Design Manual for Roadway Geocomposite Underdrain Systems

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Introduction

Water in pavement systems is one of the principal causes of pavement distress. It is well known that improved roadway drainage extends the life of a roadway system. The Romans found very quickly that drainage was essential for their roads to last (remnants of which still remain!). In the 19th century, MacAdam, the originator of modern roadway design, recognized that it was necessary to have good drainage if adequate support was to be maintained and the road was to last. Modern roadways incorporating good drainage are predicted to have a design life of up to two to three times over that of undrained pavement sections (Cedergren, 1987 and 1988). The benefits of good drainage are also recognized in many current roadway design methods (e.g. AASHTO, 1993 and US Army, 1992), which incorporate drainage factors that enable designers to take advantage of good versus poor drainage conditions. Many engineers are taking advantage of these benefits by incorporating free draining base with edgedrains into their designs (NCHRP 239). However, a vast majority of roadways are still designed without due consideration for drainage and are unlikely to perform satisfactorily.

This manual was prepared to provide design guidance for a new alternative drainage method, which incorporates a horizontal geocomposite drainage layer tied directly and continuously into an edgedrain system. This geocomposite drainage layer (Tendrain™ 100-2 by the Tenax Corporation) can be used to directly replace drainable aggregate layers in modern rigid or flexible pavement systems. The layer can also be used to significantly enhance the drainage of dense graded aggregate layers. The consequence of inadequate drainage and design modifications for good drainage are demonstrated through the use of the current AASHTO and U.S. Army Corps of Engineers pavement design codes. Design requirements for the geocomposite drainage layer are reviewed and design examples are presented to demonstrate the cost-benefit of their use. Specifications and installation guidelines are also provided.

Water in Pavement Systems

The detrimental effects of water in the pavement system are significant. AASHTO (1993) reports:

1. **Water in the asphalt surface can lead to moisture damage, modulus reduction and loss of tensile strength. Saturation can reduce the dry modulus of the asphalt by as much as 30 percent or more.**
2. **Added moisture in unbound aggregate base and subbase is anticipated to result in a loss of stiffness on the order of 50 percent or more.**
3. **Modulus reduction of up to 30 percent can be expected for asphalt-treated base and increase erosion susceptibility of cement or lime treated bases.**
4. **Saturated fine-grain roadbed soil could experience modulus reductions of over 50 percent.**

The influence of saturation on the life of the pavement can be seen from Figure 1. The severity factor shown in the figure is the anticipated relative damage during wet versus dry periods anticipated for the type of road. As an example, Figure 1 shows that if the pavement system is saturated only 10 percent of its life (e.g., one month per year), a pavement section with a moderate stability factor will be serviceable only about 50 percent of its designed performance period. The influence of poor drainage is well recognized by the current AASHTO and Army Corps of Engineers design methods. These methods are based on the principle of time to drain: the time anticipated required for pavement system drainage following any significant moisture event (i.e., rainfall, flood, snow melt or capillary rise). The definitions of poor versus excellent drainage provided by AASHTO (1993) and as used in this manual are given in Table 1. These definitions are based on the time required for 50 percent of the free water to drain from the pavement section. The definitions do not consider the water retained by the effective porosity of the material (i.e., the water that will not drain under gravity.)

Table 1. AASHTO definitions for pavement drainage recommended for use in both flexible and rigid pavement design (AASHTO, 1993).

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very Poor	Does not Drain

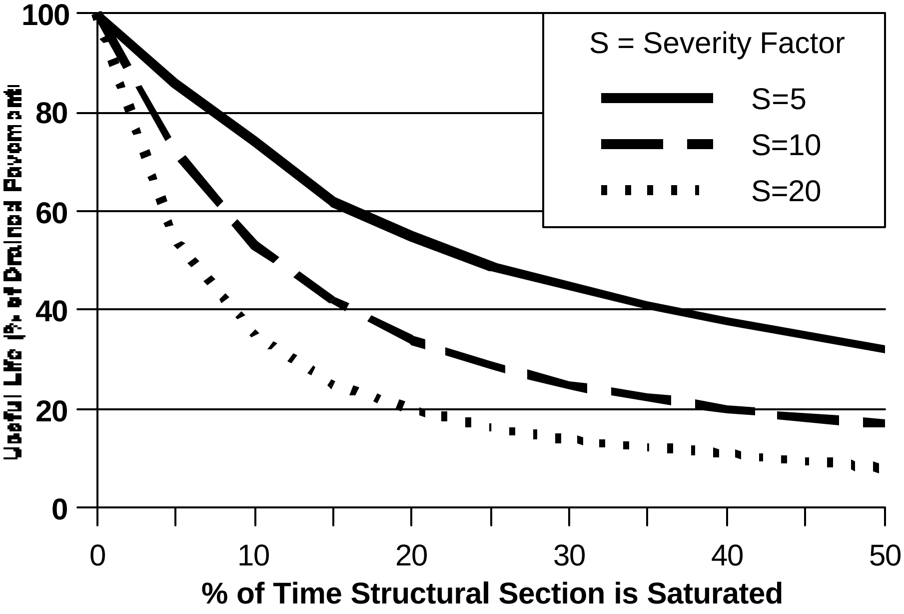

Figure 1 The Influence of Saturation on the Design Life of a Pavement System. (after Cedergren, 1987)

Design for Drainage

Designers can take advantage of improved pavement performance afforded by good drainage through use of a drainage coefficient (C_d) for rigid pavement design and a drainage modifier (m) for flexible pavement design that are included in the *AASHTO Guide for Design of Pavement Structures* (1993) and shown in Table 2. The drainage modifiers are applied to the structural number equation for flexible pavement as shown in the following equation:

$$SN = a_1 D_1 + a_2 m_2 D_2 + a_3 m_3 D_3 \qquad \textit{Eq. 1}$$

Table 2. Recommended values for drainage modifier, m_i, for untreated base and subbase materials in flexible pavements (AASHTO, 1993).

Quality of Drainage	Percent of time pavement is exposed to moisture levels approaching saturation			
	Less than 1%	1 to 5%	5 to 25%	More than 25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

For example, in high rainfall areas, the base section of a flexible pavement system with a relatively thick base layer can be reduced by as much as a factor of 2, or the design life extended by an equivalent amount, if excellent drainage is provided versus poor drainage. Likewise, an improvement in drainage (i.e., increase in C_d) leads to a reduction in Portland cement concrete (PCC) slab thickness.

Conventional Drainage Solutions

Most of the water in a pavement section infiltrates through the pavement surface during rain events. The incorporation of open-graded, free draining base layer (OGDL) into the pavement section as shown in Figure 2 provides excellent drainage. As recognized in NCHRP Synthesis 239 (Christopher and McGuffey, 1997), the use of free drainage aggregate has become the standard practice of many engineers who design pavements for extended service life. According to the FHWA (1987), the permeable base shown in Figure 2 is recommended to have a minimum permeability of 1000 ft/day. This permeability will allow for drainage of the pavement within a few hours; i.e., a condition that qualifies as "excellent drainage" as defined by AASHTO in Table 1 and 2. Figure 3 shows the relation of permeability for open graded, free-draining base as compared to denser graded base.

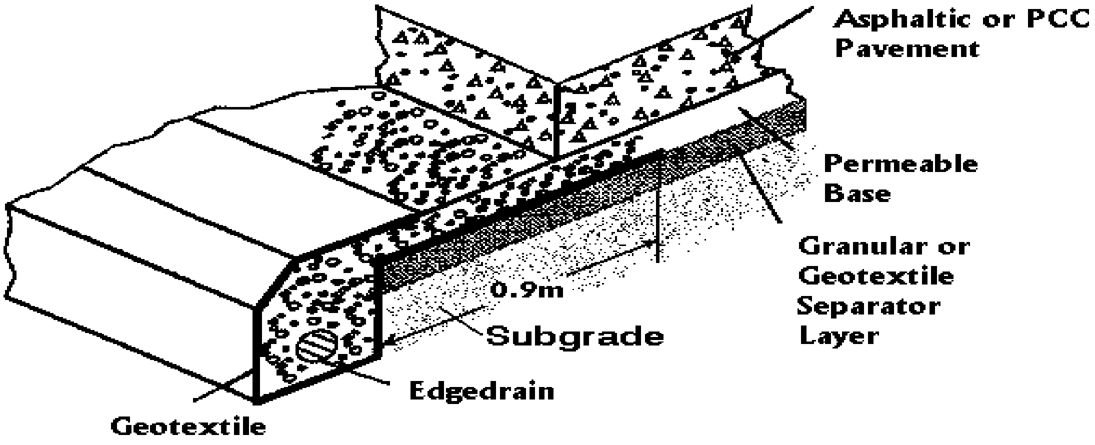

Figure 2. Drainable Pavement System (after FHWA, 1992)

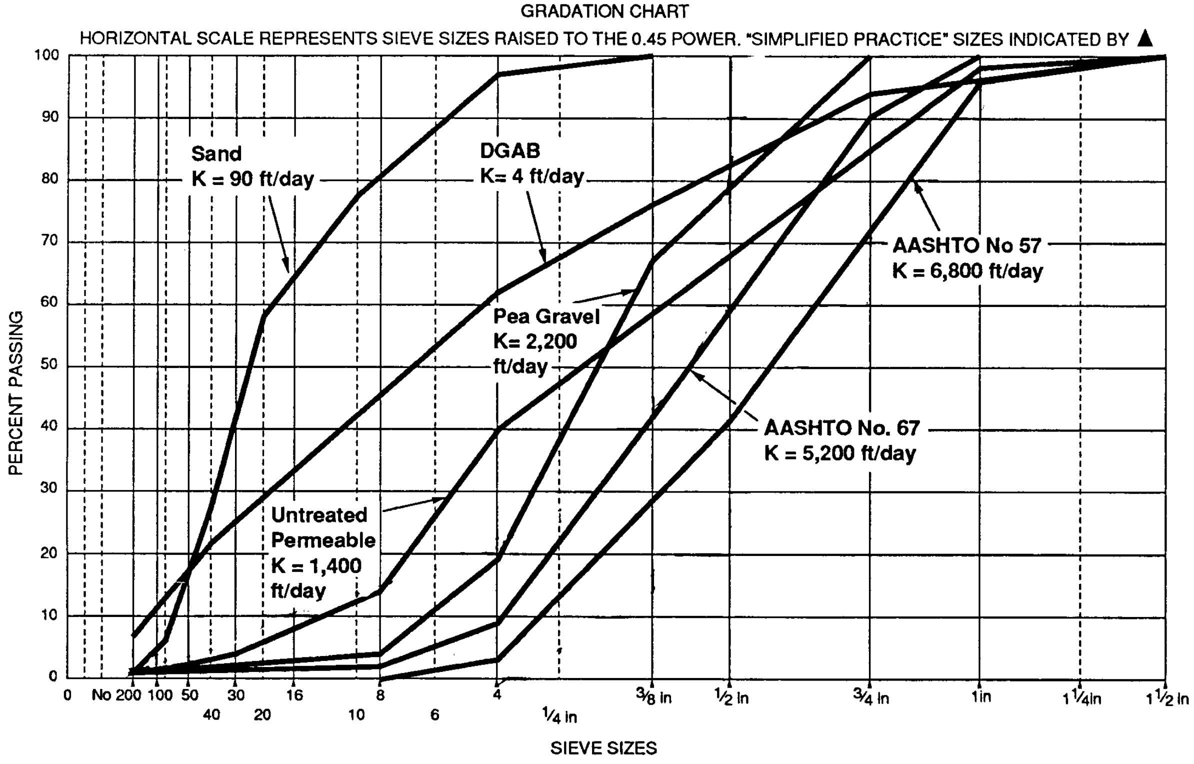

Figure 3. Gradation and Permeability of Base Course Materials

Due to the open-graded nature of free draining aggregate, asphaltic or cement stabilization binders are typically required to facilitate construction adding significantly to the cost of the roadway. The open-graded drainage layer is rarely full depth. A dense graded subbase layer is usually placed below the OGDL as a separation/filter layer to prevent migration of subgrade fines into the open graded base and provide additional support. The aggregate layer(s) or cement treated base/subbase are part of the structural design. The effective thickness of the drainage layer is usually less than that "as-placed" due to the interface with surrounding layers and the possible movement of fines and small aggregate from the subbase layer. In addition, OGDL doesn't prevent the infiltrated moisture from moving into the subbase, which will reduce its as-built resilient modulus as well as that of the underlining subgrade. When a full depth OGDL is used (e.g., to eliminate entrapment of water in the subbase), a geotextile is placed between the OGDL and subgrade to provide separation and filtration.

Due to the initial expense of drainage and constructbility of the ODGL, many designers choose to use dense graded base for its improved construction and presumed structural support over free-draining base. Unfortunately, this creates a false sense of security because the dense graded base does not drain and, as a result, structural support will probably decrease over time. Due to the low permeability of dense graded base and long drainage path to the edge of the road, drainage in dense graded base is, at best, extremely slow. For example, consider that the permeability of a dense graded base with a very low percentage of fine-grain soil is about 1ft/day and that the length of the drainage path for a two-lane road (lane width of the road draining from the centerline to the edge) is typically 12 ft. An optimistic estimate of the time required to drain a base section that is 1 ft thick and has a slope of 0.02 is 2 days. According to the definitions in Table 1 and 2, the pavement section has "good" to "fair" drainage. If the length of the drainage path is two lanes (i.e., 24 ft), it would take up to a week for the pavement to drain; a condition defined as "fair" drainage (AASHTO, 1993). However, this drainage rate cannot occur unless there is an edgedrain or comparable outlet at the edge of the road. Typically, daylighted base in side ditches will only drain during the first few years before the edge of the road becomes silted up and clogged with vegetation.

Even with edgedrains, this would be an optimistic case because of non-steady flow conditions that exist in partially filled drains. Also, the permeability estimate may be optimistic. Base materials often contain some fraction of fine-grained soil, which significantly reduces their permeability. If the base contains only a few percent fines (i.e., amount passing a No 200 sieve is greater than about 5 percent), the permeability and correspondingly the drainage can easily be an order of magnitude less than the estimated value for this case (AASHTO, 1993)[1]. A month or more will then be estimated for pavement drainage; a condition defined as "poor" to "very poor" in Table 1 and 2. In reality, capillary effects and the absence of a driving head of water often cause dense graded base to act like a sponge at low hydraulic gradients. This results in trapped water in the pavement section and "very poor" drainage (e.g., see Dawson and Hill, 1998). In order to facilitate field compaction and expedite construction, many agencies allow more than 5 percent fines.

It should also be noted that even with the drainable pavement section shown in Figure 2, as previously indicated the subbase material can trap water and cause the modulus and corresponding support of both the subbase and the foundation soil to decrease (Elseifi et al., 2001). Also, the effect of the open-graded drainage layer in the pavement system on its structural capacity has been debated for sometime. It has caused difficulties and in some cases erroneous results in the determination of pavement layers' resilient moduli, back calculated using measured deflections from falling weight deflectometer measurements.

Geocomposite Drainage Layer Solutions

An alternative for improved drainage of water which enters through cracks and joints in the pavement surface is to incorporate a geocomposite drainage layer, which is tied into roadway edgedrains as shown in Figure 4. The geocomposite drain can be placed between the base and the subgrade as shown in figure 4a. This configuration dramatically shortens the drainage path

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[1] Based on hydraulic conductivity tests, AASHTO notes a decrease in permeability from 10 ft per day with 0 percent fines down to 0.07 ft per day with the addition of only 5 percent non-plastic fines and 0.001 ft per day with 10 percent non-plastic fines. An additional order of magnitude decrease was observed with base containing plastic fines.

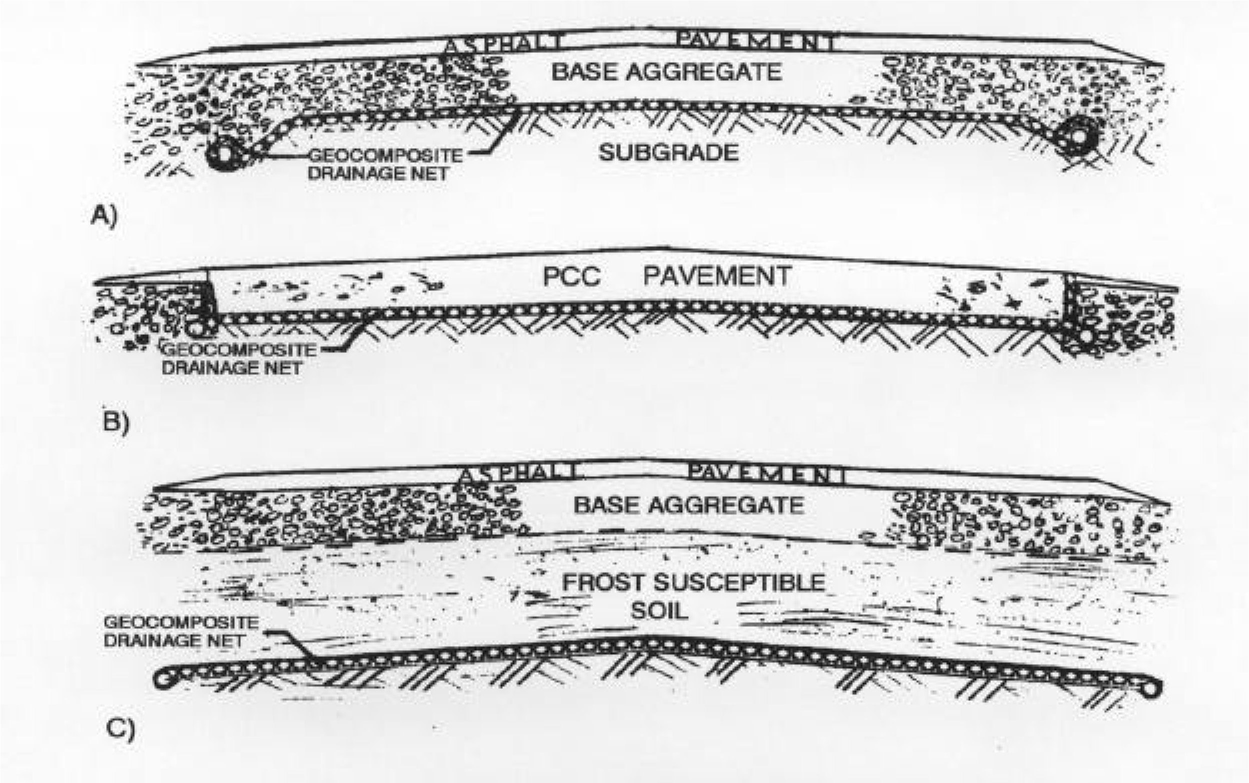


Figure 4. Potential Use of Horizontal Geocomposite Drainage Layers Including:

a) Drainage of Roadway Base or Subbase Aggregate,

b) Drainage of Surface Asphalt or Concrete Pavement, and

c) Drainage of Subgrade to Form a Capillary Break Geocomposite Property Requirement.

for the base with an effective drainage length of just the thickness of the base rather than the width of the road lane(s). The shortened drainage path significantly decreases the time to drain and allows for the use of less select base materials (i.e., those with more fines and lower permeability). Base materials with less than 5% fines should still be used to reduce the potential of water entrapment between the hot-mix asphalt and the base. Placement of the geocomposite at this location may also help alleviate problems with capillary rise by preventing moisture from entering the pavement section during thaw or other thermal events. With this approach, a higher drainage modifier (m) from Table 2 can be used for the pavement base layer that is located above the drainage geocomposite because the time to drain required for the base layer is reduced. Thus, the thickness of these layers may be reduced, the pavement section can be designed at a higher structural capacity or the pavement section can be anticipated to have a longer service life.

In addition to improved drainage and corresponding structural support, placement of the geocomposite at the subgrade prevents subgrade fines from entering the base (i.e., separation). Separation combined with drainage will allow for stabilization and improved foundation support for pavements constructed over soft foundation soils (i.e., CBR < 3). The improved drainage provided by the geocomposite will also allow soft foundation soils to consolidate and improve over time.

Also with the geocomposite drainage layer placed directly beneath the base, to a limited extent the base course aggregate can penetrate into the upper portion of the net. Thus, the geocomposite drainage net also has the potential to restrain the lateral movement of the base aggregate, and in this manner act like geogrid reinforcement. Considering that the tensile strength and stiffness of the geocomposites are often greater than that of many geogrids used in base reinforcement, this restraining effect should result in an improved base support condition. Indeed, in a side-by-side trial study of a road constructed over soft subgrade (CBR<3), the Tendrain™ geocomposite drainage net was found to provide equal performance to a geogrid during construction (Hayden et al., 1999). For more information on reinforcement and stabilization design, see "Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Pavement Structures," (GMA, 2000) and "Design of Flexible Pavements with Tenax Geogrids," (Tenax, 2000).

As the pavement ages and cracks are formed, a majority of the precipitation hitting the pavement surface will enter the pavement section. Thus, it may be advisable to install the geocomposite directly beneath the pavement surface as a substitution for drainable base (see Figure 4b). Here, the geocomposite can drain infiltration water before it enters the underlying base/subbase layers. It is even possible to incorporate a membrane on the bottom side of the composite as a moisture barrier to further and prevent water from infiltrating into the base (Elseifi et al., 2001). For rigid pavement systems, this configuration allows the pavement to be designed using a higher drainage coefficient C_d. A side benefit of this configuration may be more uniform concrete hydration (research is ongoing to determine the extent of this benefit). For both rigid and flexible pavement systems, this configuration is anticipated to extend the design life of the pavement section.

The last application shown in Figure 4c, is a special drainage case for northern climates to help mitigate frost heave problems. For deep frost penetration, the geocomposite net could be placed at a lower depth within the subgrade as a capillary break, replacing a non frost susceptible granular subbase layer often required to extend down to the frost depth. Frost-susceptible backfill could be placed directly over the geocomposite to the pavement base grade level. In this case, the system could be tied into drainage outlets to maintain the groundwater table at or below that depth. This may potentially eliminate the development of ice lenses, which in turn could result in the removal of posting traffic weight restrictions during the spring thaw in cold regions.

Design Requirements for Drainage Geocomposites.

In order to perform in this application, the geocomposite must have the stiffness required to withstand compaction and support traffic without experiencing significant damage due to compaction and deformation under cyclic traffic loading. At the same time, the geocomposite must have the flow capacity required to rapidly drain the pavement section and prevent saturation of the base. As discussed in the previous section, in order to provide optimum drainage, the outflow capacity of the drainage layer must be sufficient to drain the pavement section within a few hours of a moisture event (see Table 1). A conventional 4-inch-thick open-graded base layer has proven adequate to meet this drainage requirement for most conditions (FHWA, 1992) with some states successfully using 3-inch. As shown in Figure 3, this layer has a permeability of at least 1000 ft/day and preferably 2000 to 3000 ft/day. Therefore, a 4-inch-thick free-draining base layer has a transmissivity (i.e., permeability multiplied by the thickness) of about 300 to 1000 ft^2/day. For a typical roadway gradient of 0.02 (for a 2 percent grade), the open-graded base layer has a flow capacity between 6 to 20 ft^3/day per ft length of road.

To provide equivalent drainage, the transmissivity of a geocomposite needs to be increased by an equivalency factor E of approximately 3 over that of the 4-inch thick free draining layer (as determined using the method by Giroud et al., 2000). This increase is required to account for unconfined partially filled flow within the drainage layer. The required transmissivity for an equivalent geocomposite drain is therefore about 900 – 3000 ft^2 per day.

The geocomposite must have a high crush resistance to withstand construction loading and compaction stresses, typically ranging from 5000 to 10,000 psf beneath the base course layer to as high as 30,000 psf beneath the asphalt. Although many geocomposite drainage materials have a crush resistance greater than the stresses anticipated below the base, most materials would deform significantly and only some geonet composites would withstand the high stress levels anticipated beneath the pavement. With regard to traffic loads and tolerable deformation, the anticipated stress level on the geocomposite in a high use roadway is typically in the range of 500 to 5,000 psf depending on the location of the geocomposite within the pavement section (based on Kenlayer computer analysis from Huang, 1993. While this is substantially less than construction stress levels, dynamic traffic loading could induce significant creep deformation and potential geocomposite collapse. A factor of safety of 5 between the anticipated load and geocomposite crush resistance as determined by quick load tests is recommended by the FHWA to resist creep in geocomposite drains (Holtz et al., 1998). Considering the high cost of pavement replacement, it is prudent to consider only high modulus, high compressive resistance materials such as geonet drainage composites.

Unfortunately, at the required gradient and load levels, most commercially available geonet drainage composites do not have the drainage capacity of an open-graded base. In addition, to provide a capillary break, it is critical that an air void exists within the geocomposite. The geotextile intrusion experienced by typical, relatively thin geonets is often sufficient to allow the geotextile filters on opposite sides of the geonet to touch, thus eliminating the air void. A compromise of the capillary break is especially a concern for the lower drainage layer, which in many cases, is placed between soft clayey soils.

A high-flow geonet drainage composite (Tendrain™ 100-2 by the Tenax Corporation) has recently been introduced that provides a flow capacity that is equivalent to an open graded gravel drainage layer. Open flow is maintained by a high-density polyethylene core that does not allow the geotextile layers to touch. This new geocomposite consists of three extruded net layers to form a tri-planar geonet inner core with a needle punched nonwoven geotextile laminated to either side. The tri-planar structure provides the geocomposite with high compression resistance and flow capacity. It also does not allow geotextile intrusion into the center portion of the net, and thereby provides the void required for capillary bread applications.

The tri-planar geonet drainage composite has a transmissivity of 4500 ft^2/day under a normal load of 15,000 psf and a gradient of 0.02 based on ASTM Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products (D 4716). This would indicate a maximum flow capacity of 90 ft^3/day/ft of length of road. However, considering an estimated equivalency factor of 3 for comparison with a 4-inch drainage layer unconfined flow, the equivalent transmissivity of the drainage composite would be 1500 ft^2/day, which exceeds that of a 4-inch-thick layer of free-draining base material. The equivalent transmissivity value results in a corresponding flow capacity of 30 ft^3/day/ft of length of road. In addition, long term compressive creep tests on the tri-planar geonet core indicate that the material retains over 60 percent thickness after 10,000 hours under sustained normal load of 24,000 psf, providing assurance of long term flow.

To further evaluate the performance of this geocomposite in a roadway system, cyclic loading tests were performed at the University of Illinois, Advanced Transportation Research and Engineering Laboratory. Cyclic fatigue testing was performed on a concrete beam supported by the geocomposite overlying a clay subgrade and compared to results from a beam supported by the subgrade alone. The tests were performed at stress ratios (i.e., load versus ultimate beam strength) of 0.76 and 0.83. The test setup along with representative results at the higher stress level is shown in Figure 5. The results showed insignificant additional deformation in the concrete when the geocomposite was used. The test at the 0.83 stress ratio showed some improvement in fatigue life (visually cracked beam) and the test at 0.76 stress ratio showed some reduction in fatigue life.

Although the test results were inconclusive in relation to fatigue life, the geocomposite improved post-cracking behavior of the beam at both stress levels (i.e., minimized continued widening of the crack after break). This improvement in beam performance was attributed to a betterment in the uniformity of support under the beam after cracking and/or frictional improvement at the bottom of the beam, which reduced the post-cracking deflection.

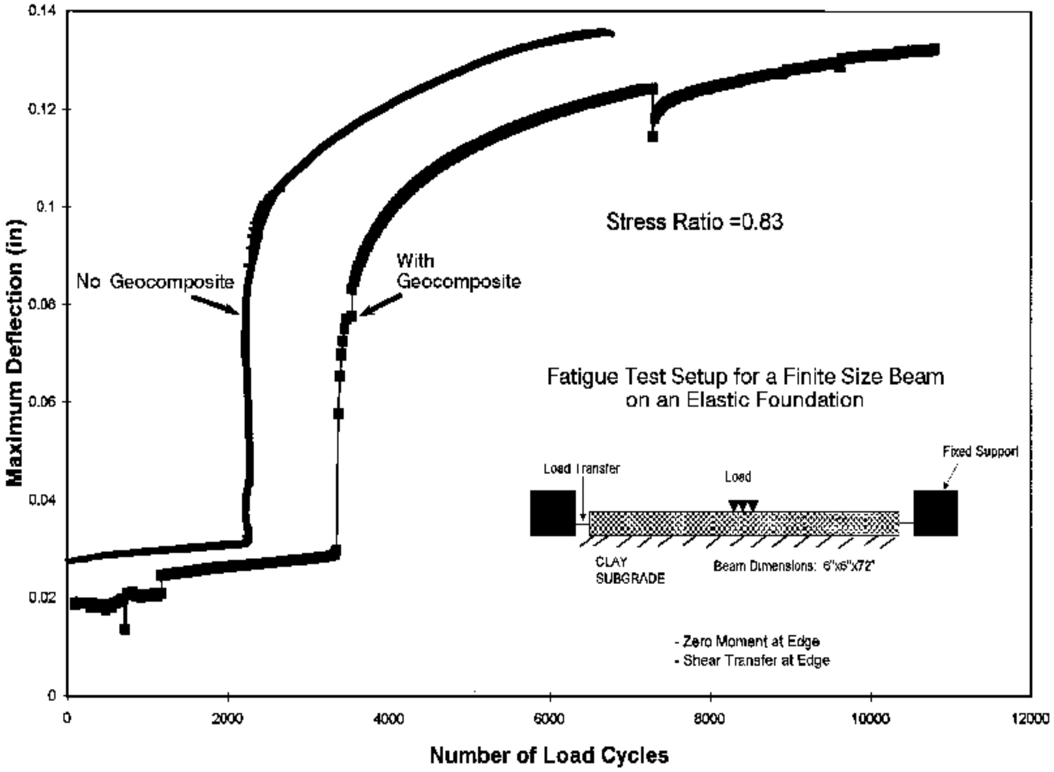


Figure 5. Fatigue Test Setup and Results the University of Illinois, Advanced Transportation Research and Engineering Laboratory

Drainage Requirements for Permeable Layer

Much of the following section is taken from the FHWA Demonstration Project 87: Drainable Pavement Systems, Participant Notebook.

Basically there are two approaches to the hydraulic design of a permeable layer:

1. Time-to-drain
2. Steady-state flow.

The time-to-drain approach was previously discussed under the Design for Drainage Section and simply means the time for 50 percent of the free water in a saturated pavement section to drain following any moisture event. In the steady-state flow approach, uniform flow conditions are assumed and the permeable layer is designed to drain the water that infiltrates the pavement surface. The time-to-drain approach will be the basis for design in this manual as it is currently the procedure recommended by the FHWA and is consistent with AASHTO's use of drainage coefficients (m or C_d) for pavement design. Elements of steady state flow will be used to determine outlet spacing. (For additional discussion of steady state flow methods see FHWA, 1992.)

The time-to-drain approach is based on the flow of water into the pavement section until it becomes saturated (base or geosynthetic drainage layer plus the material above the drainage layer). Excess precipitation will not enter the pavement section after it is saturated; this water will simply run off the pavement surface. After the rainfall event, the drainage layer will drain to the edgedrain system. Engineers must design the permeable layer to drain relatively quickly to prevent the pavement from being damaged.

There are two design approaches for determining the time to drain:

- AASHTO Percent Drained - 50 percent
- 85-Percent Saturation

Some engineers suggest that the 85 percent saturation level is a better threshold for pavement damage due to moisture. However, the two methods will produce identical results when the water loss of the drainage layer is 100 percent; that is when the effective porosity of a material (i.e., the ratio of the volume of water that can drain from a material to the total volume) is equal to its porosity (i.e., the volume of the voids divided by the total volume). For permeable bases and properly designed geocomposite drainage layers, the water loss will be quite high, in the range of 90 percent or more. Therefore, for practical purposes, the results produced by both methods will be quite close and only the 50 percent time to drain approach will be reviewed in this manual.

A time to drain 50 percent of the drainable water in 1 hour is recommended as a criterion for the highest class roads with the greatest amount of traffic (FHWA, 1992). For most other high use roadways, a time to drain 50 percent of the drainable water in 2 hours is recommended. For secondary roads, a minimum target value of 1 day is recommended (US Army Corps of Engineers). Remember, in all cases the goal of drainage is to remove all drainable water as quickly as possible.

The time to drain is determined by the following equation:

$$t = T \times m \times 24 \qquad \textit{Eq. 2}$$

where, t = time to drain in hours

T = Time Factor

m = "m" factor

A simplified design chart for determining the time factor T_{50} is provided in Figure 6. This chart was developed for one degree of drainage based on a 50 percent drained condition and is adequate for most designs. For expanded charts to cover additional degrees of drainage and desired percent drained see FHWA, 1992.

The time factor is based on the geometry of the base course or geocomposite drain. The geometry includes: the resultant slope (S_R) and length (L_R); the thickness of the drainage layer (H), which is the length the water must travel within a given layer; and, the percent drained (U), (i.e., 50%). First, the slope factor (S_l) must be calculated:

$$S_l = \frac{L_R S_R}{H} \qquad \textit{Eq. 3}$$

Figure 6 is then entered with the S_l and the resulting T_{50} is determined.

The "m" factor is determined by the equation:

$$m = \frac{N_o L_R^{\,2}}{kH} = \frac{N_o L_R^{\,2}}{y} \qquad \textit{Eq. 4}$$

where, N_o = the effective porosity of the drainage layer

ψ = the transmissivity of the drainage layer

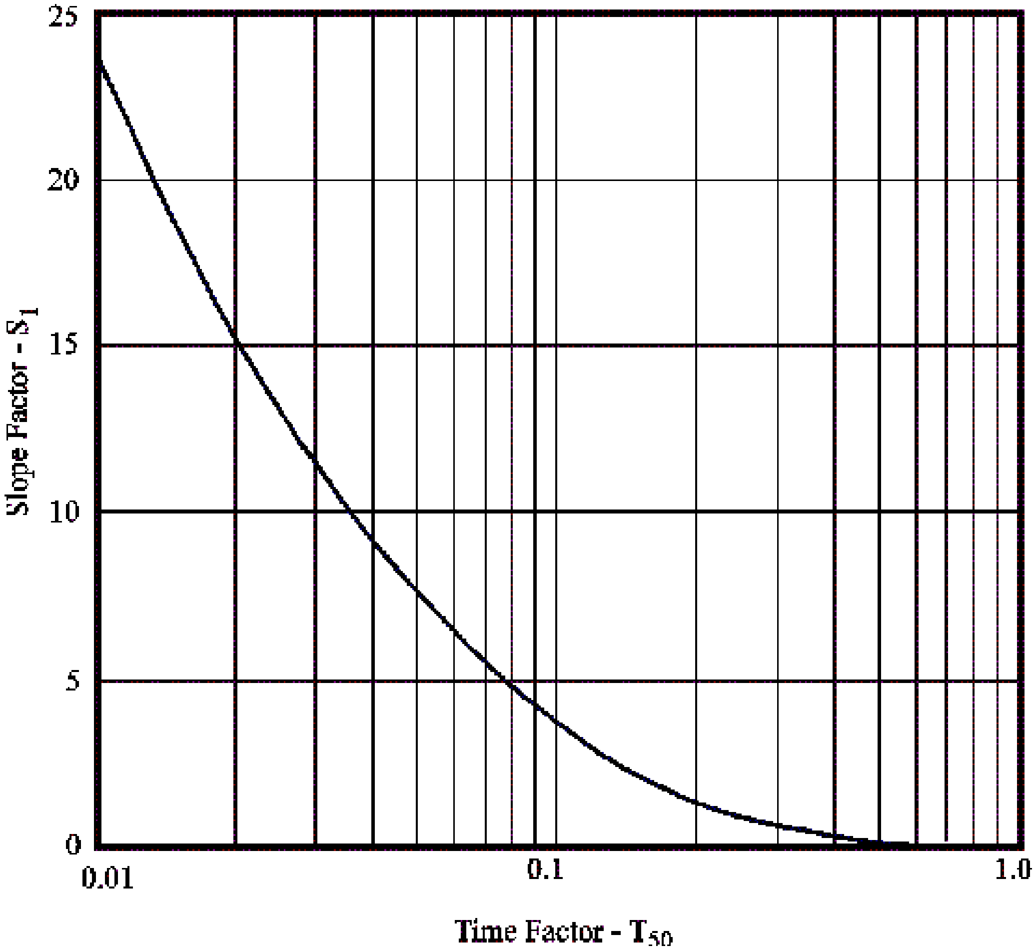


Figure 6. Time Factor for 50 Percent Drainage (after FHWA, 1992)

The intrinsic factors that represent the drainage capabilities of drainage layer base are represented by the effective porosity (N_o) and the coefficient of permeability (k) or if H is known, the transmissivity of the drainage layer. As previously indicated, the effective porosity is the ratio of the volume of water that drains under gravity from the material to the total volume of the material. It is a measure of the amount of water that can be drained from a material. Determination of these characteristics for aggregate drainage layers are covered in detail in FHWA, 1992. For geocomposite drainage layers, water can completely drain from the void space under gravity. The value can be easily determined by saturating a sample of material and measuring the amount of water that drains. The effective porosity is simply the ratio of the volume of drained water to the total volume of the sample. The effective porosity of Tendrain™ 100-2 has been measured at 0.69 and is only slightly lower than its porosity of 0.74.

Geocomposite Drainage Effectiveness

The time to drain for the geocomposite drainage system will be very brief but will vary with the application and the slope and width of the pavement section. A slope of 2 percent is recommended. For the case where the geocomposite drainage layer is placed directly beneath the pavement (Figure 1b), infiltration water coming through the pavement is completely drained by the geocomposite drainage layer and the time to drain is simply a function of the drainage rate within the geocomposite layer. For this case the time to drain equation can be used directly as demonstrated in the following:

Example 1.

The geocomposite is placed directly beneath the pavement surface of a 24-ft-wide pavement section at a 2 percent grade (i.e., a two lane road or one half of a crowned four lane road). The time to drain would be calculated as follows:

Given:	Roadway Geometry	
	Resultant slope (S_R)	0.02 ft/ft
	Resultant length (L_R)	24 ft
	Thickness of Tendrain 100-2 (H)	0.02 ft
	Effective porosity (N_o)	0.69
	Transmissivity	4500 ft^2/day

Find: Time to drain

Solution: First the slope factor is calculated:

$$S_l = \frac{L_R\,S_R}{H} = \frac{24\,ft \times 0.02}{0.02\,ft} = 24$$

Entering Figure 6 with the slope factor and a time factor (T_{50}) of 0.01 is determined. Calculate the “m” factor:

$$m = \frac{N_o\,L_R^{\,2}}{y} = \frac{0.69 \times \left(24\,ft\right)^2}{4500\,ft^2\,/\,day} = 0.088\,day$$

Now calculate the time to drain:

$$t = T_{50} \times m \times 24 = 0.01 \times 0.088\,days \times 24\,hrs\,/\,day = 0.02\,hrs$$

Example 2.

For the case where the geocomposite drainage layer will be placed beneath the base and/or the subbase layer, the time to drain will depend both on the drainage rate of the base layers into the geocomposite drain plus the time to drain for the geocomposite drainage layer. The time to drain for the base layer will of course depend on its thickness and permeability. For vertical flow the resultant slope (S_R) can be conservatively assumed to be 1 and the length (L_R) is equal to the thickness of the layer. Since the infiltration water over the entire pavement width must flow into the drain, the value H may be taken as a unit width along the pavement. The following provides an example for a 12 inch thick base section overlying the Tendrain™ drainage layer in a 24 ft wide pavement section at a 2 percent slope to illustrate the calculations.

Given: Roadway Geometry	
Thickness of Base	1 ft
Resultant slope for Base (S_R)	1 ft/ft
Resultant length (L_R)	1 ft
Thickness (H)	1 ft
Effective porosity (N_o)	0.15
Permeability of Base	1 ft/day

Find: Time to drain

Solution: First the slope factor is calculated:

$$S_l = \frac{L_R\, S_R}{H} = \frac{1ft \times 1}{1ft} = 1$$

Entering Figure 6 with the slope factor and extrapolating a time factor (T50) of 0.24 is determined.

Calculate the "m" factor:

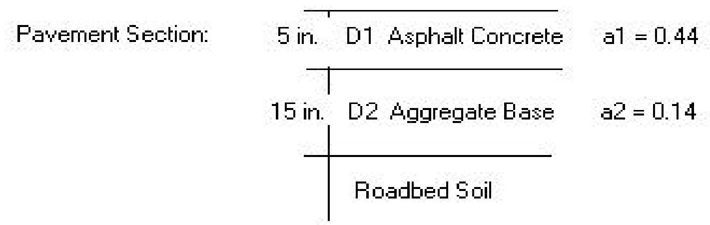
$$m = \frac{N_o\, L_R^{\,2}}{kH} = \frac{0.15 \times (1ft)^2}{1ft/day \times 1ft} = 0.15 day$$

Now calculate the time to drain:

$$t = T_{50} \times m \times 24 = 0.24 \times 0.15 days \times 24 hrs/day = 0.86 hrs$$

Adding this time to the time to drain for the Tendrain™ indicates that less than 1 hour would be required to achieve 50 percent drainage, thus providing excellent drainage for a low-permeable, dense-graded base. Table 3 provides a comparison of the two scenarios using the Tendrain™ geocomposite drain to using dense graded base alone. The improvement afforded by Tendrain™ is considerable and will provide significant and predictable cost-benefit in terms of road performance as demonstrated in the next section.

Table 3. Comparison of drainage performance with and without Tendrain geocomposite drainage net.



	Tendrain only	Base drainage only	Tendrain under base
Resultant slope	0.02	0.02	1
Resultant length	24 feet	24	1
Thickness	0.02	1	1
Effective porosity	0.69	0.15	0.15
Transmissivity	4500	1	1
Results			
Slope factor:	24	0.48	1
M:	0.088	86	0.15
Time to drain (hours):	0.02	840	0.86

Cost-Benefit

By achieving excellent drainage in the roadway section through the use of Tendrain™, cost savings can be quantified by calculating the increase in structural number, an allowable reduction in the pavement section thickness or an increase in the pavement's design life. The actual savings will depend on many factors such as the type of road (secondary or primary), the design of the structural section, the subgrade conditions and regional rainfall. The cost-benefit can be directly evaluated by using the standard AASHTO structural number equation and assigning appropriate m-values for the drainage condition. This analysis is best performed using a computer program based on the AASHTO design procedures such as *Darwin*. Table 4 illustrates the potential savings for a common high use roadway section consisting of 5 inches of hot-mix asphalt and 15 inches of base with a design structural number of 4.3 assuming good drainage (i.e., m = 1).

Table 4. Typical savings from using Tendrain™

Quality of Drainage	m	Structural Number (maintaining section)	Reduction in Base (maintaining asphalt thickness and SN = 4.3)	Reduction in Asphalt (maintaining base thickness and SN = 4.3)	Estimated Performance Period (maintaining section)*
Excellent (by using Tendrain)	1.3	4.93	- 3.5 in.	-1.43 in.	38 yrs
Good Standard Design	1.0	4.3	0	0	20 yrs
Poor – Reality for most designs	0.7	3.67	+6.5 in.	+1.43 in.	8 yrs
Total savings	-	-	10 in.	2.86 in.	Up to 30 yrs

* Base on 20-year performance period and a 3 percent growth

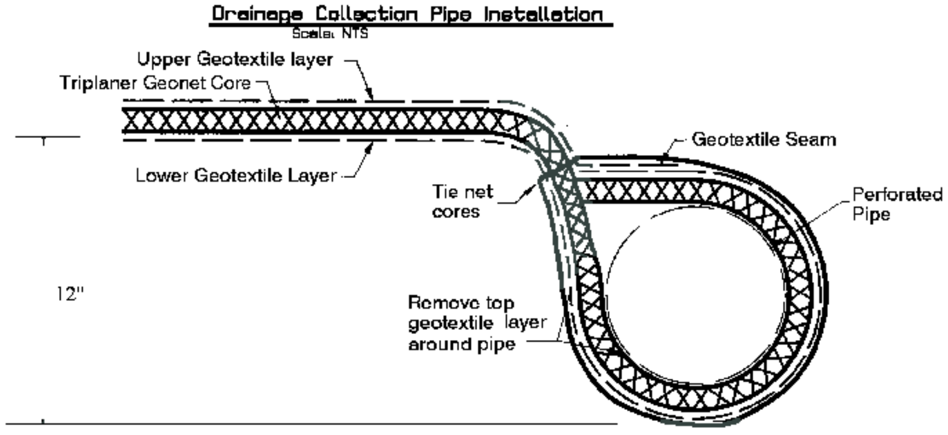


Figure 7. Edgedrain construction

Edgedrain and Outlet Requirements

The edgedrain used to collect the water from the Tendrain™ drainage layer is a relatively simple design as shown in Figure 7. It consists of wrapping a 4- to 6-inch diameter slotted pipe with the Tendrain™ and extending it into a trench beneath the shoulder at the edge of the road. The FHWA recommends a minimum pipe diameter of 4 inches and an outlet spacing of 250 ft to facilitate cleaning and video inspection. The adequacy of these requirements can be assessed by evaluating the anticipated infiltration rate or, more conservatively, from the maximum flow capacity of the Tendrain™ drainage layer.

With the first method, the estimated discharge rate from Tendrain™ at a 2 percent slope is 30 ft^3/day/ft of road as determined in the previous section on Design Requirements For Drainage Geocomposites. Thus at an outlet spacing of 250 ft, the quantity of flow at the discharge (Q) of the edgedrain system would be 7500 ft^3/day.

The capacity of a circular pipe flowing full flowing full can be determined by Manning's equation:

$$Q = \frac{53.01}{n} D^{8/3} S^{1/2} \qquad Eq. 5$$

where, Q = Pipe capacity, cu ft/day
D = Pipe diameter, in.
S = Slope, ft/ft
n = Manning's roughness coefficient
= 0.012 for smooth pipe
= 0.024 for corrugated pipe

Thus, for a 4-inch smooth wall pipe at a 1 percent grade, the flow capacity is 17800 cu ft/day, which is adequate to handle the maximum quantity of flow anticipated for the edge drain system.

In the infiltration method, a design rainfall and an infiltration ratio are selected. Pavement infiltration is determined by the equation:

$$q_i = C \times R \times 1/12 \text{ (ft/in)} \times 24 \text{ (hr/day)} \times 1 \text{ ft} \times 1 \text{ ft)} \qquad Eq. 6$$

which can be simplified to:

$$q_i = 2\, C\, R \qquad Eq. 6a$$

where, q_i = Pavement infiltration, $ft^3/day/ft^2$ of pavement
C = Infiltration ratio
R = Rainfall rate, in/hr

The infiltration ratio C represents the portion of rainfall that enters the pavement through joints and cracks. The following design guidance for selecting the infiltration coefficient is suggested (FHWA, 1992):

Asphalt concrete pavements	0.33 to 0.50
Portland cement concrete pavements	0.50 to 0.67

To simplify the analysis and provide an adequate design, FHWA suggest using a value of 0.5. The design storm whose frequency and duration will provide an adequate design must be selected. A design storm of 2-year frequency, 1- hour duration is suggested. Figure 8 provides a map of generalized rainfall intensity.

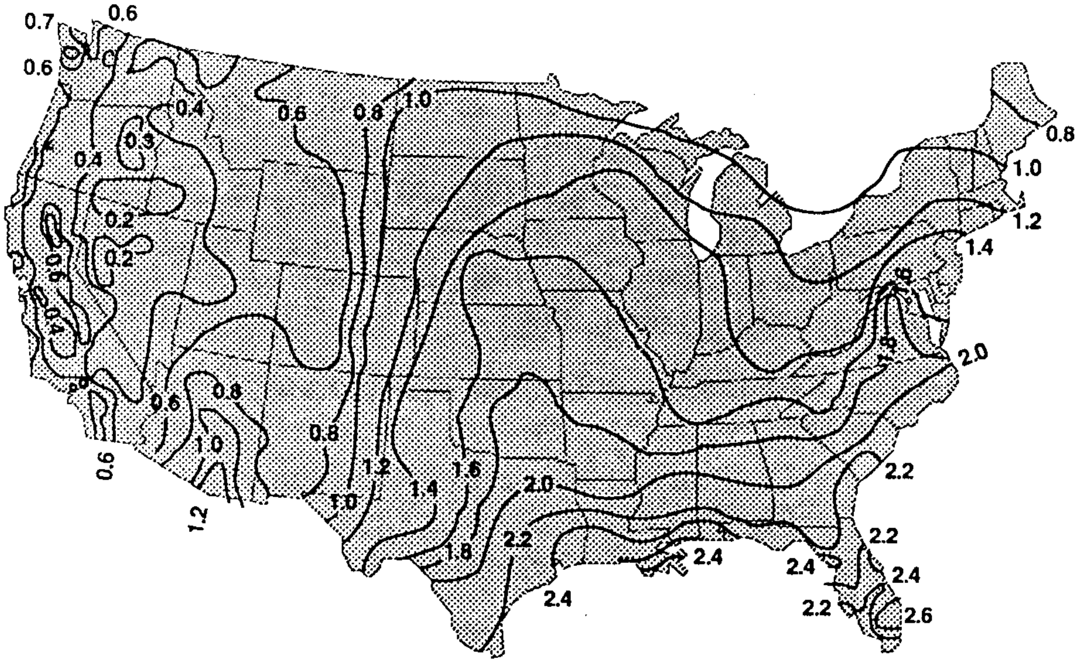


Figure 8. Rainfall Intensity for a 2-year, 1-hour Storm Event (FHWA, 1992)

The analysis is then performed by substituting into the above equation for the specific region of the country. The drainage layer discharge rate q_d can then be determined by multiplying the infiltration rate by the resultant length of the pavement section L_R as follows:

$$q_d = q_i \; L_R \qquad \text{Eq. 7}$$

This discharge rate can then be compared to the flow capacity of the Tendrain™ and the lower value of the two used to evaluate the outlet spacing and pipe size.

Geotextile Filter Design

One of the more important aspects of geocomposite drainage design is the selection of appropriate geotextiles to allow unimpeded flow of water into the tri-planar geonet over the life of the system. The geotextile must prevent soil from washing into the system without clogging over time. The FHWA presents three basic principles for geotextile design and selection:

1. If the larger pores in the geotextile filter are smaller than the largest particles of soil, these particles will not pass the filter. As with graded granular filters, the larger particles of soil form a filter bridge on the geotextile, which in turn filters the smaller particles of the soil. Thus the soil is retained and particle movement and piping is prevented.

2. If the smaller openings in the geotextile are sufficiently large so that the smaller particles of soil are able to pass through the filter, then the geotextile will not clog.

3. A large number of opening should be present in the geotextile so that proper flow can be maintained even if some of the openings later become clogged.

The geotextile filtration characteristics must be checked for compatibility with the gradation and permeability of both the base/subbase layer directly above the Tendrain™ and the subgrade. Needle punched nonwoven geotextiles are the most widely used for geocomposite drainage nets and the requirements for proper performance can appropriately selected by using the following design steps.

Step 1. Determine the gradation of the material to be filtered. The filtered material is directly above and below the geocomposite drainage layer. Determine D_{85}, D_{15} and percent finer than a No. 200 sieve.

Step 2. Determine the permeability of the base or subbase $k_{base/subbase}$, whichever is located directly above the geocomposite drainage layer. (For placement directly beneath the hot-mix or PCC pavement applications, the default permittivity requirement will be used.

Step 3. Apply design criteria to determine apparent open size (AOS), permeability (k) and permittivity (ψ) requirements for the geotextile (after Holtz et al., 1998)

$AOS \leq D_{85\ base/subbase}$ (For the upper geotextile)

$AOS \leq 1.8\ D_{85\ subgrade}$ (For the lower geotextile when placed on the subgrade)*

$k_{geotextile} > k_{base/subbase}$

$\psi \geq 0.1\ sec^{-1}$

* For noncohesive silts and other highly pumping susceptible soils, a filter bridge may not develop, especially considering the potential for dynamic, pulsating flow. A conservative (smaller) AOS # is advised and laboratory filtration tests are recommended.

Step 4. In order to perform effectively, the geotextile must also survive the installation process. AASHTO M288 (1997) provides the criteria for nonwoven geotextile strength required to survive construction of roads as shown in Table 5.

Use Class 2 where a moderate level of survivability is required for subgrade CBR > 3 and at least 150 mm of base/subbase and normal weight construction equipment is anticipated. Class 1 geotextiles are recommended for CBR < 3 and when heavy construction equipment is anticipated. In either case, a minimum of 6 inches of base/subbase should be maintained between the wheel and the geotextile at all times.

Table 5. Geotextile Survivability Requirements: AASHTO M 288-96

	Test Method	Units	Geotextile Class for Nonwoven Geotextiles (i.e., $\geq$ 50% Elongation)	
			Class 1	Class 2
Grab Strength	ASTM D 4632	lb	203	158
Seam Strength	ASTM D 4632	lb	182	142
Tear Strength	ASTM D 4533	lb	79	57
Puncture Strength	ASTM D 4833	lb	79	57
Burst Strength	ASTM D 3786	psi	247	200

Note: Elongation measured in accordance with ASTM D 4632

Specifications

The following provides generic specifications for the geocomposite subsurface drainage layer.

GEOCOMPOSITE SUBSURFACE DRAINAGE LAYER

A. DESCRIPTION

1. General:

   The Contractor shall furnish all labor, material, and equipment to complete installation of GEOCOMPOSITE SUBSURFACE DRAINAGE LAYER (GSDL) including all necessary and incidental items, in accordance with the Contract Drawings and these Specifications.

2. Reference Standards:

   The latest revision of the following standards of the American Society of Testing and Materials (ASTM) and American Association of State Transportation and Highway Officials (AASHTO) are hereby made a part of these specifications.

   AASHTO (1996) Standard Specification for Geotextiles, Designation :M288-96, American Association of State Transportation and Highway Officials, Washington, D.C.

   ASTM D 1238, Standard Test Method for Flow Rates of Thermoplastics by Extrusion Process Plastometer.

   ASTM D 792, Standard Test Method for Density and Specific Gravity (Relative) Density of Plastics by Displacement.

   ASTM D4716, Standard Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using Constant Head.

   ASTM D 4218, Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle Furnace Technique

   ASTM D 3786, Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabric – Diaphragm Bursting Strength Tester Method.

   ASTM D 4491, Standard Test Method for Water Permeability of Geotextiles by the Permitivity Method.

ASTM D 4533, Standard Test Method for Trapezoid Tearing Strength of Geotextiles.

ASTM D 4632, Standard Test Method for Breaking Load and Elongation of Geotextiles (Grab Method).

ASTM D 4751, Standard Test Method for Determining Apparent Opening Size of a Geotextile.

ASTM D4833, Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

ASTM D 904, Standard Test Methods for Comparison of Bond Strength or Ply Adhesion of Similar Laminates Made from Flexible Materials

ASTM D 5199, Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

ASTM D 4595, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method.

ASTM D 1621, Standard Test Method for Compressive Properties of Rigid Cellular Plastics.

3. Quality Assurance:

Quality Assurance during installation of GSDL will be provided by the Owner as described in the accompanying Project CQA Manual.

B. MATERIALS

1. General:

The materials supplied under these Specifications shall be polyethylene which is clean and free of any foreign contaminants. Regrind material which consists of edge trimmings and other scraps may be used to manufacture the geonet; however, post consumer recycled materials shall not be used.

Labels on each roll of GSDL shall identify the length, width, lot and roll numbers, and name of Manufacturer.

2. The Geonet shall be manufactured by extruding three sets of polyethylene strands to form a tri-planar drainage net structure consisting of a thick vertical rib with diagonally placed top and bottom ribs.

3. A Geotextile shall be heat bonded to both sides of the Geonet. Heat bonding shall be performed by the Manufacturer prior to shipping to the site. The

geotextile shall be a nonwoven needle punched synthetic fabric meeting the property requirements of Table 1.

4. The Geonet shall contain UV inhibitors to prevent ultraviolet light degradation.

5. Physical properties of the GSDL shall be as shown in Table 1 of this section.

C. SUBMITTALS

The Contractor shall submit the following to the Engineer:

1. Mill Certificate and Sample: Prior to shipping to the site, the Contractor shall submit one copy of a mill certificate or affidavit signed by a legally authorized official of the Manufacturer for the GSDL attesting that the GSDL meets the physical and manufacturing requirements stated in these Specifications. The Contractor shall also submit a sample (8" x 11") of the GSDL to be used. The sample shall be labeled with the product name and be accompanied by the Manufacturer's specifications.

2. Shipping, Handling, and Storage Instructions: The Manufacturer's plan for shipping, handling, and storage shall be submitted for review.

3. Quality Control Certificates: For GSDL delivered to the site, quality control certificates, signed by the Manufacturer's quality assurance manager shall be provided for every roll of GSDL. Each certification shall have the roll identification number(s), test methods, frequency, and test results. At a minimum, the test results and frequency of testing shall be as shown in Table 2 of this section.

4. Furnish copies of delivery tickets or other approved receipts as evidence for materials received that will be incorporated into the construction.

D. CONSTRUCTION

1. Shipping, Handling, and Storage:

   All GSDL shall be shipped, handled, and stored in strict accordance with the Manufacturer's recommendations.

2. Failing CQA Material Control Tests:

   GSDL that is rejected upon testing shall be removed from the project site and replaced at Contractor's cost. Sampling and quality assurance testing of GSDL supplied as replacement for rejected material shall be performed by the CQA Engineer at Contractor's cost.

3. Installation:

Handling and Placement

a. The Contractor and the Installer shall handle all geocomposite in such a manner as to insure it is not damaged in any way.

b. Geocomposite shall be rejected if it has defects including holes, deterioration, or damage incurred during storage or transportation.

c. The Installer shall place the geocomposite in the proper manner at the elevations and alignment as shown in the construction drawings and as directed by the Engineer.

d. In the presence of wind, all geonet shall be weighted with sandbags or the equivalent. Such sandbags shall be placed during placement and shall remain until replaced with cover material.

e. If necessary, the geocomposite shall be positioned by hand after being unrolled to minimize wrinkles.

Fill Material Requirements *{When Installed Between The Base And Subgrade}*

a. Fill material shall be back dumped onto previously placed fill from trucks or front end loaders riding on top of the previously placed fill. At no time will equipment be allowed to drive directly across the geocomposite. The specified fill material shall be placed and spread utilizing vehicles with a low ground pressure.

b. Fill material shall be bladed onto the geocomposite in such a manner that fill rolls onto the geocomposite (e.g. by gradual raising bulldozer blade while moving forward).

c. Construction equipment shall not travel over the geocomposite without a minimum compacted fill thickness of 6 inches covering the geocomposite.

d. Compaction shall be performed with a smooth drum vibratory roller to the required density.

Note: For construction over soft subgrade (CBR<3), the first lift above the geocomposite shall be compacted with a bulldozer initially and then with a smooth-drum roller (with the vibrator turned off) to obtain the minimum required compaction density minus 5%. Subsequent lifts shall be compacted to the required density with a smooth drum vibratory roller. Equipment creating ruts in initial lift shall not be allowed. This may require partially loaded dump trucks, lightweight bulldozers, etc.

Seams and Overlaps

a. The geocomposite shall be oriented such that the roll length runs perpendicular to the roadway alignment.

b. Joints of the drainage geocomposites shall be butted together and the geotextile of adjacent geonet core rolls overlapped along the roll, see Figure A.

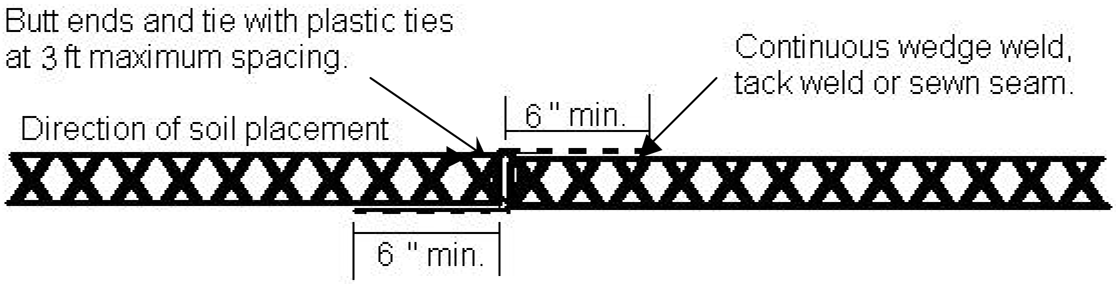


Figure A. Butt Connection and Overlaps

c. Adjacent geocomposite rolls shall be joined together by tying the geonet cores with white or yellow plastic fasteners or polymeric braid. The ties shall be spaced every 3 feet along the roll length.

d. Overlapping geotextiles must be shingled in a manner consistent with the direction of the fill placement. For geocomposites placed between base/subbase and the subgrade, continuous wedge welding, tack welding or sewing shall be used to secure the upper layer of overlapped geotextile. For sewing, a minimum length stitch “flat” or “prayer’ seam is recommended.

Note: For placement below hot-mix asphalt or PCC pavement, continuous wedge welding, or tack welding shall be used to secure the upper layer of overlapped geotextile.

Storage Requirements

a. The geocomposite rolls shall be stored in a clean, dry environment out of the pathway of construction equipment.

b. The rolls shall be stored off the ground and out of direct sunlight, and shall be protected from excessive heat, cold, mud, dirt, and dust.

c. The contractor shall be responsible for the storage of the geocomposite material at the site. The contractor shall be liable for all damages to the materials incurred prior to final acceptance of the liner system by the Engineer.

Repair Requirements

a. Prior to covering the deployed geocomposite, each roll shall be inspected for damage resulting from construction.

b. Any rips, tears or damaged areas on the deployed geocomposite shall be removed and patched by placing a patch extending 2 feet beyond the edges of the damaged areas. The patch shall be secured in the original geonet tying every 6 inches with approved tying devices. If the hole or tear width across the roll is more than 50% the width of the roll, the damaged area shall be cut out and the two portions of the geonet shall be joined in accordance with the section 3c of the construction requirements.

c. If damage occurs to the geocomposite during shipping, or installation, the damaged area(s) shall be cut out and a repair section of geocomposite shall be installed at the contractor’s expense. The repair section shall extend 12 inches beyond the limits of the removal and shall be securely tied every 6 inches.

E. MEASUREMENT AND PAYMENT

All work required for Geonet Drainage Media shall be included for payment in the Contractor's Lump Sum Price for Item **X.X**, wherein no measurement will be made.

TABLE 1: REQUIRED GEOCOMPOSITE SUBSURFACE DRAINAGE LAYER

See Appendix A

TABLE 2: REQUIRED MANUFACTURER’S QUALITY CONTROL TEST DATA

PROPERTY	TEST METHOD	UNITS	FREQUENCY
Geonet Tests			
DENSITY	ASTM D1505	g/cm^3	50,000 ft^2
MELT FLOW INDEX	ASTM D1238	g/10 min	50,000 ft^2
THICKNESS	ASTM D5199	mm	50,000 ft^2
CARBON BLACK	ASTM D4218	%	50,000 ft^2
TENSILE STRENGTH-MD	ASTM D4595	lbs/ft	50,000 ft^2
Geocomposite Tests			
PLY ADHESION	ASTM D904	lbs/in	100,000 ft^2
TRANSMISSIVITY-MD	ASTM D4716	m^2/sec	200,000 ft^2

END OF SECTION

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APPENDIX A Tendrain™ Geonet Drainage Composite Properties

Tri-Planar Roadway Drainage Geocomposite (Geotextile – Tri-Planar Geonet – Geotextile)
The drainage geocomposite is comprised of a tri-planar geonet structure consisting of thick supporting ribs with diagonally placed top and bottom ribs, and with a thermally bonded non-woven geotextile. This product is capable of quickly removing subsurface water from the pavement. The product provides a void-maintaining system under high normal loads to work as a capillary break. It also works as a separation and base reinforcement layer, and will have properties conforming to the values and test methods listed below:

PROPERTIES	TEST METHOD	UNIT	VALUE	QUALIFIER
Geocomposite				
Hydraulic Properties				
Load of 15,000 psf at gradient of 0.1				
Flow Rate – MD	ASTM D4716-99	lpm/m	13.0	c, Note 1
Permeability – MD	Calculated	m/day	25,000	C
Reinforcement Properties				
Tensile Strength – MD	ASTM D4595	lb/ft (kN/m)	2500 (36.5)	c, Note 2
Number of Load Cycles before Cracks Propagate			3000	c, Note 3
Geonet Core				
Thickness	ASTM D5199	mils (mm)	300 (7.6)	c, Note 4, 5
Compressive Creep Behavior				
Retained Thickness @25,000 psf				
after 10,000 hours		%	65	a, Note 5
Short Term Compressive Behavior				
Retained Thickness @50,000 psf	ASTM D1621	%	50	a, Note 5, 6
Density	ASTM D1505	g/cm^3	0.94	c, Note 5
Melt Flow Index	ASTM D1238	g/10 min.	1.0	d, Note 5
Carbon Black Content	ASTM D4218	%	2.0	c, Note 5
Geotextile-non woven				
Apparent Opening Size (AOS)	ASTM D4751	mm (US sieve)	0.18 (80)	b, Note 5, 7
Permittivity	ASTM D4491	sec^{-1}	1.26	b, Note 5, 7
Permeability	ASTM D4491	cm/sec	0.2	b, Note 5, 7
Puncture Strength	ASTM D4833	lbs (N)	130 (580)	b, Note 5, 7
Trapezoid Tear	ASTM D4533	lbs (N)	80 (356)	b, Note 5, 7
Grab Tensile Strength	ASTM D4632	lbs (N)	203 (900)	b, Note 5, 7
Grab Elongation	ASTM D4632	%	50	b, Note 5, 7
Mullen Burst	ASTM D3786	psi (kPa)	400 (2750)	b, Note 5, 7
UV Resistance @500 Hours	ASTM D4355	%	70	b, Note 5, 7
Survivability Class	AASHTO M288	Class	1	

Qualifiers: a=Typical Value b=Minimum Average Roll Value (MARV)
c=Minimum Value d=Maximum Value

Notes:

1. Geocomposite flow rate measured by manufacturer every 200,000 square feet of product as per ASTM D4716-99 with testing boundary conditions as follows: steel plate / uniform sand / geocomposite / steel plate and seating period of 100 hours.

2. Tensile properties tested by manufacturer every 200,000 square feet of product per ASTM D4595 with a specimen width of 8.0 in. and crosshead of 0.4 in/min.
3. Cyclic Fatigue Test as performed at the University of Illinois, Advanced Transportation Research and Engineering Laboratory. The test was performed on a concrete beam supported by the geocomposite overlying a clay subgrade. The Stress Ratio defined as : Load Stress / Flexural Strength of the Concrete Beam = 0.83.
4. Thickness measured by manufacturer every 50,000 square feet of product per ASTM D5199 with a 2.22 in. diameter presser foot and 2.9 psi pressure.
5. Geonet and Geotextile properties listed are prior to fabrication process. Both top and bottom geotextiles are attached to the triplanar geonet core. Geotextile is tested at the standard industry frequency.
6. Compression behavior tested by manufacturer every 50,000 square feet of product per ASTM D1621 with a 2 in. x 2 in. specimen and a constant rate of strain of 0.04 in./min.
7. Geotextile properties may vary with project requirements.