USE OF GEOTEXTILES TO BRIDGE THERMOKARSTS

THEORETICAL ANALYSIS AND REPORT

by

Dr. Thomas C. Kinney, P.E.
Shannon & Wilson, Inc.
Geotechnical Consultants
Fairbanks, Alaska

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STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DIVISION OF PLANNING AND PROGRAMMING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701

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Abstract

This report summarizes the results of a search of available literature and examination of various theoretical methods of analysis to develop a design scheme for using geotextiles as a reinforcement for roadway embankments. The purpose of this reinforcement is to create an embankment able to bridge voids or depressions in the foundation soils caused by melting permafrost. It was concluded that very stiff geotextile fabrics of high tensile strength must be used. The fabric should be placed as close to the bottom of the embankment as possible, and must be strong enough not to rupture under the imposed loadings. The design method proposed includes graphical solutions for the equations developed, and examples of their use.

Design Methodology

There are several ways to evaluate the beneficial effects that a tensile reinforcement member can have in an overlay section subject to severe settlement. In general, the geotextile will provide the most benefit in systems where the settlement is abrupt and deep, but limited in width. For that reason, the discussions contained herein center around problems such as melting ice wedges as shown on Figure 1.

A cross-section through a typical depression caused by melting of an ice wedge is shown in Figure 2. Note that the ice melts, allowing the material over it to fall into the hole causing a deep depression of limited extent. The severity of the depression becomes less as the distance above the melted ice increases. It will always be most beneficial from a reinforcing standpoint to place any tensile reinforcing member as low as practical in the profile where the movements are the most abrupt.

A cross section through the same profile with a geotextile included is shown on Figure 3. Note that the geotextile or other tensile reinforcing member will, if properly designed and installed, span the void caused by the melting ice thereby reducing the distress at the surface.

The geotextile or other tensile reinforcing member must be stiff and strong in order to provide the best results. In addition, it must not creep with time which would reduce the tension.

In our opinion, the most realistic of the several possible design procedures is to consider the tensile member to act like a drum holding up the soil above it. For simplicity the melted ice wedge depression is considered to be a long narrow ditch with vertical sides and the geotextile is considered to form a segment of a circular cylinder as shown on Figure 4. Six constitutive equations for the six unknowns involved in determining the design parameters are also shown on Figure 4. An iterative solution is necessary because the angle θ shows up in the equation in two different forms. One equation that could be used to solve for θ is shown on Figure 5. The derivation for this equation is shown in Figure 5. The remainder of the equations can be conveniently rewritten in terms of θ as shown on Figure 5 for easier use in calculating the required design parameters. Graphical solutions to the equations are presented on Figure 6. The graphical solutions not only provide a more rapid method of determining the parameters but they also provide a clearer evaluation of the sensitivity of changes in the various input parameters on the design parameters. The circular cylinder assumption for the shape of the tensile member necessitates the assumption that the pressure on the tensile member is equal at all points and is perpendicular to the tensile member. The pressure is not uniform nor is it perpendicular to the tensile member. However, in our opinion, the assumptions for both the pressure distribution and the deformed shape of the tensile member will provide reasonable design values. The pressure is a combination of the embankment weight and surface wheel loading. One method of estimating the average effective pressure on the geotextile is shown on Figure 7. These relationships are based on the following assumptions:

1. Unit weight of soil in overlay is pcf;
2. Vertical shear in overlay section is negligible;
3. 9000 lb. wheel load;
4. 1 ft. diameter contact area;
5. Elastic stress distribution;
6. Stress distribution is averaged over the width.

Two examples of use of the design methodology are presented below. Both consider a 4-foot wide thawing ice wedge under a 3-foot thick overlay section. In the first example a stiff geotextile is used and in the second a wire mesh is used.

Example 1

Step 1 -- Define Problem

$$\left.\begin{array}{l} W = 4 \text{ ft.} \\ H = 3 \text{ ft.} \end{array}\right\} \quad p = 720 \text{ psf (Fig. 5)}$$

Assume Pro Pex II:

$$\left.\begin{array}{l} T\ max = 3600\ lbs/ft. \\ \varepsilon\ max = 0.30 \\ E = 12{,}000\ lbs/ft. \end{array}\right\}\ \text{Literature}$$

Step 2 -- Solve Equation

θ = 53° (Eq. 10 or Fig. 6)
δ = 1.0 ft. = 12.0 in. (Eq. 12 or Fig. 6)
ε = 0.16 in/in (Eq. 14 or Fig. 6)
T = 1900 lbs. (Eq. 15 or Fig. 6)

Step 3 -- Analysis

1) Tension and strain are well within limits of geotextile.

2) The calculated displacement at the geotextile is 12 inches over the 4-foot span. The actual span will probably widen causing more displacement as the sides of the void crush. Assume: W = 6 ft. and = 16 in.

3) The displacement at the road surface should be wider and not as deep, but the volume should be the same. Assume depression spreads out @ 30° from the vertical: W = 9.5 ft. and = 10 in.

4) Constant maintenance will be required until the 10 inches of displacement has occurred. After that time minimal additional settlement should occur. Elastic displacement on the order of 1 to 2 inches should be expected as heavy trucks cross the area, resulting in pavement working and fatigue.

Example 2

Step 1 -- Define Problem

$$\left.\begin{array}{l} W = 4\ ft. \\ H = 3\ ft. \end{array}\right\}\ p = 720\ psf\ (Fig.\ 5)$$

Assume 4 in. x 4 in. x 3/16 in. wire mesh covered with thin non-woven fabric on each side:

$$\left.\begin{array}{l} T\ max = 2981\ lbs/ft. \\ \varepsilon\ max = .0012 \\ E = 2{,}400{,}000\ lbs/ft. \end{array}\right\}\ \begin{array}{l} \sigma\ max = 36{,}000\ psi \\ E = 29 \times 10^6\ psi \end{array}$$

Step 2 -- Solve Equations

θ = 8.8° (Eq. 10 or Fig. 6)
δ = 0.154 ft. = 1.86 in. (Eq. 12 or Fig. 6)
ε = .0039 in/in (Eq. 14 or Fig. 6)
T = 9360 lbs/ft. (Eq. 15 or Fig. 6)

Step 3 -- Analysis

1) Tension in the wire mesh is above yield. This in effect reduces E until equilibrium is achieved.

   E = 70,000 lbs/ft.
   θ = 28.5
   δ = 6.09 in.
   ε = 0.0424
   T = 2972 lbs/ft.

   Since 4.2% strain is within the plastic zone for steel, this condition represents equilibrium.

2) The calculated displacement at the fabric interface is 6.09 inches over a 4 ft. span. The actual span will probably widen causing more displacement as the sides of the void crush. Assume: W = 6 ft. and   = 8 in.

3) The displacement at the road surface should be wider and not as deep, but the volume should be the same. Assume depression spreads out at 30° from the vertical:
   W = 9.5 ft. and   = 5 in.

4) Constant maintenance will be required until 5 inches of displacement has occurred. After that time minimal additional settlement should occur.

Design and Construction Considerations

As can be seen in the design method outlined above, the tensile reinforcement member will do the most good if it is as low as possible in the profile. It should cross the plane of most abrupt movement.

To be of most benefit, the tensile member should be as stiff as possible. Stiff in this context means low elongation for unit tension. Stiff tensile members will develop high tensions by virtue of their stiffness, hence it is necessary to check to see that the tensile member is not overstressed to the point where it may fail or creep. Several layers of reinforcement may be used to increase strength and stiffness.

For instance, materials such as wire mesh may be used in conjunction with the geotextile. If a wire mesh is used, a geotextile should be placed on the concave side of the curvature to prevent the wire mesh from digging into the soil. It will probably be most prudent to place a geotextile on both sides.

The tensile reinforcement only works in this application when it is in tension and on a depressed (curved) surface. Therefore, it must be laid smooth and stretched tight during installation. In addition, it must be placed with enough lateral extent from the area of subsidence to keep it from pulling out. In general the height of overlying fill in feet times the extent from the edge of the subsidence in feet should be at least 0.02 times the tensile member strength in pounds per foot.

Joints in the tensile member should be overlapped sufficiently to prevent slipping or should be mechanically fastened. The overlap should be at least as much as suggested above for the lateral extent from the area of subsidence. An overlap joint extending parallel to and over a void will render the tensile member useless.

Since frozen ground features are not always uniform and easy to locate precisely, we suggest that strong consideration be given to multilayers of tensile member reinforcement, to be placed immediately on top of each other. They could be placed at right angles to each other or in some other orientation to avoid weakness at overlapping joints. Care should be maintained to keep the joints separated and in different directions if possible.

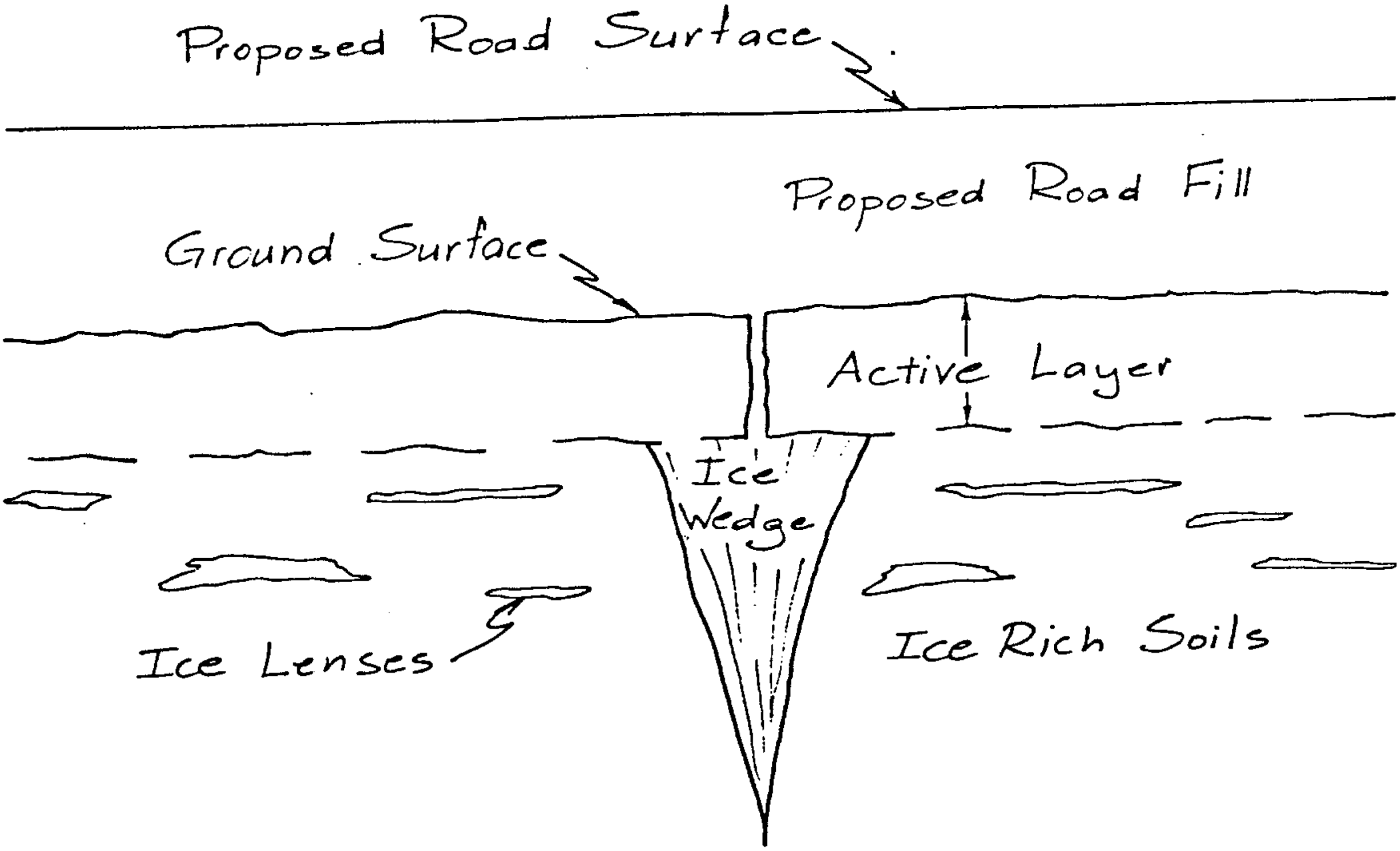
Conclusions

In our opinion, geotextiles or other tensile reinforcement members such as wire meshes can be used as reinforcement in road overlay sections to bridge small areas of severe settlement. The tensile member should be as stiff as practical and be placed as low as possible in the profile. In addition, it must be strong enough not to rupture.

Acknowledgements

We trust that the information presented herein by Shannon & Wilson, Inc. is sufficient for use in developing design criteria for fabric reinforced embankments. It should be pointed out that to our knowledge this use has not been tested. In our opinion, the design techniques and guidelines presented herein are reasonable, however, field testing is necessary to prove the concepts.

The original impetus for this analysis was to provide a design analysis for a section of the Richardson Highway near Shaw Creek which was being reconstructed. Funding for this work was provided under the "New Products Testing" program of the Research Section, Alaska Department of Transportation and Public Facilities.



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INITIAL CONDITIONS

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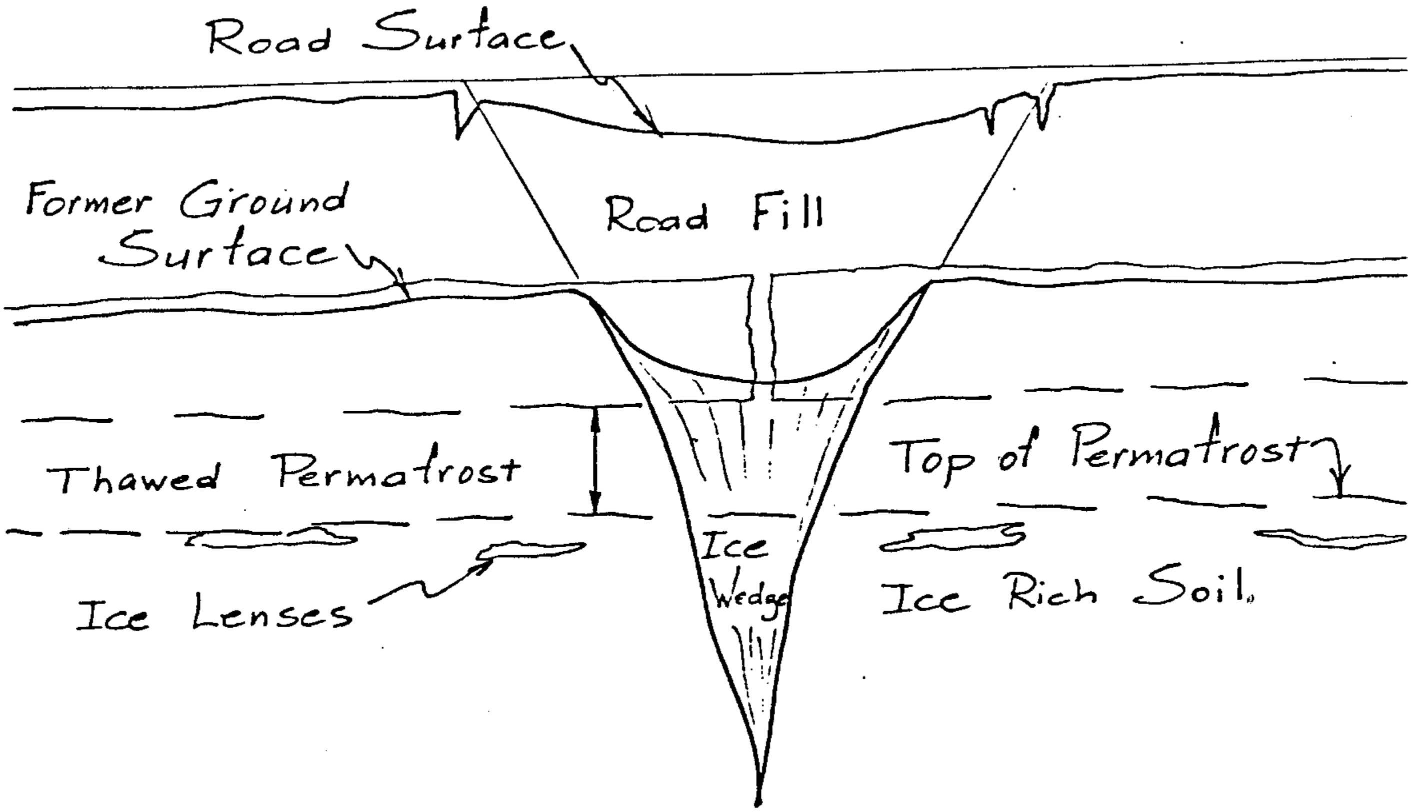
FIG. 1



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Geotextile Design Study
CONDITIONS AFTER THAWING
WITHOUT A GEOTEXTILE

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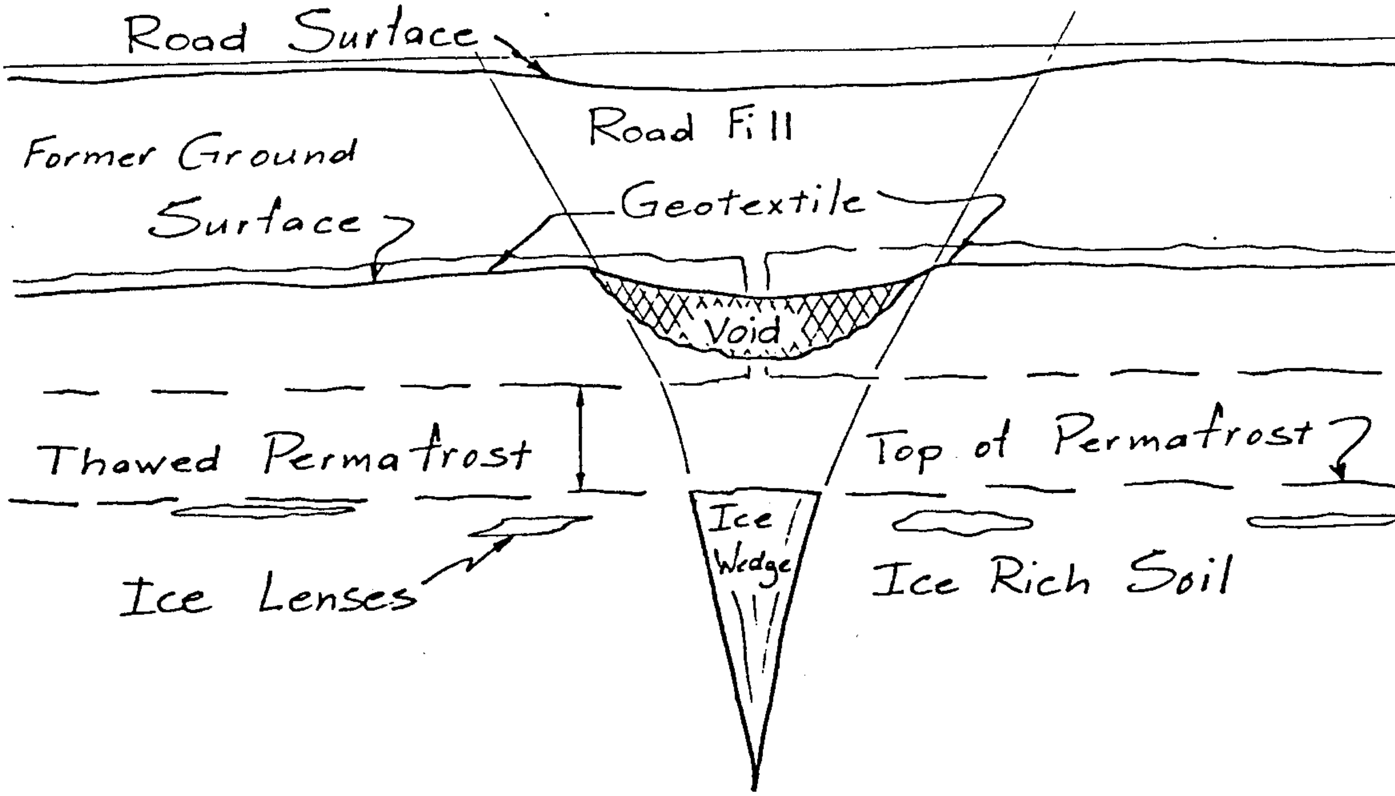
FIG. 2



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CONDITIONS AFTER THAWING
WITH A GEOTEXTILE

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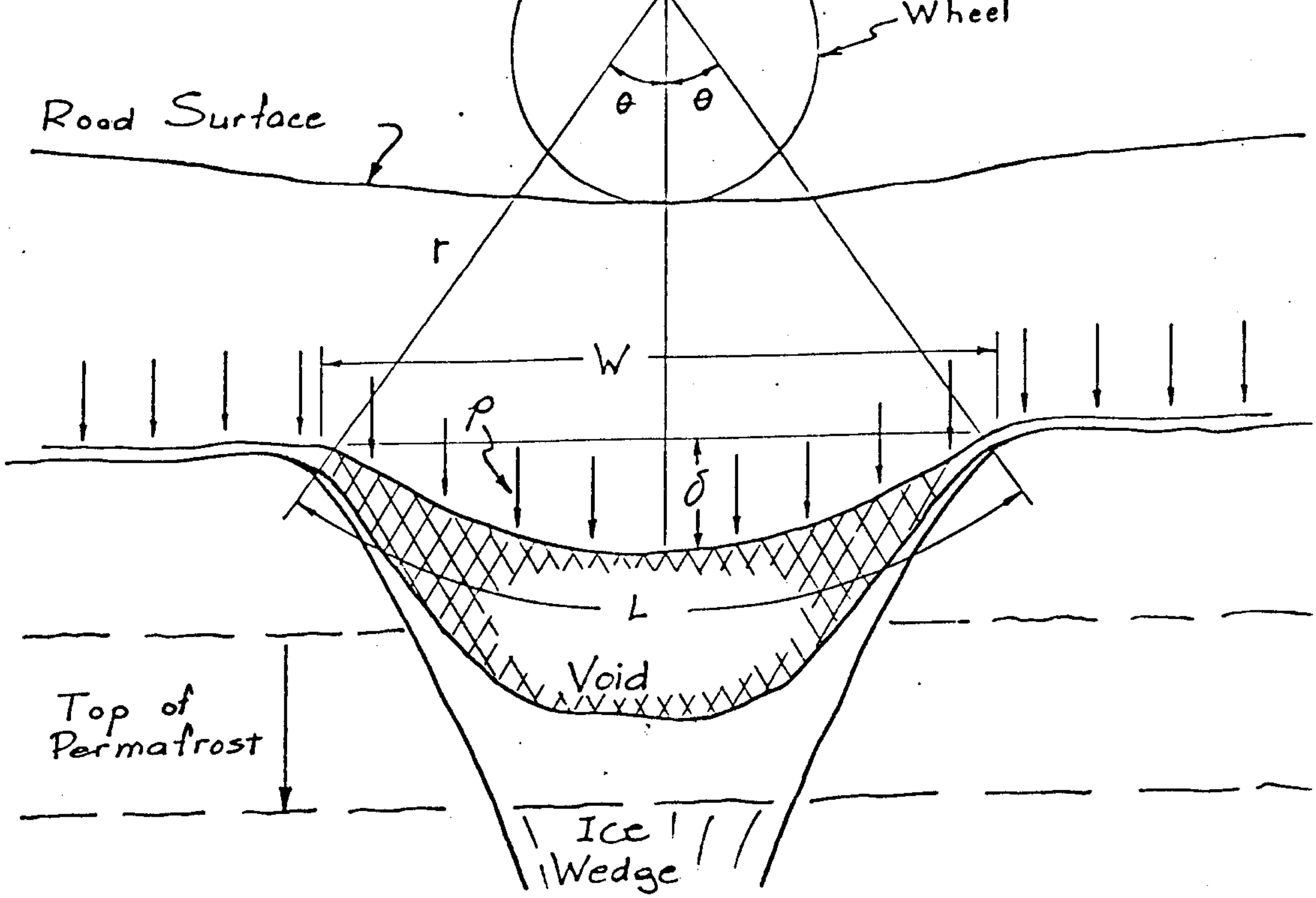
FIG. 3



Basic Equations:

Eq 1 $W = 2r \sin\theta$ (Geometry)

Eq 2 $L = 2\pi r \frac{2\theta}{360}$ (Geometry)

Eq 3 $\delta = r - r\cos\theta$ (Geometry)

Eq 4 $\epsilon^{*} = \frac{L-W}{W}$ (Definition of Strain)

Eq 5 $T = E^{\dagger}\epsilon$ (Stress Strain Relationship)

Eq 6 $T = \rho r$ (Hoop Stress)

$*\ \epsilon$ = strain in geotextile

$\dagger\ E$ = modulus of geotextile lbs/ft

Variables:

$r, \theta, L, \delta, \epsilon, T$

Knowns:

W, ρ, E

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EXAMPLE OF
DRUM EFFECT

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FIG. 4

SIMPLIFYING EQUATIONS TO SOLVE
THE BASIC GEOTEXTILE DESIGN EQUATIONS

SOLVE FOR θ

Step 1
Combine Eq. 5 & Eq. 6
Eq. 7 $\epsilon = \frac{\rho r}{E}$

Step 2
Combine Eq. 7 & Eq. 4
Eq. 8 $L = \frac{\rho r W}{E} + W$

Step 3
Combine Eq. 8 & Eq. 2
Eq. 9 $r = \frac{W}{\frac{\pi \theta}{90^\circ} - \frac{\rho W}{E}}$

Step 4
Combine Eq. 9 & Eq. 1
Eq. 10 $\boxed{0 = \sin \theta - \frac{\pi \theta}{180^\circ} + \frac{\rho W}{2E}}$ Fig. 6

SOLVE FOR δ

Step 1
From Eq. 1
Eq. 11 $r = \frac{W}{2 \sin \theta}$

Step 2
Combine Eq. 11 & Eq. 3
Eq. 12 $\boxed{\delta = W \frac{(1 - \cos \theta)}{2 \sin \theta}}$ Fig. 6

SOLVE FOR ϵ

Step 1
Substitute Eq. 2 into Eq. 4
Eq. 13 $\epsilon = \frac{\frac{\pi r \theta}{360} - W}{W}$

Step 2
Substitute Eq. 11 into Eq. 13
Eq. 14 $\boxed{\epsilon = \frac{\pi \theta}{180 \sin \theta} - 1}$ Fig. 6

SOLVE FOR T
Eq. 15 $\boxed{T = E\epsilon}$ Fig. 6

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DERIVATIONS FOR
BASIC EQUATIONS
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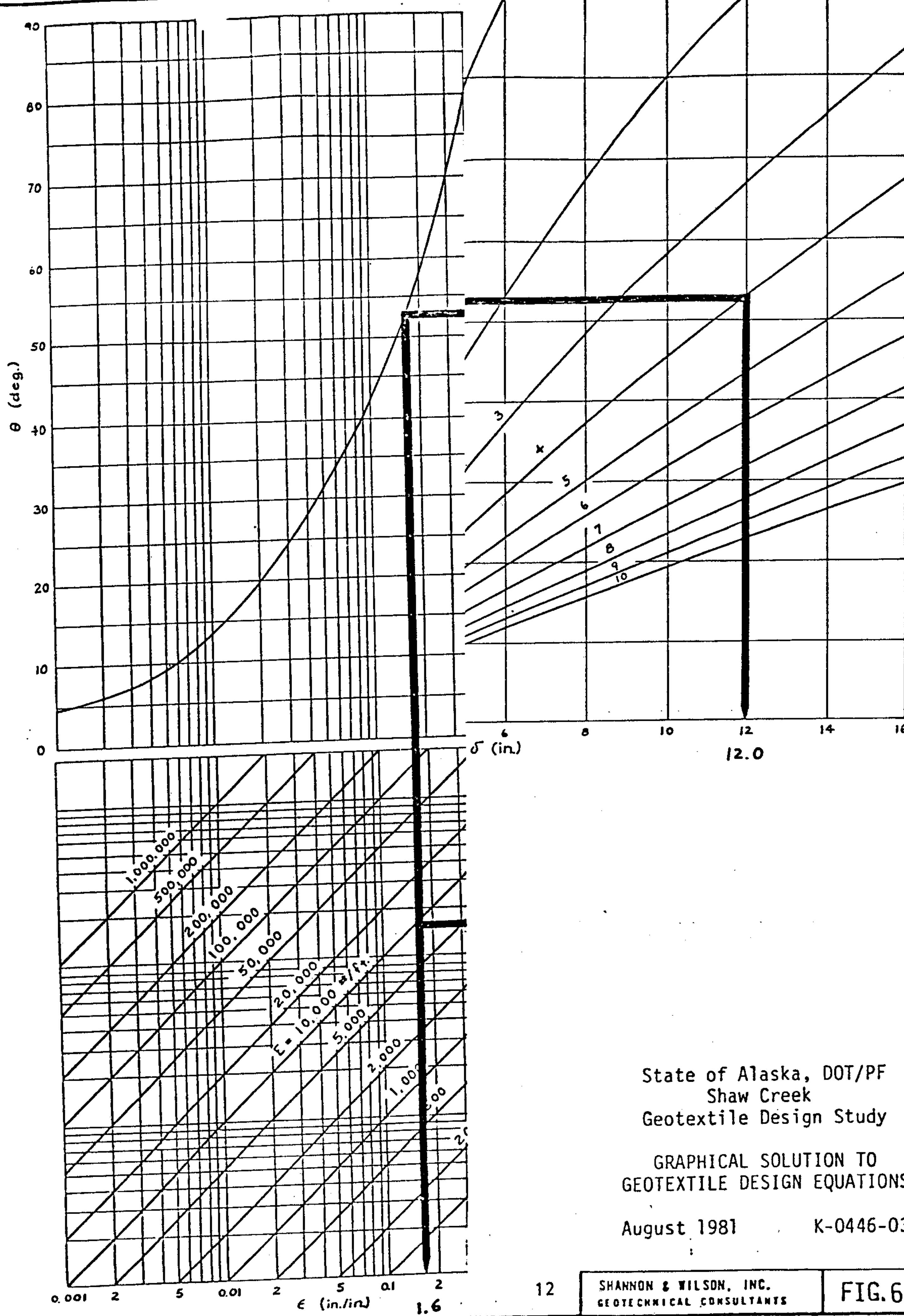
FIG. 5



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GRAPHICAL SOLUTION TO
GEOTEXTILE DESIGN EQUATIONS

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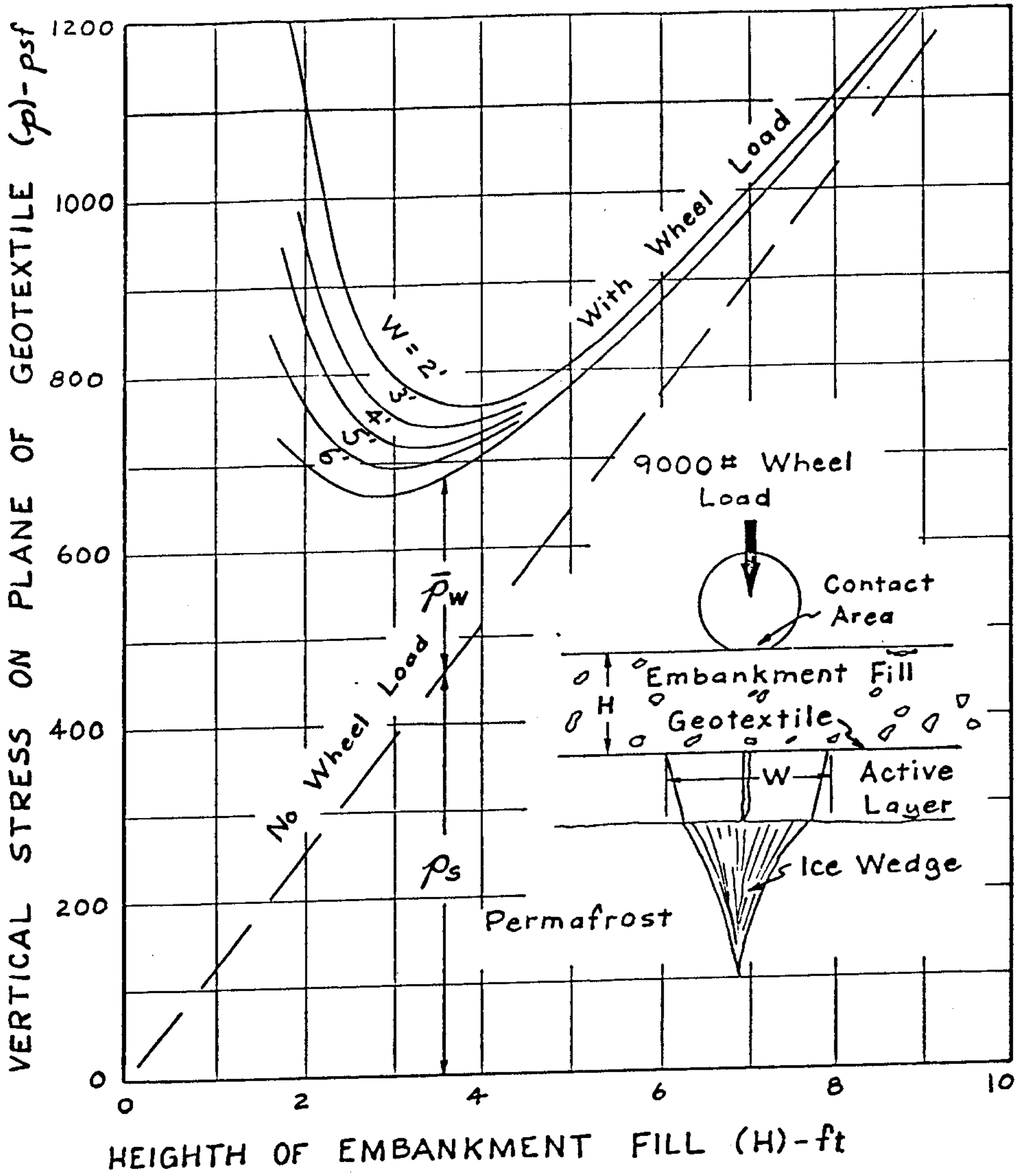
FIG. 6



$p = p_s + \bar{p}_w$

$\bar{p}_w$ = Average wheel pressure over width W using elasticity

p_s = Density of soil x H

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VERTICAL PRESSURE ON GEOTEXTILE

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FIG. 7

APPENDIX A

Fabric Property Data From

CONSTRUCTION AND GEOTECHNICAL ENGINEERING USING SYNTHETIC FABRICS

Robert M. Koerner, Ph.D., P.E.

Professor of Civil Engineering
Drexel University
Philadelphia, PA

Joseph P. Welsh, P.E.

Vice President
Hayward Baker Company
Odenton, MD

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that soil is very variable material. It ranges from ≈99 percent organic to 100 percent inorganic, has a wide range of pH values, and varies greatly in elemental compositions and microorganism contents. The test involves 12 by 12 centimeter fabric samples of polyethylene terephthalate, polypropylene, and nylon-polypropylene bicomponent fabrics. This test method is designated CGSB 4-GP-2 method 28.3 and is similar to AATCC test method 30-1974 and Federal Standard No. 191, method 5762.

Samples are removed at three-month intervals and are tested according to the diaphragm pressure (Mullen burst) test found in ASTM method D 774. Future testing will involve other fabrics and a wide range of soil conditions.

2.4 *Overview of Construction Fabrics*

Of paramount interest for the purposes of this book are the trademarks of various formed fibers. See Appendix 2 for other trademarks and note that this is by no means a complete listing. Table 2.4 lists the materials that comprise the majority of fabrics used in geotechnical construction. They are individually described in detail in Section 2.5.

2.5 *Details of Construction Fabrics*

In this section details of commonly used fabrics in geotechnical construction are presented. All properties presented (physical, mechanical, hydraulic, and environmental) are taken directly from manufacturers' literature. As such, great variations in tests, test procedures, and methods of reporting data will be noted. Most model numbers, styles, data, and so on reflect currently (1979) available information.

The products are not limited to only American or North American manufacturers; many overseas products are also listed. By no means is the listing complete since the field is in a rapid state of change with new firms entering (and some leaving) on a continuing basis. The section numbers are keyed to the numbered fabric trademarks presented in Table 2.4.

Note should also be made that manufacturers often change specifications of their fabrics while retaining the same style classifications. The

2.5.1	Adva-Felt	Polypropylene, nonwoven	Advance
2.5.2	Bay Mills	Glass, woven	Bay Mills Midland
2.5.3	Bidim	Polyester, spun bonded and needled	Monsanto
2.5.4	Cerex	Nylon, spun bonded	Monsanto
2.5.5	Cordura	Nylon, woven	duPont
2.5.6	Enkamat	Nylon, melt bonded	American Enka
2.5.7	Fibertex	Polypropylene, spun bonded and needled	Crown Zellerback
2.5.8	Filter-X	Polyvinylidene chloride, woven	Carthage Mills
2.5.9	Laurel Cloth	Polypropylene, woven	Laurel Plastics/Advance
2.5.10	Mirafi	Polypropylene and others, nonwoven and woven	Celanese
2.5.11	Monofelt	Polypropylene, nonwoven	Menardi Southern/J. P. Stevens Co.
2.5.12	Monofilter	Polypropylene, woven	Menardi Southern/J. P. Stevens Co.
2.5.13	Nicolon	Polyamide and others, woven and nonwoven	U. S. Textures Sales
2.5.14	Permealiner	Polypropylene, woven	Staff Industries
2.5.15	Petromat	Polypropylene, needle bonded	Phillips Fibers
2.5.16	Polyfelt	Polyester, needled	Advance
2.5.17	Poly-Filter	Polypropylene, woven	Carthage Mills
2.5.18	ProPex	Polypropylene, woven	Amoco Fabrics
2.5.19	Reemay	Polyester, spun bonded	duPont
2.5.20	Sontara	Polyester, spun laced	duPont
2.5.21	Stabilenka	Polyester	American Enka
2.5.22	Supac	Polypropylene, needlebonded	Phillips Fibers
2.5.23	Terrafix	Polyesters and others, nonwoven	Erosion Control
2.5.24	Terram	Polypropylene and polyethylene, thermally bonded	ICI Fibers
2.5.25	Typar	Polypropylene, spun bonded	duPont
2.5.26	Tyvek	Polyethylene, spun bonded	duPont

information can be verified by contacting the manufacturer directly. The addresses are provided in Appendix 4.2.

2.5.1 *Adva-Felt*

Adva-Felt is a nonwoven polypropylene fabric manufactured by the Docan process available through Advance Construction Specialties Co., Inc.[25] Its intended fields of application are as separation, reinforcement, drainage, and erosion control. As Table 2.5 indicates, the fabric is available in three styles.

TABLE 2.5. Properties of Adva-Felt

Property	Style Number: TS 200	TS 300	TS 400	Test Method
Weight (oz/yd²)	6	8	10.5	ASTM-D 461
Thickness (in.)	0.08	0.13	0.17	"
Tensile strength (lb)				
Dry	115	225	300	ASTM-D 1682-59T
Wet	160	270	420	"
-50°C wet	116	228	308	"
Elongations (%)				
Dry	89	101	110	"
Wet	Same	Same	Same	"
Frozen -50°C	48	51	59	"
Tear resistance, strip (lb/cm)	34	47	64	ASTM-D 2261-62
Biological or marine growth	None	None	None	C. of E.[a]
Permeability (cm/sec)	4×10^{-2}	5.7×10^{-2}	7.9×10^{-2}	C. of E.
Specific gravity	0.91	0.95	0.95	
Equivalent opening size	90	70	60	C. of E.

Source: Ref. 25.
[a] Corps of Engineers.

2.5.2 *Bay Mills*

Bay Mills[26] produces a line of fabrics woven of continuous filament glass yarns for the following general purposes:

- To reinforce gel coats.
- To give a smooth tailored appearance to the inside of parts such as boats.
- To cover wood in boats, furniture, and so on.
- As the main reinforcement in high strength laminates.
- To make molds and tooling in applications such as dies, gages, templates, workholders, drill shell, tooling masters, mockups, patterns, blue blocks, and drop hammer dies.

These fabrics have not seen wide use in civil engineering construction, although they have been considered, that is, laboratory tested, for a number of applications. The fabrics are available in four different styles, as Table 2.6 indicates.

TABLE 2.6. Properties of Bay Mills Fabrics[a]

Style Number	Thread Count (per inch): Warp	Fill	Average Tensile (lb/inch): Warp	Fill	Weight (oz/yd²)	Thickness (mils)	Weave	Approximate Yards per Roll
154	16	14	450	410	9.7	14	Plain	130
144	18	18	250	220	6.0	9	Plain	200
610	32	28	115	100	2.48	4	Plain	500
196	28	42	1200	700	32	45	Special	40

Source: Ref. 26.
[a] Note that woven fabrics consist of two perpendicular sets of interlacing fibers. The warp runs lengthwise and can be hundreds or thousands of yards long. The fill, or interlacing yarn, is made to the width of the fabric.

2.5.3 *Bidim*

Bidim® engineering fabrics are made by the Monsanto Company[10] from continuous filament polyester fibers that are spun and then mechanically entangled by needle punching. The fabrics are supplied in a choice of five different styles, depending on the type of end use, the soil condition, and the service demand on the fabric. These styles are designated C22, C28, C34, C38, and C42 in order of increasing thickness. Current uses are in separation, reinforcement, drainage, erosion control, and other construction applications. Table 2.7 shows typical values of the physical properties of the various styles.

TABLE 2.7. Bidim® Engineering Fabrics[a]

	Style Number				
Property[b]	C22	C28	C34	C38	C42
Weight/roll (lb)					
13 ft 10 in. wide	425	565	760	950	760
17 ft 5 in. wide	535	715	950	1200	950
Roll length, (ft)	984	984	984	984	492
Roll diameter (in.)	40	40	40	40	40
Thickness, ASTM D-1777 (mils)	60	75	90	110	190
Grab tensile strength (lb force)	115	160	255	300	610
Grab elongation (%)	85	80	75	65	60
Trapezoid tear strength (lb force)	62	93	125	170	250
Mullen burst strength (psi)	225	360	400	500	850
Restrained tensile test (lb force/in.)[c]	65	95	120	150	270
Elongation (%)	35	35	35	35	35
Normal permeability (10^{-3} m/sec)[c]	3	3	3	3	3
Planar permeability (10^{-3} m/sec)[c]	0.6	0.6	0.6	0.6	0.6
Equivalent opening size					
D_5	50	50	70	100	100
D_{50}	70	100	100	140	140
Abrasion resistance (grab strength) (lb)[d]	40	120	135	165	295
Heat resistance @ 50 psi loading (°F)[c]	480	480	480	480	480
pH resistance range (pH)	3 to 11				
Puncture strength ASTM D-751—modified (lb force)	55	95	125	145	255
Porosity (%)	93	92	91	91	91

Source: Ref. 10.

[a] Physical properties data represent typical values and should not be construed as absolute values or specifications.

[b] Test methods ASTM D-1117-69, D-1682, and D-2263.

[c] Monsanto test.

[d] Modified Corps of Engineers tests.

2.5.4 Cerex

Cerex® fabrics[10] are made from nylon 6.6 and are spun bonded and manufactured by the Monsanto Company. They are nonwoven fabrics made directly from the molten polymer as continuous filaments that are self-bonded at each crossover point by a proprietary process. The fabrics contain no adhesive or other additives. The main thrust of the fabric has not been the construction market, but it has been used in the drainage area in protection of porous pipe underdrains. The fabric is produced in 9 different weights from 0.3 to 2.0 ounces per square yard, as Table 2.8 indicates.

2.5.5 Cordura

Cordura® is duPont's registered trademark for its high-tenacity nylon fiber.[11] It is a producer-bulked industrial filament yarn in which the filaments have been disarranged, looped, and tangled within the yarn bundle. Being a filament nylon fiber with high bulk characteristics, it is used to make industrial broadwoven fabrics and webbings. It is used in the context of construction fabrics to make flexible fabric forms, as described in Chapter 7. Other construction uses described in this book could also make use of this material. Table 2.9 presents the properties of two types of woven fabrics made from Cordura fiber.

2.5.6 Enkamat

Enkamat® is a three-dimensional soil reinforcement matting of very open construction made from heavy nylon monofilaments bonded at their intersections. Patents are pending on this product of the American Enka Company, a part of Akzona Incorporated, Enka, North Carolina.[27] Applications include ditch lining, slope stabilization, and lakeshore and riverbank erosion situations. Table 2.10 gives the specifications of the two types of Enkamat Matting currently available.

An interesting combination of Enkamat and Stabilenka, both products of the American Enka Company, is Enkadrain. Enkadrain is a two-layer composite of the two different fabrics, where the Stabilenka is bonded to the thicker and more porous Enkamat. The combination prevents soil from entering the system and allows for extremely high in-plane flow. It is designed for relieving hydrostatic pressure adjacent to underground basement walls and retaining walls. Enkadrain is available in a 38.2-inch width plus a 3-inch filter fabric overlap, in a length of 30 meters per roll

TABLE 2.8. Physical Properties of Cerex® Fabrics[a]

Fabric Weight[b] (oz/yd^2)	Average Thickness[c] (mils)	Grab Strength[d] (lb) Machine Direction	Grab Strength[d] (lb) Transverse Direction	Tear Strength[e] (lb) Machine Direction	Tear Strength[e] (lb) Transverse Direction	Mullen Burst[f] (psi)	Air Permeability[g] [$(cm/ft)/ft^2$]
0.3	2.3	8	5	3.4	2.4	17	1300
0.4	2.5	12	7	4.3	3.0	20	1050
0.5	3.2	16	11	4.5	3.5	24	850
0.6	3.4	21	15	5.5	4.5	29	700
0.7	3.7	27	18	6.3	5.3	33	600
0.85	4.2	32	21	6.5	5.4	36	470
1.0	4.8	41	26	8.0	6.7	40	360
1.5	7.1	53	40	11.0	10	52	220
2.0	8.7	70	54	14.0	13	65	160

Source: Ref. 10.
[a]These data are representative of Cerex fabrics and are not intended to serve as specification. Detailed testing procedures are available from Monsanto on request.
[b]ASTM D-1910-64.
[c]ASTM D-1777
[d]ASTM D-1682
[e]ASTM D-2263-68
[f]ASTM D-231
[g]ASTM D-737-69

TABLE 2.9. Properties of Fabrics Made from Cordua® Fibers

Properties	500-Denier Cordura	1,000-Denier Cordura
Weight (oz/yd^2)	6.3	9.9
Thickness (in.)	0.017	0.027
Bulk (cm/g)	2.0	2.1
Grab strength—warp (lb)	413	567
Tounge tear strength—warp (lb)	34	47
Mullen burst strength (psi)	495	680
Modified Wyzenbeek abrasion—warp (cycles to failure)	1273	1463

Source: Ref. 11.

TABLE 2.10. Specifications of Enkamat® Matting

Property	Style Number 7010	Style Number 7020
Material		
Nylon 6 plus a minimum content of 0.5% by weight of carbon black		
Dimensional		
Weight (g/m^2)	265 ± 7%	405 ± 7%
Thickness, minimum (mm)	9	18
Width (cm)	97 ± 3%	97 ± 3%
Roll length (m)	150 ± 3	100 ± 3
Filament diameter, minimum (mm)	0.35	0.40
Tensile strength, minimum (kg/m)[a]		
Length direction	80	140
Width direction	40	80
Tensile Elongation, minimum (%)[a]		
Length direction	50	50
Width direction	50	50
Tensile Resiliency		
30 minute recovery (%) (3 cycles at 100 psi)	80	80
Exposure properties		
Temperature range for 80% strength retention (°F)	-100-250	
pH range for 80% strength retention	3-12	

Source: Ref. 27.
[a]ASTM 1682 strip test procedure modified to obtain filament bond strength is used to indicate tensile properties of Enkamat matting.

with a roll diameter of 38 inches, thickness of 0.8 inch, and a total weight of 715 grams per square meter.

2.5.7 *Fibretex*

Fibretex® is a nonwoven needle punched spun-bonded polypropylene fabric produced by Crown Zellerback[28] and called Construction Grade Fibretex. It is used in separation, reinforcement, drainage, erosion control, forms, and has other construction applications. There are currently six grades available, as Table 2.11 indicates.

TABLE 2.11. Properties of Fibretex® Fabric

	Grade		
Property	320	420	600
Weight (g/m^2)	320	420	600
Strip tensile (lb/in.)	75	100	150
Elongation (%)	130	150	160
Rupture energy (ft-lb/ft^2)	800	1,000	2,000
Grab tensile (lb/in.)	125	150	250

	Grade		
Property	200	300	400
Weight (g/m^2)	200	300	400
Tensile strength (lb/in.)	60	85	100
Elongation (%)	85	130	150
Permeability (cm/sec)	0.19	0.18	0.17

Source: Ref. 28.

2.5.8 *Filter-X*

Filter-X® is a registered trademark of a fabric produced by Carthage Mills[29] and consists of a pervious sheet of polyvinylidene chloride monofilament yarns. The yarn consists of at least 85 percent vinylidene chloride and contains stabilizers to make the filament resistant to ultraviolet and heat deterioration. After weaving, the fabric is calendered so that the filaments retain their relative positions with respect to one another. All edges are selvaged or serged. The fabric has been used primarily in silt curtain drainage and erosion applications and has also been used in separation, reinforcement, and other construction problem areas. Table 2.12 gives the pertinent product data.

TABLE 2.12. Filter-X® Product Data

Test	Method	Result
Breaking load and elongation	ASTM D 1682, grab test method, 1 in.-square jaws, constant rate of travel 12 in./min.	Tensile strength: stronger principal direction 200 lb; weaker principal direction 110 lb; elongation at failure between 10 and 35%
Oxygen pressure	CRD-C 577 or 7111 in Fed. Std. 601	Same as breaking load and elongation result
Effect of alkalies	Special	Tensile strength: stronger principal direction 190 lb; weaker principal direction 105 lb; elongation at failure between 10 and 35%
Effects of acids	Special	Same as breaking load and elongation result
Weight change in water	CRD-C 575 or 6631 in Fed. Std. 601	Less than 1%
Brittleness	CRD-C 575 or 6631 in Fed. Std. 601	No failure at −60°F
Freeze-thaw	CRD-C, modified	Tensile strength: stronger principal direction 195 lb; weaker principal direction 105 lb; elongation at failure between 10 and 35%
Bursting strength	ASTM D 751	260 lb/in.^{2}
Puncture strength	ASTM D 751, modified	70 lb
Seam breaking strength	ASTM D 1683	80 lb
Percent of open area	Special	4-5%
Equivalent opening size	Special	U.S. Std. Sieve #100 (0.149 mm)
Permeability	—	4.8 X 10^{-2} cm/sec
Specific gravity	—	1.70
Weight	—	≃0.833 lb/ft^2 ≃1.29 oz/yd^2

Source: Ref. 29.

2.5.9 *Laurel Cloth*

Laurel Erosion Control Cloth (LECC) is a woven polypropylene monofilament yarn made by Laurel Plastics Co., for Advance Construction Specialties Co.[25] It has been used primarily to protect against erosion of subgrade materials in water control structures and in highway and retaining system drainage cases.

The fabric is available in two different styles. Table 2.13 gives test results for the two types.

TABLE 2.13. Laurel Erosion Control Cloth Test Results

Property	Type A (I)	Type B (II)	Test Methods
Thickness (mils)	17	22	–
Weight (oz/ft²)	0.80	0.70	ASTM D 1910
Equivalent opening size (EOS)	100 U.S. Std. sieve	40 U.S. Std. sieve	C. of E.
Open area (%)	4.3	26	C. of E.
Break strength, grab (lb)			ASTM D 1682-64
Warp	399	280.2	
Fill	244	232.2	
Elongation (%)			ASTM D 1682-64
Warp	33	40.2	
Fill	33	42.4	
Trapezoidal tear strength (lb)			ASTM D 1682-64
Warp	90	–	
Fill	35	–	
Burst strength, Mullen (psi)	528	520	ASTM D 751-68
Puncture (lb)	138	133	ASTM D 751-68
Loss of strength when wet	Nil	Nil	C. of E.
Abrasion, Taber cycles	No damage at 3700 cycles	No damage at 3700 cycles	ASTM D 1175-64T D 1682-64
Seam strength (lb)	198	198	ASTM D 1683-68
Effect of salt water	Nil	Nil	
Weatherometer test, tensile strength (%)			
Warp	87	88	ASTM G 23 &
Fill	74	73	D 1682-64
Moisture absorbancy	Nil	Nil	CRD-C 575
Biological or marine growth	None	None	C. of E.
Specific gravity	0.95	0.95	

Source: Ref. 25.

2.5.10 *Mirafi*

Mirafi is a licensed trademark of the Celanese Corporation.[14] Mirafi 140® fabric is constructed from two types of continuous filament fibers. One is polypropylene, and the other is a heterofilament comprised of a polypropylene core covered with a nylon sheath. A random mixture of these filaments is formed into a sheet that is heat bonded, with the result that the heterofilaments are directly fused at their points of contact. The polypropylene filaments remain unaffected during the heat-bonding process and are held within the matrix by purely mechanical links. Mirafi 140 is marketed by the Celanese Corporation. Past uses are in separation, reinforcement, drainage, erosion, and other construction areas.

A recently introduced fabric of Celanese is Mirafi 500X®. It is a fabric woven from monofilaments of isotatic polypropylene. The fabric is then heat treated and the edges are mechanically sealed to prevent unraveling. Also recently introduced by Celanese is Mirafi 100X®, a woven fabric constructed from polypropylene fibers for applications as silt fences and brush barriers. The fabric is available in widths of 36 and 48 inches.

Table 2.14 gives typical properties of these three Mirafi fabrics. These are average values and should not be construed as minimum specification values.

2.5.11 *Monofelt*

Monofelt™ is a nonwoven polypropylene fabric marketed by Menardi Southern and produced by J. P. Stevens Co., Inc.[30] by a special process that entangles and fuses the individual fibers. Although it is specifically engineered for the erosion control market, it can be used for separation, reinforcement, and drainage applications in construction problems. Table 2.15 gives some of its important properties.

2.5.12 *Monofilter*

Monofilter® fabric is woven entirely from monofilament polypropylene yarns and then put through a specific finishing process by Menardi-Southern under the trademark of J. P. Stevens Co., Inc.[30] The yarns used in production of the fabric have been treated with ultraviolet light inhibitors for resistance to this type of degradation. Its applications have been as follows:

- Filters for shore protection and coastal structures.
- Road and area stabilization.

TABLE 2.14. Mirafi® Product Information Summary

Property	Fabric		
	Mirafi 140	Mirafi 500X	Mirafi 100X
Minimum weight (g/m^2; oz/yd^2)	140; 4.1	136; 4.0	–
Average thickness (mils)	30	25	–
Grab strength, wet (lb)	120	200	120
Retention at −70°F (%)	100	–	>90
Grab elongation, wet (%)	130	–	–
Retention at −70°F (%)	40	–	–
Burst Strength (Mullen) (psi)	–	325	200
Tear strength (lb)	65[a]	25[b]	65[a]
Air permeability	250	–	–
Fabric width	14 ft 9 in. (4.5 m)	12 ft 6 in. (3.8 m)	36 or 48 in.
Length per roll	328 ft (100 m)	430 ft (131 m)	300 or 225 yd
Average weight per roll (lb)	170	180	55 or 60
Equivalent opening size			40

Source: Ref. 14.
[a]Trapezoidal
[b]Elmendorf.

TABLE 2.15. Typical Properties of Monofelt™ Fabric

Item	Properties	Test Method
Fiber	100% Polypropylene	
Weight/yd^2 (oz)	5	ASTM: D1910-64, 32
Grab tensile, MD X CMD (lb)	Original: 130 X 165 After abrading: 100 X 112[a]	ASTM: D1682 ASTM: D1682[a]
Elongation, MD X CMD (%)	72 X 64	ASTM: D1682
Mullen burst (psi)	230	ASTM: D1117-62
Equivalent opening size	80–100	U.S. Army Corps of Engineers CW-02215–Oct. 1976

Source: Ref. 30.
[a]After abrading, as in D1175, with CS17 Celibrase wheels under 1 kg load; 1,000 revolutions.

TABLE 2.16. Fabric Specifications for Monofilter® Fabric: yarn—100% polypropylene monofilament black; weight—7 oz/yd^2 +; thickness—0.020 in.

Property	Style Number 17-980-040-72	CW-02215
Tensile strength (ASTM D-1682—grab method)		
Warp	347	200 lb—any direction
Fill	332	
Bursting strength (ASTM D-751—Mullen method), gross	532	Not specified
Puncture strength (ASTM D-751—ball burst method)	250+	120 lb (minimum)
Abrasion Resistance (ASTM D-1682 after D-1175—Taber abrasion, 1,000 cycles, CS-17 wheel, 1000 g)		
Warp	120	55 lb—any direction
Fill	304	
Open area (%)	26	
Designated EOS	35–40	

Source: Ref. 30.

- River and stream erosion control.
- Drainage systems for highways and slopes.

Table 2.16 presents the fabric specifications.

2.5.13 Nicolon

United States Textures Sales Corporation[31] is the sole supplier of Nicolon filter cloths and patented systems in America. Their fabrics consist of polyamide, polypropylene, and polyester fibers and are in both woven and nonwoven forms. Nicolon fabrics are also manufactured with loops, pockets, and in an impervious form. Application areas over the past 20 years have been mainly concerned with drainage and erosion control problems, but separation and reinforcement problems have also been addressed. In Table 2.17 physical and mechanical properties are presented for ten different Nicolon fabrics.

TABLE 2.17. Properties of Nicolon Fabrics

Property	Fabrics[a]			
North American designation	Nicolon 40	Nicolon 40L[a]	Nicolon 70	Nicolon 70L[a]
European designation	66339 (301)	66373	66424	66392
New fabrics, 1979				
Composition	Polyethylene or polypropylene monofilament	Polyethylene or polypropylene monofilament	Polyethylene or polypropylene monofilament Warp polypropylene multifilament fill	Same as Nicolon 70
Tensile strength				
ASTM D 1682 grab test (lb/in.)				
Warp	260	240	240	240
Fill	225	210	230	230
ASTM D 1682 strip test (N5cm)				
Warp	2,340	2,095	2,100	2,125
Fill	2,070	1,860	2,045	2,040
Bursting strength ASTM D 751 (psi)	500	500	>600	>600
Puncture strength, ASTM D 751 modified (lb)	150	120	120	120
Abrasion resistance, ASTM D 1175				
Abraded strength, D 1682 (lb)	115	100	>60	>60
Equivalent opening size				
U.S. standard sieve	40	35	70	70
Sieve size (microns)	420	500	210	210
Elongation percent				
Warp	30	32	30	30
Fill	25	20	40	40
Water permeability as determined by Delft hydraulic laboratory				
K value (cm/sec)	3	3.5	0.6	0.6
Hydraulic gradient	0.49	0.45	1.05	1.05
Weight				
(g/m^2)	220	195	250	240
(oz/m^2)	6.4	5.67	7.25	7
Thickness				
(mils)	30	30	24	24
(mm)	0.79	0.75	0.61	0.61
Standard widths (ft)	12-16.5	16.5	12-16.5	16.5
Principal applications	Hydraulic filter	Sinking mattresses Hydraulic filter	Hydraulic filter	Sinking mattresses Hydraulic filter

TABLE 2.17. (Continued)

Property	Fabrics[a]					
North American designation	Nicolon MD7500	Nicolon HD10,000	Nicolon HD20,000	Nicolon LD1,000	Nicolon X	Nicolon HD40,000
European designation	66186	66475				
Composition	Polyamide (nylon) multifilament	Polypropylene	Polyester multifilament Warp-polyamide multifilament fill	Polypropylene	Polypropylene monofilament	Polyester multifilament Warp-polyamide multifilament fill
ASTM D 1682 grab test (lb/in.) — Warp	400	1,250		200	>350	
ASTM D 1682 grab test (lb/in.) — Fill	400	225		200	>200	
ASTM D 1682 strip test (N5cm) — Warp	3,735	10,800	200 kN/m			
ASTM D 1682 strip test (N5cm) — Fill	3,490	2,030	60 kN/m			
Bursting strength ASTM D 751 (psi)	>600	>1,500		>325	>500	
Puncture strength, ASTM D 751 modified (lb)	120	>200			120	
Abraded strength, D 1682 (lb)	60	>200			>80	
U.S. standard sieve	100	35			70-100	
Sieve size (microns)	150	500			210-150	
Elongation percent — Warp	30	18	9		30	
Elongation percent — Fill	32	18	24		30	
K value (cm/sec)	6×10^{-2}	10×10^{-2}			$>3 \times 3^{-2}$	
Hydraulic gradient	90.5	18.7				
Weight (g/m^2)	230	730	450	140	240	
Weight (oz/m^2)	6.75	21.5	13.3	4	7	
Thickness (mils)	19.7	89	30		18	
Thickness (mm)	0.5	2.26	0.8		0.48	
Standard widths (ft)	16.5	16.5	16.5	12	6-12	
Principal applications	Reinforcement Hydraulic filter	Reinforcement Hydraulic filter	Reinforcement	Separation	Hydraulic filter	

Source: Ref. 31.

[a]Nicolon 40L and 70L are patented filters with loops woven in the fabric at 30-in. intervals to facilitate attachment of fascines.

2.5.14 *Permealiner*

Permealiner® is a woven, polypropylene fabric marketed by Staff Industries, Inc.[32] It has generally been used in drainage and erosion areas but could be used for separation and reinforcement as well. Table 2.18 gives the manufacturer's data on the two styles of woven polypropylene, M-1195 and M-1105, and on two other styles of nonwoven needle punched fabric, ISS-1 and ISS-2.

TABLE 2.18. Manufacturer's Data on Permealiner® Fabrics

Property	M-1195	M-1105	Test Method
Color	Black	Black	–
Weight (oz/ft²)	0.8	0.72	ASTM D-1910
Equivalent opening size	70–100	30	U.S. standard sieve size CW-02215
Open area (%)	4–10	22	CW-02215
Tensile strength (lb)	400 X 280	275 X 300	ASTM D-1682
Elongation (%)	34 X 32	28 X 32	ASTM D-1682
Trapezoidal tear strength (lb)	92 X 40	110 X 80	ASTM D-2263
Mullen burst (psi)	510	520	ASTM D-751
Puncture strength (lb)	150	130	ASTM D-751-M
Abrasion resistance			ASTM D-01175-71
Abraded strength (lb)	80	70 X 120	ASTM D-1682
Weather-Ometer strength retention (%)	90	90	Federal test method CCC-T-191B, Method 5804
Water permeability, water flow rates[a] (ml/min)			
6-in. head	460–520		Canvas Products Assoc. International test method
8-in. head	620–760		
36-in. head	2610–2790		

TABLE 2.18. (Continued)

Property	ISS-1	ISS-2	Test Method
Color	Black	Tan	
Count	24 X 12	16 X 15	ASTM D-3348
Thickness (mils)	14	18	
Width	15 ft	57 in.	
Tensile strength (lb)			
Warp	110	160	ASTM D-1682
Fill	70	110	ASTM D-1682
Elongation (%)			
Warp	22	12	ASTM D-1682
Fill	18	11	ASTM D-1682
Tear strength (lb)			
Warp	30	30	ASTM D-2263
Fill	40	35	ASTM D-2263
Burst (psi)	300	400	ASTM D-751
Puncture strength (lb)	35	100	ASTM D-751 (modified)
Weight (oz/yd²)	5.0	7.5	ASTM D-1910
Air permeability [(ft³/min)/ft²]	24	25	ASTM D-737-46
Sieve number, finer than	120	100	CE 1310
Water permeability [(ml/sec)/cm²]			
130–30 cm	15.2	8.5	Falling head permeability
50–30 cm	8.7	4.9	
30–10 cm	4.1		
Equivalent opening size	60	120	
Specific gravity	1.03	0.98	

Source: Ref. 32.
[a]Water flow perpendicular to fabric.

2.5.15 *Petromat*

Petromat® is a registered trademark of the Philips Petroleum Company.[33] The fabric is a needle punched nonwoven polypropylene fabric made by Philips Fibers Corporation. It has been used primarily as a waterproofing and reinforcement fabric in highway and bridge deck construction and remedial work. Table 2.19 gives some of its engineering properties.

TABLE 2.19. Properties of Petromat® Fabric

Property	Typical	Minimum
Weight (oz/yd²)	4.1	3.6
Tensile Strength, ASTM method D-1682 (lb)	115	90
Elongation at Break, ASTM method D-1682 (%)	65	55
Asphalt retention, Philips procedure (gal/yd²)	–	0.20
Color	Black	
Width (in.) (other widths available)	75 and 150	
Length per roll (yd)	100	

Source: Ref. 33.

2.5.16 *Polyfelt*

Polyfelt TS 300 fabric is a needled polyester material originally sold in America by Advance Construction Specialties Company.[25] It is currently made in Austria and marketed in Europe. Emphasis has been on its use in road construction (reinforcement) and in hydraulic construction (drainage). Test results of the fabric are given in Table 2.20.

TABLE 2.20. Test Results of Polyfelt TS 300 Fabric

Property	Value	Test Method
Weight (oz/yd²)	7.8	ASTM D-461
Thickness (in.)	0.127	ASTM D-461
Grab tensile strength (lb)	228	ASTM 1682-71
Elongation (%)	101	ASTM 1682
Tear strength (lb)	47	ASTM 2261/62
Moisture takeup (%)	730	ASTM D 461-61
Permeability (cm/sec)	0.012	–
Form of supply		
Single rolls:	8 ft 2 in. X 787 feet (6430 ft²)	
Wider rolls:	Increments of 8 ft 2 in. by lengths up to 787 ft. Standard rolls not to exceed 10,000 ft². Rolls sewn together with a serging seam.	
Weight:	7.7 oz/yd² (345 lb/single roll)	

Source: Ref. 25.

2.5.17 *Poly-Filter*

Poly-Filter X® and Poly-Filter GB® are registered trademarks of fabrics produced by Carthage Mills[29] and are made from pervious sheets woven of polypropylene monofilament yarns. The yarns consist of at least 85 percent propylene and contain stabilizers and inhibitors to make the filament resistant to ultraviolet and heat deterioration. After weaving, the cloths are calendered and palmered so that the filaments retain their relative positions with respect to one another. All edges are selvaged and/or serged. The fabrics have seen the most use in drainage and erosion applications, and have also been used in separation, reinforcement, and other applications. Table 2.21 gives some product data for the two types currently available.

TABLE 2.21. Polyfilter® Product Data

Test	Poly-Filter X	Poly-Filter GB	Method
Breaking load and elongation	380 X 220 10 and 35%	200 X 200 10 and 35%	ASTM D 1682, grab test method, 1 in. square jaws, constant rate of travel 12 in. per min.
Effect of acids	350 X 220 10 and 35%	Same as above Same as above	Special
Effects of alkalies	Same as above	Same as above	Special
Weight change in water	Less than 1%	Less than 1%	CRD-C 575 or 6631 in Fed. Std. 601
Brittleness	No failure at -60°F	No failure at -60°F	CRD-C 570 or 5311.1 in Fed. Std. 601
Bursting strength (psi)	540	600	ASTM D 751, using diaphragm bursting tester
Puncture strength (lb)	140	120	ASTM D 751, modified
Seam breaking strength (lb)	195	170	ASTM D 1683
Open area (%)	5-6	21-26.5	Special
Equivalent opening size	#70 U.S. Std. sieve (0.21 mm)	#40 U.S. Std. sieve (0.42 mm)	Special
Permeability (cm/sec)	(3.3-3.8) X 10^{-2}	–	–
Specific gravity	0.95	0.95	–
Weight			
(lb/ft²)	≃0.05	≃0.046	–
(oz/ft²)	≃0.8	≃0.736	–

Source: Ref. 29.

TABLE 2.22. Manufacturer's Properties of ProPex II® Fabric

Property	Value	Test Method
Material	Polypropylene	
Color	Black	
Tensile strength (lb)	275 X 300	ASTM D-1682
Burst strength (psi)	520	ASTM D-751
Weight (oz/yd²)	6.5	ASTM D-1910
Equivalent opening size	30	U.S. Std. Sieve size CW-02215
Open area (%)	22	CW-02215
Elongation (%)	28 X 32	ASTM D-1682
Puncture strength (lb)	130	ASTM D-751 (modified)
Weather-ometer strength retention (%)	90 X 90	Federal test method CCC-T-191B, method 5804
Abrasion resistance		ASTM D-1175-71
Abraded strength (lb)	70 X 120	ASTM D-1682
Trapezoid tear strength (lb)	110 X 80	ASTM D-2263

Source: Ref. 34.

2.5.18 ProPex

ProPex® is a woven, polypropylene fabric by Amoco Fibrics Company[34]. It has been used as a separator and as a filter fabric. Table 2.22 gives the significant properties.

2.5.19 Reemay

Reemay® spun-bonded polyester from duPont[11] is a sheet product of continuous-filament polyester fibers that are randomly arranged, highly dispersed, and bonded at filament junctions.

While this fabric has not been widely used in geotechnical engineering applications, it does appear suitable for many uses and comes in a wide variety of styles. Table 2.23 gives some of its physical properties.

2.5.20 Sontara

Sontara® spun-laced fabric is a duPont material[11] consisting of polyester staple fibers entangled to form a strong unbonded structure. Because this fabric does not have any resin binders or interfiber bonds, the fibers are free to bend and move past one another as the fabric is flexed, thus providing excellent softness and draping characteristics. The fabric comes in two different styles. Its physical properties are given in Table 2.24.

TABLE 2.23. Typical Physical Property Ranges of Reemay® Fabrics

Property	Style Number										
	2006	2011	2014	2016	2024	2033	2403	2416	2431	2441	2470
Nominal basis weight (oz/yd²)	0.6	0.73	1.0	1.35	2.1	2.9	1.1	1.5	2.4	2.9	5.8
Thickness (mils)	5-7	6-8	8-10	9-11	11-13	15-17	10-14	12-16	16-20	18-22	30-34
Grab tensile (lb)											
MD	9-12	12-15	16-28	25-36	39-64	52-88	12-19	15-29	35-54	46-66	106-127
XD	7-9	8-13	12-19	19-29	23-50	42-70	7-13	14-21	29-40	39-53	83-112
Tongue tear (lb)											
MD	1.5-1.7	1.2-2.3	1.2-2.1	1.9-4.2	1.1-3.4	2.3-4.7	2.1-3.3	3.3-4.5	4.0-6.0	5-6	8-12
XD	1.5-1.7	1.1-2.3	1.2-2.7	1.7-4.4	1.4-4.0	1.4-6.2	2.0-2.8	3.2-4.4	4-6	5-7	11-14
Mullen burst (lb)	8-15	22-40	25-36	31-61	52-78	78-114	15-26	22-33	38-54	48-68	76-100

Source: Ref. 11.

TABLE 2.24. Typical Physical Properties of Sontara® Spun-Laced Fabrics

Property	Style Number 8000	8003
Basic weight, average oz/yd²	1.2	1.9
(g/m²)	40.7	64.6
Grab break strength, MD/XD		
(lb)	25/13	40/25
(N)	111/58	178/111
Elongation to break, MD/XD (%)	40/110	40/100
Tongue tear, MD/XD		
(lb)	2.1/3.1	2.7/3.9
(N)	9.3/13.8	12.0/17.4
Thickness nominal		
3/4-in. dia. area at 0.16 psi (mils)	16	21
19.05-mm dia. area at 1.10 kPa (mm)	0.406	0.533
Mullen burst		
(lb)	35	55
(N)	156	245
Frazier air permeability		
[(ft³/min)/ft²]	400	250
[(m³/min)/m²]	122	76
Water vapor permeability		
[(g/24 hr)/m²]	900	1,000

Source: Ref. 11.

2.5.21 *Stabilenka*

Stabilenka™ is a brand name of the American Enka Company, Enka, North Carolina,[27] used to designate a family of nonwoven polyester fabrics developed specifically for soils engineering purposes. Generally, the product provides soil/water filtration and soil stabilization functions. Being a polyester product, Stabilenka filter fabric provides high resistance to outdoor deterioration and dimensional change. Three styles are available, with specifications given in Table 2.25.

2.5.22 *Supac*

Supac® is a registered trademark of the Philips Petroleum Company.[33] The fabric is a needle punched nonwoven polypropylene fabric made by the Philips Fibers Corporation. It is intended for use in separation, reinforcement, drainage, erosion control, and other construction applications. Table 2.26 gives some of its engineering properties.

TABLE 2.25. Properties of Stabilenka™ Filter Fabric

Properties	Style Number T-80	T-100	T-140	Test Method
Fabric weight (oz/yd²)	2.3	3.4	4.3	
Fabric thickness (in.)	0.02	0.03	0.03	
Roll width (in.)	42 and 84	42 and 84	42 and 84	
Roll length (linear yd)	547	547	547	
Tensiles dry grab strength (lb)				ASTM D-1682
Length	64	80	129	
Width	54	65	96	
Tensile dry grab elongation (%)				ASTM D-1682
Length	55	41	42	
Width	68	53	46	
Trapezoid tear (lb)	29	29	30	ASTM D-2263
Flow rate [(gal/min)/ft²][a]				
At ΔH = 30–10 cm	400	556	257	
At ΔH = 50–30 cm	758	956	630	

Source: Ref. 27.

[a] Flow rates were determined by measuring the time required for the height of column of water standing above the test fabric to drop from 50 to 30 cm and from 30 to 10 cm as the water passes through the fabric. The flow rate was then calculated in gallons per minute per square foot of fabric.

2.5.23 *Terrafix*

Terrafix® filter mats were developed in the mid-1960s by Terrafix Erosion Control Products, Inc.[37] to provide erosion protection for hydraulic structures. The mats are composed of a labyrinth of individual synthetic fibers in a three-dimensional structure. Certain mat types are reinforced with a polyester scrim and synthetic binder. Stated goals of Terrafix filter mats are

- Retention of fine-grained soil particles while maintaining high filter permeability.

TABLE 2.26. Typical Properties of Supac® Soil Filter Fabric Type 5-P

Property	Value
Nominal fabric weight, (ASTM D-2646) (oz/yd²)	5.3
Fabric thickness, (ASTM D-1777) (mils)	50
Tensile Properties (ASTM D-1682)	
Ultimate strength, warp direction, wet (lb)	125
Ultimate strength, filling direction, wet (lb)	150
Elongation at break, wet (%)	80
Toughness (product of strength and elongation—averaged)	10,000
Ultimate strength after abrasion (Taber abrader, CSI-17 wheel, ASTM D-1175)	114
Stretch,	
Elongation; 27 lb., 3-in. width for 10 minutes. CFFA-19 (%)	19
Set (% of unrecovered stretch. CFFA-19)	4
Trapezoidal tear, ASTM D-2263 (lb)	73
Puncture strength, ASTM D-751 modified (lb)	100
Mullen burst, ASTM D-751 (psi)	300
Permeability	
Air permeability at 0.5-in. water head, ASTM D-737 [(ft³/min)/ft²]	230
Water permeability, coefficient of, C. of E. EM 1110-2-1906 (modified) (cm/sec)	5×10^{-2}
Equivalent opening size, C. of E. CW-02215 (modified)	Fabrics of different values available

Source: Ref. 33.

- Reinforcement and support of structures located on unstable foundation materials.

The fiber diameters and density of the mats can be tailored to meet a given condition and can also be reinforced with woven fabrics or produced with multilayer construction if necessary. This gives rise to a number of different styles, as shown in Table 2.27.

2.5.24 Terram and Filtram

Terram® is ICI Fibers' trade name[38] for its fabrics for the civil engineering industry: these range from lightweight, thermally bonded, nonwoven,

TABLE 2.27. Physical and Mechanical Properties of Terrafix

Type	Fiber	Thickness (mm)	Weight (g/m²; oz/yd²)	Grab Tensile Strength, Wet (lb)	Mullen Burst (psi)	EOS U.S. Seive Number	Water Permeability at ΔH = 35 cm [(ml/cm²)/sec]
300 NA	Polyester	3.5 (137 mils)	500; 14.7	200 @ 25%	360	50	56
500 NA	Polyester	4.5 (177 mils)	700; 20.6	200 @ 25%	445	70	45
400 NR	Polyamide	4.0	550; 16	120 @ 25%	300	120	10
270 R	Polyester	3.0	270; 8	150 @ 100%	300	100	40
470 R	Polyester	4.0	470; 11	200 @ 100%	400	120	30
1000 R	Polyester	6.0	1,000; 29	425 @ 110%	800	120	10
1600 R	Polyester	6.0 (236 mils)	1,600; 47.2	700 @ 125%	Beyond machine capacity	120	5
814 B	Polyester plus polypropylene	6.0 (236 mils)	800; 22.1	350 @ 120%	536	120	16
1002 NS	Polyamide plus polyester	11.0 (433 mils)	1,110; 32.5	—	—	—	75
370 RS	Polyester	4 (157 mills)	475; 14	90 @ 30%	390	120	35
Terra-track 2415	Polypropylene	0.45 (18 mills)	125; 3.7	105 @ 20%	280	50	6

Source: Ref. 37.

permeable materials designed for use in ground stabilization, drainage, reinforcement, and erosion control (for properties see Table 2.28) to special-purpose fabrics with either unidirectional or two-directional strength (between 5 and 80 tons per meter) for soil reinforcement.

In addition, ICI has developed a laminated product, marketed under the trade name Filtram®, which promotes the flow of water within its own structure. This integrated, lamina, flexible filter drain (in which Terram is used as the filter membrane) eliminates the need for graded

TABLE 2.28. Structural Characteristics and Mechanical Properties of Terram from ICI Fibers

	Terram Product					
Property	500	700	1,000	1,500	2,000	3,000
Structural Characteristics						
Fiber diameter (μm)	35	35	35	35	35	35
Thickness in terms of fiber diameters	11	16	20	23	25	28
Porosity (% at 250 kg/m^2)	81	80	79	73	72	70
Porosity (% at 2×10^4 kg/m^2)	75	74	74	68	67	65
Mechanical Properties[a]						
1 m plane strain tensile						
Maximum load (kN/m)	3.75	6.0	8.5	11.0	13.0	14.0
Extension at maximum load (%)	35	40	45	50	55	60
Extension at break (%)	40	45	50	55	60	75
Load at 5% extension (kN/m)	1.0	2.0	2.5	3.0	3.5	3.75
25 mm grab tensile						
Maximum load (N)	400	600	850	1,200	1,400	1,600
Extension at maximum load (%)	70	75	80	80	80	80
Extension at break (%)	80	85	90	90	90	90
Tear strength-wing (N)	110	190	250	310	360	400
Burst load (N/cm^2)	50	80	110	150	180	210

Source: Ref. 38.

[a] Figures are comparable to equivalent figures obtained by testing to DIN 53857 and DIN 53858.

filters, and is of particular interest in situations where conventional drains are difficult to install.

Terram and Filtram are trademarks of Imperial Chemical Industries, Ltd., for its products for the civil engineering industry.

2.5.25 *Typar*

Typar® is a spun-bonded polypropylene developed by the duPont Company[11] as primary backing for tufted rugs and carpets. It is currently used in geotechnical engineering in separation, reinforcement, drainage, erosion, and other uses. Typar is a uniform sheet of preferentially oriented continuous filaments of 100 percent isotatic polypropylene manufactured by an integrated process of fiber spinning and bonding. There are two basic styles (3401 and 3601), as well as an EVA-coated impermeable style (T063). Table 2.29 presents the pertinent properties.

TABLE 2.29. Properties of Typar® Fabric

	Style Number			
Property	3401	3601	T063	ASTM Test
Weight (oz/yd^2)	4.0	6.0	7.5	ASTM D1910
Thickness (mils)	15	19	15.5	ASTM D1777
Grab tensile (lb)	130	225	180	ASTM D1682
Elongation to break (%)	62	63	68	ASTM D1682
Trapezoidal tear (lb)	70	75	54	ASTM D2263
Mullen burst (psi)	170	263	265	ASTM D774-46
Specific gravity	0.95	–	0.96	–
Equivalent opening size	70 to 100	140 to 170	–	CE/ASTM D422
Coefficient of H_2O permeability K (cm/sec)	2×10^{-2}	–	–	EURM-100
Modulus (lb)	1200	–	1150	ASTM D1682

Source: Ref. 11.

2.5.26 *Tyvek*

Tyvek® is a duPont product[11] made from 100 percent density polyethylene fibers by an integrated spinning and bonding process. The sheet is formed by spinning very fine polyethylene fibers and then bonding

TABLE 2.30. Physical and Mechanical Property Comparison of Fabrics

Section Number	Fabric	Style	Manufacturer or Agent	Fiber Type[a]	Process Type[b]	Physical Properties: Weight[c] (oz/yd^2)	Physical Properties: Thickness[d] (mils)	Physical Properties: EOS[e] (Sieve Number)	Mechanical Properties: Grab Strength[f] (lb)	Mechanical Properties: Elongation[g] (%)	Mechanical Properties: Burst[h] (psi)	Mechanical Properties: Trapezoidal Tear[i] (lb)
2.5.1	Adva-Felt	TS200	Advance	1	1	6.0	80	90	115	89		
		TS300				8.0	130	70	225	101		
		TS400				10.5	170	60	300	110		
2.5.2	Bay Mills	154	Bay Mills	4	4	9.7	14					
		144				6.0	9					
		610				2.5	4					
		196				32	45					
2.5.3	Bidim	C22	Monsanto	2	1, 2	4.5	60	50*	115	85	225	62
		C28				6.0	75	50*	160	80	360	93
		C34				8.0	90	70*	255	75	400	125
		C38				10.0	110	100*	300	65	500	170
		C42				16.2	190	100*	610	60	850	250
2.5.4	Cerex	–	Monsanto	3	1	0.3	2.3		8		17	3.4
						0.4	2.5		12		20	4.3
						0.5	3.2		16		24	4.5
						0.6	3.4		21		29	5.5
						0.7	3.7		27		33	6.3
						0.85	4.2		32		36	6.5
						1.0	4.8		41		40	8.0
						1.5	7.1		53		52	11.0
						2.0	8.7		70		65	14.0
2.5.5	Cordura	500	duPont	3	4	6.3	17		413		495	
		1000				9.9	27		567		680	
2.5.6	Enkamat	7010	American Enka	3	5		354			50		
		7020					710			50		
2.5.7	Fibretex	320	Crown Zellerbach	1	1, 2	9.4			125	130		
		420				12.4			150	150		
		600				17.7			250	160		
		200				5.9			–	–		
		300				8.8			–	–		
		400				11.8			–	–		
2.5.8	Filter-X	–	Carthage Mills	5	4	11.6		100	200	23	260*	70*
2.5.9	Laurel Cloth	A	Laurel Plastics	1	4	7.2	17	100	400	33	528	90
		B				6.3	22	40	280	40	520	–
2.5.10	Mirafi	140	Celanese	5	3	4.1	30	–	120*	130*	–	65
		500X		1	4	4.0	25	–	200*	–	325	–
		100X		1	4	–	–	40	120*	–	200	65
2.5.11	Monofelt	–	J. P. Stevens	1	5	5	–	90	130	72	230	
2.5.12	Monofilter	–	J. P. Stevens	1	4	7	20	40	347	–	532	
2.5.13	Nicolon	66339	U.S. Textures	5	5		30	40	260	30	500	
		66373					30	35	240	32	500	
		66424					24	70	240	30	>600	
		66392					24	70	240	30	>600	
		66186					20	100	400	30	>600	
		66475					89	35	1250	18	>1500	
		HD20,000					30	–	–	9	–	
		LD1,000					–	–	200	–	>325	
		X					18	85*	>350	30	>500	
		HD40,000					–	–	–	–	–	
2.5.14	Permealiner	M-1195	Staff Industries	1	4	7.2	–	85	400	34	510	92
		M-1105		1	4	6.5	–	30	275	28	520	110
		ISS-1		1	2	5.0	14	60	110	22	300	30
		ISS-2		1	2	7.5	18	120	160	12	400	30
2.5.15	Petromat	–	Philips	1	2	4.1			115	65		
2.5.16	Polyfelt	–	Advance	2	2	7.8	127		228	101		47
2.5.17	Poly-Filter	X	Carthage Mills	1	4	7.2		70	380	23		
		GB				6.6		40	200	23		
2.5.18	ProPex	II	Amoco Fabrics	1	4	6.5	–	30	275	28	520*	110

TABLE 2.30. (Continued)

Section Number	Fabric	Style	Manufacturer or Agent	Fiber Type[a]	Process Type[b]	Physical Properties			Mechanical Properties			
						Weight[c] (oz/yd^2)	Thickness[d] (mils)	EOS[e] (Sieve Number)	Grab Strength[f] (lb)	Elongation[g] (%)	Burst[h] (psi)	Trapezoidal Tear[i] (lb)
2.5.19	Reemay	2006	duPont	2	1	0.6	6		11		12	
		2011				0.7	7		14		31	
		2014				1.0	9		22		31	
		2016				1.3	10		31		46	
		2024				2.1	12		52		65	
		2033				2.9	16		70		96	
		2408				1.1	12		16		21	
		2416				1.5	14		22		28	
		2431				2.4	18		45		46	
		2441				2.9	20		56		58	
		2470				5.8	32		117		88	
2.5.20	Sontara	8000	duPont	2	5	1.2	16		25	40	35	
		8002				1.9	21		40	40	55	
2.5.21	Stabilenika	T-80	American Enka	2	5	2.3	20		64	55		29
		T-100				3.4	30		80	41		29
		T-140				4.3	30		129	42		30
2.5.22	Supac	5-P	Philips	1	2	5.3	50		125	80	300	73
2.5.23	Terrafix	300 NA	Erosion Control	5	5	14.7	137	50	200*	25	360	
		500 NA				20.6	177	70	200*	25	445	
		400 NR				16	160	120	120*		300	
		270R				8	118	100	150*		300	
		470R				11	160	120	200*		400	
		1000R				29	236	120	425*		800	
		1600R				47.2	236	120	700*		BMC	
		814B				22.1	236	120	350*		536	
		1002NS				32.5	433	–	–		–	
		370RS				14	157	120	90*		390	
		2415				3.7	18	50	105*		280	
2.5.24	Terram	500	ICI Fibres	5	3							
		700										
		1000										
		1500										
		2000										
		3000										
2.5.25	Typar	3401	duPont	1	1	4.0	15	85*	130	62	170	70
		3601		1	1	6.0	19	155*	225	63	263	75
		T063		5	5	7.5	15.5	–	180	68	265	54
2.5.26	Tyvek	–	duPont	5	1							

[a] Fiber type:
1. Polypropylene
2. Polyester
3. Nylon
4. Glass
5. Other or combined

[b] Process type:
1. Nonwoven, spun bonded
2. Nonwoven, needled, or mechanically bonded
3. Nonwoven, thermal, or melt bonded
4. Woven
5. Other, combined, or not known

[c] ASTM D 1910.
[d] ASTM D 1777.
[e] Corps of Engineers CW-02215.
[f] ASTM D 1682 (machine direction with dry fabric).
[g] ASTM D 1682 (machine direction with dry fabric).
[h] ASTM D 774, D 231, D 751.
[i] ASTM D 2263 (machine direction).
*Signifies a different test than above or test modified in company literature. Many values have been averaged when a test range was given.