Survivability and Durability of Geotextiles Buried in Glenwood Canyon Wall

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Geotextiles buried for up to 11 years in a geotextile-reinforced soil retaining wall constructed in 1982 in Glenwood Canyon, Colorado, by the Colorado Department of Transportation were exhumed from the wall in 1984 and again in 1993. Survivability and durability of the geotextiles were evaluated by comparing the wide-width tensile strengths of the excavated samples to the strengths measured before construction. The geotextile-reinforced wall was built by conventional methods with a very coarse, rounded, well-graded, pit-run gravel as the backfill soil. Four nonwoven geotextiles in two weights each were included in the wall. Wide-width tensile tests were performed on 31 exhumed samples of eight specimens each, resulting in 248 tests. Sample mean strengths were compared with preconstruction mean strengths. The results showed that exhumed sample strengths were lower by 4 percent to 51 percent. The average mean strength loss was 27 percent. For the conditions of this wall, construction was the dominate cause of damage. Little if any degradation occurred during the 9 years between the first and second sampling. The large sizes of the cuts and abraded areas in the exhumed geotextiles made small specimen tests, such as the burst or grab tensile tests, impractical. Some conclusions were limited by the large coefficients of variation for some damaged specimen populations, which required samples of more than eight specimens for reasonable precision.

Since their first use, there have been concerns about the survivability and durability of geotextiles. Are they damaged by construction? Are they degraded by long-term burial? This paper presents the results of a study by the Colorado Department of Transportation that provides some answers to these questions.

In spring 1982, an experimental geotextile-reinforced soil retaining wall was constructed in Glenwood Canyon, Colorado, as part of the Interstate 70 project. Four relatively low-strength nonwoven geotextiles in two weights each were included in the wall. The wall and its performance have been described elsewhere (*1*). The wall was to facilitate construction and was temporary. It was, therefore, decided to exhume geotextile samples from the wall after its design life and compare their strengths with the initial strengths of the geotextiles. The excavations were performed in two phases. The first was 2 years after construction in summer 1984 and the second was 11 years after construction in 1993.

The wall construction was the conventional U.S. Forest Service wrapped-face method. The backfill was end dumped on the geotextile, spread with a small bulldozer, and compacted by a vibratory smooth drum roller. The backfill was a free-draining, pit-run, rounded, well-graded, clean, very coarse sandy gravel. Nearly 100 percent was smaller than 150 mm (6 in.) with about 50 percent larger than 20 mm (0.75 in.) and 30 percent passing the No. 4 U.S. standard sieve. Construction specifications required compaction to 95 percent of AASHTO T-180. The wall was 4.5 m (15 ft) high and 100 m (330 ft) long. A typical section is indicated in Figure 1.

The nonwoven geotextiles used are described in Table 1. The designations are appropriate for 1982 when the wall was built. The project was divided along its length into 10 segments, each 10 m (33 ft) long, and only one geotextile type. In some segments, the top nine layers contained the lighter weight fabric and the lower layers the heavier weight.

SAMPLING AND TESTING

The scheme was to investigate the effects of burial in the wall by comparing preconstruction wide-width tensile strengths to the strengths of exhumed samples. It was reasoned that the results could be influenced by

- Duration of burial;
- Geotextile type, polymer, and weight;
- Fabric variability;
- Construction stresses;
- Wall stresses due to gravity and loads;
- Damage during excavation and storage; and
- Test methods and procedure.

To address each of these factors, it was planned to

- Sample at least two times after construction;
- Sample each geotextile and weight each time;
- Sample at several locations within the wall section;
- Test eight randomly selected specimens per sample; and
- Always follow the same procedures for excavation, storage, and testing.

Sampling

Two years after construction (1984), samples were taken to investigate survivability. At that time, degradation due to aging was assumed small, and strength loss was attributed to construction, postconstruction traffic, and internal wall stresses from gravity. The 1993 samples were taken 9 years after the first samples so aging effects could have become apparent. The study was limited by time and other constraints that made it impossible to sample all fabrics both times.

Samples were planned from five locations in the wall section, as indicated in Figure 1. Different depths were chosen to show the effects of overburden pressure. Layer 3 was the highest layer that

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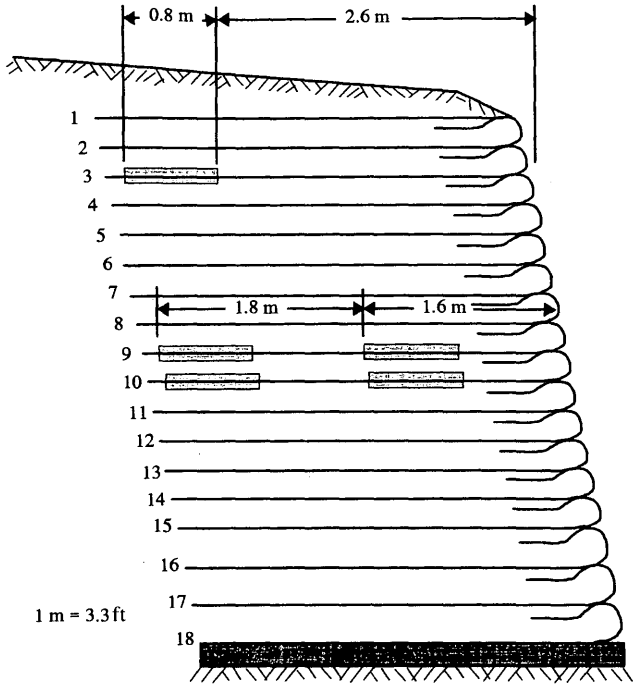

FIGURE 1 Glenwood Canyon wall section and sample locations.

contained all geotextile types and weights. In some wall segments, Layers 1 and 2 contained odd fabrics. Layer 9 was the lowest layer that contained all fabrics and weights. Layer 10 was the layer closest to Layer 9 that contained the heavier fabric in wall segments with two fabric weights.

In Layer 3, samples were planned from a zone well back from the wall face. At this location, outside of the theoretical Rankine active zone, shear stresses from the wall are nil. Also at this depth, overburden stresses are low, and the main effects should have been from construction stresses and postconstruction traffic. In Layers 9 and 10, samples were removed from zones both near the wall face and well back from the face. Back from the face, effects would be from overburden and construction; traffic and shear effects would be negligible. Near the face, shear stresses in the Rankine active wedge may also have affected the fabrics. Samples were identified by wall segment number, layer number, and whether from the front or back. For example, Sample 5-9F would be from the front of Layer 9 in wall Segment 5.

This sampling plan was strictly adhered to in 1984 except in Segment 6; Layer 11 instead of 10 was sampled as a result of misalignment of the geotextile seam in Layer 10 during construction. In 1993, because of time and other constraints, sheets were excavated from Layers 1 and 2 instead of Layer 3, and from Layer 8 instead of Layer 9. Samples from Layer 1 and some samples from Layer 2 were taken in the center of the sheet and are designated with a C.

The general excavation procedure was to dig a pit straddling the sewn seam between two desired wall segments. The pit was wide enough to give a fabric strip at least 750 mm (30 in.) wide on each side of the seam. Thus, two different fabric types were represented in each excavation pit. Power equipment was used to advance the pit, but hand methods and great care were used to remove the last soil layer above the geotextile sheet to be sampled. Any observed excavation damage was indicated on the geotextile with a marker pen. The sheets were labeled, the back and top marked, and placed in opaque plastic bags for storage and shipping.

Specimen Selection

Each test sample consisted of eight specimens 203 mm (8 in.) by 203 mm (8 in.). The scheme for selecting specimens in a sample is

TABLE 1 Test Geotextiles and Unaged (1982) Parameters

"Trade Name" (Manufacturer) Code No.	Nominal Mass g/m^2	Filament (Construction) Polymer	Unaged Strength kN/m	Failure Strain %
"Trevira" (Hoechst Fibers)		Continuous (Needled)		
H1115	170	Polyester	6.8	80
H1127	370		16.6	75
"Fibretex" (Crown Zellerbach)		Continuous (Needled)		
CZ200	200	Polypropylene	5.8	140
CZ400	400		10.1	145
"Supac" (Phillips Fibers)		Staple (Needled &		
P4oz	135	Heat Bonded*)	12.3	65
P6oz	200	Polypropylene	24.3	60
"Typar" (DuPont)		Continuous (Heat Bonded)		
D3401	135	Polypropylene	7.7	60
D3601	200		12.6	55

* One side only 1 g/m^2 = 0.03 oz./yd.^2 1 kN/m = 5.7 lb./in.

illustrated in Figure 2. Areas 610 mm (24 in.) wide by 813 mm (32 in.) along the seam were laid out on the geotextile sheets on each side of the seam as shown. For Layers 2 and 3, the two areas at the back were used. For the deeper layers, all four areas were used. Sheets from Layer 1 and some from Layer 2 were taken from the middle of the wall segments and, therefore, included only one geotextile type and did not include a seam. On these sheets a single area near the center of the exhumed geotextile sheet was used.

Eight specimens were selected from the 12 possible in each area by a blind draw. The selected specimens were cut from the sheet, labeled, and marked to show their orientation with respect to the wall. Specimens were tested regardless of fabric damage. Adjustments were made only if damage marked as due to excavation occurred in the specimen test area. In this event, a substitute specimen was cut from the nearest available location. A total of 248 wide-width tensile strength specimens from 31 samples cut from 21 exhumed geotextile sheets were tested.

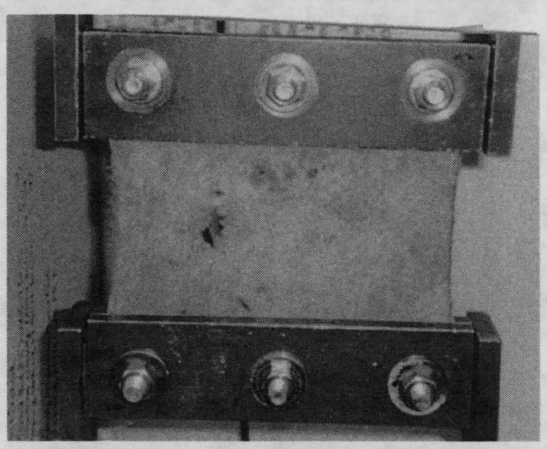

FIGURE 3 Geotextile specimen with major damage in test grips.

Test Procedure

At the time of the preconstruction testing in 1982 there was no American standard wide-width tensile strength test method; however, except for the grips, the method used (*2*) was the same as ASTM D4595 approved in 1986. All tests in 1984 and 1993 were performed by the same procedure and with the same grips used in 1982.

The full width of the 203-mm (8-in.) by 203-mm (8-in.) specimen was held by the test grips, as illustrated in Figure 3. The specimens were orientated to measure the strength perpendicular to the wall face (cross-machine direction). The initial grip spacing was 102 mm (4 in.). The specimens were placed in the grips to test the middle 102 mm (4 in.) without regard to specimen damage. The geotextile specimens were conditioned by soaking in water for a minimum of 12 hr before testing. The tests were performed at a constant deformation rate of 10.2 mm/min (10 percent per min.) in a MTS Systems Corporation test machine. Load and elongation outputs were recorded by an *x-y* plotter.

The loads on the geotextiles in force per unit width (kPa/m) at various strains (percentage) were computed from the *x-y* plots and tabulated for each specimen. The maximum, minimum, and mean were determined at each of several strains for a sample. For illustration, plots of these data for 1984 tests Typar 3601 Sample 1-3B are plotted in Figure 4 with the corresponding initial 1982 strength curves.

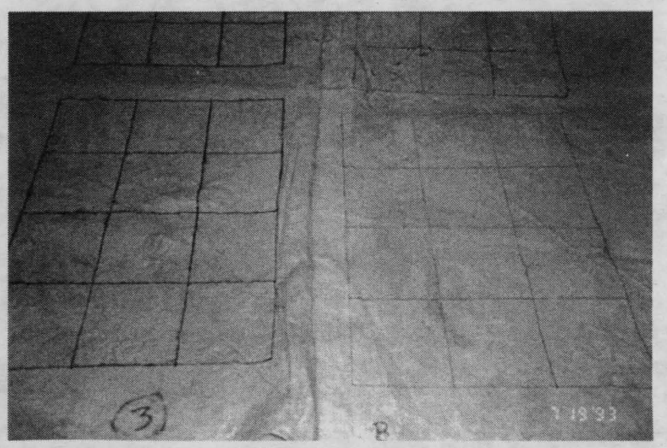

FIGURE 2 Exhumed geotextile sheet with specimen locations marked.

RESULTS

Plots such as Figure 4 are interesting and useful, but where a large number of samples are involved they are cumbersome. To simplify the results presentation, each load-strain curve is represented by the strength defined as the maximum load per unit width. The results in this form are summarized in Table 2. This table also presents failure strains and, for the mean strengths standard deviations, coefficient of variance and retained strength ratio. Coefficient of variance is defined as the ratio of the sample standard deviation to the mean and is expressed as a percentage.

The retained strength ratio is used as the measure of survivability and durability and is defined as the ratio of the mean sample strength from Table 2 to the initial (1982) mean strength from Table 1. As an example, the retained strength ratio value for Typar D3601 Sample 1-3B illustrated in Figure 4 is 65 percent. Retained strength ratio values for most samples are presented in Table 3.

Also listed in Table 2 is the number of specimens required in a sample to ensure that the mean of the sample tested represents the true mean of the geotextile sheet with an accuracy of plus or minus 10 percent with probabilities of 90 and 95 percent as calculated by the methods of ASTM D-2905. It is apparent from this table that less than half of the samples have a greater than 95 percent probability of 10 percent accuracy, and only about two-thirds have better than 90 percent probabilities of this accuracy. In the worst case, the probability of 10 percent accuracy is only about 70 percent.

DISCUSSION OF RESULTS

All the excavated samples have lower mean peak strengths than the original geotextile samples except the 1984 Fibretex 400 (CZ400) samples, which are higher. The Fibretex data are inconsistent and irrational. There is no known explanation for this inconsistency. This fabric was not sampled in 1993; therefore, although the results are included in Table 2 for completeness and to illustrate a sampling problem, further discussions ignore the CZ400 tests.

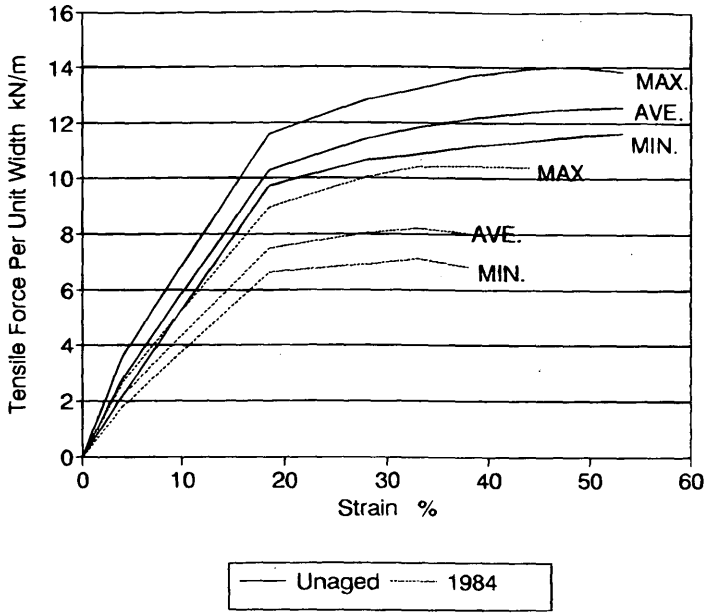

FIGURE 4 Load versus strain for D3601 1984 Sample 1-3B and unaged tests.

Layer 1 is a special case. This was a cover layer and not structurally part of the wall; therefore, the same care to protect the fabric during construction was not exercised for this layer as the others. Also, because it is the top layer, construction and postconstruction traffic may have caused greater damage to this layer than to Layers 2 and 3. Therefore, the low retained-strength ratios for Layer 1 are not considered comparable to the values from the other layers. They are included in Table 3 for D3401 and H1115 geotextiles to show the relative magnitudes of damage that did occur in some instances. The Layer 1 values are shown in parentheses in Table 3 and are not included in the averages. Layer 1 values for CZ200 and P6oz fabrics are omitted from Table 3 for simplicity and are also not included in the averages. These considerations eliminate CZ200, CZ400, and P6oz from further discussions.

The average retained strength ratio as shown in Table 4 for the samples represented in Table 3 is 73 percent and the range is 49 per-

TABLE 2 Summary of 1984 Test Results

Fabric	Sample	Strength						Required* Specimens		Mean Strain
		Max. kN/m	Min. kN/m	Meam kN/m	Retained %	Std.Dev. kN/m	Coef.Var. %	95%	90%	%
Tervira H1115	6-3B	5.2	3.6	4.4	65	0.6	14	11	8	55
	6-9B	5.7	3.6	5.1	75	0.7	15	12	8	59
	6-9F	6.1	4.5	5.2	76	0.6	12	8	6	60
Tervira H1127	2-3B	10.5	7.8	9.5	57	0.9	10	6	4	57
	2-9B	9.7	8.5	8.9	54	0.4	5	3	1	61
	2-9F	9.6	6.8	8.1	49	0.8	9	6	4	59
	6-11B/F	12.6	6.9	9.7	59	1.8	19	19	14	50
Fibretex CZ400	4-3B	17.6	10.5	13.8	137	2.9	21	24	17	141
	4-9B	16.5	10.9	14.0	139	2.2	16	14	10	140
	4-9F	14.7	10.6	13.3	132	1.4	11	7	6	150
Supac P4oz.	7-3B	13.0	9.2	10.9	89	1.3	12	8	6	44
	7-9B	11.3	6.8	9.2	75	1.5	16	14	10	58
	7-9F	13.4	10.4	11.7	96	1.2	10	6	4	55
Typar D3401	5-3B	6.4	4.8	5.7	74	0.5	9	6	4	39
	5-9B	6.2	4.5	5.4	71	0.6	12	8	6	32
	5-9F	7.7	5.4	6.5	85	0.9	13	10	7	53
Typar D3601	1-3B	10.5	7.0	8.1	65	1.1	14	11	8	31
	1-9B	11.4	9.8	10.6	85	0.6	5	3	1	42
	1-9F	13.0	8.7	10.7	85	1.3	12	8	6	36
	5-10B	11.9	9.8	11.1	89	0.7	6	3	1	38
	5-10F	12.4	9.8	10.8	86	0.8	8	4	3	42

* Number to give indicated probability of 10% accuracy. 1 kN/m = 5.7 lb./in.

TABLE 3 Summary of 1993 Test Results

Fabric	Sample	Strength Max. kN/m	Min. kN/m	Mean kN/m	Retained %	Std.Dev. kN/m	Coef.Var. %	Required* Specimens 95%	90%	Mean Strain %
Tervira H1115	6-1C	4.1	2.0	2.8	41	0.7	25	35	25	56
Tervira H1127	10-2B	11.5	7.6	10.0	60	1.6	16	14	10	61
	10-8B	11.9	9.7	11.3	68	0.7	6	3	1	59
	10-8F	11.1	7.6	9.5	58	1.1	12	8	6	59
Fibretex CZ200	9-1C	5.5	3.9	4.7	80	0.6	13	10	7	122
Supac P6oz.	10-1C	23.4	19.8	21.1	87	1.3	6	3	1	54
Typar D3401	8-1C	4.8	3.5	4.0	53	0.4	11	7	6	23
Typar D3601	9-2B	10.4	7.3	9.0	72	1.1	12	8	6	31
	9-8B	12.1	9.4	10.5	83	1.0	9	6	4	38
	9-8F	11.2	4.0	8.7	69	2.4	28	42	29	31

* Number to give 90% or 95% probability of 10% accuracy. 1 kN/m = 5.7 lb./in.

cent to 96 percent. Also, failure strains are generally lower for the exhumed samples. It is important to note that the percentage reduction in peak strength may be either more or less than the percentage reduction in stress at low strains. The general trend is for the stress reduction to be less at low strains; therefore, the interpretations made in this paper may be conservative when considered relative to working stresses.

Only one backfill soil was used in the wall and, although this material was not the worst that could have been selected, it probably was more damaging to the geotextiles than most backfills would have been. The large particle sizes concentrated stresses and a geotextile directly between two large particles might have suffered greater damage than if the backfill had been finer. The material was, however, well graded and the particles were rounded. Compaction was greater than usually specified, which could have contributed to geotextile damage.

Only one construction procedure and one set of equipment were used. The construction methods were conventional. Greater care may have reduced geotextile damage but would probably not have been cost effective.

Figure 3 shows a geotextile test specimen with major visible damage. Nearly all specimens had some visible damage but there were great variations. Sometimes there was only slight abrasion. Sometimes there were cuts and tears more than 20 mm (0.75 in.) long, as in Figure 3. Some specimens had several visible cuts and some had none. This resulted in high sample standard deviations and reduced accuracy, making it impossible, with the number of specimens tested, to identify minor effects or make fine distinctions between factors. Only relatively large differences are statistically significant.

Early in the planning of the study, it had been anticipated that relatively few wide-width tensile strength tests could be used to measure the retained strength and a large number of burst tests could be used to evaluate variability. The large sizes of many of the damaged areas made the burst test impractical. This required many more large specimen wide-width tensile tests, increased the cost, and reduced the total number of tests possible.

TABLE 4 Retained Strength Ratio Values

	Layer and Location	Year Sampled	Retained Strength Ratio (%) Geotextile D3601	D3401	H1127	H1115	P4oz
Upper Layer Values	1C	1993		(53)		(41)	
	2B	1993	72		60		
	3B	1984	65	74	57	65	89
Lower Layer Values	8B	1993	83		68		
	8F	1993	69		58		
	9B	1984	85	71	54	75	75
	9F	1984	85	85	49	76	96
	10B	1984	89				
	10F	1984	86				
	11B/F	1984			59		
Average* Values	Upper		69	74	59	65	89
	Lower		83	78	58	76	86
	1984		82	77	55	72	87
	1993		75		62		
	All		79	77	58	72	87
	Heat Bonded Polypropylene Samples				79		
	Needle-punched Polypropylene Samples				87		
	Needle-punched Polyester Samples				62		
	All Samples				73		

Values in ( ) not included in averages.

With the data available, comparisons may be attempted for the following factors:

- Duration of burial,
- Location in a layer (front or back),
- Depth in the wall,
- Geotextile mass,
- Geotextile construction, and
- Geotextile polymer.

Duration of Burial

Figure 5 presents the average retained strength ratios for the exhumed geotextiles by year sampled. There is no trend of increased damage with time of burial for the two fabrics sampled both years. Comparing the data in Table 3 for front versus back and upper versus lower leads to the same conclusion. Chemical tests are in progress and may show some time effects, but long-term durability as indicated by wide-width tensile strength is not a problem for the 9-year period between tests and for the conditions of this wall would probably not be a significant factor for any reasonable design life.

It is concluded that durability is not a factor in this wall. All loss of strength is due to construction and postconstruction traffic, which for this wall had ceased by 1984. Survivability, however, with sample strength reductions of up to 50 percent, is important and must be considered in design with appropriate partial factors of safety.

Since durability is not a factor, 1984 and 1993 test results are combined to increase the data base for all further comparisons.

Location in Layer

Excavated geotextile sheets from the lower layers were sampled front and back. Table 3 shows eight pairs of samples. These are presented graphically in Figure 6. Of the eight, three have nearly the same retained strength ratios, three have greater, and two have lower retained strength ratios for the back samples. When all pairs are averaged, the ratio of front-to-back strength ratios is nearly one. There is indication that there may be somewhat greater damage to the geotextiles near the face of the wall relative to the fabrics well back from the face and that the damage is progressive. This would suggest the shear stresses in the Rankine active wedge contribute to the fabric damage, but considering the variations of the samples the evidence is not persuasive.

Depth in Wall

Table 4 separates the geotextiles in the upper part of the wall (Layers 1, 2, and 3) from those in the lower part (Layers 8, 9, 10, and 11). The averages of the retained strength ratios for upper, lower, and all samples for each geotextile are plotted on Figure 7. Of the five geotextiles for which there are data for both zones, two indicate what may be significantly greater damage in the upper layers and three show no significant difference. This supports the conclusion that damage is due to construction with some additional damage by postconstruction traffic in the upper layers. There is no indication, for the depth investigated, that the weight of the overlying material contributes to the geosynthetic damage.

Geotextile Mass

Two heavier geotextiles (D3601 and H1127) are compared with the lighter weight fabrics of the same type (D3401 and H1115) in Figure 7. H1127 and H1115 show considerable difference, but comparison indicates the heavier fabric suffers greater relative damage. This is counterintuitive. Table 3 shows that there are only three samples for H1115, and the overall average for this fabric is strongly influenced by the two lower samples, which have the highest retained strength ratios of all the 10 Trevira samples. It appears

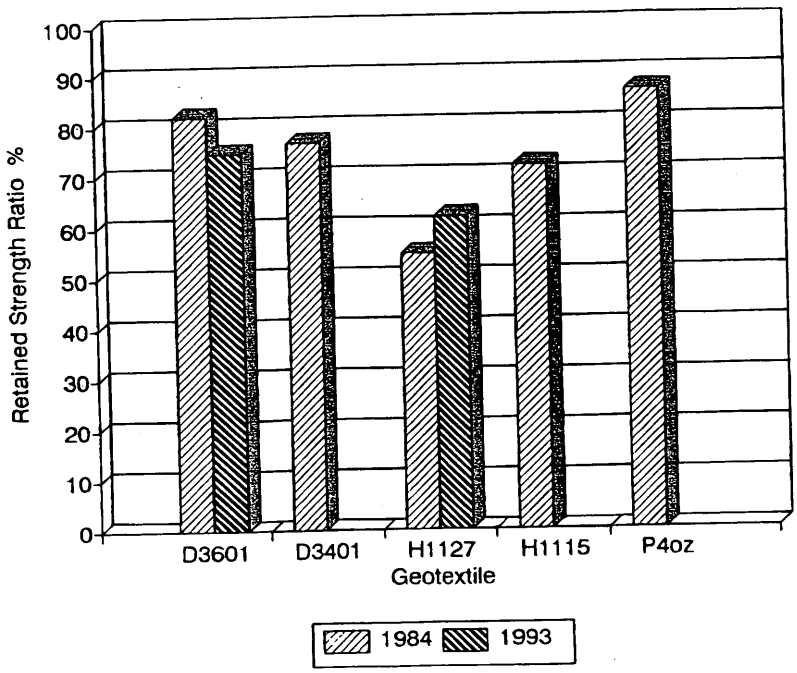

FIGURE 5 Retained strength ratio and year sampled.

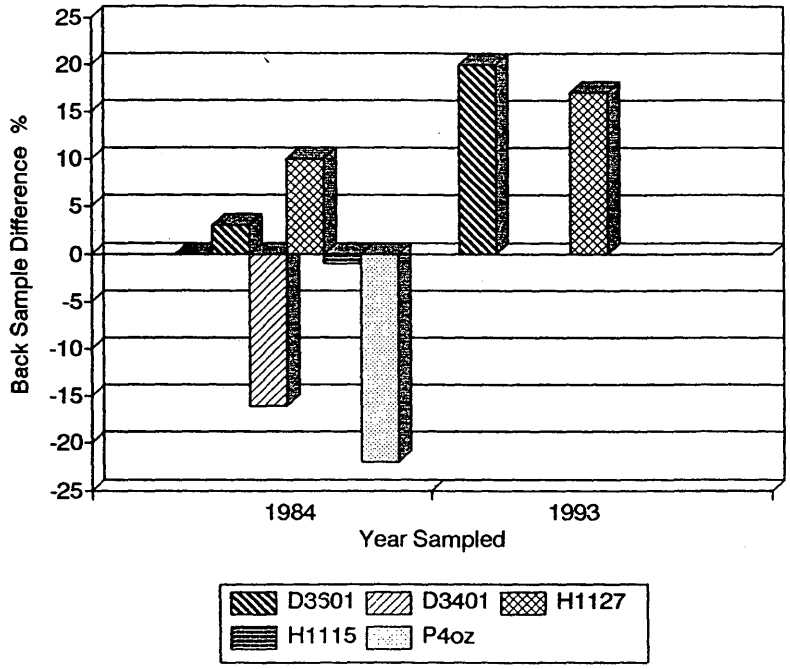

FIGURE 6 Retained strength of back samples relative to front samples.

that for the test conditions and the geotextiles used, little if any variation exists in the relative damage of different weights of the same geotextile.

Geotextile Construction and Polymer

The averages of all retained strength ratios for the three types of geotextiles represented by the data are presented in Figure 8. These are a heat-bonded polypropylene, a needle-punched polyester, and a needle-punched polypropylene. The first two are each represented in two weights. Only one weight of needle-punched polypropylene was tested. This needled polypropylene (Sumac P4oz) is constructed of staple filaments; the others have continuous filaments. This geotextile is also lightly heat bonded on one side. This needled polypropylene is represented by only four samples (32 specimens). There are at least 10 samples (80 specimens) each for the other two.

The polypropylene geotextiles samples retained an average of 81 percent of their initial strengths, and the polyester fabrics retained an average of 62 percent. The needled polypropylene may suffer slightly less relative damage than the heat-bonded polypropylene, but there are too few samples to consider this difference significant, so all polypropylene samples are considered in the above average. These data suggest partial factors of safety of 1.25 and 1.6 for nonwoven polypropylene and polyester geotextiles, respectively. It appears reasonable that partial factors of safety for survivability should be different for different polymers because they have different mechanical characteristics.

Summary

The greatest damage is mechanical abrasion and cutting due to construction operations. At least for the duration of this study, there is no significant decrease in strength with time after the first excavations to indicate chemical aging or continued degradation from in situ stresses. There is some indication of reduced strength in the upper layers that may be from postconstruction traffic.

CONCLUSIONS AND RECOMMENDATIONS

The study included a coincident series of 10 geotextile reinforced earth-retaining walls. Each was 10 m (33 ft) wide and 4.5 m high, and all were constructed with coarse, rounded, well-graded pit-run gravel backfill and with a variety of relatively low-strength, nonwoven geotextile reinforcements. The wall was constructed using the traditional U.S. Forest Service wrapped-face methodology. The backfill was compacted to at least 95 percent of AASHTO T-180 with a large vibratory smooth drum roller. The test walls were faced with shotcrete 3 months following construction.

Viable survivability and durability data were obtained from three nonwoven geotextiles. Survivability and durability were evaluated by comparing wide-width tensile strength of samples exhumed in 1984 and 1993 with initial strengths measured before construction in 1982. Conclusions are limited to these specific conditions and geotextiles.

- There was no loss of strength in samples obtained and tested in 1993 compared with 1984. Durability was not a problem in this wall.
- There was an average loss of strength for all samples of 27 percent, principally as a result of construction damage. Survivability was a significant factor for this wall.
- Not all geotextile were equal in construction survivability. The polypropylene geotextile samples lost an average of 19 percent of their strength to construction damage, and the polyester geotextile samples lost an average of 38 percent.

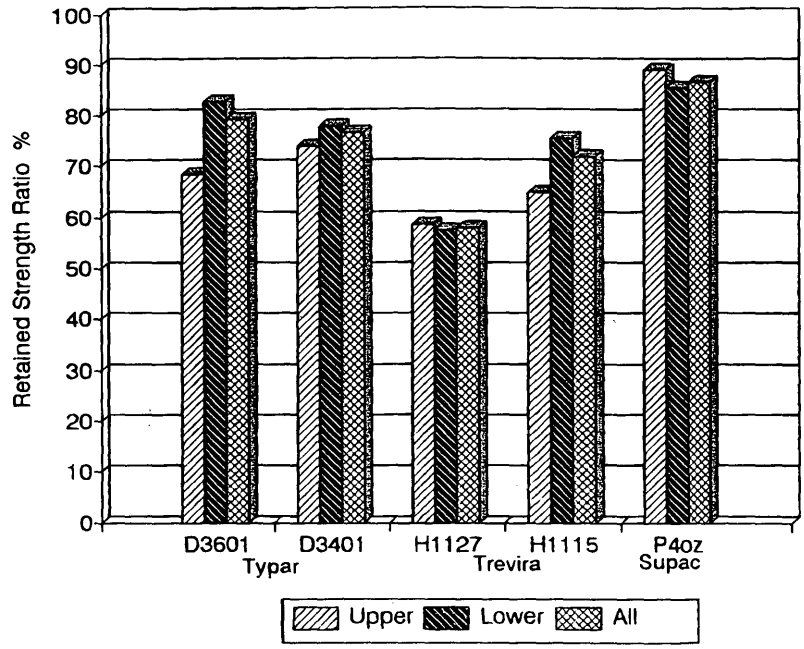

FIGURE 7 Retained strength ratio versus vertical location in the wall and mass.

- Choice of backfill and construction methods and equipment contributed to the initial loss of strength. These could be considered moderately severe conditions.
- There was little difference in relative strength loss between lighter weight and heavier weight fabrics of the same type and polymer.
- The large coefficients of variance for the damaged specimen populations required relatively large samples to yield reasonable accuracy. Further, the large sizes of the cut and abraded areas within the specimens eliminated the use of index tests, such as the burst or grab tensile tests.

This study provides preliminary design parameters for the use of nonwoven geotextiles in moderately severe construction conditions. The study shows that in situ stresses and aging did not contribute significantly to the degradation of the geotextiles. It is concluded

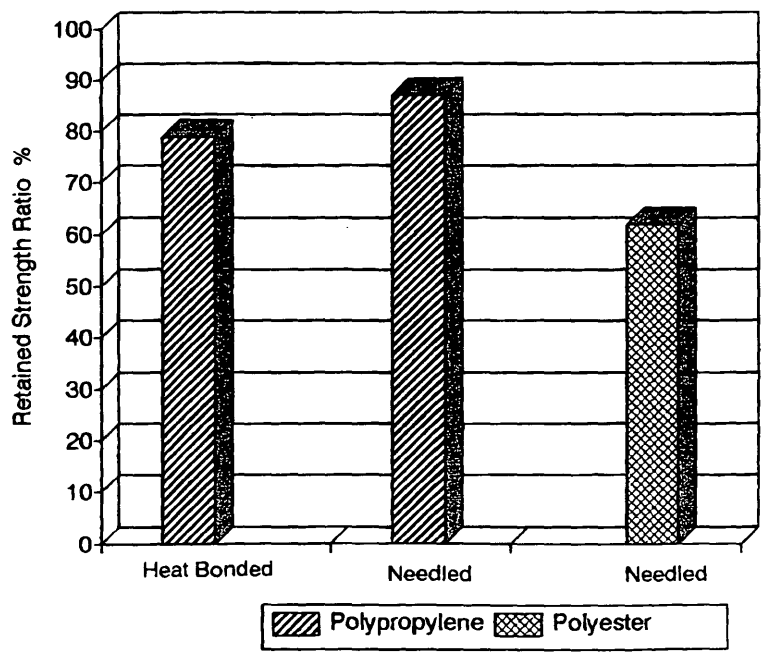

FIGURE 8 Retained strength ratio versus geotextile construction and polymer.

that the partial factors of safety for survivability of 1.25 for polypropylene and 1.6 for polyester may be used as conservative values for most reinforced walls constructed with 140 to 400 g/m^2 (4 to 8 oz) nonwoven geotextiles. These values are probably overconservative for sand backfills, but for large angular crushed rock backfills damage could easily exceed these recommendations.

Because of the many possible combinations of backfills and reinforcements and because of diverse construction specifications and equipment, extensive field testing will be required before confidence is gained in interpolated and extrapolated survivability values.

As a closing recommendation, each department of transportation and other agencies using geotextile reinforcement applications is urged to start developing suites of data for the typical backfills, construction methods, and choices of reinforcements. These data could be obtained most cost effectively through exhumations during actual construction projects, but preconstruction evaluations with test backfills approximating actual construction conditions and methods may be justified on large or critical projects, or both. Testing should be directed by the designer of record. Particular care must be exercised in exhuming the samples. To be most valuable, the results of these studies must be published.

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Fibretex, Supac, Trevira, and Typar are trade names of the companies identified in Table 1. The use of these names in this paper is for identification purposes only and does not imply preference over any similar products.

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