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DEPARTMENT OF TRANSPORTATION

PENNDOT RESEARCH

PREFABRICATED WALL DRAIN SYSTEM FOR STRUCTURES

TRANSPORTATION MATERIALS PARTNERSHIP
AGREEMENT NO. 359631, WORK ORDER 3

FINAL REPORT

JUNE 2000

By Y. Grace Hsuan and Robert M. Koerner

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Pennsylvania Transportation Institute

The Pennsylvania State University
Transportation Research Building
University Park, PA 16802-4710
(814) 865-1891 www.pti.psu.edu

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16. Abstract

The conventional method to reduce hydrostatic pressure behind vertical structures, such abutments and retaining walls, is to use coarse aggregate to capture and transmit incoming liquid. This method may be expensive depending upon the availability of the coarse aggregate. In addition, it may be difficult or unreliable to install a vertical soil drainage layer behind a structure. An alternative approach is to use prefabricated geocomposite drains (PGDs) to replace the coarse aggregate.

The objectives of this work order are to evaluate material properties and design criteria, as well as to provide a cost comparison of a PGD system behind retaining structures. The final outcomes of this work order are material specification and design guidelines, which can assist the usage of PGDs in highway construction.

The work order consists of four tasks:
1. Review of current available literature on PGD;
2. Assessment of the current available PGDs and cost comparison;
3. Assessment of the current usage of the PGDs; and
4. Development of specification and guidelines.

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PREFABRICATED WALL DRAIN SYSTEM FOR STRUCTURES

Transportation Materials Partnership
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Work Order 3

FINAL REPORT

Prepared for

Commonwealth of Pennsylvania
Department of Transportation

By

Y. Grace Hsuan and Robert M. Koerner

The Pennsylvania Transportation Institute
The Pennsylvania State University
Transportation Research Building
University Park, PA 16802-4710

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INTRODUCTION

The conventional method to reduce hydrostatic pressure behind vertical structures, such abutments and retaining walls, is to use coarse aggregate to capture and transmit incoming liquid. This method may be expensive depending upon the availability of the coarse aggregate. In addition, it may be difficult or unreliable to install a vertical soil drainage layer behind a structure. An alternative approach is to use prefabricated geocomposite drains (PGDs) to replace the coarse aggregate.

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CURRENT METHOD FOR PROVIDING DRAINAGE SYSTEMS BEHIND RETAINING STRUCTURES

This section briefly describes the current method for providing drainage behind retaining structures in the Commonwealth of Pennsylvania. The current construction design is according to Section RC-12M, "Backfill at Structures," in Publication 72M, *Roadway Construction Standards (Metric)*. In both fill and cut abutments, a large quantity of structural granular fill material is used behind the wall in order to achieve free drainage, as shown in Figure 1. The types of aggregate that can be used for structural fill include:

- AASHTO No. 1, 2, 5, or 57 coarse aggregate, meeting gradation requirements of Section 703(C), Table C.
- Type OGS coarse aggregate, meeting Type C quality requirements in Section 703.2, Table B.
- For short retaining walls with space constraints, AASHTO No. 8 aggregate can also be used.

A geotextile separation layer is required between the structural fill and in-situ embankment soil. The specified geotextile is PennDOT Class 2, Type B, according to Publication C-408/96-16, Section 735.

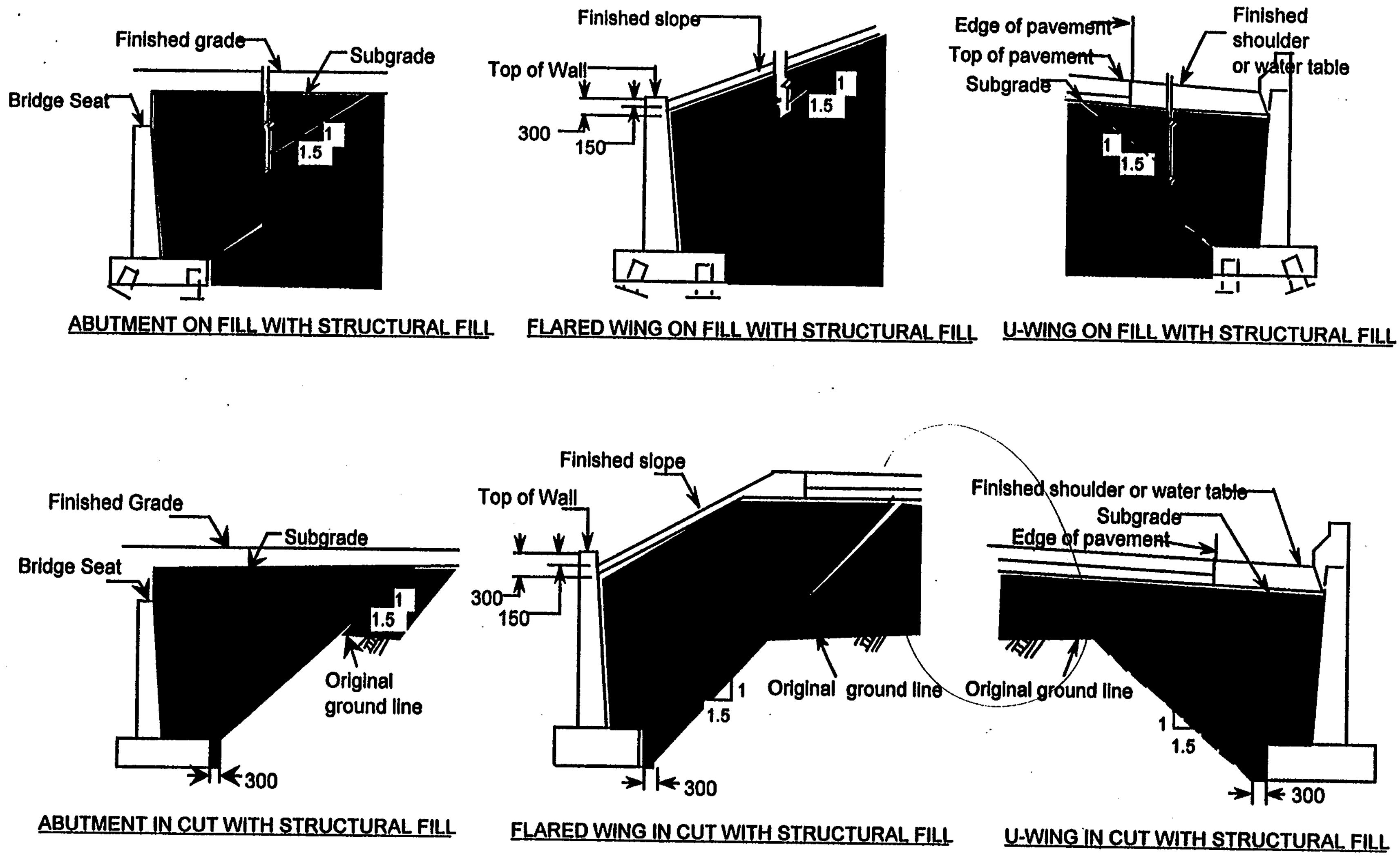

Figure 1 - Typical Cross-Sections of Abutments (ref. PennDOT Publication, Section RC-12M).

The scope of this work order is to evaluate the use of PGD, as alternatives to the above types of coarse aggregates, for drainage behind vertical retaining structures.

Task 1–Reviewing Current Available Literature on PGD

It was somewhat surprising to find that out of approximately 10,000 geosynthetic articles in the open literature, there were only a limited number of publications related to prefabricated geocomposite drains (PGDs). (The data search included the GRI web site, the NTIS web site, and the TRIS-63 search center). A total of 24 documents were found and reviewed. The reviewed literature is categorized into two sections: material properties and testing, and design.

Material Properties and Testing

The majority of the papers that are related to material properties focus on index property evaluation, such as compression core strength and in-plane flow behavior. Koerner et al. (1985) evaluated eight geocomposite products regarding compression strength and hydraulic property. They stated that certain geocomposites exhibit "yielding" as the stress increases. The yielding signified the collapsing of the core structure, as illustrated in Figure 2. In two later reports (Kraemer and Smith 1986; Koerner and Hwu 1989), data indicated that except for core structures made from a 3-D entangled web and expanded polystyrene bead block, all geocomposites exhibit yielding at certain threshold value. Thus, the yield strength, which is also referred to as the crush strength, has been adopted as one of the required properties for specifying geocomposite products. The crush strength represents the maximum compression load that the core structure can support under a constant compressive strain rate. The test commonly performed was according to ASTM D 1621. It should be recognized that the compression strength is a short-term index property. The yield stress does not reflect the creep behavior, which is essential to the long-term service performance of the geocomposite. As a result, the collapse strength from a short-term test should be used with a reduction factor to accommodate the realization that polymers can be creep-sensitive materials. Koerner (1999) recommended a factor safety of 1.3 for creep.

Since the primary function of the geocomposite is drainage, many technical papers investigated the hydraulic property of the core structure (i.e., transmissivity). The transmissivity index test is performed according to ASTM D4716 using two metal plates on the top and below the test specimen. For short-term index test, the seating time for each stress level is a minimum of 15 minutes. The typical test conditions are a hydraulic gradient of 1.0 under normal stresses of 38 kPa (5.5 psi) and 100 kPa (14.5 psi).

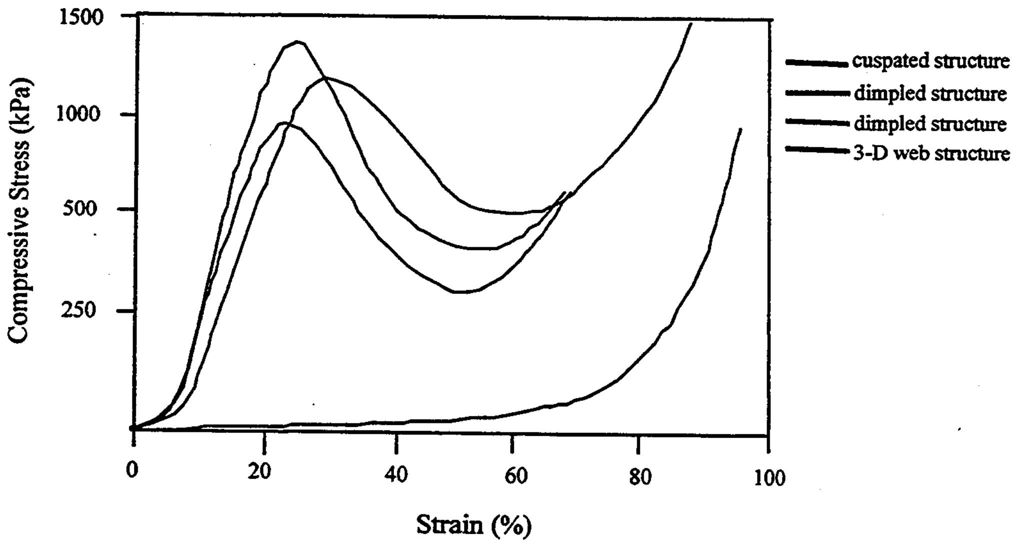

Figure 2–Compressive Stress Versus Strain Curve of Various PGDs.

Beck (1988) pointed out eight factors that could affect the transmissivity value; they are as follows:

i. Core shape,
ii. Core thickness,
iii. Fabric type,
iv. Loading magnitude,
v. Load simulation,
vi. Hydraulic gradient,
vii. Duration of the loading, and
viii. Water temperature.

Factors (i) to (iii) are product dependent, and factors (iv) to (vi) are performance related. The duration of the loading is important in the index test, since the flow rate decreases as the loading time increases due to creep of the core structure. Kraemer and Smith (1986) performed a series of step creep tests; however, the duration for each stress level was not defined. Cancelli et al. (1987) measured the long-term creep of six different PGDs (including geonets) that are available in the European market for a duration of 1300-hours. The rates of deformation of the secondary linear creep region vary from 1.67×10^{-6}/hr to 1.25×10^{-7}/hr. Corbet (1996) performed a compressive creep test according to the draft European Standard pre-Norm (prEN1897) under normal pressure, as well as shear force, for a duration of 1000 hours. The results indicated that the vertical strain and shear strain behaved in a relatively similar manner. Some of the PGDs collapsed before the end of 1000 hours. Thus, Corbet recommended that the long-term creep test should be performed for at least 1000 hours.

Instead of performing transmissivity and compression creep tests simultaneously as indicated in all the above papers, Luettich and Beck (1994) evaluated the creep and transmissivity separately. Thus, the transmissivity test device would not be occupied for the entire duration of the creep test. They performed a series of 10,000-hour creep tests in air for strain deformation data from which stress/strain isochronous curves at different times were developed. Separately, the transmissivity test under different strains was evaluated, and the resulting curves were superimposed on the stress/strain isochronous curves. A strain value was then selected dependent on the normal stress and duration, and the reduction factor for transmissivity was determined. This approach would allow the test laboratory to generate large quantities of creep and transmissivity data without the high cost of making many transmissivity devices dedicated for long testing times.

As pointed out by Beck (1988), one of the eight factors that affect the long-term transmissivity value is loading simulation. The standard creep test for the core structure is performed between two steel plates. The deformation (i.e., intrusion) of the geotextile caused by the adjacent soil is not considered. Lawrance (1987) demonstrated the intrusion of geotextile into core spaces under compressive load using Ottawa sand. Hwu et al. (1990) showed that a reduction ranging from 39 to 88 percent in 1000 hours transmissivity value was measured dependent on the soil, the type of geotextile, and the type of geocomposite. Koerner (1999) recommended a factor safety of 1.3 for geotextile intrusion in considering long-term flow. Recently, Zhao and Montanelli (1999) extended the transmissivity creep to 10,000 hours using sand and clay on two types of geonets. Neoprene has also been used to simulate soil deformation. It was found that neoprene simulates geotextile intrusion into the geonet's core reasonable well for the sand layer, but significantly underestimates intrusion of clay soil. Similar behavior would also be expected in testing PGDs.

In assessing the available references, the complexity of a performance-oriented transmissivity creep test is obvious. Without a uniform guideline, the testing can be extremely expensive without providing the required information for the engineering design. Currently, the Geosynthetic Institute (GSI) is developing a standard guide entitled "Determination of the Allowable Flow Rate of a Drainage Geocomposite" to unify the testing procedure. A copy of the draft standard guide is included as Appendix A.

Regarding the filtration property of the geotextile, currently PennDOT Class 2, Type B geotextile in Publication C-408/96-16, Section 735, is specified for separation between structural fill and in-situ soil. If the structural fill is replaced by the geocomposite wall drain, the filtration property of the geotextile must be evaluated to prevent piping or clogging phenomena. The AASHTO M 288 specification for geotextiles will be utilized in this regard.

Design Methodology

Within the 24 published documents, only a few are design related. Hunt (1982) focused on the hydraulic design of the geocomposite and the connection details between the sheet drain and outlet pipes. Kraemer and Smith (1986) described the design considerations, and pointed out several areas of concern for designers. However, no recommendation is proposed. Koerner and Hwu (1989) presented the basic design method for the drainage core strength and flow rate requirements. For the strength requirement, the compression stress acting perpendicular to the geocomposite was calculated according to backfill and surcharge loads. The hydraulic pressure behind the wall was assumed to zero. The calculated compression stress was then increased by applying a creep factor to ensure the long-term performance of the drainage core structure. The flow rate requirement was obtained using flow net analysis. Partial factors-of-safety for geotextile intrusion and clogging were then incorporated into the required flow rate to obtain the design value. Having the appropriate, i.e., site-specific, properties of the drainage core and geotextile, the design can proceed along conventional methods. It is well within the state-of-the-practice.

Task 2–Assessment of the Current Available PGDs and Cost Comparison

The focus of this task is to compile information on the type of PGDs that are currently available on the market. In addition, a cost comparison between the PGD approach and the traditional structural backfill approach is presented.

Commercially Available PGDs

Kraemer and Smith (1986) performed a comprehensive study on PGD. The data included both highway edge drains and sheet drains from 12 manufacturers with 17 styles from 1983 to 1986. Three years later, Koerner and Hwu (1989) also published a report on drainage geocomposites. The report consisted of two parts: one on highway edge drains and the other on retaining wall sheet drains. Within the sheet drain section, 26 different products from 10 companies were presented. The data represent the majority of the available wall drains at that period of time. However, because these two reports were performed 10 years ago, a new inquiry on the currently available PGD is necessary. The new survey is limited to companies that are listed in the recent Geotechnical Fabrics Report (GFR) specification guides (1998 & 1999). Product specifications of the geocomposite, as well as the geotextile, were requested from each of the manufacturers.

The current survey includes nine companies, as shown in Tables 1(a) and (b) for SI units and English units, respectively. It should be noted that geonet composites are also candidate PGDs, but are not included in this work order. The physical description of the PGD involves core structure, polymer type, dimension and thickness. There are four basic core structures: entangled mesh, single cuspated, double cuspated, and single dimpled cores. Except for the single cuspated core, the shape of the other three core structures can be seen in Figures 3 to 5. Figure 3 shows the entangled mesh core, Figure 4 shows the double cuspated core and Figures 5(a), (b), and (c) show the single dimpled core associated with three different geotextiles. High-density polyethylene (HDPE), polystyrene (PS), high impact polystyrene (HIPS) and polypropylene (PP) are the four polymers generally used to manufacture the core structures. Note that polyethylene (PE) usually is a high-density polyethylene in order to achieve high compressive strength.

Regarding properties of the PGD, compressive strength and hydraulic behavior are listed. The compressive strength (or crush strength) is performed according to the ASTM D 1621, as was shown in Figure 2 in the early section. The compressive strength signifies the collapse of the core structure. Except for the Enkadrain products, all sheet drains exhibit a maximum compressive strength. The strength value varies between products, ranging from 200 to 1000 kPa (29 to 145 psi), as indicated in Tables 1(a) and (b). The entangled mesh of the Enkadrain products exhibits a relatively compressible structure. The mesh products have no defined crush strength; rather structures are gradually compressed while placed under deformation.

In-plane flow, via ASTM D 4716, is used to characterize the hydraulic behavior of the PGD. The test is evaluated under a defined compressive load and hydraulic gradient. The typical testing condition published by manufacturers is a 100 kPa (14.5 psi) compressive load at a gradient of 1.0, which intends to model gravity flow conditions, such as those behind a vertical retaining structure. Tables 1(a) and (b) show that the in-plane flow value varies from 0.0010 to 0.0037 m^3/sec-m (4.8 to 17.8 gal/min-ft), except for Enkadrain and Nylex products, which exhibit significantly lower values. These two basic properties, compressive strength and in-plane flow, are required in many of the current state specifications that will be discussed in Task 3.

Table 1(a) - Properties of Prefabricated Geocomposite Drain Products (Ref. GFR Specifiers Giude, 1999) (SI Units).

Company	Product	Drainge Core		Geotextile	Dimension m		Thickness	Compressive	In Plane Flow Rate
		Structure	Polymer	Type	Width	Length	mm	Strength kPa	100 kPa, i = 1 m^3/sec-m
Akzo	Enkadrain 9010	EM	O/C	NW	1	30.5	9.1	na	0.00032
	Enkadrain 9120	EM	O/C	NW	1	30.5	19	na	0.00047
	Enkadrain 9611	O/C	HDPE	NW	1	30.5	9.1	na	0.00063
	Enkadrain 9615	O/C	HDPE	NW	1	30.5	10.2	na	0.00232
	Enkadrain 9811	O/C	HDPE	NW	1	30.5	7.1	na	0.00066
	Enkadrain 9812	O/C	HDPE	NW	2	15.5	9.6	na	0.00127
American Wick Drain	Amerdrain 200	SCC	O/C,PS	NW	1.22	31.7	6.35	517	0.0019
	Amerdrain 520	SCC	O/C,PS	NW	1.22	31.7	11	718	0.0034
	Amerdrain 650	SCC	O/C,PS	W	1.22	31.7	11	1005	0.0033
	Amerdrain 700	SCC	O/C,PS	NW	1.22	31.7	12.7	718	0.0037
Contech	C-Drain 15K	SDC	HIPS	NW	1.22	15.32	11	715	0.0033
Cosella Dorken	Delta Drain-6000	SDC	HIPS,O/C	NW	2.34	15.3	7.6	723	0.0013
	Delta Drain-2000	SDC	PE,PP	NW	2.34	15.3	7.6	250	0.0012
Drainage Products	Drain Away Panel	DCC	HIPS	NW	0.6-1.5	3-15.3	15.8	234	0.0010
	Drain Away 50	SDC	HIPS	NW	1.2	31.8	11.1	718	0.0033
LINQ	Battle Drain I	SDC	HIPS	NW	1.2	31.7	6.35	517	0.0019
	Battle Drain II	SDC	HIPS	NW	1.2	31.7	11.1	724	0.0033
MiraDRi	6000	SDC	HIPS/PP	NW	1.2	15.3	10.8	723	0.0035
	6200	SDC	HIPS/PP	NW	1.2	15.3	11	723	0.0035
Nylex	Coredrain	DCC	HDPE	NW	1	25	20	200	0.00055
	Zipdrain	SCC	HDPE	NW	1	25	10	200	0.00011
WEBTEC*	TerraDrain 50	SDC	HIPS	NW	1.2	15.9	6.4	517	0.0019
	TerraDrain 101	SDC	HIPS	NW	1.2	15.9	11	718	0.0034
	TerraDrain 121	SDC	HIPS	NW	1.2	15.9	11	718	0.0033
	TerraDrain 203	SDC	HIPS	W	1.2	15.9	11	1005	0.0037

* Products are manufactuered by American Wick Drain

Note:

EM = Entangled mesh
O/C = Other or Combination
SCC = Single cuspated core
SDC = Single dimpled core
DCC = Double cuspated core

HDPE = High Density Polyethylene
PS = Polystyrene
HIPS = High Impact Polystyrene
PE = Polyethylene
PP = Polypropylene

NW = Nonwoven
W = Woven
np = data not provided
na = data not applicable

Table 1(b) - Specification of Geocomposite Sheet Drain Products (Ref. GFR Specification 1999) (English Units).

Company	Product name	Core		Geotextile Style	Dimension, (ft)		Thickness (mil)	Compressive Strength (psi)	In plane flow rate 100 kPa @ i = 1 (gal/min/ft)
		Structure	Polymer		Width	Length			
Akzo	Enkadrain 9010	EM	O/C	NW	3.25	100	360	na	1.5
	Enkadrain 9120	EM	O/C	NW	3.25	100	750	na	2.3
	Enkadrain 9611	O/C	HDPE	NW	3.25	100	360	na	3.0
	Enkadrain 9615	O/C	HDPE	NW	3.25	100	400	na	11.2
	Enkadrain 9811	O/C	HDPE	NW	3.25	100	280	na	3.2
	Enkadrain 9812	O/C	HDPE	NW	6.5	50	380	na	6.1
American Wick Drain	Amerdrain 200	SCC	O/C,PS	NW	4	104	250	75	9.2
	Amerdrain 520	SCC	O/C,PS	NW	4	104	437.5	104	16.4
	Amerdrain 650	SCC	O/C,PS	W	4	104	437.5	146	15.9
	Amerdrain 700	SCC	O/C,PS	NW	4	104	437.5	104	17.9
Contech	C-Drain 15K	SDC	HIPS	NW	4	104	425	104	15.9
Cosella Dorken	Delta Drain-6000	SDC	HIPS,O/C	NW	7.7	50	300	105	6.3
	Delta Drain-2000	SDC	PE,PP	NW	7.7	50	300	36	5.8
Drainage Products	Drain Away Panel	DCC	HIPS	NW	2-5	10-50	620	34	4.8
	Drain Away 50	SDC	HIPS	NW	4	104	438	104	15.9
LINQ	Battle Drain I	SDC	HIPS	NW	4	104	250	75	9.2
	Battle Drain II	SDC	HIPS	NW	4	104	437.5	105	15.9
MiraDRi	6000	SDC	HIPS/PP	NW	4	50	425	105	16.9
	6200	SDC	HIPS/PP	NW	4	50	435	105	16.9
Nylex	Coredrain	DCC	HDPE	NW	3.28	82	790	30	2.7
	Zipdrain	SCC	HDPE	NW	3.28	82	400	30	0.5
WEBTEC	TerraDrain 50	SDC	HIPS	NW	4	52	250	75	9.2
	TerraDrain 101	SDC	HIPS	NW	4	52	430	105	16.4
	TerraDrain 121	SDC	HIPS	NW	4	52	430	105	15.9
	TerraDrain 203	SDC	HIPS	W	4	52	430	145	17.9

Note:

EM = Entangled mesh
O/C = Other or Combination
SCC = Single cuspated core
SDC = Single dimpled core
DCC = Double cuspated core

HDPE = High density polyethylene
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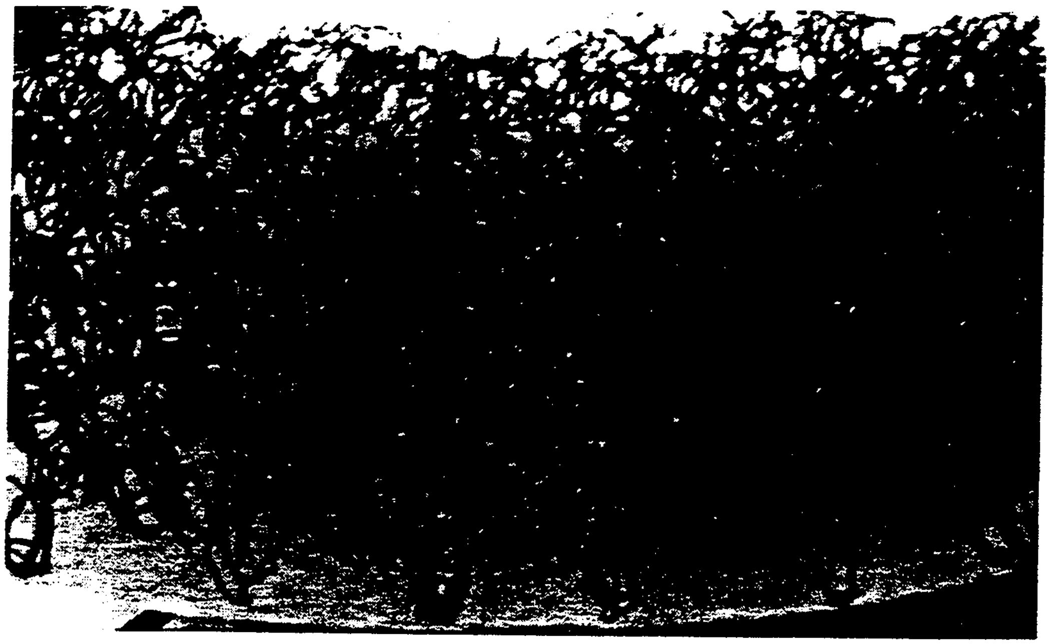

Figure 3 – A View of the Entangled Mesh Core Structure.

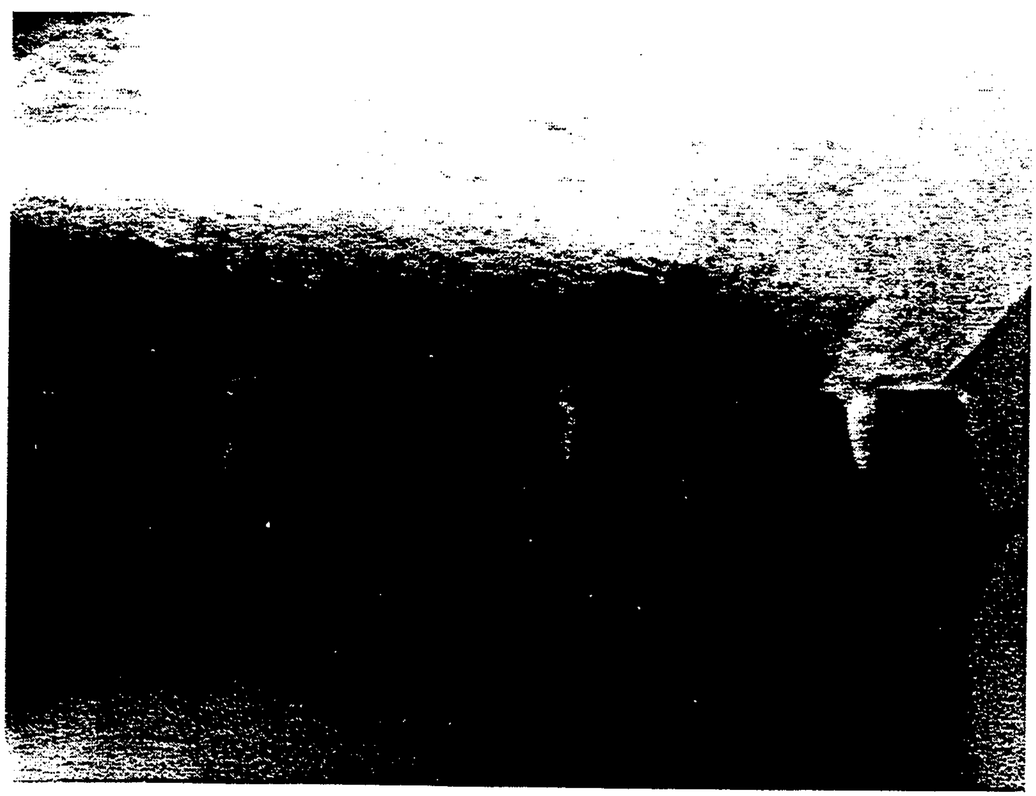

Figure 4 – A View of the Double Cuspated Core.

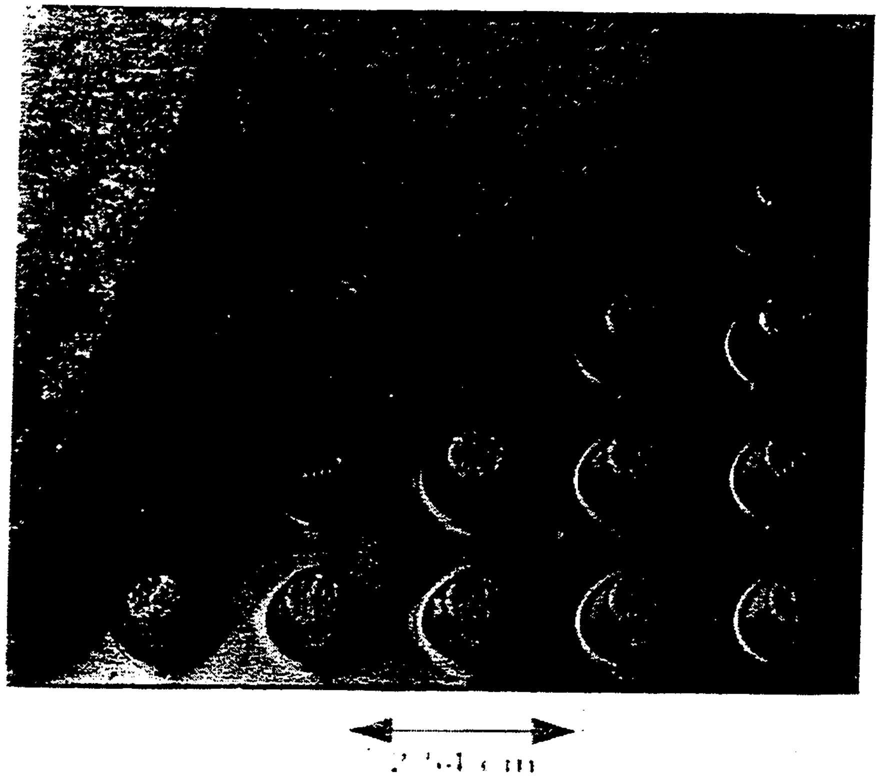

Figure 5(a) – A View of the Single Dimpled Core with Needle Punched Nonwoven Geotextile.

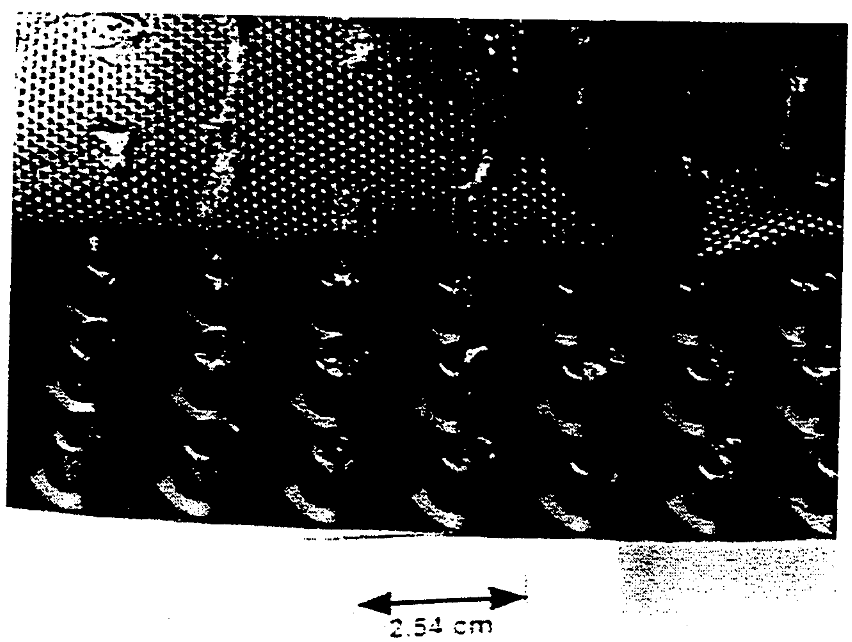

Figure 5(b) – A View of the Single Dimpled Core with Woven Geotextile.

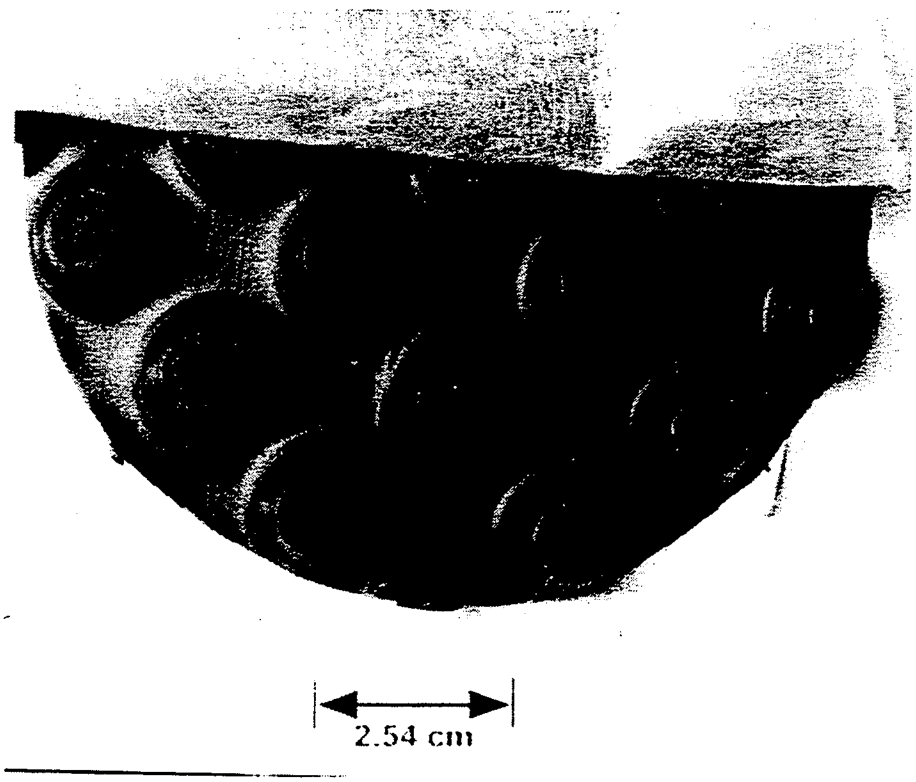

Figure 5(c) - A View of the Single Dimpled Core with Heat Set Nonwoven Geotextile.

For the geotextile component of the PGD, needle-punched nonwoven geotextiles are the most common type, although heat-bonded, nonwoven and woven geotextiles are also used. Seven of the nine sheet drain companies provided information for the geotextile, as shown in Tables 2(a) and (b) for SI units and English units, respectively. The properties listed in Tables 2(a) and (b) are based on those specified in Class 2, Type B in Publication C-408/96-16, Section 735. However, some of the properties are not provided by the manufacturer. For example, the permittivity value is reported instead of permeability as required by several states, and the seam strength and the ultraviolet resistance are not provided.

Cost Comparison between Structural Backfill and PGD with Native Soil

The overall construction cost of the current practice using structural backfill is compared with that of PGD with native soil backfill. The comparison is based on the same excavation profiles defined in Section RC-12M of Publication 72M. In each case, the structural fill with geotextile

Table 2(a) - Properties of Geotextiles Associated with Different Prefabricated Geocomposite Drains (SI Units).

Company	Product Name	Geotextile Style	Geotextile Properties									
			Grab Str. ASTM D4632 (N)	Grab Elong. ASTM D4632 (%)	Burst ASTM D3786 (kPa)	Puncture ASTM D4833 (N)	Trap. Tear ASTM D4533 (N)	O_{95} ASTM D4751 (mm)	Permeability ASTM D4491 (cm/sec)	Permittivity ASTM D4491 (sec^{-1})	Seam Str. ASTM D4632 (N)	UV ASTM D4355 (%)
American Wick Drain	Amerdrain 200	NW	485	60	1430	285	220	0.15	0.39	2	np	np
	Amerdrain 520	NW	485	60	1430	285	220	0.15	0.39	2	np	np
	Amerdrain 650	W	2070 x 1920	27 x 20	3800	655	645 x 355	0.15	0.014	0.4	np	np
	Amerdrain 700	NW	485	60	1430	285	220	0.15	0.39	2	np	np
Cosella Dorken	Delta-Drain 6000	NW	556	75	1552	289	222	0.21	np	2.5	np	70/500 hr
	Delta-Drain 2000	NW	489	60	1655	311	222	0.21	np	2	np	70/500 hr
Drainage Products	Drain Away Panel	NW	534	50	1793	311	222	0.21	0.25	1.7	np	70/150 hr
	Drain Away 50	NW	511	50	1655	311	222	0.18	0.2	2.3	np	np
LINQ	Battle Drain I	NW	512	np	np	np	np	0.25	np	0.7	np	np
	Battle Drain II	NW	512	np	np	np	np	0.18	np	2.3	np	np
MiraDRi	6000/6200	NW	450	50	np	290	np	0.21	np	1.9	np	np
	6000/6200XL	NW	710	50	np	420	np	0.21	np	1.5	np	np
Nylex	Coredrain	NW	400	np	np	np	150	np	0.01	np	np	np
WEBTEC*	TerraDrain 50	NW	485	60	1430	285	220	0.15	0.39	np	np	np
	TerraDrain 101	NW	485	60	1430	285	220	0.15	0.39	np	np	np
	TerraDrain 121	W	2070 x 1920	27 x 20	3800	655	645 x 355	0.15	0.014	np	np	np
	TerraDrain 203	NW	485	60	1430	285	220	0.15	0.39	np	np	np

* Products are manufactured by American Wick Drain

Note: np = not provided
NW = Nonwoven
W = Woven

Table 2(b) - Properties of Geotextile Associated with Different Geocomposite Sheet Drains (English Units).

Company	Product Name	Geotextile Style	Geotextile Properties									
			Grab Str. ASTM D4632 (lb)	Grab Elong. ASTM D4632 (%)	Burst ASTM D3786 (psi)	Puncture ASTM D4833 (lb)	Trap. Tear ASTM D4533 (lb)	AOS ASTM D4751 (sieve)	Permeability ASTM D4491 (in/min)	Permittivity ASTM D4491 (min^{-1})	Seam Str. ASTM D4632 (lb)	UV ASTM D4355 (%)
American Wick Drain	Amerdrain 200	NW	110	60	210	64	50	100	59	120	np	np
	Amerdrain 520	NW	110	60	210	64	50	100	59	120	np	np
	Amerdrain 650	W	470 x 430	27 x 20	550	147	145 x 80	100	2.1	24	np	np
	Amerdrain 700	NW	110	60	210	64	50	100	59	420	np	np
Cosella Dorken	Delta-Drain 6000	NW	125	75	225	65	50	70	np	150	np	70/500 hr
	Delta-Drain 2000	NW	110	60	240	70	50	70	np	120	np	70/500 hr
Drainage Products	Drain Away Panel	NW	120	50	260	70	50	70	38	102	np	70/150 hr
	Drain Away 50	NW	115	50	240	70	50	100	30.5	138	np	np
LINQ	Battle Drain I	NW	115	np	np	np	np	60	np	42	np	np
	Battle Drain II	NW	115	np	np	np	np	100	np	138	np	np
MiraDRi	6000/6200	NW	100	50	np	65	np	70	np	114	np	np
	6000/6200XL	NW	160	50	np	94	np	70	np	90	np	np
Nylex	Coredrain	NW	90	np	np	np	34	100	1.5	np	np	np
WEBTEC*	TerraDrain 50	NW	110	60	210	64	50	100	59	np	np	np
	TerraDrain 101	NW	110	60	210	64	50	100	59	np	np	np
	TerraDrain 121	W	470 x 430	27 x 20	550	147	145 x 80	100	2.1	np	np	np
	TerraDrain 203	NW	110	60	210	64	50	100	59	np	np	np

* Product are manufactured by American Wick Drain

Note: np = data not provided
NW = Nonwoven
W = Woven

separator is replaced by the PGD with recompacted native soil. Table 3 shows the cost difference between these two systems. The cost of the PGD system is approximately 35 percent less than the corresponding structural fill system.

Task 3 – Assessment of the Current Usage of PGDs

This task focuses on the usage of the PGD in various state DOTs, with particular emphasis on the available specifications. In 1995, the Geosynthetic Research Institute (GRI) published a detailed assessment of the current usage of PGDs behind vertical retaining structures (Wilson-Fahmy and Koerner 1995). Questionnaires were sent to all state DOTs and manufacturers. Twenty states responded, nine of which reported to have PGD specifications, as shown in Table 4. In addition, eight states used PGD solely for retaining walls, and three states (Missouri, Kansas, and Wyoming) used PGD mainly behind bridge abutments, as shown in Table 5. The total number of retaining wall and bridge abutments incorporating PGDs in the 20 states was about 620. In contrast, the reported number obtained from the geocomposite manufacturers was 2000. Figure 6 shows the updated number of projects associated with the products of one of the leading manufacturers.

In this work order study, the research team also updated the usage of PGDs in various state DOTs. The information was obtained by either contacting individual engineer using e-mail or telephone calls, or searching the DOT's web sites. Twelve states were using PGDs behind wall or abutment structures. Seven of the 12 states have a detailed material property specification for the core structure, as shown in Tables 6(a) and (b) for SI units and English units, respectively. Two basic required properties are the crush strength and in-plane flow rate. The crush strength, which is performed according to ASTM D 1621, ranges from 138 to 478 kPa (20 to 70 psi); however, 300 kPa (43.5 psi) is the typical value. In addition, Michigan and Missouri require a maximum compressive strain of 10 and 18 percent, respectively. For the hydraulic property, the in-plane flow rate according to ASTM D 4716 is required. Test conditions vary from state to state. A 72 kPa (10 psi) normal stress is defined by most of the states, although Arizona and Kansas require a much higher value. The hydraulic gradient of either 0.1 or 1.0 is used. The flow value is measured after 15 minutes seating time. Virginia is the only state that requires a seating time of 100 hours, which better challenges the creep resistance of the core structure.

Also listed in Tables 6(a) and (b) is the specification of Eastern Federal Lands Highway Division of the Federal Highway Administration.

Table 3 - Cost Comparison between Structural Backfill and PGD with Native Soil Backfill.

STRUCTURAL BACKFILL = \$42.4 per m^3 (\$40 per yd^3) (excavation and installation)	SHEET DRAIN COMPOSITE = \$4.84 per m^2 (\$0.45 per ft^2) (not including installation)
CLASS 2 GEOTEXTILE FOR SEPARATION = \$16 per m^2 (\$1.5 per ft^2 (including installation)	SHEET DRAIN INSTALLATION = \$11 per m^2 (\$1.0 per ft^2) NATIVE SOIL = \$26 per m^3 (\$20 per yd^3) (excavation and replacement)

5 meter high wall

Abutment Type	Height (m)	Length (m)	Quantity (m^3)	Structural Fill System			PGD System				Benefit
				Structural Fill	Geotextile	Total	Sheet Drain	Installation	Soil Placement	Total	
IN CUT AREA											
Abutment	5	21.35	646	$27,382	$1,708	**$29,090**	$518	$1,174	$16,791	**$18,483**	36%
Flared wall*	5	10	456	$19,334	$800	**$20,134**	$243	$550	$11,856	**$12,649**	37%
U-wing	5	10	293	$12,423	$800	**$13,223**	$243	$550	$7,618	**$8,411**	36%
Abutment	10	21.35	2477	$105,008	$3,416	**$108,424**	$1,035	$2,349	$64,392	**$67,776**	37%
Flared wall*	10	10	1475	$62,540	$1,600	**$64,140**	$485	$1,100	$38,350	**$39,935**	38%
U-wing	10	10	1160	$49,184	$1,600	**$50,784**	$485	$1,100	$30,160	**$31,745**	37%
Abutment	15	21.35	5491	$232,828	$5,124	**$237,952**	$1,553	$3,523	$142,772	**$147,848**	38%
Flared wall*	15	10	3050	$129,320	$2,400	**$131,720**	$728	$1,650	$79,300	**$81,678**	38%
U-wing	15	10	2572	$109,053	$2,400	**$111,453**	$728	$1,650	$66,872	**$69,250**	38%
IN FILL AREA											
Abutment	5	21.35	517	$21,907	$1,708	**$23,615**	$518	$1,174	$13,433	**$15,125**	36%
Flared wall*	5	10	192	$8,141	$800	**$8,941**	$243	$550	$4,992	**$5,785**	35%
U-wing	5	10	242	$10,261	$800	**$11,061**	$243	$550	$6,292	**$7,085**	36%
Abutment	10	21.35	2066	$87,582	$3,416	**$90,998**	$1,035	$2,349	$53,706	**$57,090**	37%
Flared wall*	10	10	766	$32,478	$1,600	**$34,078**	$485	$1,100	$19,916	**$21,501**	37%
U-wing	10	10	967	$41,009	$1,600	**$42,609**	$485	$1,100	$25,147	**$26,732**	37%
Abutment	15	21.35	4641	$196,799	$5,124	**$201,923**	$1,553	$3,523	$120,679	**$125,755**	38%
Flared wall*	15	10	1726	$73,182	$2,400	**$75,582**	$728	$1,650	$44,876	**$47,254**	37%
U-wing	15	10	2176	$92,262	$2,400	**$94,662**	$728	$1,650	$56,576	**$58,954**	38%

* assume the finished slope is at 20^{o} and is 5 m long.

Table 4 - Summary of State DOTs that Use PGDs (Wilson-Fahmy, R.F. and Koerner, R.M., 1995).

State	Sheet Drain Item in Standard Specs.		Installation Section		GT Filter Item in Standard Specs.		Backfill Item in Standard Specs.		Earth Pressure Calculation in Standard Specs.		Earth Pressure Calculation with Sheet Drain	
	RW	BA	RW	BA	RW	BA	RW	BA	RW	BA	RW	BA
Hawaii	Yes		Yes		Yes	Yes	Yes	Yes	No	No	No	No
Kansas	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Kentucky	Yes		Yes		Yes		Yes		No		No	
Michigan	Yes		No		Yes		Yes		No		No	
Missouri	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
New York	Yes		No		Yes		Yes		No		No	
North Carolina	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Ohio	Yes		No		Yes		Yes		No		No	
Wyoming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No

Note: RW = Retaining Wall
BA = Bridge Abutment

Table 5 – Number of Projects Used PGDs in State DOTs (Wilson-Fahmy, R.F. and Koerner, R.M., 1995).

State	Approximate No. of Projects with PGDs		Height Range (m) / (ft)		Required Service Life (year)	
	RW	BA	RW	BA	RW	BA
Hawaii	2	0	2-6 / (7-20)		50	50/100
Kansas	30	250				
Kentucky	Unknown					
Michigan	2	0	3-6 / (10-20)			
Missouri	0	300				
New Jersey	3	0	1-12 / (3-40)		100	100
New York	19	0			50	
North Carolina	3	0	4-8 / (13-26)		50	50
Ohio	Unknown				75	
Rhode Island	1	0				
South Carolina	3	0	2-5 / (7-13)		75	75
Wyoming	0	5-10		2-5 / (7-13)		30-50

Note: RW = Retaining Wall
BA = Bridge Abutment

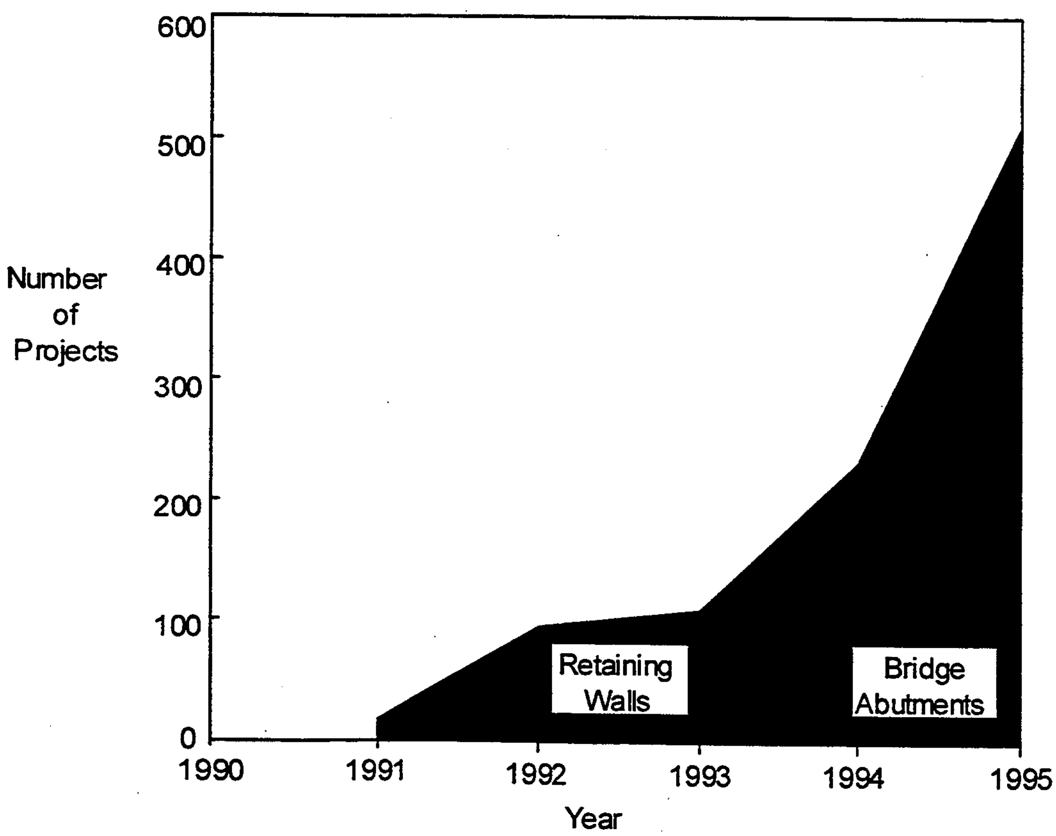

Figure 6 – Number of Projects Using PGDs Associated with One of the Leading PGD Manufacturers.

Table 6(a) - Summary of Specification for PGD in Various DOT s (SI Unites).

State	Application	Drain Type	Thickness (mm)	Property	Test Method	Test Condition	Required Value	GT Required
Arizona	wall drain	sheet drain & geonet	>5.8	flow rate	ASTM 4716	145 kPa at i = 1.0	0.0008 m^3/s-m	Drainage GT
				crush strength	ASTM D1621	-	290 kPa	
Colorado	retaining wall drain	sheet drain	> 12.7	flow rate	ASTM D4716	undefined	0.002 m^3/s-m	Drainage GT
				crush strength	ASTM D1621	-	138 kPa	
Georgia	cantilever & gravity walls	sheet drain	sheet drain coveres the entire back of the wall to replace coarse backfill material prequalified products - eight products					Filter fabric
	tie back & soil nail walls	strip drain	individual strip drain places in between the ties or nails to keep water away from the anchor heads; prequalified products - eight products					
Kansas	abutment	strip drain	6.35 min. 12.7 max.	flow rate	ASTM D4716	380 kPa at i = 1.0	0.002 m^3/s-m	Drainage GT
				crush strength (wall drain)	ASTM D1621	-	478 kPa	
				crush strength (slop drain)	ASTM D1621	-	861 kPa	
				deflection	ASTM D1621	-	20% max.	
				peel strength	ASTM D1876	-	0.073 kN/m	
Kentucky	tieback walls	vertical drain	vertical drains are applied at every 3 meters center at weephole locations. no specification (manufacturer certification)					Drainage GT (unspecified)
Ohio	structural (sometime)	sheet drain	prequalified products. Five products: Miradrain 2000, Battle Drain 1, Hyrdaway 100, Stripdrain 75, and Tensar DCF 100. No specification but have installation procedure.					Drainage GT
Michigan	wall drain regions	sheet drain	> 25	crush strength	MTM 411	-	200 kPa at ε <18%	Drainage GT
		PDS	> 25	crush strength	MTM 411	-	300 kPa at ε <18%	
				peel strength	ASTM D1876		0.5 kN/m	
		geonet	approved by engineer based upon durability, drainage capacity, crush strength tensile strength and thickness					
Missouri	abutment	vertical drain (sheet drain)	> 10	flow rate	ASTM D 4716	72 kPa at i = 0.1	0.001 m^3/s-m	Drainage GT
				crush strength	ASTM D1621	-	287 kPa at ε <10%	
New York	structural	impermeable	undefined	flow rate	ASTM D4716	72 kPa at i = 0.1	0.0008 m^3/s-m	Drainage GT
		permeable	undefined		ASTM D4716	72 kPa at i = 0.1	0.0004 m^3/s-m	
	abutment	impermeable	10	flow rate	ASTM D4716	72 kPa at i = 0.1	0.0008 m^3/s-m	Drainage GT
		permeable	10		ASTM D4716	72 kPa at i = 0.1	0.0004 m^3/s-m	
North Carolina	tieback walls	vertical drain	vertical drains are applied at every 10 feet center at weephole locations. Mirafi 6200 or equivalent					Drainage GT (unspecified)

Table 6(a) - Summary of Specification for PGD in Various DOT's (SI Unites).

State	Application	Drain Type	Thickness (mm)	Property	Test Method	Test Condition	Required Value	GT Required
Virginia	abutments (< 5 meter)	sheet drain	undefined	flow rate	ASTM D4716	72 kPa at i = 1.0 after 100 hours	0.0021 m^3/s-m	
				heat resistance	undefined	5% strength retained after 24 hour at 50°		
Wyoming	road and bridge	sheet drain	> 9.65	flow rate	ASTM D4716	72 kPa at i = 1.0	0.0003 m^3/s-m	Drainage GT (sewn pocket for inserting pipe)
				crush strength	ASTM D1621	-	239 kPa	
				fungus resistance	ASTM G21	-	No growth	
EFLHD*	abutments wingwalls & retaining walls	sheet drain	undefined	flow rate	undefined			Drainage GT (sewn pocket for inserting pipe)
				crush strength	ASTM D1621	-	275 kPa	

* EFLHD = Eastern Federal Lands Highway Division

Table 6(b) - Summary of Specification for PGD in Various DOT's (English Units).

State	Application	Drain Type	Thickness (in)	Property	Test Method	Test Condition	Required Value	GT Required
Arizona	wall drain	sheet drain & geonet	>0.2	flow rate	ASTM 4716	21 psi at i = 1.0	3.9 gal/min-ft	Drainage GT
				crush strength	ASTM D1621	-	42 psi	
Colorado	retaining wall drain	sheet drain	> 0.5	flow rate	ASTM D4716	undefined	9.6 gal/min-ft	Drainage GT
				crush strength	ASTM D1621	-	20 psi	
Georgia	cantilever & gravity walls	sheet drain	sheet drain coveres the entire back of the wall to replace coarse backfill material prequalified products - eight products					Filter fabric
	tie back & soil nail walls	strip drain	individual strip drain places in between the ties or nails to keep water away from the anchor heads; prequalified products - eight products					
Kansas	abutment	strip drain	0.25 min 0.5 max	flow rate	ASTM D4716	55 psi at i = 1.0	9.6 gal/min-ft	Drainage GT
				crush strength (wall drain)	ASTM D1621	-	69 psi	
				crush strength (slop drain)	ASTM D1621	-	125 psi	
				deflection	ASTM D1621	-	20% max	
				peel strength	ASTM D1876	-	0.4 lb/in	
Kentucky	tieback walls	vertical drain	vertical drains are applied at every 10 feet center at weephole locations. no specification (manufacturer certification)					Drainage GT (unspecified)
Ohio	structural (sometime)	sheet drain	prequalified products. Five products: Miradrain 2000, Battle Drain 1, Hyrdaway 100, Stripdrain 75, and Tensar DCF 100. No specification but have installation procedure.					Drainage GT
Michigan	wall drain regions	sheet drain	> 1.0	crush strength	MTM 411	-	29 psi at ε <18%	Drainage GT
		PDS	> 1.0	crush strength	MTM 411	-	44 psi at ε <18%	
				peel strength	ASTM D1876		2.9 lb/in	
		geonet	approved by engineer based upon durability, drainage capacity, crush strength tensile strength and thickness					
Missouri	abutment	vertical drain (sheet drain)	> 0.4	flow rate	ASTM D 4716	10.4 psi at i = 0.1	4.8 gal/min-ft	Drainage GT
				crush strength	ASTM D1621	-	42 psi at ε <10%	
New York	structural	impermeable	undefined	flow rate	ASTM D4716	10.4 psi at i = 0.1	3.9 gal/min-ft	Drainage GT
		permeable	undefined		ASTM D4716	10.4 psi at i = 0.1	1.9 gal/min-ft	
	abutment	impermeable	0.4	flow rate	ASTM D4716	10.4 psi at i = 0.1	3.9 gal/min-ft	Drainage GT
		permeable	0.4		ASTM D4716	10.4 psi at i = 0.1	1.9 gal/min-ft	
North Carolina	tieback walls	vertical drain	vertical drains are applied at every 10 feet center at weephole locations. Mirafi 6200 or equivalent					Drainage GT (unspecified)

Table 6(b) - Summary of Specification for PGD in Various DOT's (English Units).

State	Application	Drain Type	Thickness (mm)	Property	Test Method	Test Condition	Required Value	GT Required
Virginia	abutments (< 5 meter)	sheet drain	undefined	flow rate	ASTM D4716	10.4 psi at i = 1.0 after 100 hours	10 gal/min-ft	
				heat resistance	undefined	5% strength retained after 24 hour at 50°		
Wyoming	road and bridge	sheet drain	> 0.4	flow rate	ASTM D4716	10.4 psi at i = 1.0	1.4 gal/min-ft	Drainage GT (sewn pocket for inserting pipe)
				crush strength	ASTM D1621	-	35 psi	
				fungus resistance	ASTM G21	-	No growth	
EFLHD*	abutments wingwalls & retaining walls	sheet drain	undefined	flow rate	undefined			Drainage GT (sewn pocket for inserting pipe)
				crush strength	ASTM D1621	-	40 psi	

* EFLHD = Eastern Federal Lands Highway Division

Design of the PGD

In order to recommend an appropriate normal stress value to be used in the specification for the in-plane flow test, the lateral earth pressure acting on the geocomposite should be evaluated. A design methodology utilized by Koerner and Hwu (1989) is adopted in this report, and is included in Appendix B. Based on their design approach, the maximum lateral earth pressures of wall heights of 5, 10, and 15 m (15, 30 and 50 ft) are 35.4, 62.3, and 89.2 kPa (5, 9 and 13 psi), respectively. The hydraulic gradient of the in-plane flow test should be 1.0 to reflect a gravity flow condition.

Another aspect that needs to be considered is the required flow rate of the PGD. The "Maximum Flow from Wall/Abutment Drainage Systems" provided by PennDOT is utilized to determine the required flow rate of the core structure. As shown in Appendix C, the maximum flow volume of a structure backfill with a wall height of 10 m (30 ft) is 0.0033 m^3/sec-m (16 gal/min-ft). Note that the maximum flow volume depends on the wall height. A higher wall yields a higher flow value. Data that were shown in Table 1 in the earlier section indicate that the upper flow rate of the PGD is approximately 0.003 m^3/sec-m (14.5 gal/min-ft) under 100 kPa (14.5 psi) at a hydraulic gradient of 1.0, which is similar to that of a 10 m (30 ft) high wall with structure backfill. Thus, a wall height limit of 10 m (30 ft) is recommended in the proposed specification.

Tables 7(a) and (b) present the proposed specification for the designated PGD in SI units and English units, respectively. The maximum height of the vertical retaining structure is 10 m (30 ft). The minimum required core thickness is 10 mm (0.4 in). Three material properties are included in the specification. The mechanical behavior is defined by crush strength and deflection. A value of 300 kPa (43.5 psi) of crush strength, which is required by most states, is proposed. This value is well above the maximum lateral pressure load (62.3 kPa (9 psi)) of a 10 m (30 ft) high wall. Also a maximum deflection of 10 percent is required. For the hydraulic behavior, a flow rate of 0.0033 m^3/sec-m (16 gal/min-ft) is proposed. The test conditions are 100 kPa (14.5 psi) compressive stress at a hydraulic gradient of 1.0. The normal stress of 100 kPa (14.5 psi) is a factor of 1.6 higher than the maximum lateral pressure acting on the PGD of a 10 m (30 ft) high wall. Thus, the flow reduction that is caused by creep of core structure and geotextile intrusion is accommodated.

Table 7(a) Required Properties and Values for PGD (SI Units).

Application	Maximum Height (m)	Drain Type	Thickness (mm)	Property	Test Method	Test Condition	Required Value
retaining wall & abutment	10	sheet drain	> 10	crush strength	ASTM D1621	-	> 300 kPa
				deflection	ASTM D 1621	-	< 10%
				flow rate	ASTM D4716	100 kPa at i = 1.0	0.0033 m^3/s-m

Table 7(b) Required Properties and Values for PGD (English Units).

Application	Maximum Height (ft)	Drain Type	Thickness (in)	Property	Test Method	Test Condition	Required Value
retaining wall & abutment	30	sheet drain	> 0.4	crush strength	ASTM D1621	-	> 44 psi
				deflection	ASTM D 1621	-	< 10%
				flow rate	ASTM D4716	14.5 psi at i = 1.0	16 gal/min-ft

Geotextile

Regarding the geotextile component of the PGD, 10 of the 12 states have a material property specification for geotextiles used in subsurface drainage applications, as shown in Tables 8(a) and (b) for SI units and English units, respectively. In Pennsylvania, Class 2-Type B geotextile is specified for separation between in-situ soil and structure backfill behind abutments, as shown in Table 9. The required properties of this particular geotextile are very similar to what most of the states specify, except Kansas and New York, which specify a higher strength geotextile. In Tables 9(a) and (b), the properties of AASHTO M 288 Class 2 and Class 3 geotextiles are also listed for comparison. Properties listed in Table 9(a) are in SI units, whereas those in Table 9(b) are in English units. AASHTO Class 3 is the default geotextile for subsurface filtration if conditions are average. Data indicate that the PennDOT Class 2-type B geotextile has much lower required values than AASHTO Class 3; thus, it may not be adequate for use in long-term, subsurface filtration applications. The proposed specification for a geotextile that is associated with sheet drain products is AASHTO Class 3.

Table 8(a) - Summary of Geotextile Specifications by Various DOTs (SI Units).

State	Application	Geotextile Type	Classification		
			Property	Test Method	Requirement
Arizona	Geocomposite wall drain fabric	PET or PP non-woven	Permittivity, sec^{-1} (min.)	ARIZ 730	0.5
			O_{95}, mm (max.)	ASTM D4751	0.16 - 0.6
			Grab, N (min.)	ASTM D4632	400
			Grab Elongation (%)	ASTM D4632	35 min. and 115 max.
			Tear, N (min.)	ASTM D4533	130
			Puncture, N (min.)	ASTM D4833	130
			Mullen Burst, kPa (min.)	ASTM D3786	965
			Ultraviolet Stability	ASTM D4355	70% after 500 hours
Colorado	Drainage Fabric	Undefined	Permeability, cm/sec (min)	ASTM D4491	$K_{fabric} > K_{soil}$
			O_{95}, mm (max.)	ASTM D4751	0.297
			Grab, N (min.)	ASTM D4632	356
			Puncture, N (min.)	ASTM D4833	111
			Tear, N (min.)	ASTM D4533	111
			Mullen Burst, kPa (min.)	ASTM D3786	896
			Seam Strength, N (min.)	ASTM D4632	311
			Ultraviolet Stability	ASTM D4355	70% after 150 hours
Georgia	Geocomposite wall drain fabric	non-woven	Permittivity, $l/min/m^2$	ASTM D4491	Head from 75 mm to 25 mm 2000 to 14000 (max)
			Grab, N (min.)	ASTM D4632	290
			Grab Elongation (%)	ASTM D4632	40
			Puncture, N (min.)	ASTM D4533	130
Kansas	Subsurface drainage	non-woven			% In-situ Soil Passing 0.074 mm opening > 50%
			Permittivity, sec^{-1} (min.)	ASTM D4491	0.1
			O_{95}, mm (max.)	ASTM D4751	0.22
			Grab, N (min.)	ASTM D4632	700
			Elongation, % (min.)	ASTM D4632	50
			Puncture, N (min.)	ASTM D4833	250
			Tear, N (min.)	ASTM D4533	250
			Mullen Burst, kPa (min.)	ASTM D3786	1300
			Ultraviolet Stability	ASTM D4355	50% after 500 hours

Table 8(a) - Summary of Geotextile Specifications by Various DOTs (SI Units).

State	Application	GT Structural	Classification				
			Property	Test Method	Requirement		
Ohio	Underdrains and Slope drains	woven and non-woven			% In-situ Soil Passing 0.074 mm opening		
					< 50%		50 - 85% passing
			Flow rate, cm/sec (min.)	ASTM D4491	-		$1x10^{-2}$
			O_{95}, mm (max.)	ASTM D4751	0.6		0.3
			Grab, N (min.)	ASTM D4632	355		
			Puncture, N (min.)	ASTM D4833	110		
			Tear, N (min.)	ASTM D4533	110		
			Mullen Burst, kPa (min.)	ASTM D3786	900		
Michigan	Drainage Composite	undefined	Permittivity, sec^{-1} (min.)	ASTM D4491	0.5		
			O_{95}, mm (max.)	ASTM D4751	0.21		
			Grab, N (min.)	ASTM D4632	400		
			Tear, N (min.)	ASTM D4533	200		
			Puncture, N (min.)	ASTM D4833	290		
			Mullen Burst, kPa (min.)	ASTM D3786	1400		
Missouri	Subsurface Drainage	undefined			Material may be either AASHTO M 288 Class 2 or 3		
					% In-situ Soil Passing 0.074 mm opening		
					< 50%		> 50%
			Permittivity, sec^{-1} (min.)	ASTM D4491	1.3		1.3
			O_{95}, mm (max.)	ASTM D4751	0.21		0.15
New York	Drainage	non-woven			% In-situ Soil Passing 0.074 mm opening		
					< 15% (Class A)	15% to 50% (Class B)	> 50% (Class C)
			Permittivity, sec^{-1} (min.)	ASTM D4491	0.5	0.2	0.1
			O_{95}, mm (max.)	ASTM D4751	0.43	0.25	0.22
			Grab, N (min.)	ASTM D4632	700	700	700
			Tear, N (min.)	ASTM D4533	250	250	250
Virginia	Drainage	undefined	Permittivity, sec^{-1} (min.)	ASTM D4491	0.8		
			O_{95}, mm (max.)	ASTM D4751	0.3		
			Tensile, kN/m (min.)	VTM-52	4.4		
			Tensile Elongation, % (min.)	VTM-52	20		
			Durability	undefined	50% strength retained after 6 months installation		

Table 8(a) - Summary of Geotextile Specifications by Various DOTs (SI Units).

State	Application	GT Structural	Classification		
			Property	Test Method	Requirement
Wyoming	Drainage & filtration	undefined	Permittivity, sec^{-1} (min.)	ASTM D4491	0.2
			O_{95}, mm (max.)	ASTM D4751	0.425 - 0.15
			Tensile, kN/m (min.)	ASTM D4595	7
			Tensile Elongation, % (min.)	ASTM D4595	40
			Tear, N (min.)	ASTM D4533	110
			Puncture, N (min.)	ASTM D4833	110
			Mullen Burst, kPa (min.)	ASTM D3786	900

Table 8(b) - Summary of Geotextile Specifications by Various DOTs (English Units).

State	Application	Geotextile Type	Classification		
			Property	Test Method	Requirement
Arizona	Geocomposite wall drain fabric	PET or PP non-woven	Permittivity, min^{-1} (min)	ARIZ 730	30
			AOS, Sieve No. (max.)	ASTM D4751	100-30
			Grab, lb (min.)	ASTM D4632	90
			Grab Elongation (%)	ASTM D4632	35 min. and 115 max.
			Tear, lb (min.)	ASTM D4533	30
			Puncture, lb (min.)	ASTM D4833	30
			Mullen Burst, psi (min.)	ASTM D3786	140
			Ultraviolet Stability	ASTM D4355	70% after 500 hours
Colorado	Drainage Fabric	Undefined	Permeability, in/min (min)	ASTM D4491	$K_{fabric} > K_{soil}$
			AOS, Sieve No. (max.)	ASTM D4751	50
			Grab, lb (min.)	ASTM D4632	80
			Puncture, lb (min.)	ASTM D4833	25
			Tear, lb (min.)	ASTM D4533	25
			Mullen Burst, psi (min.)	ASTM D3786	130
			Seam Strength, lb (min.)	ASTM D4632	70
			Ultraviolet Stability	ASTM D4355	70% after 150 hours
Georgia	Geocomposite wall drain fabric	non-woven	Permittivity, $gal/min/in^2$	ASTM D4491	Head from 3 in to 1 in 340 to 2380 (max)
			Grab, lb (min.)	ASTM D4632	65
			Grab Elongation (%)	ASTM D4632	40
			Puncture, lb (min.)	ASTM D4533	30
Kansas	Subsurface drainage	non-woven			% In-situ Soil Passing No. 200 US Std. Sieve
					> 50%
			Permittivity, min^{-1} (min.)	ASTM D4491	6
			AOS, Sieve No. (max.)	ASTM D4751	70
			Grab, lb (min.)	ASTM D4632	157
			Elongation, % (min.)	ASTM D4632	50
			Puncture, lb (min.)	ASTM D4833	56
			Tear, lb (min.)	ASTM D4533	56
			Mullen Burst, psi (min.)	ASTM D3786	190
			Ultraviolet Stability	ASTM D4355	50% after 500 hours

Table 8(b) - Summary of Geotextile Specifications by Various DOTs (English Units).

State	Application	GT Structural	Classification				
			Property	Test Method	Requirement		
Ohio	Underdrains and Slope drains	woven and non-woven			% In-situ Soil Passing No. 200 US Std. Sieve		
					< 50%		50 - 85% passing
			Flow rate, in/min (min.)	ASTM D4491	-		1.5
			AOS, Sieve No. (max.)	ASTM D4751	30		50
			Grab, lb (min.)	ASTM D4632	90		
			Puncture, lb (min.)	ASTM D4833	25		
			Tear, lb (min.)	ASTM D4533	25		
			Mullen Burst, psi (min.)	ASTM D3786	200		
Michigan	Drainage Composite	undefined	Permittivity, min^{-1} (min.)	ASTM D4491	30		
			AOS, Sieve No. (max.)	ASTM D4751	70		
			Grab, lb (min.)	ASTM D4632	90		
			Tear, lb (min.)	ASTM D4533	45		
			Puncture, lb (min.)	ASTM D4833	65		
			Mullen Burst, psi (min.)	ASTM D3786	200		
Missouri	Subsurface Drainage	undefined			Material may be either AASHTO M 288 Class 2 or 3		
					% In-situ Soil Passing No. 200 US Std. Sieve		
					< 50%		> 50%
			Permittivity, min^{-1} (min.)	ASTM D4491	78		78
			AOS, Sieve No. (max.)	ASTM D4751	70		100
New York	Drainage	non-woven			% In-situ Soil Passing No. 200 US Std. Sieve		
					< 15% (Class A)	15% to 50% (Class B)	> 50% (Class C)
			Permittivity, min^{-1} (min.)	ASTM D4491	30	12	6
			AOS, Sieve No. (max.)	ASTM D4751	40	60	70
			Grab, lb (min.)	ASTM D4632	157	157	157
			Tear, lb (min.)	ASTM D4533	56	56	56
Virginia	Drainage	undefined	Permittivity, min^{-1} (min.)	ASTM D4491	48		
			AOS, Sieve No. (max.)	ASTM D4751	50		
			Tensile, lb/in (min.)	VTM-52	25		
			Tensile Elongation, % (min.)	VTM-52	20		
			Durability	undefined	50% strength retained after 6 months installation		

Table 8(b) - Summary of Geotextile Specifications by Various DOTs (English Units).

State	Application	GT Structural	Classification		
			Property	Test Method	Requirement
Wyoming	Drainage & filtration	undefined	Permittivity, min^{-1} (min.)	ASTM D4491	12
			AOS, Sieve No. (max.)	ASTM D4751	40-100
			Tensile, lb/in (min.)	ASTM D4595	40
			Tensile Elongation, % (min.)	ASTM D4595	40
			Tear, lb (min.)	ASTM D4533	25
			Puncture, lb (min.)	ASTM D4833	25
			Mullen Burst, psi (min.)	ASTM D3786	130

Table 9(a) - Properties of Geotextiles Required by PennDOT and AASHTO M288 (SI Units).

Fabric Properties	Test Method	AASHTO M 288-96 (Subsurface Filtration)						PennDOT		
		Class 2			Class 3 *(1)*			**Class 2 - Type B**		
		% soil passing 0.075 mm			% soil passing 0.075 mm			**% soil passing 0.075 mm**		
		< 15	15 to 50	> 50	< 15	15 to 50	> 50	**< 50%**	**> 50%**	**Design Specified**
1. Grab Tensile Strength, N	ASTM D4632	1100			800			**400**		
2. Grab Tensile Elongation, %	ASTM D4632	< 50%			< 50%			**15**		
3. Burst Strength, kPa	ASTM D3786	2700			2100			**965**		
4. Puncture, N	ASTM D4833	400			300			**178**		
5. Trapezoid Tear Strength, N	ASTM D4533	400			300			**133**		
6. Apparent Opening Size (AOS), mm	ASTM D4751	0.43	0.25	0.22	0.43	0.25	0.22	**> 0.6**	**0.3**	**Design value**
7. Permeability, K, cm/sec	ASTM D4491	-	-	-	-	-	-	**$K_{fabric} > 10 K_{soil}$**		**Design value**
8. Permitivity, sec^{-1}	ASTM D4491	0.5	0.2	0.1	0.5	0.2	0.1	-	-	-
9. Seam Strength, N. *(2)*	ASTM D4632	990			720			**356**		
10. Ultraviolet Resistance Strength Retention (%)	ASTM D4355	50 after 500 hr			50 after 500 hr			**70 after 150 hr**		

Note:

(1) Class 3 geotexile is the default geotextile selection if conditions are less severe

(2) Applied to both field and/or manufactured seams

Table 9(b) - Properties of Geotextiles Required by PennDOT and AASHTO M288 (English Units).

Fabric Properties	Test Method	AASHTO M 288-96 (Subsurface Filtration)						PennDOT		
		Class 2			Class 3 *(1)*			Class 2 - Type B		
		% soil passing 0.075 mm			% soil passing 0.075 mm			% soil passing 0.075 mm		
		< 15	15 to 50	> 50	< 15	15 to 50	> 50	< 50%	> 50%	Design Specified
1. Grab Tensile Strength, lb	ASTM D4632	247			180			90		
2. Grab Tensile Elongation, %	ASTM D4632	< 50%			< 50%			15		
3. Burst Strength, psi	ASTM D3786	392			305			140		
4. Puncture, lb	ASTM D4833	90			67			40		
5. Trapezoid Tear Strength, lb	ASTM D4533	90			67			30		
6. Apparent Opening Size (AOS) Sieve No.	ASTM D4751	40	60	70	40	60	70	> 0.6	0.3	Design value
7. Permeability, K, cm/sec	ASTM D4491	-	-	-	-	-	-	$K_{fabric} > 10 K_{soil}$		Design value
8. Permitivity, sec^{-1}	ASTM D4491	0.5	0.2	0.1	0.5	0.2	0.1	-	-	-
9. Seam Strength, lb. *(2)*	ASTM D4632	223			162			80		
10. Ultraviolet Resistance Strength Retention (%)	ASTM D4355	50 after 500 hr			50 after 500 hr			70 after 150 hr		

Note:

(1) Class 3 geotextile is the default geotextile selection if conditions are less severe.

(2) Applied to both field and/or manufactured seams.

Task 4 – Development of Specification and Guidelines

The proposal Specification and Guidelines for the PGD use behind the retained structures is enclosed as Appendices C and D, respectively.

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APPENDIX A:
DETERMINATION OF THE ALLOWABLE FLOW RATE OF A DRAINAGE GEOCOMPOSITE

Geosynthetic Research Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

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GRI Standard – GC8 (DRAFT)

Standard Guide for

Determination of the Allowable Flow Rate of a Drainage Geocomposite

1. Scope

1.1 This guide presents a methodology for determining the allowable flow rate of a candidate drainage geocomposite. The resulting value can be used directly in a hydraulics-related design to arrive at a site-specific factor of safety.
1.2 The procedure is to first determine the candidate drainage composite's flow rate under site-specific conditions, and then modify this value by means of creep reduction and clogging reduction factors.
1.3 For aggressive liquids, a "go/no-go" chemical resistance procedure is suggested. This is a product-specific verification test.
1.4 The type of drainage geocomposites under consideration necessarily consist of a drainage core whose purpose is to convey liquid within its manufactured plane. The drainage core can be a geonet, 3-D mesh, built-up columns, single or double cuspations, etc.
1.5 The drainage core usually consists of a geotextile on its upper and/or lower surface. In some cases, the drainage core is used by itself. The guide addresses all of these conditions.
1.6 The guide is also applicable to thick nonwoven geotextiles when they are utilized for their drainage capability.
1.7 All types of polymers are under consideration in this guide.
1.8 The guides does not address the required flow rate to which a comparison is made for the final factor of safety value. This is clearly a site-specific design issue.

2. Referenced Documents

2.1 ASTM Standards
D1987–"Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters."
D2240 – "The Method for Rubber Property–Durometer Hardness."

D471–"Test Method for Constant Head Hydraulic Transmissivity (In Plane Flow) of Geotextiles and Geotextile Related Products."
D5322–"Standard Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids."
D6388–"Standard Practice for Tests to Evaluate the Chemical Resistance of Geonets to Liquids" (Draft).
D6389–"Standard Practice for Tests to Evaluate the Chemical Resistance of Geotextiles to Liquids" (Draft).

2.2 GRI Standards
GN 1 Test Method for Compression Behavior of Geonets.
GS 4 Test Method for Time Dependent (Creep) Deformation Under Normal Pressure.

3. Summary of Guide

3.1 This guide presents the necessary procedure to be used in obtaining an allowable flow rate of a candidate drainage geocomposite. The resulting value is then compared to a required design flow rate for a product-specific and site-specific factor of safety. The guide does not address the required (or design) flow rate value, nor the subsequent factor of safety value.
3.2 All of the procedures recommended in this guide use ASTM or GRI test methods.
3.3 The guide is applicable to all types of drainage geocomposites, regardless of their core configuration or geotextile type. It can also be used to evaluate thick nonwoven geotextiles.

4. Significance and Use

4.1 The guide is meant to establish a uniform test method and procedure in order to determine the allowable flow rate of a candidate drainage geocomposite for design purposes.
4.2 The guide requires communication between the manufacturer, testing organization and designer in setting site-specific control variables such as stress level and orientation, type of permeating liquid, and materials below/above the geocomposite test specimen.
4.3 The guide is useful to testing laboratories in that a standard guide is at hand to provide appropriate data for both manufacturer and designer clients.

5. Structure of the Guide

5.1 Basic Formulation–This guide is focused on determination of "q_{allow}" using the following formula:

$$q_{allow} = q_{short\ term}\left[\frac{1}{RF_{CR} \times RF_{CC} \times RF_{BC}}\right] \quad (1)$$

where

q_{allow}	=	allowable flow rate
$q_{short\ term}$	=	flow rate determined under simulated conditions except for load duration
RF_{CR}	=	reduction factor for creep to account for long-term behavior
RF_{CC}	=	reduction factor for chemical clogging
RF_{BC}	=	reduction factor for biological clogging

Note 1: By simulating site-specific conditions (except for load duration and long-term clogging) in the short term, additional reduction factors such as intrusion need not be explicitly accounted for.

Note 2: The value of q_{allow} is typically used to determine the product-specific and site-specific factor of safety as follows:

$$FS = \frac{q_{allow}}{q_{reqd}} \quad (2)$$

The value of "q_{reqd}" is a design issue and is not addressed in this guide. Likewise, the numeric value of the factor of safety is not addressed in this guide. Suffice it to say that, depending on the duration and criticality of the situation, FS-values should be conservative unless experience allows otherwise.

5.2 Upon selecting the candidate drainage geocomposite product, one must obtain the short- term flow rate according to the ASTM D4716 transmissivity test. This establishes the allowable value except for long-term creep and clogging from chemicals and biological matter.

5.3 Reduction Factor for Creep–This is a long-term compressive load test focused on the stability and/or deformation of the polymeric core. The test can also be configured to assess the performance of the covering geotextile(s). Stress orientation can be perpendicular or at an angle to the test specimen.

5.4 Chemical and/or Biological Clogging–The issue of long-term reduction factors to account for clogging within the core space is a site-specific issue. The issue is essentially impractical to simulate in the laboratory, hence a table is provided for consideration by the designer.

5.5 Chemical Resistance/Durability–This procedure results in a "go/no-go" decision as to potential chemical reactions between the permeating liquid and the polymers comprising the drainage core and geotextiles. The issue will be addressed in this guide but is not a reduction factor, per se.

6. Determination of the Short Term Flow Rate ($q_{short\text{-}term}$)

6.1 Using the ASTM D4716 transmissivity test with the conditions stated below (unless otherwise agreed upon by the parties involved), determine the short-term flow rate of the drainage geocomposite under consideration.

6.1.1 The test specimen shall be the entire geocomposite. If geotextiles are bonded to the drainage core, they shall not be removed and the entire geocomposite shall be tested as a unit. A minimum of three replicates in the preferred orientation shall be tested and the results average for the reported value.

6.1.2 Specimen size shall be 300 × 300 mm (12 × 12 in.) within the stressed area.

6.1.3 Specimen substratum shall be one of the following four options. The decision of which is made by the manufacturer, testing organization and site-specific project designer. The options are (i) rapid platen, (ii) foam, (iii) sand, or (iv) site-specific soil or other material.

6.1.3.1 If closed-cell foam is used, it shall be approximately 12 mm (0.5 in.) thick and a maximum Durometer of 2.0, as measured in ASTM D2240, Type D.

6.1.3.2 If sand is used, it shall be Ottawa test sand at a relative density of 85 percent, water content of 10 percent, and compacted thickness of 25 mm (1.0 in.).

6.1.3.3 If site-specific soil or other material is used, it must be carefully considered and agreed upon by the parties involved. Size, gradation, moisture content, density, etc., are all important considerations.

6.1.4 Specimen superstratum shall also be one of the four same options as mentioned in § 6.1.3 above.

6.1.5 The applied stress level is at the discretion of the manufacturer, testing organization and designer. Unless stated otherwise, the orientation shall be normal to the test specimen.

6.1.6 The duration of the loading shall be for 100 hours. A single site-specific data point is taken at that time.

6.1.7 The hydraulic gradient at which the above data point is taken is at the discretion of the manufacturer, testing organization and designer.

6.1.8 The permeating liquid is water, unless agreed upon otherwise by the manufacturer, testing organization, and designer.

6.1.9 Calculations

$$Q = kiA \quad (3)$$

$$Q = ki(Wt)$$

$$Q / W = \theta i \quad (4)$$

$$q = \theta i \quad (5)$$

where

Q = flow rate per unit time (m^3/sec)
k = permeability (m/sec)
i = hydraulic gradient (= H/L)
H = head loss across specimen (m)
L = length of specimen (m)
A = cross sectional area of specimen (m^2)
W = width of specimen (m)
t = thickness of specimen (m)
θ = transmissivity (m^3/sec-m or m^2/sec)
q = flow rate per unit width (m^2/sec)

The results can be presented as flow rate per unit width (Q/W), or as transmissivity (θ), as agreed upon by the parties involved.

7. Reduction Factor for Creep

7.1 Using the GRI GS4 test method for time-dependent (creep) deformation, the candidate geocomposite is placed under compressive stress and its decrease in thickness (deformation) is monitored over time.

Note 3–This is not a flow rate test, although the test specimen can be immersed in a liquid to be agreed upon by the manufacturer, testing organization, and designer. However, it is usually a test conducted without liquid.

7.1.1 The test specimen shall be the entire geocomposite. If geotextiles are bonded to the drainage core, they should not be removed, and the entire composite should be tested. A minimum of three replicate tests should be performed and the results averaged for the reported value.

7.1.2 Specimen size should be 150 × 150 mm (6.0 × 6.0 in.) and placed in a rigid box made from a steel base and sides. The steel load plate above the test specimen shall be used to transmit a constant stress over time. Deformation of the upper plate is measured by at least two dial gauges and the results averaged accordingly.

Note 4–For high stress conditions requiring a large size and number of weights with respect to laboratory testing and safety, the specimen size can be reduced to 100 × 100 mm (4.0 × 4.0 in.).

7.1.3 Specimen substratum shall be a rigid platen, typically the base of the steel containment box. Alternatively, it can be a 1.5 mm- (60 mil) thick HDPE geomembrane.

7.1.4 Specimen superstratum can be of two configurations: rigid platen for core creep alone, or simulated/actual cross section for core and geotextile creep.

7.1.4.1 Rigid platen for core creep is accomplished by placing a steel platen above the geocomposite and applying a constant compressive stress.

7.1.4.2 Simulated/actual cross section for core and geotextile creep can be accomplished by one of three procedures; (i) foam, (ii) sand, or (iii) site-specific soil or waste. See sections 6.1.4.1, 6.1.4.2 and 6.1.4.3, respectively.

7.1.5 The geocomposite shall be dry, unless water or a simulated or site-specific leachate is agreed upon by the parties involved.

7.1.6 The normal stress magnitude(s) shall be the same as applied in the transmissivity test described in Section 6.0. Alternatively, it can be as agreed upon by the manufacturer, testing organization, and project designer.

7.1.7 The load inclination shall be normal to the test specimen. If there exists a tendency for the core structure to deform laterally, separate tests at the agreed upon load inclinations shall also be performed at the discretion of the parties involved.

7.1.8 The dwell time shall be 10,000 hours. If, however, this is a confirmation test (or if a substantial data base exists on similar products if the same style), the dwell time can be reduced to 1000 hours. This decision must be made with agreement between the manufacturer, testing organization, and project designer.

7.1.9 The above process results in a set of creep curves similar to Figure 1(a). The curves are to be interpreted as shown in Figure 1(b). The reduction factor for creep, for each of the respective curves shown in the direct data plots, is interpreted as follows:

Example: If the original geocomposite thickness was 5.00 mm (0.197 in.) and the deformation (Δy in Figure 1b) was 0.38 mm (0.015 in.), the reduction factor for creep based on a linear reduction would be the following:

SI Units	Standard Units
$\frac{5.0-0.38}{5.0}=0.924$ and $RF_{CR}=\frac{1}{0.924}=1.08$	$\frac{0.197-0.015}{0.197}=0.923$ and $RF_{CR}=\frac{1}{0.923}=1.08$

8. Reduction Factors for Core Clogging

There are two general types of core clogging that might occur over a long time period. They are chemical clogging and biological clogging. Both are site-specific and both are essentially impractical to simulate in the laboratory.

8.1 Chemical clogging within the drainage core space can occur with precipitates deposited from high alkalinity soils, typically calcium and magnesium. Other precipitates can also be envisioned, such as fines from turbid liquids, although this is less likely since the turbid liquid must typically pass through a geotextile filter. It is obviously a site-specific situation.

8.2 Biological clogging within the drainage core space can occur by roots growing through the overlying soil and extending downward, through the geotextile filter, and into the drainage core. It is a site-specific situation and depends on the local, or anticipated, vegetation, cover soil, hydrology, etc.

8.3 Default tables for the above two potential clogging mechanisms (chemical and biological) are very subjective and, by necessity, broad in their upper and lower limits. The following table is offered as a guide.

Range of Clogging Reduction Factors, after R. M. Koerner, "Designing with Geosynthetics." Prentice Hall, 4th Ed., 1998.

Application	Range of Reduction Factors	
	Chemical Clogging[1]	Biological Clogging[2]
Retaining wall filters	1.0 to 1.2	1.0 to 1.3
Underdrain filters	1.2 to 1.5	2.0 to 4.0
Erosion-control filters	1.0 to 1.2	3.0 to 4.0
Landfill filters	1.2 to 1.5	5.0 to 10
Gravity drainage	1.2 to 1.5	1.2 to 1.5
Pressure drainage	1.1 to 1.3	1.1 to 1.3

[1]Values can be higher particularly for high alkalinity groundwater.
[2]Values can be higher for turbidity and/or for microorganism contents greater than 5000 mg/l.

9. Polymer Degradation

9.1 Degradation of the materials from which the drainage geocomposite are made, with respect to the site-specific liquid being transmitted, is a polymer issue. Most geocomposite drainage cores are made from polyethylene, polypropylene, polyamide or polystyrene. Most geotextile filter/separators covering the drainage cores are made from polypropylene, polyester, or polyethylene.

> Note 5–It is completely inappropriate to strip the factory-bonded geotextile off the drainage core and then test one or the other components. Both geotextile and drainage core will be damaged in the process, no matter how much care is exercised.

9.2 If degradation testing is recommended, the drainage core and the geotextile should be tested separately in their as-received condition before lamination and bonding.

9.3 The incubation of the drainage cores and/or geotextile coupons is to be done according to the ASTM D5322 immersion procedure.

9.4 The testing of the incubated drainage cores is to be done according to ASTM D6388, test methods for evaluation of incubated geonets.

> Note 6–For drainage cores other than geonets, e.g., columnar, cuspated, meshes, etc., it may be necessary to conduct additional tests that appear in ASTM D6388. These tests, and their procedures, should be discussed and agreed upon by the manufacturer, testing organization, and project designer.

9.5 The testing of the incubated geotextiles is to be done according to ASTM D6389, test methods for evaluation of incubated geotextiles.

> Note 7–The information obtained in testing the drainage core (Section 8.4) and the geotextile (Section 8.5) result in a "go/no-go" situation and not in a reduction factor, per se. If a chemical reaction is indicated, one selects a different type of geocomposite material (drainage core and/or geotextile).

10. Summary

10.1 For a candidate drainage geocomposite, the short-term flow rate behavior under the site-specific set of variables is to be obtained per ASTM D4716 and presented following procedures of Section 6.0.

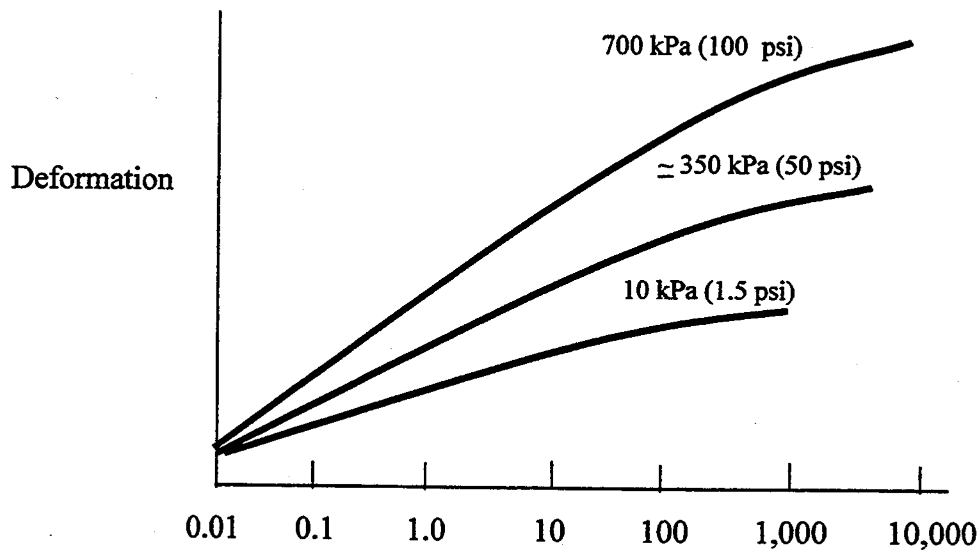
10.2 A reduction factor for creep of the drainage core, or the entire geocomposite, following Section 7.0 per GRI GS4 is presented. The result is usually a unique value for a given set of conditions.

10.3 A reduction factor for chemical and/or biological clogging, as discussed in Section 8.0 can be included. It is very much a site-specific situation at the discretion of the designer.

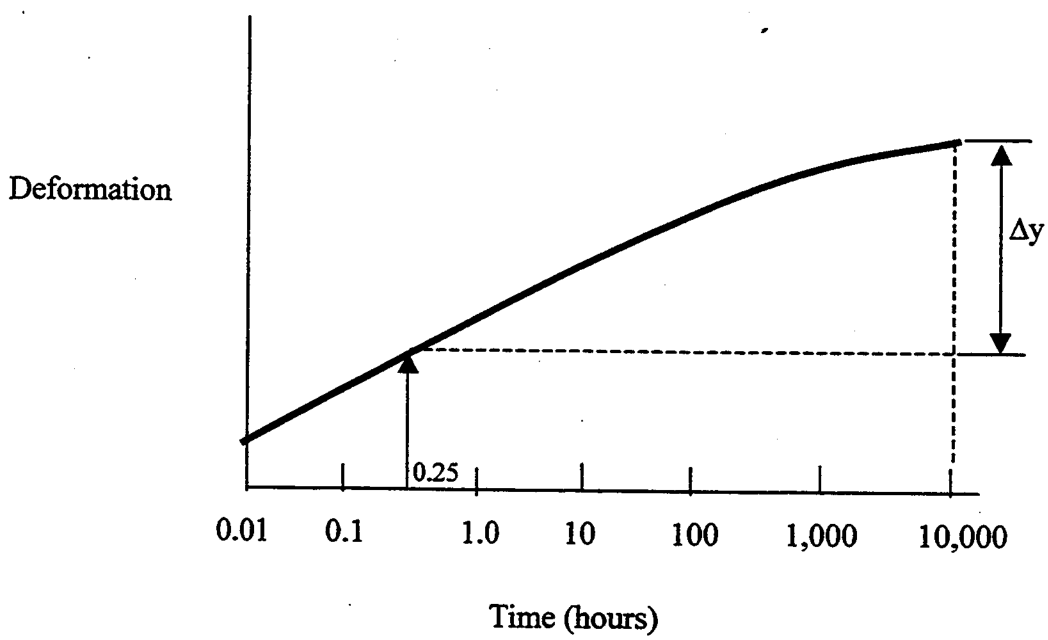
10.4 Polymer degradation to harsh liquids is covered in separate immersion and test protocols, e.g., ASTM D5322 (immersion), ASTM D6388 (geonets), and ASTM

D6389 (geotextiles). The procedure does not result in a reduction factor, rather in a "go/no-go" decision with the product under consideration.

10.5 Other possible flow rate reductions and/or concerns of flow in overlap regions, effect of high or low temperatures, etc., are site-specific and cannot readily be generalized in a guide such as this.



(a) Direct data from creep testing



(b) Interpretation to obtain creep reduction factor

Figure A-1–Hypothetical example of creep test data and data interpretation to obtain creep reduction factor.

APPENDIX B:
STRENGTH REQUIREMENT FOR SHEET DRAIN BEHIND RETAINING STRUCTURES

Calculation for Minimum Strength Requirement for Sheet Drain Behind Vertical Retaining Structure

Stress due to Backfill Soil and Surcharge:

After backfilling of the sheet drain is completed and the wall is functional, the major stress comes from the backfill soils' self-weight plus any surcharge loads to the upper ground surface. The situation is shown in the sketch of Figure B-1.

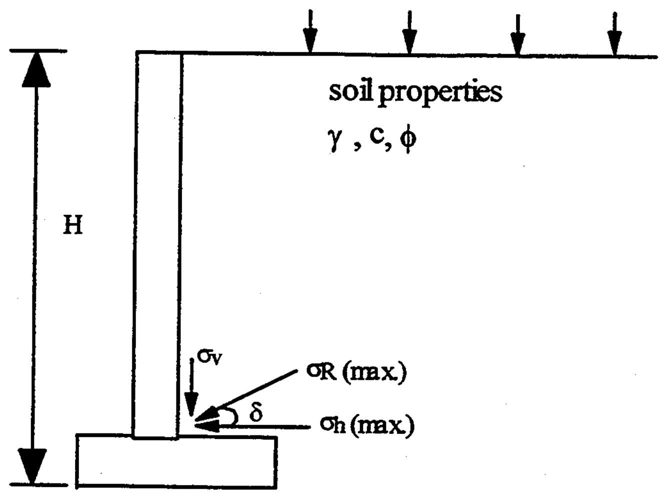


Figure B-1. Cross-section of retaining wall details and soil and surcharge stresses.

Using conventional geotechnical engineering principles, the maximum stress is at the deepest part of the wall stem. Using Rankine theory, the calculation proceed as follows:

$$\sigma_R = \gamma H K_a + \sigma_q K_a$$

where:

σ_R	= resultant stress (kPa)
γ	= unit weight of backfill soil (kN/m^3)
H	= wall height (m)
K_a	= coefficient of active earth pressure = $\tan^2(45 - \phi/2)$
ϕ	= friction angle of backfill soil (degree)
σ_q	= surcharge stress at ground surface (includes live loads) (kPa)

For a retaining structure of 5 m in height, the backfill soil is a silty sand with unit weight of 19 kN/m^3 and a friction angle of 34°. It is assumed that the total of surcharge and live load together is 30 kPa. The σ_R value is calculated as follows:

$$K_a = \tan^2(45 - \phi/2)$$
$$= \tan^2(45 - 34/2)$$
$$= 0.283$$

$$\sigma_R = \gamma H K_a + \sigma_q K_a$$
$$= (19)*(5)*(0.283) + (30)*(0.283)$$
$$= 26.9 + 8.5$$
$$= \underline{35.4\ kPa}$$

For a retaining structure of 10 m in height, the σ_R is calculated as follows:

$$\begin{aligned}\sigma_R &= \gamma H K_a + \sigma_q K_a \\ &= (19)*(10)*(0.283) + (30)*(0.283) \\ &= 53.8 + 8.5 \\ &= \underline{62.3\ \text{kPa}}\end{aligned}$$

For a retaining structure of 15 m in height, the σ_R is calculated as follows:

$$\begin{aligned}\sigma_R &= \gamma H K_a + \sigma_q K_a \\ &= (19)*(15)*(0.283) + (30)*(0.283) \\ &= 80.7 + 8.5 \\ &= \underline{89.2\ \text{kPa}}\end{aligned}$$

For a retaining structure of 15 ft in height, the backfill soil is a silty sand with unit weight of 121 lb/ft^3 and a friction angle of 34°. It is assumed that the total of surcharge and live load together is 4.35 psi. The σ_R value is calculated as follows:

$$\begin{aligned}K_a &= \tan^2(45 - \phi/2) \\ &= \tan^2(45 - 34/2) \\ &= 0.283 \\ \sigma_R &= \gamma H K_a + \sigma_q K_a \\ &= (121)*(15)*(1/144)*(0.283) + (4.35)*(0.283) \\ &= 3.6 + 1.2 \\ &= \underline{4.8\ \text{psi}}\end{aligned}$$

For a retaining structure of 30 ft in height, the σ_R is calculated as follows:

$$\begin{aligned}\sigma_R &= \gamma H K_a + \sigma_q K_a \\ &= (121)*(30)*(1/144)*(0.283) + (4.35)*(0.283) \\ &= 7.1 + 1.2 \\ &= \underline{8.3\ \text{psi}}\end{aligned}$$

For a retaining structure of 50 ft in height, the σ_R is calculated as follows:

$$\begin{aligned}\sigma_R &= \gamma H K_a + \sigma_q K_a \\ &= (121)*(50)*(1/144)*(0.283) + (4.35)*(0.283) \\ &= 11.9 + 1.2 \\ &= \underline{13.1\ \text{psi}}\end{aligned}$$

APPENDIX C:
MAXIMUM FLOW FROM WALL/ABUTMENT DRAINAGE SYSTEMS

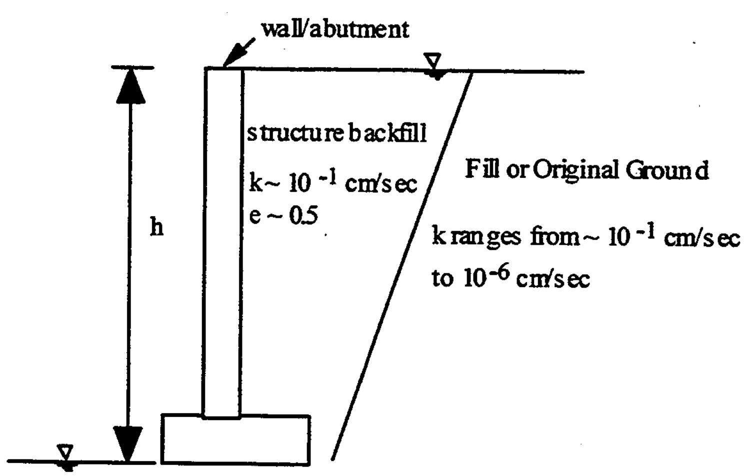
Maximum Flow From Wall/Abutment Drainage Systems

Issues:

1. Permeability/Hydraulic Conductivity (k)
2. Void Ratio, e (of structure backfill)
3. Darcy's Law (Q = kiA)
4. Hydraulic Gradient (i)
5. Degree of Saturation, S (percent)

Assumptions:

1. For maximum flow, the "k" of the structure backfill controls.
2. Assume fully saturated (S = 100 percent) structure backfill with rapid drawdown condition.
3. Estimate hydraulic gradient, $i = \Delta h/\Delta L \approx 1$.
4. Assume constant head for calculation of flow (Q).
5. Above assumptions were derived for a worst case, maximum possible flow condition.



Calculation:

1. Given void ration, $e = V_v/V_s = V_v/(V-V_v)$
2. If normalize V = 1, then $V_v = 0.33$
3. Therefore total flow "channel" area, A = 3.55*h per sq. meter (0.33*h per sq. ft) of wall/abutment face
4. Maximum possible flow volume, Q = kiA = 0.0011*h ft^3/sec-ft

APPENDIX D:
SPECIFICATION FOR PREFABRICATED GEOCOMPOSITE DRAINS USED BEHIND VERTICAL STRUCTURES

PREFABRICATED GEOCOMPOSITE DRAINS

I. DESCRIPTION - This work consists of furnishing and installing prefabricated geocomposite drains (PGD) behind abutments, wing walls and retaining walls as shown on the plans as an alternative to aggregate structural backfill when approved by the Engineer.

II. MATERIALS –

(a) General. PGDs shall be at least 1.2 m (4 ft) wide, flexible, rectangular mats consisting of a supporting drainage core material and a geotextile filter permanently bonded to the core material on one side only. The product shall be supplied by one of the approved manufacturers listed and meeting the following requirements:

1. Prefabricate geocomposite drainage core.

1.a General. The prefabricated geocomposite drainage core shall be manufactured from a preformed, stable polymer with a cuspated or dimple structure. The polymer shall be resistant to commonly encountered chemicals and hydrocarbons, and resistant to ultraviolet exposure. The drainage core shall provide support for and shall be bonded to the geotextile filter at intervals not exceeding 30 mm (1.2 in) in any direction.

1.b Physical Requirement. Table D-1(a) and (b) show the minimum property values in SI units and English units, respectively.

Table D-1(a) – Required Properties and Values for PGD (SI units).

Application	Maximum Height (m)	Drain	Thickness (mm)	Property	Test Method	Test Condition	Required Value
Retaining wall & abutment	10	Wall drain	> 10	Crush strength	ASTM D1621	-	300 kPa
				Deflection	ASTM D1621	-	< 10%
				Flow rate	ASTM D4716	100 kPa at i = 1.0	0.0033 $m^3/s\text{-}m$

Table D-1(b) – Required Properties and Values for PGD (English units).

Application	Maximum Height (ft)	Drain Type	Thickness (in)	Property	Test Method	Test Condition	Required Value
Retaining wall & abutment	30	Wall drain	> 0.4	Crush strength	ASTM D1621	-	43.5 psi
				Deflection	ASTM D1621	-	< 10%
				Flow rate	ASTM D4716	14.5 psi at i = 1.0	16 gal/min-ft

2. Geotextile.

2.a General. Use geotextile consisting of long chain polymeric filaments or yarns such as polyethylene, polyamide, polypropylene, or polyester formed into a stable network so that the filaments or yarns retain their relative position to each other. Use geotextile inert to commonly encountered construction chemicals.

2.b Physical Requirements. Table D-2 (a) and (b) show the minimum property values in SI units and English units, respectively. (Note that they are the same as the AASHTO M 288-96 Class 3, subsurface filtration).

Table D-2(a) – Required Properties and Values of Geotextile Filter (SI unites).

Fabric Property	Test Method	Required Value		
		% soil passing 0.075 mm		
		< 15	15 to 50	> 50
1. Grab Tensile Strength (N)	ASTM D4632	800		
2. Grab Tensile Elongation (%)	ASTM D4632	< 50		
3. Burst Strength (kPa)	ASTM D3786	2100		
4. Puncture (N)	ASTM D4833	300		
5. Trapezoid Tear Strength (N)	ASTM D4533	300		
6. O_{95} (mm)	ASTM D4751	0.43	0.25	0.22
7. Permittivity (sec^{-1})	ASTM D4491	0.5	0.2	0.1
8. Seam Strength (N)	ASTM 4632	720		
9. Ultraviolet Resistance Strength Retained (%)	ASTM D4355	50 after 500 hours		

Table D-2(b) – Required Properties and Values of Geotextile Filter (English units).

Fabric Property	Test Method	Required Value		
		% soil passing #200 sieve		
		< 15	15 to 50	> 50
1. Grab Tensile Strength (lb)	ASTM D4632	180		
2. Grab Tensile Elongation (%)	ASTM D4632	< 50		
3. Burst Strength (psi)	ASTM D3786	305		
4. Puncture (lb)	ASTM D4833	67		
5. Trapezoid Tear Strength (lb)	ASTM D4533	67		
6. Apparent Opening Size (sieve no.)	ASTM D4751	40	60	70
7. Permittivity (sec^{-1})	ASTM D4491	0.5	0.2	0.1
8. Seam Strength (lb)	ASTM 4632	162		
9. Ultraviolet Resistance Strength Retained (%)	ASTM D4355	50 after 500 hours		

(b) Acceptance. Acceptance of the prefabricated geocomposite drain (PGD) will be based on certified test data submitted by the manufacturer and on testing by MTD.

(c) Certification. Certify each shipment as specified in Section 106.03(b)3. Visibly label all shipments on the PGD or its container with the manufacturer's name or trade name, lot number and material quantity.

III. CONSTRUCTION –

(a) Prior to beginning installation, the contractor shall furnish the Engineer with copies of the manufacturer's information, which include details, specifications, and recommended installation requirements for the PGDs and outlet pipes.

(b) During all periods of shipment and storage, the PGD shall be wrapped and protected from direct exposure to sunlight, mud, dirt and debris. The unwrapped PGD shall not be exposed to sunlight for more than 48 hours total at which time it must be covered with soil.

(c) The excavation of in-situ soil shall be of such dimensions to provide ample room for attachment of the PGD. The excavation shall be according to Class 3 excavation guidelines in Publication 408-2000, Section 204. The embankment foundation area shall be prepared as specified in Section 201. The construction of embankment and backfills shall be according to Section 206.

(d) PGD shall be constructed on the backfill side of the walls with geotextile facing the backfill soil, as indicated in Figure 1. The surface of the walls against PGD shall be free of soil, debris and excessive irregularities that will prevent intimate contact between the wall and the PGD. The PGD shall be secured using metal stick clips or adhesives. Nails shall not be used when a waterproofing membrane has been applied between the wall facing and the PGD.

(e) All joints shall be formed by peeling or trimming the geotextile off the attached core to expose 75 mm (3 in) of core. The overlap core of the adjacent section must be by 50 mm (2 in) and must interlock the two core sections. Cover the joint with the geotextile flap and securely fasten to the lower fabric by means of a continuous strip of 75 mm (3 in) wide waterproof plastic tape.

(f) All exposed edges shall be sealed with the geotextile, with at least 100 mm (4 in) minimum overlap, to prevent intrusion of the backfill. All edges shall be attached to the wall.

(g) The underdrain pipes shall be placed as shown in Figure 1 or as directed by the Engineer.

(h) Backfill must be placed as soon as possible, so the PGD is not exposed for more than 48 hours. The backfill shall be compacted without disturbance to the PGD. Compaction of backfill within 1 m (3 ft) of the PGD shall be achieved by requiring at least 3 passes of a light mechanical tamper. No tamping is permitted within 100 mm (4 in) of the PGD.

IV. METHOD OF MEASURMENT – The quantity of material shall be the actual amount of drainage material installed and accepted.

V. BASIS OF PAYMENT – The accepted quantity of PGD will be paid for at the contract unit price per square meter (or square feet), complete in place. The payment will be full compensation for furnishing and installing the PGD, anchoring system, and all labor, materials, equipment, tools, and incidentals necessary to complete the work.

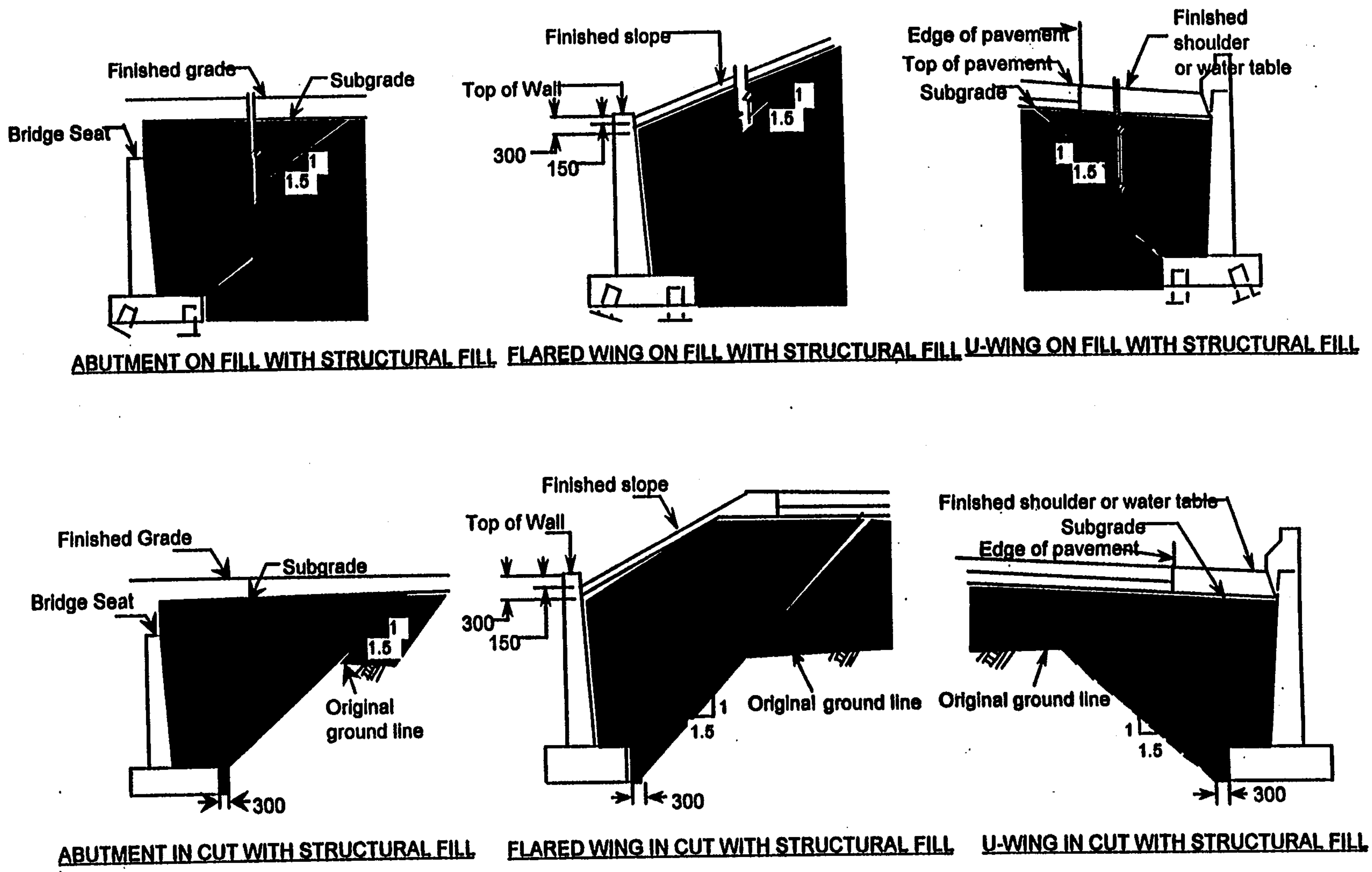


Figure D-1. Typical Cross-Sections of Abutments (ref. PennDOT Publication, Section RC-12M)

APPENDIX E:
GUIDELINES FOR PREFABRICATED GEOCOMPOSITE DRAINS USED BEHIND VERTICAL STRUCTURES

Prefabricated geocomposite drains (PGDs) are used behind retaining walls and abutments to replace conventional soil drainage layers. This guide is intended to accompany a specification entitled "Specification for Prefabricated Geocomposite Drains Used behind Vertical Structures."

The purpose of this guide is to introduce various types of PGDs, functions of the wall drains, and critical construction issues that are related to the usage of PGDs.

General Description of the PGD

PGDs consist of a polymer drainage core and a geotextile. The geotextile is bonded to the core by adhesive materials. The dimensions of PGDs are 1 to 2 m (3 to 7 ft) wide, and 16 to 32 m (53 to 105 ft) long. The thickness of the core ranges from 6 to 16 mm (0.2 to 0.6 in). The product is delivered in roll form with an attached geotextile.

The core style can be categorized into four basic types: entangled mesh, single cuspated, double cuspated, and single dimpled cores. Polymers used to manufacture the core structure include: polyamide (PA), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), and high impact polystyrene (HIPS).

For the geotextile component of the composite, needle-punched nonwovens are the most common type, although heat-bonded nonwovens and woven geotextiles are also used. The most common polymer used in manufacturing geotextiles is polypropylene.

Function and Properties of the PGD

Polymeric Core Structure

PGDs used as drainage products behind vertical retaining structures are used to replace drainage soil. The function of the polymeric core is to accumulate and transmit the anticipated water from the backfill soil. The in-plane flow of the PGD must be able to convey water from the backfill soil to weep holes or underdrains so as not to mobilize hydrostatic stresses on the wall itself. At the same time, the PGD must be able to sustain the lateral earth pressure that the backfill soil applied. Two essential properties of PGD products shall be specified: compressive strength and hydraulic behavior.

In order to recommend an appropriate compressive strength and normal stress value to be used in the specification for the in-plane flow test, the lateral earth pressure acting on the geocomposite should be evaluated. The design approach utilized by Koerner and Hwu (1989) is adopted. The calculation for a 10-m (33 ft) high wall is illustrated as below:

The maximum lateral pressure load is calculated based on Rankine theory, as shown in Equation (1):

$$\sigma_R = \gamma H K_a + \sigma_q K_a \qquad (1)$$

where:

σ_R = resultant stress
γ = unit weight of backfill soil
H = wall height
K_a = coefficient of active earth pressure = $\tan^2(45 - \phi/2)$
ϕ = friction angle of backfill soil
σ_q = surcharge stress at ground surface (includes live loads)

For a retaining structure of 10 m (30 ft) in height, the backfill soil is a silty sand with unit weight of 19 kN/m^3 (121 lb/ft^3) and a friction angle of 34°. It is assumed that the total of surcharge and live load together is 30 kPa (4.35 psi). The σ_R value is calculated as follows:

$$K_a = \tan^2(45 - \phi/2)$$
$$= \tan^2(45 - 34/2)$$

$= 0.283$

$\sigma_R \quad = \gamma H K_a + \sigma_q K_a$

$= (19)*(10)*(0.283)\ \text{kPa} + (30)*(0.283)\ \text{kPa}$

$= 53.8 + 8.5$

$= \underline{\textbf{62.3 kPa}}$

or

$\sigma_R \quad = \gamma H K_a + \sigma_q K_a$

$= (121)*(30)*(1/144)*(0.283)\ \text{psi} + (4.35)*(0.283)\ \text{psi}$

$= 7.1\ \text{psi} + 1.23\ \text{psi}$

$= \underline{\textbf{8.3 psi}}$

Another aspect that needs to be considered is the required flow rate of the PGD. The required flow value is determined according to Equation (2), which is embodied in the PennDOT procedure, "Maximum Flow from Wall/Abutment Drainage Systems."

Maximum possible flow volume, $Q = kiA = 0.0011*h\ (ft^3/sec\text{-}ft)$ (2)

Where:

h = height of the wall or abutment

Based on a wall height of 10 m (30 ft), the resultant flow rate shall be equal or greater than 0.0033 m^3/s-m (16 gal/min-ft). Note that the flow volume depends on the wall height. A higher wall yields a higher flow value. The current published manufacturer's data indicate that the upper flow rate of most PGDs ranges from 0.003 to 0.004 m^3/sec-m (14.5 to 19.3 gal/min-ft) under 100 kPa (14.5 psi) at hydraulic gradient of 1.0. This is similar to that of 10 m (30 ft) high wall with structure backfill. Thus, a wall height limit of 10 m (30 ft) is recommended in the specification.

Compressive Strength

The PGD is subjected to a constant compressive force from the backfill soil. The compressive strength of the PGD shall be assessed to demonstrate the integrity of core structure to compressive stress. The test procedure shall follow the ASTM D 1621. The maximum compressive strength (i.e., the yield strength) shall be equal or greater than 300 kPa (43.5 psi), and the deflection at the maximum strength shall be less than 10 percent. The 300 kPa (43.5 psi) is 4.8 higher than the maximum lateral pressure acting on the PGD of a 10 m (30 ft) high wall to ensure core structural stabilization.

Hydraulic Behavior

The hydraulic behavior of the PGD is evaluated using an in-plane flow test according to ASTM D 4716. The test measures the flow rate per unit width of the PGD under a specific normal stress, which is defined to be 100 kPa (14.5 psi). The specified normal stress is 1.60 factor higher then the maximum lateral pressure acting on the PGD of a 10 m (30 ft) high wall to accommodate the flow reduction that is caused by creep and geotextile intrusion. In addition, the test is performed under a hydraulic gradient of 1.0, which reflects a gravity flow condition.

Geotextile Component

For the geotextile component of the PGD, the AASHTO Class 3 is specified. The AASHTO Class 3 geotextile has a higher strength requirement than the current PennDOT Class 2 – Type B geotextile that is used as separator and filter between the structural fill and native soil behind the abutments. A higher strength is required to ensure the integrity of the geotextile during the installation, since the geotextile is the filter layer for the drainage system of the structure.

In addition to the strength of geotextile, the apparent opening size must also be considered, together with the particle size distribution of native soil. In the AASHTO Class 3 specification, the required AOS of the geotextile is associated with the percent soil passing the 0.075 mm (No. 200 sieve).

Construction Related Issues

The construction procedure is described in Specification Section 3. After installing the PGD, backfill of the native soil should be performed within one week to minimize potential ultraviolet degradation on the geotextile. The soil adjacent to the PGD should be well compacted to minimize the potential migration of fine soil into the geotextile.