Long-Term Durability of Geosynthetics Based on Exhumed Samples From Construction Projects

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FHWA-RD-00-157

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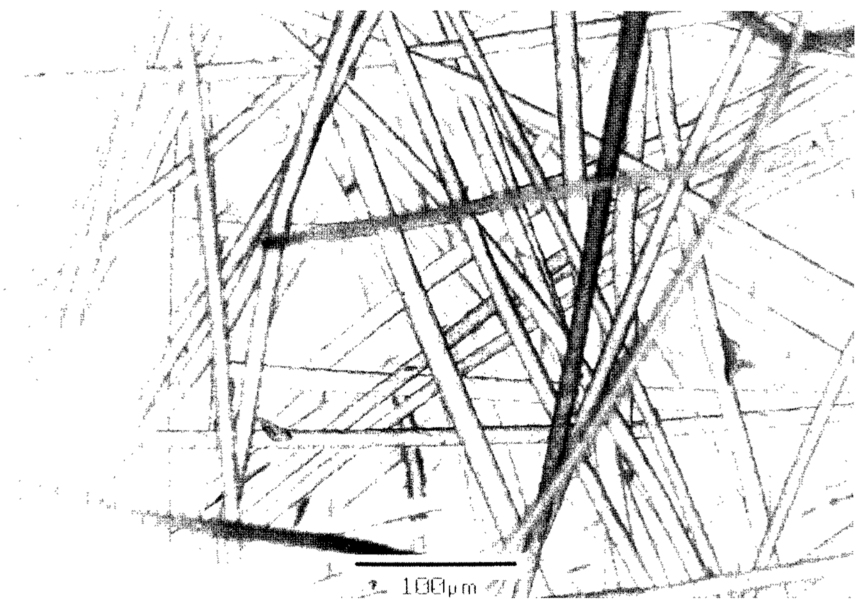

Nonwoven Polyester Geosynthetic

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This report documents part of a comprehensive study entitled, "Durability of Geosynthetics for Highway Application." The report presents the results of physical and chemical tests on 24 retrieved geosynthetic samples from 12 sites across the United States. They represent a wide spectrum of geosynthetics, soil, water, and stress regimes, and structure age. It was concluded that the exhumed samples have not been significantly affected by burials lasting up to 18 years. The reported information suggests that the laboratory testing degradation protocols, developed and described in previous reports, can be used to predict in situ degradation rates. The report should be of interest to geotechnical and bridge engineers who are concerned with the durability of geosynthetic reinforced soil structures.

T. Paul Teng, P.E.
Director, Office of Infrastructure
Research and Development

NOTICE

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16. Abstract

This report presents the results of mechanical and chemical tests on 24 retrieved geosynthetics from 12 sites across the United States and provides a baseline databank of mechanical and chemical properties of many commonly used geosynthetics in transportation applications as tested by industry.

It also provides a summary and synthesis of results and methods from site retrievals and comments on the significance of laboratory index testing in developing durability design protocols.

This report is the last report of a comprehensive study on the "Durability of Geosynthetic Materials for Highway Applications." Previously published reports include:

1. FHWA RD-97-142 – Stress Cracking Potential for HDPE Geogrids
2. FHWA RD-97-143 – Testing Protocols for Confined Creep and Extension Testing of Geosynthetics
3. FHWA RD-97-144 – Testing Protocols for Oxidation and Hydrolysis of Geosynthetics

COVER PHOTO: Scanning electron micrograph of nonwoven polyester geosynthetic.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1

INTRODUCTION

This report is the last of a series of reports summarizing research conducted under a pooled fund research program titled *"Durability of Geosynthetics for Highway Applications."*

The report is divided into four main parts. Chapter 1 details the development of retrieval protocols and the site identification process. Chapter 2, Task B, presents the results of mechanical and chemical testing on retrieved geosynthetics from 12 sites across the United States. Chapter 3, Task C, presents a baseline databank of mechanical and chemical properties for commonly used geosynthetic products (1994) in reinforcement and/or transportation related applications. Chapter 4 is a focused engineering synthesis of significant findings for Task B and C detailed above, and describes how they relate to laboratory testing for oxidative or hydrolytic degradation detailed in Federal Highway Administration (FHWA)-RD-97-144, previously developed under this research program.

REVIEWS

The research tasks were initially developed by a project Interdisciplinary Advisor Team and formalized in a Task A Final Report, which formed the basis of the research program.

The Task A Final Report was reviewed by a project Peer Advisory Group whose valuable suggestions have been incorporated whenever possible before the research commenced. The Peer Advisory Group consisted of:

Dr. Robert Koerner - Geosynthetic Research Institute
Dr. Robert Holtz - University of Washington
Dr. Robert Duvall - Engineering Systems, Inc.

During the course of the research, progress reviews were held with FHWA personnel and Mr. Tony Allen, Washington Department of Transportation (DOT), to monitor progress, review interim draft reports, and suggest modifications to the research.

RESEARCH OBJECTIVES, TASK B

The intent of this task was to develop a databank of geosynthetic performance used for reinforcement/stabilization/separation that could potentially serve as a performance benchmark for laboratory studies undertaken under this project. Twenty-four materials in 12 locations were exhumed for this task. It was intended that these sites would represent a wide spectrum of geosynthetics, soil, water, stress regimes, and structure age with preference given to sites where there is availability of baseline data, or where multiple geosynthetics were buried.

The program required the performance of physical, mechanical, and chemical molecular structure tests, to characterize the "as is" properties of each material exhumed and, whenever possible, of archive samples, where located. Sites were located in cooperation with Industrial Fabrics Association International (IFAI) members, State Transportation Agencies, FHWA, Forest Service, and the Corps of Engineers. Sufficient samples were recovered from each site to perform the testing indicated.

The first step under this task was to identify sites and to develop a consistent protocol for exhuming, sampling, and preparing samples for further testing.

The evaluations can be grouped into the following areas:

- Physical property tests for geosynthetics and soil regime.
- Mechanical property tests for geosynthetics.
- Performance tests for geosynthetics.
- Chemical and molecular structure tests for geosynthetics.
- In-situ stress/deformation history of geosynthetics where available.
- Description of the site physical conditions.

IDENTIFICATION OF POTENTIAL SITES

The identification process consisted of contacting the following:

1) State Transportation Agencies contributing to this study.
2) All other State Transportation Agencies identified as users of geosynthetics by a 1989 Drexel University study.

3) All Transportation Research Board (TRB) A2KO7 members.

4) The Corps of Engineers at the headquarters and division level.

5) IFAI member companies.

6) All FHWA regional geotechnical engineers and direct Federal offices.

7) Selected consulting engineers and academics with interest in this field.

8) The U.S. Forest Service.

9) Bureau of Reclamation, Denver.

A total of 65 inquiries by letter were initially made in support of this effort.

From this initial 65 inquiries, 25 primary retrieval sites were identified as shown in table 1. Additional identified retrieval sites are listed in the appendix in table A-1. A number of these "sites" have multiple geosynthetics available for retrieval.

The selection process endeavored to include as wide a range of geosynthetic products as possible consistent with available sites and their access. Both retaining wall projects and stabilization/separation projects were included within these primary identified sites. Preference is always given to older sites.

DEVELOPMENT OF RETRIEVAL PROTOCOLS

Previous retrievals for forensic studies have used a number of methods and protocols to uncover the geosynthetic specimen and to determine the required number of samples subsequently tested for mechanical, physical, endurance, and chemical properties. The European Standardization Committee (CEN/TC 189/WG5) protocol has been incorporated whenever possible. The protocol has the following elements:

- Identification of site conditions and structure description.
- Testing of control samples, where available.
- Retrieval methods.

Table 1. Retrieval sites.

NO.	OWNER	SITE IDENTIFICATION	GEOSYNTHETIC TYPE	REMARKS
1	New York DOT	Thruway detour, Montgomery Co.	AMOCO 2006	Sample recovered by NY DOT in 1993. Constructed in 1987.
2	Corps of Engineers New Orleans District	Test embankment Bonnet Carre Spillway. Site may be available for further retrievals.	Woven PET of 2 weights Nicolon	Sample recovered by COE in February 1993. Archive data tested. Constructed in 1989.
3A-1 3A-2	Washington DOT A-1, aged A-2, construction-damaged	Laboratory incubation samples at 100% RH insoil including construction-damaged samples.	PP silt film woven Exxon GTF-200 Exxon GTF-1225 PET woven	Sample recovered in 1996. Archive data available. Excavated samples from 1989.
4A 4B 4C 4D	Colorado DOT 4A-1, Trevira 1115 4A-2, Trevira 1127 4B, Petromat 6 oz 4C-1, Typar 3401 4C-2, Typar 3601 4D, Fibretex CZ-200	Colorado Test Walls I-70 Glenwood Springs. Site available for further retrievals.	Trevira – PET Petromat – PP Typar – PP Fibretex – PP	Sites excavated in May 1993. Previous data available. Installed in 1982.
5A 5B	U.S. Forest Service	Shelton Forest Retaining wall in Olympic Peninsula. Site available for further retrievals.	Bidim Fibretex	Forest service excavated upper two rows of fabric in May of 1993. Constructed in 1975. Some archive data.
6	Pima Co. Tucson, AZ	Tanque Verde Walls Tucson, AZ. Site available for further retrievals.	HDPE SR-Tensar	Retrieved August 1993. Constructed in 1985. Archive data tested.

Table 1. Retrieval sites (continued).

NO.	OWNER	SITE IDENTIFICATION	GEOSYNTHETIC TYPE	REMARKS
7A	OK DOT (Phillips)	State Rd 131, OK. Site available for further retrievals.	PP Supac, 8N	Site excavated in June 1993. Recovered both samples. Installed in 1984.
7B			5 WS	
8A	Washington DOT	Pacific Way Site.	Trevira 1115	Separator sites exhumed by U. of Washington. Mechanical tests performed by U. of Washington. Duplicate samples of fabric available. Full documentation available of excavation procedures.
8B		Coal Creek Rd 8-yr-old site.	Typar 3401	
8C		SR-9 Marsh Road Site with iron stailings.	Permatex 2350 (2500)	
9	AZKO Plan Test Wall	Arnhem, The Netherlands.	Stabilenka PP/PET fabric	Excavated in 1994. Archive data available. Built in 1980.
10A	U.S. Forest Service	Quinnalt Forest Subgrade Stabilization Test site. Olympic Peninsula. Sites available for further retrievals.	Fibertex	Stabilization test site constructed in 1976. Retrievals in 1978 with data available. Excavated in May 1993.
10B			Typar	
10C			Mirafi 140	
10D			Supac	
10E			BIDIM	
11	Washington DOT	Aberdeen wood chip fill.	Permatex 2500 (Synthetic Ind.)	Excavated in 1996. Constructed in 1988.
12	St. Croix Mall	St. Croix Mall Stillwater, MN.	Wheeler 260 PET geogrid (Huesker)	Excavated in 1995. Constructed in 1989.

PET = Polyester
PP = Polypropylene
HDPE = High Density Polyethylene

- Geosynthetic testing
  - mechanical tests
  - chemical tests (optional)
  - performance tests (optional)

- Soil testing for identification of environmental regime.

- Testing methods using American Society of Testing Materials (ASTM), specially developed, or industry protocols.

- Report format.

The protocol developed for retrievals on this project is as follows:

1) Identification of Site Conditions and Structure Description

   Each site should be described as to the functional use of the geosynthetic mapped for retrieval. Such description includes a location plan indicating the location, plan, and elevation of the geosynthetic in the structure, an estimate of the loading conditions, including piezometric surfaces, design service life, and any other pertinent observations as to the functionality of the structure since construction. Available performance data such as deflection measurements and or strain gauge data where available should be included, as well as availability of control data for both chemical and mechanical properties.

2) Testing of Control Sample Data

   Testing protocols for all required mechanical, physical, endurance, and chemical testing have been qualified, modified, and/or developed as required, through a joint effort between industry, represented by IFAI Geotextile Division Task Group, E2Si, and Polytechnic University.

   An unpublished report to FHWA titled "Procedures and Test Standards for Evaluating the Properties of Geosynthetics," dated December 1993, includes all applicable ASTM tests, deviations/additions in the ASTM format, and industry procedures where no ASTM standard exists. This report formed the basis for testing methods.

   Mechanical, Physical, and Endurance Testings

   Results of testing from control specimens, either from quality assurance/quality control

(QA/QC) manufacturers' data or owner's compliance testing should be reported where available. For this project, mechanical strength test data (WW tensile, ASTM D-4595, grab tensile ASTM D-4632) mass per unit area (ASTM D-5261), and thickness (ASTM D-5199), if appropriate, is reported. In addition, endurance properties as obtained by ASTM D-5262 "Test method for evaluating the unconfined tension creep behavior of geosynthetics" may be reported.

Where the control data outlined above are not available, but samples from production runs manufactured during the same period are available, they may be tested and reported in lieu of control data, with appropriate notation as to their origin and past storage conditions.

Chemical Tests

Where control specimens are available or the site will be available for future retrievals the following tests are indicated:

- Differential scanning calorimetry (DSC). Oxidation induction time (OIT) for polyolefin products.

- Melt flow index. ASTM 1238 for polyolefin products.

- Molecular weight determination for PET products only. Methods are indicated under the test section. Intrinsic viscosity determinations may be substituted.

- Carboxyl end group (CEG) determinations for PET products only. Methods are indicated under the test section.

- High performance liquid chromatography (HPLC) to identify and quantify antioxidants present in polyolefin products. Methods are indicated in the test methods section. This test is optional.

3) Retrieval Methods

Sampling must be performed carefully in order to avoid damage to the product. The excavation operation may begin with power equipment, but such excavation methods must terminate within 6-8 in (150-200 mm) of the geosynthetic. Excavation must then continue manually with a hand trowel, hand rake, and broom to remove the remaining soil gently over a minimum 3- by 6-ft (1.6 m^2) surface area. It is recommended that the 6-ft (1.83-m) length be parallel to the machine direction. High-strength geotextile products requiring roller grips for testing will require a longer total sample. Damage during this excavation phase should be noted and marked on the product. The site should be photographed and the visual appearance of the product be noted with emphasis on existing holes, tears, folds, root penetration, presence of water, and uniformity of backfill.

The sample is then cut along the sides and lifted carefully. Excess soil is shaken off and the sample is placed in black polyethylene bags, sealed, and marked with appropriate identification. The sample must be identified with respect to machine and cross direction, which must be noted on the location sketch.

Concurrently, a soil sample must be secured adjacent to the product sample retrieval. Separate samples are required if the soils above and below differ visually in composition.

4) Sample Preparation for Testing

Total Sample

Prior to specimen selection, the sample shall be prepared by removal of any soil by gentle shaking of the sample.

The full sample shall then be hand washed gently under tap water, removing only any adhering surface soil cake that had formed. No attempt should be made to remove any soil that does not easily wash away.

The washed sample shall then be laid out horizontally in a darkened room and allowed to dry under ambient temperature.

Specimens for Chemical Testing

Specimens selected for chemical testing not sufficiently cleaned of colloidal soil particles may be ultrasonically cleaned using water and/or a mild wetting agent at room temperature. A 2 percent solution of Micro Cleaner has been successfully used in 2- to 5-min cycles in a stainless steel basket.

5) Specimen Selection for Wide Width Testing

The selection of specimens from the recovered product sample shall be made in accordance with the following structured random process to avoid bias.

A primary template 0.6 m by 0.8 m shall be laid out in the machine direction on the recovered sample by locating it 150 mm from the top edge and centering it along the recovered width as shown in figure 1. The primary template length should be increased for high strength geotextiles tested with roller grips.

Twelve adjacent specimens 200 mm by nominally 200 mm shall be cut and numbered in accordance with figure 1. Specimens having areas marked with damage from the retrieval process shall not be tested. A minimum of nine specimens with consecutive marked numbers shall be tested initially. For high-strength geotextiles, the length shall be increased to accommodate the roller grip requirement. For stiff geogrids, the specimen size shall be such to contain three ribs in the machine direction and five ribs in the cross direction. For flexible geogrids, up to seven cross direction ribs may be necessary to accommodate the required roller clamps.

Wide Width (WW) tensile force data obtained from these nine primary tests shall be analyzed to determine the coefficient of variation, as outlined in ASTM D4595, with an allowable 5 percent variation from true average values.

Based on the obtained actual coefficient of variation, the required number of specimens shall be recomputed. If greater than nine, additional specimens as available shall be secured from a secondary template location also shown in figure 1. No more than 18 specimens per recovered sample shall be tested for WW strength.

Prior to WW tensile testing, mass per unit area shall be determined from specimens marked 9 through 12 in accordance with ASTM D-5261. Specimens tested for strength shall be reserved for chemical testing, using principally those portions of the product held in the jaws of the testing apparatus.

TESTING PROTOCOLS FOR RETRIEVED SAMPLES

Mechanical Tests on Retrieved Product Specimens

The principal test method to characterize residual strength shall be the WW tensile test performed in accordance with ASTM D-4595 in the machine direction. Where strength in previous retrievals has been characterized by the grab tensile test performed in accordance with ASTM D-4632, it shall be considered the principal test for that specific site.

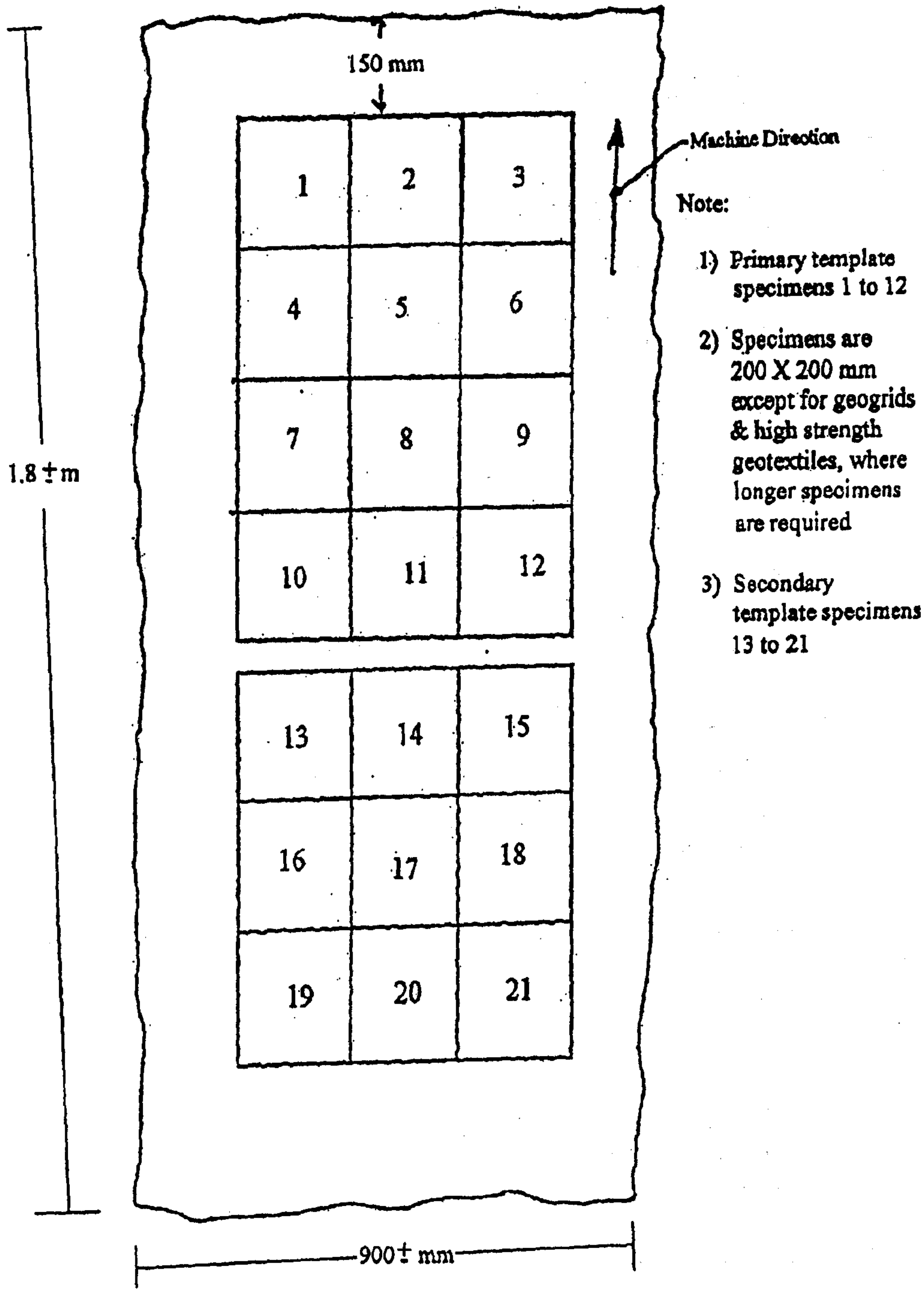


Figure 1. Scheme for sampling test specimens.

Physical Property Tests on Retrieved Product Specimens

Mass per unit area shall be measured for geotextiles in accordance with ASTM D-3776 Option C using at least one specimen retrieved. Thickness may be measured on polyolefin grid products in accordance with ASTM D-5199.

Density/specific gravity shall be measured in accordance with ASTM D-792.

The level of abrasion if visible shall be noted. For geogrids rib cuts, bruises and percentage of ribs severed across the specimen width shall be noted. This assessment is subjective and no standard exists. Photographs may be taken to illustrate special conditions.

Chemical Tests on Product Specimens

For PET (polyester products)

- The principal tests performed on geotextiles and the fibers of coated grid products are molecular weight determinations (M_n) and determination of carboxyl end groups (CEG number). A minimum of three tests shall be performed.

- Where product control data for molecular weight has been expressed in terms of intrinsic viscosity and where reagents and test temperatures are known, it may be substituted from molecular weight (M_n) determinations. Temperature and reagents must be indicated.

- Scanning electron microscopy (SEM) at a magnification of at least 1000x to determine surface erosion or decrease in fiber diameter and/or other damage.

The following tests are indicated for polyolefin products (PP and HDPE):

- Melt flow index, ASTM 1238.

- Differential scanning calorimetry (DSC) to obtain oxidation induction time (OIT). Three specimens should be tested per retrieved sample.

- SEM at a magnification of 750x to 3000x to determine fiber cracking and/or other damage.

- HPLC is optional and to be used if the antioxidant package is known.

Performance Tests

In isolation creep tests in general accordance with ASTM D-5262 for a 1000-hr maximum duration may be conducted on selected retrieval specimens only if control data for this particular product are available for comparison, or if the site will be available for future retrievals and the functional use of the geosynthetic on the project is for reinforcement.

Where conducted, two specimens shall be tested at each of two load levels. The first load level shall be approximately equal to the specimen creep load limit as defined by the virgin creep limit (as a fraction of ultimate strength) multiplied by the ultimate tensile strength retained after damage, the second load level at the design load used for the project.

Soil Tests

The ambient soil regime shall be characterized by the following:

- Grain size distribution, ASTM D-854.
- Atterberg Limits for fine grained soils, ASTM D-4318.
- PH, Soil Survey Procedure 8C1a or AASHTO T-289-91.
- Electrical conductivity or resistivity, AASHTO T-288-91.
- Organic Content, AASHTO T-267.
- Transition metals determination, EPA SW 6010.
- Chloride, Sulfate, Carbonate, ASTM 4327.
- Calcium, Sodium, EPA, SW 6010.

CHAPTER 2

RETRIEVAL SITES

The data obtained from each site are described on a site-per-site basis. Mechanical properties for backfill soils for all sites are tabulated in table 2. Where the backfill is substantially different between the upper and lower surface of the geosynthetic, it is noted. Chemical analyses of the backfills are tabulated for all sites in table 3.

Table 2. Backfill mechanical properties.

Site #	Classification	Gradation			D_{50} mm	P.I.
		% Gravel	% Sand	% Silt/Clay		
1	Gray clayey silt, lower	0	15	85	0.001	28
	Gray crushed stone, upper	93	6	1	30	NP
2L	Gray silty clay	0	27	73	0.04	24
2U	Gray silty clay	0	16	84	0.02	29
3A	Gray brown gravelly sand	43	56	1	2	NP
3B	Gray brown gravelly sand	33	65	2	1.2	NP
4	Brown sandy gravel	61	34	5	8	NP
5A/B	Brown silty sand and gravel	42	40	18	3.3	NP
6	Brown sand little gravel	17	78	5	1.7	NP
7U	Gray brown sandy gravel	50	39	11	4.8	NP
7L	Brown silty clay some sand	11	21	68	0.01	25
8A	Brown clayey sand	1	55	44	0.1	18
8B-U	Gray sandy silt	0	26	74	0.45	NP
8B-L	Wood debris with sand and silt	50	25	25	4	NP
8C	Gray gravelly silty sand	24	43	33	0.12	6
9	Brown coarse to fine sand	5	80	15	0.8	NP
10A/B/C	Gray sandy silt	10	40	50	0.07	11
10D	Gray gravel some sand and silt	62	25	13	8.5	4
10E-U	Gray gravel some sand and silt	59	28	13	8.5	4
10E-B	Gray organic sandy silt	2	37	61	0.4	14
11	Wood chips	N/A	N/A	N/A	N/A	N/A
12	Silty sand, little gravel	4	66	30	0.2	NP

P.I. = Plasticity Index NP = Non Plastic

Table 3. Chemical analysis of backfills.

CHEMICAL ANALYSIS	SITE									
	#1 Subgrade	#2 Lower	#2 Upper	#3A	#3B	#4	#5	#6	#7 Upper	#7 Lower	8A
Organic Content %	-	-	0.5	-	-	-	-	-	-	-	-
PH	6.5	7.6	7.4	7.4	7.5	7.7	7.1	7.3	6.9	7.6	6.2
Conductivity m s/cm	306	135	140	16.6	9.4	90.2	38	59.3	756	238	19.2
Chloride mg/kg	28	70	17	2.3	1.8	14	2.4	1.2	3.3	13	5.2
Sulfate mg/kg	810	170	120	3.0	2.2	19	6.7	4.3	3100	570	49
Carbonate mg/kg	5.2	6.2	6.1	10.7	10.8	5	5.2	4.8	5	5.4	5.8
Calcium mg/kg	5290	6010	5130	2090	2220	29,300	9580	3170	96,400	17,300	1800
Sodium mg/kg	165	309	248	240	243	303	3320	87	193	318	137
Chromium mg/kg	18.2	12.3	10.8	13.2	14	7.5	12.2	1	3	17.8	9.5
Cobalt mg/kg	5.7	6.3	6.3	5.6	5	4.8	28.3	4.3	4.3	6.8	4.8
Copper mg/kg	10.1	11.9	11	8.7	9.5	4.3	181	6.8	22	6.2	9.1
Iron - Total mg/kg	29,700	16,200	15,800	11,100	11,100	11,800	53,000	2430	6500	17,800	14,000
Manganese mg/kg	218	411	408	177	157	334	588	96	347	255	144

CHEMICAL ANALYSIS	SITE									
	#8B Lower	#8B Upper	#8C	#9	#10A/B/C	#10D	#10E Upper	#10E Lower	#11 Lower	#11	#12
Organic Content %	67.6	-	-	-	24.3	2.5		15.6	-	89.4	
PH	5.8	5.5	5.8	5.1-6.5	5.2	6.2	6.3	6.7	7.5	7.3	7.4
Conductivity m s/cm	187	279	122	50	82	284	128	235	10.5	7.7	45.2
Chloride mg/kg	4.3	7.1	7.0	35	25	3.4	2	24	6.7	4.8	3.8
Sulfate mg/kg	1700	1000	84	1000	690	870	390	2300	30	8.4	15
Carbonate mg/kg	11.3	5.1	5.8	0.9	10.2	5.3	5.3	9.9	14.7	28.3	5.3
Calcium mg/kg	8730	4700	2850	940	3440	1930	1120	1340	3130	1840	2990
Sodium mg/kg	457	4810	273		207	89.5	105	205	246	264	182
Chromium mg/kg	275	13.1	42	100	3	14.1	14.8	3.9	94	2.5	15.3
Cobalt mg/kg	11.5	8.3	11.3	20	10	13.1	11.3	10	31	13.2	5.6
Copper mg/kg	25.4	33.7	35.2	36	3.3	20.5	25.5	7.2	85	5.4	18.1
Iron - Total mg/kg	13,800	18,100	26,100		5180	31,300	30,500	22,100	73,800	1510	13,900
Manganese mg/kg	501	247	388		149	457	578	134	901	147	27

SITE #1 - New York State Thruway Detour, Montgomery County, NY

Site Description

This project was a subgrade stabilization constructed in connection with a required traffic detour in conjunction with a bridge rehabilitation project constructed in 1987. The geotextile used, a woven polypropylene AMOCO 2006, was placed over a generally wet subgrade and backfilled with a crushed dolomitic stone to a height of 5- to 6-ft. (1.5-1.8 m). The geotextile was loaded by a combination of dead load (5 to 6-ft of fill) and live traffic loads. The backfill properties are summarized in table 2 and their chemical properties in table 3.

Excavation of the geosynthetic occurred in 1993, approximately 6 years after placement. The excavated sample contained no tears or visual abrasions or holes. Figure 2 shows the site and excavated geotextile.

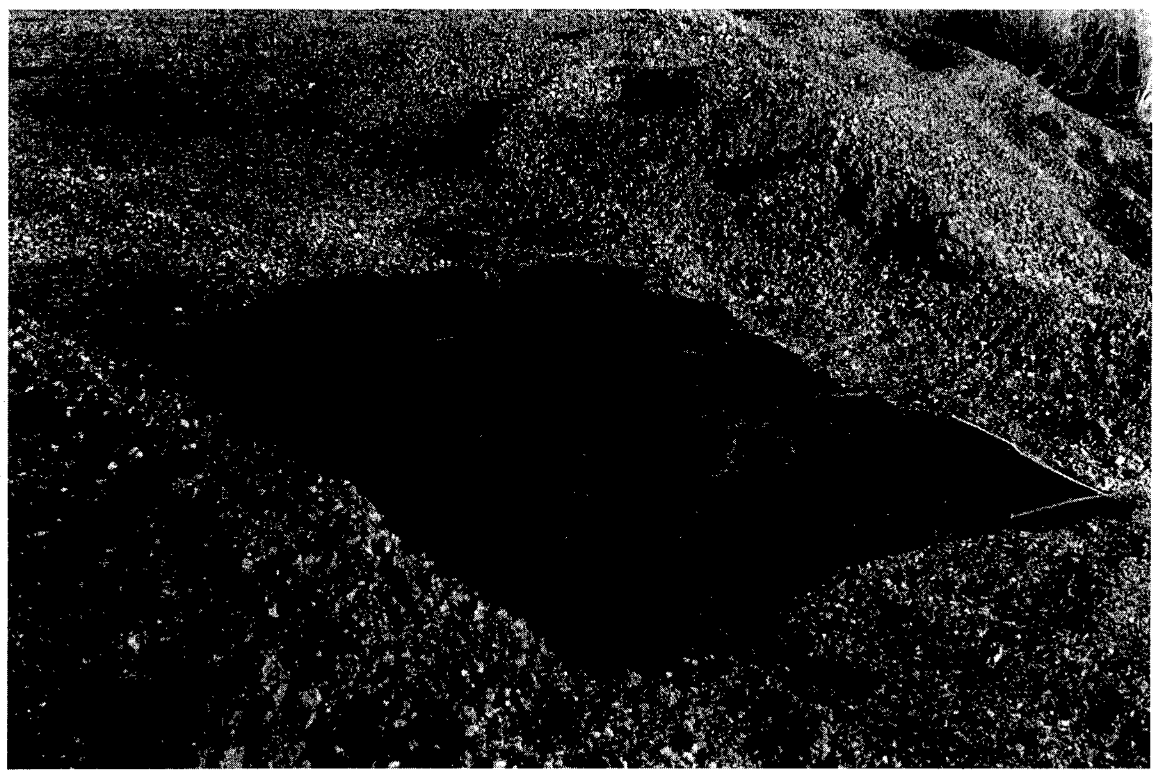


Figure 2. Excavated geotextile on site.

Data Analysis

No archive samples from the production rolls was available, but Task C testing by industry and strength data from a 1992 control sample of AMOCO 2006 tested at Polytechnic University indicated a WW tensile strength of approximately 230 lb/in (41 kg/cm) at 21 percent strain with a standard deviation of 6 percent. Retrieved WW tensile strength based on 9 samples averaged 186 lb/in (33 kg/cm) and a standard deviation of 6.5 percent suggesting a total strength loss of approximately 25 percent.

Chemical analyses of product manufactured in 1992 (Polytechnic control samples) indicated OIT values of 77 min at 175°C and 53 min at 200°C with a coefficient of variation of up to 30 percent as compared with retrieved sample OIT of 48 min at 175°C. This would suggest that approximately 2/3 of the antioxidant was still present at the time of retrieval, suggesting that no loss of strength can be attributed to oxidation.

The melt flow index for the 1992 control sample tested by industry (table 4) indicated a historic melt flow of 4.2 to 4.8 g/10 min compared with the retrieved sample melt flow of 2.4 g/10 min. This decrease suggests an increase in molecular weight potentially indicating a cross-linking phase of oxidation to which significant strength loss is typically not attributed. Strength loss is typically attributed with the initiation of a dominant chain-scission phase oxidation.

A strength loss of approximately 25 percent due to construction damage alone is reasonable considering that the D_{50} size of the backfill is approximately 30 mm. The soil chemistry is unremarkable.

No aging losses after 6 years in the ground due to oxidation are suggested as the OIT of the retrieved sample is 48 min at 175°C, indicating that the antioxidants have not been consumed and the SEM indicates no circumferential cracking although the images are poor due to an inability to clean the geotextile surface.

The melt flow data suggest that a cross-linking phase of oxidation is occurring. The significance of this phase with respect to strength loss is presently unknown.

SITE #2 - Bonnet Carre Test Embankments

Site Description

This test embankment project was undertaken to verify design assumptions in connection with

Table 4. Industry reported chemical properties.

Polymer	Product	DSC in °C		Melt Flow g/10 min.	Intrinsic Viscosity dl/g	CEG meq/kg	OIT @ 200°C min	Additives >50 PPM in PPM
		Melt	Crystal					
PP	AMOCO – 2006	ON = 150 PK = 168	ON = 118 PK = 114	4.2 – 4.8			53.5	Irganox 1076, 846 Goodrite 3114, 891
PP	REEMAY – 3601	ON = 156 PK = 165	ON = 111 PK = 106	6.7 – 7.3			10.6	Irganox 3114, 300 Irgafox 168, 480
PP	SYNTHTIC – Monofilament	ON = 152 PK = 168	ON = 110 PK = 105	3.0 – 3.5			24.4	Irganox 1010, 200-250 Irganox 1076, 1000
PP	NICOLON – HP-600	ON = 152 PK = 169	ON = 115 PK = 106	5.0 – 5.2			35.6	N/T
PP	POLYFELT – TS-700	ON = 150 PK = 160	ON = 108 PK = 104	18 – 21			3.8[1]	Irganox 1010, 170 Ultranox 626, 400
PP	SUPAC – 8N	ON = 151 PK = 170	ON = 116 PK = 111	8.8 - 9.6			13.8	Irganox 3114, 550-650 Ultranox 626, 400-580
PP	TENSAR – BX-1100	ON = 160 PK = 168	ON = 115 PK = 111	1.1 – 1.2			30.8	Irganox 1076, 120 Irganox 1010, 140 Topanol CA, 910
PP	TENAX – MS-1000	ON = 157 PK = 165	ON = 116 PK = 113	0.4			67.3	Irgafos 168, 140 Irganox 1076, 220 Irganox 1010, 1250
HDPE	TENSAR – UX-1400	ON = 121 PK = 132	ON = 116 PK = 111	0.09			42.1	Irganox 3114, 110 Irganox 1010, 480 2,4 DTB Phenol, 160
PET	HC, TREVIRA 1155	ON = 240 PK = 255	ON = 201 PK = 207		0.622	45		
PET	NICOLON, HCT-250	ON = 233 PK = 252	ON = 199 PK = 179		0.875	12		
PET	MATREX – 240	ON = 179 PK = 224	ON = 211 PK = 168		0.872	20		
PET	MIRAGRID 15T	ON = 241 PK = 255	ON = 198 PK = 174		0.978	16		

[1] Polyfelt Literature, indicates HALS only

N/T – Not tested

the construction of a test levee over soft foundations utilizing woven PET geotextiles as reinforcements to increase stability.

Approximately 16 ft (4.9 m) of fill were placed in the winter of 1989 on a test section that was fully instrumented to monitor the embankment and geotextile performance. Excavation of the geotextiles occurred in the winter of 1993 or after 4 full years of performance at the embankment base, which was below the water table. The backfill properties around the upper geotextile (2U) and the lower geotextile (2L) are summarized in table 5 and their chemical properties in table 6. Figure 3 shows the surface of the excavated upper sample.

Data Analysis

The mechanical properties of the as supplied material were independently tested by the owner and can be compared with the retrieved sample properties as follows:

Table 5. Mechanical properties.

Sample	Wide Width Tensile Strength lb/in	Elongation %
2L prior to construction	2150	9.6
2L after retrieval	1900	9.0
2U prior to construction	1200	11.0
2U after construction	1000	10.5

It should be noted that the coefficient of variation for the retrieved samples was 6 and 9 percent, respectively. The coefficient of variation for the as produced material is unknown.

Chemical analyses of archive and retrieved samples yielded the following:

Table 6. Chemical properties.

Sample	Viscosity	CEG
2L (Retrieved)	0.76	32
2L (Archive)	0.78	43
2U (Retrieved)	0.77	26
2U (Archive)	0.79	33

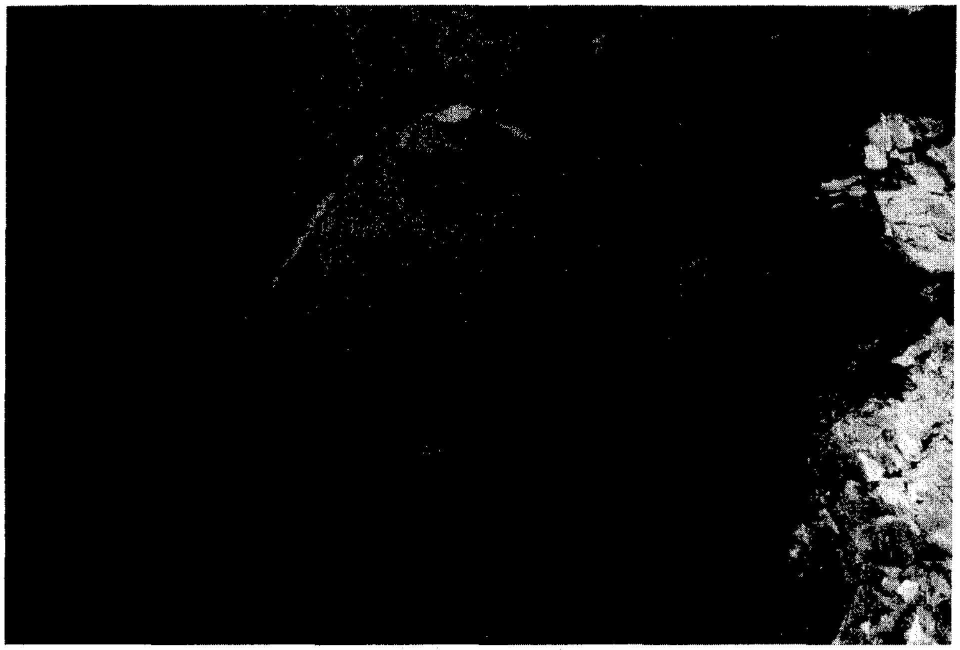


Figure 3. Surface of excavated upper sample.

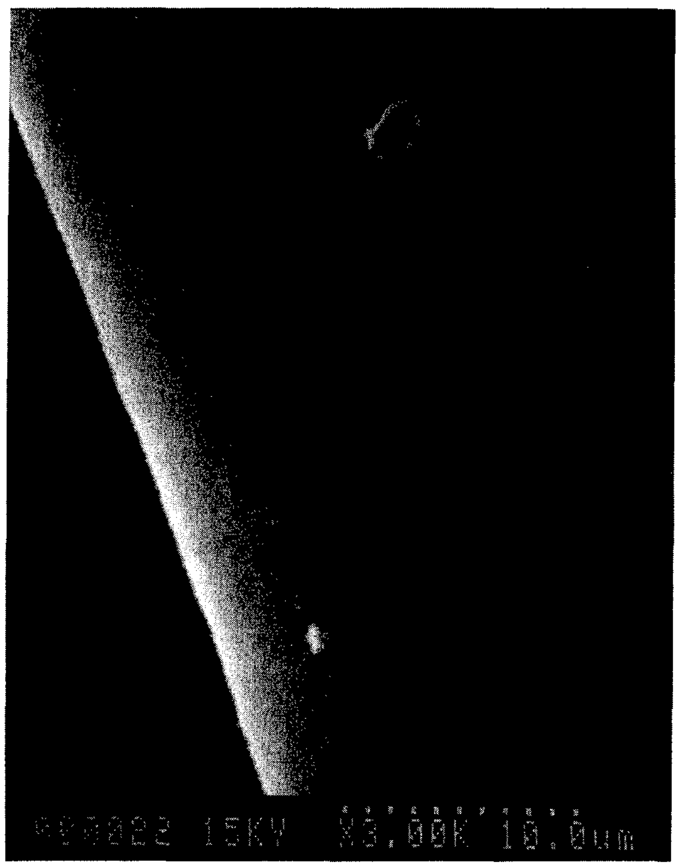


Figure 4. SEM of upper sample.

Based on viscosity measurements, it appears that some minor initial hydrolysis can be inferred. The CEG measurements show a decrease in CEG, which is puzzling as the CEG should increase with the onset of hydrolysis. Examination of the archive SEM for the upper geotextile indicates a fiber diameter of approximately 20 μm, which is equal to the fiber diameter of the retrieved upper geotextile. Further, the retrieved sample, figure 4, shows no sign of surface erosion, which is consistent with the nearly neutral site pH. It can therefore be inferred that less than 2 percent strength loss can be attributed to hydrolysis for the 4 years of burial. This would average ½ to ¼ percent per year, which is on the upper end of hydrolysis losses that could be inferred from laboratory testing reported in FHWA-RD-97-144.

The soil chemistry at the site is relatively neutral.

SITE #3 – Incubated Samples from Washington DOT Laboratory

Site Description

Samples of a PP slit film woven geotextile, GTF-200 (3A), and a PET woven monofilament, GTF-1225T (3B), were obtained in connection with a cooperative study with Washington DOT, which extensively instrumented a geotextile retaining wall constructed in 1989. The long-term durability aspect of the study consisted of placing samples from the delivered product in site soil backfilled trays in a moist room maintained at 100 percent relative humidity and 70°F. The mechanical and chemical properties of the backfill soil are shown in tables 2 and 3. These samples are identified as 3A-1 and 3B-1. Additional samples (construction-damaged) were retrieved in 1989 from the construction site and then laboratory incubated under the same conditions. They are identified as 3A-2 and 3B-2. All samples were removed from incubation for testing in late 1996. The results of the testing, including data from archive samples 3A-AR and 3B-AR, are tabulated in tables 7 and 8.

Table 7. GTF-200 test data.

Sample ID	Weight/ Unit Area g/m^2	Wide Width Tensile Strength lb/in	OIT min	Melt Flow Index g/10 min
3A-AR – Archive	181	170	120	4.09
3A-1 – Aged	182	127	104	3.94
3A-2 – Construction-damaged	181	100	76	2.84

Table 8. GTF-1225T.

Sample ID	Weight/ Unit Area G/m^2	Wide Width Tensile Strength lbs/in	Viscosity	CEG
3B-AR - Archive	461	657	0.80*	55
3B-1 - Aged	461	640	0.77	50
3B-2 - Construction-damaged	460	490	0.75	50

* M_n = 28,000

Data Analysis

For both materials (PP and PET) the aged virgin and construction-damaged samples were incubated approximately 7 years.

The WW tensile strength data for the PP slit film indicates a strength loss of approximately 25 percent for the aged virgin sample, although the measured OIT loss was less than 15 percent. Based on the literature and oven aging trends reported in FHWA-RD-97-144, it was anticipated that no strength loss would occur until at least an 80 percent reduction in OIT occurred. No explanation for this unanticipated behavior has been determined.

The significant measured reduction of melt flow index of the construction-damaged sample, which is an indication of molecular weight increase, is puzzling and inconsistent with the reduction of OIT of only about 35 percent.

The construction-damaged PP geotextile had a greater decrease in both OIT and melt flow than the virgin sample both of which were incubated for 7 years. Examination of SEMs for both the aged and construction-damaged sample does not show any circumferential cracking, and the soil backfill analyses do not indicate the presence of highly aggressive constituents. The soil chemistry is quite benign.

The PET woven geotextile exhibited a more predictable performance.

Strength data indicate a loss of approximately 2.5 percent in 7 years for the aged virgin sample. The net construction damage loss can be therefore be computed at approximately 23 percent, which is reasonable for this type of geosynthetic.

The viscosity decrease for the virgin sample is somewhat less than the construction-damaged sample, and confirms the measured strength loss. The greater decrease in viscosity for the construction-damaged sample potentially suggests that fiber damage accelerates hydrolysis. CEG measurements and examination of SEMs were inconclusive.

In summary, the hydrolysis-attributed losses for the virgin PET appear to be in the range of ¼ to ½ percent per year, which is consistent with the trends reported in FHWA-RD-97-144 for laboratory-incubated samples in neutral pH. The greater viscosity loss measured for the construction-damaged sample strongly suggests that hydrolysis may be accelerated when fibers are damaged.

The soil chemistry is quite neutral.

SITE #4 – Colorado I-70 Test Wall in Glenwood Canyon

Site Description

An experimental geotextile retaining wall utilizing four geotextiles was constructed in 1982 and excavated in 1984 and again in 1993 to determine the survivability and durability of the geosynthetics. A full description of the site and methods used to retrieve samples for mechanical testing has been published in TRB 1474 by Bell and Barrett. As a cooperative feature, selective soil and geosynthetic samples were retrieved concurrently during the 1993 excavations and further tested to complement the strength testing reported in TRB 1474.

The retrieved samples were dry on recovery. The backfill, mechanical, and chemical properties are tabulated in tables 2 and 3. The PP strength test data for all comparative retrievals are tabulated in table 9.

Table 9. Glenwood Canyon site.

Type	Sample ID	Depth of Sample, m	Strip Strength kN/m				
			1982	1984		1993	
			Archive	Mean	Variation Coefficient %	Mean	Variation Coefficient %
PET	4A-1 (H1115)	1	6.8	4.4	14	2.8	25
PET	4A-2 (H1127)	3	16.6	8.5	7	10.4	9
PP	4B (6 oz)	1	24.3	N/A	N/A	21.1	6
PP	4C-1 (3401)	1	7.7	5.7	9	4.0	11
PP	4C-2 (3601)	3	12.6	10.7	8	9.6	18
PP	4D (CZ200)	1	5.8	N/A	N/A	4.7	13

Site 4A geotextile is identified as a nonwoven continuous needled polyester (Trevira), 4B as a nonwoven staple polypropylene (Petromat), 4C as a nonwoven continuous filament heat bonded polypropylene (Typar), and 4D as a nonwoven continuous needled filament polypropylene (Fibretex).

The loss of strength as measured in the 1984 retrieval can be reasonably attributed to construction damage in light of the gravelly sand backfill (D_{50} - 1.2 to 2 mm).

The results of the polymer index tests are tabulated in table 10. Archive samples (AR) were available for testing under this program, although the effects of 15 years of storage could not be evaluated.

Table 10. Polymer index data.

Sample ID	Wt/Unit Area g/m^2	OIT min	Melt Flow Index	Viscosity	CEG
4A-1-AR	172	-	-	0.60	52
4A-1	174	-	-	0.52	37
4A-2-AR	280	-	-	0.60	53
4A-2	282	-	-	0.52	32
4B-AR	281	198	2.86	-	-
4B	283	139	2.76	-	-
4C-1AR	113	13	2.91	-	-
4C-1	113	12	2.42	-	-
4C-2-AR	226	18	2.59	-	-
4C-2	226	13	2.35	-	-
4D-AR	284	13	25.2	-	-
4D	195	10	23.9	-	-

Data Analysis

The polyester geosynthetics, 4A-1 and 4A-2, present a mixed picture both from mechanical test results and polymer analyses. The 1984 retrieval and strength test results clearly and consistently indicate the level of construction damage and establish a conservative base strength level to assess potential aging losses. The 4A-1 installation-damaged geosynthetic retained 65 percent of its initial strength and the 4A-2, 54 percent. No polymer identification tests were performed on the 1984 retrieved samples.

For the 1993 retrieval, the 4A-1 geotextile appeared to lose strength to a mean level of approximately 42 percent of initial, although the variation coefficient of the retrieved samples was considerably higher. By contrast the heavier 4A-2 geotextile exhibited a higher mean strength than the samples retrieved in 1984. This could suggest no strength loss due to hydrolysis. The polymer viscosity data, however, consistently indicate a decrease of approximately 13 percent, which based on laboratory testing reported in FHWA-RD-97-144, may indicate a strength loss of 5 percent or less in 11 years. The CEG measurements yielded apparently inconsistent data, a decrease in CEG, for which no explanation is evident. Examination of SEM disclosed no evidence of pitting or loss of section.

The 4B nonwoven staple PP was not excavated in 1984. The 1993 retrieval indicates approximately 86 percent retained strength. OIT measurements indicate 70 percent retention suggesting low antioxidant usage in the 11 years of burial. The melt flow index data indicate a small decrease suggesting some molecular weight increase due to the cross-linking phase of oxidation but more likely it may simply indicate that the archive sample did not come from the same production lot. Examination of SEM indicates no fiber circumferential cracking and a slight occasional evidence of fiber damage, typical of construction damage.

The mechanical strength and polymer index data all suggest that the loss strength is construction based with no evidence of oxidation-caused strength loss.

The 4C-1 and 4C-2 geotextiles are nonwoven continuous filament heat-bonded PP of two weights. Based on the 1984 retrieval, 74 and 85 percent strength was retained by the 4C-1 and 4C-2 geotextile, respectively. The retained strength is consistent with the expected level of construction damage. The 1993 retrieval indicated a consistent additional loss to levels of 52 and 76 percent retained, respectively, although with a higher coefficient of variation, strongly suggesting potential additional time-dependent strength losses that cannot be attributed to construction damage.

The polymer index data are either inconclusive or corroborate the strength data. The OIT measurements are inconclusive since the decrease of OIT min between the archive sample and the retrieved sample is within the anticipated variation coefficient for this test.

The melt flow index decrease which is more consistent with other retrievals for this project indicates some molecular weight increase again suggesting a cross-linking phase of oxidation or that the archive sample was not from the same production lot.

SEM examinations do not indicate any obvious cracking patterns that could be attributed to oxidation or UV degradation.

The 4D geotextile is a nonwoven continuous needled filament PP. For this geotextile no 1984 retrieval data are available. The 1993 retrieval indicates a retained strength of 76 percent suggesting losses primarily caused by installation damage. Polymer index data suggest a slight increase in molecular weight. The high melt flow index indicates that the polymer used in the manufacture of this geotextile was of relatively low molecular weight. Its performance was therefore somewhat surprising in indicating no oxidative degradation.

The SEM images show no evidence of cracking.

Soil chemistry appears to be neutral and benign. The location is climatically dry and yearly rainfall is limited, about 250 mm per year.

SITE #5 – Shelton Forest Retaining Wall, U.S. Forest Service – Olympic Peninsula, Washington

Site Description

Construction of this fabric retaining wall was completed in 1975. The wall has a maximum height of 5.6 m and a total length of 50 m. One half of the wall was constructed using a PET nonwoven geotextile (Bidim 200) and the other half using a PP needlepunched nonwoven [Fibertex 420 and 600(?)].

Samples from a depth of approximately 1 m to 1.5 m near the face, between the curb of the roadway and the face of the wall, were retrieved cooperatively with the U.S. Forest Service in 1993. Figures 5 and 6 were taken at site #5A (PET). The results of tensile tests from the retrieved sample have been previously published in TRB 1439 by Powell and Mohney. Note that both the original strength tests and the retrieved strength tests were performed in accordance with ASTM 1682 (Grab Test) using the same test grips to limit the amount of test variability.

Although excavated from the same depth below the unpaved area between the asphalt gutter and the wall face, within 15 m of each other, the PET sample (Bidim) was completely soaked while the PP sample (Fibretex) was essentially dry. This would suggest that PET retains infiltrating moisture to a greater extent than PP. Climatological data indicate average precipitation in the Olympic Peninsula in the range of 1500 to 2000 mm per year. By contrast the PET samples from about the same depth excavated from Site #4, Glenwood Canyon, were dry, which was not surprising since the average rainfall in the area is on the order of 250 mm per year.

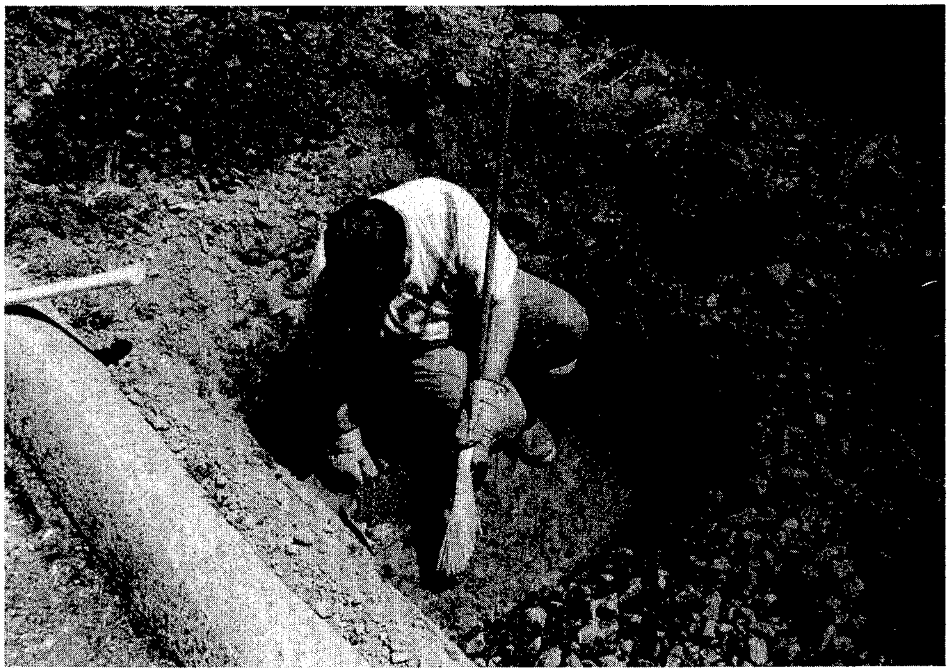


Figure 5. Excavation of PET geotextile. Layer 1.

Figure 6. Excavated PET geotextile. Layer 1.

Strength data from retrievals is shown in table 11.

Table 11. Shelton Forest site.

Type	Sample ID	Unit Weight g/m^2	Grab Strength lb/in			
			1975		1993	
			Mean	Std. Dev. %	Mean	Std. Dev. %
PET	5A-AR	200 [(1)]	198	5.4	-	-
PET	5A-1 - Layer 1	258	-	-	96	19.8
PET	5A-2 - Layer 2	263	-	-	102	24.2
PP	5B-1 - Layer 1	612	-	-	318	10.2
PP	5B-2 - Layer 2	390	-	-	327	8.5
PP	5B-1 - AR	600[(1)]	N/A	N/A	-	-
PP	5B-2 - AR	420[(1)]	550	2.8	-	-

[(1)] From manufacturers' published data

Data Analysis

The total strength reduction is on the order of 50 percent for the PET geotextile and 40 percent for the PP, of which a major portion may be attributed to construction damage judging from the gravelly backfill (D_{50} - 3.3 mm). Note that the coefficient of variation on tested PET retrieved samples is quite high. The apparent unit weight increase is due to embedded soil particles that were not removed after gentle washing and drying. This effect on strength measurements is unknown.

Chemical index tests were performed on the retrieved samples that were ultrasonically cleaned and on unaged samples of 5A from the same era obtained as swatches from manufacturers brochure. These latter samples are not true archive samples, but may represent the original product. Again the effects of 15+ years of storage cannot be evaluated.

The results are tabulated in table 12.

Table 12. Polymer index data.

Sample ID	OIT min	Melt Flow Index g/10 min	Viscosity	CEG
5A-AR	-	-	0.61*	59-66
5A-1	-	-	0.57	50
5A-2	-	-	0.58	49
5B-1	15	7.4	-	-
5B-2	12	7.3	-	-

* M_n = 17,500

The PET geotextile loss of almost 50 percent of its initial strength appears to be mostly attributable to installation damage. The viscosity decrease suggests that only 3 to 4 percent of the strength loss could be attributed to hydrolysis in the 18 years of burial or about 20 to 25 percent per 100 years. The small decrease of CEG from the archive sample is unexplainable, but consistent with the CEG data developed at the Glenwood Canyon site (#4) where the similar Trevira nonwoven PET geotextile was retrieved.

Since the archive (?) sample was not from the same manufactured lot, the CEG decrease can be attributed to manufacturing variations over the years.

The SEM photographs for the retrieved sample appear to have some longitudinal cracking not visible in the "archive" sample and appear to have a slightly reduced diameter. The latter measurements may be questionable as the "archive" sample is simply a sample believed to be representative of production in that area. Figures 7 and 8 indicate the above effects.

The PP geotextile strength loss appears to be consistent with installation damage. Polymer index tests indicate a small decrease of antioxidant and no molecular weight change. SEM examination indicates no cracking and no obvious evidence of construction damage as shown in figure 9.

Soil chemistry at the site is quite neutral and/or benign.

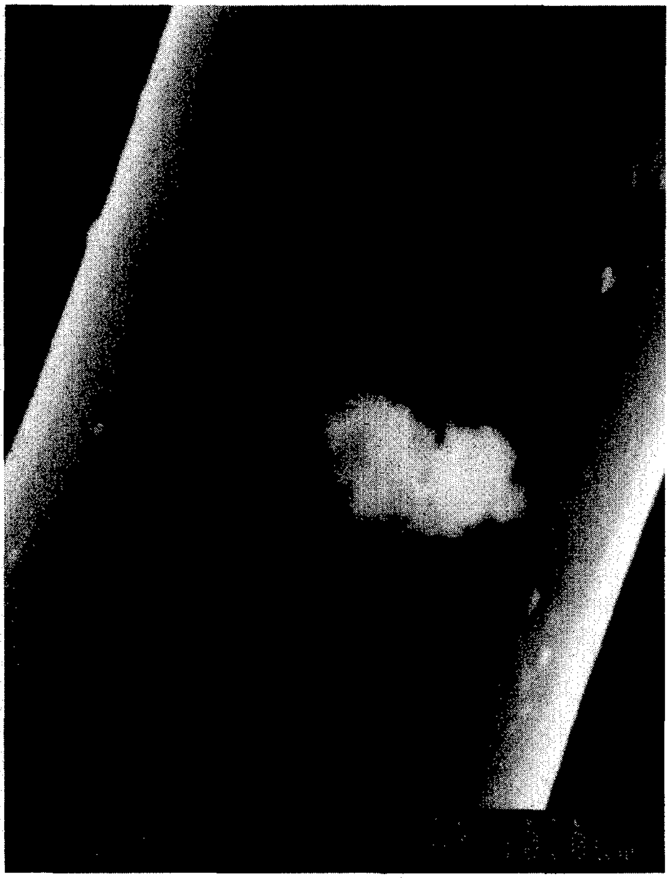


Figure 7. SEM, "archive" sample 5A-AR.

Figure 8. SEM, retrieved sample 5A-2.

Figure 9. SEM, retrieved sample 5B-1.

SITE #6 – Tanque Verde Walls, Tucson Arizona.

Site Description

The construction of a series of concrete-faced mechanically stabilized earth walls utilizing an HDPE geogrid (SR-2) was completed in 1985. The walls varied in height from 1 to 6 m and have been extensively instrumented to provide data on both temperature gradients within the reinforced geogrid. A summary of the developed data has been published as FHWA-EP-90-001-005 and other publications.

In 1993, cooperatively with Tensar, samples were exhumed from a portion of the site to assess the durability of this product under fairly adverse temperature conditions. Duplicate samples have been obtained, with Tensar testing one-half of the samples. Their results were reported in TRB 1439 by Bright et al. The samples were recovered from a depth of 0.4 m below the surface, where previous temperature readings would suggest in-ground temperatures would range from 15 to 40°C with transient readings as high as 49°C. Given the thin soil cover and the gravelly sandy backfill, it was anticipated that a in-air oxygen content would prevail at this depth, suggesting optimum conditions for potential oxidative degradation.

Data Analysis

The tensile strength measured by a single rib tensile test indicated a strength of 1.41 KN/rib. Archive samples were not available, but a search of the literature of that era indicated that, characteristically, 1.59 KN/rib could be anticipated. It is interesting to note that in TRB 1439, Bright et al. reported archive and exhumed values of approximately 1.9 KN/rib. Part of the difference in exhumed values can be attributed to the selection of ribs for testing. The tested ribs from the exhumed sample under this program included ribs that had some visible construction damage. The small loss of strength (approximately 10 percent) appears to be from construction damage, which is confirmed by the insignificant reduction in OIT values from 65 to 62 min which is within the range of repeatability for this test. The reduction in OIT is even smaller than reported in TRB 1439, although the testing methodology was significantly different. The melt flow index of 0.14 g/10 min is less than the reported archive melt flow of 0.22 g/10 min. Assuming that the archive melt flow reported in the literature is correct, the decrease would indicate a typical initial increase in molecular weight indicating a cross-linking phase of oxidation to which strength loss is typically not attributed, or that the testing methods reported in the literature varied from those used in this program. The small loss of strength is clearly the result of either construction or exhumation damage. No evidence of strength loss due to oxidation is indicated.

Soil chemistry is neutral and benign. The excavated site and sample are shown in figure 10.

Figure 10. Site excavation, #6.

SITE #7 - State Road 131, Atoka Co., Oklahoma

Site Description

Two geotextiles, a nonwoven Supac 8N(7A) and a woven Supac 5WS(7B), were used as subgrade separators on State Road 131, Atoka Co., OK, between a clay subgrade and a 6-in-thick (0.2 m) aggregate base. Construction was completed in 1984 and samples were exhumed in 1993.

Archive samples were not available for comparison, but a 1992 production sample of the 8N was available and tested. Based on manufacturer's published data and 1984 project data sheets, it appeared that the manufacturing process and typical strip test strengths and other properties were identical and therefore the 1992 sample could be used as a reasonable representation of archive strength. Further, by comparing the ratio of WW strength (ASTM-

4595) to strip strength (ASTM 1682) for nonwovens based on typical published data (IFAI, 1986), a ratio of 0.30 to 0.35 was indicated. This would suggest a 1984 equivalent WW strength of 99 to 115 lb/in, based on the project typical strip strength of 330 lb. This equivalent strength is consistent with the 1992 archive sample strength of 99 lb/in with a standard derivation of 3 percent. For the 5WS, the project data sheet indicates a typical grab test strength of 295 lb and the ratio to WW strength based on the same published data for slit film products suggests a range of 0.65 to 0.8. The above would suggest an equivalent 1984 WW strength between 190 to 235 lb/in. The developed data for the "archive" and retrieved samples is tabulated in table 13.

Table 13. Atoka Co., Oklahoma.

Sample ID	Unit Wt. g/m^2	Wide Width Strength lb/in	OIT min	Melt Flow Index
7A-AR		99[1]	11 ± 3	
7A	300	59	10	2.39
7B-AR		190[1] - 235[1]		
7B	225	65	29	1.72

[1] Projected equivalent data

Data Analysis

Tensile strength testing of exhumed samples indicates significant strength loss. Based on a visual examination of the samples tested, it is clear that a major cause for the strength loss is construction damage. For the nonwoven geotextile (7A), OIT data suggest that antioxidant consumption was minimal, although at the levels measured ($\pm$ 10 min) for both archive and exhumed, the significance of OIT measurements is uncertain. Examination of SEM fibers for geotextile 7A indicates no evidence of oxidation. Examination of SEM for the woven geotextile (7B) does not indicate any evidence of oxidation, but does show significant evidence of construction damage. The soil chemistry is quite neutral except that the upper subgrade material is high in calcium, which should not, however, affect the degradation process.

A parallel sample (7A) was retrieved by Guram et al. and limited strength data were reported in TRB 1439. It showed considerably less strength loss when compared with the Minimum Average Roll Value (MARV) published value.

SITE #8 – Washington State Separator Sites

Site Description

The three separate sites sampled were part of a study for a masters thesis (1993) by R. Metcalf at the University of Washington who studied the survivability of geotextiles as subgrade separators. The mechanical strength tests were performed by Mr. Metcalf and the soil chemistry and polymer analyses under this contract.[1] Each site is separately described as follows:

1. Pacific Way, Cowlitz Co. This site identified as 8A, located at M.P. 2.66 Pacific Way, was constructed in 1982 by placing a PET (Trevira 1115) needled punched nonwoven geotextile over a fine colluvial silty clay deposit and backfilled with a gravelly base course. The sample was excavated in 1992 from a depth of 600 mm below the pavement surface and was quite wet with visible brown iron stains on both surfaces.

2. Coal Creek, Cowlitz Co. This site identified as 8B, located at M.P. 0.15 Coal Creek Rd., was constructed in 1984 by placing a heat bonded nonwoven geotextile (Typar 3401) on fine grained silty clay and wood debris and backfilled with a base rock ballast material. The site appears to be a old timber holding area for a local lumber mill.

3. Marsh Rd, Snohomish River Bridge, SR-9. This site identified as 8C, located at M.P. 8.35 on SR-9, was constructed in 1989 by placing a woven slit film geotextile (Permatex 2350) over silty clay subsoils and backfilled with a clean sand with some gravel.

   Although the geotextile was identified as a Permatex style 2350, manufacturer literature of that era indicates that only styles 2300 and 2500 were being manufactured by Synthetic Industries and distributed under the Perma-Tex label locally. Unit weight determinations of the retrieved sample further indicate that the sample was closer to the 5.5 oz/sy weight of a style 2500 than the 4.8 oz/sy suggested for a 2350 style. The thickness measurements appear to further corroborate that the 2350 was a 2500 style geotextile. The retrieved sample showed significant pore clogging with what appeared to be iron oxides.

   No actual archive samples were available for comparison, although typical values for grab strength were obtained from manufacturer literature as part of the project records. These values and the strengths from retrieved samples are tabulated in table 14.

Table 14. Washington DOT, separator sites, tensile strength.

Sample ID	Tensile Strength			
	Manufact. Typical Grab Strength, kN	Retrieved Grab Strength, kN	Retrieved Wide Width, kN/m	% Grab Retained
8A	0.579	0.477	5.1	83
8B	0.645	0.384	4.8	60
8C (2500)	1.336	1.024	28.3	77

The measured polymer index data for the exhumed samples are tabulated in table 15.

Table 15. Washington DOT, separator sites, polymer index data.

Sample ID	Wt./Unit Area g/m^2	OIT min	Melt Flow Index g/10 min	Viscosity	CEG
8A	165			0.4	22
8B	151	13	2.17		
8C	189	21	2.55		

Data Analysis

Site 8A

The indicated strength loss at site 8A appears to be predominantly from construction damage, although some strength loss may be attributed to hydrolysis as evidenced by the low viscosity measured and the wetness of the exhumed sample. Although no archive sample was available for testing, early 1980 era Trevira geotextiles (Site #4) and 1994 industry testing clearly indicated a consistent production viscosity for this product of approximately 0.6 and CEGs in the range of 45-55. Based on hydrolysis testing reported in FHWA-RD-97-144 the reduction of viscosity clearly indicates that hydrolysis has occurred in the nearly neutral pH soil environment with a potential loss of strength on the order of 3 percent for the 10 years of burial. The balance of the measured strength loss can be attributed to construction damage. As for Site #4 the decrease of CEG is consistent, but without current explanation as hydrolysis would increase CEG. Examination of SEM shows no surface pitting since the soil regime is nearly neutral.

Site 8B

The measured strength loss at this site can be attributed to construction damage based on the field description of the recovery process and visual examination of the recovered samples. Archive samples were not available but OIT testing of samples from that era as well as testing of samples from the early 1990s would indicate a OIT of 10-15 min. The average measured OIT of 13 is within this range and would strongly suggest that no significant oxidation has occurred with a concurrent loss of strength. The melt flow index shows the typical initial decrease measured at all other sites.

Site 8C

The loss of strength can be principally or wholly attributed to construction damage as slit film geotextiles are most prone to construction damage.

Archive samples were not available, although Synthetic Industries, the geotextile producer (not distributor), supplied archive samples of that era (see also Site #11). The supplied information indicated it was produced with a resin whose melt flow index was 4 and further contained 3.5 percent LLDPE.[2] The archive OIT (see Site #11) was on the order of 55-64 min, with exhumed OIT on the order of 21-28 min. The effect of LLDPE even in minor quantities on OIT is presently unknown, but since the OIT measurements were made by the same operator within days of each other, the relative loss in OIT is considered to be correct. The OIT loss in only 3 years could indicate accelerated depletion of antioxidants at this site due to the significant presence of iron oxides, although the total iron content of the soil (table 3) does not appear to be extraordinarily high. The SEM indicates typical longitudinal tears associated with production slit film products.

SITE #9 - AKZO Test Wall, Arnhem, The Netherlands

Site Description

A Stabilenka 200/45 geotextile was recovered in 1993 from a lower layer of a test wall constructed in 1980 at the AKZO plant. This geotextile was manufactured with PET in the warp and polyamide in the weft direction. The sample was from a bottom layer embedded in a sand backfill. Samples were obtained from the face of the fabric retaining wall and from unexposed reinforcing layers within the structure. The results from all samples tested has been previously reported by Troost et.al.[3]

Samples of the reinforcing layer within the structure were tested in connection with this project in Europe and in the United States.

The sample of particular interest for this project was excavated from the south embankment and was fully embedded in the dike sand backfill. Archive samples were available for testing, although their storage conditions were not documented. Since the soil samples and limited archive material could not be transported to the United States because of customs restrictions, most testing was performed in Europe by an independent laboratory using European standard methods.

Data Analysis

The sand backfill contained from trace to little gravel and was slightly acidic. The chemical analysis disclosed no unusual concentrations of measured salts or metals. Based on testing from 10 samples the archive strength was established at 234 kN/m with an elongation at break of 8.5 percent.

The recovered average sample strength was measured as 227 kN/m with an elongation at break of 8.5 percent. The standard deviation of the measured recovered samples was approximately 15 kN/m or 3 times that of archive samples. Based on these results, it can be inferred that the 200/45 geotextile lost 3 to 6 percent of its strength as a result of the 13-year burial.

Previous data developed by Troost and Ploeg [(4)] indicated a loss of strength due to construction damage for this geotextile and a sand backfill on the order of 10 to 14 percent. Therefore, the strength measurements imply that no loss of strength should be attributed to hydrolysis.

Chemical molecular testing indicates an archive molecular weight M_n of 33,000 and a CEG of 23. These values are generally consistent with those previously reported by Risseeuw and Schmidt [(5)] for the Diolon 770 fiber used on the 200/45 geotextile. Chemical testing of the retrieved samples indicated no statistically measurable changes. SEM examination of fiber surfaces indicated clean surfaces, no pitting, and no diameter reduction as shown in figure 11.

SITE #10 – Quinnalt National Forest, Subgrade Stabilization Test Sites, U.S. Forest Service

Site Description

Five stabilization geotextiles were used in the construction of a logging road in 1976 by the U.S. Forest Service in the Quinnalt Forest in the Olympic peninsula and incorporated in a test section.

Samples were initially retrieved in 1978 and then again in 1993 to determine changes in physical and polymer properties. They are identified as follows:

1. Sample 10A – Fibertex 420 nonwoven needle punched PP.
2. Sample 10B – TYPAR 140 heat bonded nonwoven PP.
3. Sample 10C – Mirafi 140 heat bonded needle punched PP.
4. Sample 10D – SUPAC 140 nonwoven needle punched PP.
5. Sample 10E – Bidim 150 nonwoven needle punched PET.

Figure 11. SEM, Site #9.

The initial 1978 retrieval and testing was performed by the U.S. Forest Service, while the 1993 retrieval for this project was cooperatively performed with testing performed under this contract using the same methods and grips as for the initial and 1978 retrievals. The tensile test results have been previously reported by Powell and Mohney in TRB 1439. Although actual archive samples were not available for polymer index testing, a few samples from the same era were secured and tested for comparison.

All of the samples were wet on excavation as the groundwater table was at or near the depth of the geotextiles.

The strength data from successive retrievals are shown in table 16.

Table 16. Quinnalt Forest Site, strength tests.

Polymer	Sample ID	Grab Strength, lb/in					
		1976 - Archive		1978		1993	
		Strength	C.O.V.%	Strength	C.O.V.%	Strength	C.O.V.%
PP	10A	550	15.1	395	18.3	339	14.8
PP	10B	144	18.2	119	18.6	116	8.6
PP	10C	124	11.2	112	18.0	97	9.1
PP	10D	86	10.8	93	8.9	93	10.3
PET	10E	234	11.2	135	10.0	124	9.4

The polymer index data developed from the 1993 exhumed samples are tabulated in table 17.

Table 17. Quinnalt Forest site, polymer index data.

Sample 1I	OIT min	Melt Flow Index g/10 min	Viscosity	CEG
10A	10	12		
10B	19	1.8		
10C	23	3.7		
10D	10	8		
10E			0.45	50-60

Data Analysis

Sample A, Nonwoven Needle Punched PP

The loss of strength in excess of 25 percent as measured from archive data to the first 1978 retrieval can be associated wholly to construction damage. The subsequent 10 percent loss, based on initial strength, may be partially associated with oxidation losses although the polymer index data is inconclusive at best since no true archive samples were available for index testing.

The exhumed samples produced OITs on the order of 10 min and a melt flow index on the order of 12 g/10 min. The latter suggests a relatively low molecular weight geotextile. SEM examination does not revel any cracking potentially indicative of advanced oxidation.

Sample B, Heat Bonded Nonwoven PP

The loss of strength on the order of 15-20 percent as measured to the 1978 retrieval can be wholly attributed to construction damage. The subsequent apparent minor strength loss to the 1993 retrieval is not conclusively demonstrated as the coefficient of variation for the 1978 retrieval was approximately twice as great as for 1993 samples. The inference is that there was no further strength loss. The polymer index data based on OIT tends to confirm this conclusion as OIT in the range of 17-20 were measured for comparison to OIT from samples of that era of 13-18. The "archive" materials were similarly manufactured but were not of the same weight.

The SEM shows no indication of oxidation cracking, but does indicates tears indicative of construction damage.

Site C, Heat Bonded Needle Punched PP

The initial loss of strength can be attributed to construction damage, although the coefficient of variation for the 1978 retrieval was significantly higher than either the archive data or the 1993 retrieval data. Without archive polymer data no inference can be made as to whether any of the 1978-1993 strength loss can be attributed to oxidation, although the measured post construction strength loss was greater than for any other geosynthetic buried at this site.

The SEM shows no indication of cracking.

Site D, Nonwoven Needle Punched PP

This site geotextile shows no statistically measurable loss of strength from construction damage, which is suspect and suggests that the archive data testing methods or equipment was inconsistent with strength data developed in subsequent retrievals. The OIT and melt flow index are consistent with production data (1993) of this product. However, there is no available corroboration that the antioxidant package remained constant in the period 1976 to 1993. Examination of SEM suggests some construction damage and no evidence of cracking caused by oxidation.

Site E, Nonwoven Needle Punched PET

The loss of strength in excess of 40 percent as measured from archive to first retrieval should be substantially associated with construction damage. The subsequent strength loss on the order of 5 percent can be ascribed to hydrolysis as the coefficient of variation for both retrievals and archive samples were substantially equal. The initial strength loss is similar to the strength loss measured at Site #5, where the same geotextile style was used.

Although a project-specific archive sample was not available, testing of a sample produced in that era indicated a viscosity on the order of 0.6 and CEG in the range of 59-65. The retrieved sample viscosity was in the range of 0.45 with CEG in the range of 50 to 60. The polymer index data strongly suggest that some hydrolysis has occurred, which would lead to strength loss. The SEM micrograph, figure 12 clearly shows minor fiber erosion and cracking, which is indicative of strength loss due to hydrolysis. The level of strength loss of 0.25 to 0.35 percent per year is consistent with laboratory data developed in FHWA-RD-97-144, although the viscosity decrease suggests a potential greater strength loss. The relatively small change of CEG is also indicative of a minor strength loss.

Figure 12. SEM, sample 10E, PET.

SITE #11 - Abardeen, Washington, Wood Chip Embankment

Site Description

A Permatex 2500 geotextile was used as base reinforcement in multiple layers during the construction of a 13-m-high wood chip fill mainly of organic silt. Fill construction was completed in 1986. Details of the project have been extensively reported by Allen and Kilian in TRB 1422. A sample of the geotextile in contact with the wood chips was excavated and recovered in 1996 for durability testing. Figure 13 shows the sample prior to recovery. The Permatex geotextile is believed to be manufactured by Synthetic Industries as its style 960 and is identical in polymer index properties to the geotextile used and described in Site 8C. A summary of testing performed is shown in table 18.

Table 18. Abardeen, WA site.

Sample	Weight/Unit Area g/m^2	Wide Width lb/in	OIT min	Melt Flow Index g/10 min
11AR	204	118	55-64	2.35
11	223	90	32-55	2.25

Data Analysis

The reduction in tensile strength should be attributed to construction damage, as the polymer index properties (OIT) strongly suggest that significant antioxidant is still present after 10 years of burial even though the lower soil material exhibited very high total iron concentrations, which is consistent with fill leachates measured by others and reported in TRB 1422. The construction damage level is somewhat surprising given that the fill (wood chips) does not appear to be abrasive. It is interesting to note that both the archive sample (AR) and the retrieved sample exhibit longitudinal cracking, which is typical for production slit film geotextiles as shown in figure 14.

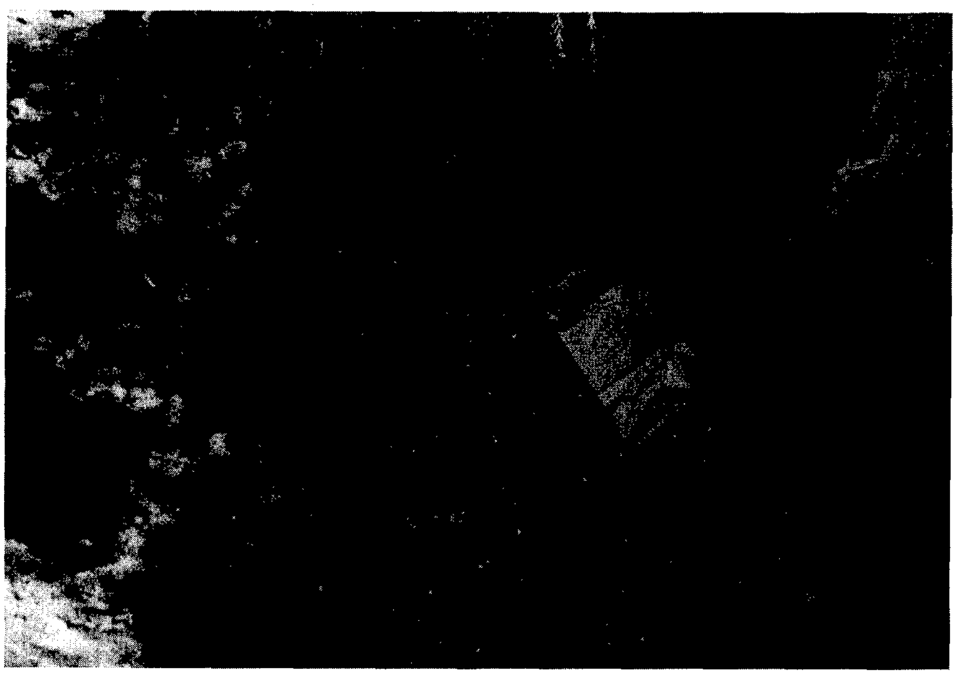
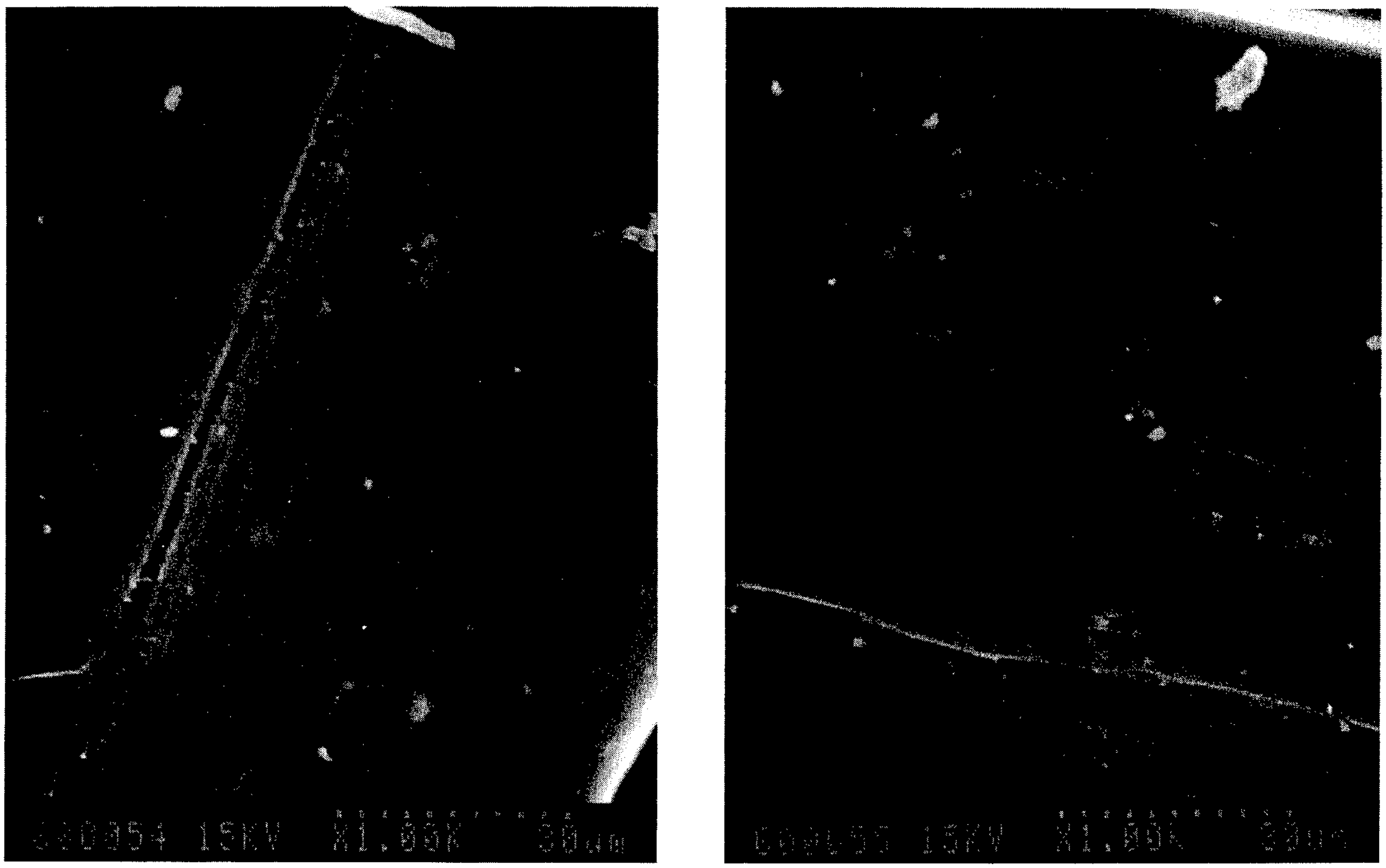


Figure 13. Site #11 excavation.



a) Archive b) Retrieved

Figure 14. SEM, archive and retrieved sample.

SITE #12 - St. Croix Mall, Stillwater, MN

Site Description

The geogrid recovered from this project was used in the construction of a retaining wall in connection with the development of a mall near Highway 36 in Stillwater, MN, in late 1989. The retaining wall developed significant bulging during construction, which became more pronounced in subsequent years. The owners decided to reconstruct the wall and redirect surface and subsurface water from the face of the wall. As a result of reconstruction in early 1995, samples of the geogrid used and identified as a Wheeler 260 (Huesker) were recovered, as well as an archive sample of that era obtained from the distributor's literature. A summary of testing performed is shown in table 19.

Table 19. St. Croix Mall, MN.

Sample	Wide Width lb/in	Viscosity	CEG
12 AR	116	0.70	47
12	102	0.60	42

Data Analysis

The strength loss measured is principally related to construction damage, as shown in SEM reproduced as figure 15.

Figure 15. SEM, sample 12.

The viscosity decrease is indicative of the initial stages of hydrolysis, which, however, in 5-to-6 years could not have contributed to a strength loss greater than 1 to 2 percent.

The surprising element is the rather low viscosity of the archive sample (1988 era) and its relatively high CEG. According to manufacturer's literature, current Huesker geogrids are manufactured with higher viscosities and lower CEG.

CHAPTER 3

TASK C, LABORATORY CHARACTERIZATION OF UNAGED SAMPLES

OBJECTIVE

The objective of this task was to provide a baseline databank of mechanical and chemical properties for commonly used geosynthetic products (1993) in reinforcement and/or transportation applications.

This task was performed by cooperating IFAI industry laboratories headed by an industry task force that selected the geosynthetics, developed the testing protocols in cooperation with Polytechnic University, and reviewed the developed data.

The principal elements of this task can be summarized as follows:

- Selection of geosynthetic products to be tested that represented major geosynthetic classes of products used for stabilization/reinforcement.
- Development of testing matrices.
- Development of testing protocols.
- Industry testing.

SELECTION OF GEOSYNTHETIC PRODUCTS

In cooperation with the industry task group formed under the auspices of IFAI, the following typical geosynthetics were selected and tested for mechanical and chemical properties by cooperating industry laboratories:

1. Amoco 2006 - (PP) woven slit film type yarn
2. REEMAY 3601 - (PP) nonwoven thermally spun bonded fibers
3. Synthetic Industries - (PP) woven monofilament yarn
4. NICOLON HP-600 - (PP) woven fibrillated yarn
5. Polyfelt TS-700 - (PP) nonwoven needle punched continuous filament
6. SUPAC - 8N - (PP) nonwoven needle punched staple fiber

7. TREVIRA 1155 - (PET) nonwoven continuous filament
8. NICOLON HCT-250 - (PET) woven filament
9. MATREX, MX-240 - (PET) PVC coated geogrid
10. MIRAGRID, 15T - (PET) acrylic coated geogrid
11. TENSAR, UX-1400 - (HDPE) uniaxially stretched geogrid
12. TENSAR, BX-1100 - (PP) biaxially stretched geogrid
13. TENAX, MS-1000 - (PP) multilayer biaxial geogrid

These materials represented a broad spectrum of geosynthetics in use (1993) marketed for civil engineering applications for separation, stabilization, and reinforcement.

DEVELOPMENT OF TESTING MATRICES

The testing matrix for each product consisted of the following:

1. Physical Properties – (a) mass per unit area, (b) thickness, and (c) density/specific gravity.
2. Mechanical Properties – WW tensile strength and elongation.
3. Chemical and Molecular Structure – (a) DSC, (b) melt flow, (c) intrinsic viscosity, (d) CEG determination, (e) OIT, and (f) antioxidant extraction and quantification by HPLC.

DEVELOPMENT OF TESTING METHODS AND PROTOCOLS

In cooperation with industry (IFAI, 1993), testing protocols were agreed upon. Whenever possible, current ASTM standards were adopted or formed the basis of agreed upon protocols. When no ASTM standards were available, industry or testing methods found in the polymer chemistry literature were adopted.

The full test methods have been compiled as "Procedures and Test Standards for Evaluating the Properties of Geosynthetics," IFAI, Geotextile Division, December 3, 1993.

The testing protocol required that multiple IFAI participating laboratories perform the same test on each geosynthetic sample from the same roll as a check, and that Polytechnic University would perform additional checks typically on geosynthetics tested and reported in FHWA-RD-97-144 under Tasks D & E. Due to the retrenchment and consolidation within this industry in 1993-1995, IFAI was not able to fulfill this commitment and relatively few interlaboratory checks were accomplished. It should be further noted that, although the developed methods recommended that OIT measurements for polypropylenes be made at 175°C, participating laboratories used current ASTM procedures and measured OIT at 200°C for testing performed under this task.

SUMMARY OF RESULTS

The results submitted by IFAI are reported in table 20 for mechanical properties and table 3 for chemical properties.

The few interlaboratory comparative strength tests (WW) indicated significant variance for woven or grid products and even for a nonwoven geotextile (SUPAC 8N). The latter was quite surprising as the IFAI laboratory reported almost twice the manufacturer's published strength, which was confirmed at Polytechnic's laboratory. For chemical testing, melting peak temperatures matched closely when compared with Polytechnic University determinations. OIT results are not comparable since the methodology and temperature strongly influence results as discussed under Task D & E in FHWA-RD-97-144.

Antioxidant extraction studies, with comparison available for a few geosynthetics, yielded reasonably good agreement in identifying all except HALS antioxidants (see TS-700). These results generally matched results obtained at Polytechnic University laboratory.

For PET products, generally good interlaboratory correlation was found between IFAI and Polytechnic. For the low tenacity product (Trevira), the correlation for both intrinsic viscosity and CEG was excellent. For the high tenacity products, the correlation for intrinsic viscosity was within 5 percent, which is considered good especially since different solvent systems were used. CEG determinations were generally comparable.

Table 20. Industry reported mechanical properties.

Polymer	Product	Mass g/m^2	Thickness mm		Specific Gravity @ 23°C	WW Tensile & Elongation lb/in
			Type	Sheet		
PP	AMOCO – 2006 Woven slit film tape yarn	245	28.4 die cut	41.7	0.90	MD – 262 @ 7.8% XD – 173 @ 10.9% MD – 233 @ 21%[(a)]
PP	REEMAY 3601 Nonwoven thermally spun bonded	204	18 Melt		0.907	MD – 70 to 78 @ 78 to 81% XD – 81 to 88 @ 74%

Table 20. Industry reported mechanical properties (continued).

Polymer	Product	Mass g/m²	Thickness mm		Specific Gravity @ 23°C	WW Tensile & Elongation lb/in
			Type	Sheet		
PP	SYNTHETIC Industries Woven monofilament yarn	232	15.1 die cut	16.2	0.907 – 0.914	MD – 258 @ 25.6% XD – 170 @ 26.3%
PP	NICOLON – HP-600 Woven fibrillated yarn	444	66.5 die cut	66.7	0.911 – 0.916	MD – 625 @ 8.3% XD – 386 @ 12.8% MD – 482 @ 20.5%[(a)]
PP	POLYFELT – TS-700 Nonwoven needle punched continuous filament	321	138 die cut	145	0.911 – 0.916	MD – 85 @ 117%[(a)]
PP	SUPAC – 8N Nonwoven needle punched staple	336	111.7 die cut	117	0.902 – 0.915	MD – 228 @ 105% XD – 208 @ 79% MD 99 @ 83%[(a)]
PP	TENSAR – BX-1100 Biaxially stretched geogrid	193	105 die cut		0.902 - 0.908 in alcohol	MD – 102 @ 7.7%
PP	TENAX – MS-1000 Multilayer biaxial geogrid					MD – 120.4 @ 22.4%[(b)] XD – 106.3 @ 33.6%[(b)]
HDPE	TENSAR – UX-1400 Uniaxially stretched geogrid	724		113	0.953 – 0.955	MD – 259 @ 12.8%
PET	HCC TREVIRA–1155 Nonwoven continuous filament	574	178 die cut			MD – 214 @ 67% XD – 195 @ 67% MD – 204 @ 75%[(a)]
PET	NICOLON– HCT-250 Woven filament	353	27 melt			MD – 544 @ 18%
PET	MATREX – MX-240 PVC coated PET geogrid	1256				MD – 1040 @ 175 lb/rib[(a)]
PET	MIRAGRID – 15T Acrylic coated PET geogrid	446				MD – 761 @ 15.3%

(a) By Polytechnic University

(b) TENAX claims higher

CHAPTER 4

TASK SUMMARY AND CONCLUSIONS

OVERVIEW

The 12 retrieval sites and 24 geosynthetics retrieved and tested represent a cross section of materials, applications, and soil burial regimes that is believed to be representative of current usage. The developed strength and polymer index data, when viewed in totality, do corroborate the general trends with respect to durability determinations suggested by the laboratory protocol development phase reported in FHWA-RD-97-144 and supported by the index testing provided by industry and tabulated in chapter 3.

Retrospectively, it appears that a successful retrieval program must have all of the following elements:

- Standardization for methods of measuring polymer index data, especially OIT, viscosity, and CEG determinations.
- Archive data with respect to both mechanical and polymer index properties developed on the actual materials used in construction.
- For polyolefin geosynthetics, sites that are 30 or more years in age.
- For polyester geosynthetics, sites that are at least 20 years in age.
- A retrieval soon after construction (0-2 years) to establish the level of construction damage.

It is clear from the site descriptions in chapter 2 that none of the 12 sites or 24 geosynthetics met the outlined criteria and therefore the retrieval program will be considered reasonably successful only if additional retrievals are undertaken at some or most of the sites sampled and reported within the next decade. Should additional sampling at the sites be undertaken, it is essential that polymer index testing methods detailed in Appendix A of FHWA-RD-97-144 be used.

General conclusions from the retrieval phase are summarized on a resin basis in the subsequent sections.

POLYPROPYLENE GEOSYNTHETICS (PP)

A review of developed strength and polymer index data from PP sites strongly suggests that strength loss measured in the limited burial periods (less than 20 years) can be principally or wholly attributed to construction damage.

The decrease of measured OIT simply indicates a given level of antioxidant consumption. Loss of strength due to oxidation can only begin after significant or near total depletion of antioxidants has occurred. Such levels were not sampled. Low OIT times do not indicate low initial antioxidant content but rather are a measure of antioxidant type and testing methods, principally test temperature as outlined in FHWA RD 97-144. The consistent decrease of melt flow index for the retrieved samples compared with archive samples is puzzling and counterintuitive. Where the decrease is small it simply reflects that the archive sample and the retrieved samples were not from the same production lot. The larger decreases noted are initially counterintuitive as they suggest an increase of molecular weight, which typically indicates a stronger or more resistant material to degradation processes. A possible hypothesis to explain this trend suggests that the consumption of antioxidants, which are generally of lower molecular weight, leads to an average increase of molecular weight for the product during this "induction" phase, or as suggested earlier, some type of cross-linking reaction could be occurring initially, causing molecular weight increase.

In conclusion, the polymer index data strongly suggest that the short burial time (less than 20 years) is insufficient to deplete the geosynthetic from the protection afforded by the included antioxidants and therefore initiate oxidation induced strength loss.

This conclusion is consistent with the laboratory data developed under FHWA-RD-97-144 which demonstrated that most of the typical antioxidants used in commercial geosynthetics protect the geosynthetic from oxidative degradation strength loss for periods of time ranging from 25 to more than 100 years, as a function of the type and quantity of antioxidant included.

HIGH-DENSITY POLYETHELENE (HDPE) GEOGRIDS

Only one site was retrieved in which a HDPE geogrid was used under the most taxing burial regime of high temperature and near atmospheric oxygen.

No statistically significant changes of polymer index properties were measured for the approximate 8 years of burial, and the minor loss of strength can be attributed to construction damage. Again, this finding is consistent with the developed laboratory accelerated oxidation studies reported in FHWA-RD-97-144, which indicated that the antioxidant package used in Tensar HDPE geogrids should be effective for periods of more than 50 years under average in-ground temperatures (± 12° C). Therefore, no significant loss of strength due to oxidation should be anticipated or measured during this "induction" period in which antioxidants are still present within the body of the geogrid.

POLYESTER (PET) GEOSYNTHETICS

A review of developed strength and polymer index data from PET sites strongly indicates evidence of some hydrolysis in nearly all cases where low tenacity and/or or low viscosity, high CEG products have been exhumed. For the few sites with nonwoven PET geotextiles where previous retrievals established strength losses due to construction damage, the level of yearly hydrolysis losses was determined and found to be on the same order of magnitude predicted by accelerated hydrolysis testing detailed in FHWA-RD-97-144. For the one PET geogrid excavated, the polymer index data surprisingly indicated a relatively low viscosity ($\pm$ 0.7) when compared with the high viscosity ($\pm$ 0.9) products presently on the market. For low tenacity, low viscosity, high CEG products, typically nonwoven PET geotextiles, both the field retrievals and laboratory data have shown that in neutral saturated soil regimes, a strength loss of between 0.25 to 0.5 percent per year should be anticipated.

The typical decrease of CEG measured on all retrieved PET geosynthetics is unexplained. Based on the laboratory testing and classical polymer chemistry concepts, CEG should increase if hydrolysis is occurring. The decrease cannot be ascribed to method or operator differences as the same operator tested both archive and retrieved samples using the same methodology.

FURTHER RESEARCH NEEDS AND OBSERVATIONS

As detailed in the overview, additional retrievals from the same sites are necessary to make the developed data completely useful. Polyester sites should be at least 25 years old and polyolefin sites preferably at least 30 years of age.

This program polymer index data raised questions as to the relevance of melt flow index and CEG testing of retrieved samples as the retrieved samples yielded index properties that appear to be counterintuitive when compared with archive index properties: specifically, the inferred increase of molecular weight for polyolefin as indicated by consistent decreases in the melt flow index and consistent decreases of CEG in concert with decreases of viscosity, which are counter to classical polymer concepts. Therefore, further investigation of the early stages of degradation are necessary to further explain these apparent anomalies.

Future studies of resistance to oxidative or hydrolytic degradation for geosynthetics used in transportation applications would be more accurately and efficiently conducted if the specifications for the geosynthetic product used would require the manufacturer to certify as to the following polymer index properties for the production lots delivered to the site.

- Viscosity and CEG for PET products.
- Melt flow index and OIT (either standard or high pressure) for PP and HDPE products.
- WW strength.

This requirement is consistent with the model specifications for geosynthetic products used for reinforcement contained in FHWA-SA-96-071 *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes; Design and Construction Guidelines*.

Based on very limited data, there is some indication that installation damage may cause hydrolysis and antioxidant consumption rates to increase somewhat. Additional study on this issue may be warranted.

CHAPTER 5

DURABILITY RESEARCH PROGRAM SUMMARY

The broad objectives for research program DTFH61-91-C-00054 were set forth in 1991 as a program "to develop procedures that can be used to predict long-term strength losses of geosynthetics used in highway applications." This information was essential to designers in developing allowable tensile capacity for geosynthetics used primarily for soil reinforcement applications as in MSE retaining walls, reinforced soil slopes, and foundation stabilization.

It was postulated that such a broad and far-reaching program would have to be implemented in stages, each stage building on the knowledge previously gained.

The program was specifically focused on developing testing and interpretation protocols necessary to quantify strength reduction due to aging or stress (stress cracking only) mechanisms for polymeric reinforcement materials (geosynthetics). A secondary, more limited, objective was to develop testing protocols for confined stress-strain testing, which held promise to more accurately characterize key engineering properties including the creep rupture strength of geosynthetics.

A follow-up program, not funded under this contract, would consider all possible synergy between "aging" and stress. This final objective would be initiated substantially at the conclusion of this pooled fund study.

The results and engineering implications of the major experimental tasks under this contract are reported in a number of FHWA RD reports, which are summarized as follows:

DEVELOPMENT OF TESTING PROTOCOLS FOR OXIDATION AND HYDROLYSIS OF GEOSYNTHETICS. FHWA-RD-97-144

Overview

The focus was to develop laboratory testing and interpretation protocols to assess strength losses of geosynthetics due to "aging" phenomena. Consideration and quantification of these losses is required by the AASHTO specifications in order to determine the allowable tension load resistance of geosynthetic materials over their design life.

The existing polymer literature identified oxidation as the primary aging degradation mechanism for polyoleofin thermoplastics (PP and HDPE) and hydrolysis for polyester (PET) geosynthetics.

The literature further indicated that antioxidants are added as stabilizers to polyoleofin thermoplastics to protect them during high temperature processing and long-term exposure to degradation mechanisms such as exposure to UV radiation and/or other oxygen-rich regimes (as in-ground).

Existing literature indicated that polyester geosynthetics degrade in any aqueous environment, the rate of degradation being more rapid for low molecular weight (M_n) products in highly acidic or highly alkaline in-situ regimes.

The research was conducted in phases, where the first phase provided baseline chemical and physical characteristics for the commercial geosynthetics used in the program as well as defined the scope of the long-term experimental degradation program carried out under phase 2. It further defined and characterized typical in-use environments.

Phase 2 focused on the modification of existing procedures, protocols, and techniques for determining thermo-oxidation (for PP and HDPE) and hydrolytic degradation (for PET) of commercial geosynthetics and the performance of limited preliminary experiments using the developed and/or modified techniques to assess potential degradation rates and required testing periods.

Phase 3 consisted of the implementation of a long-term systematic experimental program with sufficient exposure variables to permit the calculation of degradation rates over usage time in conditions consistent with end-use environments.

Major Conclusions, Phase 1 and 2

The major aspects of phase 1 and 2 dealt with determining the applicability of available chemical and physical characterization methods and the development and/or modification of long-term testing protocols to determine strength losses attributable to oxidation and hydrolysis as a function of time. The following major conclusions were reached.

With respect to polymer characterization of geosynthetics:

- OIT measurements were found to be reasonably effective as a measure of oxidative stability, but did not provide a quantitative estimate of the concentration of multi-component antioxidant additives. Comparative OIT measurements between geosynthetics are of no value in assessing oxidative degradation resistance.

- Standard OIT measurements should be conducted at 175°C for PP products and 200°C for HDPE, and in accordance with a recommended revision to the ASTM standard provided in the research report (Method B).

- Hindered amines (HALS) type antioxidants cannot be monitored by standard OIT methods. The newer high pressure OIT should be further investigated in this regard.

- HPLC was found to be an ineffective method for routine monitoring of antioxidant content.

- Measurement of molecular weight M_n (or intrinsic viscosity) and CEG number are the key polymer tracking methods in degradation studies for PET geosynthetics.

- SEM is effective in visually examining surface morphology for evidence of oxidation, typically circumferential cracking, or hydrolysis, which is evidenced by fiber surface erosion.

With respect to laboratory incubation time/temperature and methods:

- Incubations at multiple temperatures (three minimum) are necessary for determining degradation rates.

- Incubation temperatures for PP and PET geosynthetics should be generally less than 80°C. Unfortunately up to 3 years of incubation time may be necessary to produce significant and measurable degradation at the lower required temperatures.

- It was determined that incubation temperatures of less than 70°C are required for HDPE geosynthetics, resulting in an even longer incubation time.

- Oxidative incubations should be conducted in circulating air ovens, which provide a more uniform regime.

- Hydrolysis incubations should be conducted in aqueous media in heated reactors in which the solution is constantly stirred. Again, incubation in excess of 3 years is necessary to produce significant degradation at the lower required temperatures.

Major Conclusions Phase 3

- For PP and HDPE, the long-term incubation studies validated that the oxidative degradation process can be divided in two main phases as predicted by the basic auto-oxidation scheme (BAS). During phase 1, the induction period, antioxidants are consumed with no appreciable tensile strength loss. In phase 2, after the substantial consumption of the antioxidants, the oxidative degradation process progressively reduces the tensile strength.

- The length of the induction period, which is dependent on antioxidant levels and type, controls the useful life of the geosynthetic. The depletion of antioxidants can be monitored by OIT measurements.

- Unstabilized polyoleofin products have relatively short useful lives.

- Modified Arrhenius techniques have been developed to analyze laboratory oxidative incubation data and predict tensile strength degradation rates.

- Antioxidant depletion is also a function of the burial regime, specifically the oxygen concentration and the level of transition metal present.

- Products such as most slit-film PP geosynthetics develop initial cracks during the manufacturing process. Oxidation studies for such materials cannot be conducted at elevated temperatures.

- Given the required duration of incubation to obtain meaningful results, accelerated degradation testing methods using pressure and a full oxygen atmosphere to reduce incubation time, should be further developed. The research program demonstrated the viability of such an approach.

- For PET, the long-term incubation studies validated that conventional Arrhenius modeling techniques can be used to analyze hydrolysis data and predict tensile strength degradation rates.

- Tensile strength degradation rates for PET are accelerated in pH environments greater than 9 and in acidic environments of less than 3.

- PET commercial geosynthetics produced with low molecular weight (low intrinsic viscosity) and or high CEG will degrade at a faster rate. Typically these are nonwoven products.

- Hydrolytic degradation for PET can be tracked by viscosity measurements.

LONG-TERM DURABILITY OF GEOSYNTHETICS BASED ON EXHUMED SAMPLES FROM CONSTRUCTION PROJECTS

Overview

This study, details of which are reported in chapters 1 through 3 of this research report, was initiated to develop a databank detailing the oxidative and/or hydrolytic performance based on retrieved geosynthetic materials from constructed works. The databank includes both mechanical and polymer characteristics to potentially serve both as a performance benchmark for the laboratory-based predictions previously developed, and for future retrieval programs.

The major conclusions and further research needs are outlined in chapter 4 of this research report.

DEVELOPMENT OF STRESS-CRACKING POTENTIAL AND TESTING PROTOCOLS. FHWA-RD-97-142

Overview

This study was initiated to allay concerns that stress-cracking potential was not being considered in developing the allowable tension load capacity for design when using HDPE geogrids.

Stress cracking is a potential mode of failure for thermoplastic materials that are under a sustained stress significantly lower than the material's room temperature yield strength, resulting in quasi-brittle fracture of the material. This is also known as slow crack growth and environmental stress cracking (ESC) when in contact with certain aqueous solutions.

This extensive laboratory study developed testing and interpretation protocols to measure the potential for stress cracking for intact and damaged HDPE geogrids.

Major Conclusions

The detailed laboratory results and analyses reported concluded and/or demonstrated for the presently available commercial (one) HDPE geogrid, the following:

- It demonstrated that stress cracking is a potential failure mode for HDPE uniaxially drawn geogrids at their nodes only, which are not highly drawn. Rib areas, which are highly drawn, are not prone to stress - cracking.

- It demonstrated that stress cracking is a less stringent or equal consideration than creep rupture in developing allowable tensile capacity for intact geogrids.

- It proposed a testing protocol for damaged geogrids using a notched constant testing load (NCTL) procedure, as the stress crack derived allowable tensile capacity may be lower than projected simply by applying a construction damage reduction factor.

- It recommended that damage to geogrid can be significantly limited by using a backfill with a maximum size on the order of 20 mm to limit damage to levels that are not likely to significantly initiate stress cracking failures at lower levels than those indicated by creep testing.

DEVELOPMENT OF CONFINED EXTENSION/CREEP TESTING PROTOCOL. FHWA-RD-97-143

Overview

The research was initiated to develop a testing protocol to characterize the confined stress-strain response of geosynthetic materials used as tension carrying reinforcement for in-ground applications.

Current testing methods for stress-strain properties are conducted in an unconfined mode, which does not represent the actual field conditions and is believed to be for some materials overly conservative. The benefits of using confined stress-strain testing to improve characterization of design properties may result in considerable material savings for tensile load applications.

Major Conclusions

The detailed laboratory testing results, equipment selection studies, review of current research based testing methods, and analyses of results concluded:

- Soil confinement creates beneficial effects to the stress-strain response of geosynthetic materials, particularly for nonwoven geotextiles.

- For nonwoven geotextiles, stiffness and, therefore, modulus, is significantly enhanced as a result of confinement. Therefore the use of unconfined stress-strain properties in design with nonwoven geotextiles appears to be overly conservative. Increase of 50 to 400 percent for modulus has been measured.

- The effect of confined stiffness on woven geotextiles and geogrids is considerably smaller but not necessarily insignificant. Increases of 5 to 30 percent have been measured.

- Confined extension testing should be performed to determine the modulus and peak strength of nonwoven geotextiles and could be used to more accurately determine the properties of all geosynthetic reinforcement materials. Unconfined stress-strain testing should be relegated to a QA/QC function.

- Confined creep-rupture testing should be performed to determine the long-term strength of nonwoven geotextiles.

- Confined extension and/or confined creep rupture testing *must* be conducted for calibrating instrumentation to be used in field monitoring and for assessing input parameters for numerical analyses. The use of this testing technique is essential in calibrating in situ stress conditions from field instrumentation.

RECOMMENDED FURTHER RESEARCH OR ACTION

Recommended further research items were included at the end of each FHWA RD report summarized above. The key recommendations have been reviewed, assembled, and repeated for convenience in this section.

- The developed protocols for oxidative and hydrolytic testing should be submitted to ASTM or AASHTO for tentative adoption as standards.

- The polymer characterization methods, OIT, melt flow index, CEG, and viscosity require standardization or minor/major revision where ASTM methods are available. Industry should be advised/encouraged by specifying Agencies to publish these polymer index properties as part of their Technical Information Sheets.

- Additional retrieval programs should be initiated within the next few years focused on the four or six sites sampled under this program where multiple previous retrievals were made.

- The NCLT testing procedure for stress cracking should be submitted to an appropriate ASTM committee for potential adoption as a standard method. A similar testing method for geomembranes is being considered.

- The confined extension/creep testing protocol should be submitted to the appropriate ASTM or AASHTO committee for consideration and/tentative adoption.

- Research is needed to define the quality of coatings used in PET geogrids. PET geogrids presently use PVC, acrylic latex, etc., to provide protection to the underlying load carrying fibers during construction. Criteria to define and judge the quality, nature, thickness, durability, are presently lacking.

- A comprehensive program should be developed to study synergy between stress and oxidation and/or hydrolysis. This program may be implemented in phases beginning with a literature survey, progressing to a demonstration of equipment and testing methods, and then finally to a systematic experimental program.

ADDITIONAL COMPLEMENTARY STUDIES PRESENTLY UNDER WAY/COMPLETED

Based on "Further Research Needs" summarized in FHWA-RD-97-144, additional studies in several areas of significance to the research implementation process were identified. A number of additional studies have been undertaken, and one has been essentially completed. The additional study areas are summarized as follows:

- *Initiate investigation to define in-ground oxygen content in MSE/RSS fills.*
  Research reported in FHWA-RD-97-144 demonstrated that partial oxygen pressure (oxygen content) is an important variable in determining the useful life and oxidation rate of polyoleofin geosynthetics. Certain technical literature has suggested that the oxygen content in fills may be significantly lower than atmospheric.

To resolve this issue the Geosynthetic Research Institute (GRI) was funded to implement a program to measure in-ground oxygen content in commercial/public reinforced MSE fills. This 2-year program is nearly complete after having monitored the in-ground oxygen content of three MSE recently constructed fills. The program will conclude that, for the granular fills normally used for MSE construction, atmospheric oxygen content (21%) should be anticipated. Therefore, laboratory oxidation incubation studies should be conducted in conventional forced air ovens.

- *Investigate and define further the effect of a common transition metal found in many fills (iron) on the oxidation rate of polyoleofin geosynthetics.*
  Research under FHWA-RD-97-144 demonstrated that high levels of transition metals potentially accelerate oxidative degradation. A GRI study is currently in progress to more completely define required levels of contamination to significantly accelerate oxidation.

  The preliminary results confirm the trends previously established and will provide more detailed recommendations for implementation to design practice.

- *Demonstrate that laboratory oxidative degradation can be accelerated in high-pressure chambers with either air or oxygen at room temperature.*
  The viability of this approach was demonstrated under FHWA-RD-97-144. It suggested that incubation times could be accelerated at room temperature by a factor as great as 200. A GRI study is currently in progress, partially funded by the National Science Foundation, to fully develop a testing and interpretation protocol using this methodology initially demonstrated under the durability research program. It has the promise of becoming an industry standard and reducing testing costs by one order of magnitude.

  In addition to strength, the viability of OIT and melt flow index to track mechanical and polymer changes will be further refined.

Table A-1. Additional identified retrieval sites.

No.	Owner	Site Identification	Geosynthetic Type	Remarks
13A 13B	Exxon (Reemay)	Reemay Texas A and Texas B, Harris Co. Tx	Typar 3401	Site previously excavated and reported by GeoSyntec Cons. in 1987. Baseline data published in STP-18.
14	Reemay (Du Pont test) site	Smyrna Delaware Stabilization Test Section	Typar SE Reemay Woven PP	Some archive data available from DuPont. Site accessible.
14A 14B	Georgia DOT	1. Torres Causeway Brunswick 2. Dike Area 14B Savannah		Archive data available from DOT files.
15	Kansas DOT	I-35 & U.S. 119 Slope repair project	PP Geogrid	
16A 16B	Montana DOT	1. Swan Lake 2. Helmville	Geotextiles	
17	Corps of Engineers Norfolk District	Craney Island Disposal Site	PET PP	
18	S. Carolina DOT	Greenpond Rd. Watersboro SC	PP Supac 5N	Installed in 1978.
19	Oregon DOT	Retaining wall at abandoned detour road	Fibretex	Installed in 1983. U.S. 26 at Elderberry Inn.
20	Maryland DOT	Rt 50 – Cape St. Clair Interchange A		
21	Louisiana DOT	Test embankments stabilization fabrics		
22	North Carolina DOT	Friar Swamp embankment	Geolon 1500	Constructed 1987 as stabilization fabric.
23	Mississippi DOT	U.S. 49 Sunflower Co.		Stabilization fabric
24	California DOT	Dumbarton Bridge Approach Fill		
25	New Mexico DOT	1. Tierra Amadella Slide 2. Raton I-25 Slide	Geogrid/Fabric	

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