DESIGNER'S FORUM

Geotextiles in drainage systems

By Gregory N. Richardson and Barry Christopher

WE HAVE SPENT MUCH OF THE last 15 months presenting one-day seminars on using geotextiles in transportation-related systems. Amoco Fabrics and Fibers Co., Atlanta, has sponsored these seminars and was brave enough to step back and let Barry and I develop a pragmatic course for design professionals. It's a brave manufacturer that lets go of the microphone and actually tolerates a course not totally flattering to their *entire* product line. It also was encouraging to discover that Barry and I approach many common filtration applications in essentially the same simplistic fashion.

Our approach here also serves as a good lead-in to a more in-depth series of articles on filtration that will begin in the August issue and for subsequent columns on roadway stabilization and separation applications. *GFR's* filtration series will help you evaluate some of the difficult applications skirted here by addressing design procedures for final critical and extremely challenging applications.

First, some simple background. The removal of water is important to the success of many types of civil structures. In filtration applications, the geotextile must allow water to freely pass through, while at the same time retain the finer soil up-gradient from the geotextile. Filtration applications include trench drains (**Figure 1**), vertical drains behind retaining walls, and coastal erosion-control applications. In these instances, the retained soil may be plastic or granular. The classic filtration application—first used by the late Bob Barrett of Carthage Mills, Cincinnati, almost 40 years ago—was a geotextile to prevent loss of fine sands beneath shoreline-armoring systems. In this application, the flow may be continual or even reversing in nature.

Filtration requires the removal of water in a controlled fashion. Otherwise, severe erosion, piping, or settlement of soils may result in undermining adjacent structures or rendering facilities useless. Hence, a drainage system should provide for the removal of water without excessive loss of the retained soil. This can be accomplished by using either a graded soil or geotextile filter. Now, we'll address the design of a geotextile filter for common filtration system applications, and identify soil types that may require a more rigorous evaluation.

The filtration process

A filter consists of any porous material that has openings small enough to prevent movement of soil into the drain, and that is sufficiently pervious to offer little resistance to seepage. For most soils (we'll refer to them as stable soils), it is not necessary for a filter to screen out all the particles in the soil. Instead, a filter need only restrain the coarse fraction of the various particle sizes present. As flow across the filter occurs, the coarse particles collect against the filter, bridging the filter openings. The voids of the coarse particles create smaller openings to trap even smaller particles of soil. In this manner a filter bridge is developed. It is this filter bridge that actually performs the filtration function. Additionally, the geotextile must be properly seated into the retained soil such that water cannot flow or pool between the retained soil and the geotextile.

Filter criteria

Geotextiles present an attractive alternative to graded-granular filters for many projects because they are comparatively inexpensive and easy to install. As the use of geotextile filters has increased, so has the understanding of their capabilities and limitations. We won't go into a detailed analysis for determining the required geotextile-hydraulic properties in this column. Rather, we'll recommend specific types of woven and nonwoven fabrics on the basis of soil criteria.

This simplified approach should not be used for heat-calendered nonwovens, i.e., set by running fibers between hot rollers, or woven geotextiles made exclusively from slit tape. If you desire a detailed analysis of required geotextile hydraulic properties, I suggest you refer to Holtz et al. (1995), Luettich et al. (1991), Koerner (1994), and *GFR's* pending filtration series.

Steady-state vs. dynamic flow

The type of flow in the drainage system must be identified before proceeding with a filter design. Flow can be classified as either steady-state or dynamic. Steady-state flow is usually present in trench drains adjacent to roads and parking lots, behind retaining walls, under foundations, and below recreational fields. Steady-state flow means that water moves in one principle direction; this is the simplest application for a geotextile filter.

Dynamic flow is usually encountered in permanent erosion-control applications for shorelines and canals. In contrast to static flow, dynamic flow occurs in more than one direction. It is important to recognize cases of dynamic flow because, under these conditions, the development of a filter bridge adjacent to the geotextile may not be possible unless the geotextile is properly seated to the retained soil. In such cases, the dynamic, cyclic or pulsating loads can create very high localized-flow gradients that may cause actual free flow of water and movement of the coarse fraction behind the geotextile. This is typically the case in shoreline erosion-control applications where a single layer of large stones is placed directly on the geotextile (**Photo 1**).

Soil properties

Most geotextile filter designs can be performed on the basis of the *retained* soil

Figure 1. Trench drain illustration (used with permission from Synthetic Industries).

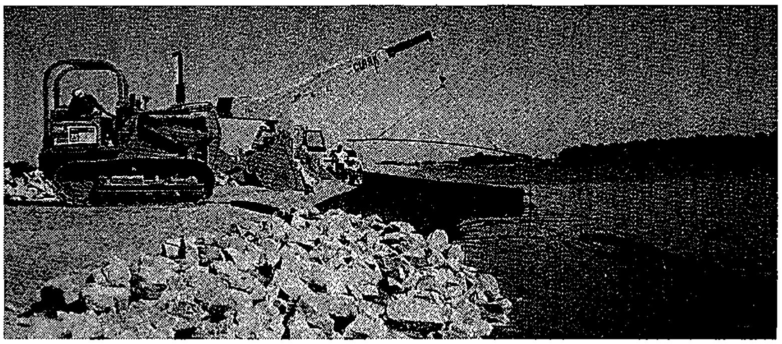

Photo 1. The dynamic flow encountered in permanent erosion-control applications, such as this project on the Ohio River, can create very high localized-flow gradients that may cause actual free flow of water and movement of the coarse fraction behind the geotextile.

characteristics. Atterberg limits and grain-size distribution often provide adequate soil information for most filter designs. Since these tests are very inexpensive, such data can be obtained for even small applications. Atterberg limits (ASTM D 4318) indicate the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of the soil—information that is helpful in assessing the flow capacity and clogging potential of a geotextile. The following information enables the designer to quickly decide if the retained soil is stable (suitable for this simple filtration evaluation) or unstable (requires a more rigorous geotextile evaluation):

- **Stable soils** can perform the self-filtration process, i.e., develop a filter bridge, previously described. Typically, these soil types include both plastic, uniformly graded granular, and well-graded soils.
- **Unstable soils** cannot perform self-filtration, i.e., they have the potential to pipe internally. Such soils may include gap-graded, and nonplastic broad-graded soils. In gap-graded soils, there is a coarse and fine fraction, but very little medium fraction. The fine-soil particles pipe through the coarse fraction and a filter bridge cannot form behind the geotextile. In some broad-graded soils, the medium fraction also is limited and soil fines tend to pipe through the coarser particles without forming a filter bridge.

This column focuses on selecting a geotextile for filtration and typical separation applications with stable soils. When unstable soils are present, we urge you to refer to more rigorous methods.

Stable soils

Plastic, uniform and well-graded soils provide the easiest application of a geotextile filter. Such soils can be defined as one of the following:

- **Plastic soils** with a PI greater than 15. Generally, *particles do not move within soils with a PI higher than 15 percent.* Bedded cohesive soil layers separated by thin sand or silt seams are an exception to this general rule. The clogging potential of cohesive soils is minimal and not normally of concern.
- **Uniformly graded, sandy soils** are actually a class of poorly graded soils that contain only one grain size. They are characterized by having a coefficient of uniformity, C_u, less than approximately 3. C_u is defined as D_{60}/D_{10} where D_{60} = the diameter at which 60 percent of the soil is finer, and D_{10} = the diameter at which 10 percent of the soil is finer. Common beach sand is a good example of a uniform soil.
- **Well-graded soils** must meet the following criteria:

$$\frac{D_{60}}{D_{10}} > 4 \qquad 1 < \frac{D_{30}^2}{D_{10} \bullet D_{60}}$$

where:

D_{10} = the diameter at which 10 percent of the soil is finer

D_{30} = the diameter at which 30 percent of the soil is finer

D_{60} = the diameter at which 60 percent of the soil is finer.

Figure 2 shows sample gradation curves of stable well-graded and uniformly graded granular soils. These soils are recommended for the simple geotextile filter design procedure presented in this column.

Potentially unstable soils

Gap-graded and broad-graded soils are the most common potentially unstable soils. These soils are unstable if the percentage of nonplastic fines is so large that the coarse fraction particles are not in contact, but float within the fine fraction. When the percentage of nonplastic fines is so large, the filter bridge will not be established adjacent to the geotextile and all the fines will be lost. **Figure 3** shows typical grain-size distribution curves for such soils. One characteristic that distinguishes an unstable, broad-graded soil from a well-graded soil is the value of D_{60}/D_{10}. For broad-graded soils, this value exceeds 20. Another characteristic of unstable, broad-graded soils is that the gradation curve is concave upward. Broad-graded soils with a gradation curve that is concave downward, have a large coarse fraction, will be stable, and can be treated as well-graded soils.

The simplified design procedures presented here should *not* be applied to unstable soils. For such soils, consult an expert and plan on performing soil-specific laboratory testing.

Geotextile requirements

A filter geotextile must be designed to satisfy both survivability and hydraulic requirements for the particular installation. Barry and I perform the following geotextile filter evaluation for *stable* soil applications.

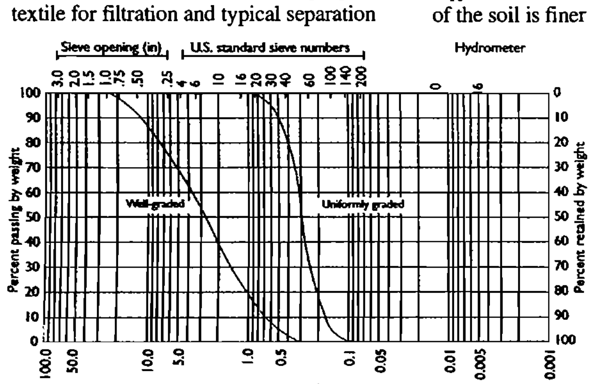

Figure 2. Sample gradation curves of stable well-graded and uniformly graded granular soils.

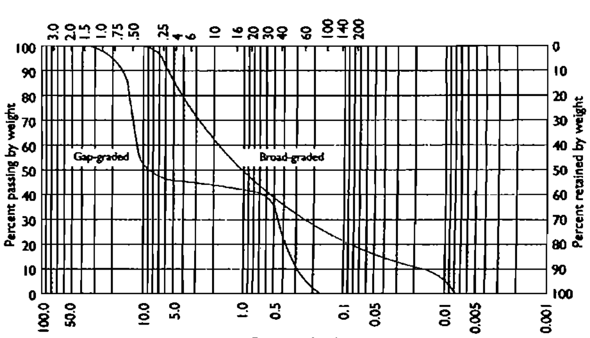

Figure 3. Typical grain-size distribution curves for potentially unstable soils.

Survivability requirements for filtration

It is generally agreed that the installation day is most difficult in the life of a filter geotextile. Installation damage may result from trafficking by construction equipment and from stone drainage layers placed over the geotextile. In general, the stronger the geotextile, the greater its resistance to installation damage, i.e., the greater its potential for survivability. The ability of a geotextile to survive installation damage is difficult to quantify using design equations, but you can do it based on past experience.

We recommend using the survivability criteria in AASHTO M 288-96. This document defines three geotextile-strength categories (**Table 1**) that are required for survivability under typical installation conditions for different geotextile functions. **Table 2** shows the particular class required for a given function or application. M 288 recommends a Class 2 geotextile for typical filtration applications. If you are going to use unusually aggressive stone immediately adjacent to the geotextile—or if you anticipate the contractor from hell—you may opt to increase the survivability class.

Hydraulic requirements for filtration

For **stable soils**, the geotextile selected should have openings small enough to retain the coarse fraction, but large enough to allow the fine fraction to move through the geotextile. For stable soils, we recommend using the M 288 filtration hydraulic criteria (**Tables 3** and **4**). It is the simplest to understand for each stable-soil type.

Plastic soils that have a PI greater than 15 do not have clogging problems or high internal-flow rates. Geotextile filters for such soils must provide only a minimum permittivity, Ψ. The M 288 permittivity requirement for such soils is $\Psi \geq 0.1$ sec^{-1} for all applications. According to M 288, the geotextile's AOS should be equal to or less than 0.22 mm. Both woven and nonwoven geotextiles can be used in this application, though both Barry and I acknowledge a historic bias towards nonwovens.

Uniformly graded, sandy soils typically have a sand fraction of less than 5 percent passing the No. 200 sieve (0.75 mm). Such soils may have a fairly high internal-flow rate and require higher permittivity, Ψ. The M 288 permittivity requirement for such soils is $\Psi \geq 0.5$ sec^{-1} for steady-state applications, and $\Psi \geq 0.7$ sec^{-1} for dynamic applications. The AOS of the geotextile must be selected to retain the sand particles. For uniform sandy soils, the AOS should be equal to or less than 0.43 mm. This is approximately the D_{85} of typical sands. In dynamic applications, we also recommend a minimum percent open area (POA) of 4 percent. Again, both woven and nonwoven geotextiles can be used for this application, however, we still have a bias towards wovens.

Well-graded soils require an assessment of the geotextile's flow capacity and clogging potential based on the percent fines. Soils with less than 15 percent passing the No. 200 sieve (0.75 mm) may have a high internal-flow capacity and low-clogging potential. Thus, geotextiles with higher permittivities (e.g., greater than 0.5 sec^{-1} for steady-state flow and 0.7 sec^{-1} for dynamic flow) may be required. The AOS for such soils should be less than 0.43 mm. Non- or low-plastic soils with fine contents greater than 15 percent have reduced flow capacity, but a higher clogging potential. For such soils, geotextiles with lower permittivities, e.g., greater than 0.2 sec^{-1}, may be used, but their clogging resistance must be evaluated. The AOS for such soils should be less than 0.25 mm.

For soils containing more than 5 percent nonplastic fines, we commonly perform a simple field test to empirically assess the clogging potential of a geotextile filter. While certainly not a standardized test by ASTM rules, we have found the simple jar test to be very useful. It is essentially a fine-fraction filtration test and permits a quali-

TABLE 1. AASHTO M 288-96 GEOTEXTILE SURVIVABILITY REQUIREMENTS

Property	ASTM test method	Units	Geotextile class: Class 1 <W 50%*	Class 1 >NW 50%	Class 2 <W 50%	Class 2 >NW 50%	Class 3 <W 50%	Class 3 >NW 50%
Grab strength	D 4632	N (lb)	1400 (315)	900 (205)	1100 (250)	700 (160)	800 (180)	600 (115)
Seam strength	D 4632	N (lb)	1260 (280)	810 (185)	990 (220)	630 (140)	720 (165)	450 (100)
Tear strength	D 4533	N (lb)	500 (115)	350 (80)	400 (90)	250 (55)	300 (70)	180 (40)
Puncture strength	D 4833	N (lb)	500 (115)	350 (80)	400 (90)	250 (55)	300 (70)	180 (40)
Burst strength	D 3786	kPa (psi)	3500 (510)	1700 (255)	2700 (400)	1300 (200)	2100 (305)	950 (140)

* Elongation at break as measured in accordance with ASTM D 4632

TABLE 2. AASHTO M 288-96 DEFAULT GEOTEXTILE CLASS

Application	Default geotextile class
Subsurface drainage	2
Separation	2
Stabilization	1
Permanent erosion control	2 for woven monofilament 1 for all others

TABLE 3. GEOTEXTILE CRITERIA FOR SUBSURFACE DRAINAGE

	Percent soil passing No. 200 (0.75 mm) sieve: <15	15 to 50	>50
Survivability	Class 2		
Minimum permittivity ASTM D 4491	0.5 sec^{-1}	0.2 sec^{-1}	0.1 sec^{-1}
Maximum AOS ASTM D 4751	0.43 mm	0.25 mm	0.22 mm

* after AASHTO M 288-96

TABLE 4. GEOTEXTILE CRITERIA FOR PERMANENT EROSION CONTROL

	Percent soil passing No. 200 (0.75 mm) sieve: <15	15 to 50	>50
Survivability	Class 2—woven monofilaments Class 1—all other geotextiles		
Minimum permittivity ASTM D 4491	0.7 sec^{-1}	0.2 sec^{-1}	0.1 sec^{-1}
Maximum AOS ASTM D 4751	0.43 mm	0.25 mm	0.22 mm

* after AASHTO M 288-96

tative evaluation of the ability of fines to pass through a geotextile.

To perform the jar test, place a small amount of soil in a jar (approximately ¼ full). The jar should preferably have a removable center lid (e.g., a Mason jar). Fill the jar with water, replace and secure the lid. Then shake to form a soil-water slurry. Cover the jar opening with a sample of the candidate geotextile and secure it. Allow the jar to stand for about one minute to allow coarser particles to settle. Pour the liquid from the jar through the geotextile, tilting the jar such that trapped air does not impede water flow.

If the fines pass through the geotextile, it should not clog. If very little fine soil passes and a significant buildup of fines is observed on the surface of the geotextile, a clogging potential may exist. Either evaluate another geotextile or perform a more sophisticated filtration test (i.e., the ASTM D 5101 Gradient Ratio Test).

The success of the geotextile filter also is very dependent on the quality of installation. Proper installation requires seating the geotextile against the soil to be retained and placing the overlying stone without excessively damaging the geotextile.

Geotextile filter design

Step 1: Evaluate the soil to be filtered (the retained soil). As a minimum, this should include:

- visual classification (ASTM D 2488)
- Atterburg limits (ASTM D 4318)
- grain-size distribution analysis (ASTM D 422)

Proceed with the simplified design if the soil is stable.

Step 2: Determine the geotextile's minimum survivability requirements by using the M 288 guidelines in Tables 1 and 2. M 288 recommends a Class 2 geotextile.

Step 3: Determine the geotextile's minimum hydraulic requirements by using the M 288 guidelines in Tables 3 and 4.

Step 4: Select the geotextile in accordance with Steps 2 and 3.

Step 5: Perform the jar test if required.

Design example: geotextile filter

Design a geotextile filter for a trench drain that will be used to de-water a construction site. Limited site investigation has indicated that the trench will be excavated in silty-sand-type soils.

Step 1: Visual identification and classification indicate that the soil to be filtered is a silty sand (SM), and that the silt fraction is relatively nonplastic. A grain-size analysis has indicated that the soil is uniformly graded and is, therefore, likely to be internally stable. The analysis also showed that 15 percent passed the No. 200 (0.75 mm) sieve.

Step 2: Determine the minimum survivability requirements for the geotextile using the M 288 guidelines in Tables 1 and 2. This should be a Class 2 geotextile with the minimum (MARV) strength values in **Table 5.**

Step 3: Determine the geotextile's minimum hydraulic requirements by using the M 288 guidelines in Tables 3 and 4. The permittivity of the geotextile must be greater than 0.2 sec^{-1}, and the AOS must be less than 0.25 mm.

Step 4: Select a suitable geotextile that meets the criteria in Steps 2 and 3. With the exception of woven geotextiles constructed exclusively from slit tape and heat-calendered nonwovens, almost any woven or nonwoven geotextile can be used if it meets the requirements in Steps 2 an 3. The geotextile specifications, therefore, can be written as follows:

- The geotextile shall be a woven with monofilament or fibrillated yarns or a needlepunched nonwoven geotextile.
- The geotextile shall have MARV strength properties that meet the requirements of an M 288 Class 2 geotextile.
- The geotextile shall have MARV hydraulic properties that meet the requirements of M 288 geotextile criteria for subsurface drainage for soils having 15 to 50 percent fines.

Step 5: If a jar test is run, it will be necessary to obtain samples of candidate geotextiles for evaluation.

The geotextile specifications can simply reference the M 288 guidelines or they can reference the guidelines and present the actual specifications referenced. Placing the actual strength and hydraulic values in the specifications makes it easier to verify that the materials submitted in the field meet the requirements. Conversely, using only the M 288 reference produces very compact specifications and eliminates the possibility of errors between M 288 criteria and the actual material properties specified. It is clear, however, that using the M288 guidelines provides the designer with a very quick method of evaluating and designing geotextiles for most filtration applications for stable soils.

I hope one day the geotextile suppliers will reduce the mind-boggling array of geotextiles now sold and provide generic geotextiles that satisfy, and are so marked, the M288 Class X requirements. This would simplify the design and field inspection of common separators, stabilizers, and erosion-control geotextiles.

TABLE 5. MARV STRENGTH VALUES FOR STEP 2 OF THE GEOTEXTILE FILTER DESIGN EXAMPLE

Property	ASTM test method	Units	Woven geotextiles *	Nonwoven geotextiles**
Grab	D 4632	lb	250	160
Seam	D 4632	lb	220	140
Tear	D 4533	lb	90	55
Puncture	D 4833	lb	90	55
Burst	D 3786	lb	400	200

* No woven slit tapes ** No heat-calendered

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