Durability of Geotextiles Used in Reinforcement of Walls and Road Subgrade

BILL POWELL AND JOHN MOHNEY

The USDA Forest Service began using geotextiles in the early 1970s, actively contributing to the early stages of technology development. As part of that development, two test projects were completed in the Olympic National Forest in the state of Washington. One project evaluated geotextiles used as reinforcment layers in a "fabric wall" and the other evaluated road subgrade reinforcement. The test wall was constructed in 1975 using two different nonwoven materials, one polypropylene and the other polyester. To help evaluate the long-term durability, samples were retrieved in 1993 and tested to determine changes in strength. Also the original wall design was compared to current design standards. The test road sections were constructed in 1976 using nonwoven fabric and were used for heavy timber hauling during 1977. In 1978 samples of fabric were extracted from the road and retested. Samples were extracted in 1993 to conduct tests for determining the existing fabric strength, which should provide an indication of the long-term durability of the materials. Testing was completed under the FHWA Pooled Fund Study for durability of geosynthetics for highway applications. Test results indicate a strength loss ranging from 20 to 50 percent. Most of the strength loss appeared to be a result of the angular fill material piercing the geotextiles. The FHWA design procedure for walls is more conservative than the procedure used for the test wall, primarily due to the creep reduction and lateral resistance factors of safety.

Geotextiles have been used for construction on USDA Forest Service projects since the early 1970s. The early Forest Service work resulted in development of comprehensive standards and guidelines published in 1977, *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads* (*1*). As part of the Forest service's technical development of the use of geotextiles, several construction projects were used to test the materials in actual applications. Before this time geotextiles had limited use, so there was little information on the long-term durability of the materials. The intent of this paper is to take two of these projects one step further and report on the durability of the materials since construction. Both projects are in the Olympic National Forest in Washington State. Project 1 is an internally reinforced "fabric wall" and Project 2 is a reinforced saturated subgrade for a logging road. Extensive testing and documentation was conducted on these projects at the time of construction because they were used as test structures for evaluating geotextile materials. Additional samples were obtained on both projects in May 1993 to determine the loss in strength over time.

Forest Service, U.S. Department of Agriculture, Pacific N.W. Region, 333 SW First Avenue, Portland, Oreg. 97208.

PROJECT INFORMATION

Fabric Wall

In conjunction with Oregon State University (OSU), the Forest Service completed the design and construction of a retaining structure used to correct an unstable fill on an existing Forest Service road in 1975. The wall had a maximum height of 5.6 m (18.5 ft) and the total length was 50 m (166 ft). Two types of geotextiles were selected for evaluation: a nonwoven polypropylene (Fibertex) and a nonwoven polyester (Bidim). Two different material thicknesses were selected for each geotextile type. Material properties are given in Table 1, and summaries of the 1993 tests are presented in Table 2.

Design Parameters

Design parameters are as follows:

- Live load: 50 000-kg (110,000 lb) loaded log truck.
- Backfill: crushed rock, angle of internal friction = 40 degrees, dry density = 2 g/cm^3 (125 lb/ft^3).
- Dead load: at rest pressure.
- Foundation: moist unit weight = 2.08 g/cm^3 (130 lb/ft^3), angle of internal friction = 35 degrees, cohesion = 0.

Wall design was completed in 1975 using the same standards outlined in *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads* (*1*). Detailed information for the design and monitoring of the wall is documented in the guidelines. The wall is 3.7 m (12 ft) in width, and the vertical spacing between geotextiles is 22.9 cm (.75 ft) and 30.5 cm (1 ft) in thickness. Figure 1 is a photograph taken when the wall was nearly complete, with emulsified asphalt being sprayed on the exposed front face to be used for ultraviolet protection. A cross-section of the wall is shown in Figure 2.

Using the same geometry and materials testing information, the wall was analyzed using today's design standards from *FHWA Reinforced Soil Structures, Volume 1, Design and Construction Guidelines* (*2*). The width of the wall would be the same (3.7 m) but it would require more layers or higher strength geotextiles. The layer thickness would be 30 percent less with the polyester (Bidim) and 65 percent less with the polypropylene (Fibertex). There would be 1.4 times as many layers with polyester and 2.8 times as many layers with polypropylene. To make this comparison, correlations were made among different testing methods used to determine strength. Extensive testing was completed for

TABLE 1 Material Properties of Fabric Wall

Trade Name	Thickness mils	Weight gm/m^2	1975 Grab Test ASTM D-1682 Mach Dir lbs.	1975 OSU Ring Test Mach Dir lbs./in	1993 Grab Test ASTM D-4632 Mach Dir lbs.	Strength Reduction 1975-93 %
Bidim C-28	95	200	198	62	99	50
Bidim C-38	114	420	--	106	--	--
Fibertex 420	190	420	550	67	327	40
Fibertex 600	250	600	--	95	--	

the original fabric wall design. The OSU ring test used in the wall design produced values that were about 33 percent of the grab test (ASTM D1682). The new design standards recommend using the wide width test (ASTM D4695-86), which is about 50 percent of the grab test using product information testing results or about 35 percent higher allowable strength than for the original design (OSU ring test result).

It is difficult to directly compare the design methods because different parameters are used in each method. The new design standards have higher requirements for reinforcement materials due primarily to the strength reduction factors for construction (creep and durability) referred to in Task Force 27 (*2*) (see Figure 3). Although the Olympic National Forest wall would be substantially underdesigned by today's design standards, it does not show any signs of distress after 18 years of use. The emulsified asphalt used to protect the front face has deteriorated and small holes in the fabric face are starting to appear. Although the holes are on the face, there are no deformities or loss of materials on the wall face. In time the face will be repaired by shotcrete sprayed on the surface.

Subgrade Reinforcement

The Quinault Test Road Project, located on the state of Washington's Olympic Peninsula, was constructed in October 1976 (*1*). As with the fabric wall, extensive testing was conducted as part of this project. During 1977 the road was used for log hauling. In

TABLE 2 1993 Fabric Wall Test Results, Site 5

Material	Weight gm *	Tensile Force, lbs	St. Dev.	lb.	Coeff. Var %	Strain %	Comments
	5.1	88	Orig			62	
	5.22	85	1975	10.6	5.4	74	
5A1	4.8	94				72	Layer 1
	5.02	96				78	
Bidim	6.79	135	1993	19.0	19.8	89	Ave. = 96
200	5.67	105				72	Range = 69 - 135
	5.47	99				69	
	4.72	69				65	
	5.7	87	Orig			48	
	5.2	83	1975	10.6	5.4	53	
5A2	4.75	122				64	Layer 2
	5.34	119				61	
Bidim	4.94	118	1993	24.7	24.2	56	Ave. = 102
200	5.7	55				55	Range = 55 - 122
	5.3	122				65	
	6.61	113				60	
	7.68	287	Orig			118	
	8.1	355	1975	15.1	2.8	169	
5B2	8.1	346				164	Layer 2
	8.6	333				125	
Fibertex	7.33	318	1993	27.9	8.5	158	Ave. = 327
420	8.2	327				134	Range = 279 - 358
	8.84	358				150	
	7.32	279				121	
	8.35	336				160	

* 4"x8" Sample Size

FIGURE 1 Geotextile wall, with exposed material being sprayed with emulsified asphalt after construction.

$$X = \frac{S}{FS\ \sigma_h} = \frac{.33\ (Grab\ Strength)}{(1.75)\ (130)\ (.36)\ depth} = \frac{.004\ (Grab\ Strength)}{depth}$$

Where
- X = Layer Spacing
- S = Fabric Strength
- OSU Ring Test = 33% of Grab Test
- σ_h = Horizontal Stress (at rest K_o)
- F.S. = 1.75 (Factor of Safety)

$$S = \frac{T_d}{\sigma_h} \qquad T_d = \frac{T_L\ CRF}{C_c\ C_r\ C_v}$$

$$= \frac{T_d}{(depth)\ (.22)\ (130)}$$

$$= \frac{.0014\ (Grab\ Strength)}{depth}\ (polypropylene)$$

$$= \frac{.0028\ (Grab\ Strength)}{depth}\ (polyester)$$

Where
- T_d = Design Tensile Strength
- T_L = Wide width Geotextile Strength
- CRF = Creep Reduction Factor
  - = .2 for Polypropylene
  - = .4 for Polyester
- Cc = Factor of Safety for construction
  - = 1.1 to 1.3
- C_r = Factor of Safety for Durability
  - = 1.1 to 2.0
- C_v = Uncertainty
  - = 1.5
- σ_h = Horizontal Stress (active Pressure, K_a)

FIGURE 3 Layer spacing for fabric wall: *top*, Forest Service (*1*); *bottom*, FHWA (*2*).

1978 the test sections were excavated to obtain geotextile samples for comparative strength testing. These test results have been reported (*3*), giving an indication of the construction damage sustained by the geotextiles. In May 1993 the test sections were again excavated to obtain geotextile samples for strength testing. These tests provide information on the deterioration of the geotextiles in the ground during the 15 years since the 1978 tests. Tables 3 and 4 present a summary of strength testing. Figure 4 shows rockfill material being placed on geotextile during initial construction.

Geotextiles used in the test sections were those available in the northwestern United States at the time of construction. These were

- Bidim needle-punched nonwoven polyester—150, 325, 420 g/m^2.
- Fibertex needle-punched nonwoven polypropylene—320 and 420 g/m^2.
- TYPAR heat-bonded nonwoven polypropylene and nylon—140 g/m^2.
- Mirafi heat-bonded polypropylene.
- SUPAC needle-punched polypropylene—140 g/m^2.

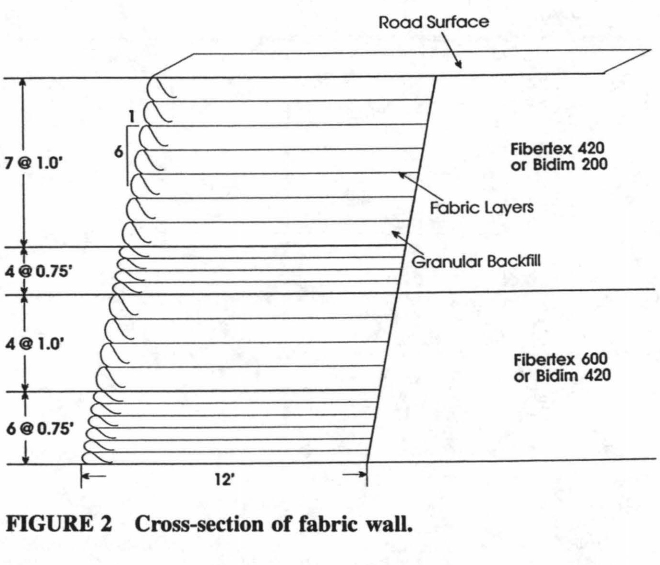

FIGURE 2 Cross-section of fabric wall.

Subgrade soils were highly organic clays and silts (Unified Soil Classification OH) with California bearing ratio (CBR) values less than 1. The geotextiles were placed directly on the subgrade. Then 0.5 to 1 m (2 to 3 ft of "shot rock" fill was dumped on the geotextile and spread at full depth using a Caterpillar D-6 dozer. The rock fill was surfaced with 0.2 to 0.3 m (8 to 12 in.) of glacial pit run gravels.

The original design called for 0.7 m (2 ft) of rock fill, and the rock contained pieces up to 1 m (3 ft) in size. Because of this the rock fill was generally thicker than the design and actual stresses under load were less than designed. Questions of construction damage and long-term durability can be answered, however. Traffic consisted of rock-hauling trucks during construction, and highway-legal (36 000-kg or 80,000-lb gross vehicle weight) log trucks during logging.

DURABILITY SAMPLING AND TESTING

In May 1993 samples of the buried materials were retrieved by excavating into the embankments of both the wall and the road. The excavation was started using a hydraulic excavator. To prevent damage to the geotextiles, final excavations were completed by hand digging. The samples were retrieved in cooperation with Earth Engineering and Sciences, the FHWA contractor for the Pooled Fund Study, then wrapped in black plastic. The 1993 samples retrieved were Bidim 150, Fibertex 420, Mirafi 140, Typar 140, and Supac 140. These samples were tested using the 102-mm (4-in.) grab test (ASTM D1682). The tests were performed at Polytechnic University of Brooklyn using the same test grips used for the original tests to limit the amount of testing error.

RESULTS

Fabric Wall

Test results for the wall are displayed in Tables 1 and 2. The test results are consistent, with minor variations. The loss in strength

TABLE 3 Results of Grab Tests, Quinault

Fabric	Wt. gm/m^2	4" Grab Test, lbs. 1976	1978	1993	% Lost 1976-78	% Lost 1978-93
Bidim	150	234	135	124	42	5
Fibretex	420	550	395	339	28	10
Mirafi	140	124	112	97	10	12
Typar	140	144	119	116	18	2
Supac	140	86	93	92	--	--

TABLE 4 Subgrade Reinforcement Test Results, Site 10

Material	Weight gm *	Tensile Force, lbs	St. Dev.	lb.	Coef. Var %	Strain %	Comments
	13.42	360	Orig			183	Ave. = 339
	13.18	345	1976	15.1	2.8	196	Range = 317- 360
A	14.01	352				185	
	12.92	317	1978	88.3	22.4	168	
Fibertex	13.25	329				179	
	11.72	240	1993	14.8	4.4	126	Slippage
	12.7	338				149	
	12.7	330				146	
	4.42	101	Orig			61	Ave. = 116
	3.6	125	1976	18.2	12.6	81	Range = 101 - 125
B	3.52	116				88	
	3.5	122	1978	18.6	15.7	90	
Typar	3.42	105				64	
	3.44	116	1993	8.6	7.4	68	
	3.31	86				40	Broke in jaw
	3.38	121				74	
	3.3	121				61	
	3.33	99	Orig			128	Ave. = 97
	3.54	102	1976	11.2	10.0	121	Range = 79 - 105
C	3.74	79				122	
	3.31	91	1978	18.0	16.1	129	
Mirafi	3.4	105				153	
	3.12	104	1993	9.1	9.4	102	
	3.14	76				77	Broke in jaw
	3.34	90				120	
	2.93	102				162	
	4.15	88	Orig			59	Ave. = 93
	3.98	100	1976	10.8	7.7	79	Range = 80 - 109
D	3.99	80				59	
	4.3	86	1978	8.9	9.6	65	
Supac	4.24	109				82	
	3.93	85	1993	9.6	10.3	69	
	4.05	93				73	
	3.35	68				85	Broke in jaw
	5.15	99				86	
	4.51	115	Orig			90	Ave. = 124
	4.51	113	1976	11.2	4.8	60	Range = 113 - 142
E	4.63	124				72	
	7.03	86	1978	10.0	7.4	57	Slippage
Bidim	7.18	88				39	Slippage
	5.1	142	1993	11.6	9.4	48	
	8.26	119				60	
	10.92	132				55	

* 4"x8" Sample Size

FIGURE 4 Dozer spreading rockfill on geotextile.

during the 18 years since the wall was built was 50 percent for the Bidim (nonwoven needle-punched polyester) and 40 percent for the Fibertex (nonwoven needle-punched polyester) and 40% for the Fibertex (nonwoven needle-punched polypropylene). Although there was a reduction in material strength, the wall has performed well and the original design is probably appropriate. If we consider that all losses of strength measured in the initial construction are due to construction damage, differences in the designs are a function of the creep reduction factors and the factor of safety for uncertainty. It would therefore be appropriate to further evaluate the creep reduction factors in a confined mode and conduct wall monitoring aimed at evaluating movement and stresses in the materials.

The original material testing done in 1975 had a low coefficient of variation: 5.4 percent for the Bidim 200 and 2.8 percent for the Fibertex 420. The coefficient of variation increased significantly for the 1993 tests: 19.8 percent and 24.2 percent for the Bidim and 8.5 percent for the Fibertex (see Table 2). Based on these results it could be concluded that the 1993 tests cannot be used to indicate chemical degradation of the geotextiles. The 1993 coefficients of variation for the Bidim and Fibertex from the wall are consistent with the data obtained in 1978 from the subgrade that was for construction damage. The material that was retrieved in 1993 had numerous holes caused by punctures from the sharp, angular rock material in the fill. Additional sampling may reduce the coefficient of variation, but not significantly enough to warrant a different conclusion.

Subgrade Reinforcement

The test results are summarized in Tables 3 and 4. Initial construction damage resulted in a loss of strength of 10 to 42 percent of the initial strength. It is interesting to note the two lightest weight geotextiles sustained less damage than the heavier geotextiles.

During the 15-year period from 1978 to 1993 an additional loss of strength ranged from 2 to 12 percent. Total strength loss from construction and long-term degradation was 20 to 47 percent for all geotextiles.

Generally the standard deviation of test results is consistent except for the Fibertex (see Table 4). The rock used in the road construction was larger than the material used in the fabric wall, but the individual particles were either rounded or angular and soft. Also there was a large amount of fines mixed with the rock, which had a cushioning effect, and there seemed to be substantially less damage to the fabric during construction.

Judging from the coefficient of variation, the 1978 and 1993 tests only varied slightly for the Supac and Bidim geotextiles, and it could be concluded that the 1978 to 1993 loss of strength of 8 percent for Bidim could be attributed to hydrolysis. No detectable loss of oxidation for the polypropylene could be inferred from the data by considering the coefficients of variation measured.

Although the geotextiles have a reduced strength they are still functioning as designed. Because geotextile strength is not an input in the design procedure, a large loss of strength is not critical to performance. The primary purpose of a strength requirement for subgrade reinforcement geotextiles is to ensure construction survivability. Stresses from traffic loads have not caused failure of the geotextiles.

REFERENCES

1. Steward, J., R. Williamson, and J. Mohney. *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads*. Report FHWA-TS-78-205. USDA Forest Service; FHWA, U.S. Department of Transportation, 1977.
2. *Reinforced Soil Structures, Volume 1: Design and Construction Guidelines*. Publication FHWA-RD-89-043. FHWA, U.S. Department of Transportation, 1990.
3. Mohney, J., and J. Steward. Construction and Evaluation of Roads over Low Strength Soils Using Nonwoven Geotextiles. *Proc., 19th Annual Engineering Geology and Soils Engineering Symposium*, Idaho State University, Pocatello, 1982.