical to life safety and where the in-place material cannot easily be periodically inspected or easily replaced if it should become degraded (for example filtration and/or drainage functions within an earth dam), current practice is to use only geologic materials (which are orders of magnitude more resistant to these weathering effects than polyesters).

GEOTEXTILES IN GENERAL.

1.4 Geotextile Functions and Applications.

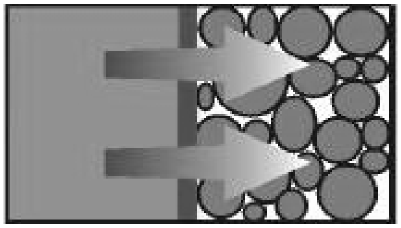
1.4.1 Functions. Geotextiles perform one or more basic functions: ***filtration, drainage, separation, erosion control, sediment control, reinforcement***, and (when impregnated with asphalt***) moisture barrier***. In any one application, a geotextile may be performing several of these functions.

1.4.2 Filtration. The use of geotextiles in filter applications is probably the oldest, the most widely known, and the most used function of geotextiles. In this application, the geotextile is placed in contact with and down gradient of soil to be drained. The plane of to the expected direction of water flow. The capacity for flow of water normal to the plane of the geotextile is referred to as permittivity. Water and any particles suspended in the water which are smaller than a given size flow through the geotextile.

GEOTEXTILES IN GENERAL.

FILTRATION

Geotextile provides an interface for the creation of a reverse filter in the soil adjacent to the geotextile.



GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Filtration

Those soil particles larger than that size are stopped and prevented from being carried away. The geotextile openings should be sized to prevent soil particle movement. The geotextiles substitute for and serve the same function as the traditional granular filter. Both the granular filter and the geotextile filter must allow water (or gas) to pass without significant buildup of hydrostatic pressure. A geotextile-lined drainage trench along the edge of a road pavement is an example using a geotextile as a filter. Most geotextiles are capable of performing this function. Slit film geotextiles are not preferred because opening sizes are unpredictable. Long term clogging is a concern when geotextiles are used for filtration.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.3 Drainage. When functioning as a drain, a geotextile acts as a conduit for the movement of liquids or gases in the plane of the geotextile. Examples are geotextiles used as wick drains and blanket drains. The relatively thick nonwoven geotextiles are the products most commonly used. Selection should be based on transmissivity, which is the capacity for in-plane flow. Questions exist as to long term clogging potential of geotextile drains. They are known to be effective in short duration applications.

The geotextile acts as a filter through which water passes while it restricts fine-grained soil from entering into coarse-grained soil (sand or gravel). An example is in an underdrain where gravel-filled trenches lined with a geotextile fabric are constructed along the edges of roads. The fabric allows water to drain into the trench, while it permanently separates the different soil materials. The gravel remains clean and cannot "plug up" with fine material. Not only can it be used in roadways, but also under parking lots, walls, athletic fields, lawns, tennis courts, and other areas.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Drainage

Normally, nonwoven fabrics are used because of their small pore size (opening size) and high flow capacity. They should be at least 4 oz./sq. yd. If installation stresses are more severe such as where sharp angular aggregate is in contact with the fabric, or a heavy degree of compaction is required, then a heavier nonwoven with a minimum of 8 oz./sq. yd. should be used. Woven fabrics can be used but they should be of the "monofilament" variety. "Slit-tape" wovens should not be used for drainage applications because of their poor capacity to pass water.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.4 Erosion Control. In erosion control the geotextile protects soil surfaces from the tractive forces of moving water or wind and rainfall erosion. Geotextiles can be used in ditch linings to protect erodible fine sands or cohesionless silts. The geotextile is placed in the ditch and is secured in place by stakes or is covered with rock or gravel to secure the geotextile, shield it from ultraviolet light, and dissipate the energy of the flowing water. Geotextiles are also used for temporary protection against erosion on newly seeded slopes. After the slope has been seeded, the geotextile is anchored to the slope holding the soil and seed in-place until the seeds germinate and vegetative cover is established. The erosion control function can be thought of as a special case of the combination of the filtration and separation functions.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Erosion Control

A layer of heavy stones or broken rocks (riprap) is commonly used to provide erosion protection for stream banks, culverts, ditches, stream channels, shorelines, and bridge structures. A geotextile placed between the rock layer and the underlying soil surface provides anchorage of the underlying soil and protects it from erosion and wave attack.
Two key properties are important for proper erosion control. It must have sufficient capacity to pass water, especially if water is coming from behind the fabric. Second, the geotextile must be able to retain the finer soil particles under the fabric. Typical geotextiles used for erosion control are medium weight (8 oz./sq. yd.) nonwoven fabrics or "monofilament" woven fabrics. In some instances where the riprap is rounded or the fabric is protected by a this sand cushion before the riprap is placed, a lighter weight fabric (4 oz./sq. yd.) could be used, if care is exercised during riprap placement.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Erosion Control

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GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.5 Sediment Control. A geotextile serves to control sediment when it stops particles suspended in surface fluid flow while allowing the fluid to pass through. After some period of time, particles accumulate against the geotextile, reducing the flow of fluid and increasing the pressure against the geotextile. Examples of this application are silt fences placed to reduce the amount of sediment carried off construction sites and into nearby water courses. The sediment control function is actually a filtration function.

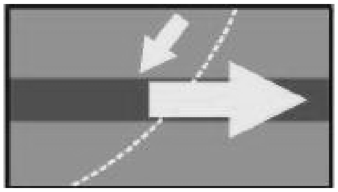
GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Sediment Control

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.6 Reinforcement. In the most common reinforcement application, the geotextile interacts with soil through frictional or adhesion forces to resist tensile or shear forces. To provide reinforcement, a geotextile must have sufficient strength and embedment length to resist the tensile forces generated, and the strength must be developed at sufficiently small strains (i.e. high modulus) to prevent excessive movement of the reinforced structure. To reinforce embankments and retaining structures, a woven geotextile is recommended because it can provide high strength at small strains.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
REINFORCEMENT

Due to their high soil fabric friction coefficient and high tensile strength, heavy grades of geotextiles are used to reinforce earth structures.



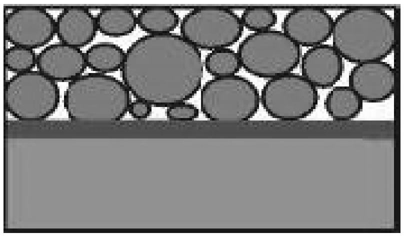
GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.7 Separation. Separation is the process of preventing two dissimilar materials from mixing. In this function, a geotextile is most often required to prevent the undesirable mixing of fill and natural soils or two different types of fills. A geotextile can be placed between a railroad subgrade and track ballast to prevent contamination and resulting strength loss of the ballast by intrusion of the subgrade soil. In construction of roads over soft soil, a geotextile can be placed over the soft subgrade, and then gravel or crushed stone placed on the geotextile. The geotextile prevents mixing of the two materials.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

SEPARATION

Geotextiles function to prevent mutual mixing between 2 layers of soil having different particle sizes or different properties.

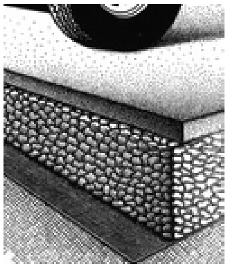


GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Separation

The geotextile is used to permanently separate two distinct layers of soil in a roadway. The classic example is where a road is to be built across a poorly drained, fine-grained soil (clay or silt) and a geotextile is laid down prior to placing gravel. This keeps the soft, underlying soil from working its way up into the expensive gravel and it keeps the gravel form punching down into the soft soil. The full gravel thickness remains intact and provides full support for many years.

Typically, woven and nonwoven geotextiles are used in this application. If a woven product is used, it should be at least 4 oz./sq. yd. and could be a "slit-tape" or monofilament" type for *routine, non-critical* situations. If a nonwoven product is used, it should be at least 8 oz./sq. yd. for survivability during construction.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Separation



GEOTEXTILES IN GENERAL
Geotextile Functions and Applications

1.4.8 Moisture Barrier. Both woven and nonwoven geotextiles can serve as moisture barriers when impregnated with bituminous, rubber-bitumen, or polymeric mixtures. Such impregnation reduces both the cross-plane and in-plane flow capacity of the geotextiles to a minimum. This function plays an important role in the use of geotextiles in paving overlay systems. In such systems, the impregnated material seals the existing pavement and reduces the amount of surface water entering the base and subgrade. This prevents a reduction in strength of these components and improves the performance of the pavement system.

GEOTEXTILES IN GENERAL
Geotextile Functions and Applications
Moisture Barrier

Typically, woven and nonwoven geotextiles are used in this application. If a woven product is used, it should be at least 4 oz./sq. yd. and could be a "slit-tape" or monofilament" type for *routine, non-critical* situations. If a nonwoven product is used, it should be at least 8 oz./sq. yd. for survivability during construction.

GEOTEXTILES IN GENERAL
Selecting Geotextiles – some general comments

Selection will depend on the actual soil and hydraulic conditions, the following general considerations seem appropriate for the soil conditions given:

- Graded gravels and coarse sands - Very open monofilament or multifilament wovens may be required to permit high rates of flow and a low risk of blinding.

- Sands and gravels with less than 20% fines (very "dirty" or silty sand and gravel) - Open monofilament wovens and needlepunched nonwovens with large openings are preferable to reduce the risk of blinding. For thin heat-bonded nonwoven geotextiles and thick needlepunched nonwoven geotextiles, filtration tests should be performed.

- Soils with 20% to 60% fines (silt or silty sand) - Filtration tests should be performed on all fabric types.

GEOTEXTILES IN GENERAL
Selecting Geotextiles – some general comments

- Soils with greater than 60% fines (silt or clayey silt) - Heavy weight needlepunched and heat-bonded nonwoven geotextiles tend to work best as fines will not pass. If blinding does occur, the permeability of the blinding cake would equal that of the soil.

- Gap graded cohesionless soils - Consider using a uniform sand filter with a woven monofilament as a filter for the sand.

- Silts with sand seams - Consider using a uniform sand filter over the soil with a woven geotextile to prevent movement of the filter sand; alternatively, consider using a heavy weight (thick) needlepunched nonwoven directly against soil as water can flow laterally through the geotextile should it become locally clogged.

These general observations are not recommendations but are intended to provide some insight into some considerations for selecting the best material. They do not exclude other possible geotextiles from consideration

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Provider of geosynthetic lining products and services.
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Cooley Group Companies
Designs, develops, and manufactures materials used worldwide in applications such as environmental containment liners, safety clothing, medical products, illuminated signs, and truck tarps.
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Polyfelt GmbH
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GEOfabrics Ltd
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Solmax International
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Geofabrics Australasia Pty Ltd
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REPRESENTATIVE MANUFACTURERS/SUPPLIERS

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Manufacturers of geotextiles, technical sheets, fiber-fill products, and home textiles.
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Concord Geotechnical
Supplies geosynthetic lining installation equipment.
www.concordgeotech.com
XR Geomembrane Technology
Containment uses include tank farms, impoundments, and landfills, in addition to potable water applications. Developed by the Seaman Corporation.
www.xr-5.com
Hui Kwang Chemical Co., Ltd.
Manufacturer of the Huitex geomembrane series and distributor of geosynthetic products for environmental applications.
www.hkc.com.tw
US Fabrics
Geosynthetic products company specializes in woven and nonwoven geotextiles, geogrids, and geomembranes.
www.usfabricsinc.com

2. PAVEMENT APPLICATIONS

2.1 Applications

This discussion covers the use of geotextiles for asphalt concrete (AC) overlays on roads and airfields and the separation and reinforcement of materials in new construction. The functions performed by the geotextile and the design considerations are different for these two applications. In an AC pavement system, the geotextile provides a stress-relieving interlayer between the existing pavement and the overlay that reduces and retards reflective cracks under certain conditions and acts as a moisture barrier to prevent surface water from entering the pavement structure. When a geotextile is used as a separator, it is placed between the soft subgrade and the granular material. It acts as a filter to allow water but not fine material to pass through it, preventing any mixing of the soft soil and granular material under the action of the construction equipment or subsequent traffic.

PAVEMENT APPLICATIONS

2.2 Paved Surface Rehabilitation

2.2.1 General. Old and weathered pavements contain transverse and longitudinal cracks that are both temperature and load related. The method most often used to rehabilitate these pavements is to overlay the pavement with AC. This temporarily covers the cracks. After the overlay has been placed, any lateral or vertical movement of the pavement at the cracks due to load or thermal effects causes the cracks from the existing pavement to propagate up through the new AC overlay (called reflective cracking). This movement causes raveling and spalling along the reflective cracks and provides a path for surface water to reach the base and subgrade which decreases the ride quality and accelerates pavement deterioration.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

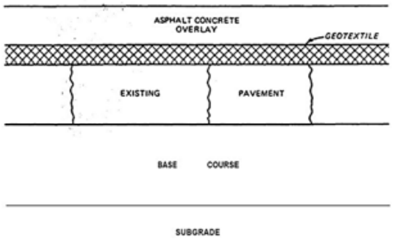
2.2.2 Concept. Under an AC overlay, a geotextile may provide sufficient tensile strength to relieve stresses exerted by movement of the existing pavement. The geotextile acts as a stress-relieving interlayer as the cracks move horizontally or vertically. A typical pavement structure with a geotextile interlayer is shown in Figure 2-1. Impregnation of the geotextile with a bitumen provides a degree of moisture protection for the underlying layers whether or not reflective cracking occurs.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.3 Reflective Crack Treatment for Pavements

2.3.1 General. Geotextiles can be used successfully in pavement rehabilitation projects. Conditions that are compatible for the pavement applications of geotextiles are AC pavements that may have transverse and longitudinal cracks but are relatively smooth and structurally sound, and PCC pavements that have minimum slab movement. The geographic location and climate of the project site have an important part in determining whether or not geotextiles can be successfully used in pavement rehabilitation. Geotextiles have been successful in reducing and retarding reflective cracking in mild and dry climates when temperature and moisture changes are less likely to contribute to movement of the underlying pavement; whereas, geotextiles in cold climates have not been as successful.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Reflective Crack Treatment for Pavements



Geotextile in Asphalt Concrete Overlay
Figure 2-1

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Reflective Crack Treatment for Pavements

Figure 2-2 gives guidance in using geotextiles to minimize reflective cracking on AC pavements. Geotextiles interlayers are recommended for use in Areas I and II, but are not recommended for use in Area III. Since geotextiles do not seem to increase the performance of thin overlays, minimum overlay thicknesses for Areas I and II are given in Figure 2-2. Even when the climate and thickness requirements are met, there has been no consistent increase in the time it takes for reflective cracking to develop in the overlay indicating that other factors are influencing performance. Other factors affecting performance of geotextile interlayers are construction techniques involving pavement preparation, asphalt sealant application, geotextile installation, and AC overlay as well as the condition of the underlying pavement.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Reflective Crack Treatment for Pavements

2.3.2 Surface Preparation. Prior to using geotextiles to minimize reflective cracks, the existing pavement should be evaluated to determine pavement distress. The size of the cracks and joints in the existing pavement should be determined. All cracks and joints larger than ¼ inch in width should be sealed. Differential slab movement should be evaluated, since deflections greater than 0.002 inch cause early reflective cracks. Areas of the pavement that are structurally deficient should be repaired prior to geotextile installation. Placement of a leveling course is recommended when the existing pavement is excessively cracked and uneven.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Reflective Crack Treatment for Pavements

Guidance for Geotextile Use in Minimizing Reflective Cracking
Figure 2-2

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.3.3 Geotextile Selection.

2.3.3.1 Geotextile interlayers are used in two different capacities-the full-width and strip methods. The full-width method involves sealing cracks and joints and placing a nonwoven material across the entire width of the existing pavement. The material should have the properties shown in Table 2-1. Nonwoven materials provide more flexibility and are recommended for reflective crack treatment of AC pavements.

2.3.3.2 The strip method is primarily used on Portland cement concrete (PCC) pavements and involves preparing the existing cracks and joints, and placing a 12 to 24 inch wide geotextile and sufficient asphalt directly on the cracks and joints. The required physical properties are shown in Table 2-1, however nonwoven geotextiles are not normally used in the strip method. Membrane systems have been developed for strip repairs.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.3.4 Asphalt Sealant. The asphalt sealant is used to impregnate and seal the geotextile and bond it to both the base pavement and overlay. The grade of asphalt cement specified for hot-mix AC pavements in each geographic location is generally the most acceptable material. Either anionic or cationic emulsion can also be used. Cutback asphalts and emulsions which contain solvents should not be used.

2.3.5 AC Overlay. The thickness of the AC overlay should be determined from the pavement structural requirements. For AC pavements, Area I shown in Figure 2-2 should have a minimum overlay thickness of 2 inches; whereas, Area II should have a minimum overlay thickness of 3 inches. The minimum thickness of an AC overlay for geotextile application on PCC pavements is 4 inches.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.3.6 Spot Repairs. Rehabilitation of localized distressed areas and utility cuts can be improved with the application of geotextiles. Isolated distressed areas that are excessively cracked can be repaired with geotextiles prior to an AC overlay. Either a full-width membrane strip application can be used depending on the size of the distressed area. Localized distressed areas of existing AC pavement that are caused by base failure should be repaired prior to any pavement rehabilitation. Geotextiles are not capable of bridging structurally deficient pavements.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

Property	*Requirements*	*Test Method*
Breaking load, pounds/inch of width	80 minimum	ASTM D 4632
Elongation-at-break, percent	50 minimum	ASTM D 4632
Asphalt retention, gallons per square yard	0.2 minimum	AASHTO M288
Melting point, degrees Fahrenheit	300 minimum	ASTM D 276
Weight, ounce per square yard	3-9	ASTM D 3776 Option B

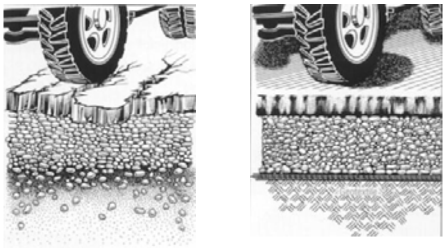
Property Requirements of Nonwoven Geotextiles.
Table 2-1

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.4 Separation and Reinforcement

Soft subgrade materials may mix with the granular base or subbase material as a result of loads applied to the base course during construction and/or loads applied to the pavement surface that force the granular material downward into the soft subgrade or as a result of water moving upward into the granular material and carrying the subgrade material with it. A sand blanket or filter layer between the soft subgrade and the granular material can be used in this situation. Also, the subgrade can be stabilized with lime or cement or the thickness of granular material can be increased to reduce the stress on the subgrade. Geotextiles have been used in construction of gravel roads and airfields over soft soils to solve these problems and either increase the life of the pavement or reduce the initial cost. The placement of a permeable geotextile between the soft subgrade and the granular material may provide one or more of the following functions: (1) a filter to allow water but not soil to pass through it, (2) a separator to prevent the mixing of the soft soil and the granular material, and (3) a reinforcement layer to resist the development of rutting. The reinforcement application is primarily for gravel surfaced pavements. The required thicknesses of gravel surfaced roads and airfields have been reduced because of the presence of the geotextile. There is no established criteria for designing gravel surfaced airfields containing a geotextile.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Separation and Reinforcement

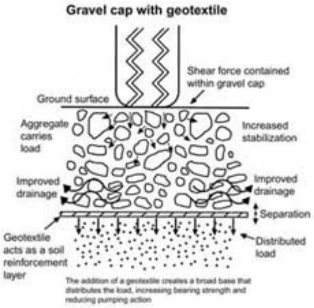


PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.5 Design for Separation

When serving as a separator, the geotextile prevents fines from migrating into the base course and/or prevents base course aggregate from penetrating into, the subgrade. The soil retention properties of the geotextile are basically the same as those required for drainage or filtration. Therefore, the retention and permeability criteria required for drainage should be met. In addition, the geotextile should withstand the stresses resulting from the load applied to the pavement. The nature of these stresses depend on the condition of the subgrade, type of construction equipment, and the cover over the subgrade. Since the geotextile serves to prevent aggregate from penetrating the subgrade, it must meet puncture, burst, grab and tear strengths specified in the following paragraphs.

PAVEMENT APPLICATIONS
Paved Surface Separation and Reinforcement



PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2-6. Geotextile Survivability

Table 2-2 has been developed for the Federal Highway Administration (FHWA) to consider survivability requirements as related to subgrade conditions and construction equipment; whereas, table 2-3 relates survivability to cover material and construction equipment. Table 2-4 gives minimum geotextile grab, puncture, burst, and tear strengths for the survivability required for the conditions indicated in tables 2-2 and 2-3.

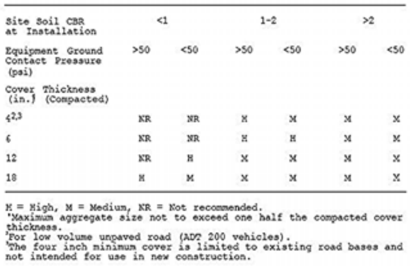
PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.7 Design for Reinforcement
Use of geotextiles for reinforcement of gravel surfaced roads is generally limited to use over soft cohesive soils (CBR < 4). One procedure for determining the thickness requirements of aggregate above the geotextile was developed by the US Forest Service (Steward, et al. 1977) and is as follows:

2.7.1 Determine In-Situ Soil Strength. Determine the in-situ soil strength using the field California Bearing Ratio (CBR), cone penetrometer, or Vane Shear device. Make several readings and use the lower quartile value.

2.7.2 Convert Soil Strength. Convert the soil strength to an equivalent cohesion (C) value using the correlation shown in Figure 2-3. The shear strength is equal to the C value.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

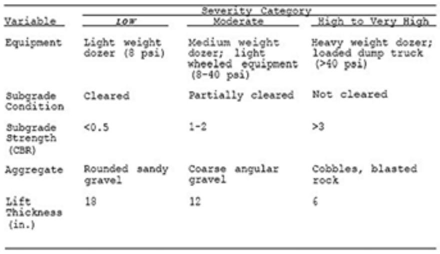


Site Soil CBR at Installation	<1		1-2		>2	
Equipment Ground Contact Pressure (psi)	>50	<50	>50	<50	>50	<50
Cover Thickness (in.)[1] (Compacted)						
4[2,3]	NR	NR	H	M	M	M
6	NR	NR	H	H	M	M
12	NR	H	M	M	M	M
18	H	M	M	M	M	M

H = High, M = Medium, NR = Not recommended.
[1] Maximum aggregate size not to exceed one half the compacted cover thickness.
[2] For low volume unpaved road (ADT 200 vehicles).
[3] The four inch minimum cover is limited to existing road bases and not intended for use in new construction.

<u>Construction Survivability Ratings (FHWA 1989)</u>
Table 2-2

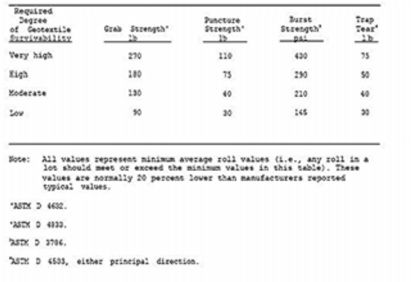
PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



Variable	Severity Category Low	 Moderate	 High to Very High
Equipment	Light weight dozer (8 psi)	Medium weight dozer; light wheeled equipment (8-40 psi)	Heavy weight dozer; loaded dump truck (>40 psi)
Subgrade Condition	Cleared	Partially cleared	Not cleared
Subgrade Strength (CBR)	<0.5	1-2	>3
Aggregate	Rounded sandy gravel	Coarse angular gravel	Cobbles, blasted rock
Lift Thickness (in.)	18	12	6

Relationship of Construction Elements to Severity of Loading Imposed on Geotextile in Roadway Construction
Table 2-3

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



Required Degree of Geotextile Survivability	Grab Strength[a] lb	Puncture Strength[b] lb	Burst Strength[c] psi	Trap Tear[d] lb
Very high	270	110	430	75
High	180	75	290	50
Moderate	130	40	210	40
Low	90	30	145	30

Note: All values represent minimum average roll values (i.e., any roll in a lot should meet or exceed the minimum values in this table). These values are normally 20 percent lower than manufacturers reported typical values.

[a] ASTM D 4632.

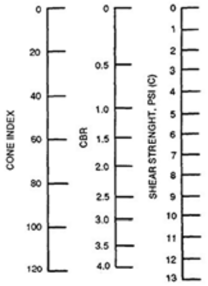
[b] ASTM D 4833.

[c] ASTM D 3786.

[d] ASTM D 4533, either principal direction.

Minimum Geotextile Strength Properties for Survivability
Table 2-4

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



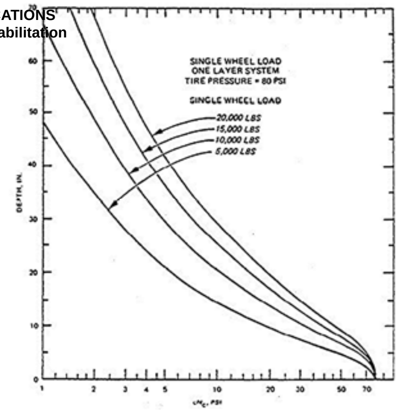
Relationship Between Shear Strength, CBR, and Cone Index
Figure 2-3

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.7.3 Select Design Loading. Select the desired design loading, normally the maximum axle loads.

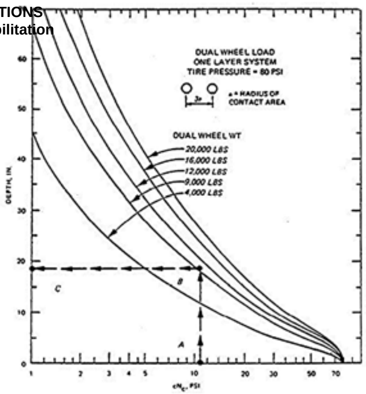
2.7.4 Determine Required Thickness of Aggregate. Determine the required thickness of aggregate above the geotextile using Figures 2-4, 2-5, and 2-6. These figures relate the depth of aggregate above the geotextile to the cohesion of the soil (C) and to a bearing capacity factor (NC). The product of C and NC is the bearing capacity for a rapidly loaded soil without permitting drainage. The significance of the value used for NC as it relates to the design thickness using Figures 2-4, 2-5, and 2-6 is as follows:

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



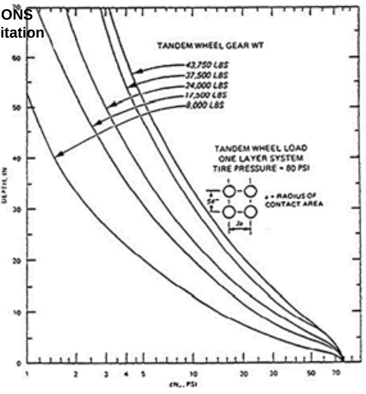
Thickness Design Curve for Single-Wheel Load on Gravel-Surfaced Roads
Figure 2-4

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



Thickness Design Curve for Dual- Wheel Load on Gravel-Surfaced Roads
Table 2-5

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation



Thickness Design Curve for Tandem- Wheel Load on Gravel-Surfaced Roads
Table 2-6

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.7.4.1 For thickness design without using geotextile.

- A value of 2.8 for NC would result in a thickness design that would perform with very little rutting (less than 2 inches) at traffic volumes greater than 1,000 equivalent 18-kip axle loadings.

- A value of 3.3 for NC would result in a thickness design that would rut 4 inches or more under a small amount of traffic (probably less than 100 equivalent 18-kip axle loadings).

2.7.4.2 For thickness design using geotextile.

- A value of 5.0 for NC would result in a thickness design that would perform with very little rutting (less than 2 inches) at traffic volumes greater than 1,000 equivalent 18-kip axle loadings.

- A value of 6.0 for NC would result in a thickness design that would rut 4 inches or more under a small amount of traffic (probably less than 100 equivalent 18-kip axle loadings).

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation

2.7.5 Geotextile reinforced gravel road design example. Design a geotextile reinforced gravel road for a 24,000-pound-tandem-wheel load on a soil having a CBR of 1. The road will have to support several thousand truck passes and very little rutting will be allowed.

2.7.5.1 Determine the required aggregate thickness with geotextile reinforcement.

- From figure 2-3 a 1 CBR is equal to a C value of 4.20.

- Choose a value of 5 for NC since very little rutting will be allowed.

- Calculate CNC as: CNC = 4.20(5) = 21.

- Enter figure 2-6 with CNC of 21 to obtain a value of 14 inches as the required aggregate thickness above the geotextile.

- Select geotextile requirements based on survivability requirements in tables 2-2 and 2-3.

PAVEMENT APPLICATIONS
Paved Surface Rehabilitation
Geotextile reinforced gravel road design example

2.7.5.2 Determine the required aggregate thickness when a geotextile is not used.

- Use a value of 2.8 for NC since a geotextile is not used and only a small amount of rutting will be allowed.

- Calculate CNC as: CNC = 4.20(2.8) = 11.8.

- Enter figure 2-6 with CNC of 11.8 to obtain a value of 22 inches as the required aggregate thickness above the subgrade without the geotextile.

2.7.5.3 Compare cost and benefits of the alternatives. Even with nearby economical gravel sources, the use of a geotextile usually is the more economical alternative for constructing low volume roads and airfields over soft cohesive soils. Additionally, it results in a faster time to completion once the geotextiles are delivered on site.

3. DRAINAGE APPLICATIONS

3.1 Water Control

Control of water is critical to the performance of buildings, pavements, embankments, retaining walls, and other structures. Drains are used to relieve hydrostatic pressure against underground and retaining walls, slabs, and underground tanks and to prevent loss of soil strength and stability in slopes, embankments, and beneath pavements. A properly functioning drain must retain the surrounding soil while readily accepting water from the soil and removing it from the area. These general requirements apply to granular and geotextile filters. While granular drains have a long performance history, geotextile use in drains is relatively recent and performance data are limited to approximately 25 years. Where not exposed to sunlight or abrasive contact with rocks moving in response to moving surface loads or wave action, long-term performance of properly selected geotextiles has been good. Since long-term experience is limited, geotextiles should not be used as a substitute for granular filters within or on the upstream face of earth dams or within any inaccessible portion of the dam embankment. Geotextiles have been used in toe drains of embankments where they are easily accessible if maintenance is required and where malfunction can be detected. Caution is advised in using geotextiles to wrap permanent piezometers and relief wells where they form part of the safety system of a water retaining structure. Geotextiles have been used to prevent infiltration of fine-grained materials into piezometer screens but long-term performance has not been measured.

DRAINAGE APPLICATIONS

3.2 Granular Drain Performance

To assure proper performance in granular drains, the designer requires drain materials to meet grain-size requirements based on grain size of the surrounding soil. The two principal granular filter criteria, piping and permeability have been developed empirically through project experience and laboratory testing.

3.3 Geotextile Characteristics Influencing Filter Functions

The primary geotextile characteristics influencing filter functions are opening size (as related to soil retention), flow capacity, and clogging potential. These properties are indirectly measured by the apparent opening size (AOS) (ASTM D 4751), permittivity (ASTM D 4491), and gradient ratio test (ASTM D 5101). The geotextile must also have the strength and durability to survive construction and long-term conditions for the design life of the drain. Additionally, construction methods have a critical influence on geotextile drain performance.

DRAINAGE APPLICATIONS

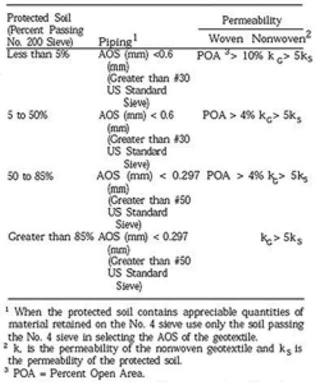
3.4 Piping Resistance

3.4.1 Basic Criteria. Piping resistance is the ability of a geotextile to retain solid particles and is related to the sizes and complexity of the openings or pores in the geotextile. For both woven and nonwoven geotextiles, the critical parameter is the AOS. Table 3-1 gives the relation of AOS to the gradation of the soil passing the number 200 sieve for use in selecting geotextiles.

3.4.2 Percent Open Area Determination Procedure for Woven Geotextiles.

3.4.2.1 Installation of geotextile. A small section of the geotextile to be tested should be installed in a standard 2 by 2 inch slide cover, so that it can be put into a slide projector and projected onto a screen. Any method to hold the geotextile section and maintain it perpendicular to the projected light can be used.
3.4.2.2 Slide projector. The slide projector should be placed level to eliminate any distortion of the geotextile openings. After placing the slide in the projector and focusing on a sheet of paper approximately 8 to 10 feet away, the opening outlines can be traced.

DRAINAGE APPLICATIONS
Piping Resistance
Percent Open Area
Determination Procedure for Woven Geotextiles



Protected Soil (Percent Passing No. 200 Sieve)	Piping[1]	Permeability	
		Woven	Nonwoven[2]
Less than 5%	AOS (mm) <0.6 (mm) (Greater than #30 US Standard Sieve)	POA [3]> 10%	$k_c > 5k_s$
5 to 50%	AOS (mm) < 0.6 (mm) (Greater than #30 US Standard Sieve)	POA > 4%	$k_c > 5k_s$
50 to 85%	AOS (mm) < 0.297 (mm) (Greater than #50 US Standard Sieve)	POA > 4%	$k_c > 5k_s$
Greater than 85%	AOS (mm) < 0.297 (mm) (Greater than #50 US Standard Sieve)		$k_c > 5k_s$

[1] When the protected soil contains appreciable quantities of material retained on the No. 4 sieve use only the soil passing the No. 4 sieve in selecting the AOS of the geotextile.
[2] k, is the permeability of the nonwoven geotextile and k_s is the permeability of the protected soil.
[3] POA = Percent Open Area.

Geotextile Filter Design Criteria
Table 3-1

DRAINAGE APPLICATIONS
Piping Resistance
Percent Open Area Determination Procedure for Woven Geotextiles

3.4.2.3 Representative area. Draw a rectangle of about 0.5 to 1 square foot area on the "projection screen" sheet of paper to obtain a representative area to test; then trace the outline of all openings inside the designated rectangle.
3.4.2.4 Finding the area. After removing the sheet, find the area of the rectangle, using a planimeter. If necessary, the given area may be divided to accommodate the planimeter.
3.4.2.5 Total area of openings. Find the total area of openings inside rectangle, measuring the area of each with a planimeter.
3.4.2.6 Compute percent. Compute POA by the equation:

$$\text{POA}=\frac{\text{Total Area Occupied by Openings}}{\text{Total Area of Test Rectangle}} \times 100$$

DRAINAGE APPLICATIONS
Piping Resistance

3.4.3 Flow Reversals. Piping criteria are based on granular drain criteria for preventing drain material from entering openings in drain pipes. If flow through the geotextile drain installation will be reversing and/or under high gradients (especially if reversals are very quick and involve large changes in head), tests, modeling prototype conditions, should be performed to determine geotextile requirements.

3.4.4 Clogging. There is limited evidence (Giroud 1982) that degree of uniformity and density of granular soils (in addition to the D size) influence the ability of geotextiles to retain the drained soil. For very uniform soils (uniformity coefficient 2 to 4), the maximum AOS may not be as critical as for more well graded soils (uniformity coefficient greater than 5). A gradient ratio test with observation of material passing the geotextile may be necessary to determine the adequacy of the material. In normal soil-geotextile filter systems, detrimental clogging only occurs when there is migration of fine soil particles through the soil matrix to the geotextile surface or into the geotextile. For most natural soils, minimal internal migration will take place. However, internal migration may take place under sufficient gradient if one of the following conditions exists:

DRAINAGE APPLICATIONS
Piping Resistance
Clogging

3.4.4.1 The soil is very widely graded, having a coefficient of uniformity C_U greater than 20.

3.4.4.2 The soil is gap graded. (Soils lacking a range of grain sizes within their maximum and minimum grain sizes are called "gap graded" or "skip graded" soils.) Should these conditions exist in combination with risk of extremely high repair costs if failure of the filtration system occurs the gradient ratio test may be required.

DRAINAGE APPLICATIONS
Piping Resistance

3.4.5 Clogging Resistance. Clogging is the reduction in permeability or permittivity of a geotextile due to blocking of the pores by either soil particles or biological or chemical deposits. Some clogging takes place with all geotextiles in contact with soil. Therefore, permeability test results can only be used as a guide for geotextile suitability. For woven geotextiles, if the POA is sufficiently large, the geotextiles will be resistant to clogging. The POA has proved to be a useful measure of clogging resistance for woven textiles but is limited to woven geotextiles having distinct, easily measured openings. For geotextiles which cannot be evaluated by POA, soil-geotextile permeameters have been developed for measuring soil-geotextile permeability and clogging. As a measure of the degree to which the presence of geotextile affects the permeability of the soil- geotextile system, the gradient ratio test can be used (ASTM D 5101). The gradient ratio is defined as the ratio of the hydraulic gradient across the geotextile and the 1 inch of soil immediately above the geotextile to the hydraulic gradient between 1 and 3 inches above the geotextile.

DRAINAGE APPLICATIONS

3.5 Permeability

3.5.1 Transverse Permeability. After installation, geotextiles used in filtration and drainage applications must have a flow capacity adequate to prevent significant the soil being drained. This flow capacity must be maintained for the range of flow conditions for that particular installation. For soils, the indicator of flow capacity is the coefficient of permeability as expressed in Darcy's Law. The proper application of Darcy's Law requires that geotextile thickness be considered. Since the ease of flow through a geotextile regardless of its thickness is the property of primary interest, Darcy's Law can be modified to define the term permittivity, ψ, with units of sec., as follows:

DRAINAGE APPLICATIONS
Permeability
Transverse Permeability

$$\Psi = \frac{k}{L_f} = \frac{q}{(\Delta h)A} \qquad \text{(Eq. 3-1)}$$

where
k = Darcy coefficient of permeability, L/T
L_f = length of flow path (geotextile thickness) over which Δh occurs, L
q = hydraulic discharge rate, L^3/T
Δh = hydraulic head loss through the geotextile, L
A = total cross-sectional area available to flow, L^2
L = units of length
T = units of time

DRAINAGE APPLICATIONS
Permeability
Transverse Permeability

The limitation of directly measuring the permeability and permittivity of geotextiles is that Darcy's Law applies only as long as laminar flow exists. This is very difficult to achieve for geotextiles since the hydraulic heads required to assure laminar flow are so small that they are difficult to accurately measure. Despite the fact that Darcy's equation does not apply for most measurements of permeability, the values obtained are considered useful as a relative measure of the permeabilities and permittivities of various geotextiles. Values of permeability reported in the literature, or obtained from testing laboratories, should not be used without first establishing the actual test conditions used to determine the permeability value. ASTM Method D 4491 should be used for establishing the permeability and permittivity of geotextiles. The permeability of some geotextiles decreases significantly when compressed by surrounding soil or rock. ASTM D 5493 can be used for measuring the permeabilities of geotextiles under load.

DRAINAGE APPLICATIONS
Permeability

3.5.2 In-plane Permeability. Thick nonwoven geotextiles and special products as prefabricated drainage panels and strip drains have substantial fluid flow capacity in their plane. Flow capacity in a plane of a geotextile is best expressed independently of the material's thickness since the thickness of various materials may differ considerably, while the ability to transmit fluid under a given head and confining pressure is the property of interest. The property of in-plane flow capacity of a geotextile is termed "transmissivity," θ , and is expressed as:

DRAINAGE APPLICATIONS
Permeability
In-Plane Permeability

$$\Theta = k_p t = \frac{ql}{\Theta h w} \qquad \text{(eq 3-2)}$$

where
k_p = in-plane coefficient of permeability (hydraulic conductivity), L/T
t = thickness of geotextile, L (ASTM D 5199)
q = hydraulic discharge rate, $L^3 3/T$
l = length of geotextile through which liquid is flowing, L
Δh = hydraulic head loss, L
w = width of geotextile, L
L = units of length, length between geotextile grips
T = units of time

DRAINAGE APPLICATIONS
Permeability
In-Plane Permeability

Certain testing conditions must be considered if meaningful values of transmissivity are to be acquired. These conditions include the hydraulic gradients used, the normal pressure applied to the product being tested, the potential for reduction of transmissivity over time due to creep of the drainage material, and the possibility that intermittent flow will result in only partial saturation of the drainage material and reduced flow capacity. ASTM D 4716 may be used for evaluating the transmissivity of drainage materials.

DRAINAGE APPLICATIONS
Permeability

3.5.3 Limiting Criteria. Permeability criteria for nonwoven geotextiles require that the permeability of the geotextile be at least five times the permeability of the surrounding soil. Permeability criteria for woven geotextiles are in terms of the POA. When the protected soil has less than 0.5 percent passing the No. 200 sieve, the POA should be equal to or greater than 10 percent. When the protected soil has more than 5 percent but less than 85 percent passing the No. 200 sieve, the POA should be equal to or greater than 4 percent.

DRAINAGE APPLICATIONS

3.6 Other Filter Considerations

3.6.1 To prevent clogging or blinding of the geotextile, intimate contact between the soil and geotextile should be assured during construction. Voids between the soil and geotextile can expose the geotextile to a slurry or muddy water mixture during seepage. This condition promotes erosion of soil behind the geotextile and clogging of the geotextile.

3.6.2 Very fine-grained non-cohesive soils, such as rock flour, present a special problem, and design of drain installations in this type of soil should be based on tests with expected hydraulic conditions using the soil and candidate geotextiles.

3.6.3 As a general rule slit-film geotextiles are unacceptable for drainage applications. They may meet AOS criteria but generally have a very low POA or permeability. The wide filament in many slit films is prone to move relative to the cross filaments during handling and thus change AOS and POA.

DRAINAGE APPLICATIONS
Other Filter Considerations

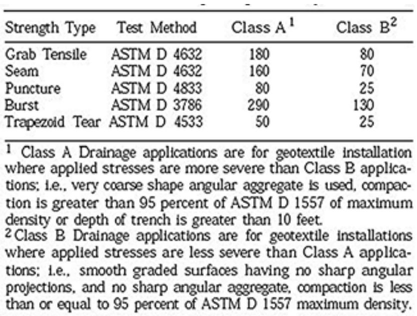
3.6.4 The designer must consider that in certain areas an ochre formation may occur on the geotextile. Ochre is an iron deposit usually a red or tan gelatinous mass associated with bacterial slimes. It can, under certain conditions, form on and in subsurface drains. The designer may be able to determine the potential for ochre formation by reviewing local experience with highway, agricultural, embankment, or other drains with local or state agencies. If there is reasonable expectation for ochre formation, use of geotextiles is discouraged since geotextiles may be more prone to clog. Once ochre clogging occurs, removal from geotextiles is generally very difficult to impossible, since chemicals or acids used for ochre removal can damage geotextiles, and high pressure jetting through the perforated pipe is relatively ineffective on clogged geotextiles.

DRAINAGE APPLICATIONS

3.7 Strength Requirements

Unless geotextiles used in drainage applications have secondary functions (separation, reinforcement, etc.) requiring high strength, the requirements shown in Table 3-2 will provide adequate strength.

DRAINAGE APPLICATIONS
Strength Requirements



Strength Type	Test Method	Class A[1]	Class B[2]
Grab Tensile	ASTM D 4632	180	80
Seam	ASTM D 4632	160	70
Puncture	ASTM D 4833	80	25
Burst	ASTM D 3786	290	130
Trapezoid Tear	ASTM D 4533	50	25

[1] Class A Drainage applications are for geotextile installation where applied stresses are more severe than Class B applications; i.e., very coarse shape angular aggregate is used, compaction is greater than 95 percent of ASTM D 1557 of maximum density or depth of trench is greater than 10 feet.

[2] Class B Drainage applications are for geotextile installations where applied stresses are less severe than Class A applications; i.e., smooth graded surfaces having no sharp angular projections, and no sharp angular aggregate, compaction is less than or equal to 95 percent of ASTM D 1557 maximum density.

Geotextile Strength Requirements for Drains
Table 3-2

DRAINAGE APPLICATIONS

3.8 Design and Construction Considerations

3.8.1 Installation Factors. In addition to the requirement for continuous, intimate geotextile contact with the soil, several other installation factors strongly influence geotextile drain performance. These include:
3.8.1.1 How the geotextile is held in place during construction.
3.8.1.2 Method of joining consecutive geotextile elements.
3.8.1.3 Preventing geotextile contamination.
3.8.1.4 Preventing geotextile deterioration from exposure to sunlight. Geotextile should retain 70 percent of its strength after 150 hours of exposure to ultraviolet sunlight (ASTM D 4355).

DRAINAGE APPLICATIONS
Design and Construction Considerations

3.8.2 Placement. Pinning the geotextile with long nail-like pins placed through the geotextile into the soil has been a common method of securing the geotextile until the other components of the drain have been placed; however, in some applications, this method has created problems. Placement of aggregate on the pinned geotextile normally puts the geotextile into tension which increases potential for puncture and reduces contact of the geotextile with soil, particularly when placing the geotextile against vertical and/or irregular soil surfaces. It is much better to keep the geotextile loose but relatively unwrinkled during aggregate placement. This can be done by using small amounts of aggregate to hold the geotextile in place or using loose pinning and re-pinning as necessary to keep the geotextile loose. This method of placement will typically require 10 to 15 percent more geotextile than predicted by measurement of the drain's planer surfaces.

DRAINAGE APPLICATIONS
Design and Construction Considerations

3.8.3 Joints.

3.8.3.1 Secure lapping or joining of consecutive pieces of geotextile prevents movement of soil into the drain. A variety of methods such as sewing, heat bonding, and overlapping are acceptable joints. Normally, where the geotextile joint will not be stressed after installation, a minimum 12-inch overlap is required with the overlapping inspected to ensure complete geotextile-to-geotextile contact. When movement of the geotextile sections is possible after placement, appropriate overlap distances or more secure joining methods should be specified. Field joints are much more difficult to control than those made at the factory or fabrication site and every effort should be made to minimize field joining.

DRAINAGE APPLICATIONS
Design and Construction Considerations
Joints

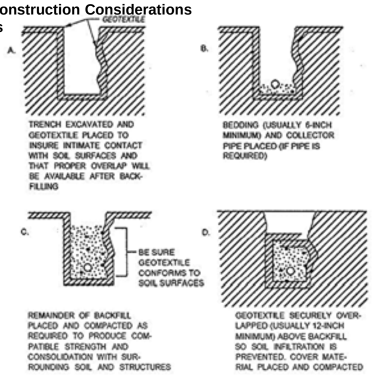
3.8.3.2 Seams are described earlier. Strength requirements for seams may vary from just enough to hold the geotextile sections together for installation to that required for the geotextile. Additional guidance for seams is contained in AASHTO M 288. Seam strength is determined using ASTM 4632.

DRAINAGE APPLICATIONS
Design and Construction Considerations

3.8.4 Trench Drains.

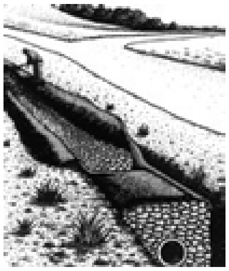
3.8.4.1 Variations of the basic trench drain are the most common geotextile drain application. Typically, the geotextile lines the trench allowing use of a very permeable backfill which quickly removes water entering the drain. Trench drains intercept surface infiltration in pavements and seepage in slopes and embankments as well as lowering ground-water levels beneath pavements and other structures. The normal construction sequence is shown in Figure 3-l. In addition to techniques shown in Figure 3-1, if high compactive efforts are required (e.g., 95 percent of ASTM D 1557 maximum density), the puncture strength requirements should be doubled. Granular backfill does not have to meet piping criteria but should be highly permeable, large enough to prevent movement into the pipe, and meet durability and structural requirements of the project. This allows the designer to be much less stringent on backfill requirements than would be necessary for a totally granular trench drain. Some compaction of the backfill should always be applied.

DRAINAGE APPLICATIONS
Design and Construction Considerations
Trench Drains



<u>Trench Drain Construction</u>
Figure 3-1

DRAINAGE APPLICATIONS
Design and Construction Considerations
Trench Drains



DRAINAGE APPLICATIONS
Design and Construction Considerations
Trench Drains

3.8.4.2 Wrapping of the perforated drain pipe with a geotextile when finer grained filter backfill is used is a less common practice. Normally not used in engineering applications, this method is less efficient than lining the trench with a geotextile because the reduced area of high permeability material concentrates flow and lowers a drain efficiency. Wrapping of the pipe may be useful when finer grained filter materials are best suited because of availability and/or grain size requirements. In this case, the geotextile functions as a cover for the pipe perforations preventing backfill infiltration. If the geotextile can be separated a small distance from the pipe surface, the flow through the geotextile into the pipe openings will be much more efficient. Use of plastic corrugated, perforated pipe with openings in the depressed portion of the corrugation is an easy way of doing this.

DRAINAGE APPLICATIONS
Design and Construction Considerations
Under Drains

Constructing an underdrain from large rocks, with geotextile serving as a separator between surface material and large rocks.

4. REINFORCED EMBANKMENTS

4.1 General

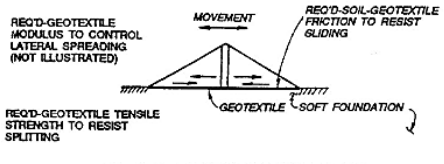
Quite often, conventional construction techniques will not allow dikes or levees to be constructed on very soft foundations because it may not be cost effective, operationally practical, or technically feasible. Nevertheless, geotextile-reinforced dikes have been designed and constructed by being made to float on very soft foundations. Geotextiles used in those dikes alleviated many soft-ground foundation dike construction problems because they permit better equipment mobility, allow expedient construction, and allow construction to design elevation without failure. This chapter will address the potential failure modes and requirements for design and selection of geotextiles for reinforced embankments.

REINFORCED EMBANKMENTS

4.2 Potential Embankment Failure Modes

The design and construction of geotextile-reinforced dikes on soft foundations are technically feasible, operationally practical, and cost effective when compared with conventional soft foundation construction methods and techniques. To successfully design a dike on a very soft foundation, three potential failure modes must be investigated (fig 4-1).

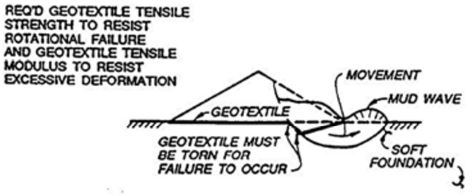
REINFORCED EMBANKMENTS
Potential Embankment Failure Modes



a POTENTIAL EMBANKMENT FAILURE FROM LATERAL EARTH PRESSURE

Potential Geotextile-Reinforced Embankment Failure Modes.
Figure 4.1 (a)

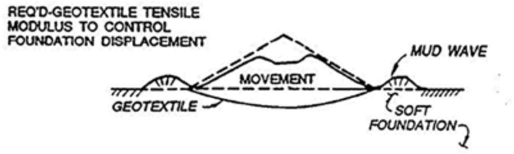
REINFORCED EMBANKMENTS
Potential Embankment Failure Modes



b. POTENTIAL EMBANKMENT ROTATIONAL SLOPE/FOUNDATION FAILURE

Potential Geotextile-Reinforced Embankment Failure Modes.
Figure 4.1 (b)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes



c. POTENTIAL EMBANKMENT FAILURE FROM EXCESSIVE DISPLACEMENT

Potential Geotextile-Reinforced Embankment Failure Modes.
Figure 4.1 (c)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes

4.2.1 Horizontal sliding, and spreading of the embankment and foundation.
4.2.2 Rotational slope and/or foundation failure.
4.2.3 Excessive vertical foundation displacement.

The geotextile must resist the unbalanced forces necessary for dike stability and must develop moderate-to-high tensile forces at relatively low-to moderate strains. It must exhibit enough soil/fabric resistance to prevent pullout. The geotextile tensile forces resist the unbalanced forces, and its tensile modulus controls the vertical and horizontal displacement of dike and foundation. Adequate development of soil-geotextile friction allows the transfer of dike load to the geotextile. Developing geotextile tensile stresses during construction at small material elongations or strains is essential.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes

4.2.4 Horizontal Sliding and Spreading.

These types of failure of the dike and/or foundation may result from excessive lateral earth pressure (fig 4-1a). These forces are determined from the dike height, slopes, and fill material properties. During conventional construction the dikes would resist these modes of failure through shear forces developed along the dike-foundation interface. Where geotextiles are used between the soft foundation and the dike, the geotextile will increase the resisting forces of the foundation. Geotextile reinforced dikes may fail by fill material sliding off the geotextile surface, geotextile tensile failure, or excessive geotextile elongation. These failures can be prevented by specifying the geotextiles that meet the required tensile strength, tensile modulus, and soil-geotextile friction properties.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes

4.2.5 Rotational Slope and/or Foundation Failure.

Geotextile-reinforced dikes constructed to a given height and side slope will resist classic rotational failure if the foundation and dike shear strengths plus the geotextile tensile strength are adequate (fig 4-l b). The rotational failure mode of the dike can only occur through the foundation layer and geotextile. For cohesionless fill materials, the dike side slopes are less than the internal angle of friction. Since the geotextile does not have flexural strength, it must be placed such that the critical arc determined from a conventional slope stability analysis intercepts the horizontal layer. Dikes constructed on very soft foundations will require a high tensile strength geotextile to control the large unbalanced rotational moments.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes

4.2.6 Excessive Vertical Foundation Displacements.

Consolidation settlements of dike foundations, whether geotextile-reinforced or not, will be similar. Consolidation of geotextile-reinforced dikes usually results in more uniform settlements than for non reinforced dikes. Classic consolidation analysis is a well-known theory, and foundation consolidation analysis for geotextile-reinforced dikes seems to agree with predicted classical consolidation values. Soft foundations may fail partially or totally in bearing capacity before classic foundation consolidation can occur. One purpose of geotextile reinforcement is to hold the dike together until foundation consolidation and strength increase can occur. Generally, only two types of foundation bearing capacity failures may occur partial or center-section foundation failure and rotational slope stability/foundation stability. Partial bearing failure, or “center sag” along the dike alignment (fig 4-1 c), may be caused by improper construction procedure, like working in the center of the dike before the geotextile edges are covered with fill materials to provide anchorage.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Excessive Vertical Foundation Displacement

If this procedure is used, geotextile tensile forces are not developed and no benefit is gained from the geotextile used. A foundation bearing capacity failure may occur as in conventional dike construction. Center sag failure may also occur when low-tensile strength or low-modulus geotextiles are used, and embankment spreading occurs before adequate geotextile stresses can be developed to carry the dike weight and reduce the stresses on the foundation. If the foundation capacity is exceeded, then the geotextile must elongate to develop the required geotextile stress to support the dike weight. Foundation bearing-capacity deformation will occur until either the geotextile fails in tension or carries the excess load. Low modulus geotextiles generally fail because of excessive foundation displacement that causes these low tensile strength geotextiles to elongate beyond their ultimate strength. High modulus geotextiles may also fail if their strength is insufficient. This type of failure may occur where very steep dikes are constructed, and where outside edge anchorage is insufficient.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes

4. 3 Recommended Criteria

The limit equilibrium analysis is recommended for design of geotextile-reinforced embankments. These design procedures are quite similar to conventional bearing capacity or slope stability analysis. Even though the rotational stability analysis assumes that ultimate tensile strength will occur instantly to resist the active moment, some geotextile strain, and consequently embankment displacement, will be necessary to develop tensile stress in the geotextile. The amount of movement within the embankment may be limited by the use of high tensile modulus geotextiles that exhibit good soil-geotextile frictional properties. Conventional slope stability analysis assumes that the geotextile reinforcement acts as a horizontal force to increase the resisting moment. The following analytical procedures should be conducted for the design of a geotextile-reinforced embankment: (1) overall bearing capacity, (2) edge bearing capacity or slope stability, (3) sliding wedge analysis for embankment spreading/splitting, (4) analysis to limit geotextile deformation, and (5) determine geotextile strength in a direction transverse to the longitudinal axis of the embankment or the longitudinal direction of the geotextile. In addition, embankment settlements and creep must also be considered in the overall analysis.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

4.3.1 Overall Bearing Capacity.

The overall bearing capacity of an embankment must be determined whether or not geotextile reinforcement is used. If the overall stability of the embankment is not satisfied, then there is no point in reinforcing the embankment. Several bearing capacity procedures are given in standard foundation engineering textbooks. Bearing capacity analyses follow classical limiting equilibrium analysis for strip footings, using assumed logarithmic spiral or circular failure surfaces. Another bearing capacity failure is the possibility of lateral squeeze (plastic flow) of the underlying soils. Therefore, the lateral stress and corresponding shear forces developed under the embankment should be compared with the sum of the resisting passive forces and the product of the shear strength of the soil failure plane area.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Overall Bearing Capacity

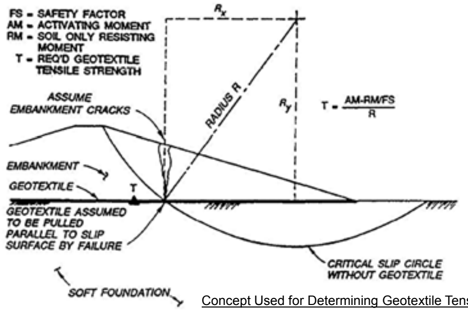
If the overall bearing capacity analysis indicates an unsafe condition, stability can be improved by adding berms or by extending the base of the embankment to provide a wide mat, thus spreading the load to a greater area. These berms or mats may be reinforced by properly designing geotextiles to maintain continuity within the embankment to reduce the risk of lateral spreading. Wick drains may be used in case of low bearing capacity to consolidate the soil rapidly and achieve the desired strength. The construction time may be expedited by using geotextile reinforcement.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

4.3.2 Slope Stability Analysis.

If the overall bearing capacity of the embankment is determined to be satisfactory, then the rotational failure potential should be evaluated with conventional limit equilibrium slope stability analysis or wedge analysis. The potential failure mode for a circular arc analysis is shown in figure 4-2. The circular arc method simply adds the strength of the geotextile layers to the resistance forces opposing rotational sliding because the geotextile must be physically torn for the embankment to slide. This analysis consists of determining the most critical failure surfaces, then adding one or more layers of geotextile at the base of the embankment with sufficient strength at acceptable strain levels to provide the necessary resistance to prevent failure at an acceptable factor of safety. Depending on the nature of the problem, a wedge-type slope stability analysis may be more appropriate. The analysis may be conducted by accepted wedge stability methods, where the geotextile is assumed to provide horizontal resistance to outward wedge sliding and solving for the tensile strength necessary to give the desired factor of safety. The critical slip circle or potential failure surfaces can be determined by conventional geotechnical limited equilibrium analysis methods. These methods may be simplified by the following assumptions:

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Slope Stability Analysis



Concept Used for Determining Geotextile Tensile Strength Necessary to Prevent Slope Failure.
Figure 4-2

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Slope Stability Analysis

4.3.2.1 Soil shear strength and geotextile tensile strength are mobilized simultaneously.
4.3.2.2 Because of possible tensile crack formations in a cohesionless embankment along the critical slip surface, any shear strength developed by the embankment (above the geotextile) should be neglected.
4.3.2.3 The conventional assumption is that critical slip circles will be the same for both the geotextile-reinforced and non-reinforced embankments although theoretically they may be different. Under these conditions, a stability analysis is performed for the no-geotextile condition, and a critical slip circle and minimum factor of safety is obtained. A driving moment or active moment (AM) and soil resistance moment (RM) are determined for each of the critical circles. If the factor of safety (FS) without geotextile is inadequate, then an additional reinforcement resistance moment can be computed from the following equation:

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Slope Stability Analysis

$TR + RM/FS = AM$ (eq 4-1)

where

T = geotextile tensile strength
R = radius of critical slip circle
RM = soil resistance moment
FS = factor of safety
AM = driving or active moment

This equation can be solved for T so that the geotextile reinforcement can also be determined to provide the necessary resisting moment and required FS.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

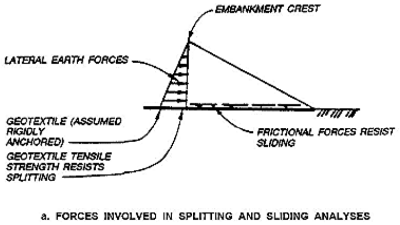
4.3.3 Sliding Wedge Analysis. The forces involved in an analysis for embankment sliding are shown in figure 4-3. These forces consist of an actuating force composed of lateral earth pressure and a resisting force created by frictional resistance between the embankment fill and geotextile. To provide the adequate resistance to sliding failure, the embankment side slopes may have to be adjusted, and a proper value of soil-geotextile friction needs to be selected. Lateral earth pressures are maximum beneath the embankment crest. The resultant of the active earth pressure per unit length P_A for the given cross section may be calculated as follows:

$P_A = 0.5\, \gamma_m H^2 K_A$ (eq 4-2)

where

γ_m = embankment fill compacted density-force per length cubed
H = maximum embankment height
K_A = coefficient of active earth pressure (dimensionless)

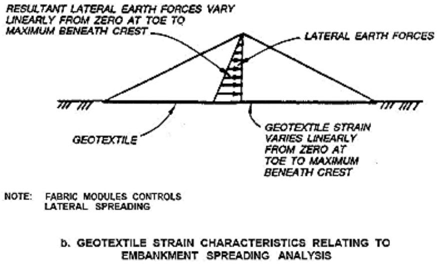
REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis



a. FORCES INVOLVED IN SPLITTING AND SLIDING ANALYSES

Assumed Stresses and Strains Related to Lateral Earth Pressures
Figure 4-3 (a)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis



b. GEOTEXTILE STRAIN CHARACTERISTICS RELATING TO EMBANKMENT SPREADING ANALYSIS

Assumed Stresses and Strains Related to Lateral Earth Pressures
Figure 4-3 (b)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis

For a cohesionless embankment fill, the equation becomes:

$P_A = 0.5\, \gamma_m H^2 \tan^2 (45 - Ø/2)$ (eq 4-3)

Resistance to sliding may be calculated per unit length of embankment as follows:

$PR = 0.5\, \gamma_m XH^2 \tan Ø_{SG}$ (eq 4-4)

where

PR = resultant of resisting forces
X = dimensionless slope parameter (i.e., for 3H on 1V slope, X = 3 or an average slope may be used for different embankment configurations)
$Ø_{SG}$ = soil-geotextile friction angle (degrees)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis

A factor of safety against embankment sliding failure may be determined by taking the ratio of the resisting forces to the actuating forces. For a given embankment geometry the FS is controlled by the soil-geotextile friction. A minimum FS of 1.5 is recommended against sliding failure. By combining the previous equations with a factor of 2, and solving for $Ø_{SG}$, the soil geotextile friction angle gives the following equation:

$Ø_{SG} = (\tan^{-1} (FS/X)) (\tan^2 (45^{O} - Ø/2))$ (eq 4-5)

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis

If it is determined that the required soil-geotextile friction angle exceeds what might be achieved with the soil and geotextile chosen, then the embankment side slopes must be flattened, or additional berms may be considered. Most high strength geotextiles exhibit a fairly high soil-geotextile friction angle that is equal to or greater than 30 degrees, where loose sand-size fill material is utilized. Assuming that the embankment sliding analysis results in the selection of a geotextile that prevents embankment fill material from sliding along the geotextile interface, then the resultant force because of lateral earth pressure must be less than the tensile strength at the working load of the geotextile reinforcement to prevent spreading or tearing. For an FS of 1, the tensile strength would be equal to the resultant of the active earth pressure per unit length of embankment. A minimum FS of 1.5 should be used for the geotextile to prevent embankment sliding. Therefore, the minimum required tensile strength to prevent sliding is:

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Sliding Wedge Analysis

$T_G = 1.5\ P_A$ (eq 4-6)

Where

T_G = minimum geotextile tensile strength.

4.3.4 Embankment Spreading Failure Analysis. Geotextile tensile forces necessary to prevent lateral spreading failure are not developed without some geotextile strain in the lateral direction of the embankment. Consequently, some lateral movement of the embankment must be expected. Figure 4-3 shows the geotextile strain distribution that will occur from incipient embankment spreading if it is assumed that strain in the embankment varies linearly from zero at the embankment toe to a maximum value beneath embankment crest. Therefore, an FS of 1.5 is recommended in determining the minimum required geotextile tensile modulus. If the geotextile tensile strength determined by equation 4-6 is used to determine the required tensile modulus an FS of 1.5 will be automatically taken into account, and the minimum required geotextile tensile modulus maybe calculated as follows:

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria
Embankment Spreading Failure Analysis

$E_G = T_g / \varepsilon_{max}$ (eq 4-7)

where ε_{max} = maximum strain which the geotextile is permitted to undergo at the embankment center line.

The maximum geotextile strain is embankment is equal to twice the average strain over the embankment width. A reasonable average strain value of 2.5 percent for lateral spreading is satisfactory from a construction and geotextile property stand point. This value should be used in design but depending on the specific project requirements larger strains may be specified. Using 2.5 percent as the average strain, then the maximum strain which would occur is 5 percent.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

4.3.5 Potential Embankment Rotational Displacement.

It is assumed that the geotextile ultimate tensile resistance is instantaneously developed to prevent rotational slope/foundation failure and is inherently included in the slope stability limit equilibrium analysis. But for the geotextile to develop tensile resistance, the geotextile must strain in the vicinity of the potential failure plane. To prevent excessive rotational displacement, a high-tensile-modulus geotextile should be used. The minimum required geotextile tensile modulus to limit or control incipient rotational displacement is the same as for preventing spreading failure.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

4.3.6 Longitudinal Geotextile Strength Requirements.

Geotextile strength requirements must be evaluated and specified for both the transverse and longitudinal direction of the embankment. Stresses in the warp direction of the geotextile or longitudinal direction of the embankment result from foundation movement where soils are very soft and create wave or a mud flow that drags on the underside of the geotextile. The mud wave not only drags the geotextile in a longitudinal direction but also in a lateral direction toward the embankment toes. By knowing the shear strength of the mud wave and the length along which it drags against the underneath portion of the geotextile, then the spreading force induced can be calculated. Forces induced during construction in the longitudinal direction of the embankment may result from the lateral earth pressure of the fill being placed. These loads can be determined by the methods described earlier where $T_G = 1.5\ P_A$ and $E_G = 20T_G$ at 5 percent strain. The geotextile strength required to support the height of the embankment in the direction of construction must also be evaluated. The maximum load during construction includes the height or thickness of the working table, the maximum height of soil and the equipment live and dead loads. The geotextile strength requirements for these construction loads must be evaluated using the survivability criteria discussed previously.

REINFORCED EMBANKMENTS
Potential Embankment Failure Modes
Recommended Criteria

4.3.7 Embankment Deformation

One of the primary purposes of geotextile reinforcement in an embankment is to reduce the vertical and horizontal deformations. The effect of this reinforcement on horizontal movement in the embankment spreading modes has been addressed previously. One of the more difficult tasks is to estimate the deformation or subsidence caused by consolidation and by plastic flow or creep of very soft foundation materials. Elastic deformations are a function of the subgrade modulus. The presence of a geotextile increases the overall modulus of the reinforced embankment. Since the lateral movement is minimized by the geotextile, the applied loads to the soft foundation materials are similar to the applied loads in a laboratory consolidation test.

5. CASE STUDIES

5.1 Lafayette County, Arkansas: Roadway Erosion

Beginning April 28, 2009, the State of Arkansas experienced severe storms and flooding, affecting 37 counties and causing damage to infrastructures. In Lafayette County alone, four roads were washed out, necessitating repairs and mitigation.

When technical advice from FEMA recommended using a geo-textile to stabilize the embankment and make the road more resilient once repairs were completed, Lafayette County's Emergency Management Coordinator became concerned about how well it would work. As a mitigation measure, the geo-textile increases resistance to localized flooding damage by reinforcing roadway sub-base and by improving sub-base drainage. Geo-textiles are designed to be permeable to allow the flow of water through it. The terms “fabric” and “cloth” raised skepticism.

CASE STUDIES
Lafayette County, Arkansas: Roadway Erosion

Very heavy rainfall from a series of storms produced large volumes of surface runoff, which overtopped CR 22 and resulted in a washout of a large section of the road and two culverts. CR 22 is primarily used as a short-cut road between the cities of Stamps and Lewisville. “Water was probably six to eight inches over the road during the flood event of May 2009. This was the first time CR 22 had ever washed out,” said a county spokesman. “After the flood event, we replaced the two culverts. Before we could do any kind of mitigation, more rain came and one of the culverts washed out again. When we were advised to try the geo-textile fabric, we were really skeptical. We just didn't think that stuff would work. We had never done this before.”

The hazard mitigation proposal included compacting soil and installing the geo-textile drainage blanket. A layer of riprap was placed over the geo-textile. At an estimated cost of $5,220.00 the mitigation project was initiated on May 21, 2009, and took four and one-half hours to complete. “It wasn't that hard to do. In fact, it's fast and easy,” said Barnes. “Some counties turn the idea down because they assume that it's time consuming,” added Teresa Smith, Arkansas' southeast area coordinator.

CASE STUDIES
Lafayette County, Arkansas: Roadway Erosion

When placed between the soil and a culvert, gabion, or retaining wall, geo-textiles enhance water movement and retard soil movement, and serves as a blanket to add reinforcement and separation. Geo-textiles are useful for moderate-flow storm water channels, banks, and steep slopes where both immediate and long-term erosion control is needed. Woven and nonwoven geo-textiles are specifically designed to protect roadways from subsurface saturation, strengthen and consolidate soil, reduce maintenance costs, and make a project easier to manage.

CASE STUDIES
Lafayette County, Arkansas: Roadway Erosion

CASE STUDIES
Lafayette County, Arkansas: Roadway Erosion

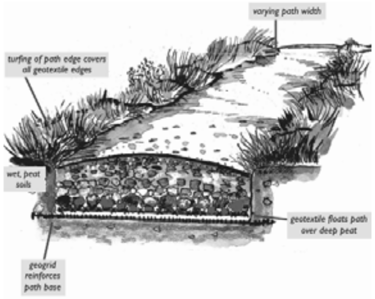
CASE STUDIES

5.2 UK: Aggregate Path on Peat

Path construction through peat can require deep excavation to reach a solid base. Where the peat depth exceeds 500mm this may be impractical. Either large quantities of material are required, or, without a firm base, the path structure will be unstable. The use of synthetic geotextiles to provide the foundation, and ‘float’ the path over deep peat has developed from road engineering and construction methods.

Geotextile laid under the path separates the path material from the peat; it prevents aggregate loss and the path subsequently disappearing. Selection of appropriate geotextiles will also provide a strong path base. If laid well this results in a stable and durable path. This technique reduces the amount of excavation and aggregate required compared to excavating to a hard base and infilling with stone.

CASE STUDIES
UK: Aggregate Path on Peat



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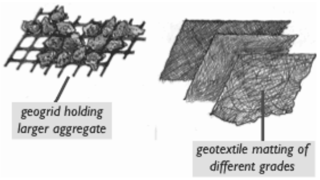

***And* now….**

….the **QUIZ**

QUIZ

1. ________________ is not a method for manufacturing nonwoven geotextiles.
    a. Needle punching
    b. Heat bonding
    c. Resin bonding
    d. Twill weave
2. Warp and fill is/are ___________________.
    a. a common geotextile packaging
    b. structural layers in some geotextiles
    c. a geotextile manufacturing technique
    d. directions for woven geotextiles
3. __________________ is not a basic geotextile function.
    a. Filtration
    b. Compaction
    c. Drainage
    d. Erosion control

QUIZ

4. Reflective cracks occur in pavement _______________.
    a. cross drains
    b. subgrades
    c. subbases
    d. overlays
5. Piping resistance is _______________________.
    a. head loss per linear foot
    b. unitless
    c. the ability of a geotextile to retain solid particles
    d. a measure of retention rate
6. With regard to Geotextile Filter Design Criteria, "POA" is the ___________________.
    a. percent open area
    b. pavement on asphalt
    c. placement on asphalt
    d. peripheral open area

QUIZ

7. ____________________ is the reduction in permeability or permittivity of a geotextile due to blocking of the pores.
    a. Flow reversal
    b. Transverse permeability
    c. Clogging resistance
    d. In-plane permeability
8. The limitation of directly measuring the permeability and permittivity of geotextiles is that Darcy's Law applies ___________________.
    a. only as long as laminar flow exists
    b. only as long as turbulent flow exists
    c. only as long as transitional flow exists
    d. only at L/d > 100
9. Permeability criteria for nonwoven geotextiles require that the permeability of the geotextile be at least __________ times the permeability of the surrounding soil.
    a. five
    b. ten
    c. twenty
    d. one hundred

QUIZ

10. To prevent clogging or binding of the geotextile in a filtration application, ______________ between the soil and geotextile should be assured during construction.

    a. a separation membrane
    b. a sand drainage layer
    c. a PVC membrane
    d. intimate contact

11. Geotextiles should retain _________ percent of their strength after 150 hours of exposure to ultraviolet sunlight, using the ASTM D 4355 test method.

    a. 50
    b. 60
    c. 70
    d. 80

12. Consecutive pieces of geotextile in drainage applications should lapped or joined by ________________.

    a. sewing
    b. heat bonding
    c. overlapping
    d. "a", "b" or "c"

QUIZ

13. Which of the following is not a basic function of geotextiles?

    a. filtration
    b. drainage
    c. sealing
    d. separation

14. In erosion control the geotextile protects soil surfaces from the __________ forces of moving water, wind and/or rainfall.

    a. sedimentary
    b. tractive
    c. laminar
    d. static

15. Woven and nonwoven geotextiles can serve as moisture barriers when impregnated with _____________ mixtures.

    a. bituminous
    b. sand/soil
    c. POL (petroleum-oil-lubricant)
    d. all of the above

That's all folks!