Long-Term In Situ Properties of Geotextiles

GARY L. HOFFMAN AND ROBERT TURGEON

Although substantial research of geotextiles (e.g., physical properties, testing procedures, specification requirements) has been accomplished, the majority of this work dealt with original fabric properties (i.e., before installation). The Pennsylvania Department of Transportation (PennDOT) foresaw the potential usefulness of fabrics and undertook one of the earliest field evaluations aimed specifically at monitoring the characteristics of the in-place fabrics over a period of years. Initial fabric properties were well documented before installation in a longitudinal pavement edge drain system. Fabrics were exhumed and tested for permeability and strength properties at 1-, 2-, and 6-year intervals after placement. Results indicated that, even though some reductions in fabric permeabilities and strengths were evident, all fabrics were still substantial enough to perform the intended drainage and filtration functions better than the standard control section without fabric. Permeabilities of each of the six fabric types were still at least 10^{-2} cm/sec after 6 years. The minimum average tensile strength in the weakest direction was still 82 lb after 6 years of service. This work partly influenced PennDOT's recent inclusion of geotextiles in their general specifications and standard drawings for subsurface drainage.

The use of geotextiles (engineering fabrics) as a standard item in the construction of transportation facilities is increasing in Pennsylvania and in many other states. Some agencies have realized significant initial cost and performance benefits by using geotextiles. Although substantial research on the physical properties, testing procedures, and specification requirements has been done by manufacturers, public agencies, and academicians, the bulk of this work dealt with the original properties of the geotextiles (i.e., before installation). Insufficient data are available on the characteristics and performance of various types of fabrics after they have functioned in a facility or system for a number of years. This lack of performance data is understandable because fabrics have only gained acceptance and use in engineering applications over the past decade. The long-term in situ characteristics of geotextiles are of primary interest to the user because the fabrics must perform adequately throughout the design life of the system in which they are being used.

The Pennsylvania Department of Transportation (PennDOT) foresaw the potential usefulness of fabrics and undertook one of the earliest field evaluations aimed specifically at monitoring the characteristics of in-place fabrics over a number of years. Initial fabric properties were well documented (1) before they were installed in a longitudinal pavement drain system. Fabrics were exhumed and tested for permeability and strength properties at 1-, 2-, and 6-year intervals after placement. Results of this testing and the performance of the installation are reported in this paper.

PROJECT INSTALLATION

The project site is located in the northwestern section of Pennsylvania on Traffic Route 321 in the village of Wilcox in Elk County [Figure 1 (1)]. The site was a two-lane reinforced-concrete pavement with flexible shoulders that was completed in fall 1974. The typical pavement cross section is shown in Figure 2. The project was showing shoulder and joint distress in less than 2 years because no pavement drainage was included in the construction. The shoulders were soft and wet, and obvious differential frost-heave-induced cracking had occurred in the flexible shoulder. The reinforced-cement-concrete (RCC) pavement also showed distress; there was pumping along the centerline, shoulder, and transverse joints; and there was occasional transverse cracking. An investigation revealed that the problem was caused by infiltrated surface water and not groundwater. When the decision was made to retrofit longitudinal pavement base drains to correct the water problem, 12 experimental drainage sections that incorporated various types of fabric were included.

The 12 experimental sites were constructed in September 1976 by Department maintenance personnel

Figure 1. Location map.

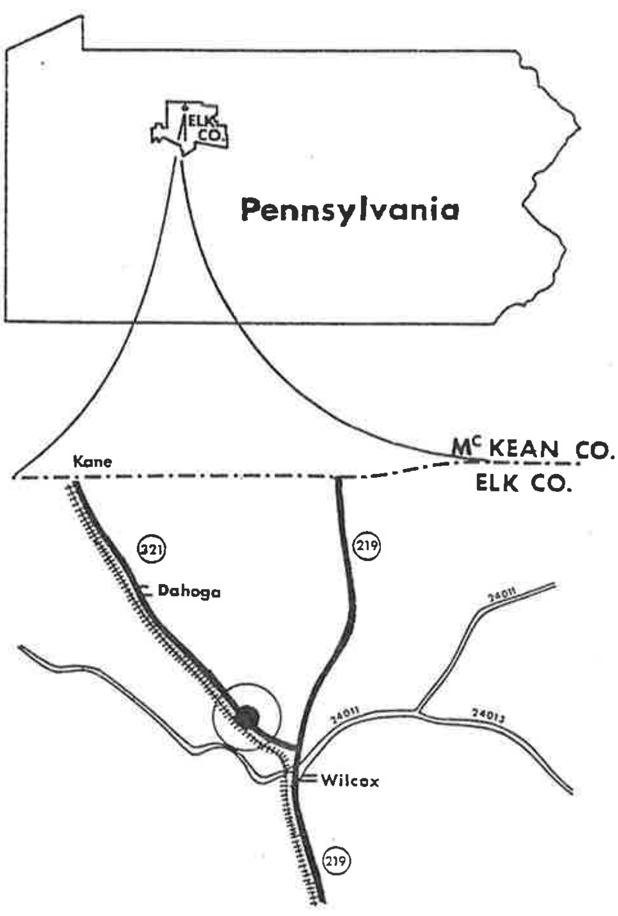

Figure 2. Typical pavement cross section.

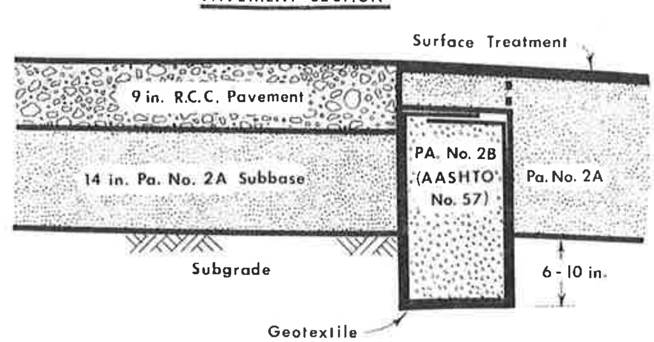

Figure 3. Typical drain cross section and plan section.

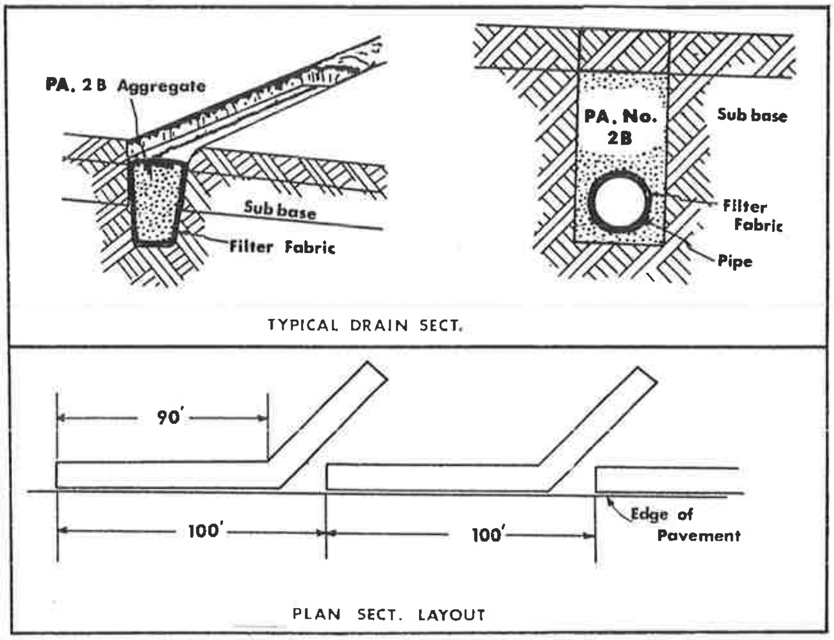

Table 1. Construction details of 12 sites.

Site	Trench Width (in.)	Construction Details
1	24	6-in. porous concrete pipe; 2B aggregate backfill
2	24	Trench lined with Typar 3401; 2B aggregate backfill
3	24	Trench lined with Mirafi 140; 2B aggregate backfill
4	24	Trench lined with Phillips Duon; 2B aggregate backfill
5	24	Trench lined with Bidim C-22; 2B aggregate backfill
6	15	Trench lined with Poly-Filter X; 2B aggregate backfill
7	15	4-in. fiber pipe wrapped with Duon; 2B aggregate backfill
8	15	6-in. corrugated metal pipe (cmp) wrapped with Typar-3401; 2B aggregate backfill
9	15	6-in. cmp wrapped with Bidim C-22; 2B aggregate backfill
10	15	6-in. porous concrete pipe wrapped with Mirafi 140; 2B aggregate backfill
11	15	4-in. fiber pipe; 2B aggregate backfill
12	15	Trench lined with International Paper Company (IPC) 502; 2B aggregate backfill

Figure 4. Physical properties of subgrade soil and pH's of water samples.

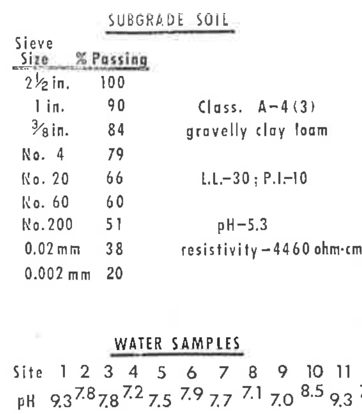

Table 2. General descriptions of fabrics used in project.

Fabric Type	Sites	General Description
Typar 3401 (cloth type)	2 and 8	Gray, nonwoven, heat-bonded polypropylene monofilament; 4.0 oz/yd^2 weight; 15-mil thickness
Mirafi 140 (cloth type)	3 and 10	White, nonwoven polypropylene and nylon random-oriented monofilament; 4.1 oz/yd^2 weight; 30-mil thickness
Supac (felt type)	4 and 7	Gray, nonwoven entangled olefin monofilament; 4.0 oz/yd^2 weight; 60-mil thickness
Bidim C-22 (felt type)	5 and 9	Gray, nonwoven, mechanically entangled continuous filament polyester; 4.5 oz/yd^2 weight; 75-mil thickness
Poly-Filter X (woven)	6	Black, woven polypropylene monofilament; 7.2 oz/yd^2 weight; 16-mil thickness
IPC 503 (cloth type)	12	White, nonwoven, bonded polypropylene monofilament; 3.4 oz/yd^2 weight; 27-mil thickness

from Elk County. Typical cross-section and plan-section details of the experimental drainage sites are shown in Figure 3 (1). These sites were all located in a tangent section in 3 to 6 ft of fill. The trenches were excavated with a backhoe immediately adjacent to the edge of the RCC pavement to a depth that varied from 6 to 10 in. below the bottom of the subbase. Each of the 12 sites was about 100 ft long and terminated with an outlet pipe through the embankment slope. Site 1 was the Department's standard section at that time and was the control section. Sites 2-6 and 12 had fabric wrapped around the stone backfill in the trench, and no pipe was included. Sites 7-11 had the same fabric types that were used in sites 2-6, but the fabric was wrapped directly around a perforated pipe and then the sites were backfilled with PA No. 2B (AASHTO No. 57) crushed stone. The construction details of the 12 sites are given in Table 1 (1).

Six different fabrics were included in the experiment. A general description of each of these six fabrics is given in Table 2 (1,2). Five nonwoven fabrics were used; three were heat-bonded cloth type and two were needle-punched felt type. One woven fabric was also used. As each type of fabric was installed, random samples were obtained for laboratory testing.

Both the subbase and subgrade were unsatisfactory draining materials. The PA No. 2A dense-graded subbase material was a crushed gravel with AASHTO A-1-b(0) classification and typically had a permeability of 10^{-4} cm/sec. The subgrade material was

Table 3. Typical drain cross section and plan section.

		As Supplied		After 6 Years in Service				Change from Original[c] (%)	
				t_{soiled}[a]		t_{orig}[b]			
Fabric Type	Site	Permeability (cm/sec x 10^{-2})	Permittivity (sec^{-1})	Permeability (cm/sec x 10^{-2})	Permittivity (sec^{-1})	Permeability (cm/sec x 10^{-2})	Permittivity (sec^{-1})	Permeability	Permittivity
Typar 3401	2	4.6	1.13	1.4	0.16	0.7	0.16	−70	−86
Mirafi 140	3	4.1	0.65	2.5	0.27	1.7	0.27	−39	−58
Supac	4	7.8	0.48	6.4	0.44	7.9	0.44	−18	+2
Bidim C-22	5	5.0	0.24	51.6	2.22	46.3	2.22	+930	+825
Poly-Filter X	6	1.5	0.37	2.0	0.27	1.1	2.27	+33	−27
IPC 503	12	1.8	0.30	2.7	0.30	1.8	0.30	+50	0

Note: All results are from a minimum of five measurements.

[a]Calculated by using respective thicknesses of soiled fabric from Table 4.

[b]Calculated by using respective thicknesses of original, clean fabric from Table 4.

[c]Percentage change is the difference between the as supplied and 6-year figures divided by the as supplied figures.

classified as an AASHTO A-4(3) with a permeability of 10^{-5} cm/sec. The physical properties of this subgrade soil along with the pH's of water samples taken from the outlet pipe of each of the 12 sites are shown in Figure 4.

OBSERVATIONS AND PERFORMANCE

Portions of the 12 sites were exhumed and visually inspected in September 1977, 1978, and 1982--1, 2, and 6 years after installation. Samples of the fabrics from sites 2-6 and 12 were also obtained at these times and retested in the laboratory.

Care was taken not to alter the in situ condition of the fabric before testing. The samples were removed with the built-up layer of soil intact and immediately placed in plastic bags. They were then placed in a sealed container to maintain the in-place moisture condition.

All drainage sites were still functioning after 6 years, as evidenced by positive outflow and the reduction of the aforementioned water-related distress along the shoulder and the outside edge of the pavements. Pumping still existed along the centerline joint because the dense-graded subbase was draining too slow to transmit the water laterally from beneath the pavement in a reasonably short time.

All of the exhumed fabrics, except the Bidim C-22, appeared intact and did not have tears or holes. Pea-sized holes were noted in some of the lapped portions (top of trench) of the Bidim C-22 fabric. The visual appearance of the Bidim C-22 indicated manufacturing inconsistencies of spinnerette and spin-beam placement, which resulted in thin areas. It was concluded that these holes were the result of puncture in these thin areas by the PA No. 2A aggregate that was on top of the fabric. In areas where traffic had eroded the surface of the shoulder along the pavement edge as little as 2 in. of the aggregate existed on top of the fabric. The puncture failure mechanism was also substantiated by studying the filament breaks under 50X magnification.

At control site 1 the unprotected crushed-gravel backfill was becoming progressively more contaminated with fines throughout its entire depth. Although this trench backfill still appeared more permeable than the adjacent subbase and subgrade, it can be projected that at some point the unprotected backfill will approach the slow permeability of these adjacent materials.

In sites 2-6, where the trench backfill was wrapped with fabric and no pipes were installed, minimal contamination of the backfill with fines existed. A discoloration of the aggregate surfaces in the lower 4 to 5 in. of the trench was noted, but substantial filling of the voids with fines was not present. A layer of colloidal-sized sediments about 0.1 in. thick existed on the inside of the fabric on the bottom of the trench. A buildup of migrated soil was present on all of the outside surfaces of the fabrics, which indicated filtering effectiveness. It was evident from the visual inspection that more fines had been allowed to pass through the woven Poly-Filter X fabric and into the backfill material than through the nonwovens. Also, the retained layer of migrated soil on the outside of the Poly-Filter X was not as pronounced as with the nonwovens.

In sites 7-11, where the pipes were wrapped with the fabric, the backfill contamination appeared similar to control site 1. Again the migrated soil buildup was evident on the outside of the fabric. Some colloidal-sized sediments were present in the bottom of the pipe, but these had little effect on the pipe hydraulics.

FABRIC PROPERTIES

Permeability

Permeabilities were determined before installation of the fabrics with the prototype permeameter from the Celonese Fibers Marketing Company (test method FFET-2). All permeabilities were calculated by using Darcy's equation for laminar flow conditions. All six fabrics had an initial permeability on the order of 10^{-2} cm/sec (see Table 3). The AASHTO T-215 constant-head permeability test equipment was used to test the permeability of the 1-, 2-, and 6-year-old fabric samples because the Celanese equipment was not available.

During the initial testing phases of the 6-year-old fabric with the T-215 equipment it became evident that the inflow and outflow capabilities of this equipment were insufficient to measure the relatively high permeabilities of the fabric, even when working with relatively low heads. Thus previously developed permeabilities on the 1- and 2-year-old fabrics were discounted as being incorrect and were not presented. The AASHTO T-215 equipment was then modified by removing the top and bottom of the 4-in.-diameter mold, and PA No. 2B crushed stone was placed below and in contact with the fabric (Figure 5). The fabric was clamped between the mold and its collar in such a way that leaks did not occur. The test was then performed with a 4-in. constant head. The flow capabilities of the various components of the equipment were checked to assure that the permeability of the fabric was actually being measured. The resulting permeabilities on the soiled 6-year-old fabric are also presented in Table 3.

The permeabilities for all of the 6-year-old fabrics were still on the order of 10^{-2} cm/sec and were high enough to function satisfactorily in most soil conditions that might be encountered in Pennsylvania. The Department's specifications on geotextiles require fabric permeability to be one order of magnitude greater than that of the soil to be drained. A comparison of the permeabilities for the 6-year-old fabrics to the respective original permeabilities can be made on a relative basis with the consideration that two different types of testing equipment were used. The cloth-type fabrics (Typar 3401 and Mirafi 140) apparently had the greatest reduction in permeability. The reason for the order-of-magnitude increase in the permeability of the Bidim C-22 fabric might be related to the previously discussed holes, although care was taken to select intact samples for permeability testing.

The fabric permittivities (i.e., the coefficients of permeability divided by the thicknesses) are also presented for comparison purposes. Thicknesses of the soiled fabric (Table 4) were, for the most part, greater than the original, clean fabric thicknesses. The soiled fabric thicknesses (t_{soiled}) were used to compute 6-year permeabilities because the head losses occurred over these total, actual thicknesses during testing.

Strength

A constant-rate-of-extension (CRE) tensile testing machine was used to perform grab tensile testing. Some modifications to the current ASTM D-1682 procedures were made when testing the 6-year-old samples in order to exactly duplicate the procedures used to test the initial and the 1- and 2-year-old samples. The modifications along with the specified items are shown in Figure 6. Essentially, the differences were

1. A CRE of 12 in./min was used for all fabrics instead of an adjusted rate that would cause failure in 20 ± 3 sec,
2. A 5x8-in. fabric sample was used instead of a 4x8-in. sample, and
3. Grips 2.125 in. perpendicular to the direction of pull and 1.75 in. parallel to the direction of pull were used instead of the specified 1x2- or 1x1-in. grips.

The average strengths for the initial and the 1-, 2-, and 6-year-old fabrics are given in Table 5. Elongations for these same tests are given in Table 6. All fabrics experienced some decrease in maximum strength; the Mirafi 140 exhibited the greatest decrease (40 to 45 percent). A sample of the Poly-Filter X that had been exposed to direct sunlight also decreased in strength by about 45 percent, whereas the buried Poly-Filter X only decreased in strength from 20 to 33 percent.

The average elongations at failure decreased for all fabrics except the IPC 503. This indicates that most of the fabrics either became less plastic with age because of enviornmental conditions or had flaws induced from installation that caused them to break at lower strains.

All of these strengths and elongations still met the Department's minimum specification criteria for new fabrics of 90 lb and 20 percent. However, these specifications referred to the ASTM D-1682 procedure.

Figure 5. Permeability test apparatus.

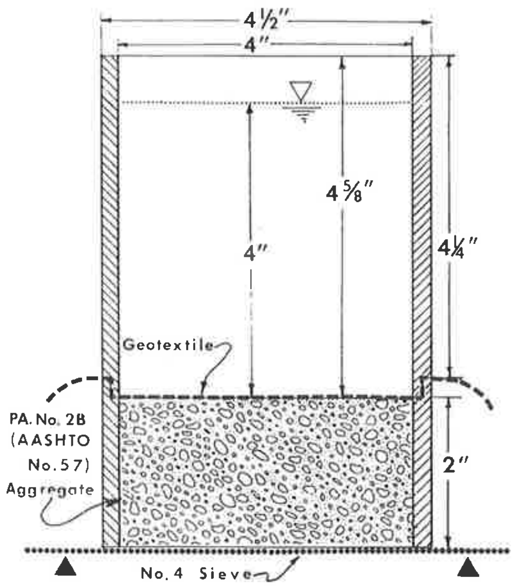

Figure 6. Modifications to grab tensile test as compared with specified procedure.

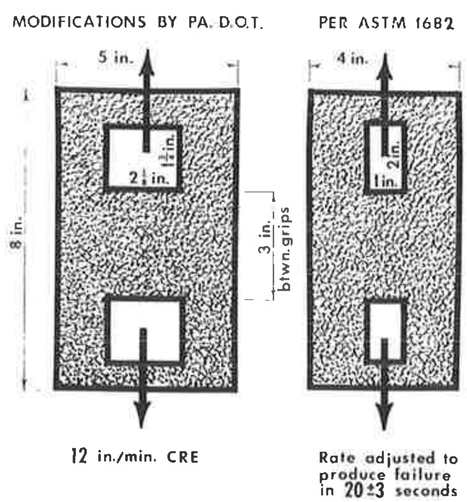

Table 4. Thicknesses of fabrics.

Fabric Type	Site	Avg Fabric Thickness[a] (in.) As Supplied	1 Year in Service	2 Years in Service	6 Years in Service[b]	Change from Original (%)
Typar 3401	2	0.016	0.015	0.014	0.034	+113
Mirafi 140	3	0.025	0.025	0.023	0.037	+48
Supac	4	0.071	0.043	0.038	0.056	-21
Bidim C-22	5	0.082	0.043	0.064	0.091	+11
Poly-Filter X	6	0.016	0.017	0.017	0.030	+88
IPC 503	12	0.024	0.029	0.030	0.036	+50

[a] From a minimum of 10 measurements.
[b] The soiled 6-year samples were hand brushed lightly to remove loose soil before measurements were made.

Table 5. Average strength of fabrics.

		Avg Strength (lb) of Fabrics Used on Projects[a]									
		As Supplied		1 Year in Service		2 Years in Service		6 Years in Service		Change from Original (%)	
Fabric Type	Site	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Typar 3401	2	193	192	208	129	164	173	150	161	-22	-16
Mirafi 140	3	205	188	208	129	163	165	112	111	-45	-41
Supac	4	266	131	216	130	162	138	217	124	-18	-5
Bidim C-22	5	185	177	235	115	154	99	185	131	0	-26
Poly-Filter X	6	752	468	632	377	360	348	598	313	-20	-33
Poly-Filter X[b]	6	752	468	—[c]	—[c]	—[c]	—[c]	411	269	-45	-43
IPC 503	12	93	112	138	174	—[c]	—[c]	91	117	-2	+4

Note: MD = machine direction and CD = cross direction.
[a]All values are the average of a minimum of three tests in each direction.
[b]Fabric was not properly covered and therefore was exposed to the environment for the entire test period.
[c]No test.

Table 6. Average elongation of fabrics.

		Avg Elongation (%) of Fabric Used on Project[a]									
		As Supplied		1 Year in Service		2 Years in Service		6 Years in Service		Change from Original (%)	
Fabric Type	Site	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Typar 3401	2	63	60	68	60	50	60	61	61	-3	+2
Mirafi 140	3	125	129	104	76	93	105	85	106	-32	-18
Supac	4	79	102	83	81	67	85	73	95	-8	-14
Bidim C-22	5	78	75	62	101	65	64	67	74	-14	-1
Poly-Filter X	6	37	35	36	34	28	27	38	28	+3	-23
Poly-Filter X[b]	6	37	35	—[c]	—[c]	—[c]	—[c]	30	20	-19	-43
IPC 503	12	29	23	30	28	—[c]	—[c]	42	26	+45	+13

Note: MD = machine direction and CD = cross direction.
[a]All values are the average of a minimum of three tests in each direction.
[b]Fabric was not properly covered and therefore was exposed to the environment for the entire period.
[c]No test.

Table 7. Comparison of strength and elongation results for PennDOT modified grab tensile test with results for ASTM D-1682 procedure.

		Avg Strength (lb) on 6-Year-Old Fabric[a]				Avg Elongation (%) on 6-Year-Old Fabric[a]			
		PennDOT Modifications		ASTM D-1682 Procedure		PennDOT Modifications		ASTM D-1682 Procedure	
Fabric Type	Site	MD	CD	MD	CD	MD	CD	MD	CD
Typar 3401	2	150	161	145	110	61	61	80	80
Mirafi 140	3	112	111	123	108	85	106	118	116
Supac	4	217	124	121	85	73	95	47	84
Bidim C-22	5	185	131	123	101	67	74	82	79
Poly-Filter X	6	598	313	343	242	38	28	24	26
IPC 503	12	91	117	82	88	42	26	54	37

Note: MD = machine direction and CD = cross direction.
[a]All values are the average of a minimum of three tests in each direction.

Because data in Tables 5 and 6 were developed with the modified procedures, a new set of test data was developed in strict compliance with the methods of ASTM D-1682. These latter results on the 6-year-old fabrics are presented in Table 7 along with the respective results obtained with the modified procedures.

A review of the data in Table 7 indicates that the slower elongation rates and narrower test specimens and grips used in the ASTM D-1682 procedure had a noticeable effect on the results. In fact, all but one of the strength values were lower; the majority of the elongations at failure were greater. According to the ASTM D-1682 data, Supac and IPC 503 minimum strengths were below the specified minimum requirement of 90 lb for the new fabric. These two fabrics would still meet the minimum average roll value (weakest direction) for drainage specifications of 80 lb, which was proposed by the Geotextile Committee of the International Nonwovens and Disposables Association (INDA) as part of their revisions to the FHWA "Fabric Workshop Manual."

Even though strength losses have occurred, sufficient strength to satisfactorily perform the intended function after installation still exists. Specification requirements for this drainage application may require adjustments as manufacturers develop more uniformity in determining and presenting fabric properties, and as more information becomes available on the effects that installation stresses and long-term contact with the environment have on these properties.

CONCLUSIONS

1. All sites with various fabrics were still performing satisfactorily after 6 years.
2. The standard (control) trench section without

fabric was still draining the adjacent soil; however, progressive contamination of the aggregate backfill with migrating fines was evident.

3. All of the exhumed fabrics were intact and without blemish, except for the Bidim C-22. The Bidim C-22 apparently had manufacturing irregularities and was punctured through the lapped portion on top of the trench in areas where insufficient cover material thicknesses existed.

4. Laboratory permeability tests on the 6-year-old soiled fabric indicated that, although some decreases had occurred, all fabrics had permeabilities of 10^{-2} cm/sec or greater. These permeabilities met PennDOT criteria that the fabrics be 10 times more permeable than the adjacent soils being drained.

5. All of the fabrics experienced strength reductions, which varied from a few percent to about 45 percent. However, all of the fabrics still met the Department's minimum strength requirement of 90 lb for new fabric, except Supac and IPC 503. The Supac and IPC 503 would still meet the minimum average roll value of 80 lb proposed by INDA. All of the fabrics exhibited sufficient strength and satisfactorily performed the intended drainage function in the field.

6. Engineering fabrics can be expected to effectively function as a filter and separator in a drainage trench application for years. These fabrics should be included as a standard part of the drainage system design where open-graded aggregate backfill requires protection from adjacent, low-plasticity fine soils that are prone to migrate.

7. The recent inclusion of geotextiles in the PennDOT standard drawings for subsurface drains (RC-30) was influenced, in part, by this work. The trench backfill, instead of only the pipe, is wrapped with fabric to protect the high-quality aggregate from contamination.

ACKNOWLEDGMENT

We wish to acknowledge the Office of Research and Special Studies and the Materials and Testing Division of PennDOT and Region 3 of FHWA, whose approval and financial sponsorship made this work possible.

Allen D. Forshey is acknowledged for the significant work he did in coordinating the installation and the evaluations at 1 and 2 years after installation. Henry Lahr, Dennis Leahy, and Lori Stewart are thanked for their field assistance in retrieving fabric samples from the field. Thanks are also expressed to Dean Riland, Soil and Foundations Laboratory supervisor, and to Thomas Green, Physical Testing Laboratory supervisor, for their respective efforts in permeability and strength testing. Karen Ford is acknowledged for her skill and patience in typing this manuscript.

REFERENCES

1. A.D. Forshey. Use of Filter Fabrics for Subgrade Drainage Systems for Highways. Pennsylvania Department of Transportation, Harrisburg, Res. Rept. 76-16, May 1979.
2. T.A. Haliburton. Testing of Geotechnical Fabric for Use as Reinforcement. Geotechnical Testing Journal, GTJODJ, Vol. 1, Dec. 1978, pp. 203-212.

Notice: The Transportation Research Board does not endorse products or manufacturers. Trade and manufacturers' names appear in this paper because they are considered essential to its object.

Publication of this paper sponsored by Task Force on Engineering Fabrics.