

Permeability Testing of Geotextiles

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In recent years, geotextiles (filter fabrics) have been used extensively as filters for drainage systems. Unfortunately, the increase in use has not been accompanied by the development of suitable testing methods or specifications. This paper investigates fabric permeability tests and factors that affect the measurement of permeability and provides recommendations for a method to measure permeability. Both water and air permeability tests were evaluated by using nine geotextiles. For the water tests, a falling-head permeameter was used. The results indicated that the permeability of geotextiles was quite variable both within and between lots and the effect of the hydraulic gradient in the water test was significant. Data were also obtained to show the effects of sample size and operator and the number of samples needed to ensure a given level of accuracy. The term "permittivity," or permeability divided by fabric thickness, is presented. Fabrics that have high permeability do not always have high permittivity. Also, there is a linear relation between permittivity measured by the air and by the water tests. Because of its simplicity, the falling-head permeameter is recommended for adoption. The air-permeability test also shows potential for providing accurate results.

Control of subsurface water is often a problem during and after construction of an engineering project. Drainage must be provided so that excessive water pressures or seepage forces do not develop. Inadequate drainage may result in the instability of a soil mass and subsequent structural failure.

The need for adequate drainage of highways has become especially apparent in recent years because of the increasing number of pavement failures attributed to poor drainage (1). Conventional drainage design specifies graded aggregate filters so that soil movement into hydraulic structures is prevented. However, due to recent technological advances in the textile industry, geotextiles (filter fabrics) have gained increased acceptance as effective filters in drainage systems (2). The replacement of conventional aggregate filters with fabric reduces the amount of aggregate needed, eliminates the need for strict gradation control during filter placement, provides greater ease of construction, and, in most cases, reduces the overall cost of the drain.

Unfortunately, the rapid increase in fabric use has not been accompanied by the development of suitable design, testing, and evaluation technology. Basically, it is known that the geotextile must satisfy two requirements in filtration applications. First, the fabric must be sufficiently permeable to allow removal of groundwater without the buildup of excessive water pressures. Second, the fabric must be able to prevent piping or subsurface erosion of the soil mass being drained. Recent studies suggest that design for the retention of soil particles suspended in water might be accomplished through the use of relationships between soil grain size and the coefficient of permeability (3,4). Thus, the importance of geotextile permeability in drainage design is to permit the removal of groundwater without the buildup of excessive water pressures and to prevent the erosion of soil particles.

Several studies have been conducted to evaluate the permeability of systems of soil and fabric in direct contact (5-8). However, to provide a simple comparison of permeability of different geotextiles, the fabrics must be evaluated in isolation to eliminate variations due to different soil characteristics.

The purposes of this paper are (a) to investigate fabric permeability tests and factors that affect the measurement of permeability and (b) to recommend a method for measuring fabric permeability. The scope is limited to testing fabrics in isolation.

Mechanisms of filtration of soil particles are not considered nor is the influence of biological growth or chemical deposits and chemical, biological, or mechanical degradation on hydraulic behavior.

PERMEABILITY TESTING

Permeability is normally expressed in the form of Darcy's law, which assumes laminar flow. Then

$$k = q/(iA) \quad (1)$$

where

k = coefficient of permeability,
 q = volume of flow per unit time,
 i = hydraulic gradient ($= h/L$, where h is head loss and L is thickness of fabric), and
 A = cross-sectional area (9).

When turbulence occurs, a linear relationship between velocity and hydraulic gradient no longer exists. Darcy's law may be modified to account for turbulence as follows:

$$v^n = ki \quad (2)$$

where n is the turbulence coefficient (10,11). Values of n are greater than 1 for turbulent flow.

Fabric permeability testing by using water as the fluid has been performed by others (11-13; personal communication from J.P. Giroud, Woodward-Clyde Consultants of Chicago, IL). Both constant and falling-head test methods have been employed. In most cases, the number of specimens tested was small; however, several significant factors that affect test results were noted. These included turbulence, air in the system, and fabric compressibility.

Variation in fabric types is also a major factor that must be considered in test evaluation. Fabric characteristics that can affect test results are fiber diameter, type of construction, thickness, fiber density, and rigidity of structure.

Because the geotextiles are thin, it may be more meaningful to relate the flow through the fabric to the total hydraulic head loss across the fabric rather than to permeability. The permittivity (P), which is the ratio of the permeability to the geotextile thickness (k/L), provides this alternative. Permittivity is the volume of water that will flow per unit area of geotextile in a unit of time with a unit head loss across the fabric.

Numerous factors deserve consideration in geotextile permeability (permittivity) testing. As in all testing, the sample size and selection must be appropriate (sufficient specimens) to represent the material with the desired accuracy. There are also the usual permeability testing problems of deairing the water, the specimen, and the system; controlling or measuring temperature; and providing water of adequate quality. Further, the apparatus and procedure should not be sensitive to operator skill.

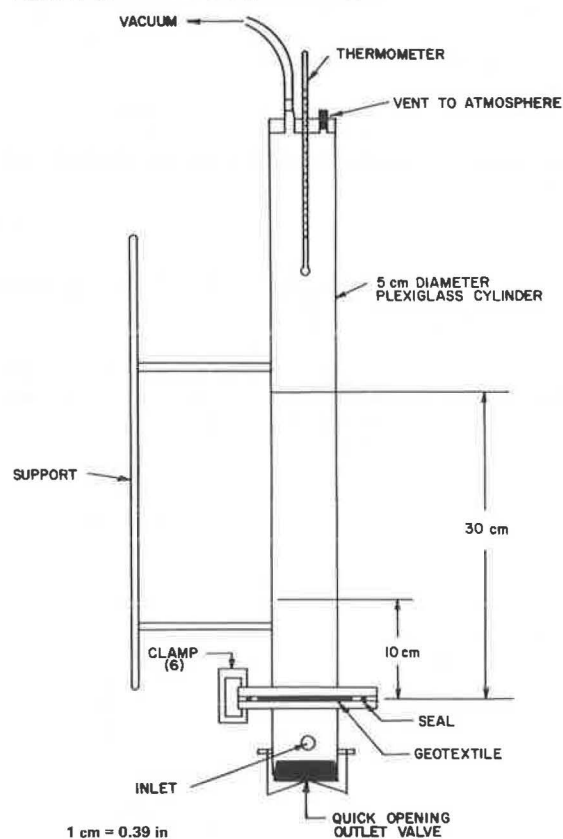
The combination of high permeability and small thickness creates special problems for testing geotextiles in a water-permeability test. With moderate gradients the flow rate is very high in a constant-head device. This requires large volumes of water, which creates supply problems if deaired

Table 1. Geotextiles tested.

Identification No.	Fiber Polymer(s)	Construction	Nominal Weight (g/m ²)	Average Thickness (mm)
Nonwoven Geotextile				
NW-1(3)	Polyester	Resin-bonded staple filament	100	0.86
NW-2(4)	Polypropylene and polyamide	Heat-bonded continuous filament	140	0.74
NW-3(4)	Polypropylene	Heat-bonded continuous filament	140	0.38
NW-4(8)	Polyester	Needle-punched continuous filament	270	3.00
NW-5(13)	Polypropylene	Needle-punched continuous filament	400	5.16
Woven Geotextile				
W-1(4)	Polyamide	Woven multifilament	240	0.51
W-2(7)	Polypropylene	Woven monofilament	220	0.41
W-3(8)	Polypropylene	Woven slit film	150	0.56
Combination Geotextile				
C-1(4)	Polypropylene	Woven slit film with needle-punched nap	140	0.97

Note: 1 gm/m² = 0.029 oz/yd²; 1 mm = 0.004 mil.

Figure 1. Schematic of falling-head test apparatus.



and filtered or distilled water is to be used. The gradient may be reduced by reducing the head loss across the specimen or by stacking several fabric specimens to increase the length of flow. The low head causes problems of accurate control. Stacked specimens create problems with deairing, clamping, and leakage.

A falling-head test solves the problem of needing large volumes of water, but the water level tends to drop very rapidly in the standpipe, which makes accurate time measurement difficult. This can be overcome by selecting a standpipe diameter larger than the specimen diameter. This tends to reduce practical specimen size and requires more tests to

obtain a reliable mean. Times and head changes large enough for convenient, accurate determinations result in gradients too large to assure laminar flow.

An alternative to trying to resolve these problems is to use a gas rather than a liquid to measure the permeability. It is theoretically possible to relate gas permeability to water permeability (10).

TEST PROGRAM

Two tests were conducted. An air test was selected to investigate the feasibility of this method for predicting water permeability. A falling-head water test was chosen for comparison because of its simplicity.

Nine geotextiles were investigated. They were selected to represent a range of types and weights commonly used in the United States in 1979. Table 1 lists the fabrics and their thickness, nominal weight, polymer type(s), and construction.

Seven specimens of each fabric were tested by using each method. The means of these tests were used to estimate the sample sizes required for specific desired accuracies. Some studies were also made of the effects of sampling within and between lots. The effects of gradient (turbulence) were also investigated for two geotextiles in the falling-head test by testing stacks of different numbers of specimens.

Air Permeability

Air-permeability tests were performed in accordance with ASTM D737. All fabrics were tested by using a pressure difference equivalent to 1.27 cm (0.5 in) of water across the fabric. The tests were performed by using a United States Testing Company, Inc., Air Flow Tester, Model 9025.

Water Permeability

The falling-head test apparatus consisted of a cylinder 5.08 cm (2 in) in diameter that had a 2.54-cm (1-in) opening at the flanges, as shown in Figure 1. The fabric was clamped between the flanges. After all openings had been sealed, a vacuum of 64 cm (25 in) of mercury was applied to the permeameter to ensure that air did not remain entrapped within the fabric. The permeameter was filled with deaired, distilled water from the bottom with the vacuum applied. After the temperature had been noted, the time for the water level to fall from 30 to 10 cm (11.8-3.9 in) above the fabric was re-

corded. The number of timings for each sample was determined after seven runs had been performed on the first specimen. The number of runs with one specimen required to yield a mean time within 5 percent of the true mean with a 95 percent probability was calculated by using Equation 3:

$$n_t = 0.154v^2 \quad (3)$$

where n_t is the number of timings required and v is the coefficient of variation as a percentage (ASTM D2905). Two to five runs per specimen were required for the fabrics studied; three runs were most common. With the ratio of standpipe to sample of 2, the time required for the head to drop from 30 to 10 cm ranged from 1.5 to 50 s. This allowed accurate manual timing.

Deaired water was used to eliminate variations in test results due to entrapped air within the fabric. This action and application of the vacuum before filling eliminated any need for prewetting the samples to ensure saturated samples. For some samples, a fiber coating would make prewetting difficult.

Water-permeability tests should also be performed by using distilled water or filtered tap water. Tap-water impurities may plug the fabric, which results in a lower coefficient of fabric permeability.

Thickness Measurement

Thickness was measured according to the procedure described in ASTM D1777 except that a 125-g (4.3-oz) load was applied over a 25-cm² (3.88-in²) pressure plate bearing on the fabric. These values were selected so that a nominal pressure would minimize fabric compression and a fairly large area would allow for fabric irregularities.

Calculations

The apparent coefficients of permeability for the geotextiles (for water at 20°C, assuming laminar flow) were calculated from the falling-head test data by the usual falling-head equation (1):

$$k_f = \left[\frac{aL}{At} \right] \left[\ln(h_i/h_f) \right] (\mu_{wt}/\mu_{w20}) \quad (4)$$

where

k_f = coefficient of permeability at 20°C measured by using water in a falling-head test,

a = area of standpipe,

A = area of fabric,

L = fabric thickness,

h_i = original height of water above fabric,

h_f = final height of water above fabric,

μ_{wt} = absolute viscosity of water at test temperature,

μ_{w20} = absolute viscosity of water at 20°C, and

t = average time for water surface to fall from h_i to h_f .

The coefficients of permeability for the geotextiles for water at 20°C were calculated from the air-test data by the following equation (10):

$$k_a = q \left\{ \left[\frac{(\mu_{at})L}{(\Delta P A)} \right] (\gamma_{w20}/\mu_{w20}) \right\} \quad (5)$$

where

k_a = coefficient of permeability at 20°C measured by using air,

ΔP = pressure difference across fabric,

q = air volume rate of flow at mean pressure,
 γ_{w20} = unit weight of water at 20°C, and
 μ_{at} = absolute viscosity of air at test temperature.

Permittivity was calculated from the following equation:

$$P = k/L \quad (6)$$

by using either k_a or k_f .

For each fabric, the number of specimens required to obtain a mean value of the coefficient of permeability within 5 percent of the true mean at a probability level of 95, 90, and 80 percent was calculated by assuming a student's t -distribution as follows (ASTM D2905):

Probability (%)	No. of Samples Required
95	$0.154v^2$
90	$0.108v^2$
80	$0.066v^2$

The test results are summarized in Tables 2 and 3.

DISCUSSION OF RESULTS

For the geotextiles tested, apparent coefficients of permeability from falling-head water tests (k_f) ranged from 0.2×10^{-2} to 37.8×10^{-2} cm/s. Permittivity values ranged from 0.03 to 1.44 s⁻¹. The relationship between apparent permeability and permittivity is illustrated by considering fabrics NW-4(8) and NW-2(4). Fabric NW-4(8) ($k_f = 3.38 \times 10^{-1}$ cm/s) is about four and one-half times as permeable as NW-2(4) ($k_f = 0.78 \times 10^{-1}$ cm/s), but both have the capacity to pass nearly the same quantity of water per unit time with permittivities of 1.15 s⁻¹ and 1.07 s⁻¹, respectively. Considering all the fabrics tested, the maximum apparent permeability coefficient is 189 times the minimum, but the maximum permittivity is only 48 times its corresponding minimum. The orders also change. The most permeable geotextile in terms of coefficient of permeability is only fourth in terms of permittivity.

The effect of gradient on the apparent coefficient of permeability measured in the falling-head test is indicated in Figure 2. These data are obtained from tests run by using from one to five layers of fabric in the permeability device. When more layers are used, the total thickness increases and, with other conditions being equal, the gradient through the geotextile decreases. The resulting increase in apparent permeability is probably due to reduced turbulence. The apparent coefficient of permeability increases until a constant value is approached. This corresponds to the maximum gradient for which flow is laminar and Darcy's law is valid. For the two fabrics tested, the true coefficient of permeability is approximately twice the apparent value obtained by using one layer of geotextile.

Experimentally, the problem of turbulence in tests that use water may be overcome either by increasing the number of fabric layers within the laminar range of flow or by performing tests at very low gradients. As mentioned previously, both these alternatives present problems. Another possibility may be to test by using a gas rather than a liquid.

The relationship between permittivities of the geotextiles to water as measured by air- and water-permeability tests is shown in Figure 3. There is a very good linear correlation between the two sets of data. The air-determined permittivity, however, is approximately twice the value measured in the

Table 2. Summary of air-permeability test results.

Fabric No.	Coefficient of Permeability					
	k_a (cm/s x 10 ²)	Coefficient of Variation (%)	Required No. of Samples ^a			Permittivity ρ_a (s ⁻¹ x 10)
			n_{95}	n_{90}	n_{80}	
Nonwoven						
NW-1(3)	22.1	5.0	4	3	2	25.9
NW-2(4)	15.8	10.3	17	12	7	21.8
NW-3(4)	2.2	15.8	39	27	17	5.7
NW-4(8)	64.3	4.4	3	3	2	21.5
NW-5(13)	65.5	13.1	27	19	12	12.8
Woven						
W-1(4)	0.3	6.9	8	6	4	0.5
W-2(7)	4.2	11.9	22	16	10	10.4
W-3(8)	0.3	13.4	28	20	12	0.7
Combination						
C-1(4)	1.9	13.4	28	20	12	2.0

Note: 1 cm/s = 0.39 in/s.

^aRequired to yield a mean within 5 percent of the true mean at probability levels of 95, 90, and 80 percent.

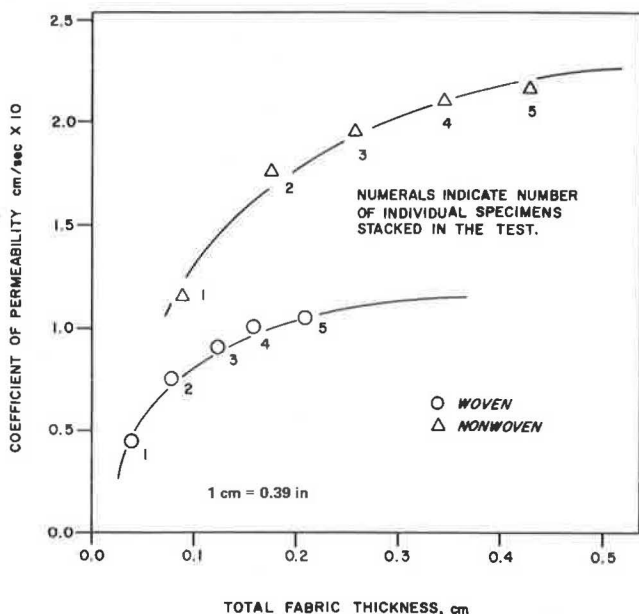
Table 3. Summary of falling-head permeability test results.

Fabric No.	k _u (cm/s x 10 ⁻²)	Coefficient of Variation (%)	Coefficient of Permeability			Permittivity P _r (s ⁻¹ x 10)
			Required No. of Samples ^d			
			n ₉₅	n ₉₀	n ₈₀	
Nonwoven						
NW-1(3)	12.3	8.4	11	8	5	14.4
NW-2(4)	7.8	8.3	11	8	5	10.7
NW-3(4)	1.3	12.3	24	17	10	3.4
NW-4(8)	33.8	17.0	45	32	20	11.5
NW-5(17)	37.8	9.8	15	11	7	7.4
Woven						
W-1(4)	0.2	9.3	14	10	6	0.4
W-2(7)	1.8	16.2	41	29	18	4.5
W-3(8)	0.2	14.7	33	24	15	0.3
Combination						
C-1(4)	1.0	23.4	85	60	37	1.1

Note: 1 cm/s = 0.39 in/s.

^aRequired to yield a mean within 5 percent of the true mean at probability levels of 95, 90, and 80 percent.

Figure 2. Relationship between total fabric thickness and coefficient of permeability for two geotextiles.



falling-head test by using water. This ratio of the air-determined to water-determined values is close to the ratio of multilayer to single-layer specimen values. It appears that the air-permeability test may be a simple, practical means of measuring geotextile permeability. Also the air-permeability test can be performed more quickly. However, initial expenditures are higher. This test deserves additional study to confirm the results of this investigation.

Data obtained in this study allow the evaluation of specimen variability, sample variability, operator variability, and the number of specimens required for desired accuracies.

Table 4 identifies the effects of sample selection on air-permeability test results. For two of the three fabrics, the coefficient of variation was essentially independent of where specimens were cut, provided that they were taken from the same lot. However, for the other fabric, the coefficient of variation was much greater when specimens were selected randomly over a large area than when they were taken from one localized area. This indicates that fabric variability may be high over a large area; therefore, specimens should be taken over a large area to obtain a representative value of permeability.

The variation in air-permeability results between

Figure 3. Relationship between air-test and water-test permittivities.

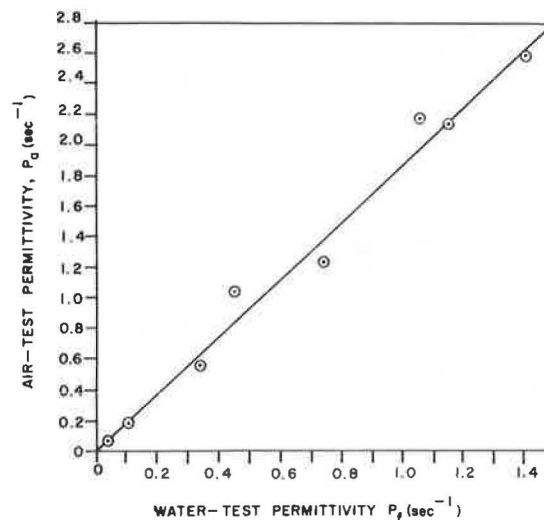


Table 4. Effect of sampling on air-permeability results.

Fabric Samples	Mean Flow Rate (ft ³ /ft ² /min)	Standard Deviation	Coefficient of Variation (%)
NW-4(4)			
A	458.3	49.80	10.87
B	425.6	43.32	10.18
C	319.7	12.03	3.76
W-2(7)			
A	146.2	18.5	12.7
B	147.4	15.08	10.64
C	109.4	34.77	31.78
NW-3(6)			
A	23.3	1.85	7.92
B	20.6	3.00	14.57
C	27.5	4.47	16.30

Notes: 1 ft³ = 0.028 m³; 1 ft² = 0.092 m².

A and B were taken from the same lot. The A specimens were cut from a large area. The B specimens were randomly selected from a large area. The C specimens originated from a different fabric lot. There were seven specimens in each sample.

Table 5. Effect of operator variance on falling-head test results on one fabric specimen.

Parameter	Operator		
	A	B	C
Calculated mean permeability k_f (cm/s)	0.113	0.114	0.120
Standard deviation	0.0087	0.0143	0.0077
Coefficient of variation (%)	2.91	4.77	2.42
Number of timings	7	7	7

Note: 1 cm = 0.39 in.

different lots of fabric is also exemplified in Table 4. In all cases, there is a 30-45 percent variation in the mean flow rate between lots. In addition, for two cases the higher flow rates corresponded to fabrics that had greater thicknesses. This combination of high flow rates and greater thicknesses results in even greater variability between coefficients of permeability. For example, the coefficient of permeability varied by almost a factor of 3 between lots for NW-4(4). It cannot be assumed that the mean permeability will be constant for all fabric lots. Values of permeability should be checked each time new fabric is introduced.

Specimen size logically should have an effect on the coefficient of variation. Larger specimens should tend to represent a more-average value of permeability and therefore have a smaller coefficient of variation. Attempts were made to identify such a trend between the air-permeability sample area of 6.99-cm (2.75-in) diameter and the falling-head sample area of 2.54-cm diameter. However, no such trend was apparent for the geotextiles tested. Therefore, a recommendation of sample size on the basis of coefficient of variation cannot be made from these data.

Since the coefficient of variation shows no consistency between fabric types, the number of samples required to achieve a given accuracy cannot be generally specified. For the tested fabrics, the number of samples required to achieve a mean within 5 percent of the true mean at a 95 percent probability level ranged from 4 to 69. Woven fabrics were not better as a group than nonwoven fabrics. Sample size should be chosen as discussed in ASTM D2905 for each application.

Since the specific falling-head test is a newly developed method for geotextiles, it is necessary to consider the variability in results as a function of operator. Table 5 presents test results obtained for one fabric sample tested by three different operators. A small variation of 10 percent occurs, probably as a result of timing errors. Based on this evidence, it appears that operator variance does not significantly affect the overall test results.

Some of the thick fabrics are compressible. The permeabilities can be expected to change as a function of the pressure on the geotextile, but this was not investigated in this study.

CONCLUSIONS AND RECOMMENDATIONS

Water-permeability tests should use deaired distilled or filtered water and care should be exercised to deair the specimen. Even with care, simple water tests on only a few specimens and with relatively high gradients may only be accurate within an order of magnitude. In many instances, soil permeability and other data are not precisely known and this accuracy is satisfactory. If, however, the permeabilities of geotextiles are to be measured accurately, special procedures must be followed to

assure laminar flow and adequate samples. Laminar flow may be assured by testing with very small differences in pressure across the specimen or by testing stacks of geotextile specimens to increase thickness. Each creates special testing problems.

Air-permeability testing shows potential for providing accurate results and for solving the turbulent-flow problem in a simple, economical way. Additional research should be conducted on this method.

Geotextiles are quite variable both within and between lots. Samples should consist of specimens from widely spaced locations within lots. Samples should be tested from each lot. The number of specimens in a sample should be determined according to ASTM D2905 to give the desired accuracy.

Often it is more informative to know the ease with which water will flow through a geotextile as a function of the head loss across the fabric than to know the coefficient of permeability per se. The permittivity, defined as the flow velocity divided by the head loss and which is equal to the coefficient of permeability divided by the fabric thickness, indicates this characteristic. If permittivity is used, it also eliminates the need to determine geotextile thickness.

Geotextile permeability is an important property. Approximate values may be determined from simple rapid permeability tests; however, accurate permeability determination requires care and specialized equipment. Permeability testing of geotextiles needs and deserves additional research.

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Performance of Soil-Aggregate-Fabric Systems in Frost-Susceptible Roads, Linn County, Iowa

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Results of a three-year laboratory and field evaluation of a first-generation geotechnical construction fabric applied in soil-aggregate and granular-surfaced low-volume roadways indicate that fabric systems can, under certain circumstances, reduce thaw-induced deformations and improve field performance. Eleven test sections that involved different soil-aggregate-fabric systems were constructed on subgrades that displayed varying degrees of frost-related performance. Field evaluations were conducted over three cycles of spring thaw plus summer healing. Laboratory simulation of freeze-thaw action along with strength and deformation parameters obtained through the Iowa K-test were used on a fabric-reinforced, frost-susceptible soil to provide insight into soil-fabric mechanisms and the potential for predicting field performance. Variation in the constructed soil-aggregate-fabric systems was achieved by locating fabric at different positions relative to layers of soil-aggregate or existing roadway materials, a choked macadam base course, and a thick granular backfill. Improvement was most noticeable where fabric was used as a reinforcement between a soil-aggregate surface and a frost-prone subgrade. Fabric used in conjunction with granular backfill, macadam base, and non-frost-susceptible subgrade did not appear justifiable.

Among the economic losses incurred by frost action are costs of repair and maintenance of the damaged roadway. Economic implications affect highway users if a weight-limit embargo is imposed or more severely if complete closure of the roadway is dictated by thaw-induced lack of support capacity.

In the spring, downward melting of ice lenses causes a supersaturated condition in the soil, and the diminishing layer of ice impedes gravitational drainage. During this period, a secondary roadway is vulnerable to severe traffic rutting or loss of support, skid-resistant surface aggregate is pushed into the supersaturated region, and displaced subgrade may be pumped to the surface.

It was the purpose of this investigation to evaluate the laboratory and in situ performance of a first-generation nonwoven polypropylene fabric as an interlayer reinforcement in the construction and maintenance of soil-aggregate-surface and granular-base roadways that overlie frost-susceptible fine-grained subgrades.

TEST SECTIONS

In the fall of 1976, fabric was placed in seven test sections located at two sites in Linn County, Iowa.

Each section was paired with an adjacent control section constructed in the same manner as the test section except that it lacked fabric (1).

In sections 1A, 1B, 2A, and 2B at the Alburnett site (Figure 1), fabric was combined with a commonly used method to combat frost action in which the existing soil-aggregate surface course was removed, the frost-susceptible subgrade was undercut about 0.6 m (2 ft) and backfilled by using a coarse aggregate, and the soil-aggregate surface course was replaced and compacted.

Following removal of the soil-aggregate surface, the subgrade of sections 3 and 4 was shaped by using a blade grader and compacted by using a sheep's-foot roller. In section 3 a layer of fabric was placed on the subgrade prior to replacement of the soil-aggregate surfacing (Figure 2).

Sections 5 (fabric) and 6 were constructed in a manner identical to that used for sections 3 and 4, except on a frost-stable subgrade as a means of overall comparative control between stable and frost-prone subgrades and fabric-treated and untreated systems. All test sections at the Alburnett site were constructed by Linn County maintenance personnel by using conventional county-owned equipment.

Fairfax site test sections were constructed following a contracted geometrical change of the embankment that consisted primarily of widening the ditch and the shoulder, with little or no change in longitudinal profile or elevation. Fabric was incorporated between the subgrade and a contracted macadam-base surface course. Test sections 1 and 2, by using the granular-backfill-replacement method, were eliminated because of the expense incurred by using a force account for a nearly completed contract.

Fairfax sections 3 and 4 were built in an area that presumably contained frost-susceptible subgrade soils (Figure 3). Sections 5 (fabric) and 6 were built on frost-stable subgrades. A layer of fabric was placed on the subgrade in sections 3 and 5; then all sections were overlaid with 203 mm (8 in) of an open-graded macadam stone of 102-mm (4-in) top