

Effect of a Geotextile on Water Migration and Frost Heave in a Large-Scale Test Basin

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The objective of this study was to examine the effect of a needle-punched polyester geotextile on moisture migration and frost heave during freezing and thawing in a large test basin. In the past, nonwoven polypropylene geotextiles have been effective in reducing frost heave in laboratory tests. In this case, a needle-punched polyester geotextile separator was monitored for its influence on frost heave and soil moisture tension for four freeze-thaw cycles in a large test basin. Results from freezing tests in the test basin without a water table and with a water table present 12.7 cm below the fabric suggest that use of the fabric results in greater frost heave. When the water table was above the fabric, the fabric had no influence on frost heave or water distribution in the soil. Laboratory tests indicate that the separator had no effect on frost heave. Tensiometer data in the test basin indicate that lateral transmission of water through the fabric may have occurred, so transmission of water from thawed soil to freezing soil may have contributed to increased frost heave. It is concluded that if a geotextile is used in frost-susceptible soil, proper drainage and the correct fabric type must be used to prevent increased frost heave. The role of geotextile surface properties is important and their influence on moisture migration should be investigated further.

The objective of this study was to determine the effect of a needle-punched polyester geotextile separator on moisture migration during freezing in a large-scale test basin. The capillary breaking action of polypropylene geotextiles has recently been found effective for reducing frost heave in the laboratory (1). Testing geotextiles for this purpose on a larger scale was desirable and, therefore, implemented as an adjunct study of a project evaluating vehicle mobility on thawing soils (2). The geotextile that was used as a soil separator was also monitored for its effect on frost heave.

SOIL MOISTURE AND CAPILLARY BARRIERS IN FREEZING SOILS

Moisture Migration in Freezing Soils

When a frost-susceptible soil freezes in the presence of an adequate water supply, soil water will migrate from warmer regions to the location of the freezing front and form ice lenses. Ice lens formation, also called ice segregation, is the primary cause of frost heave. As water freezes and becomes depleted adjacent to the ice, water pressure in that vicinity drops (tension increases) and water migrates to this location.

If a soil is not saturated, frost heave can still occur. In this case, water moves in adsorbed films and capillary spaces to the freezing front. Hence, the water available in the capillary fringe of a water table has always been a concern of geotechnical engineers when designing to prevent frost heave. U.S. Army Corps of Engineers guidance states that a water table within 2 m of the surface at any time of the year constitutes an adequate water supply for frost heaving to be troublesome (3).

Geotextiles as Capillary Barriers

Scandinavian countries have used capillary barriers consisting of coarse granular material (i.e., sands and gravels) to break the capillary rise of water in roads built on frost-susceptible subgrades (4,5). The capillary barrier layer is placed above the water table and below the maximum depth of frost. It then reduces water availability to the freezing front and thus reduces frost heave.

Laboratory research has indicated that geotextiles can reduce frost heave in soils when placed above the water table and below the freezing front (1,6,7). Results from an instrumented soil column subjected to freezing from the top down indicated that a needle-punched polypropylene geotextile interrupted a constant soil moisture tension gradient (i.e., moisture content gradient); also, the soil above the fabric progressively dried during freezing, indicating that the geotextile layer restricted upward water migration (6,8).

Geotextile properties used in capillary barriers include relatively large pore sizes and hydrophobic fibers. The equation for the height of capillary rise in a cylinder demonstrates the importance of these parameters, even though the pore space in a soil is very complex (9):

$$h = \frac{2T \cos \alpha}{R\gamma} \quad (1)$$

where

- h = height of capillary rise,
- T = surface tension of liquid,
- R = radius of the tube,
- γ = unit weight of the liquid, and
- α = contact angle between the liquid and the tube (wetting angle).

If a geotextile has larger pores than the surrounding soil or a higher wetting angle, it will have a lower height of capillary rise, as well as lower hydraulic conductivity when the soil is not saturated.

Soil Moisture Measurement in Freezing Soils

The total soil-water potential consists of the sum of the matric potential, the osmotic potential, the gravitational potential, and other effects that may influence the energy status of soil water (10). The matric potential of soil water depicts the tenacity with which soil water is held by the soil matrix and is related to the soil wetness through the soil-moisture characteristic curve. Thus, measurement of the soil matric potential, also called soil-moisture tension, can be converted to soil water content through use of the soil-moisture characteristic curve.

The soil-moisture characteristic is determined in the laboratory; there is a hysteresis effect for wetting and drying processes. The density of the soil also affects the soil-moisture characteristic. Because of hysteresis and the dependence of soil density, the in situ measurement of soil moisture tension and its conversion to moisture content by use of the soil-moisture characteristic provide only an estimate of soil wetness.

When a soil is not frozen or saturated, its matric potential can be measured with soil-moisture tensiometers. A tensiometer is composed of a porous ceramic tip connected to a manometer through a tube (see Figure 1). Normally, all parts of the tensiometer are filled with water. When the tensiometers were subjected to freeze-thaw cycles, they were filled with propylene glycol to avoid damage from freezing. McKim et al. (11) found that the tensiometer response is the same whether filled with glycol or water. When the porous cup is placed in the soil, the fluid inside the cup equilibrates with the soil water through the pores in the ceramic tip. When the soil is not saturated, the soil water is at less-than-atmospheric pressure, and it will draw fluid from the tensiometer. The resulting drop in pressure (rise in tension) is indicated on the tensiometer gage.

EXPERIMENTAL METHOD

The experimental program was conducted as an adjunct to an off-road vehicle mobility test program in thawing soils (2).

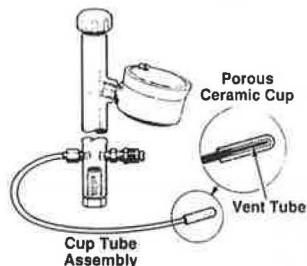


FIGURE 1 Construction and components of a soil moisture probe tensiometer.

It was designed to determine how a needle-punched polyester geotextile separator affected frost heave and moisture migration during freezing. Open-system freezing tests (i.e., freezing tests with water freely available to the soil) were also conducted in the laboratory on specimens containing the test basin soils, with and without the geotextile as a separator, in order to examine its influence on frost heave.

Freezing and thawing in the test basin were controlled using refrigeration panels placed on the soil surface. Moisture content in the soil was varied by changing the water table depth or by adding surface water to simulate rain or snow melt. The soil moisture tension and temperature profile were recorded throughout freezing and the amount of frost heave was measured by surface elevation surveys.

FERF Test Basin

The large-scale experimental work was done in the Frost Effects Research Facility (FERF) of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. The unique capabilities of the FERG allow large-scale experimental conditions to be carefully controlled. The conditions varied were freeze rate, depth of frost, water table elevation, and soil moisture content. The test basin used was 36.6 m long and 12.3 m across, as shown in Figure 2. For freezing and testing, it was only used one-half at a time; vehicle mobility testing occurred on one-half of the test basin during the thaw while the other half of the test basin was being frozen.

Soils

The test section consisted of a bottom layer of fill and a top layer of test soil, separated by a geotextile (Figure 3). The purpose of the fill material was to simulate a natural environment (i.e., having no rigid, impermeable layer directly below the layer of test soil) and to allow for a water table to be added and varied relatively quickly. The test soil was chosen to simulate an off-road condition for vehicle mobility testing. It is a typical subgrade or off-road material in this part of New England. The fill soil was a bank run gravelly sand from Pompy Pit, Thetford, Vermont, and the test soil was a silty sand from Lebanon, New Hampshire. The grain size distribution curves and moisture characteristics for both soils are shown in Figures 4 and 5. The height of saturated capillary rise can be estimated from the moisture-tension curves. Examination of the drying curves (arrow toward increasing tension) in Figure 5 indicates that the breakthrough pressure (nearly 100 percent saturation) for the Lebanon sand is approximately 6 kPa; it is approximately 3 kPa for the Pompy pit sand. Dividing by the unit weight of water yields the height of capillary rise—0.6 m for the Lebanon sand and 0.3 m for the Pompy pit sand.

The frost susceptibility of the base material (gravelly sand) is classified as low, on the basis of the standard CRREL frost heave test and the Corps of Engineers classification scheme (3,12). The silty sand test soil is highly frost susceptible, having a frost heave rate of 7.4 mm/day when subjected to the

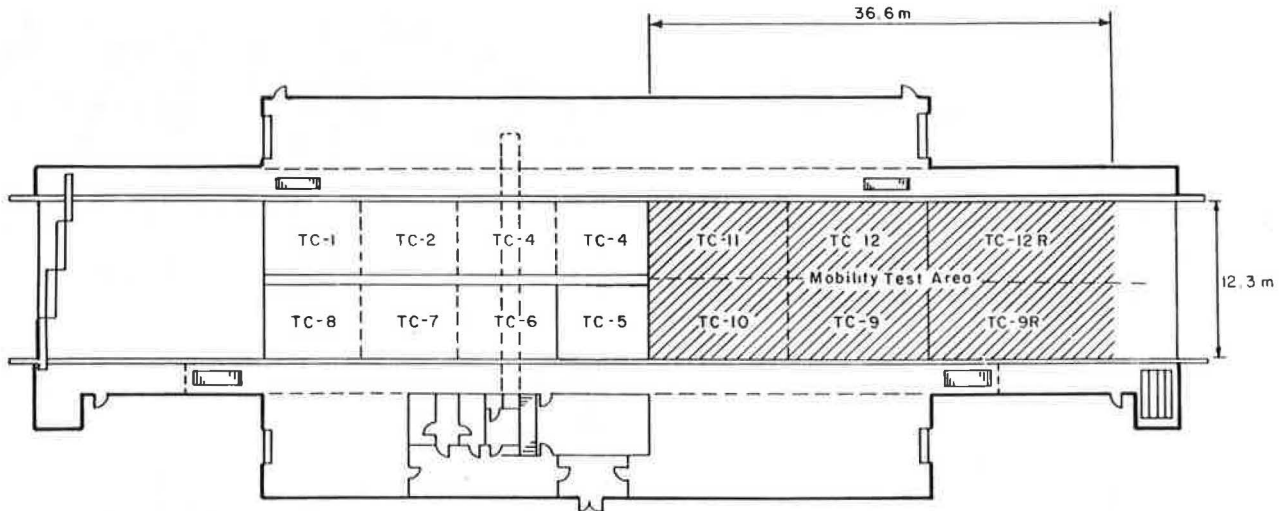


FIGURE 2 Plan view of the soil test basin (hatched area) in the Frost Effects Research Facility.

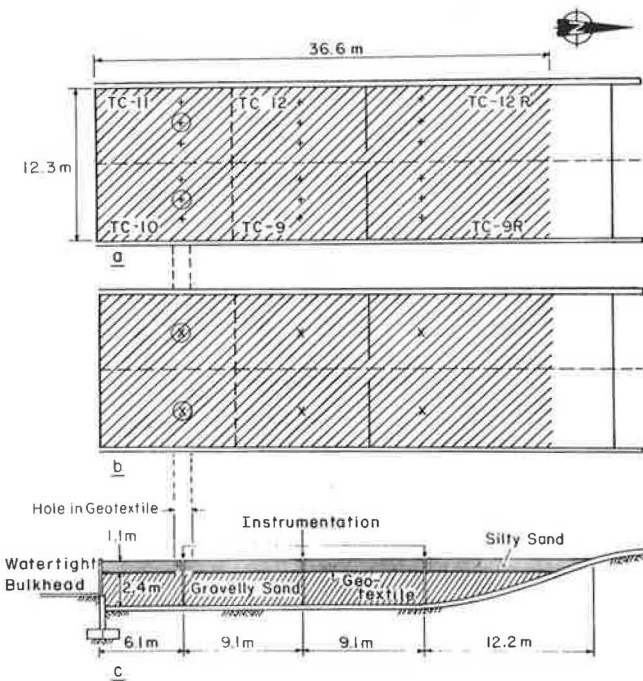


FIGURE 3 Plan view and cross section of the test basin: (a) location of frost heave survey stations, (b) instrumentation locations, and (c) cross section of the soil basin showing configuration of test soil, base fill, and geotextile as well as location of instrumentation.

standard CRREL frost heave test. Frost heave test data and additional soil properties have been provided by Shoop (13).

Geotextile

The geotextile used was a needle-punched polyester. It was chosen as a separator for the two soils on the basis of the Corps of Engineers Civil Works Guide Specification, #CW-

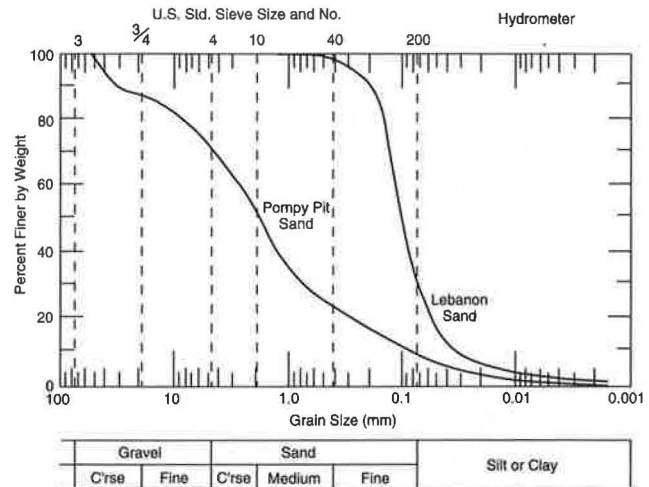


FIGURE 4 Grain size distribution curves of the bank run gravelly sand used for the base fill (below the fabric) and the silty sand used as the test soil (above the fabric).

02215, March 1986, using Filter Design Criteria. Specifications are as follows:

Characteristic	Specification
Thickness	3.3 mm
Weight	0.34 kg/m ²
Equivalent opening size	70 to 100 mm
Permittivity	300 sec ⁻¹
Puncture	578 N
Mullen burst	2700 kPa
Grab tensile/Elongation	1156/100 N per percent

On the basis of past work, polypropylene would have been chosen for a capillary barrier material owing to its hydrophobic nature (e.g., 1). However, a polyester fabric was selected so that water could easily move across the layer of the fabric. Polyester is less hydrophobic than polypropylene (adsorbing and absorbing water more readily). It may still act as a cap-

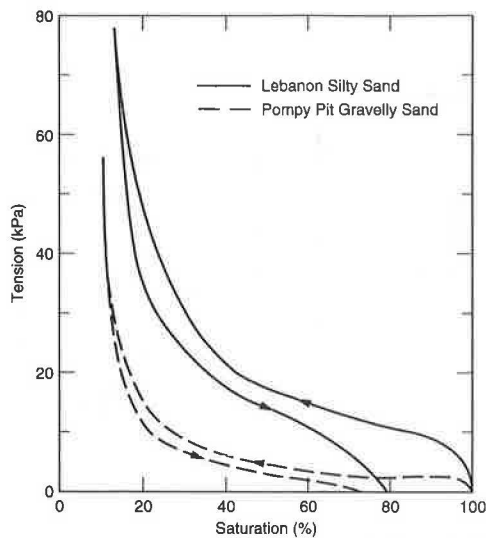


FIGURE 5 Moisture tension curves for the Pompy Pit bank run (gravelly sand) and Lebanon sand (silty sand).

illary barrier because, on average, it had larger pore sizes than the surrounding soil, and possibly was somewhat more hydrophobic than the soil. Specifying that the fabric be made of polyester did not guarantee the wetting behavior because surface finishes can change the wetting properties of the fibers (14).

The fabric separated the test soil and the base fill at a depth of 107 cm. It was placed over the entire test basin with the exception of two circular holes, of 1.2-m (4-ft) diameter, cut into the fabric as shown in Figures 3 and 6. Each circle had a vertical string of tensiometers and thermistors located in its center; these sections were used as reference sections. Entire sections were not left without the geotextile separator because the separator was necessary for maintaining the test sections for vehicle mobility testing. The fabric was present at the other four instrumentation locations (Figure 3).

Instrumentation

Thermistors and tensiometers were used to monitor soil temperature and moisture tension throughout each freeze–thaw cycle. The soil instrumentation was concentrated in the upper 30 cm because this is the area of most concern for vehicle mobility. Near the fabric, the thermistors were placed symmetrically at 2.5 and 30.5 cm above and below the fabric. Figure 7 shows the vertical configuration and location of the instrumentation.

Water Table

Water was added to the basin through four standpipes, one in each corner of the basin. These pipes were connected to horizontal pipes located 0.3 m from the bottom of the test cell in the base fill. The lower pipes were perforated to allow water seepage, and the water level was measured at each of



FIGURE 6 Geotextile being installed and the 1.2-m-diameter hole in the geotextile around the instrumentation in Test Cells 10 and 11.

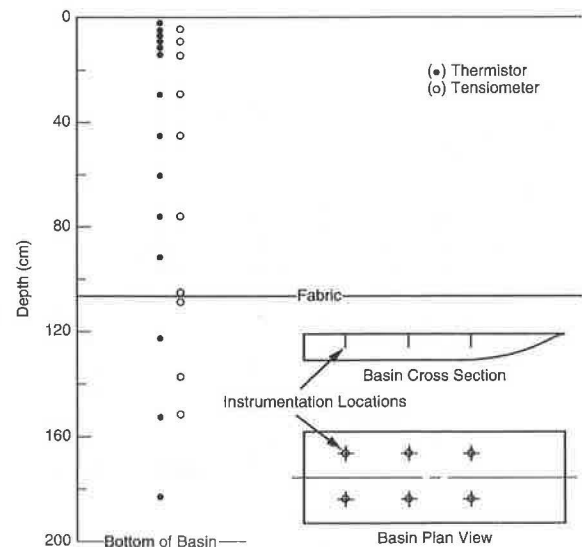


FIGURE 7 Instrumentation configuration in the test basin.

the standpipes. To lower the water table, water was drained through four drains in the test basin floor.

Test Basin Procedure

The soil was placed in the basin in 15-cm lifts, tilled, then compacted to 95 percent of maximum density as determined using modified Proctor compaction tests (ASTM D 1557); compaction curves were provided by Shoop (13). If desired, water was added and allowed to equilibrate. The soil surface elevation was then surveyed (Figure 3a). Freezing panels were placed on the soil surface and the soil was frozen from the top down. The freezing rate was controlled by adjusting the temperature of the coolant in the refrigeration panels. The soil was frozen to depths ranging from 43 to 66 cm. When the desired frost depth was obtained, the panels were removed.

While the soil was still frozen, the soil surface was surveyed to determine the amount of frost heaving. The soil was then allowed to thaw by maintaining spring-like conditions within the building (7°C to 13°C). Vehicle mobility was tested during thawing. After the soil was thoroughly thawed, it was tilled and compacted for the next frost cycle.

Laboratory Freezing Tests

Standard CRREL frost susceptibility tests were conducted on four specimens prepared from the test basin soils. The details of the procedure were provided by Chamberlain (12). Usually, cylindrical soil specimens, 150 mm in diameter by 150 mm in height, are compacted to a specified uniform density and subjected to two freeze-thaw cycles. Before freezing, the samples are saturated for 24 hr, then the water table is lowered to 1 cm above the base of the sample. Water is freely available through porous base plates during the test, and each freeze or thaw cycle lasts for 24 hr.

For this test program, a few modifications were made to the standard procedure. Four specimens were prepared, and each one consisted of one-half Pompy Pit gravelly sand, placed in the bottom of the cylinder, and one-half of Lebanon fine sand, placed in the top of the cylinder. Two of the specimens contained disks of the geotextile separating the soil layers. The fabric was glued to the edge of the container with silicone adhesive. In addition, the specimens were subjected to five freeze-thaw cycles.

For the laboratory freezing tests, the Pompy Pit bank run gravel was compacted to 2.00 Mg/m³ (125 lb/ft³) dry density, which is 93 percent of maximum dry density, and the silty sand was compacted to 1.68 Mg/m³ (105 lb/ft³), which is also 93 percent of maximum dry density.

CONDITIONS TESTED AND RESULTS

Frost heave, soil moisture tension, and temperature were monitored for the freeze cycles and conditions presented in Table 1. The soil moisture tension profiles during freezing were studied to determine the influence of the geotextile on moisture in the soil. The surface of the soil was surveyed before and after each freeze to measure the total amount of

frost heave. The results of tests are discussed for three different water tables: no (or deep) water table, a water table 12.7 cm below the geotextile, and a water table 11.4 cm above the geotextile. Data from the test sections in the ramp area of the test basin were not consistent with the other test data and were believed to be influenced by outside conditions. Therefore, they are not included.

No Water Table

The first two freeze cycles on the test basin were done without a water table. Water was added to the soil surface to aid soil compaction when preparing the test section and this surface water quickly drained into the soil. The initial moisture conditions, the length of the freeze, and the frost depth were different for the two tests as indicated in Table 1 and Figure 8.

The soil tension profiles before each of the freeze cycles are shown in Figure 8. The drying portion of the soil-moisture characteristic (Figure 5) was used with the tensiometer data to estimate the soil-moisture contents. The drying portion of the curve was used because the soil had been wetted to field capacity (specific retention) during compaction. Tensiometer data before freezing (Figures 8a and 8b) indicate that the soil immediately above the interface between the fine sand and gravelly sand was near saturation regardless of whether the fabric was present. Both cases indicate that the soil below the fabric was drier than the soil at the same depth when no fabric is present. Before the first freeze test began, the soil below the fabric was at 14 percent saturation compared to 48 percent for the soil below the hole in the fabric. Before the second freeze, this difference was smaller—25 percent saturation below the fabric versus 44 percent saturation when no fabric was present.

During freezing, all of the unfrozen soil below the depth of frost became drier (soil tension increased) as the soil moisture was drawn to the freezing front. Figures 9 and 10 show selected soil tension profiles throughout Freeze Cycles 1 and 2, respectively. Only the data below the frost line are shown because tensiometers do not work reliably in frozen soils. When the fabric was present, there was a significant break in the soil-moisture tension gradient (approximately 12 kPa), and the soil below the fabric is drier than that above the fabric.

TABLE 1 FROST HEAVE, FROST DEPTH, AND WATER LEVEL FOR EACH OF THE FREEZE CYCLES

Freeze cycle	Julian days	Frost depth (cm)	Water level (cm)	Frost heave (cm)		
				Above hole	Above fabric	
				Ave.	(Std. dev.)	
1	120-138	56	no water table	0.61	1.45	(0.95)
2	160-201	43	no water table	0.91	2.67	(1.89)
3	63-311	66	12.7 cm below fabric	4.88	7.01	(2.68)
4	313-361	52	1.4 cm above fabric	7.93	7.77	(0.88)

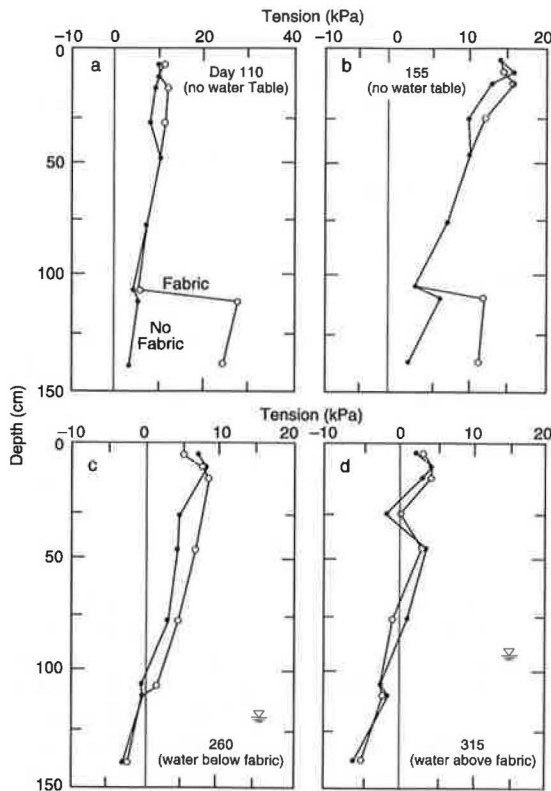


FIGURE 8 Tension profiles before each freeze cycle (a) tension measured on Julian Day 110, no water table; (b) tension measured on Julian Day 155, no water table; (c) tension profiles on Julian Day 260, water below fabric; and (d) tension profile on Julian Day 315, water above fabric.

However, the soil moisture tension gradient is essentially constant on either side of this discontinuity. Furthermore, throughout the test, the soil above the interface between the base fill and test soil is at about the same degree of wetness (90 to 100 percent saturated) regardless of whether the fabric is present.

During the first freeze cycle (Julian Days 120 to 138, Figure 9), the soil both above and below the fabric, as well as the soil without fabric, continually dried as freezing progressed. Furthermore, the fabric did not appear to restrict the moisture movement because the soil above the fabric did not dry out any faster than the soil below (Figure 9b).

During the second freeze cycle (Julian Days 160 to 210, Figure 10), when no fabric was present, the tension profiles indicate increased moisture in both the upper and lower soils after Day 175. When fabric was present, tension profiles exhibited progressively wetter conditions above the fabric whereas the soil below the fabric continued to dry. When no fabric was present, both the silty sand and the gravelly sand became wetter as freezing progressed. Because water was added to Test Cells 11 and 12 for compaction while freezing was occurring in Test Cells 9 and 10, the water added during compaction (or released during the thaw of Test Cells 11, 12, and 12R) may have migrated through the fabric to the east side of the basin where the soil was freezing, being drawn into the soil above by the capillarity of the fine sand.

The frost heave calculated from the elevation surveys for all freeze cycles are presented in Table 1. For the no-water-table condition (Cycles 1 and 2), the data suggest that frost heave above the hole is less than the frost heave above the fabric. However, the frost heave above the hole in the fabric falls within one standard deviation of the mean, leaving some doubt as to the statistical significance of the lower frost heave value.

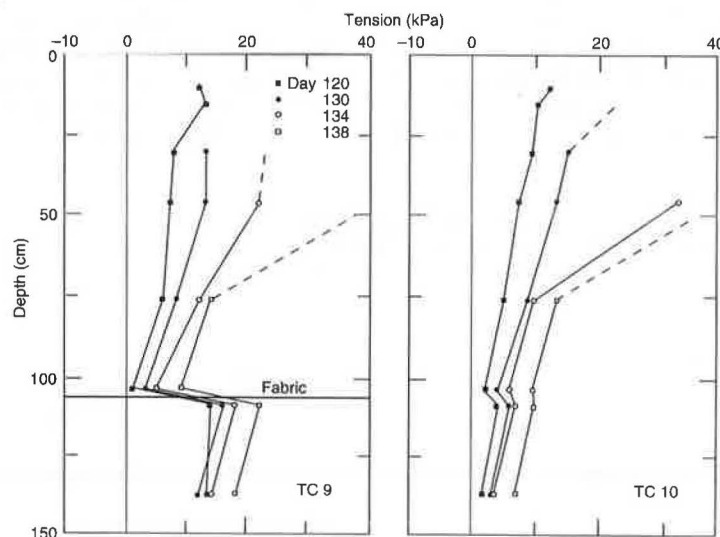


FIGURE 9 Representative tension profiles throughout the freeze cycle during Julian Days 120 to 138 (no water table).

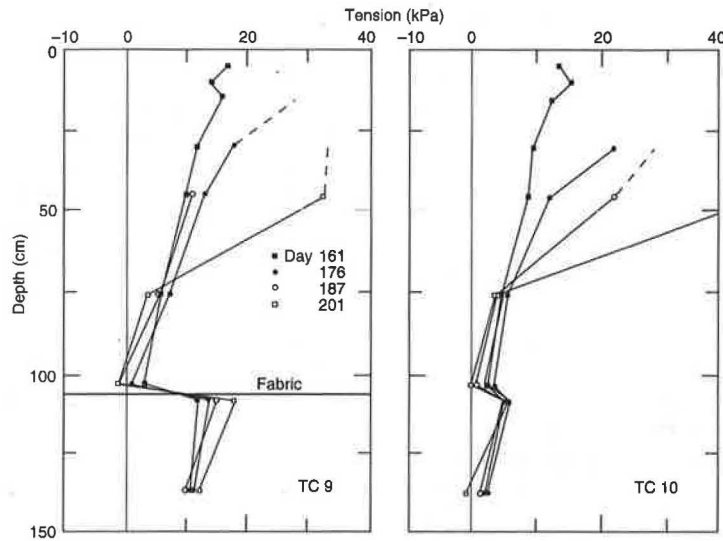


FIGURE 10 Tension profiles for the freeze cycle during Julian Days 160 to 201 (no water table).

Water Table Below Fabric

The third freeze test was conducted to examine the influence of the geotextile on water migration and frost heave when a water table was present below the fabric. The water level was initially raised to 2.5 cm below the fabric and then allowed to fluctuate between 2.5 and 20.0 cm below the fabric to simulate natural fluctuations in a water table. The average water table elevation was 12.7 cm below the fabric.

Before freezing, the soil tension profiles indicate that the depth of the water table was immediately below the fabric (Figure 8c), and this agrees with the water levels measured in the wells. The soil above the fabric was slightly drier than the soil above the hole in the fabric. The tension data also indicate that the water level was about 12 cm higher when

there was no fabric. The capillary fringe may have extended up into the silty fine sand, and when the fabric was present, the fabric may have prevented the capillary rise of water.

The soil moisture tension profiles during freezing for this test are shown in Figure 11. For both the fabric and no-fabric locations, the tension gradient, and thus the moisture conditions, did not change much during freezing. Below the fabric, the tensiometers indicate a positive pressure of 1 to 4 kPa (when corrected for elevation), reflecting that they are below the water table. There was little or no change in the tension gradient at the soil interface whether or not the fabric was present.

The heave measured above the hole in the fabric is 4.9 cm and the average of the heave measured at stations above the fabric is 7.0 cm. These frost heave data again suggest that the

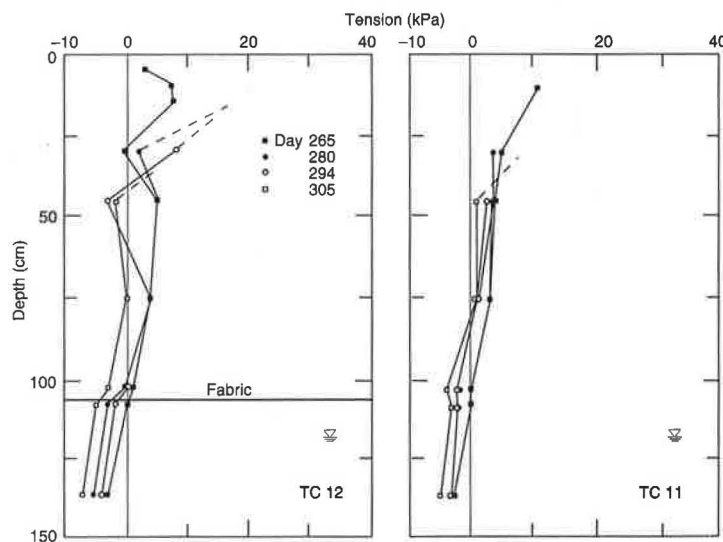


FIGURE 11 Tension profiles for the freeze cycle during Julian Days 263 to 311. The water level averages 12.7 cm below the level of the fabric.

use of the fabric resulted in more frost heave; but the heave above the hole in the fabric falls well within one standard deviation of the average of the heave above the fabric. Again, the effect of fabric on frost heave cannot be stated with certainty.

Water Table Above Fabric

During the fourth freeze cycle on Julian Days 313 to 361, the water table was held an average of 11.4 cm above the fabric (fluctuating between 3 and 18 cm above the fabric). The soil moisture tension profiles shown in Figure 12 exhibit little change with the progression of freezing. The small fluctuations seen were related to the changes in the water table level. As expected, the fabric had no significant influence on the soil moisture tension. Furthermore, there is no offset in the soil moisture tension profile at the change in soil type, regardless of whether fabric is present. There was no difference in frost heave above the reference and fabric sections (Table 1).

Laboratory Test Results

The results of the laboratory freezing tests, in terms of frost heave as a function of time for the first and fifth (last) freezing cycles are shown in Figures 13a and 13b. Table 2 presents the frost heave rates during the sixth to eighth hour of freezing [the dependent variable recommended by Chamberlain (12)]. The fabric had no significant influence on the rate of frost heave in these freezing tests. Neither the shape of the frost heave curve, nor the rates of frost heave are significantly different for the tests with fabric compared to the tests without fabric. Differences in overall heave at the end of the first freeze cycle most likely originate from the time in which ice began nucleating in the soil.

DISCUSSION OF RESULTS

In the test basin, the soil above the fabric was nearly always close to saturation (90 to 100 percent saturated before freezing), even when no water table was present. This condition indicates that the fabric may be preventing or retarding the downward, gravity-driven flow of water that had been added to the soil surface during test basin construction and soil preparation. This process is supported by the observation that the base soil is considerably drier below the fabric during Freeze Cycles 1 and 2 (ranging from 14 to 25 percent saturation), whereas the base soil below the hole in the fabric is significantly wetter (starting at about 50 percent saturation for both cycles and drying to approximately 30 percent in Cycle 1). Additional information suggesting that the fabric affects soil moisture distribution is the tensiometer data during the third freeze cycle when the water table was added below the fabric. Here, the test soil above the hole in the fabric is wetter than the test soil above the fabric. It reflects the same type of conditions as the first two freeze cycles, only now the water is available from below the fabric instead of draining from above, and the source of greater moisture above the hole in the fabric is the capillary fringe above the water table (rather than gravity drainage), which is apparently restricted by the fabric.

During all tests, the tension gradient with depth was constant although interrupted by the presence of the fabric. The gradient offset attributable to the fabric was greatest during Freeze Cycles 1 and 2 when no water table was present. For these cases, the tension gradient was offset by 10 to 20 kPa at the fabric, with the soil below being drier. Normally, water will flow from an area of low soil moisture tension to high soil moisture tension. Thus, the individual curves of Figures 9b and 10b may indicate that soil water moves from the region just above the fabric to the region just below the fabric. If this were true, the soil above the fabric would exhibit increased soil moisture tension with time, whereas the soil below

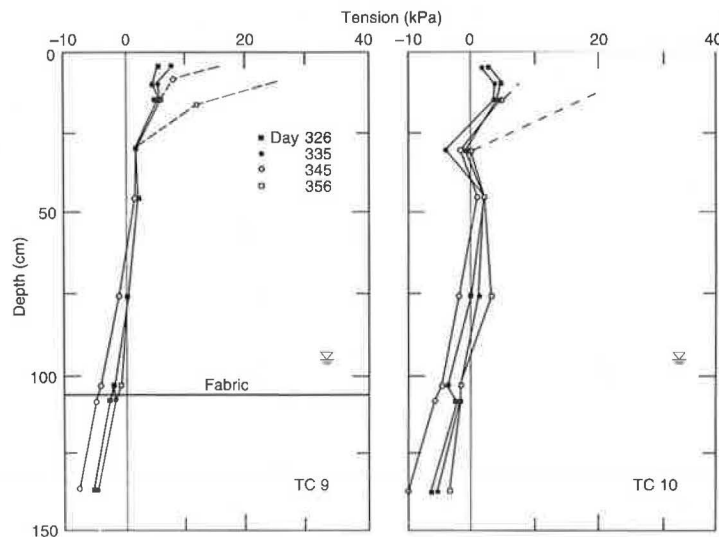


FIGURE 12 Tension profiles for the freeze cycle during Julian Days 313 to 361. The water level averages 11.4 cm above the fabric level.

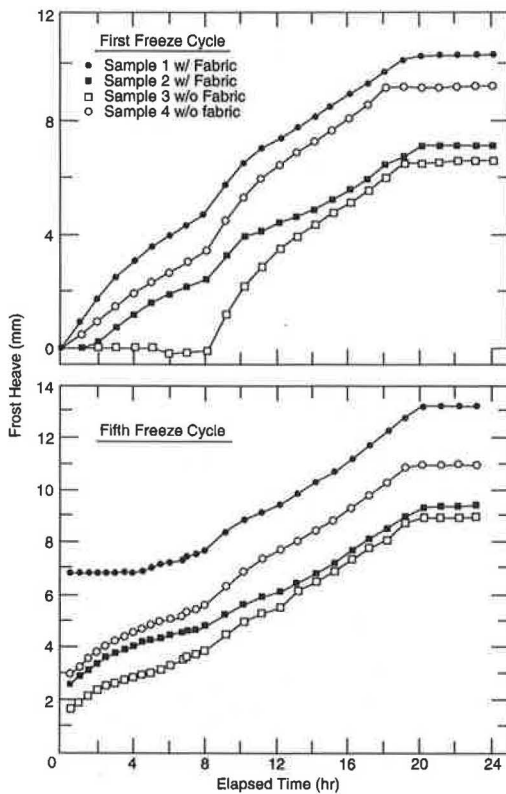


FIGURE 13 Laboratory frost heave test data—frost heave versus time for the first and fifth freeze cycles.

the fabric would exhibit decreased soil moisture tension. This trend did not occur in the data. Furthermore, it is not prudent to project what is known about soil moisture movement in soils onto soil movement across the geotextile layer. In the analysis, the tensiometer data were considered to be providing information about soil moisture in the soils only, and not in the geotextile.

The tension profiles remained essentially the same shape during Freeze Cycle 1, i.e., the soils both above and below the fabric were drying at the same rate, indicating that water was moving through the fabric. However, during Freeze Cycle 2, the moisture increased during freezing directly above the fabric while the soil below continued to dry (Figure 10). This additional moisture must have migrated through the fabric from the other side of the test basin where the soil was thawing and water had been added for reprocessing the soil. This behavior was unexpected but laboratory tests indicated that

the fabric readily transported or siphoned moisture laterally even when no pressure differential was applied. Syphoning behavior of geotextiles has also been reported by Zerfass (15).

Frost heave measurements indicated that when the water table was below the fabric or absent, the frost heave above the fabric was greater than the frost heave when fabric is absent. However, because the magnitude of the difference is within one standard deviation of the mean, the significance of the difference is questionable. (The relatively high standard deviation of the frost heave measurements is ascribable to the roughness of the frozen ground.)

Open-system freezing tests of the soil-geotextile system in the laboratory indicated that the fabric did not affect frost heave. The difference between freezing in the test basin and the laboratory procedure was that the water in the laboratory freezing tests must flow vertically to cause frost heave, whereas in the test basin water was not constrained to flow only vertically. In addition, the laboratory tests were performed by first fully saturating the sample and then lowering the water table before freezing began. Freezing took place with a constant-head water supply, again not the same conditions as the large-scale basin tests.

Past work has indicated that nonwoven polypropylene (i.e., hydrophobic) geotextiles reduce frost heave up to 75 percent in open-system laboratory freezing tests (1,7). The most significant difference in the experimental parameters between past work and the laboratory tests conducted for this program is the nature of the polymer from which the fabric is manufactured. The polymer significantly influences the wetting properties of the geotextile. There are no standard tests for determining fiber wettability; however, a simple measurement was made of the relative performance of two geotextiles by placing the bottom 1 mm of a strip of geotextile into a dish of water. The observations were that the polyester geotextile used in this study wetted easily and displayed a capillary rise of 9 mm, which occurred in less than 2 min, whereas a similar geotextile made of polypropylene did not wet even after 48 hr. This result demonstrates the need for more work to define the role of fiber surface properties in geotextiles acting as capillary barriers.

SUMMARY AND CONCLUSIONS

The results of freezing tests conducted in the large test basin suggest that the use of the geotextile separator resulted in greater frost heave when the water level was either quite deep or just below the fabric. As expected, the fabric had no influence on frost heave when the water level was above it. An

TABLE 2 LABORATORY FREEZING TEST FROST HEAVE RATES (mm/hr) FOR THE SIXTH TO EIGHTH HOUR OF FREEZING

	With fabric		Without fabric	
	Sample 1	Sample 2	Sample 3	Sample 4
Cycle 1	0.45	0.30	—	0.40
Cycle 5	0.20	0.20	0.33	0.15

interesting result of the tests is the apparent lateral transmission of water through the fabric from the thawed section to the freezing section in the second freeze cycle.

The test results indicate that caution should be exercised when selecting a geotextile for any function that would place frost-susceptible soil above it in a frost prone region. Until more research is conducted, if a fabric is selected for use as a separator in frost-susceptible soils, it appears prudent to include drainage at the level of the geotextile if it is desirable to minimize frost heave.

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