
Geosynthetic Engineering: *Geotextile Filters*

Course No: G04-004

Credit: 4 PDH

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16. ABSTRACT This manual is an updated version of the Geotextile Design & Construction Guidelines, used for the FHWA training course Geosynthetic Engineering Workshop. The update was performed to reflect current practices and codes for geotextile design, and has been expanded to address geogrid and geomembrane materials. The manual was prepared to enable the Highway Engineer to correctly identify and evaluate potential applications of geosynthetics as an alternative to other construction methods and as a means to solve construction problems. With the aid of this text, the Highway Engineer should be able to properly design, select, test, specify, and construct with geotextiles, geocomposite drains, geogrids and related materials in drainage, sediment control, erosion control, roadway, and embankment on soft soils applications. Steepened slope and retaining wall applications also are addressed, but designers are referred to the FHWA Demonstration Project No. 82 references on mechanically stabilized earth structures for details on design. Application of geomembranes and other barrier materials to highway works are summarized within. This manual is directed toward geotechnical, hydraulic, roadway, bridge and structures, and route layout highway engineers.			
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2.0 GEOSYNTHETICS IN SUBSURFACE DRAINAGE SYSTEMS

2.1 BACKGROUND

One major area of geotextile use is as filters in drain applications such as trench and interception drains, blanket drains, pavement edge drains, structure drains, and beneath permeable roadway bases. The *filter* restricts movement of soil particles as water flows into the *drain* structure and is collected and/or transported downstream. Geocomposites consisting of a drainage core surrounded by a geotextile filter are often used as the drain itself in these applications. Geotextiles are also used as filters beneath hard armor erosion control systems, and this application will be discussed in Chapter 3.

Because of their comparable performance, improved economy, consistent properties, and ease of placement, geotextiles have been used successfully to replace graded granular filters in almost all drainage applications. Thus, they must perform the same functions as graded granular filters:

- to allow water to flow through the filter into the drain, and to continue doing this throughout the life of the project; and
- to retain the soil particles in place and prevent their migration (*pipng*) through the filter (if some soil particles do move, they must be able to pass through the filter without blinding or clogging the downstream media during the life of the project).

Geotextiles, like graded granular filters, require proper engineering design or they may not perform as desired. Unless flow requirements, piping resistance, clogging resistance and constructability requirements (defined later) are properly specified, the geotextile/soil filtration system may not perform properly. In addition, construction must be monitored to ensure that materials are installed correctly.

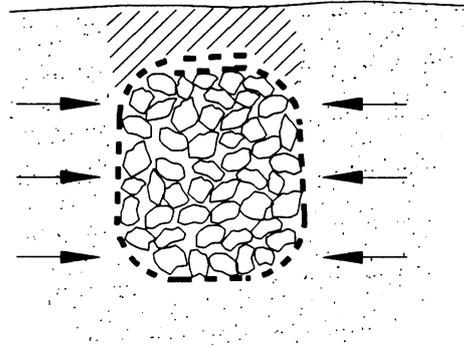
In most drainage and filtration applications, geotextile use can be justified over conventional graded granular filter material use because of cost advantages from:

- the use of less-costly drainage aggregate;
- the possible use of smaller-sized drains;
- the possible elimination of collector pipes;
- expedient construction;
- lower risk of contamination and segregation of drainage aggregate during construction;
- reduced excavation.

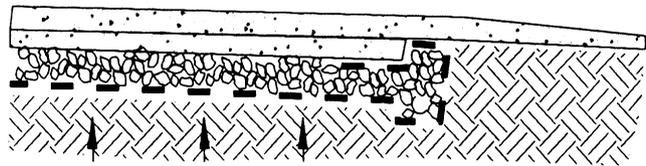
2.2 APPLICATIONS

Properly designed geotextiles can be used as a replacement for, or in conjunction with, conventional graded granular filters in almost any drainage application. Properly designed geocomposites can be used as a replacement for granular drains in many applications (*e.g.*, pavement edge drains). Below are a few examples of drainage applications.

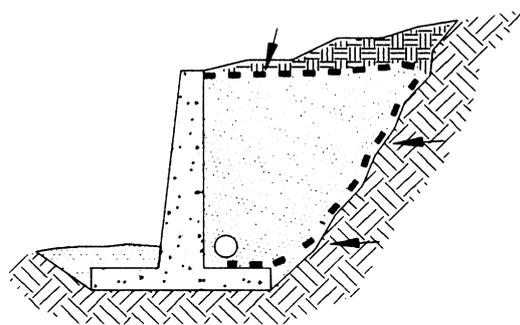
- Filters around trench drains and edge drains -- to prevent soil from migrating into the drainage aggregate or system, while allowing water to exit from the soil.



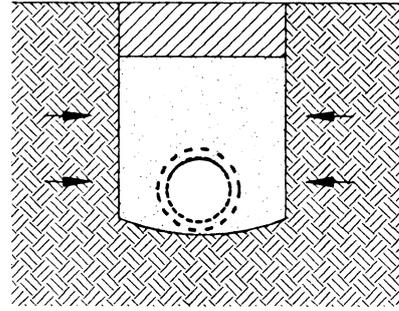
- Filters beneath pavement permeable bases, blanket drains and base courses. Prefabricated geocomposite drains and geotextile-wrapped trenches are used in pavement edge drain construction.



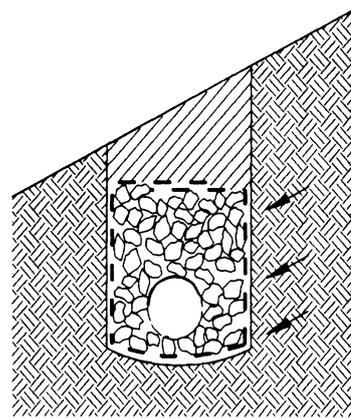
- Drains for structures such as retaining walls and bridge abutments. They separate the drainage aggregate or system from the backfill soil, while allowing free drainage of ground and infiltration water. Geocomposite drains are especially useful in this application.



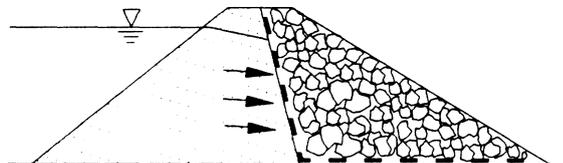
- Geotextile wraps for slotted or jointed drain and well pipes -- to prevent filter aggregate from entering the pipe, while allowing the free flow of water into the pipe.



- Interceptor, toe drains, and surface drains -- to aid in the stabilization of slopes by allowing excess pore pressures within the slope to dissipate, and by preventing surface erosion. Again, geocomposites have been successfully used in this application.



- Chimney and toe drains for earth dams and levees -- to provide seepage control.



In each of these applications, flow is through the geotextile -- that is, perpendicular to the plane of the fabric. In other applications, such as vertical drains in soft foundation soils, lateral drains below slabs and behind retaining walls, and gas transfer media, flow may occur both perpendicular to and transversely in the plane of the geotextile. In many of these applications, geocomposite drains may be appropriate. Design with geocomposite systems is covered in Section 2.11.

All geosynthetic designs should begin with a criticality and severity assessment of the project conditions (see Table 2-1) for a particular application. Although first developed by Carroll (1983) for drainage and filtration applications, the concept of critical-severe projects -- and, thus, the level of engineering responsibility required -- will be applied to other geosynthetic applications throughout this manual.

TABLE 2-1
GUIDELINES FOR EVALUATING THE CRITICAL NATURE OR SEVERITY
OF DRAINAGE AND EROSION CONTROL APPLICATIONS
(after Carroll, 1983)

A. Critical Nature of the Project		
<u>Item</u>	<u>Critical</u>	<u>Less Critical</u>
1. Risk of loss of life and/or structural damage due to drain failure:	High	None
2. Repair costs versus installation costs of drain:	> > >	= or <
3. Evidence of drain clogging before potential catastrophic failure:	None	Yes
B. Severity of the Conditions		
<u>Item</u>	<u>Severe</u>	<u>Less Severe</u>
1. Soil to be drained:	Gap-graded, pipable, or dispersible	Well-graded or uniform
2. Hydraulic gradient:	High	Low
3. Flow conditions:	Dynamic, cyclic, or pulsating	Steady state

A few words about the condition of the soil to be drained (Table 2-1) are in order. First, gap-graded, well-graded and uniform soils are illustrated in Figure 2-1. Certain gap-graded and broadly graded soils may be *internally unstable*; that is, they can experience piping or internal erosion. On the other hand, a soil is *internally stable* if it is self-filtering and if its own fine particles do not move through the pores of its coarser fraction (LaFluer, et al., 1993). Criteria for deciding whether a soil is internally unstable will be given in the next section.

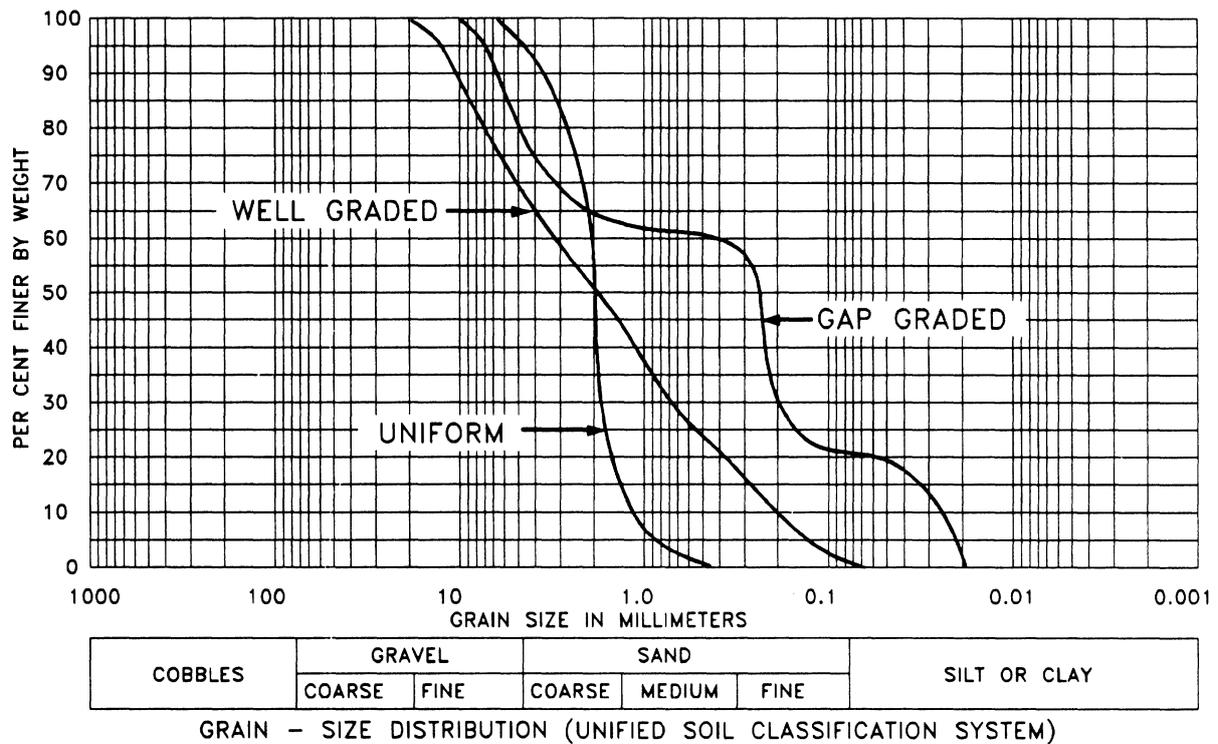


Figure 2-1 Soil descriptions.

Dispersible soils are fine-grained natural soils which deflocculate in the presence of water and, therefore, are highly susceptible to erosion and piping (Sherard, et al., 1972). See also Sherard and Decker (1977) for more information on dispersible soils.

2.3 GEOTEXTILE FILTER DESIGN

Designing with geotextiles for filtration is essentially the same as designing graded granular filters. A geotextile is similar to a soil in that it has voids (pores) and particles (filaments and fibers). However, because of the shape and arrangement of the filaments and the compressibility of the structure with geotextiles, the geometric relationships between filaments and voids is more complex than in soils. In geotextiles, pore size is measured directly, rather than using particle size as an estimate of pore size, as is done with soils. Since pore size can be directly measured, relatively simple relationships between the pore sizes and particle sizes of the soil to be retained can be developed. Three simple filtration concepts are used in the design process:

1. If the size of the largest pore in the geotextile filter is smaller than the larger particles of soil, the soil will be retained by the filter. As with graded granular filters, the larger

particles of soil will form a filter bridge over the hole, which in turn, filters smaller particles of soil, which then retain the soil and prevent piping (Figure 2-2).

2. If the smaller openings in the geotextile are sufficiently large enough to allow smaller particles of soil to pass through the filter, then the geotextile will not *blind* or *clog* (see Figure 2-3).
3. A large number of openings should be present in the geotextile so proper flow can be maintained even if some of the openings later become plugged.

These simple concepts and analogies with soil filter design criteria are used to establish design criteria for geotextiles. Specifically, these criteria state:

- the geotextile must retain the soil (retention criterion), while
- allowing water to pass (permeability criterion), throughout
- the life of the structure (clogging resistance criterion).

To perform effectively, the geotextile must also survive the installation process (survivability criterion).

After a detailed study of research carried out both in North America and in Europe on conventional and geotextile filters, Christopher and Holtz (1985) developed the following design procedure for geotextile filters for drainage (this chapter) and permanent erosion control applications (Chapter 3). The level of design required depends on the critical nature of the project and the severity of the hydraulic and soil conditions (Table 2-1). Especially for critical projects, consideration of the risks and the consequences of geotextile filter failure require great care in selecting the appropriate geotextile. For such projects, and for severe hydraulic conditions, conservative designs are recommended. **Geotextile selection should not be based on cost alone.** The cost of the geotextile is usually minor in comparison to the other components and the construction costs of a drainage system. Also, do not try to save money by eliminating laboratory soil-geotextile performance testing when such testing is required by the design procedure.

A recent National Cooperative Highway Research Program (NCHRP) study (Koerner et al., 1994) of the performance of geotextile drainage systems indicated that the FHWA design criteria developed by Christopher and Holtz (1985) were an excellent prediction of filter performance, particularly for granular soils (<50% passing a 0.075 mm sieve).

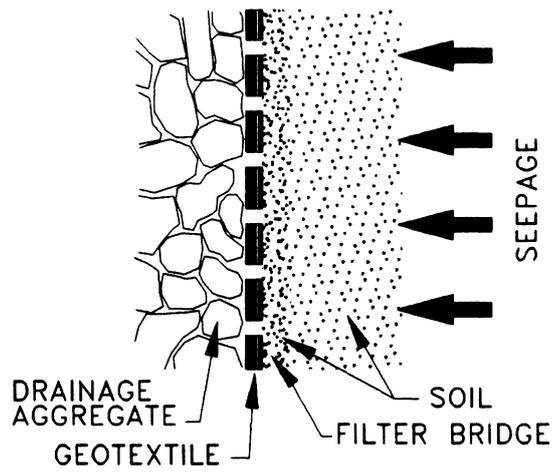


Figure 2-2 Filter bridge formation.

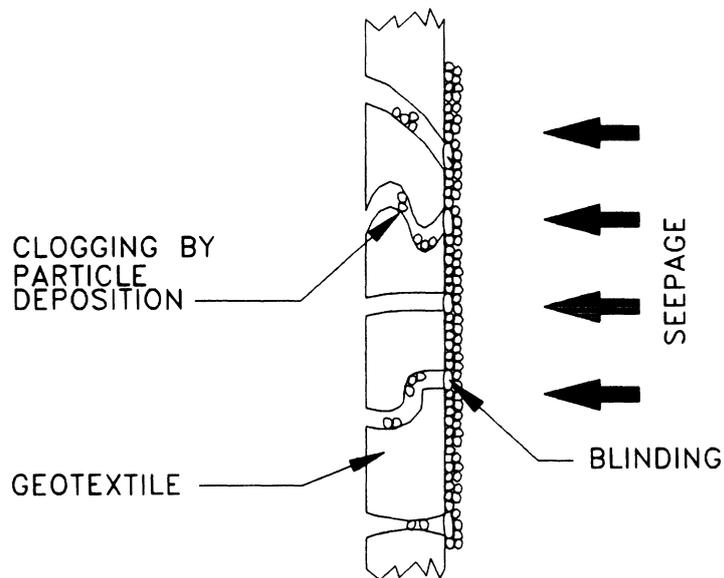


Figure 2-3 Definitions of clogging and blinding (Bell and Hicks, 1980).

2.3-1 Retention Criteria

2.3-1.a Steady State Flow Conditions

$$\text{AOS or } O_{95(\text{geotextile})} \leq B D_{85(\text{soil})} \quad [2 - 1]$$

where:

AOS = apparent opening size (see Table 1-3) (mm);

O_{95} = opening size in the geotextile for which 95% are smaller (mm);

AOS $\approx O_{95}$;

B = a coefficient (dimensionless); and

D_{85} = soil particle size for which 85% are smaller (mm).

The coefficient B ranges from 0.5 to 2 and is a function of the type of soil to be filtered, its density, the uniformity coefficient C_u if the soil is granular, the type of geotextile (woven or nonwoven), and the flow conditions.

For *sands*, *gravelly sands*, *silty sands*, and *clayey sands* (with less than 50% passing the 0.075 mm sieve per the Unified Soil Classification System), B is a function of the uniformity coefficient, C_u . Therefore, for

$$C_u \leq 2 \text{ or } \geq 8: \quad B = 1 \quad [2 - 2a]$$

$$2 \leq C_u \leq 4: \quad B = 0.5 C_u \quad [2 - 2b]$$

$$4 < C_u < 8 \quad B = 8/C_u \quad [2 - 2c]$$

where:

$$C_u = D_{60}/D_{10}.$$

Sandy soils which are not uniform (Figure 2-1) tend to bridge across the openings; thus, the larger pores may actually be up to twice as large ($B \leq 2$) as the larger soil particles because, quite simply, two particles cannot pass through the same hole at the same time. Therefore, use of the criterion $B = 1$ would be quite conservative for retention, and such a criterion has been used by, for example, the Corps of Engineers.

If the protected soil contains any fines, use only the portion passing the 4.75 mm sieve for selecting the geotextile (*i.e.*, scalp off the +4.75 mm material).

For *silts and clays* (with more than 50% passing the 0.075 mm sieve), B is a function of the type of geotextile:

$$\text{for wovens,} \quad B = 1; O_{95} \leq D_{85} \quad [2 - 3]$$

$$\text{for nonwovens,} \quad B = 1.8; O_{95} \leq 1.8 D_{85} \quad [2 - 4]$$

$$\text{and for both,} \quad \text{AOS or } O_{95} \leq 0.3 \text{ mm} \quad [2 - 5]$$

Due to their random pore characteristics and, in some types, their felt-like nature, nonwovens will generally retain finer particles than a woven geotextile of the same AOS. Therefore, the use of $B = 1$ will be even more conservative for nonwovens.

In absence of detailed design, the AASHTO M 288 Standard Specification for Geotextiles (1997) provides the following recommended maximum AOS values in relation to percent of situ soil passing the 0.075 mm sieve: (i) 0.43 mm for less than 15% passing; (ii) 0.25 mm for 15 to 50% passing; and (iii) 0.22 mm for more than 50% passing. However, for cohesive soils with a plasticity index greater than 7, the maximum AOS size is 0.30 mm. These default AOS values are based upon the predominant particle sizes of the in situ soil. The engineer may require performance testing based on engineering design for drainage systems in problematic soil environments. Site specific testing should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as non-cohesive silts; gap graded soils; alternating sand/silt laminated soils; dispersive clays; and/or rock flour.

2.3-1.b Dynamic Flow Conditions

If the geotextile is not properly weighted down and in *intimate contact* with the soil to be protected, or if dynamic, cyclic, or pulsating loading conditions produce high localized hydraulic gradients, then soil particles can move behind the geotextile. Thus, the use of $B = 1$ is not conservative, because the bridging network will not develop and the geotextile will be required to retain even finer particles. When retention is the primary criteria, B should be reduced to 0.5; or:

$$O_{95} \leq 0.5 D_{85} \quad [2 - 6]$$

Dynamic flow conditions can occur in pavement drainage applications. For reversing inflow-outflow or high-gradient situations, it is best to maintain sufficient weight or load on the filter to prevent particle movement. Dynamic flow conditions with erosion control systems are discussed in Chapter 3.

2.3-1.c *Stable versus Unstable Soils*

The above retention criteria assumes that the soil to be filtered is internally stable -- it will not pipe internally. If unstable soil conditions are encountered, performance tests should be conducted to select suitable geotextiles. According to Kenney and Lau (1985, 1986) and LaFluer, et al. (1989), broadly graded ($C_u > 20$) soils with concave upward grain size distributions tend to be internally unstable. The Kenney and Lau (1985, 1986) procedure utilizes a mass fraction analysis. Research by Skempton and Brogan (1994) verified the Kenney and Lau (1985, 1986) procedure.

2.3-2 Permeability/Permittivity Criteria

Permeability requirements:

-- for *less critical applications* and *less severe conditions*:

$$k_{\text{geotextile}} \geq k_{\text{soil}} \quad [2 - 7a]$$

-- and, for *critical applications* and *severe conditions*:

$$k_{\text{geotextile}} \geq 10 k_{\text{soil}} \quad [2 - 7b]$$

Permittivity requirements:

$$\psi \geq 0.5 \text{ sec}^{-1} \text{ for } < 15\% \text{ passing } 0.075 \text{ mm} \quad [2 - 8a]$$

$$\psi \geq 0.2 \text{ sec}^{-1} \text{ for } 15 \text{ to } 50\% \text{ passing } 0.075 \text{ mm} \quad [2 - 8b]$$

$$\psi \geq 0.1 \text{ sec}^{-1} \text{ for } > 50\% \text{ passing } 0.075 \text{ mm} \quad [2 - 8c]$$

In these equations:

k = Darcy coefficient of permeability (m/s); and

ψ = geotextile permittivity, which is equal to $k_{\text{geotextile}}/t_{\text{geotextile}}$ (1/s) and is a function of the hydraulic head.

For actual flow capacity, the permeability criteria for noncritical applications is conservative, since an equal quantity of flow through a relatively thin geotextile takes significantly less time than through a thick granular filter. Even so, some pores in the geotextile may become blocked or plugged with time. Therefore, for critical or severe applications, Equation 2-7b is recommended to provide an additional level of conservatism. Equation 2-7a may be used where flow reduction is judged not to be a problem, such as in clean, medium to coarse sands and gravels.

The AASHTO M 288 Standard Specification for Geotextiles (1997) presents recommended minimum permittivity values in relation to percent of situ soil passing the 0.075 mm sieve. The

values are the same as presented in Equations 2-8a, 2-8b, and 2-8c above. The default permittivity values are based upon the predominant particle sizes of the in situ soil. Again, the engineer may require performance testing based on engineering design for drainage systems in problematic soil environments.

The required flow rate, q , through the system should also be determined, and the geotextile and drainage aggregate selected to provide adequate capacity. As indicated above, flow capacities should not be a problem for most applications, provided the geotextile permeability is greater than the soil permeability. However, in certain situations, such as where geotextiles are used to span joints in rigid structures and where they are used as pipe wraps, portions of the geotextile may be blocked. For these applications, the following criteria should be used together with the permeability criteria:

$$q_{\text{required}} = q_{\text{geotextile}}(A_g/A_t) \quad [2 - 9]$$

where:

A_g = geotextile area available for flow; and
 A_t = total geotextile area.

2.3-3 Clogging Resistance

2.3-3.a Less Critical/Less Severe Conditions

For *less critical/less severe* conditions:

$$O_{95 \text{ (geotextile)}} \geq 3 D_{15 \text{ (soil)}} \quad [2 - 10]$$

Equation 2-10 applies to soils with $C_u > 3$. For $C_u \leq 3$, select a geotextile with the maximum AOS value from Section 2.3.1.

In situations where clogging is a possibility (*e.g.*, gap-graded or silty soils), the following *optional* qualifiers may be applied:

for *nonwovens* -

$$\text{porosity of the geotextile, } n \geq 50\% \quad [2 - 11]$$

for *woven monofilament* and *slit film wovens* -

$$\text{percent open area, POA} \geq 4\% \quad [2 - 12]$$

NOTE: See Section 1.5 for comments on porosity and POA.

Most common nonwovens have porosities much greater than 70%. Most woven monofilaments easily meet the criterion of Equation 2-12; tightly woven slit films do not, and are therefore not recommended for subsurface drainage applications.

Filtration tests provide another option for consideration, especially by *inexperienced users*.

2.3-3.b Critical/Severe Conditions

For *critical/severe* conditions, select geotextiles that meet the retention and permeability criteria in Sections 2.3-1 and 2.3-2. Then perform a filtration test using samples of on-site soils and hydraulic conditions. One type of filtration test is the gradient ratio test (ASTM D 5101).

Although several empirical methods have been proposed to evaluate geotextile filtration characteristics (*i.e.*, the clogging potential), the most realistic approach for all applications is to perform a laboratory test which simulates or models field conditions. We recommend the gradient ratio test, ASTM D 5101, Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio. This test utilizes a rigid-wall soil permeameter with piezometer taps that allow for simultaneous measurement of the head losses in the soil and the head loss across the soil/geotextile interface (Figure 2-4). The ratio of the head loss across this interface (nominally

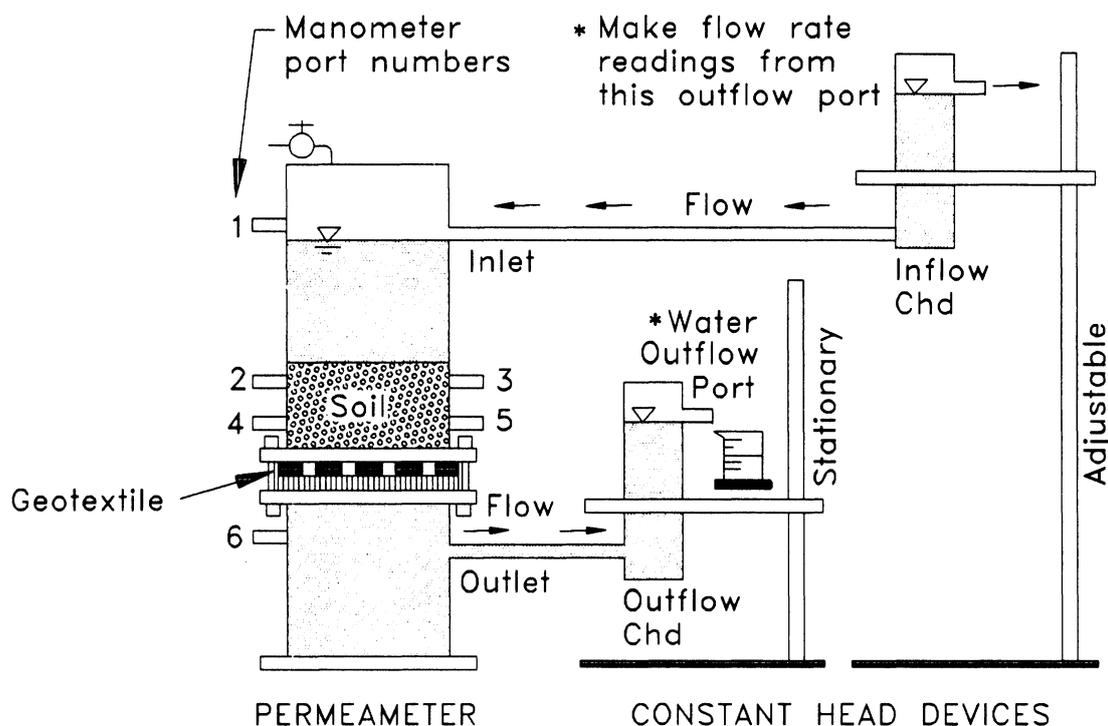


Figure 2-4 U.S. Army Corps of Engineers gradient ratio test device.

25 mm) to the head loss across 50 mm of soil is termed the *gradient ratio*. As fine soil particles adjacent to the geotextile become trapped inside or blind the surface, the gradient ratio will increase. A gradient ratio less than 3 is recommended by the U.S. Army Corps of Engineers (1977), based upon limited testing with severely gap-graded soils. Because the test is conducted in a rigid-wall permeameter, it is most appropriate for sandy and silty soils with $k \geq 10^{-7}$ m/s.

For soils with permeabilities less than about 10^{-7} m/s, long-term filtration tests should be conducted in a flexible wall or triaxial type apparatus to insure that flow is through the soil rather than along the sides of the specimen. The soil flexible wall test is ASTM D 5084, while the Hydraulic Conductivity Ratio (HCR) test (ASTM D 5567) has been suggested for geotextiles (see Section 1.5). Unfortunately, neither test is able to measure the permeability near the soil-geotextile interface nor determine changes in permeability and hydraulic gradient within the soil sample itself - a serious disadvantage (Fischer, 1994). Fortunately, very fine-grained, low-permeability soils rarely present a filtration problem unless they are dispersive (Sherard and Decker, 1977) or subject to hydraulic fracturing, such as might occur in dams under high hydraulic gradients (Sherard, 1986).

Again, we emphasize that these filtration tests are *performance tests*. They must be conducted on samples of project site soil by the specifying agency or its representative. These tests are the responsibility of the engineer because manufacturers generally do not have soil laboratories or samples of on-site soils. Therefore, realistically, the manufacturers are unable to certify the clogging resistance of a geotextile.

For *less critical/less severe* conditions, a simple way to avoid clogging, especially with silty soils, is to allow fine particles already in suspension to pass through the geotextile. Then the *bridge network* (Figure 2-2) formed by the larger particles retains the smaller particles. The bridge network should develop rather quickly, and the quantity of fine particles actually passing through the geotextile is relatively small. This is why the less critical/less severe clogging resistance criteria requires an AOS (O_{95}) sufficiently larger than the finer soil particles (D_{15}). Those are the particles that will pass through the geotextile. Unfortunately, the AOS value only indicates the size and not the number of O_{95} -sized holes available. Thus, the finer soil particles will be retained by the smaller holes in the geotextile, and if there are sufficient fines, a significant reduction in flow rate can occur.

Consequently, to control the number of holes in the geotextile, it may be desirable to increase other qualifiers such as the porosity and open area requirements. There should always be a sufficient number of holes in the geotextile to maintain permeability and drainage, even if some of them clog.

It should be pointed out that some soil types and gradations, may result in calculated AOS values that cannot reasonably be met by any available product. In these cases, the design must be modified accordingly to accommodate available products or possibly use multistage filters. In either case, performance tests should then be performed on the selected system.

2.3-4 Survivability and Endurance Criteria

To be sure the geotextile will survive the construction process, certain geotextile strength and endurance properties are required for filtration and drainage applications. These **minimum** requirements are given in Table 2-2. Note that stated values are for less critical/less severe applications.

It is important to realize that these **minimum** survivability values are not based on any systematic research, but on the properties of existing geotextiles which are known to have performed satisfactorily in drainage applications. The values are meant to serve as guidelines for inexperienced users in selecting geotextiles for routine projects. They are not intended to replace site-specific evaluation, testing, and design.

Geotextile endurance relates to its longevity. Geotextiles have been shown to be basically inert materials for most environments and applications. However, certain applications may expose the geotextile to chemical or biological activity that could drastically influence its filtration properties or durability. For example, in drains, granular filters and geotextiles can become chemically clogged by iron or carbonate precipitates, and biologically clogged by algae, mosses, etc. Biological clogging is a potential problem when filters and drains are periodically inundated then exposed to air. Excessive chemical and biological clogging can significantly influence filter and drain performance. These conditions are present, for example, in landfills.

Biological clogging potential can be examined with ASTM D 1987, Standard Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters (1991). If biological clogging is a concern, a higher-porosity geotextile may be used, and/or the drain design and operation can include an inspection and maintenance program to flush the drainage system.

TABLE 2-2
GEOTEXTILE STRENGTH PROPERTY REQUIREMENTS^{1,2,3,4}
FOR DRAINAGE GEOTEXTILES
(after AASHTO, 1997)

Property	ASTM Test Method	Units	Geotextile Class 2 ⁵	
			Elongation	
			< 50% ⁶	≥ 50% ⁶
Grab Strength	D 4632	N	1100	700
Sewn Seam Strength ⁷	D 4632	N	990	630
Tear Strength	D 4533	N	400 ⁸	250
Puncture Strength	D 4833	N	400	250
Burst Strength	D 3786	kPa	2700	1300

NOTES:

1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. Minimum; use value in weaker principal direction. All numerical values represent minimum average roll value (*i.e.*, test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Woven slit film geotextiles will not be allowed.
5. Default geotextile selection. The engineer may specify a Class 3 geotextile (see Appendix D) for trench drain applications based on one or more of the following:
 - a) The engineer has found Class 3 geotextiles to have sufficient survivability based on field experience.
 - b) The engineer has found Class 3 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
 - c) Subsurface drain depth is less than 2 m, drain aggregate diameter is less than 30 mm and compaction requirement is equal to or less than 95% of AASHTO T-99.
6. As measured in accordance with ASTM D 4632.
7. When seams are required. Values apply to both field and manufactured seams.
8. The required MARV tear strength for woven monofilament geotextiles is 250 N.

2.4 DRAINAGE SYSTEM DESIGN GUIDELINES

In this section, step-by-step design procedures are given. As with a chain, the integrity of the resulting design will depend on its weakest link; thus, no steps should be compromised or omitted.

STEP 1. Evaluate the critical nature and site conditions (see Table 2.1) of the application.

Reasonable judgment should be used in categorizing a project, since there may be a significant cost difference for geotextiles required for critical/severe conditions. Final selection should *not* be based on the lowest material cost alone, nor should costs be reduced by eliminating laboratory soil-geotextile performance testing, if such testing is appropriate.

STEP 2. Obtain soil samples from the site and:

A. Perform grain size analyses.

- Calculate $C_u = D_{60}/D_{10}$ (Eq. 2 - 3)
- Select the *worst case* soil for retention (*i.e.*, usually the soil with smallest $B \times D_{85}$)

NOTE: When the soil contains particles 25 mm and larger, use only the gradation of soil passing the 4.75 mm sieve in selecting the geotextile (*i.e.*, scalp off the +4.75 mm material).

B. Perform field or laboratory permeability tests.

- Select worst case soil (*i.e.*, soil with highest coefficient of permeability, k).
- The permeability of clean sands with $0.1 \text{ mm} < D_{10} < 3 \text{ mm}$ and $C_u < 5$ can be estimated by the Hazen formula, $k = (D_{10})^2$ (k in cm/s; D_{10} in mm). This formula should **not** be used for soils with appreciable fines.

C. Select drainage aggregate.

- Use free-draining, open-graded material and determine its permeability (*e.g.*, Figure 2-5). If possible, sharp, angular aggregate should be avoided. If it must be used, then

a geotextile meeting the property requirements for high survivability in Table 2-2 should be specified. For an accurate design cost comparison, compare cost of open-graded aggregate with select well-graded, free-draining filter aggregate.

STEP 3. Calculate anticipated flow into and through drainage system and dimension the system. Use collector pipe to reduce size of drain.

A. General Case

Use Darcy's Law

$$q = k i A \quad [2 - 13]$$

where:

- q = infiltration rate (L³/T)
- k = effective permeability of soil (from Step 2B above) (L/T)
- i = average hydraulic gradient in soil and in drain (L/L)
- A = area of soil and drain material normal to the direction of flow (L²)

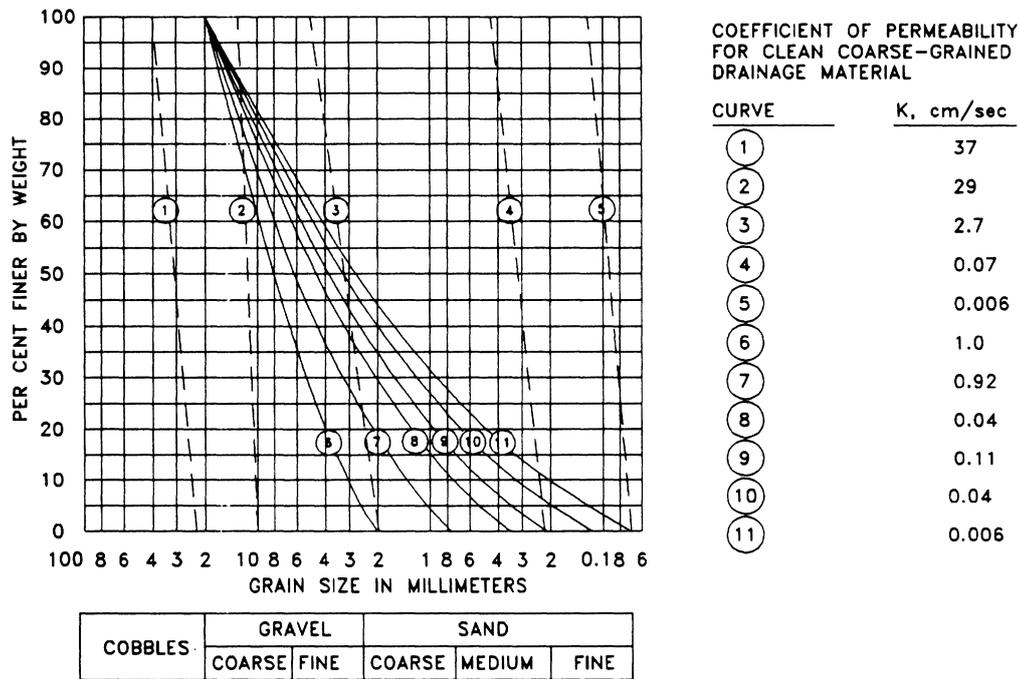


Figure 2-5 Typical gradations and Darcy permeabilities of several aggregate and graded filter materials (U.S. Navy, 1982).

Use conventional flow net analysis to calculate the hydraulic gradient (Cedergren, 1977) and Darcy's Law for estimating infiltration rates into drain; then use Darcy's Law to design drain (*i.e.*, calculate cross-sectional area A for flow through open-graded aggregate). Note that typical values of hydraulic gradients in the soil adjacent to a geotextile filter (Giroud, 1988) are:

- $i < 1$ for drainage under roads, embankments, slopes, etc., when the main source of water is precipitation; and
- $i = 1.5$ in the case of drainage trenches and vertical drains behind walls.

B. Specific Drainage Systems

Estimates of surface infiltration, runoff infiltration rates, and drainage dimensions can be determined using accepted principles of hydraulic engineering (Moulton, 1980). Specific references are:

1. *Flow into trenches* -- Mansur and Kaufman (1962)
2. *Horizontal blanket drains* -- Cedergren (1977)
3. *Slope drains* -- Cedergren (1977)

STEP 4. Determine geotextile requirements.

A. Retention Criteria

From Step 2A, obtain D_{85} and C_u ; then determine largest pore size allowed.

$$\text{AOS} \leq B D_{85} \quad (\text{Eq. 2 - 1})$$

where:

$B = 1$ for a conservative design. For a less-conservative design, and for $\leq 50\%$ passing 0.075 mm sieve:

$$B = 1 \quad \text{for } C_u \leq 2 \text{ or } \geq 8 \quad (\text{Eq. 2 - 2a})$$

$$B = 0.5 C_u \quad \text{for } 2 \leq C_u \leq 4 \quad (\text{Eq. 2 - 2b})$$

$$B = 8/C_u \quad \text{for } 4 < C_u < 8 \quad (\text{Eq. 2 - 2c})$$

and, for $\geq 50\%$ passing 0.075 mm sieve:

$B = 1$ for wovens,

$B = 1.8$ for nonwovens,

and $\text{AOS (geotextile)} \leq 0.3 \text{ mm} \quad (\text{Eq. 2 - 5})$

NOTE: Soils with a C_u of greater than 20 may be unstable (see section 2.3-1.c): if so, performance tests should be conducted to select suitable geotextiles.

B. Permeability/Permittivity Criteria

1. Less Critical/Less Severe

$$k_{\text{geotextile}} \geq k_{\text{soil}} \quad (\text{Eq. 2 - 7a})$$

2. Critical/Severe

$$k_{\text{geotextile}} \geq 10 k_{\text{soil}} \quad (\text{Eq. 2 - 7b})$$

3. Permittivity Requirements

$$\psi \geq 0.5 \text{ sec}^{-1} \text{ for } < 15\% \text{ passing } 0.075 \text{ mm} \quad (\text{Eq. 2 - 8a})$$

$$\psi \geq 0.2 \text{ sec}^{-1} \text{ for } 15 \text{ to } 50\% \text{ passing } 0.075 \text{ mm} \quad (\text{Eq. 2 - 8b})$$

$$\psi \geq 0.1 \text{ sec}^{-1} \text{ for } > 50\% \text{ passing } 0.075 \text{ mm} \quad (\text{Eq. 2 - 8c})$$

4. Flow Capacity Requirement

$$q_{\text{required}} = q_{\text{geotextile}} / (A_g / A_t), \text{ or} \quad (\text{Eq. 2 - 9})$$

$$(k_{\text{geotextile}}/t) h A_g \geq q_{\text{required}} \quad [2 - 14]$$

where:

q_{required} is obtained from STEP 3B (Eq. 2-14) above;

$k_{\text{geotextile}}/t = \psi =$ permittivity;

$t =$ geotextile thickness;

$h =$ average head in field;

$A_g =$ geotextile area available for flow (*i.e.*, if 80% of geotextile is covered by the wall of a pipe, $A_g = 0.2 \times$ total area); and

$A_t =$ total area of geotextile.

C. Clogging Criteria

1. Less Critical/Less Severe

a. From Step 2A obtain D_{15} ; then determine minimum pore size requirement from

$$O_{95} \geq 3 D_{15}, \text{ for } C_u > 3 \quad (\text{Eq. 2 - 10})$$

b. Other qualifiers:

Nonwovens:

$$\text{Porosity (geotextile)} \geq 50\% \quad (\text{Eq. 2 - 11})$$

Wovens:

$$\text{Percent open area} \geq 4\% \quad (\text{Eq. 2 - 12})$$

Alternative: Run filtration tests

2. Critical/Severe

Select geotextiles that meet retention, permeability, and survivability criteria, as well as the criteria in Step 4C.1 above, and perform a filtration test.

Suggested filtration test for sandy and silty soils is the gradient ratio test. The hydraulic conductivity ratio test is recommended by some people for fine-grained soils, but as noted in Section 2.3-3, the test has serious disadvantages.

Alternative: Long-term filtration tests, F^3 tests, etc.

NOTE: Experience is required to obtain reproducible results from the gradient ratio test. See Fischer (1994) and Maré (1994).

D. Survivability

Select geotextile properties required for survivability from Table 2-2. Add durability requirements if appropriate.

STEP 5. Estimate costs.

Calculate the pipe size (if required), the volume of aggregate, and the area of the geotextile. Apply appropriate unit cost values.

Pipe (if required) (/m)	_____
Aggregate (/m ³)	_____
Geotextile (/m ²)	_____
Geotextile placement (/m ²)	_____
Construction (LS)	_____
Total Cost:	_____

STEP 6. Prepare specifications.

Include for the geotextile:

A. General requirements

- B. Specific geotextile properties
 - C. Seams and overlaps
 - D. Placement procedures
 - E. Repairs
 - F. Testing and placement observation requirements
- See Sections 1.6 and 2.7 for specification details.

STEP 7. Collect samples of aggregate and geotextile before acceptance.

STEP 8. Monitor installation during and after construction.

STEP 9. Observe drainage system during and after storm events.

2.5 DESIGN EXAMPLE

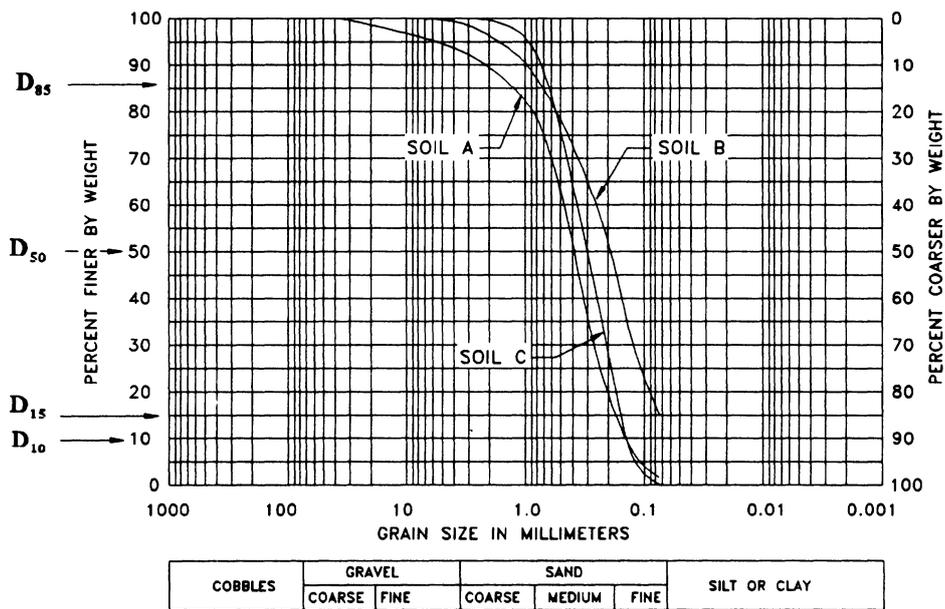
DEFINITION OF DESIGN EXAMPLE

- Project Description: drains to intercept groundwater are to be placed adjacent to a two-lane highway
- Type of Structure: trench drain
- Type of Application: geotextile wrapping of aggregate drain stone
- Alternatives:
 - i) graded soil filter between aggregate and soil being drained; or
 - ii) geotextile wrapping of aggregate

GIVEN DATA

- site has a high groundwater table
- drain is to prevent seepage and shallow slope failures, which are currently a maintenance problem
- depth of trench drain is 1 meter
- soil samples along the proposed drain alignment are nonplastic
- gradations of three *representative* soil samples along the proposed drain alignment

SIEVE SIZE (mm)	PERCENT PASSING, BY WEIGHT		
	Sample A	Sample B	Sample C
25	99	100	100
13	97	100	100
4.76	95	100	100
1.68	90	96	100
0.84	78	86	93
0.42	55	74	70
0.15	10	40	11
0.074	1	15	0



Grain Size Distribution Curve

DEFINE

- A. Geotextile function(s)
- B. Geotextile properties required
- C. Geotextile specification

SOLUTION

- A. Geotextile function(s):
 - Primary - filtration
 - Secondary - separation

- B. Geotextile properties required:
 apparent opening size (AOS)
 permittivity
 survivability

DESIGN

STEP 1. EVALUATE CRITICAL NATURE AND SITE CONDITIONS

From given data, assume that this is a noncritical application.
 Soils are well-graded, hydraulic gradient is low for this type of application, and flow conditions are steady state for this type of application.

STEP 2. OBTAIN SOIL SAMPLES

A. GRAIN SIZE ANALYSES

Plot gradations of representative soils. The D_{60} , D_{10} , and D_{85} sizes from the gradation plot are noted in the table below for Samples A, B, and C. Determine uniformity coefficient, C_u , coefficient B, and the maximum AOS.

Worst case soil for retention (*i.e.*, smallest $B \times D_{85}$) is Soil C, from the following table.

Soil Sample	$D_{60} \div D_{10} = C_u$	$B =$	$AOS (mm) \leq B \times D_{85}$
A	$0.48 \div 0.15 = 3.2$	$0.5 C_u = 0.5 \times 3.2 = 1.6$	$1.6 \times 1.0 = 1.6$
B	$0.25 \div 0.06 = 4.2$	$8 \div C_u = 8 \div 4.2 = 1.9$	$1.9 \times 0.75 = 1.4$
C	$0.36 \div 0.14 = 2.6$	$0.5 C_u = 0.5 \times 2.6 = 1.3$	$1.3 \times 0.55 = 0.72$

B. PERMEABILITY TESTS

Noncritical application, drain will be conservatively designed with an estimated permeability.

The largest D_{10} controls permeability; therefore, Soil A with $D_{10} = 0.15$ mm controls. Therefore,
 $k \approx (D_{10})^2 = (0.15)^2 = 2 (10)^{-2} \text{ cm/s} = 2 (10)^{-4} \text{ m/s}$

C. SELECT DRAIN AGGREGATE

Assume drain stone is a rounded aggregate.

STEP 3. DIMENSION DRAIN SYSTEM

Determine depth and width of drain trench and whether a pipe is required to carry flow - details of which are not included within this example.

STEP 4. DETERMINE GEOTEXTILE REQUIREMENTS

A. RETENTION CRITERIA

Sample C controls (see table above), therefore, $AOS \leq 0.72 \text{ mm}$

B. PERMEABILITY CRITERIA

From given data, it has been judged that this application is a less critical/less severe application. Therefore, $k_{\text{geotextile}} \geq k_{\text{soil}}$

Soil C controls, therefore $k_{\text{geotextile}} \geq 2 (10)^{-4} \text{ m/sec}$

Flow capacity requirements of the system - details of which are not included within this example.

C. PERMITTIVITY CRITERIA

All three soils have < 15% passing the 0.075 mm, therefore $\psi \geq 0.5 \text{ sec}^{-1}$

D. CLOGGING CRITERIA

From given data, it has been judged that this application is a less critical/less severe application, and Soils A and B have a C_u greater than 3. Therefore, for soils A and B, $O_{95} \geq 3 D_{15}$

$O_{95} \geq 3 \times 0.15 = 0.45 \text{ mm}$ for Sample A
 $3 \times 0.075 = 0.22 \text{ mm}$ for Sample B

Soil A controls [Note that sand size particles typically don't create clogging problems, therefore, Soil B could have been used as the design control.], therefore, $AOS \geq 0.45 \text{ mm}$

For Soil C, a geotextile with the maximum AOS value determined from the retention criteria should be used. Therefore $AOS \approx 0.72 \text{ mm}$

Also,

nonwoven porosity $\geq 50\%$

and

woven percent open area $\geq 4\%$

For the primary function of filtration, the geotextile should have $0.45 \text{ mm} \leq AOS \leq 0.72 \text{ mm}$; and $k_{\text{geotextile}} \geq 2 (10)^{-2} \text{ cm/sec}$ and, $\psi \geq 0.5 \text{ sec}^{-1}$. Woven slit film geotextiles are not allowed.

E. SURVIVABILITY

From Table 2-2, the following minimum values are recommended:

For Survivability, the geotextile shall have the following minimum values (values are MARV) -

	<u>Woven Geotextile</u>	<u>Nonwoven Geotextile</u>
Grab Strength	1100 N	700 N
Sewn Seam Strength	990 N	630 N
Tear Strength	400* N	250 N
Puncture Strength	400 N	250 N
Trapezoidal Tear	2700 N	1300 N

*250 N for monofilament geotextiles

NOTE: With lightweight compaction equipment and field inspection, Class 3 geotextile (see Appendix D) could be used.

Complete Steps 5 through 9 to finish design.

STEP 5. ESTIMATE COSTS

STEP 6. PREPARE SPECIFICATIONS

STEP 7. COLLECT SAMPLES

STEP 8. MONITOR INSTALLATION

STEP 9. OBSERVE DRAIN SYSTEM DURING AND AFTER STORM EVENTS

2.6 COST CONSIDERATIONS

Determining the cost effectiveness of geotextiles versus conventional drainage systems is a straightforward process. Simply compare the cost of the geotextile with the cost of a conventional granular filter layer, while keeping in mind the following:

- *Overall material costs including a geotextile versus a conventional system* - For example, the geotextile system will allow the use of poorly graded (less-select) aggregates, which may reduce the need for a collector pipe, provided the amount of fines is small (Q decreases considerably if the percent passing the 0.075 mm sieve is greater than 5%, even in gravel).
- *Construction requirements* - There is, of course, a cost for placing the geotextile; but in most cases, it is less than the cost of constructing dual-layered, granular filters, for example, which are often necessary with conventional filters and fine-grained soils.
- *Possible dimensional design improvements* - If an open-graded aggregate is used (especially with a collector pipe), a considerable reduction in the physical dimensions of the drain can be made without a decrease in flow capacity. This size reduction also reduces the volume of the excavation, the volume of filter material required, and the construction time necessary per unit length of drain.

In general, the cost of the geotextile material in drainage applications will typically range from \$1.00 to \$1.50 per square meter, depending upon the type specified and quantity ordered. Installation costs will depend upon the project difficulty and contractor's experience; typically, they range from \$0.50 to \$1.50 per square meter of geotextile. Higher costs should be anticipated for below-water placement. Labor installation costs for the geotextile are easily repaid because construction can proceed at a faster pace, less care is needed to prevent segregation and contamination of granular filter materials, and multilayered granular filters are typically not necessary.

2.7 SPECIFICATIONS

The following guide specification is provided as an example. It is a combination of the AASHTO M288 (1997) geotextile material specification and its accompanying construction/installation guidelines; developed for routine drainage and filtration applications. The actual hydraulic and physical properties of the geotextile must be selected by considering of the nature of the project (critical/less critical), hydraulic conditions (severe/less severe), soil conditions at the site, and construction and installation procedures appropriate for the project.

SUBSURFACE DRAINAGE GEOTEXTILES

(after AASHTO M288, 1997)

1. SCOPE

1.1 *Description.* This specification is applicable to placing a geotextile against the soil to allow long-term passage of water into a subsurface drain system retaining the in situ soils. The primary function of the geotextile in subsurface drainage applications is filtration. Geotextile filtration properties are a function of the in situ soil gradation, plasticity, and hydraulic conditions.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards

T88	Particle Size Analysis of Soils
T90	Determining the Plastic Limit and Plasticity Index of Soils
T99	The Moisture-Density Relationships of Soils Using a 2.5 kg Rammer and a 305 mm Drop

2.2 ASTM Standards

D 123	Standard Terminology Relating to Textiles
D 276	Test Methods for Identification of Fibers in Textiles
D 3786	Test Method for Hydraulic Burst Strength of Knitted Goods and Nonwoven Fabrics, Diaphragm Bursting Strength Tester Method
D 4354	Practice for Sampling of Geosynthetics for Testing
D 4355	Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon Arc Type Apparatus)
D 4439	Terminology for Geosynthetics
D 4491	Test Methods for Water Permeability of Geotextiles by Permittivity
D 4632	Test Method for Grab Breaking Load and Elongation of Geotextiles
D 4751	Test Method for Determining Apparent Opening Size of a Geotextile
D 4759	Practice for Determining the Specification Conformance of Geosynthetics
D 4833	Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 4873	Guide for Identification, Storage, and Handling of Geotextiles
D 5141	Test Method to Determine Filtering Efficiency and Flow Rate for Silt Fence Applications Using Site Specific Soil

3. PHYSICAL AND CHEMICAL REQUIREMENTS

3.1 Fibers used in the manufacture of geotextiles and the threads used in joining geotextiles by sewing, shall consist of long chain synthetic polymers, composed of at least 95 % by weight polyolefins or polyesters. They shall be formed into a stable network such that the filaments or yarns retain their dimensional stability relative to each other, including selvages.

3.2 *Geotextile Requirements.* The geotextile shall meet the requirements of following Table. Woven slit film geotextiles (*i.e.*, geotextiles made from yarns of a flat, tape-like character) will not be allowed. All numeric values in the following table, except AOS, represent minimum average roll values (MARV) in the weakest principal direction (*i.e.*, average test results of any roll in a lot sampled for conformance or quality assurance testing shall meet or exceed the minimum values). Values for AOS represent maximum average roll values.

NOTE: The property values in the following table represent default values which provide for sufficient geotextile survivability under most conditions. Minimum property requirements may be reduced when sufficient survivability information is available [see Note 2 of Table 2-2 and Appendix D]. The Engineer may also specify properties different from those listed in the following Table based on engineering design and experience.

Subsurface Drainage Geotextile Requirements

Property	ASTM Test Method	Units	Elongation ⁽¹⁾		
			< 50 % ⁽¹⁾	≥ 50 % ⁽¹⁾	
Grab Strength	D 4632	N	1100	700	
Sewn Seam Strength ⁽²⁾	D 4632	N	990	630	
Tear Strength	D 4533	N	400 ⁽³⁾	250	
Puncture Strength	D 4833	N	400	250	
Burst Strength	D 3786	kPa	2700	1300	
			Percent In Situ Passing 0.075 mm Sieve ⁽⁴⁾		
			< 15	15 to 50	> 50
Permittivity	D 4491	sec ⁻¹	0.5	0.2	0.1
Apparent Opening Size	D 4751	mm	0.43	0.25	0.22 ⁽⁵⁾
Ultraviolet Stability	D 4355	%	50 % after 500 hours of exposure		
<p>NOTES:</p> <p>(1) As measured in accordance with ASTM D 4632.</p> <p>(2) When sewn seams are required.</p> <p>(3) The required MARV tear strength for woven monofilament geotextiles is 250 N.</p> <p>(4) Based on grain size analysis of in situ soil in accordance with AASHTO T88.</p> <p>(5) For cohesive soils with a plasticity index greater than 7, geotextile maximum average roll value for apparent opening size is 0.30 mm.</p>					

4. CERTIFICATION

- 4.1 The Contractor shall provide to the Engineer a certificate stating the name of the manufacturer, product name, style number, chemical composition of the filaments or yarns and other pertinent information to fully describe the geotextile.
- 4.2 The Manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of the specification. Documentation describing the quality control program shall be made available upon request.
- 4.3 The Manufacturer's certificate shall state that the furnished geotextile meets MARV requirements of the specification as evaluated under the Manufacturer's quality control program. The certificate shall be attested to be a person having legal authority to bind the Manufacturer.
- 4.4 Either mislabeling or misrepresentation of materials shall be reason to reject those geotextile products.

5. SAMPLING, TESTING, AND ACCEPTANCE

- 5.1 Geotextiles shall be subject to sampling and testing to verify conformance with this specification. Sampling for testing shall be in accordance with ASTM D 4354. Acceptance shall be based on testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354. A lot size for conformance or quality assurance sampling shall be considered to be the shipment quantity of the given product or a truckload of the given product, whichever is smaller.
- 5.2 Testing shall be performed in accordance with the methods referenced in this specification for the indicated application. The number of specimens to test per sample is specified by each test method. Geotextile product acceptance shall be based on ASTM D 4759. Product acceptance is determined by comparing the average test results of all specimens within a given sample to the specification MARV. Refer to ASTM D 4759 for more details regarding geotextile acceptance procedures.

6. SHIPMENT AND STORAGE

- 6.1 Geotextile labeling, shipment, and storage shall follow ASTM D 4873. Product labels shall clearly show the manufacturer or supplier name, style number, and roll number. Each shipping document shall include a notation certifying that the material is in accordance with the manufacturer's certificate.
- 6.2 Each geotextile roll shall be wrapped with a material that will protect the geotextile from damage due to shipment, water, sunlight, and contaminants. The protective wrapping shall be maintained during periods of shipment and storage.
- 6.3 During storage, geotextile rolls shall be elevated off the ground and adequately covered to protect them from the following: site construction damage, precipitation, extended ultraviolet radiation including sunlight, chemicals that are strong acids or strong bases, flames including welding sparks, temperatures in excess of 71°C (160°F), and any other environmental condition that may damage the physical property values of the geotextile.

7. CONSTRUCTION

7.1 General. Atmospheric exposure of geotextiles to the elements following lay down shall be a maximum of 14 days to minimize damage potential.

7.2 Seaming.

a. If a sewn seam is to be used for the seaming of the geotextile, the thread used shall consist of high strength polypropylene, or polyester. Nylon thread shall not be used. For erosion control applications, the thread shall also be resistant to ultraviolet radiation. The thread shall be of contrasting color to that of the geotextile itself.

b. For seams which are sewn in the field, the Contractor shall provide at least a 2 m length of sewn seam for sampling by the Engineer before the geotextile is installed. For seams which are sewn in the factory, the Engineer shall obtain samples of the factory seams at random from any roll of geotextile which is to be used on the project.

b.1 For seams that are field sewn, the seams sewn for sampling shall be sewn using the same equipment and procedures as will be used for the production of seams. If seams are to be sewn in both the machine and cross machine directions, samples of seams from both directions shall be provided.

b.2 The seam assembly description shall be submitted by the Contractor along with the sample of the seam. The description shall include the seam type, stitch type, sewing thread, and stitch density.

7.3 Trench. Trench excavation shall be done in accordance with details of the project plans. In all instances excavation shall be done in such a way so as to prevent large voids from occurring in the sides and bottom of the trench. The graded surface shall be smooth and free of debris.

7.4 Geotextile Placement.

a. In placement of the geotextile for drainage applications, the geotextile shall be placed loosely with no wrinkles or folds, and with not void spaces between the geotextile and the ground surface. Successive sheets of geotextiles shall be overlapped a minimum of 300 mm, with the upstream sheet overlapping the downstream sheet.

a.1 In trenches equal to or greater than 300 mm in width, after placing the drainage aggregate the geotextile shall be folded over the top of the backfill material in a manner to produce a minimum overlap of 300 mm. In trenches less than 300 mm but greater than 100 mm wide, the overlap shall be equal to the width of the trench. Where the trench is less than 100 mm the geotextile overlap shall be sewn or otherwise bonded. All seams shall be subject to the approval of the Engineer.

a.2 Should the geotextile be damaged during installation, or drainage aggregate placement, a geotextile patch shall be placed over the damaged area extending beyond the damaged area a distance of 300 mm, or the specified seam overlap, whichever is greater.

7.5 Drainage Aggregate

a. Placement of drainage aggregate should proceed immediately following placement of the geotextile. The geotextile should be covered with a minimum of 300 mm of loosely placed aggregate prior to compaction. If a

perforated collector pipe is to be installed in the trench, a bedding layer of drainage aggregate should be placed below the pipe, with the remainder of the aggregate placed to the minimum required construction depth.

- a.1 The aggregate should be compacted with vibratory equipment to a minimum of 95% Standard AASHTO density unless the trench is required for structural support. If higher compactive effort is required, a Class 1 geotextile as per Table 1 of the M288 Specification is needed.

8. METHOD OF MEASUREMENT

8.1 The geotextile shall be measured by the number of square meters computed from the payment lines shown on the plans or from payment lines established in writing by the Engineer. This excludes seam overlaps, but shall include geotextiles used in crest and toe of slope treatments.

8.2 Slope preparation, excavation and backfill, bedding, and cover material are separate pay items.

9. BASIS OF PAYMENT

9.1 The accepted quantities of geotextile shall be paid for per square meter in place.

9.2 Payment will be made under:

Pay Item	Pay Unit
Subsurface Drainage Geotextile	Square Meter

2.8 INSTALLATION PROCEDURES

For all drainage applications, the following construction steps should be followed:

1. The surface on which the geotextile is to be placed should be excavated to design grade to provide a smooth, graded surface free of debris and large cavities.
2. Between preparation of the subgrade and construction of the system itself, the geotextile should be well-protected to prevent any degradation due to exposure to the elements.
3. After excavating to design grade, the geotextile should be cut (if required) to the desired width (including allowances for *non-tight* placement in trenches and overlaps of the ends of adjacent rolls) or cut at the top of the trench after placement of the drainage aggregate.
4. Care should be taken during construction to avoid contamination of the geotextile. If it becomes contaminated, it must be removed and replaced with new material.
5. In drainage systems, the geotextile should be placed with the machine direction following the direction of water flow; for pavements, the geotextile should be parallel to the roadway. It should be placed loosely (not taut), but with no wrinkles or folds. Care should be taken to place the geotextile in intimate contact with the soil so that no void spaces occur behind it.

6. The ends for subsequent rolls and parallel rolls of geotextile should be overlapped a minimum of 0.3 m in roadways and 0.3 to 0.6 m in drains, depending on the anticipated severity of hydraulic flow and the placement conditions. For high hydraulic flow conditions and heavy construction, such as with deep trenches or large stone, the overlaps should be increased. For large open sites using base drains, overlaps should be pinned or anchored to hold the geotextile in place until placement of the aggregate. Upstream geotextile should always overlap over downstream geotextile.
7. To limit exposure of the geotextile to sunlight, dirt, damage, etc., placement of drainage or roadway base aggregate should proceed immediately following placement of the geotextile. The geotextile should be covered with a minimum of 0.3 m of loosely placed aggregate prior to compaction. If thinner lifts are used, higher survivability fabrics may be required. For drainage trenches, at least 0.1 m of drainage stone should be placed as a bedding layer below the slotted collector pipe (if required), with additional aggregate placed to the minimum required construction depth. Compaction is necessary to seat the drainage system against the natural soil and to reduce settlement within the drain. The aggregate should be compacted with vibratory equipment to a minimum of 95% Standard AASHTO T99 density unless the trench is required for structural support. If higher compactive efforts are required, the geotextiles meeting the property values listed under the high survivability category in Table 2-2 should be utilized.
8. After compaction, for trench drains, the two protruding edges of the geotextile should be overlapped at the top of the compacted granular drainage material. A minimum overlap of 0.3 m is recommended to ensure complete coverage of the trench width. The overlap is important because it protects the drainage aggregate from surface contamination. After completing the overlap, backfill should be placed and compacted to the desired final grade.

A schematic of the construction procedures for a geotextile-lined underdrain trench is shown in Figure 2-6. Construction photographs of an underdrain trench are shown in Figure 2-7, and diagrams of geosynthetic placement beneath a permeable roadway base are shown in Figure 2-8.

2.9 FIELD INSPECTION

The field inspector should review the field inspection guidelines in Section 1.7. Special attention should be given to aggregate placement and potential for geotextile damage. Also, maintaining the appropriate geotextile overlap at the top of the trench and at roll ends is especially important.

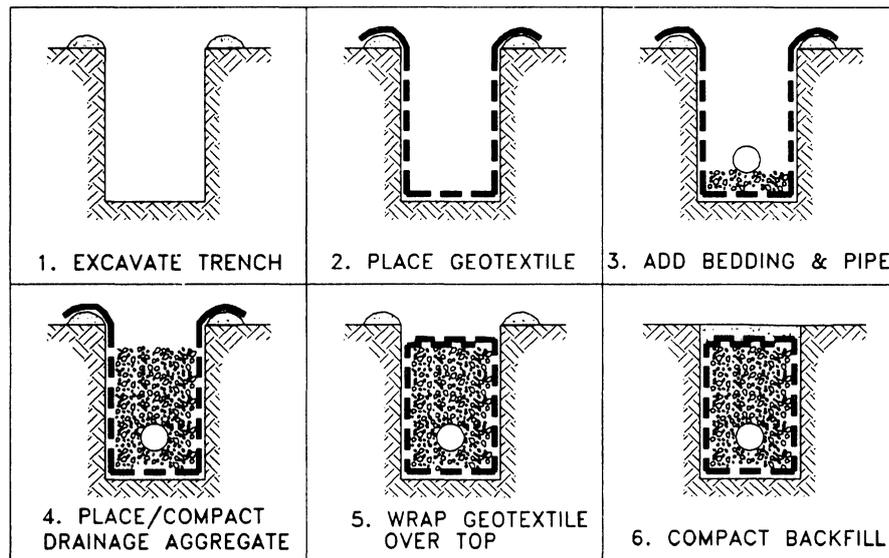


Figure 2-6 Construction procedure for geotextile-lined underdrains.

2.10 ADDITIONAL SELECTION CONSIDERATIONS

The late Dr. Allan Haliburton, a geotextile pioneer, noted that all geotextiles will work in some applications, but no one geotextile will work in all applications. Even though several types of geotextiles (monofilament wovens and an array of light- to heavy-weight nonwovens) may meet all of the desired design criteria, it may be preferable to use one type over another to enhance system performance. Selection will depend on the actual soil and hydraulic conditions, as well as the intended function of the design. Intuitively, the following considerations seem appropriate for the soil conditions given.

1. Graded gravels and coarse sands -- Very open monofilament or even multifilament wovens may be required to permit high rates of flow and low-risk of blinding.
2. Sands and gravels with less than 20% fines -- Open monofilament wovens and needlepunched nonwovens with large openings are preferable to reduce the risk of blinding. For thin, heat-bonded geotextiles and thick, needlepunched nonwoven geotextiles, filtration tests should be performed.
3. Soils with 20% to 60% fines -- Filtration tests should be performed on all types of geotextiles.



(a)



(b)

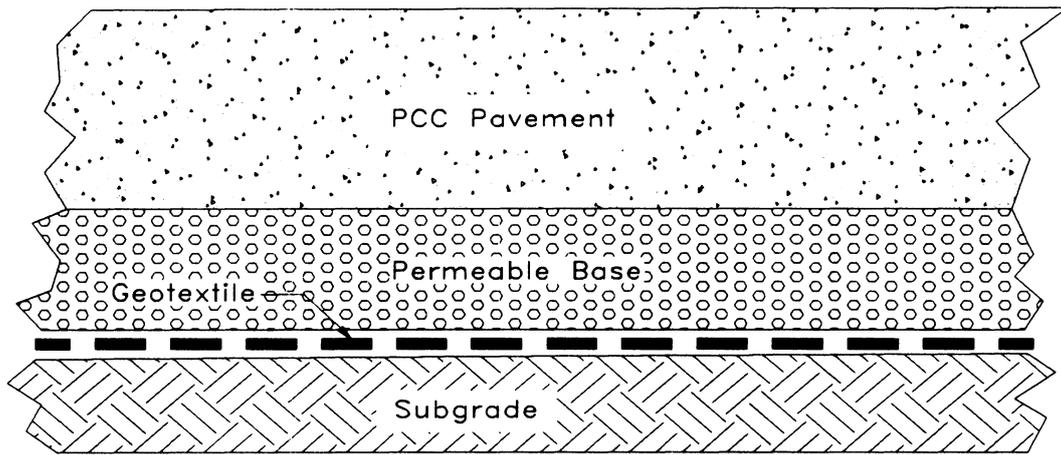


(c)

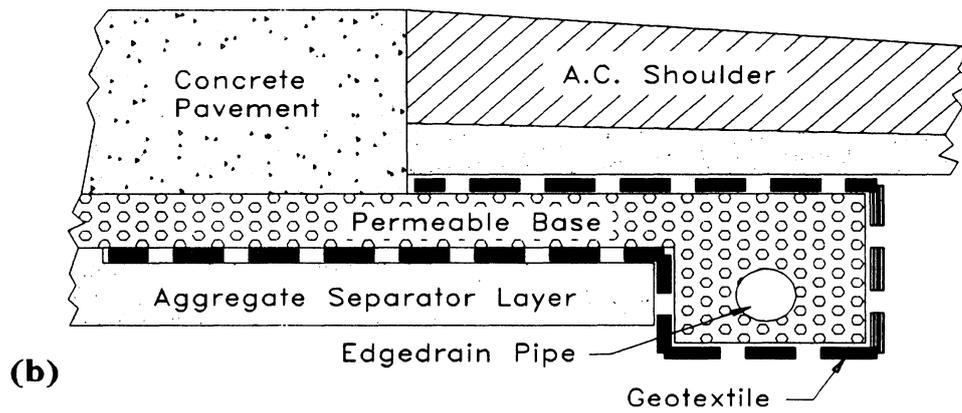


(d)

Figure 2-7 Construction of geotextile drainage systems: a.) geotextile placement in drainage ditch; b.) aggregate placement; c.) compaction of aggregate; and d.) geotextile overlap prior to final cover.



(a)



(b)

Figure 2-8 Construction geotextile filters and separators beneath permeable pavement base: a.) geotextile used as a separator; and b.) permeable base and edge drain combination. (Baumgardner, 1994)

4. Soils with greater than 60% fines -- Heavy-weight, needlepunched geotextiles and heat-bonded 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.
5. Gap-graded cohesionless soils -- Consider using a uniform sand filter with a very open geotextile designed to allow fines to pass.
6. Silts with sand seams -- Consider using a uniform sand filter over the soil with a very open geotextile, designed to allow the silt to pass but to prevent movement of the filter sand; alternatively, consider using a heavy-weight (thick) needlepunched nonwoven directly against soil so water can flow laterally through the geotextile should it become locally clogged.

These general observations are not meant to serve as recommendations, but are offered to provide insight for selecting optimum materials. They are not intended to exclude other possible geotextiles that you may want to consider.

2.11 IN-PLANE DRAINAGE; PREFABRICATED GEOCOMPOSITE DRAINS

Geotextiles with high in-plane drainage ability and prefabricated geocomposite drains are potentially quite effective in several applications.

The ability of geotextiles to transmit water in the plane of the geotextile itself may be an added benefit in certain drainage applications where lateral transmission of water is desirable or where reduction of pore water pressures in the soil can be accelerated. These applications include interceptor drains, transmission of seepage water below pavement base course layers, horizontal and vertical strip drains to accelerate consolidation of soft foundation soils, dissipation of seepage forces in earth and rock slopes, as part of chimney drains in earth dams, dissipaters of pore water pressures in embankments and fills, gas venting below containment liner systems, etc. However, it should be realized that the seepage quantities transmitted by in-plane flow of geotextiles (typically on the order of 2×10^{-5} m³/s/linear meter of geotextile under a pressure equivalent to 0.6 m of soil) are relatively small when compared to the seepage capacity of 0.150 to 0.3 m of sand or other typical filter materials. Therefore, geotextiles should only replace sand or other filter layers where they can handle high seepage quantities. Remember, too, that seepage quantities are highly affected by compressive forces, incomplete saturation, and hydraulic gradients.

In recent years, special geocomposite materials have been developed which consist of cores of extruded and fluted plastics sheets, three-dimensional meshes and mats, plastic waffles, and nets and channels to convey water, which are covered by a geotextile on one or both sides to act as a

filter. Geocomposite drains may be prefabricated or fabricated on site. They generally range in thickness from 5 mm to 25 mm or greater and have transmission capabilities of between 0.0002 and 0.01 m³/s/linear width of drain. Some geocomposite systems are shown in Figure 2-9. Geocomposite drains have been used in six major areas:

1. Edge drains for pavements.
2. Interceptor trenches on slopes.
3. Drainage behind abutments and retaining structures.
4. Relief of water pressures on buried structures.
5. Substitute for conventional sand drains.
6. Waste containment systems for leachate collection and gas venting.

Prefabricated geocomposite drains are essentially used to replace or support conventional drainage systems. According to Hunt (1982), prefabricated drains offer a readily available material with known filtration and hydraulic flow properties; easy installation, and, therefore, construction economies; and protection of any waterproofing applied to the structure's exterior. Cost of prefabricated drains typically ranges from \$4.50 to \$25.00 per square meter. The high material cost is usually offset by expedient construction and reduction in required quantities of select granular materials. For example, geocomposites used for pavement edge drains typically cost \$1.75 to \$5.00/linear meter installed.

2.11-1 Design Criteria

For the geotextile design and selection with in-plane drainage capabilities and geocomposite drainage systems, there are three basic design considerations:

1. Adequate filtration without clogging or piping.
2. Adequate inflow/outflow capacity under design loads to provide maximum anticipated seepage during design life.
3. System performance considerations.

As with conventional drainage systems, geotextile selection should be based on the grain size of the material to be protected, permeability requirements, clogging resistance, and physical property requirements, as described in Section 2.3. In pavement drainage systems, dynamic loading means severe hydraulic conditions (Table 2-1). If, for example, the geotextile supplied with the geocomposite drainage system is not appropriate for your design conditions, system safety will be compromised and you should specify alternate geotextiles. This is important especially when prefabricated drains are used in critical situations and where failure system could lead to structure failure.

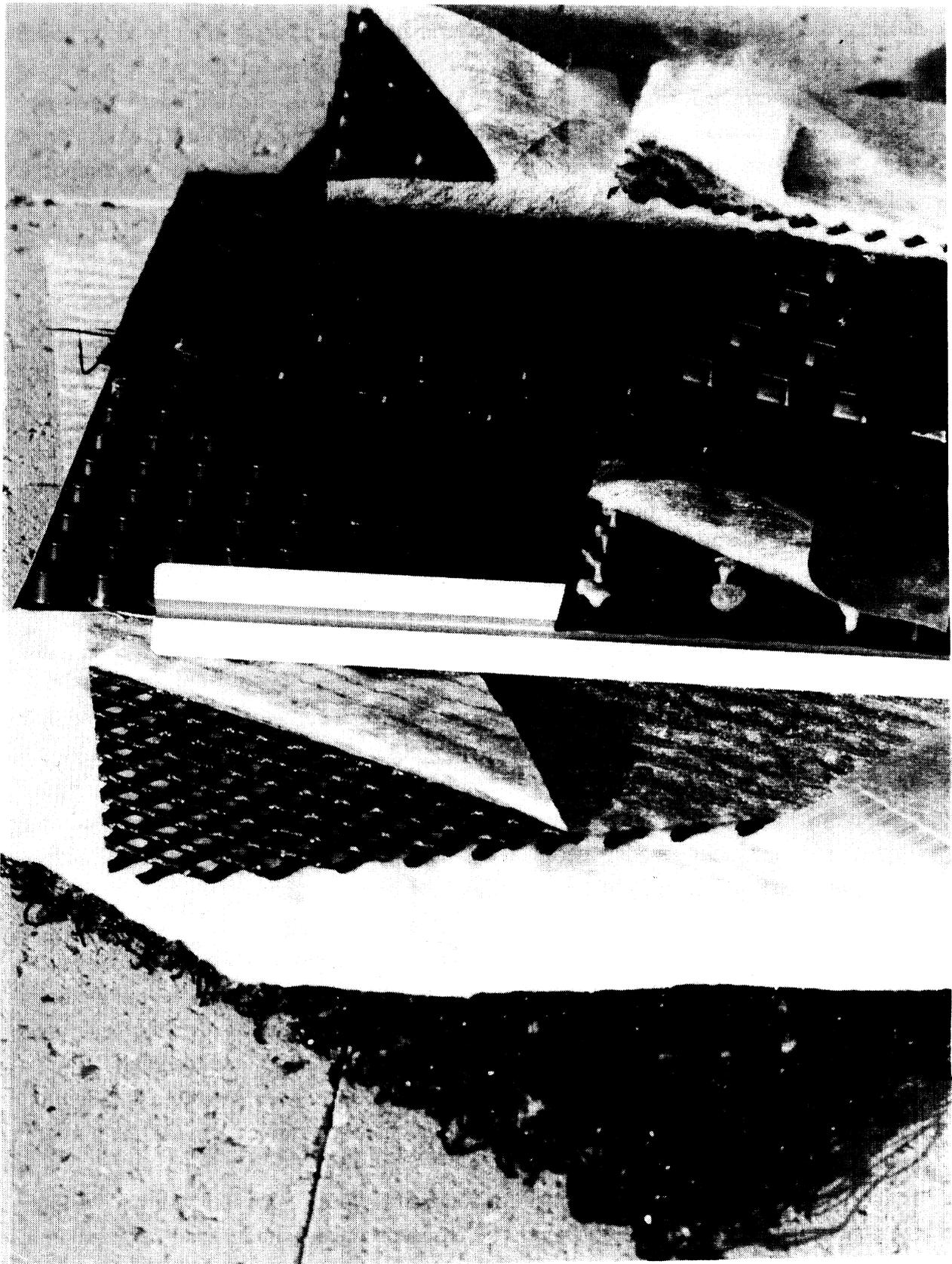


Figure 2-9 Geocomposite drains.

The maximum seepage flow into the system must be estimated and the geotextile or geocomposite selected on the basis of seepage requirements. The flow capacity of the geocomposite or geotextile can be determined from the transmissivity of the material. The test for transmissivity is ASTM D 4716, Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products. The flow capacity per unit width of the geotextile or geocomposite can then be calculated using Darcy's Law:

$$q = k_p i A = k_p i B t \quad [2 - 15]$$

or,

$$q/B = \theta i \quad [2 - 16]$$

where:

q	= flow rate (L ³ /T)
k _p	= in-plane coefficient of permeability for the geosynthetic (L/T)
B	= width of geosynthetic (L)
t	= thickness of geosynthetic (L)
θ	= transmissivity of geosynthetic (= k _p t) (L ² /T)
i	= hydraulic gradient (L/L)

The flow rate per unit width of the geosynthetic can then be compared with the flow rate per unit width required of the drainage system. It should be recognized that the in-plane flow capacity for geosynthetic drains reduces significantly under compression (Giroud, 1980). Additional decreases in transmissivity may occur with time due to creep. Therefore, the material should be evaluated by an appropriate laboratory model (performance) test, under the anticipated design loading conditions (with a safety factor) for the design life of the project.

Long-term compressive stress and eccentric loadings on the core of a geocomposite should be considered during design and selection. Though not yet addressed in standardized test methods or standards of practice, the following criteria (Berg, 1993) are suggested for addressing core compression. The design pressure on a geocomposite core should be limited to either:

- i) the maximum pressure sustained on the core in a test of 10,000 hour minimum duration; or
- ii) the crushing pressure of a core, as defined with a quick loading test, divided by a safety factor of 5.

Note that crushing pressure can only be defined for some core types. For cases where a crushing pressure cannot be defined, suitability should be based on the maximum load resulting in a residual thickness of the core adequate to provide the required flow after 10,000 hours.

Intrusion of the geotextiles into the core and long-term outflow capacity should be measured with a sustained transmissivity test (Berg, 1993). The ASTM D 4716 test procedure (1987), Constant Head Hydraulic Transmissivity of Geotextiles and Geotextile Related Products, should be followed. Test procedure should be modified for sustained testing and for use of sand substratum and super-stratum in lieu of closed cell foam rubber. Load should be maintained for 300 hours or until equilibrium is reached, whichever is greater.

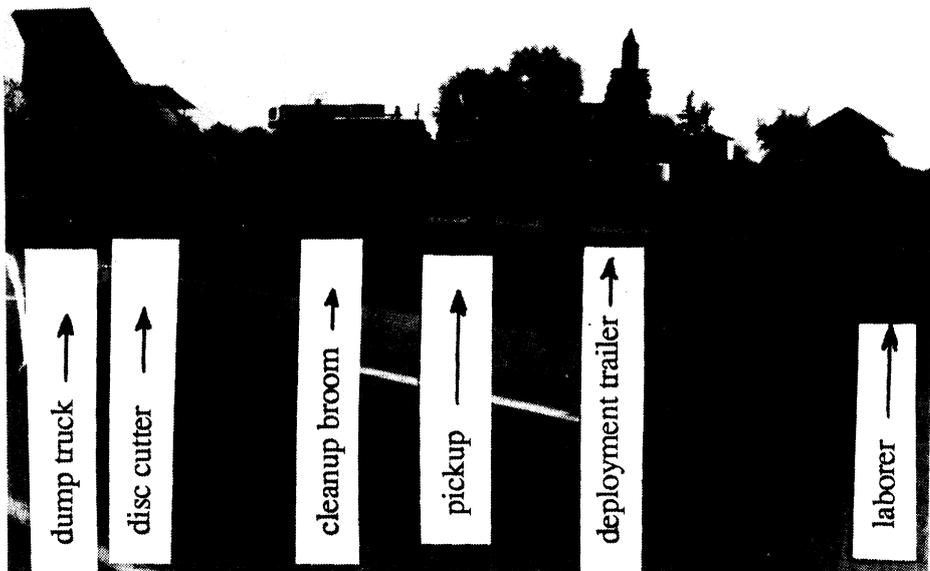
Finally, special consideration must be given to drain location and pressures on the wall when using geosynthetics to drain earth retaining structures and abutments. It is important that the drain be located away from the back of the wall and be appropriately inclined so it can intercept seepage before it impinges on the back of the wall. Placement of a thin vertical drain directly against a retaining wall may actually increase seepage forces on the wall due to rainwater infiltration (Terzaghi and Peck, 1967; and Cedergren, 1989). For further discussion of this point, see Christopher and Holtz (1985).

2.11-2 Construction Considerations

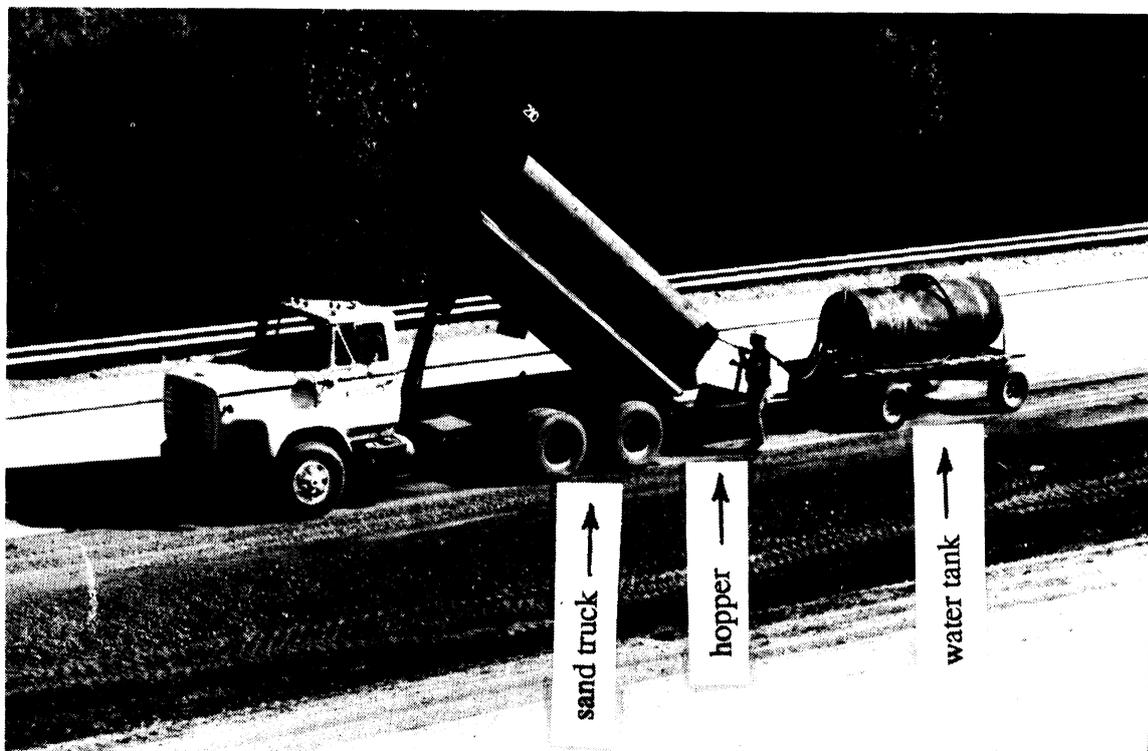
The following are considerations specific to the installation of geocomposite drains:

1. As with all geotextile applications, care should be taken during storage and placement to avoid damage to the material.
2. Placement of the backfill directly against the geotextile must be closely observed, and compaction of soil directly against the material should be avoided. Otherwise, loading during placement of backfill could damage the filter or even crush the drain. Use of clean granular backfill reduces the compaction energy requirements.
3. At the joints, where the sheets or strips of geocomposite butt together, the geotextile must be carefully overlapped to prevent soil infiltration. Also, the geotextile should extend beyond the ends of the drain to prevent soil from entering at the edges.
4. Details must be provided on how the prefabricated drains tie into the collector drainage systems.

Construction of an edge drain installation is shown in Figures 2-10 and 2-11. Additional information and recommendations regarding proper edge drain installation can be found in Koerner, et al. (1993) and in ASTM D 6088 Practice for Installation of Geocomposite Edge Drains.



(a) Equipment train used to install PGEDs according to Figure 2-11.



(b) Sand installation and backfilling equipment at end of equipment train according to Figure 2-11.

Figure 2-10 Prefabricated geocomposite edge drain construction using sand fill upstream of composite (as illustrated in Figure 2-11) (from Koerner, et al., 1993).

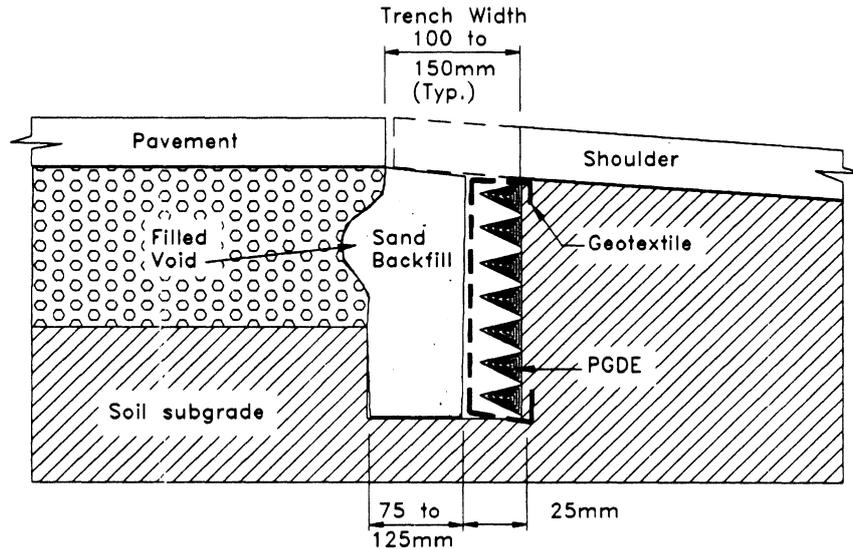


Figure 2-11 Recommended installation method for prefabricated geocomposite edge drains (from Koerner, et al., 1993).

2.12 REFERENCES

References quoted within this section are listed below. Detailed lists of specific ASTM and GRI test procedures are presented in Appendix E. A *key* reference for design is this manual (FHWA Geosynthetics Manual) and its predecessor Christopher and Holtz (1985). The recent NCHRP report (Koerner et al., 1994) specifically addresses pavement edge drain systems and is based upon analysis of failed systems. It also is a *key* reference for design. These and other *key* references are noted in bold type.

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