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Abridgment

Mechanism of Geotextile Performance in Soil-Fabric Systems for Drainage and Erosion Control

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Over the past 15 years, more than 250 000 000 m^2 (300,000,000 yd^2) of geotextiles have been used in drainage and erosion-control systems. Initial geotextile specifications established a decade ago were based on the best-available understanding of fabric function in fabric-soil systems. Considerable research over the past 10 years has significantly changed the understanding of how fabrics function in these systems. As a consequence, fabric specifications now need modification to achieve maximum cost-effective performance. Therefore, a state-of-the-art model of soil-fabric systems is given, and the key physical properties of geotextiles needed for acceptable performance are suggested. Knowing how fabrics function and which properties are important, the designers and contractors of drainage and erosion-control systems can properly specify and install the geotextiles needed in a given system for acceptable performance at minimum cost.

Nonwoven geotextiles account for more than 90 percent of the fabrics used outside of the United States. Within the United States they have only recently reached the same rate of use as wovens because they were introduced 10 years later than wovens. On a worldwide basis, 80 percent of the geotextiles used in erosion control have been nonwoven. The first table gives data on the types of geotextiles installed:

	Geotextiles Installed, 1968-1981 (m² 000 000s)			
	United States		Worldwide	
Item	No.	Percent	No.	Percent
All fabrics	200		690	
Nonwovens	120	60	590	85
Wovens	80	40	100	15

The second table gives data on the use of geotextiles:

	Geotextiles Installed, 1968-1981 (m² 000 000s)			
	United States		Worldwide	
Item	Nonwoven	Woven	Nonwoven	Woven
Drainage	40	10	125	15
Support	65	55	375	65
Erosion Control	15	15	90	20

(Note: In the above tables, geotextiles installed include only those in drainage, support, and erosion control; worldwide figures include U.S. values; and 1 m^2 = 1.196 yd^2.)

More than 110 000 000 m^2 (130,000,000 yd^2) of geotextiles has been installed during the past decade, and these geotextiles have demonstrated acceptable performance in a wide spectrum of erosion-control systems. In drainage systems, 140 000 000 m^2 (165,000,000 yd^2) of fabrics was installed in the past 10 years and have performed satisfactorily.

FUNCTIONS OF GEOTEXTILES IN DRAINAGE AND EROSION CONTROL

In erosion-control systems, geotextiles perform the same functions as in drainage except for some applications, such as protection from wave action, where they are submitted to greater stresses during service than during installation. The three specific functions performed by geotextiles in drainage and erosion-control applications are

1. Prevention of soil movement,
2. Allowing free passage of groundwater, and
3. Prevention of intrusion of the cover material into the protected soil.

In addition, fabrics must be able to withstand installation stresses and must survive in place at least throughout the expected life of the system.

Prevention of Soil Movement

The major function of geotextiles in erosion control and drainage is to prevent the exposed surface soil from being moved by dynamic environmental forces.

To prevent movement of the surface soil, the geotextile must be in intimate contact with the soil (i.e., there must be no space between the fabric and the soil); otherwise the fabric will be forced to act as a true filter at a lower level, where it and the soil come in intimate contact again. Here the fabric actually stops the soil particles from moving and allows water to pass through (Figure 1). However, wherever the geotextile is in intimate contact with the soil, the soil is prevented from moving in the first place (Figure 2). The fabric performs as a permeable constraint, not as a filter. This concept was presented by McGown (1) in 1978 in Europe. Ball and others (2) described this function in 1979 based on their work for the Alabama Department of Highways.

Bell (3) described the constraint function of geotextiles in drainage and erosion control in more

Figure 1. Fabric separated from protected soil.

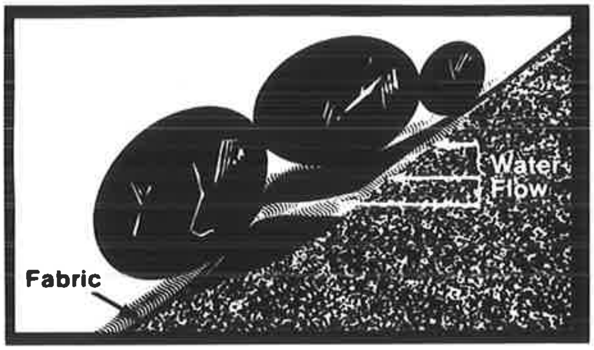


Figure 2. Fabric maintained in intimate contact with protected soil.

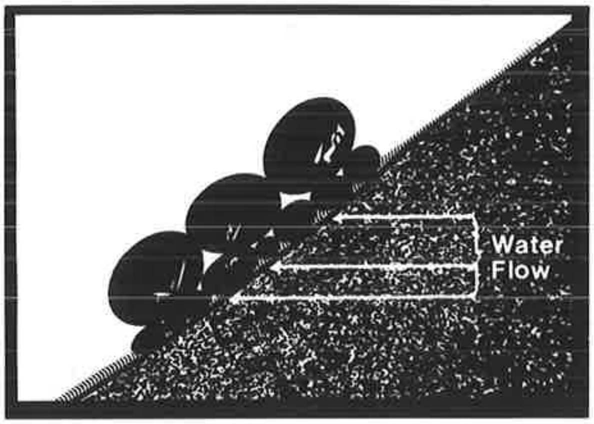
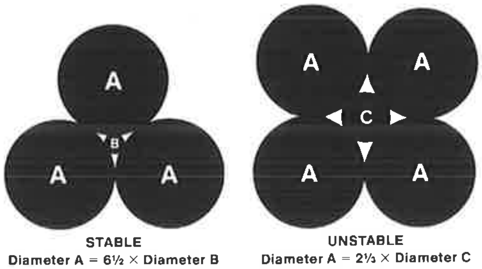


Figure 3. Filter criteria.



The diameter of an opening in a filter medium should be three (3) times greater than the diameter of the particles being separated from a fluid.

detail. His conclusions were based on information gathered from the report on geotextiles prepared for FHWA (4) and from his own studies:

> The geotextile is commonly referred to as a filter; however, the real objective is to prevent the geotextile from performing as a true filter. A filter removes suspended particles from a fluid and by this action a filter must plug. Therefore, a geotextile filter application must be designed so that it does not remove large quantities of suspended particles from the pore water. The system must be designed so that, 1) particles do not go into suspension and, therefore, are not filtered by the geotextile; or 2) particles that are in suspension are allowed to pass through the geotextile so that it does not plug.

Bell (3) summarized the fabric function for constraint purposes and suggested that there were three general objectives of a geotextile filter:

1. To allow the free flow of water from the soil into the drain,
2. To prevent piping of the soil around the drain, and
3. To prevent plugging of the filter (Figure 3).

Allowing Free Passage of Groundwater

A fabric must maintain the ability to allow groundwater seepage to pass freely through the fabric throughout the service life of the system. The principal design uncertainty is how to match the water permeability of the fabric to that of the soil being protected. Marks (5) and Carroll (6) carried out major laboratory studies with nonwovens, which demonstrated that each of several different soil types, not fabric type, controlled the rate of water flow.

Chen and others (7) demonstrated that these results were to be expected. The equation that describes the velocity of water flow (V) through a system of materials that has different permeability coefficients is

$$V = H/\left[\sum_{i}^{n} (d_i/k_i)\right] \qquad (1)$$

where

V = water flow velocity through the system,
H = hydrostatic pressure,
d_i = thickness of a material segment, and
k_i = permeability coefficient of a material segment.

Therefore, if $k_s = k_f$, and $d_s >>> d_f$ (when s = soil and f = fabric), then $d_s/k_s = (d_s/k_s) + (d_f/k_f)$. Because the protected soil is so much thicker than the geotextile, the soil controls water flow when $k_s \approx k_f$.

Turning from theoretical considerations to practical applications, Table 1 gives water flow rates of soils and fabrics that have the same permeability coefficients.

Because geotextiles have approximately 1,000-fold greater flow capacities than soil at equivalent values of k, a standardized flow index [e.g., permittivity = k_f ÷ (fabric thickness)] is needed to match fabrics to soil.

Prevention of Intrusion of Cover Material into Protected Soil

In fabric-containing erosion-control systems, the aggregate cover material (e.g., gravel, rip-rap, armor stone) serves two main functions:

1. It minimizes the kinetic energy of the water that contacts the fabric from the outside, and
2. It keeps the geotextile in intimate contact with the soil.

The function of the fabric in relation to the cover material is to keep the aggregate separated from the soil below and to prevent the stones from sinking.

To keep the geotextile in continuous intimate contact with the soil throughout the life of the

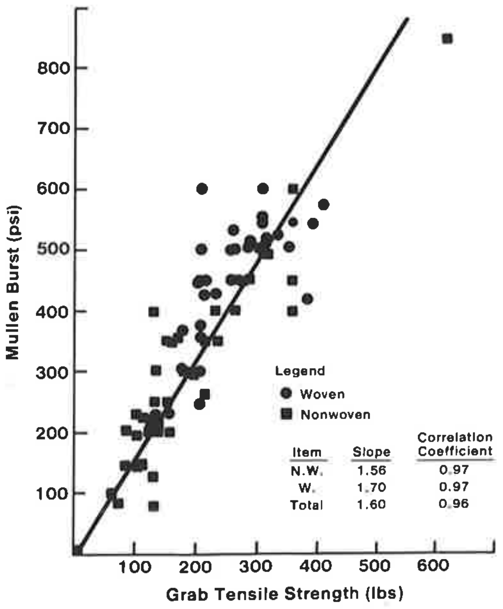
Table 1. Flow rates of soils and fabrics that have the same permeability coefficients under equivalent pressure.

Permeability Coefficient, k (cm/sec)	Soil Flow Rate[a]		Fabric Flow Rate (gal/min/ft^2)
	Type	Rate (gal/min/ft^2)	
0.001	Well-graded silty sand and gravel	0.005	15
0.01	Clean, well-graded sand and gravel	0.05	100
0.1	Uniform, medium sand	0.5	400
1	Uniform, coarse sand	5	
10	Clean, fine to coarse gravel	50	
100	Derrick stone	500	

Note: A hydrostatic pressure of 25 cm (10 in.) was used.

[a] A soil thickness of 100 cm (40 in.) was used.

Figure 4. Grab tensile strength versus burst strength for some geotextiles.



erosion-control system, the cover material must be appropriately designed and properly installed to ensure that it will remain in place during the life of the system. A covering aggregate that is too lightweight and placed on a properly selected fabric in a system that is subjected to high wave action may be moved during service.

The stone placed inside a fabric-enclosed drain system should be well compacted to ensure that the geotextile is in intimate contact with the soil for these same reasons.

Another important consideration in designing cover material is to be certain that the material itself is at least as permeable as the soil, and that it will remain so.

Because proper installation methods can prevent premature failure, any new or innovative procedures must be specified by the designers, at least until they become common practice in the construction industry.

DESIGN CRITERIA

Fabric characteristics important in erosion control and drainage are permeability, soil retention abilities, durability, and strength properties. The generally greater physical property (strength) requirements for erosion-control applications are discussed below. Requirements for drainage fabrics are usually lower than those for erosion control.

Permeability

The ability of nonwoven fabrics to allow water to pass freely is 1,000-fold greater than that of soil of an equal permeability coefficient. To satisfy the immediate need for an acceptable method for matching the flow levels of fabrics to soil with high margins of safety, the recommendation is to allow $k_f = k_s$ for noncritical applications, and $k_f = 10 \times k_s$ for critical applications.

Soil Retention Abilities

Extensive laboratory testing and in-use experience have shown how currently available nonwoven geotextiles that have opening size values of ≤ 0.8 mm ($\geq$ No. 20 sieve) and wovens with opening size values of ≤ 0.6 mm ($\geq$ No. 30 sieve), as determined by the U.S. Army Corps of Engineers' equivalent opening size (EOS) test, perform acceptably in erosion-control and drainage applications.

Soil-fabric problems that have occurred to date were not caused by fabrics that have excessively open structures. Problems have occurred from one or both of two causes. Foremost, the fabric was not placed in intimate contact with the soil and it was forced to become a true filter. Second, the fabric openings were too small to allow the usual, initial, short-term passage of suspended fine particles through the fabric.

Currently, no established correlation between EOS values and the performance of geotextiles (5,8) has been found, despite the efforts of many researchers.

Durability

Durability criteria commonly include chemical, biological, thermal, and ultraviolet stability. These properties are addressed by Bell and others (4) and many other researchers.

Strength Properties

There is general agreement among researchers that at least two levels of the strength requirement are needed to differentiate between the general minimum requirements and those fabrics that will be submitted to unusually high stresses during installation or in service.

The majority of drainage applications are satisfied by one set of specifications because there are seldom significant in-use stresses. Where necessary, specifications for erosion control in critical applications may be used.

The lower level of strength requirements was developed to ensure that the fabric will survive construction of the system. Fabrics that have greater strength levels will survive severe in-use stresses. The physical properties generally considered of primary importance are tensile strength, elongation, puncture resistance, tear propagation resistance, and burst strength.

Other properties described by Bell and others (4) that are of secondary importance are bulkiness, weight (dry and wet), specific gravity, flexibility, cutting resistance, and seam strength. Of the specifications on primary properties, burst strength is redundant because it is indexed by fabric tensile strength values, as shown in Figure 4.

SUMMARY

In summary, it should be stressed again that the majority of specifications in place today and the concepts on which they were developed were formulated in the late 1960s and early 1970s. Currently, a rapidly growing body of information demands that these older concepts be modified to accommodate an increased understanding of how fabrics and systems function. Current understanding will change further in this decade. Nevertheless, what is known today must be used as the basis for guidelines and practice. This is the continuing dilemma of working with a dynamic, essential technology.

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Permeability Tests of Selected Filter Fabrics for Use with a Loess-Derived Alluvium

G.T. WADE, F.W. KLAIBER, AND R.A. LOHNES

Permeability tests on six nonwoven and two woven geotextiles with a silty-clay alluvium indicate that all of the fabrics tested will prevent piping of the soil, regardless of the state of compaction. When a discontinuity (such as a hole) was introduced into the soil, some soils were observed to pipe. The range of permeabilities of soil-fabric systems was observed to be narrow, even though the range of fabric permeability was wide and the soil compaction varied. A theoretical analysis shows that the permeability of the soil is the controlling factor in permeability testing of the soil-fabric system. A piping test similar to the test for dispersive clays is suggested as an alternative to permeability testing of soils and filter fabrics.

Drainage problems have traditionally been solved by using aggregate filters. Loess-derived silty soils (like those in western Iowa) require multilayer filters, which are both expensive to produce and labor intensive to construct. The need for more economical methods of filter construction with silts resulted in a study of geotextile filters for use with these soils. There are currently more than 100 (1) different geotextiles available in the United States, which consist of both woven and nonwoven fabrics.

Several weaving techniques are used, but the products are essentially the same: a relatively thin cloth that has a rectilinear pattern of openings. The sizes of the openings differ, depending on the thickness of the filament and the number of picks per inch, but for any given fabric there is only slight variability in the size of the openings.

Nonwoven fabrics are produced by several techniques, depending on the manufacturer, and may be thin or more than a centimeter thick. Regardless of thickness, the irregular filament pattern produces various pore sizes through the fabric. Thicker nonwoven fabrics are often arbitrarily classified as mats.

LITERATURE REVIEW

Cotton cloth was first used in North Carolina in 1926 to improve subgrade strength, and the U.S. Army Corps of Engineers began using fabrics in the early 1950s to control shore erosion. Increased construction costs and the development of synthetics resulted in the expanded use of geotextiles, including embankment stabilization, grade stabilization for highways and railroads, retaining walls, consolidation of soils, drainage, and silt fences for erosion control. The product technology and availability of geotextiles have progressed ahead of published research results.

The Corps of Engineers used research conducted at the Waterways Experiment Station to develop guidelines for the use of plastic filter cloth (2). Six woven and one nonwoven filter cloths were tested for various chemical and physical properties. Two characterization tests of particular interest for drainage applications are the equivalent size of the openings and the percentage of openings in the fabric. Rounded sand of known gradation was sieved through the fabric, and the percentage retained was used to determine an equivalent opening size (EOS). The percent open area (%OA) was determined by projecting an image of the cloth on a grid and measuring the amount of open area at randomly selected points on the grid.

Filtration and clogging tests were conducted with several gap-graded soils that exhibited a suscepti-