Evaluation of Two Geotextile Installations in Excess of a Decade Old

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Many erosion-protection installations for roadway embankments were designed and constructed by using geotextiles during the 1960s. Two such installations constructed in 1969 were studied to evaluate the long-term field performance of the facilities and the geotextile material. These projects were the 79th Street Causeway in Miami Beach, Florida, and the Bahia Honda Bridge in Bahia Honda Key, Florida. The 79th Street Causeway was constructed with a woven geotextile as a filter in a rip-rap revetment-type seawall to protect one of the bridge abutments and a segment of the causeway. The geotextile design was used in place of a conventional granular filter design to prevent erosion of the subgrade soils through the rip-rap. The protected section was designed for 3-ft waves and and a 3-ft tidal variation. The Bahia Honda Bridge project was constructed with a woven geotextile as a subgrade-protection filter beneath sand-cement rip-rap-constructed bridge abutments, drains, and seawalls at both ends of the bridge. In this system, a geotextile was used to act as a filter between the rip-rap and underlying soil subgrade to prevent loss of soil due to weathering or wave action through cracks and holes in the rip-rap. The abutments and drains at the Bahia Honda Bridge were exposed to weathering conditions, and the seawall was designed to resist wave action and tidal variations. The performance evaluation of these installations consisted of a review of the design, visual observations, and testing of representative rip-rap, fabric, and underlying soil samples. In the laboratory study, the condition of the excavated fabrics was compared with new fabric characteristics. The study included strength and filtration evaluation of the fabric and gradation analysis of the surrounding soils. Field observations of the performance of the structures, evaluation procedures, and the results of laboratory tests are presented. The effects of construction procedures on long-term performance are also reviewed.

One of the most valuable methods of developing design criteria and predictive capabilities is to study the design and performance of existing installations. Field evaluation studies performed in 1979 at two installations constructed in 1969, in which geotextiles were used in erosion-protection systems for roadway embankments, are presented in this paper. The first project reviewed is the 79th Street Causeway in Miami Beach, Florida. A monofilament woven polypropylene geotextile was used in this project as a reverse filter in a stone rip-rap revetment-type seawall to protect one of the bridge abutments and a section of the causeway. The second project is the Bahia Honda Bridge project in which a woven polypropylene geotextile was used as a protection filter beneath sand-cement rip-rap-constructed bridge abutments, drains, and seawalls.

The sites were evaluated by STS Consultants, Ltd. (formerly Soil Testing Services) under contract to Carthage Mills Erosion Control Company, Inc., the manufacturer of the geotextile (Poly-Filter X) that was used in both projects. The studies were performed to evaluate the in-place geotextiles produced by Carthage Mills. The two projects were selected on the basis of their age (10 years or older), type of application, availability of background design information, and performance requirements.

It should be noted that, at the time these projects were constructed, there was little or no design information concerning geotextiles. Also, because only a few geotextiles were in general use in the United States at that time (all of which were monofilament wovens), selection was generally based on intuitive judgment.

79TH STREET CAUSEWAY

The 79th Street Causeway (also referred to as the North Bay Causeway) connects Miami to Miami Beach by traversing Biscayne Bay. In 1969 a bridge was constructed over the intracoastal waterway at the westernmost part of the causeway by the Florida Department of Transportation (DOT) to replace the causeway in that section. The bridge extends from Miami to the first island along the 79th Street Causeway, as shown in Figure 1. For construction east of the bridge, a limestone rip-rap placed over a geotextile was used as an erosion-control system to protect the north portion of the bridge abutment and the north part of the causeway.

A geotextile was used as a reverse filter beneath the limestone rip-rap for the design of the seawall. The actual proposed design of the seawall is shown in Figure 2. The original design drawings did not include details for fabric placement or the head or toe of the slope. At that time proper fabric anchorage was not well understood. The actual design was found to be somewhat different than the proposed design, as will be subsequently discussed.

Revetments constructed by using rubble on the upslope of seawalls is a common procedure. The nature of the rubble gives a rough surface, which helps break up on-rushing waves and dissipate the force and energy in the wave. The need for a filter layer beneath the rubble is important in seawall construction because the voids between the pieces of rubble are large, and constant wave action will draw the foundation materials through the rubble, thereby causing the rubble to settle and eventually collapse.

The protected section was designed for 3-ft wave and tidal variation. Several major storms have occurred in the Miami area since construction, periodically exposing the protection system to conditions more severe than design conditions. Florida DOT records indicated that no maintenance had been performed on the abutment section since construction was completed.

Field Study

A field study of the site was performed in October 1979. A photographic and visual survey of the site indicated that the seawall was functioning as designed, as no apparent erosion problems were observed. Several visually different sections along the length of the seawall were observed. From the north end of the bridge abutment to an area just beyond the northwestern corner of the site, several inches of geotextile material protruded from beneath the rip-rap in the uppermost part of the slope. The surface rip-rap in that section was 2 to 3 ft in diameter. The seawall appeared to be constructed as proposed.

To the east of the northwestern corner of the site the geotextile was visible at the surface through the seawall. The fabric was placed over the rip-rap with one boulder layer at the surface. Apparently a lack of knowledge of protecting these materials from ultaviolet rays from the sun and improper construction control were responsible for this condition. However, a majority of the fabric was intact, even though sections of the material have been exposed to the sun and wave action possibly throughout the 10-year life of the project.

The next part of the seawall, which was east of where the fabric was exposed, appeared to be con-

Figure 1. Location diagram for 79th Street Causeway.

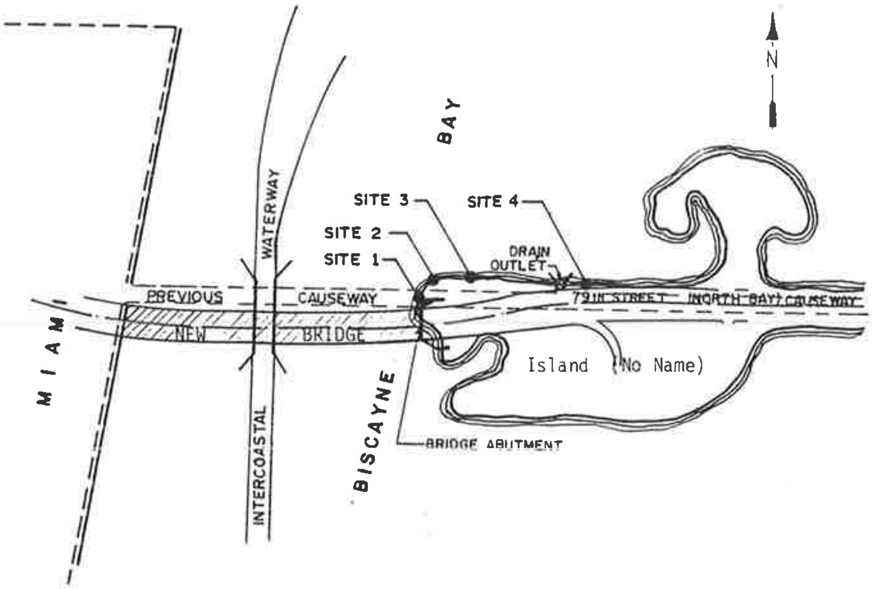
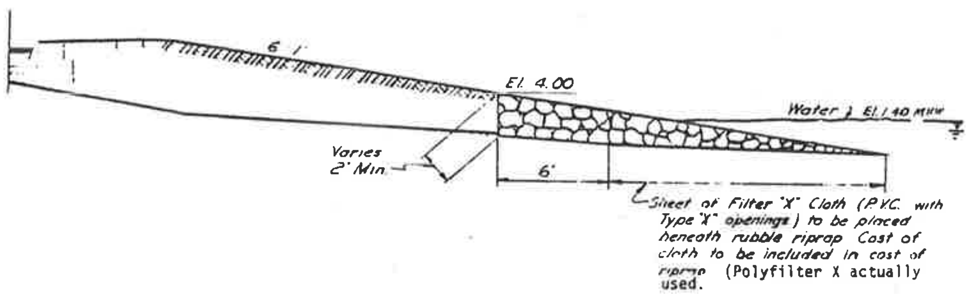


Figure 2. Proposed design of seawall.



structed as designed and was similar to the first section. Fabric was only observed at the top of the seawall where the rip-rap ended. This section continued eastward several hundred feet to a drainage outlet in the seawall.

To the east of the drainage outlet the surface rip-rap was smaller than the surface rip-rap observed in the western portion of the site. The rip-rap was approximately 1 ft in mean diameter. Subsequent evalution of that section indicated that no fabric had been used.

The morning and afternoon high tides covered most of the seawall, which had approximately 6 ft of the face of the upper slope exposed. The morning low tide was approximately 3 ft lower than the high tide and exposed approximately 15 ft of the slope. The afternoon low tide was about 1.0 to 1.5 ft lower than high tide and exposed approximately 9 ft of the slope. Wave action during the visit was generally on the order of 6 in. to 1 ft in height, with up to 2-ft waves observed when boat traffic was present. This appears to coincide with the normal conditions for which the structure was designed.

Other areas of the causeway were observed where erosion-control systems were not in use. At the southern part of the east bridge abutment, opposite the rip-rap fabric-protected section, erosion problems were evident. Concrete that had little aggregate had been poured against the abutment and over the exposed soil, apparently to check erosion. However large voids (up to 1 ft in diameter) were present in the concrete mat and beneath the mat where the soil and concrete had eroded. Eroded areas south of the causeway on the island shore were also observed. It appeared that rip-rap with no filter layer was placed in these areas following the erosion to check the erosion process. The areas appeared to still be washing out, which indicated that the minimal amount of erosion control was not successful. It was reported by Florida DOT that maintenance had been required for several other unprotected sections of the causeway during the past 10 years as a result of erosion damage during storms.

Excavation of Soil-Fabric System

Four sites were selected for further examination of the soil-geotextile system, as indicated in Figure 1. Site 1 was located approximately 3 ft north of the north corner of the causeway bridge abutment. The north corner of the concrete abutment and the location of site 1 are shown in Figures 3 and 4. This area was selected due to the relatively smaller size of rip-rap covering the area and the location in reference to protection of the bridge abutment. Also, due to a relatively flat slope in this section, the majority of the excavation could be performed above the water level at low tide.

Site 2 was located at the northwest corner of the causeway approximately 55 ft north and 18 ft east of the north corner of the bridge abutment. This section appeared to be exposed to more direct wave action than the other sections of the causeway.

A third site (site 3) was selected in the area where the fabric was improperly placed and exposed to the sun. This site was located approximately 70 ft north and 110 ft east of the bridge abutment.

The fourth site was located in the eastern sec-

Figure 3. Limestone rip-rap covering fabric at site 1.

Figure 4. Excavated section at bridge abutment corner at site 1.

tion of the causeway where it appeared that no geotextile had been placed. Subsequent excavation of site 4 indicated that geotextiles were not present and, therefore, this site will not be discussed further.

At site 1 an area approximately 3x12 ft was excavated with the limestone rip-rap and other materials removed by hand down to the fabric. Figures 3 and 4 show the area excavated. The surface rip-rap consisted of fossiliferous limestone boulders that had a mean diameter of 12 to 18 in. The surface rip-rap used throughout the site was highly weathered limestone, which was rough and had many sharp edges. (As an example of the abrasiveness of the rip-rap, the subsequent excavation of the rip-rap for this project resulted in the destruction of several pairs of work gloves due to abrasion.)

Beneath the large surface rip-rap a 1-ft layer of 6- to 12-in.-diameter rip-rap was encountered. Beneath the total depth of rip-rap a 3-in. layer of coarse sand and gravel was underlain by approximately 0.25 to 0.50 in. of fine to medium sand. Note that the 3-in. cushion layer of sand and gravel was not shown in the proposed design (Figure 2). The sand was located directly on the surface of the geotextile and was probably the result of sand being washed down from the upper slope above the protection system or as a result of landward sediment transport (normal shore nourishment process). Samples of all materials over the fabric were collected. Thin-walled 2-in.-diameter shelby tubes were driven into the fabric at several locations to obtain intact samples of the soil-fabric interface.

The exposed surface of the fabric was gently washed with water to remove the sand from the surface. The fabric appeared to be in excellent condition, and no large tears or punctures were observed. Small perforations and punctures were present, which probably resulted from the placement of the rip-rap during construction. On average, two to three 0.125- to 0.25-in.-diameter holes were noted for each square foot of material. Some smaller holes were also observed. Little abrasion from sliding of the rip-rap was apparent, even though the relatively light wave action during the visit was sufficient to move rip-rap as large as 6 in. in diameter.

The geotextile was cut and carefully peeled off the underlying soils. Light was readily seen through a section of the fabric. Some particle retention was noted in the fabric; however, water was observed to readily flow through the fabric. Samples of the fabric were returned to the STS laboratory for testing.

Directly beneath the exposed section, very fine sand to silt-sized particles were noted, with grain size of the sand increasing with depth. Fine sand with less silt was observed approximately 0.5 to 1.0 in. beneath the fabric. At the lower part of the slope, gravel-sized material mixed with sand was found directly beneath the fabric. Samples of the soils encountered above and below the fabric were returned to the laboratory for further examination and testing.

New fabric was placed over the excavated area with an overlap in excess of 1 ft over the old fabric. Then gravel and rip-rap were replaced in the proper order.

The rip-rap from site 2 was then removed. An area of approximately 3x3 ft was excavated. The rip-rap consisted of larger boulders at the surface that had a mean fragment diameter of 1 to 3 ft. At site 2, 6- to 12-in.-diameter rip-rap was also encountered beneath the surface rip-rap. Gravel to medium-sized (2- to 6-in.) rip-rap was encountered beneath the surface rip-rap and directly over the geotextile. The geotextile itself was then encountered. The fabric was located several inches below the water level at low tide.

A 2-ft^2 section of the geotextile was cut and removed. As at site 1, no abrasion of the material was apparent. Only one small tear was noted. The same magnitude and size of small perforations that were encountered at site 1 were present. Some fines were retained by the fabric, and it was observed that gentle washing would remove some of these materials. Fine sand and silt-sized particles mixed with gravel and cobbles were encountered directly beneath the fabric. Samples of these materials were collected, and then new fabric was placed over the entire area and the rip-rap was replaced.

The excavation at site 3 consisted of removing two boulders approximately 0.5 and 2.0 ft in diameter. The geotextile was marked to note the location of the boulders and the location of areas exposed to the sun. A 1.5-ft^2 section of the fabric was removed. Cobbles and up to 6-in.-diameter rip-rap were noted beneath the fabric. No fines were present. Observations of the fabric after removal indicated several tears and punctures. However, considering the exposed condition and the one-boulder cover (which moved visibly under wave action), the material was in satisfactory condition. The fabric was replaced with new fabric and covered with the removed boulders. All soil and fabric samples were returned to the STS laboratory for further examination and testing.

Laboratory Testing Program

A series of laboratory tests were performed to determine the physical properties of the exhumed geotextile samples. These tests provided results that could then be compared with the manufacturer's specifications for new samples of the fabric. In this way the performance of the fabric under field conditions could be evaluated.

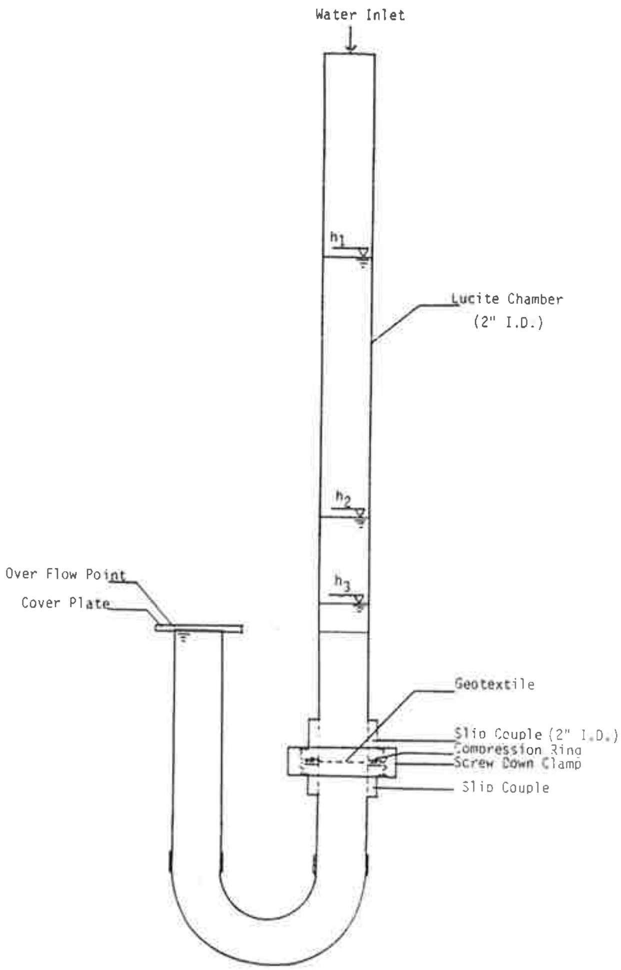


Figure 5. STS geotextile permeameter.

Tests to determine strength and permeability, and tests to evaluate the particle retention of the geotextile, were performed. In addition, grain-size analyses were performed on soil samples taken from above and below the fabric. The tests followed the procedures recommended by the U.S. Army Corps of Engineers and ASTM (1). Tests were also performed on samples of new geotextiles by using the same equipment and procedures to obtain comparison values.

Two strength tests were performed following the procedures detailed in ASTM D-1682 (Breaking Load and Elongation of Textile Fabrics); these tests were used in the initial evaluation of fabric strength at the time of construction. These test methods are currently being evaluated by ASTM as to their reliability in determining the strength of geotextiles.

Permeability of the geotextile specimens was determined by using the STS U-tube geotextile permeameter. A falling-head technique, from a head of 10 cm to a head of 3.7 cm, was used. This equipment in shown in Figure 5.

The particle retention of the fabric was evaluated by using the Corps of Engineers Waterways Experiment Station AD-745-085 procedure for determining the open area of a geotextile. The number of openings that contained particles was compared to the total number of openings in the fabric. Several samples were flushed with water continuously for several hours at a head of 3 ft to simulate water-flow action on the fabric. The percent open area was again determined to assess how many of the openings were permanently closed.

Grain-size analyses were performed on soil samples taken above and below the fabric in order to evaluate the segregating functions of the fabric. These tests were performed in accordance with ASTM D-422 (Particle-Size Analysis of Soils) and used both sieve and hydrometer methods.

Test Results

In general, the geotextile maintained a high degree of strength. Variations in strength results observed for each site are given in Table 1. The data in the table also present comparisons of field data with tests performed on new fabric at the time of the study. The strength test results on new fabrics were in accordance with the manufacturer's published values. Laboratory strength evaluation indicated a strength reduction of properly installed fabric (sites 1 and 2) ranging from 5 to 40 percent from that of new fabric. Elongation of the 10-year-old material at failure was no more than 5 percent greater than elongation of new fabric at failure. Tests on samples of the geotextile material that were partly exposed to sunlight at site 3 indicated a strength loss of approximately 40 to 50 percent,

Table 1. Summary of grap strength test results.

	Weaker			Stronger		
Specimen	Principal Direction (kg)	Apparent Elongation at Failure (%)	Percentage of Original Strength (% of 100 kg)	Principal Direction (kg)	Apparent Elongation at Failure (%)	Percentage of Original Strength (% of 170 kg)
Site 1						
Section 1	89	37	89	130	38	76
Section 2	96	40	96	144	38	84
Section 3	100	40	100	136	39	80
Section 4	96	37	96	161	38	95
Site 2	67	38	67	104	25	61
Site 3	51	25	51	111	47	65
New 1[a]	97	50	–	171	30	–
New 2[a]	101	43	–	163	35	–

[a]Two lots tested.

Figure 6. Strength of fabric versus position on slope at site 1.

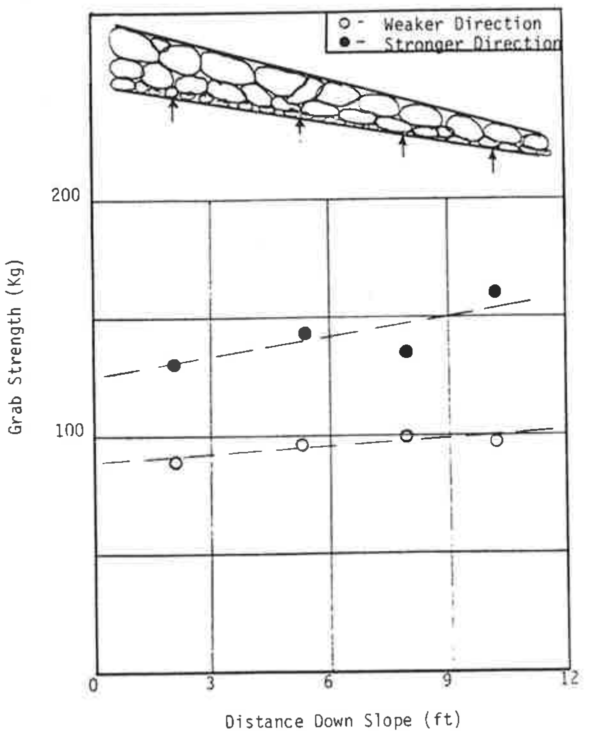
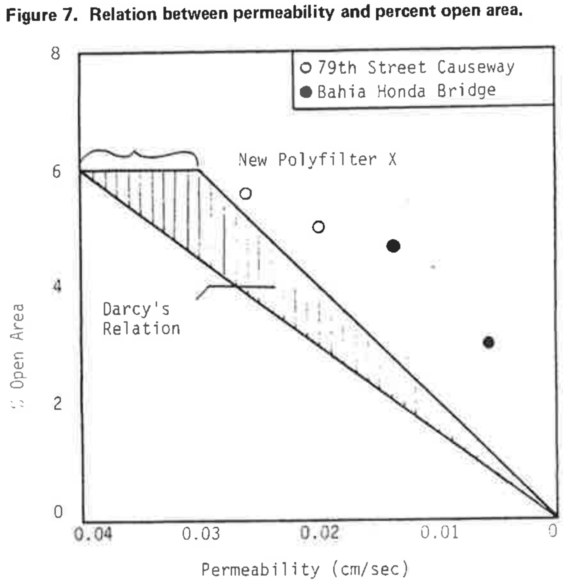


Table 2. Filtration test results.

Specimen	Permeability (cm/sec)	Percent Open Area	Percentage of Openings Containing Particles	Percent Open Area Completely Closed
Site 1				
Section 1	2.6×10^{-2}	5.5	29	6
Section 2	2.2×10^{-2}	5.7	20; 19.5[a]	4
Section 3	1.8×10^{-2}	5.4	29	6
Section 4	1.9×10^{-2}	4.8	44; 44[a]	9
Site 2	2.3×10^{-2}	5.0	40 to 48	8 to 10
		5.1	35 to 42[a]	
New	3 to 4×10^{-2}	6	—	—

[a]Washed with 3-ft head of water.

Figure 7. Relation between permeability and percent open area.



which was probably partly due to ultraviolet exposure.

As indicated by the data in Table 1, the strength of the geotextile from site 2 was found to be about 30 percent less than the fabric from site 1. As previously mentioned, site 2 received more direct waves and had a steeper slope than site 1. Abrasion potential at site 2 was also increased due to the absence of the cushion layer of sand and gravel observed directly over the fabric at site 1. Either of these factors may have resulted in strength differences.

The data in Figure 6 indicate that strength variations at site 1 may exist due to the location of the test specimens at the site. These data are based on limited testing and may be influenced by nonuniformities in the test specimens (such as perforations). Product variation may also have contributed to the relatively small variations observed. Nevertheless, the grab strength appears to increase with location in the downslope direction. The relation appears to occur for both mutually perpendicular test directions. This general pattern indicates that the observed strength differences are due to tidal fluctuations, which result in differences in exposure to water, air, and temperature.

The fabric has been exposed to more than 7,000 saltwater tide cycles and various degrees of wetting and drying, depending on the location of the materials and the installation (top of slope versus bottom of slope). The fabric at the base of the riprap slope (section 4), which was probably under water during most of the 10-year history, had the greatest strength. The data in Figure 6 also show a difference in the change in strength with stronger and weaker principal directions. These differences may be due to the effects of pull from wave action and the direction of pull. Cyclic loading from waves may affect one direction more than the other.

The filtration studies consisted of both permeability and particle-retention evaluations of the fabric. The results of the permeability tests and corresponding particle retention for the same section of fabric are given in Table 2. There was a slight reduction in permeability of 4×10^{-2} cm/sec for new fabric and 2×10^{-2} cm/sec for the excavated fabric.

Figure 7 was developed from Darcy's relation among permeability, porosity, and seepage:

$$k = v_s n_e / i \quad (1)$$

where

- k = coefficient of permeability,
- v_s = seepage velocity,
- n_e = porosity = percent open area for woven fabrics, and
- i = gradient.

The data in Figure 7 indicate the theoretical decrease in permeability of the fabric with a decrease in the percent open area for a gradient of 1. Percent open area is defined as the area of the openings (times 100) divided by the total surface area of the unit of fabric; it is equivalent to the porosity of the soil. Note that the data in the figure are only applicable to the particular material tested; other fabrics may react in a different manner. Permeability values obtained from the field study are included on the graph. (Also included in this graph are the test values obtained from a similar fabric-exhuming project at Bahia Honda Key, which will be subsequently discussed.) Note that the decrease in permeability due to particle retention in the fabric generally follows the relation of decrease in porosity for a soil filter. The test results do not fall within the theoretical curve, probably because actual tests were performed under a gradient much higher than 1 (10 to 3.7 cm of water over the thickness of the fabric), which probably resulted in turbulent flow.

The data on the laboratory particle-retention analysis given in Table 2 indicate that less than 40 percent of the openings in the fabric were partly closed with particles. The percent open area was reduced from approximately 5.8 to approximately 5.2 percent, which is within the range of error in determining percent open area. The net results were a decrease of less than 10 percent in the open area of the fabric.

Grain-size distribution curves for the soil from 0 to 0.25 in. below the fabric and soils several inches below the fabric for sites 1 and 2 are shown in Figures 8 and 9. The fabric retained medium to fine sand and silt-sized particles, with up to 20 percent passing a No. 200 mesh sieve. Up to 50 percent of the soil particles directly against the fabric were smaller than the fabric opening. This is in agreement with the work on filter media done by Calhoun (2) and Cedergren (3).

Summary

The project indicates excellent long-term stability of the monofilament woven geotextiles used in this type of rip-rap revetment for the soil and design conditions encountered. The geotextile retained a significant amount of strength after 10 years. No maintenance was required for this erosion-control structure in areas where geotextiles were used. Laboratory studies of the fabric indicated that the filtration characteristics have not been significantly reduced from the filtration capabilities of new fabric. Therefore, it can be concluded that the filtration characteristics of the fabric were functioning according to the design requirements.

BAHIA HONDA BRIDGE

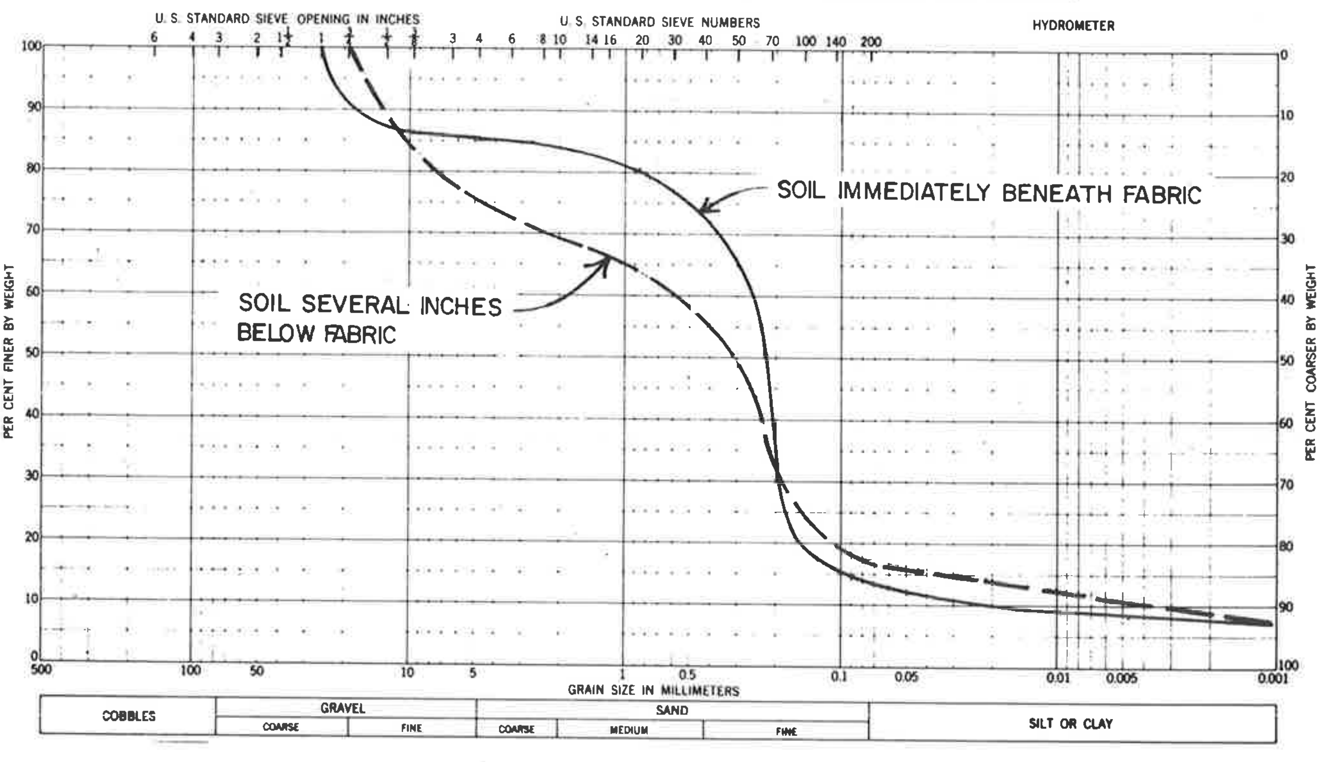
The Bahia Honda Bridge was constructed in 1969 to replace an older bridge between Bahia Honda Key and Spanish Harbor Key in Florida. The older bridge still exists; however, it is no longer used. The location of the new bridge is shown in Figure 10.

Both bridge abutments of the new bridge were constructed with a monofilament geotextile (Poly-Filter X) as a protection filter beneath sand-cement rip-rap-constructed abutment slopes, drains, and seawalls. The proposed designs for each of these sections are shown in Figure 11. The fabric in this system acts as a filter between the erosion-control armoring and the underlying soil to prevent loss of soil due to weathering or wave action through cracks or holes in the rip-rap. Sand-cement armoring construction consists of laying successive courses of burlap or jute sacks, which generally contain a mixture of one part cement to five parts sand. The sandbags are placed with broken joints. Header courses are used to tie the units together. The sacks are rammed or packed against each other so as to form a molded contact after the cement and sand mixture has set up.

The need for a filter layer beneath the armoring is important to prevent the loss of soil on which the construction rests. Erosion of soil can occur through the face of the structure or from beneath the structure due to wave action and weathering. These types of construction have little strength by themselves and rely entirely on the underlying soil for stability. They are surface treatments and are designed to be supported by the soils that they protect.

The design elevation of the top of the bulkhead that protects the toe of the bridge abutments is located approximately 5 ft above the normal water level. The 100-year water level in the area of the Bahia Honda Bridge, which occurred in 1960, was more than 4 ft higher than the bulkhead design eleva-

Figure 8. Grain-size distributions for soil immediately beneath and several inches below bridge abutment protection fabric from site 1.



tion. Such an extreme condition would place the wave action directly against the bridge abutments. Several major storms have occurred in the Florida Keys in the past 10 years, which have exposed the bridge abutments to gale and hurricane-type storm conditions, but Florida DOT reported that maintenance had not been required for any section of the project area.

Field Study

A site visit was made in October 1979. The intent was to make visual observations of the site, observe the fabric peformance, and, if possible, collect samples of the fabric to perform a laboratory evaluation of its condition. A photographic and visual survey of the site indicated excellent long-term

Figure 9. Grain-size distributions for soil immediately beneath and several inches below slope protection fabric from site 2.

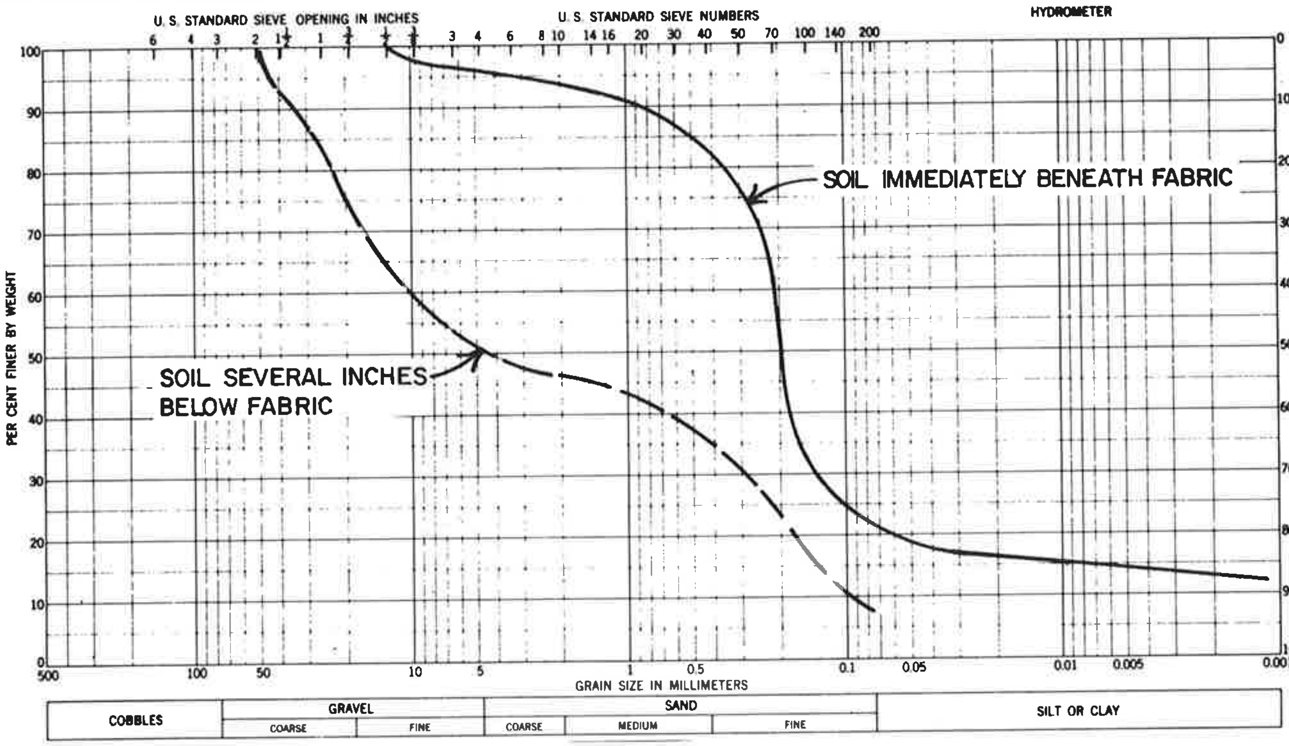


Figure 10. Location diagram of Bahia Honda Bridge.

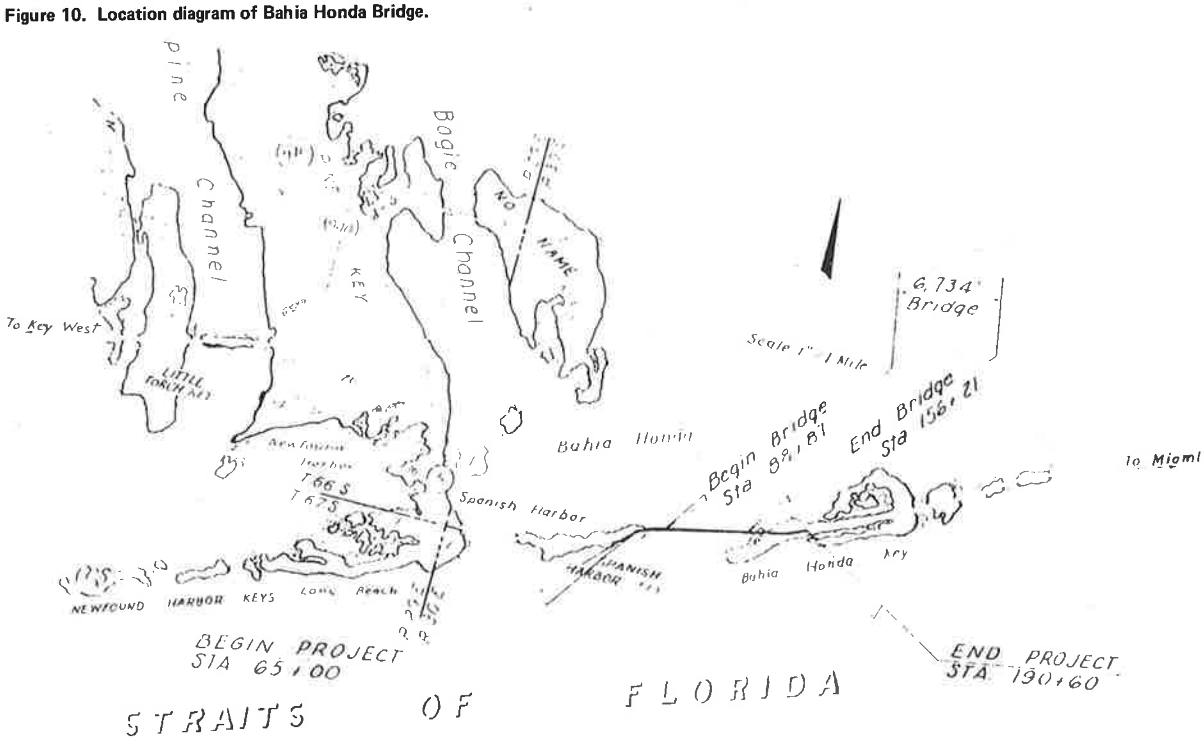


Figure 11. Proposed design of bridge abutments.

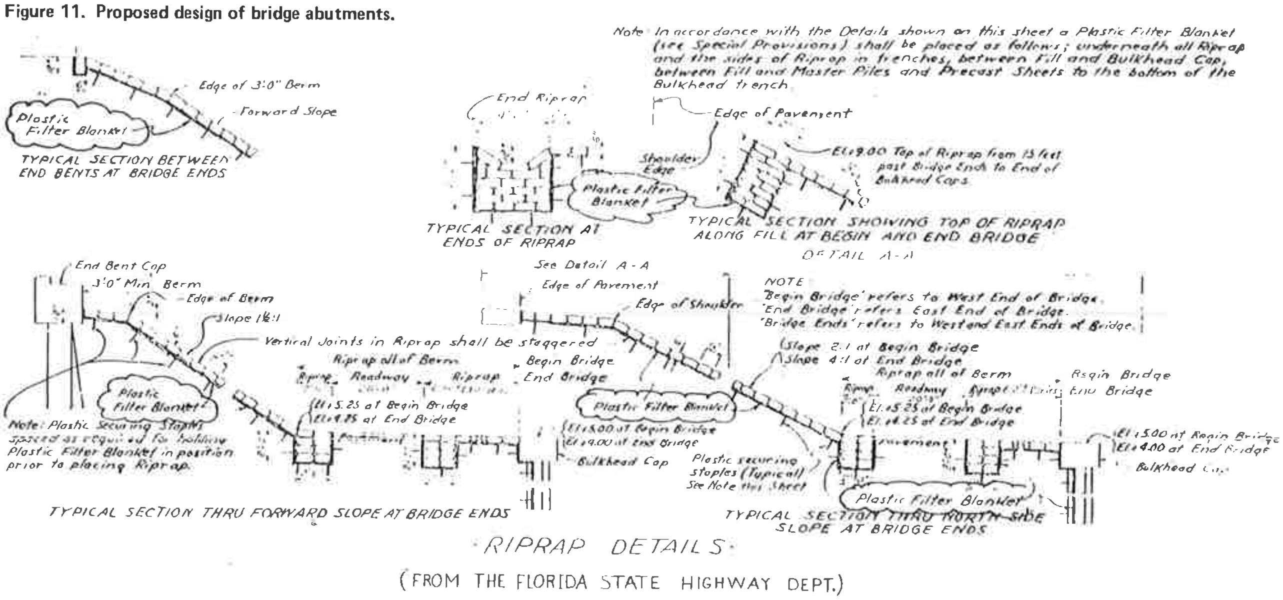


Figure 12. Armoring system: bridge abutment and drain, Bahia Honda Bridge.

Figure 13. Armoring system: bridge side slopes and top of seawall, Bahia Honda Bridge.

stability of the sand-cement constructed facilities, as shown in Figures 12 and 13. No erosion problems were apparent at any of the drains, slopes, and seawalls protected by the sand-cement armoring system, which indicated that the installation was functioning as designed. The armoring, in most cases, has held up completely. Some surface wear was noticeable; however, no washouts of the rip-rap were observed.

Fabric could be seen in several sections protruding from beneath the rip-rap at the edge of the structures. The rip-rap, and in two cases the underlying fabric, had been removed in several areas. Two sections of rip-rap, one at each end of the bridge between the two lanes of the bridge, were recently removed for construction of a future pipeline. Other areas that had been removed were possibly the result of vandalism. Exposed fabric was observed in the abutments, drains, and seawall. In all cases, the fabric appeared to be in excellent condition and could not be distinguished from new fabric.

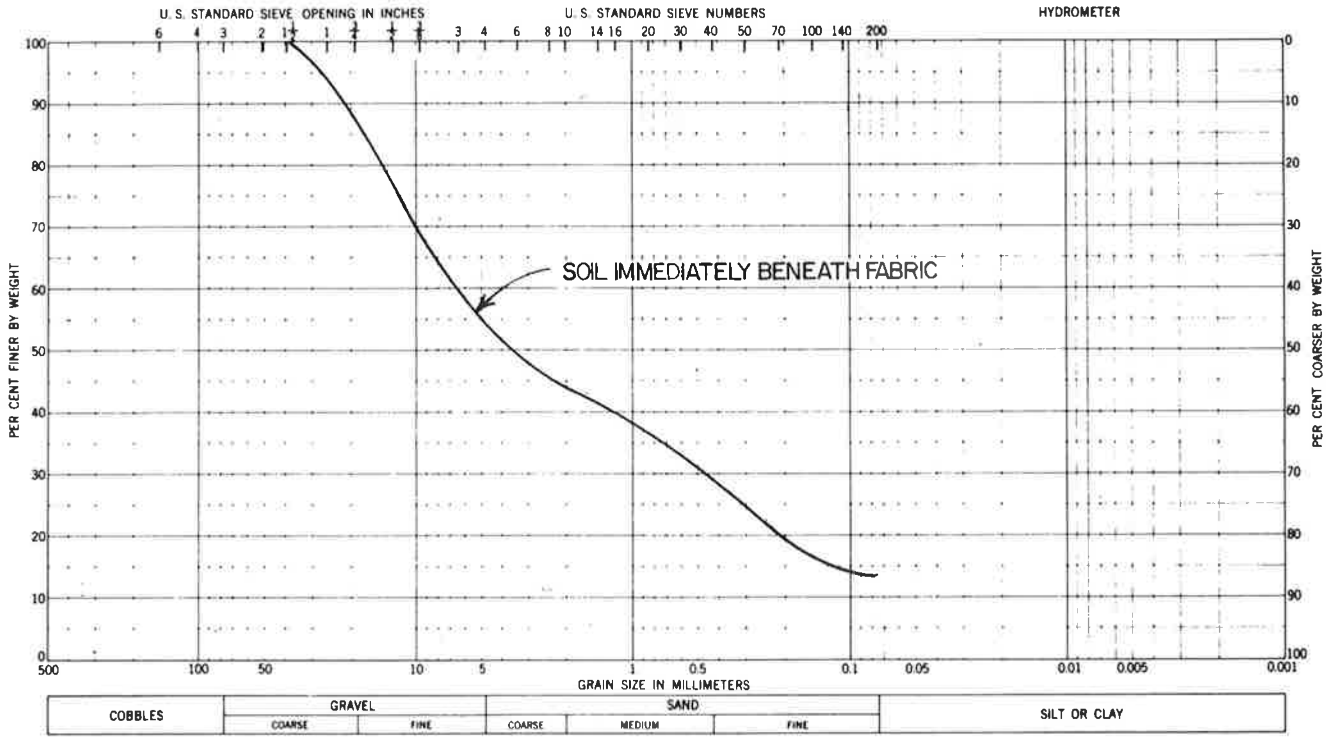
Other areas near the bridge were also examined. Visual observation of the old bridge abutment found signs of severe erosion problems. Large deformations of the steps and abutment slopes adjacent to the seawall had occurred. At the north end of the bridge, adjacent to the north end of the filter-protected rip-rap seawall, boulders had been placed to protect the slope. This area showed obvious signs of erosion; holes and washouts were present in the bank. The rip-rap seawall and the filter-protected drain adjacent to this area have been exposed to the same wave action and weathering conditions; however, they showed no signs of erosion.

The installation of a utility pipe at the time of the site visit allowed the removal of several sandbags from the bridge abutments. This enabled samples of fabric and soil beneath the fabric from the bridge abutment areas to be collected for laboratory analysis. Samples of the fabric and soil beneath the drains and seawalls could not be collected. All soil and fabric samples were returned to the STS laboratory for further examination and testing.

Laboratory Testing Program

Laboratory tests similar to those performed in the

Figure 14. Grain-size distribution of soil immediately beneath fabric in bridge abutment.



previous 79th Street Causeway study were performed on the fabric samples removed from the abutments. Tests to determine strength and permeability, and tests to evaluate particle retention of the filter fabric, were performed. Results were compared to tests on new samples of the fabric. In addition, a grain-size analysis was performed on soil samples taken directly beneath the fabric. Note that the abutment had not been exposed to wave action as had the seawall; therefore, the laboratory results may not reflect the condition of the fabric in the seawall.

Grab strength and elongation and strip tensile strength and elongation tests were performed in accordance with ASTM D-1682 in order to evaluate the strength of the fabric. Permeability of the fabric specimen was determined with the STS geotextile permeameter (Figure 5) by using a falling-head procedure. (The test procedure and equipment were described in the 79th Street Causeway study.) The particle retention of the fabric was evaluated by the Corps of Engineers procedure for the open area of a geotextile. One of the test specimens was flushed with water continuously for several hours under a head of 3 ft to crudely simulate wave action. The percent open area was then repeated to assess how many of the openings were permanently closed.

A grain-size analysis was performed on the soil sample taken from below the fabric in order to evaluate the particle-retention capability of the fabric. This test was performed in accordance with ASTM D-422 (Particle-Size Analysis of Soils) and used both sieve and hydrometer methodologies.

Test Results

The strength evaluation tests indicated that the fabric had a grab strength of 167 kg in the stronger principal direction and 111 kg in the weaker principal direction. This strength is equivalent to the strength of the new fabric, which had a strength of 170 kg in the stronger principal direction and 100 kg in the weaker principal direction. The material had a strip tensile breaking load of 115 kg in the stronger principal direction. Elongation of the material at failure was approximately 43 percent for both stronger and weaker principal directions in the grab tests and approximately 49 percent for the strip tensile tests. The elongation of the material at failure was approximately 10 percent greater than elongation of new fabric.

Permeability and particle-retention evaluations were performed for the filtration studies. The permeability and corresponding particle retention for particular fabric specimens are shown in Figure 7. The fabric between the sandbags had an average permeability of 1.2×10^{-2} cm/sec, and the fabric located directly beneath the sandbags had a permeability of 5.7×10^{-3} cm/sec. This corresponds with the particle-retention analysis, which indicates that the particle retention of the fabric was different, depending on the location of the test specimen.

The fabric between the sandbags had less than 10 percent of the openings closed by particles (an open area of 5 percent). Conversely, fabric beneath the sandbags had up to 50 percent of the space closed by particles (open area of 3 percent). It appears that the large amount of clogging found beneath the sandbags resulted from construction of the armoring system. The particles contained in the pore spaces consisted of sand and cement, which indicated that, at the time of construction, cement washed into and closed some of the pore spaces. The reduction in permeability and corresponding particle retention appears to be related to Darcy's relation among permeability, porosity, and seepage, as previously shown in Figure 7. The graph indicates that the decrease in permeability due to particle retention generally follows Darcy's law.

The grain-size curve for the material retained by the fabric is shown in Figure 14. The fabric was generally found to retain medium- to fine-sand-sized particles, with up to 15 percent silt. The Poly-

Filter X used in the installation had an opening size equivalent to a No. 70 mesh sieve. The data in the figure reveal that 20 percent of the soil particles directly behind the fabric were smaller than the fabric openings. When used in drainage applications the fabric has been able to retain particles in which the equivalent opening size of the fabric is less than or equal to the D85 (mean particle diameter of 85 percent of the material) size of the protected soil. However, for wave action problems, model studies should be performed to analyze cyclic gradients.

Summary

No maintenance was required for the structure in any area where geotextiles were used. The lack of maintenance, combined with the visual observation and laboratory test results, indicates that filtration characteristics of the fabric were functioning according to design requirements. The properties of the geotextiles collected from the installation in the abutment area indicated that the material has the strength characteristics of new fabric. Also, the filtration characteristics have not been significantly altered except directly below the sandbags where drainage was not required.

CONCLUSIONS

Both projects indicated the excellent long-term stability of properly designed geotextiles when used in the roadway and bridge abutment erosion-control designs reviewed. Case histories indicated that the filtration characteristics of the fabric and the armoring systems were functioning according to the design requirements and, as such, no maintenance had been required for either structure. A review of the design criteria established by Calhoun (2) for using monofilament woven geotextiles for filtering sand, in conjunction with the soils data presented for both projects, indicated that the geotextile in both projects satisfied the requirements for fabric suitability. Geotextiles that were not exposed to sunlight retained a significant amount of strength after a 10-year period. In most cases, less than a 20 percent decrease from the strength of the new fabric was found, and in some cases only a 5 percent decrease or less was noted. There are indications that the strength of the fabric may be affected by cyclic wetting and drying or repeated loading from wave and tidal variations. In the specific installations, abrasion was not a problem.

The incorrect placement of the fabric in a section of the 79th Street Causeway reflects the need for construction review by the design engineer, especially because many contractors are still inexperienced in placing these materials. The effects of construction procedures can have a pronounced effect on the long-term performance of a geotextile.

As a closing comment, it was noted during the site visits that the causeways extending through the Florida Keys were being rehabilitated by using rip-rap over fabric armoring systems. The Florida DOT should be commended for their extended use of these design concepts over the past 10 years. It is hoped that the case histories included in this paper, combined with other studies, will provide a useful information base for modifying and improving design criteria and predicted capabilities of geotextiles.

ACKNOWLEDGMENT

Many thanks to the Florida DOT for their assistance in providing design and performance information for these projects, and to Carthage Mills Erosion Control Company for their sponsorship, which made this study possible.

The field study of the 79th Street Causeway was performed by Ed Bernett of Carthage Mills and myself, and I made the field study of the Bahia Honda Bridge.

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Long-Term In Situ Properties of Geotextiles

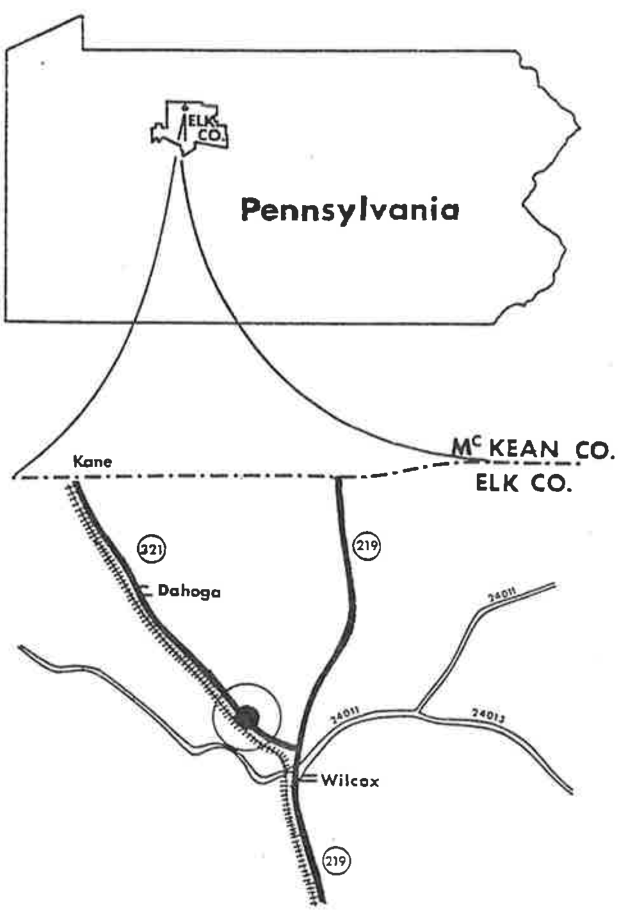
GARY L. HOFFMAN AND ROBERT TURGEON

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.

Figure 1. Location map.



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 2. Typical pavement cross section.

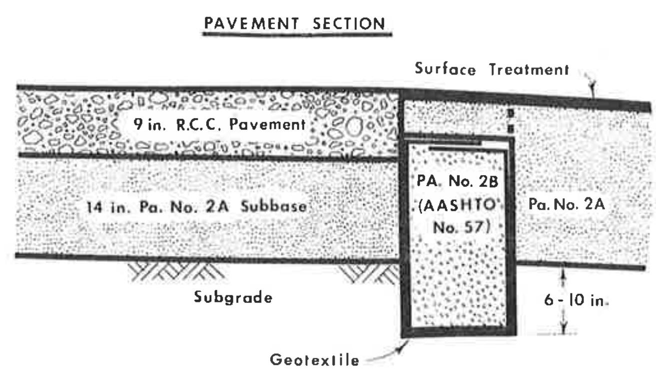


Figure 3. Typical drain cross section and plan section.

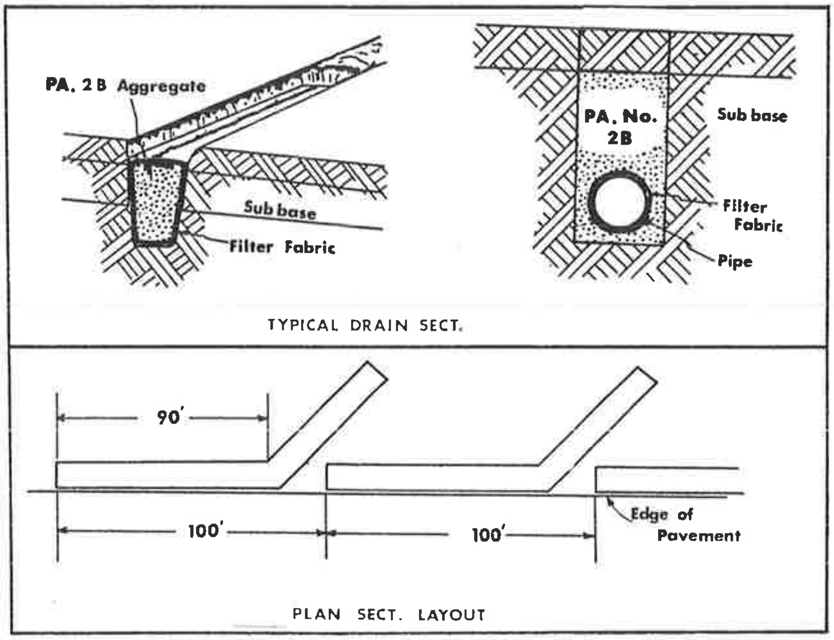


Table 1. Construction details of 12 sites.

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

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

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

SUBGRADE SOIL

Sieve Size	% Passing
2½ in.	100
1 in.	90
⅜ in.	84
No. 4	79
No. 20	66
No. 60	60
No. 200	51
0.02 mm	38
0.002 mm	20

Class. A-4(3) gravelly clay loam

L.L.-30; P.I.-10

pH-5.3

resistivity-4460 ohm-cm

WATER SAMPLES

Site	1	2	3	4	5	6	7	8	9	10	11	12
pH	9.3	7.8	7.8	7.2	7.5	7.9	7.7	7.1	7.0	8.5	9.3	7.9

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.

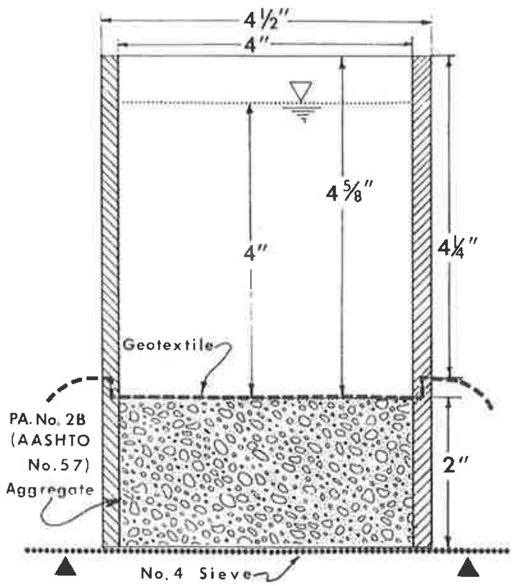


Figure 6. Modifications to grab tensile test as compared with specified procedure.

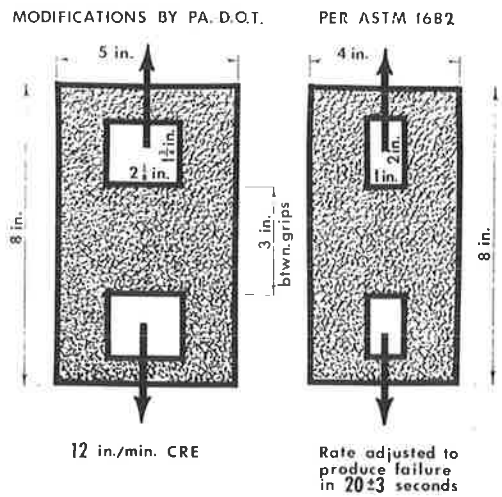


Table 4. Thicknesses of fabrics.

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.

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