portation-Related Applications. Haliburton Associates, Stillwater, OK, Dec. 1981.
5. T.A. Haliburton and J.D. Lawmaster. Experiments in Geotechnical Fabric-Reinforced Soil Behavior. Geotechnical Testing Journal, ASTM, Vol. 4, No. 4, Dec. 1981, pp. 153-160.
6. D.M. Burmister. The Theory of Stresses and Displacements in Layered Systems and Applications to the Design of Airport Runways. Proc., HRB, Vol. 23, 1943, pp. 126-144.
7. E.J. Yoder and M.W. Witczak. Principles of Pavement Design. Wiley, New York, 1975.
8. Nicolon Corporation Criteria for the Design of Geolon Fabric-Reinforced Unsurfaced Roads. Haliburton Associates, Stillwater, OK, July 1981.

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Dynamic Test to Predict Field Behavior of Filter Fabrics Used in Pavement Subdrains

DONALD J. JANSSEN

A dynamic test that attempts to duplicate field conditions for filter fabrics used in pavement subdrains is described. A filter fabric sample under a saturated silty-sand test soil is subjected to repeated axial loading while water flow is maintained through the sample under a unit hydraulic gradient. Sample permeability is monitored continuously. Results are presented in the form of a plot of sample permeability versus accumulated loads, and plots that show the movement in soil after 1 million loads.

The use of engineering fabrics in filter applications has become widespread in the past 10 years. They can be effective in protecting soil from erosion while permitting water to pass through the fabric to the drain. However, with the large number of filter fabrics available, some means must be found to determine the fabrics best suited for each application. The fabric must not clog or in any way significantly decrease the rate of flow. At the same time, the fabric must not let too much material pass through it because clogging of the drainage material and loss of subgrade support could occur (1).

Various tests have been proposed to help evaluate filter fabrics for various uses. The U.S. Army Corps of Engineers employs a test in which the fabric is used as a dry sieve in order to determine the largest size of glass beads that pass through the fabric (2). The largest size opening that at least 5 percent of the beads pass through the fabric is called the equivalent opening size (EOS) (2).

Calhoun (3) developed a constant-head permeameter test to examine fabric clogging under constant-head water flow. The overall hydraulic gradient across the soil sample could be changed in order to evaluate clogging under differing hydraulic conditions. In addition, piezometric pressure taps were installed at various depths in order to measure the hydraulic gradient throughout the sample. The Corps of Engineers used the ratio of the hydraulic gradient in the 2.5 cm (1 in.) of the sample directly above the fabric to the hydraulic gradient in the next 5 cm (2 in.) of the sample as one criterion for accepting a filter fabric for a given filter application [see Figure 1 (2)].

In the actual soil and filter fabric interaction, a rather complex bridging or arching occurs in the soil next to the fabric that permits particles much smaller than the openings in the fabric to be retained. Copeland (4) provides a good discussion of this process along with results of tests she performed with various fabrics and soils under constant hydraulic gradients. She considers failure of the soil-fabric system as either excessive piping of soil particles through the fabric or as a substantial decrease in permeability through the fabric and adjacent soil. She also identifies the hydraulic gradient through the sample that causes the failure.

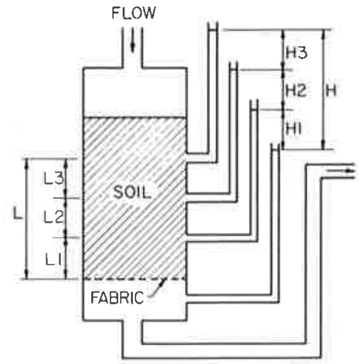
The use of filter fabrics in highway subdrains requires the consideration of an additional factor. A highway is subjected to repeated dynamic loading by traffic. Dempsey (5) found that this loading can lead to substantial pore-pressure pulses in a saturated pavement system.

A soil and filter fabric system at the pavement edge may be subjected not only to a possible unit hydraulic gradient during heavy rain, but also to an additional gradient caused by highway traffic loading. The fact that this gradient would be changing in magnitude rather than remaining constant means that any comparison with constant-gradient soil-fabric tests would be difficult. Instead, a test that duplicates the effects of repeated traffic loading would be useful in predicting filter fabric behavior in highway subdrain applications. The conditions to be duplicated should also include continuous water flow (as in a heavy rainfall) and the use of a test soil that would show any soil movement and cause clogging under test conditions.

OBJECTIVES

This study was conducted in order to determine the behavior of filter fabrics to be used in pavement subdrain systems in the field. Specific test objectives were to

1. Develop a repeated triaxial-loading test to simulate truck traffic on the pavement;
2. Develop a continuous water-flow system to provide a unit hydraulic gradient through the soil sample, such as would be caused by heavy rainfall;
3. Select a soil that will cover the size ranges expected to be the most likely to move under water pressures created by the combined water flow and dynamic loading; and
4. Develop a system for the test to permit continuous monitoring of the flow rate in order to evaluate filter performance.



L1=L2=L3=2.5 CM

$$\text{GRADIENT RATIO} = \frac{\frac{H1}{L1}}{\frac{(H2 + H3)}{(L2 + L3)}}$$

Figure 1. Method of determining Corps of Engineers' gradient ratio with Calhoun-type constant-head apparatus.

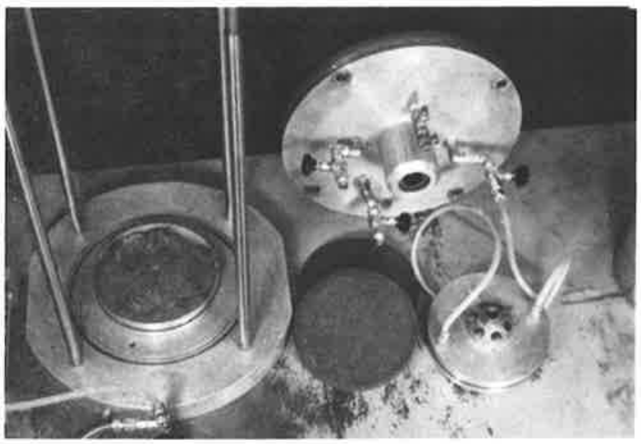


Figure 2. Triaxial cell parts. [Shown (from left to right) are the cell base, loading cap, and porous stone; the cell cap is in the back.]

TESTING EQUIPMENT

Triaxial Cell

The triaxial cell used to hold the sample (Figures 2 and 3) has been used at the University of Illinois for several years. It will hold a 203-mm (8-in.) diameter sample that is 406 mm (16 in.) high (6).

The top of the cell is adapted to allow tube connections to the sample loading head for flushing and to permit water flow through the sample. An additional tube connection is made to allow for a piezometric pressure tap at the base of the soil sample (Figure 4).

Loading

The flexible confining membrane used to contain the sample is made of 0.8-mm (0.03-in.) thick neoprene rubber cut to size and glued with a 7.5-cm (3-in.) overlap to form a cylinder. Two membranes are used: one attached directly to the filter fabric and containing the soil, and a second membrane to contain the entire sample setup. A small hole is cut in the outer membrane below the filter fabric to permit the installation of a piezometric pressure tap.

Porous carborundum stones [20 cm (8 in.) in diameter and 2.5 cm (1 in.) thick] are placed on both ends of the sample to facilitate water flow through the entire sample cross section.

Figure 3. Assembled triaxial cell.

Repeated axial loading is produced by an air-actuated diaphragm air cylinder. The loading rate is approximately once every 2 sec. This rate is slow enough to permit the damping out of residual pressure fluctuations after each load pulse. The magnitude of the load pulse is 17.5 kN/m² (2.5 psi). The confining pressure was maintained at 12.1 kN/m² (1.75 psi). These values were determined from elastic-layer and finite-element analyses as typical stresses in the subgrade from truck loadings on an Interstate pavement. Water is used as the confining medium, and pressure is controlled by a single-stage air-pressure regulator. A mercury manometer is used to read the pressure difference between inside and outside the sample membrane to determine the net confining pressure.

Permeameter

A schematic for the equipment used to maintain water flow through the sample is shown in Figure 5. A similar device for permeability measurement has been in use at the University of Illinois for several years and is reliable (7). The apparatus consists of a water reservoir, manometer tube, bleeder valve, micro-adjust valve, and valves for sample isolation. In practice, there is an additional water reservoir and assorted valves to permit operation while one reservoir is being refilled. The apparatus is shown in Figure 6.

The water used in the system is de-aired under vacuum in order to prevent air bubbles from forming in the system and to dissolve any bubbles already present. The whole system is back-pressured to about 220 kN/m² (32 psi). In order to keep the water de-aired, a layer of mineral oil covers the water in the reservoir tanks, thereby separating the water and air.

Water flow is accomplished by means of the bleeder valve connected to the bottom of the sample. By allowing water to drain from the bottom of the sample, a pressure difference across the sample is created. This pressure difference is read on the manometer connected to the piezometric tap and is

Figure 4. Triaxial cell schematic.

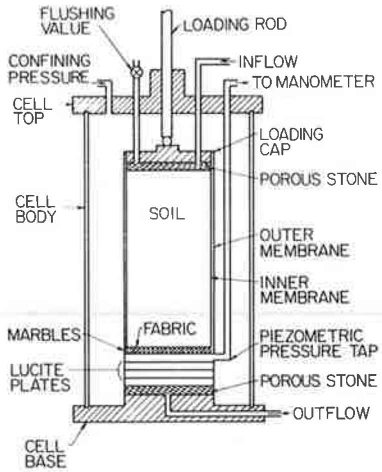
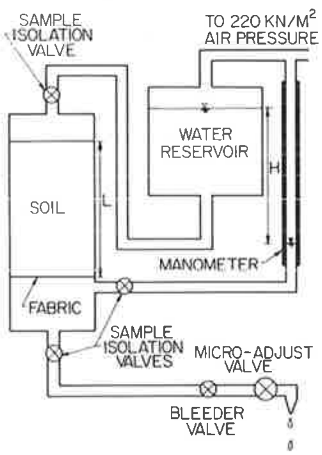


Figure 5. Permeameter schematic.



controlled by adjusting the flow rate with the micro-adjust valve.

The practical range of permeability values for this equipment is from 2×10^{-2} to 1×10^{-6} cm/sec.

Sample

The test sample consists of soil, filter fabric, 1.5-cm (0.625-in.) diameter glass spheres (marbles) for fabric support, confining membranes, and soil collection plates (see Figure 3).

The soil is a mixture of 90 percent class X concrete sand (no material smaller than the No. 200 sieve) and 10 percent Roxana silt, all of which pass the No. 200 sieve. This mixture was chosen to provide a test soil with silt and fine sand that is most likely to move due to hydraulic gradient (8). The coarse sand fraction provides a supporting matrix. The complete gradation is shown in Figure 7.

The fabric is supported on a layer of marbles, and beneath the marbles are four perforated Lucite plates. The faces of the plates are recessed to provide space to collect the soil that passes through the fabric.

SAMPLE PREPARATION

The outer sample membrane is placed on the triaxial cell base and tied with multiple wraps of cotton cord. A watertight seal is ensured by the use of silicone vacuum grease on both the membrane and the cell base. A porous stone and the four Lucite plates are then placed inside the membrane. The

Figure 6. Permeameter apparatus.

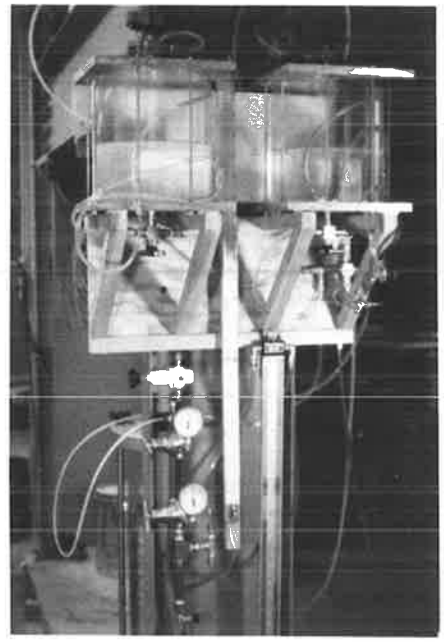
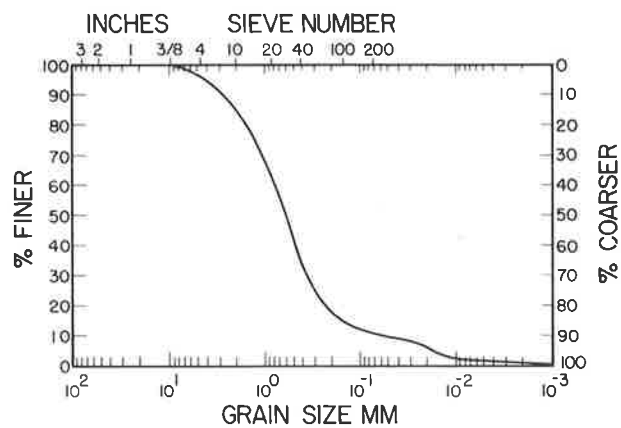


Figure 7. Test soil gradation.



piezometric pressure tap is installed through the membrane just below the top Lucite plate. This is also sealed with a liberal coating of vacuum grease. A single layer of marbles is placed on the top Lucite plate, and a second membrane that has the filter fabric attached is inserted into the confining membrane. A coating of vacuum grease is used to prevent water from flowing between the two membranes.

The bottom of the sample confining membrane is now filled with water to above the filter fabric and then drained so that the water level is at the level of the filter fabric. This filling is done from the bottom with frequent tapping and shaking to loosen any trapped air bubbles.

Dry soil [13.6 kg (30 lb)] is thoroughly mixed with water [2 L (4.4 lb)] to produce a mixture close to 100 percent saturation. This mixture is placed by hand in the sample membrane. Excess water is allowed to drain through the sample and out the piezometric tap, the open end of which is about 1 cm (0.4 in.) above the level of the filter fabric. A dry density of about 1620 kg/m³ (101 lb/ft³) is produced by this method and is easily reproducible.

The sample is allowed to sit until any excess water on the top of the sample has drained through the sample. A porous stone and the loading cap are then placed on the sample, and the loading cap is tied in place. Again, vacuum grease is used to ensure a watertight seal.

The Lucite cell body is placed on the cell base. Water tubes are connected from the cell top to the sample. The cell top is then tightened onto the cell body and the loading rod is attached through the cell top onto the loading cap. The cell is then filled to the top of the sample with water, and the remaining water tubes are connected to the cell to complete sample preparation (Figure 3).

TEST PROCEDURE

The sample is saturated from the bottom up, and the system is then closed to permit pressurization. Both the confining pressure and the internal pressure are increased slowly, keeping the confining pressure at least 15-cm (6-in.) mercury greater than the internal pressure. This pressure difference is read on the mercury manometer. Pressure is increased until the internal pressure is 220 kN/m^2. The final confining pressure is adjusted to 16.5-cm (6.5-in.) mercury greater than the internal pressure. The net confining pressure (P) is computed by the following equation:

$$P = 1.33[H - (Hw/13.6)] \tag{1}$$

where

- P = net confining pressure (kN/m^2),
- 1.33 = conversion from centimeters mercury to kilonewtons per square meter,
- H = pressure difference (cm mercury),
- Hw = distance (cm) from middle of reservoir tank to top of confining water in triaxial cell, and
- 13.6 = conversion from centimeters mercury to centimeters water.

Flow is initiated in the sample by opening the bleeder valve. The flow rate is adjusted with the micro-adjust valve to give a pressure difference across the sample in the range of 24 to 26 cm (9.5 to 10.25 in.). Readings of quantity of flow, time for collection, and head difference are taken until the permeability is stabilized, which is usually 10 to 15 min. Loading is then started.

Readings are taken after 1, 10, 100, and 500 loads, and after that as needed, depending on how much the permeability is changing. On long-term tests, readings are generally taken at least every 6 hr. Notes are also made on whether or not the water is cloudy.

At the conclusion of the test, the system is depressurized, keeping the confining pressure at least 15-cm mercury greater than the internal pressure. In addition, the pressure gradient in the sample is kept to less than 25-cm (10-in.) water.

The cell is then taken apart and the sample divided into eight layers [approximately 3 cm (1.2 in.) thick] for grain-size analysis. In addition, the soil that has passed through the fabric is collected for grain-size analysis.

RESULTS

The water bled off is collected and the flow rate is used to calculate the sample permeability by the following equation:

$$K = QL/HAT \tag{2}$$

where

- K = sample permeability (cm/sec);
- Q = measured volume of flow (cm^3);
- L = length of soil sample (cm); see Figure 5;
- H = pressure head difference across sample (cm); see Figure 5;
- A = cross-sectional area of sample (cm^2); and
- T = time required to collect volume Q (sec).

The sample permeability is then plotted versus the accumulated number of loads (see Figure 8).

Cloudy water was noted from about 300,000 to 320,000 loads. It also occurred at about 650,000 loads and gradually cleared until about 900,000 loads, when it was again clear.

Gradation analysis is run on the soil taken from the sample in 3-cm (1.2-in.) layers. The gradation for each layer can be plotted for comparison with the original retained soil gradation.

Assuming that no movement of materials larger than the No. 10 sieve has occurred, the percentage of the original for each of the smaller-sized fractions can be calculated by the following equation:

$$\%DR = [(wtD)(\% + 10)]/[(\%D)(wt + 10)] \tag{3}$$

where

- %DR = percentage of size range D retained,
- wtD = actual weight of size range D for soil layer being considered,
- %D = percentage of size range D in original gradation,
- % + 10 = percentage of material larger than No. 10 sieve in original gradation, and
- wt + 10 = actual weight of material larger than No. 10 sieve found in layer in question.

The percentage of material retained versus height in the sample can then be plotted for each size range. Figures 9 and 10 show this for material finer than the No. 80 sieve but retained on the No. 200, and for material finer than the No. 200 sieve.

DISCUSSION OF RESULTS

The usefulness of this test for the evaluation of filter fabrics is probably most easily shown by the examination of a set of results for a test run to 1 million loads. The data are for a nonwoven, needle-punched, and heat-bonded fabric with a minimum EOS of 70 (the largest pores are equivalent to the openings in a No. 70 sieve).

Figure 8 shows that the first few loads caused a rapid increase in sample permeability. This is probably due to the washing out of any fines that accumulated in the fabric during sample preparation. Then the permeability gradually dropped until 300,000 loads, where it dropped abruptly. This was accompanied by cloudy water coming through the permeameter. It is believed that a graded soil-filter structure was being built up adjacent to the fabric as fines migrated down through the sample. At 300,000 loads, this structure collapsed, causing a rapid decrease in permeability. From here the permeability again gradually decreased, possibly caused by the accumulation of fines adjacent to the fabric.

At about 675,000 loads, the permeability suddenly increased. Before that, at about 650,000 loads, the water again appeared cloudy. It appears that the high hydraulic gradient right above the filter fabric, along with the stretching of the fabric and fabric pores, caused piping of the fines through the fabric. This gives the appearance of a self-cleaning action. The wide fluctuations in permeability between 675,000 and 700,000 loads may possi-

Figure 8. Sample permeability versus accumulated loads.

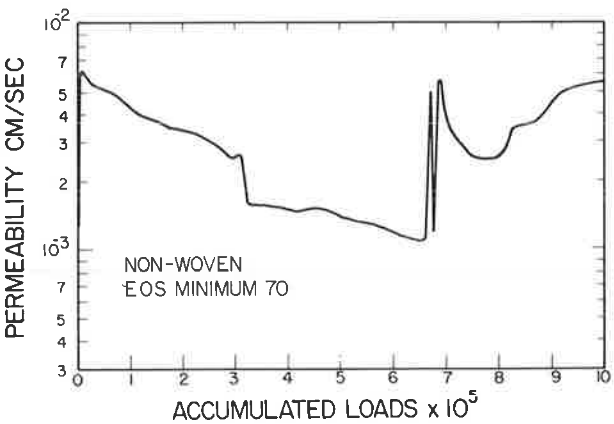


Figure 9. Percentage of material smaller than No. 80 sieve and larger than No. 200 sieve remaining in sample versus position in sample.

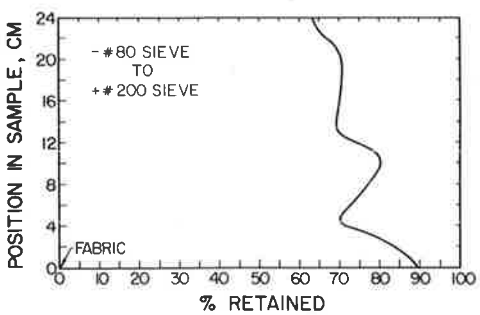
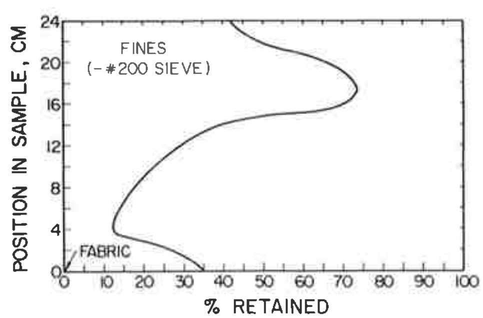


Figure 10. Percentage of fines (smaller than No. 200 sieve) remaining in sample versus position in sample.



bly have been caused by soil structure collapse followed by more soil piping.

The permeability again decreased from 700,000 to about 820,000 loads. The water was still slightly cloudy. Then at 820,000 loads the permeability increased and continued to increase to the end of the test at 1,000,000 loads. It appears that a more stable soil-filter structure had formed by this time that allowed some of the fines to pass through the fabric without clogging behind the fabric, which would have decreased permeability.

The fact that the fabric was able to clean itself is probably due to the nature of the loading. If the total hydraulic gradient in the sample had been constant, plugging of the soil-fabric system and loss of permeability would probably have been irreversible. However, the hydraulic gradient is pulsed. The accelerating water velocity caused by the changing hydraulic gradient transfers momentum to the soil particles and dislodges them from their existing structure. Each gradient pulse, although short in duration, is able to move the soil particles a bit. This can combine with stretching of the fabric between points of support and enlarging of the fabric pores. Eventually the soil particles are able to pass through the fabric, which assumes that the openings in the fabric are large enough. If the openings in the fabric are too small or too infrequent, soil particles will not pass through and the fabric will not be self-cleaning.

Figures 9 and 10 show the migration of material through the soil and fabric. Much of the material smaller than the No. 200 sieve and some of the material with gradations smaller than the No. 80 sieve to larger than the No. 200 sieve have been lost through the fabric. It should be noted that there is a relative accumulation of material right above the fabric. This was also visible when the sample was disassembled.

SUMMARY AND CONCLUSIONS

The test described in this paper provides an important step in the evaluation of filter fabrics when used in highway subdrains because it attempts to duplicate actual field conditions. The parameters of loading, soil, and hydraulic gradient can be varied to attain any type of field condition expected for the evaluation of filter fabrics for use in conjunction with drainage in pavement systems.

Additional tests are being conducted in order to compare the behaviors of various filter fabrics.

ACKNOWLEDGMENT

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The contents of this paper reflect my views, and I am responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Monsanto Plastics and Resins Company. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. E.J. Barenberg and S.D. Tayabji. Evaluation of Typical Pavement Systems Using Open-Graded Bituminous Aggregate Mixture Drainage Layers. Department of Civil Engineering, Univ. of Illinois, Urbana-Champaign, Transportation Engineering Series 10, May 1974.
2. T.A. Haliburton, J.D. Lawmaster, and V.C. McGuffey. Use of Engineering Fabrics in Transportation-Related Applications. Office of Development, FHWA, Oct. 1981.
3. C.C. Calhoun, Jr. Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloth. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, Tech. Rept. F-72-7, 1972.
4. J.A. Copeland. Fabrics in Subdrains: Mechanisms of Filtration and the Measurement of Permeability. Department of Civil Engineering, Oregon State Univ., Corvallis, Transportation Res. Rept. 80-2, Jan. 1980.

5. B.J. Dempsey. Laboratory and Field Studies of Channeling and Pumping. TRB, Transportation Research Record 849, 1982, pp. 1-12.
6. R.M. Knutson and M.R. Thompson. Permanent-Deformation Behavior of Railway Ballast. TRB, Transportation Research Record 694, 1978, pp. 60-65.
7. D.J. Janssen and B.J. Dempsey. Soil Water Properties of Subgrade Soils. Department of Civil Engineering, Univ. of Illinois, Urbana-Champaign, Transportation Engineering Series 184, April 1980.
8. K. Terzaghi and R.B. Peck. Soil Mechanics in Engineering Practice. Wiley, New York, 1967.

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Abridgment

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

RICHARD D. WEIMAR, JR.

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	Non-woven	Woven	Non-woven	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 m² = 1.196 yd².)

More than 110 000 000 m² (130,000,000 yd²) 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 m² (165,000,000 yd²) 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