

FREEZING TESTS ON LEAN CLAY WITH TENAX TRI-PLANAR
GEOCOMPOSITE AS CAPILLARY BARRIER

by

Karen S. Henry and Rosa T. Affleck

Preface

This work was conducted in accordance with the 1997 Cooperative Research and Development Agreement (CRDA) between the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) and Tenax, Inc., of Baltimore, Maryland. The tests conducted for Tenax, Incorporated and reported herein were developed by Karen Henry, with assistance from many CRREL employees, including Rosa Affleck, who was especially helpful in specimen preparation. The experimental techniques are documented in detail in Henry (in preparation) where results of many experiments of a similar nature are reported.

INTRODUCTION

A capillary barrier is a layer of relatively large-pored material placed in a finer-pored soil to either 1) reduce unsaturated flow upwards due to the capillary rise, evaporation and/or freezing of water or 2) prevent water in overlying fine-pored unsaturated soil from infiltrating the soil below the capillary barrier. A capillary barrier can potentially reduce frost heave by preventing (or, greatly reducing) water flow between the water table and the freezing front in freezing soils when it is placed above the water table and below the depth of freezing. This report presents the results of a laboratory study conducted to determine the frost susceptibility (FS) of subgrade soil collected at Winterport, Maine and the influence of a Tenax Tri-Planar geocomposite, functioning as a capillary barrier, on frost heave of that soil. The soil tested was collected from Route 1A in Winterport, Maine during August 1997, when pavement test sections containing the geocomposite capillary barriers (provided by Tenax) were being constructed.

The Maine Department of Transportation (MDOT) constructed several test sections containing geosynthetics along a 3 km (1.9 mile) portion of Route 1A in the

towns of Frankfort and Winterport. A drainage geocomposite was installed at 0.5 m (18 in.) below the subgrade in test section D-1 (survey stations 251+00 to 261+50) in order to study potential benefits of its use as a capillary barrier (Fig. 1). During soil freezing, it is hoped that the capillary barrier would prevent upward migration of water to the freezing front and thereby reduce the frost heave of the soil above it as well as the water content of the soil when thawing commences.

FREEZING TEST

Introduction

The purpose of the freezing tests was to determine the frost susceptibility of the test soil and to determine whether the geocomposite capillary barrier could reduce frost heave in the specimens frozen under typical freezing conditions and “worse case” hydraulic conditions. Four cylindrical 150-mm-high by 100-mm-diameter soil specimens were compacted to approximate field conditions, then frozen from the top down with water freely available at the base of the specimen. Three of the specimens contained a circular disk of geocomposite placed at about 25 mm above the base of the specimen, about 12.5 mm above the water table, to determine whether they could reduce frost heave. Specimen 1 contained a geocomposite as received from the manufacturer, specimen 2 contained a geocomposite removed from a long term gradient ratio test, specimen 3 contained a geocomposite that contained soil fines, and specimen 4 was a control specimen. The geocomposites in specimens 2 and 3 were prepared to simulate field conditions, and were moistened prior to freezing.

The specimens were frozen from the top down. Heat was supplied to and extracted from the soil specimens through heat transfer plates located below the porous base plates and on top of the specimens, respectively. Freezing was controlled by manually adjusting the top and bottom bath temperatures. Freezing of the soil took place inside of an insulated cabinet that is kept in a refrigerated room, held at temperatures between 0 and 4°C. The specimens were surrounded with granular insulation to limit radial heat transfer.

Materials

Two subgrade soils were collected--one from the top of the geocomposite and one from below it (see Fig. 2 for grain size distributions). The soil below the geocomposite is classified as a CL (lean clay) according to ASTM D 2487, and is rated as an F3 soil according to the U.S. Army Corps of Engineers frost susceptibility classification (e.g., Berg and Johnson, 1983). It is not suitable for use as base material. Based on the grain size distribution and soil classification, it could have a frost susceptibility ranging from low to very high. The maximum density is 1.80 Mg/m^3 , and the optimum water content is 18% (Scott Hayden, personal communication, 1997). At the time of construction (August, 1997), this soil had an estimated dry density of 1.80 Mg/m^3 and water contents were 18 to 24%.

The plasticity index of the soil placed above the geocomposite was not determined so that it is not classified. It had been excavated from the site, stored while the geocomposite was installed, then replaced on top of the geocomposite. It is probably a blend of the above-described subgrade and the pre-existing base course material. The maximum density is 2.11 Mg/m^3 , and the optimum water content is 9%. The estimated field compaction for this soil was about 85% of the maximum density (1.80 Mg/m^3), and at the time of construction it was slightly wet of optimum at 11% water content (Scott Hayden, personal communication, 1997). Based on this information, and the fact that the percentage of soil finer than 0.02 mm is still quite high at about 33%, the frost susceptibility of this soil is most likely the same as the soil below the geocomposite, which is rated at F3.

The geocomposite properties applicable to the use of geocomposite capillary barriers are listed in Table 1. All properties except the pore dimensions of the geonet core were supplied by Tenax, Inc. A complete list of geocomposite specifications supplied by Tenax, Inc., is included in the Appendix. Pore opening sizes in the plane of the geonet were measured with calipers. They are of interest because pore sizes in the plane perpendicular to water flow significantly influence capillary barrier behavior.

Table 1: Properties of Tenax Tri-planar geocomposite used in freezing tests.

	Value	Test standard
Geonet core properties:		
Tensile strength, MD (N/m)	14,750	ASTM D 4595
Thickness (mm)	7.6	ASTM D 5199
Minimum pore opening (mm)	6.0	NA
Maximum pore opening (mm)	10.1	NA
Percent thickness retained with 1,197 kPa applied for up to 10,000 hours	60	
Geotextile properties:		
Apparent opening size (mm)	0.15	ASTM D 4751
Mass per unit area (g/m ²)	270	ASTM D 3776
Grab tensile strength (N)	890	ASTM D 4632
Geocomposite property:		
In-soil transmissivity, MD (m ² /s) Normal pressure=1197 kPa Gradient=0.1	1 x 10 ⁻³	ASTM D 4716

MD=machine direction, NA=not applicable, measured in the laboratory

Specimen preparation

The soil was air-dried, and the soil from above the geocomposite was screened on a 10-mm mesh sieve, while the soil from below the geocomposite was screened on a 20-mm mesh sieve. The portions retained on each of the sieves were discarded. Tap water was added to both soils to achieve the water contents to match those in the field. To simulate field conditions, the soil collected from below the geocomposite was mixed at 20% water content and the soil above the geocomposite was mixed at 11% water content. Both soils were set overnight in a closed container to equilibrate. The target dry density for both soils was 1.80 Mg/m³.

The mold consisted of a porous base, filter paper which was placed on top of the porous base, six acrylic rings which were stacked and taped together, a 100-mm-diameter by 0.3-mm-thick latex membrane, and a rubber band. The latex membrane was attached on to the base plate with the rubber band to keep the membrane in place, the acrylic rings were placed over the outside of the membrane and it was folded over the top of the stacked rings (Fig. 3). The base plate, acrylic rings, paper, membrane and rubber band were weighed for later determination of dry density of the soil. A compaction collar was

placed around the acrylic rings and fastened to the base plate to hold the mold in place during the compaction (Fig. 4).

The diameter, thickness and weight of the three 100-mm-diameter geocomposite disks were measured. Soil fines were placed into the geocomposite of specimen 2 in the following way: a cardboard template with a 100-mm-diameter circular hole was placed into a standard (3-in.) sieve. The geocomposite was then placed on the circular hole of the cardboard template and taped around the edges on the cardboard to hold it in place. About 200 grams of the test soil was poured on the geocomposite and the sieve was covered and placed into a mechanical shaker used for grain size distribution determination for 5 minutes, only the hammer was not used. The geocomposite was then placed in a 100-mm-diameter permeameter, a 20-mm-thick layer of test soil was poured on the geocomposite, and then water was poured gently onto it until it reached a height of 100 mm. After the water flowed through the geocomposite, it was removed from the vessel, the excess soil fines on the surface were gently rinsed off and it was weighed, placed it on a paper towel and allowed to lose about 10 g of water prior to placement in the soil specimen. The geocomposite in specimen 3 was subjected to a long-term gradient ratio test described in Affleck and Henry (1998), prior to freezing.

The soil was compacted into the mold in five 30-mm-thick layers with 44.5 N hammer dropped from a height of 457 mm. The first layer was compacted with 30 blows and then the soil surface was scarified using a fork, the mold was weighed, the volume was measured and the soil was sampled for moisture content determination. For specimens 1, 2 and 3, the geocomposite disk was then placed after the first layer and glued with silicon cement around the edge of the disk on to the rubber membrane. The mold was weighed and the volume was measured once again. The second to fifth layers were compacted with 8 blows each layer, scarifying every layer before the next layer was compacted. After the compaction of the last layer, the sample was carefully trimmed and extra soil from the trimmings was used for the moisture content determination. The specimen was weighed and the soil densities were determined. Table 2 lists the water contents and dry densities of the layers of the soil in each test specimen.

Table 2: Soil specimens water contents and dry densities prior to freezing.

Specimen Number	Geocomposite Description	Layer	% Water Content	Dry Density Mg/m ³ (lb/ft ³)
1	Clean	Below geocomposite	20.60	1.72 (107.59)
		Above geocomposite	11.62	1.86 (116.33)
2	Used from filtration test and moistened	Below geocomposite	20.60	1.71 (106.84)
		Above geocomposite	11.20	1.89 (117.83)
3	Contained soil fines and moistened	Below geocomposite	20.88	1.68 (105.04)
		Above geocomposite	11.22	1.88 (117.14)
4	No geocomposite	1 st layer	20.43	1.72 (106.85)
		2 nd to 5 th layer	11.80	1.82 (113.93)

Specimen conditioning

The specimens were placed on the bottom heat transfer plate of the cabinet inside the cold room. Mariotte tube¹ water supplies were attached to the base plate of each mold. The water supply hoses exiting the base plates were lowered to induce flow through the water supply tubes and the tubes were purged of all bubbles. Thermocouples were installed into each soil specimen at the bottom, top and depths of 12.5, 37.5, 62.5, 87.5, and 113.5 mm.

The top cooling plates were placed on top of the specimens along with 25-mm-thick styrofoam insulation and a 20 N surcharge. Once the thermocouples, and water supplies and cooling plates were installed, loose granular insulation (vermiculite) was poured into the box to surround the specimens in order to prevent radial heat transfer.

The linear motion potentiometers (LMPs) were then attached to a vertical rod screwed into the base plate. The temperature baths were turned on for conditioning to -0.5°C for the top and 0.7°C for the bottom cooling plates. The specimens were left at this condition for 24 hours.

Test data were collected by datalogger, which was connected to a compatible PC. LabVIEW, a graphically-based computer code, was used to control the data acquisition

¹ A Mariotte tube is a constant-head water supply to a specimen base consisting of a cylinder sealed on the top and bottom. A glass tube is inserted through a vacuum-tight fitting in the top, and the water pressure head is fixed at the bottom of the glass tube. A hose connects the bottom of the water supply to the base plate. See ASTM D 5918 for a detailed description of Mariotte tubes.

and stored information on floppy disks. The frost heave, frost penetration, bath and specimen temperatures were recorded every 30 minutes.

Conducting the test:

Before starting the freezing test, the initial dial gage, temperature, and water levels readings were noted. The LabVIEW program was started. The top bath temperature was set to -2.5°C to achieve a top temperature of the specimens of about -1.5°C . The bottom bath temperature was set so that the bottom temperature of the specimens was about 0.7°C (Fig. 5). These temperatures were estimated to represent typical freezing conditions in the field by Henry (in preparation).

During the test, the water flow into each specimen was manually recorded every 24 hours. For the duration of the test, all four specimens had a constant water table at a level of 25 mm above the bottom of the specimen, about 5 mm below the bottom of the geocomposite. When the freezing test was completed, the specimens were then taken out of the cold room and examined. Using a band saw, the specimen was then cut in pieces with thickness ranging from 16 mm to 40 mm to determine the final moisture content profiles. Specimen 2 after freezing, just prior to slicing is shown in Figure 6, and specimen 4 is shown in Figure 7.

Results and discussion

Figure 8 shows frost penetration and heave versus time. Specimens 1, 2 and 3 were frozen to the level of the geocomposite and specimen 4 was frozen to a depth of about 110 mm. Specimens 1 and 2 were frozen after 20 and 23 hours respectively, specimen 3 was frozen after 3 days and the bottom portion of specimen 4 remained unfrozen. The total frost heave of specimen 4 (control) was 9 mm. The rate of heave for the soil above the geocomposite between the elapsed times of 0.5 and 2.5 days indicates that it has low frost susceptibility (e.g. Berg and Johnson, 1983). Specimens 1, 2 and 3 containing geocomposite did not heave. The soils below the geocomposite on specimens 1, 2 and 3 were saturated and unfrozen, and the soil above the geocomposite looked dry

and frozen but had no ice lenses. There were cracks up to 5 mm thick and 30 mm long partially filled with ice in specimen 4 (e.g. Fig. 7).

The freezing tests caused no observable physical changes to the geocomposites. The geocomposites removed from all of the specimens were moist and had thin layers of moist soil fines on top and on the bottom. Soil and water contents of the geocomposites tested are listed in Table 3.

Table 3: Soil and water contents of geocomposites removed from specimens in the freezing test².

Specimen	Water amount before freezing (g)	Water amount after freezing (g)	Soil amount before freezing (g)	Soil amount after freezing (g)
1	0.00	2.86	0.0	2.4
2	9.19	4.08	1.3	6.3
3	14.39	7.21	4.2	16.2

Figure 9 shows the moisture content profiles of the specimens at the end of the test. For the specimens with geocomposites, the soil moisture content decreased from the top of the specimen to the geocomposite layer. However, the soil moisture content increased for the control specimen.

Conclusion and recommendation

The geocomposite was a very effective capillary barrier and eliminated frost heave in specimens of Winterport soil compacted to simulate field conditions and frozen at typical freezing conditions. Furthermore, the freezing did not cause any observable physical changes to the geocomposite.

Because the effectiveness of the capillary barrier depends on the degree of saturation of the overlying soil (e.g., Henry, in review) and because the water mass balance of pavement sections has not been widely studied, it is recommended that field

² The amount of water before freezing in geocomposites 2 and 3 was estimated based on the assumption that the soil fines present in the geocomposite at the end of the test were present before freezing. The information from geocomposite 1, however, indicates that some soil fines were emplaced during compaction and/or freezing.

trials of geocomposites be carefully monitored for their effectiveness as capillary barriers to reduce frost heave and water contents of overlying soils.

Acknowledgments

The financial support of Tenax, Inc., and the interest and enthusiasm of Dr. Aigen Zhao for the subject of geocomposite capillary barriers is gratefully acknowledged. This work was completed with assistance from the Maine Department of Transportation, especially Mr. Scott Hayden, as well as the University of Maine, including Professor Dana Humphrey and Civil Engineering student Adam Smart. In addition, Dr. Barry Christopher provided advice and assistance in the field.

REFERENCES

Affleck, R. and K.S. Henry (1998) Filtration Test using Tenax Tri planar geocomposite with lean clay, Contract Report to Tenax, Inc., from U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 9 p.

ASTM D 413 Standard test methods for rubber property-adhesion to flexible substrate, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 1651 Standard test method for compressive properties of rigid cellular plastics, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 2487 Standard classification of soils for engineering purposes (Unified Soil Classification System), 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 3776 Standard test methods for mass per unit area (weight) of fabric, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 4595 Standard test method for tensile properties of geotextiles by the wide-width strip method, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 4632 Standard test method for grab breaking load and elongation of geotextiles, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 4716 Test method for determining the (in-plane) flow rate per unit width and hydraulic transmissivity of a geosynthetic using a constant head, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 4751 Standard test method for determining the apparent opening size of a geotextile, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

ASTM D 5199 Standard test method for measuring nominal thickness of geotextiles and geomembranes, 1998 Annual Book of ASTM Standards, ASTM, W. Conshohocken, PA.

Berg, R. and T. Johnson (1983), "Revised procedure for pavement design under seasonal frost conditions", CRREL Special Report 83-27, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH 30755-1290, 129 p.

Hayden, S. and P. Dunn (1996) "The use of geosynthetics with reinforcement, separation and drainage applications for highway reconstruction along a 1.9 mile portion of Route 1A in the towns of Frankfort and Winterport," unpublished report, Maine Department of Transportation, 16 State House Station, Child Street Augusta, Maine 03333, 18p.

Hayden, Scott (personal communication, 1997), Geologist, Maine Department of Transportation, Geotechnical Section, 219 Hogan Road, Bangor, Maine.

Henry, K.S. (1990) "A case study of the potential causes of frost heave," CRREL Special Report 90-9, CRREL, Hanover, NH, 42 p.

Henry, K.S. (in preparation) "The use of geosynthetics to mitigate frost heave in soils," Ph. D. Dissertation, Civil Engineering Department, University of Washington, Seattle.

Saarelainen, S. (1992) "Modelling frost heaving and frost penetration in soils at some observation sites in Finland: The SSR model," VTT Publications 95, Technical Research Centre of Finland, Espoo, 120 p.

Figure 1: Typical cross-section of test section D-1, constructed by the Maine Department of Transportation in Winterport, Maine.

Figure 2: Grain size distributions of subgrade soils placed above and below the geocomposite in test section D-1 in Winterport, Maine. The grain size distribution for the subgrade below the geocomposite was obtained from Hayden and Dunn (1996), and the grain size distribution for the soil above the geocomposite was obtained from Hayden (personal communication, 1997).

Figure 3: Stacked acrylic rings, lined with a latex membrane, placed on the porous base plate.

Figure 4: Compaction mold that was placed on the specimen base plate and surrounds the membrane-lined rings during specimen compaction.

Figure 5: Top and bottom bath temperatures.

Figure 6: Specimen 2 after freezing.

Figure 7: Specimen 4 after freezing.

Figure 8: Frost heave and penetration of test specimens.

Figure 9: Post test water contents for test 1 specimens.

APPENDIX

TENDRAIN 100-2**DOUBLE-SIDED GEOCOMPOSITE (GEOTEXTILE - TRI-PLANAR GEONET -GEOTEXTILE)**

The drainage geocomposite is comprised of a tri-planar geonet structure consisting of thick supporting ribs with diagonally placed top and bottom ribs and with a thermally bonded, non-woven geotextile on both sides. The product is capable of providing high flow rates in a soil environment under high normal loads and will have properties conforming with the values and test methods listed below

PROPERTIES	TEST METHOD	UNIT	VALUE	QUALIFIER
GEONET CORE				
Tensile Strength - MD	ASTM D4595	lb/ft	1000	c, Note 1
Compressive Behavior (% Retained thickness) @50,000 psf (short term)	ASTM D1621	%	50	a, Note 2
@25,000 psf (10,000 hours)		%	60	a
Resin Density	ASTM D1505	g/cm ³	0.94	c
Resin Melt Index	ASTM D1238	g/10 min.	1.0	d
Carbon Black Content	ASTM D4218	%	2.0	c
Thickness	ASTM D5199	mils	300	c, Note 3
GEOTEXTILE				
Apparent Opening Size (AOS)	ASTM D4751	US Sieve (mm)	100(0.15)	b,4
Weight	ASTM D3776	oz/sy	8	b,4
Water Flow Rate	ASTM D4491	gal/min/ft ²	100	b,4
Permeability	ASTM D4491	cm/sec	0.3	b,4
Puncture	ASTM D4833	lbs	130	b,4
Trapezoid Tear	ASTM D4533	lbs	80	b,4
Grab Tensile Strength	ASTM D4632	lbs	200	b,4
Grab Elongation	ASTM D4632	%	50	b,4
Mullen Burst	ASTM D3786	psi	450	b,4
UV Resistance @500 Hours	ASTM D4355	%	70	b,4
GEOCOMPOSITE				
Roll Width		ft	6.7	a, Note 5
Roll Length		ft	200	a, Note 5
Ply Adhesion	ASTM D413	lbs/in	2	c, Note 6
HYDRAULIC BEHAVIOR OF GEOCOMPOSITE IN SOIL				
Transmissivity - MD (X 10 ⁻⁴ m ² /sec)	ASTM D 4716-95			Notes 7
<u>Gradient/Load:</u>	<u>15,000 psf</u>		<u>25,000 psf</u>	
0.1	22.5		10	
0.5	12		5	
1	8		4	
Flow Rate Per Unit Width - MD (gpm/ft)	ASTM D 4716-95			Notes 7
<u>Gradient/Load:</u>	<u>15,000 psf</u>		<u>25,000 psf</u>	
0.1	1.1		0.5	
0.5	2.9		1.2	
1	3.9		1.9	

Qualifiers: a = Typical Value b = Minimum Average Roll Value (MARV)
c = Minimum Value d = Maximum Value

NOTES:

- Tensile properties tested by manufacturer every 40,000 square feet of product per ASTM D4595 with a specimen width of 8.0 in. and cross-head speed of 0.04 in./min.
- Compression behavior tested by manufacturer every 40,000 square feet of product per ASTM D1621 with a 2 in. x 2 in. specimen and a constant rate of strain of 0.04 in./min.
- Thickness measured by manufacturer every 40,000 square feet of product per ASTM D5199 with a 2.22 in. diameter presser foot and 2.9 psi pressure.
- Geotextile properties listed are prior to lamination.
- Roll dimensions are measured at the time of manufacture.
- Ply adhesion tested by manufacturer every 40,000 square feet of product per ASTM D413 with a 2 in. wide strip where the geotextile bonded to either side of the geonet is pulled apart at a speed of 2.0 in/min. The value reported for each laminated side is the average of the 5 peak values from each specimen. Both the top and bottom geotextile interfaces must be evaluated.
- Geocomposite transmissivity measured by manufacturer every 100,000 square feet of product as per ASTM D4716-95 with testing boundary conditions as follows: steel plate / uniform sand / geocomposite / 60 mil HDPE geomembrane / steel plate