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Laboratory Studies on Long-Term Drainage Capability of Geotextiles

Etudes de laboratoires sur la capacité d'écoulement de long terme de géotextiles

While it is generally recognized that the initial hydraulic permittivity of geotextiles is far greater than most soils they are protecting, their long-term performance has not been firmly established. Such concepts as filter cake formation, arching, blinding and clogging are often discussed as being explanations of limiting behavior. This study focused on long-term hydraulic tests in which both the soil and the geotextile were systematically varied. Typical behavior was bi-linear where soil compaction dominated the initial flow, followed by a strong dependence on the soil/fabric interaction. Tests showed that the drainage characteristics of the soil was significantly more important than the type or manufacture of the fabric and for a particularly poor draining fine grained soil, all fabrics tested gave essentially equivalent performance. Long-term flow tests, rather than gradient ratios, are suggested as being the preferred way to evaluate a particular soil/fabric performance.

Bien qu'il soit généralement reconnu que la permutabilité hydraulique initiale des géotextiles soit bien plus grande que la plupart des sols qu'ils protègent, leur performance à long terme n'a pas été fermement établie. De telles conceptions comme la formation de résidu pâteux, courbement, obstruction et blocage sont souvent traitées comme étant des explications de limitations de comportement. Cette étude était dirigée sur des tests hydrauliques à long terme dans lesquels le sol et le géotextile étaient systématiquement variés. Là où la compacité du sol dominait l'écoulement initial, le comportement typique était bi-linéaire, suivi par une forte dépendance sur l'interaction du sol avec le tissu. Les tests ont démontré que les caractéristiques du drainage du sol étaient nettement plus importantes que le type ou la fabrication du tissu et, pour un sol de grain fin particulièrement mal drainé, tous les tissus testés donnèrent essentiellement une performance équivalente. Les tests d'écoulement à long terme sont recommandés comme étant le meilleur moyen pour évaluer une performance particulière d'un sol et d'un tissue.

INTRODUCTION

Almost every geotextile application involving separation, reinforcement, drainage and fabric forming deals with water and its proper dissipation (1,2). This feature underscores the necessity of determining a given fabrics' hydraulic properties; more specifically, its flow rate, permeability or permittivity (the permeability divided by thickness). Toward this end many organizations have recommended test methods and specifications for the laboratory determination of these fabric properties. Note should be made, however, that these procedures are generally for the fabric alone, e.g., ASTM's "Standard Method for Testing the Water Permeability of Geotextiles - Permittivity Method" as proposed by Subcommittee D13.61 on Geotextiles. While of interest in comparing one fabric to another, these tests give no indication of the hydraulic behavior of the combined soil/fabric system.

As soon as soil is placed adjacent to the fabric, it is seen that the soils' hydraulic properties dominate the initial behavior (3,4,5). Only after a period of time does the fabric begin to play a role and, in the long-term situation, not at all, e.g., when a properly designed configuration exists. In this latter instance the flow passing through the soil/fabric system becomes constant and an equilibrium situation exists thereafter.

To verify and quantify these concepts one must perform long-term hydraulic tests on various soil/fabric systems. This is the goal of this paper, where the following items are specific objectives:

- To observe the nature and rate of soil adjustment in the initial flow stages.
- To determine the time required for a given soil/fabric system to reach a stable interactive stage.
- To determine if an equilibrium flow situation exists for a wide variety of soils and fabrics in specific soil/fabric configurations.

With the above objectives at hand, it then becomes possible to hypothesize as to the possible soil/fabric mechanisms that are occurring within the system. The ultimate objective of the proper hydraulic design of soil/fabric systems can then be addressed.

EXPERIMENTAL TEST SETUP

The experimental test setup for the flow tests used in this study was quite basic. Water at a constant head, flowed downward through the soil, then through the fabric and out of the system where it was collected and a flow rate was calculated. Figure 1 shows the apparatus where four tests can be simultaneously performed with sequential variation of either soil or fabric. The 9.5 cm (3.7") diameter plastic tubes were flanged near the base to hold the fabric. A known amount of soil was placed directly on the fabric (usually 720 gm) and a constant water head of 38.0 cm (15.0") was maintained above the fabric for the duration of the test. Due to large flow rates for some of the soils tested, deaired water was not used. Temperature corrections and losses due to evaporation were included. Physical and hydraulic properties of the soil used in this study are given in Table 1. Here it is seen that soil permeabilities ranged from 0.12 cm/sec to 6 x 10^{-7} cm/sec thereby covering a wide spectrum of situations.

Presented in Table 2 are the physical and hydraulic properties of the fabrics which were used. The fabric thickness and permeability values listed were obtained using the procedures of reference 5.

Table 1 - Soil Tested in This Study.

Type	Class.[1]	d_{10}[2]	CU[3]	k[4]	γ_s[5]
Sand	SP	.30	3	1.2 x 10^{-1}	2.11
Mica Silt	ML	.02	10	9 x 10^{-4}	2.07
River Silt	ML	.01	17	3 x 10^{-4}	2.10
Silty Clay	CL	<.001	-	6 x 10^{-7}	2.09

Notes:

1 - Unified Soil Classification System
2 - 10% finer than size in mm
3 - coefficient of uniformity (= d_{60}/d_{10})
4 - coefficient of permeability, cm/sec
5 - saturated unit weight, gm/cc

Table 2 - Fabrics Tested in This Study

Type	Material	Construction	Wt.[1]	t[2]	k[3]	ω[4]
nonwoven	polyprop.	needled	400	3.6	0.21	.58
nonwoven	polyprop.	spunbonded	135	.38	0.02	.53
woven	polyprop.	slit film	135	.63	0.04	.63
woven	polyprop.	plain	245	.52	0.035	.67
knit	fiberglass	WIWK[5]	350	.63	0.014	.22

Notes:

1 - weight in gm/sq. m
2 - thickness in mm
3 - permeability in cm/sec
4 - permittivity in sec^{-1}
5 - WIWK - weft insertion warp knit

TEST RESULTS

A series of tests were performed using a single fabric (the nonwoven, needled polypropylene in Table 2) with the four soils listed in Table 1. The results are shown in Figure 2 for times approaching 1000 hours. This test series was followed by another one where the silty clay soil (the most troublesome as far as long-term flow is concerned) was used with four of the fabrics listed in Table 2. Results are shown in Figure 3 for times up to 1700 hours. Additional tests using the mica silt soil with both commercial and non-commercial fabrics listed in Table 2 resulted in the curves of Figure 4.

Observing the trends in these results, the different aspects of the flow mentioned earlier can be noted. By constructing tangents to the initial portion and to the final portion of each curve (and calculating their slopes), and by intersecting these tangents for an approximate transition time, the data of Table 3 was obtained. Note should be made that data scatter did indeed occur and that some liberty was taken in the interpretation, however, the basic trends were always quite obvious.

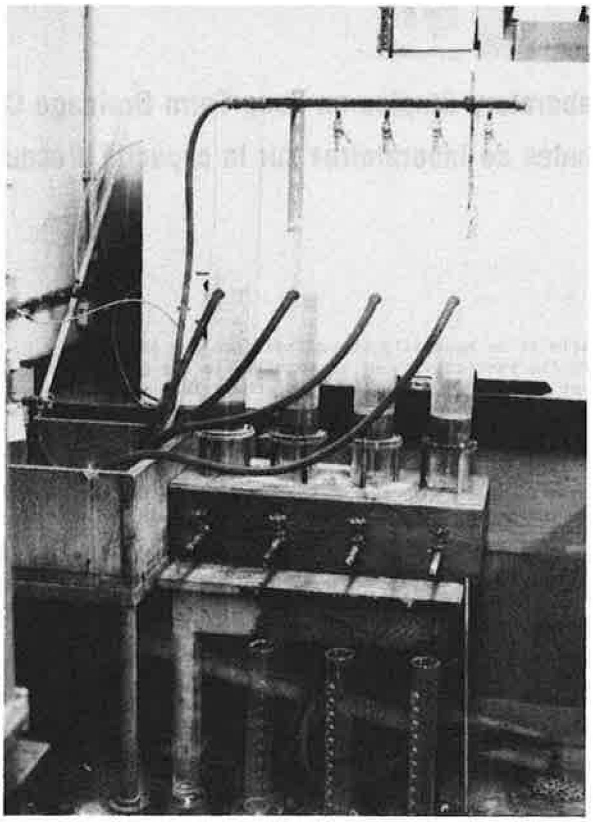

Fig. 1. - Experimental Test Setup for Long-Term Soil/Fabric Constant Head Flow Tests

Table 3 gives the averaged slopes (in units of cc/min/hr or q/t) of the flow curves of Figures 2, 3, and 4. Here it is seen that the decrease in flow rate is very great in the initial part of the test. This is completely the result of soil compaction during downward flow of the water through the initially placed loose soil. Of far greater importance is the long-term slope of these curves which when equal to zero suggests that equilibrium is established between the soil/fabric system and the particular hydraulic situation being imposed. If the slope of the curve is different from zero, interaction of the soil and the fabric is ongoing. The exact mechanism is difficult to establish but several conceptual ideas will be suggested in the next section. It is also important to note in Table 3 the time for transition between the slopes of the curves. This tells how long one must test before some type of stable soil/fabric system is established. As noted, the finer soils require relatively long periods of time, in excess of 100 hours, for testing.

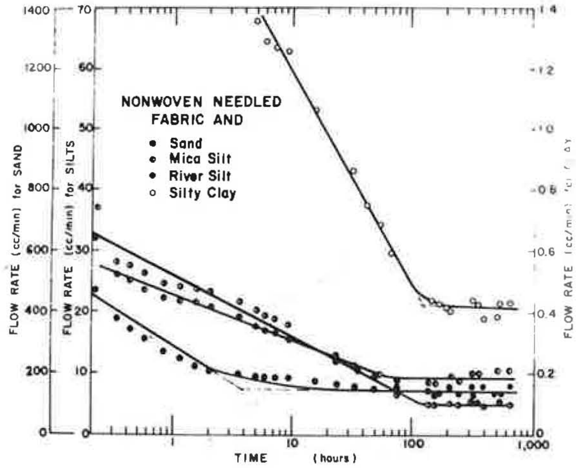

Fig. 2. - Long-Term Flow Curves for Nonwoven Needled Fabric and Four Soil Types.

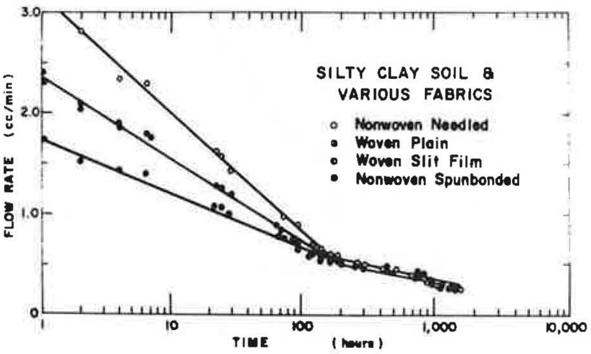

Fig. 3. - Long-Term Flow Curves for Silty Clay Soil and Four Different Fabrics

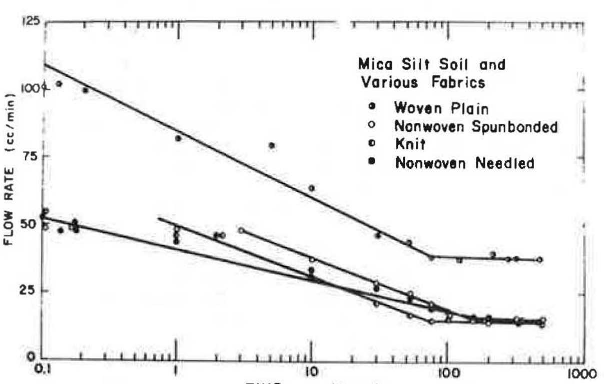

Fig. 4. - Long-Term Flow Curves for Mica Silt Soil and Four Different Fabrics.

Table 3 - Averaged Data from Long-Term Hydraulic Tests Shown in Figures 2, 3 and 4.

Soil	Fabric	m_i [1]	time [2]	m_f [3]
sand	nonwoven needled	270	4	0
mica silt	nonwoven needled	8	70	0
river silt	nonwoven needled	10	120	0
silty clay	nonwoven needled	0.7	130	.1
silty clay	nonwoven needled	1.1	160	.2
silty clay	woven plain	0.8	180	.2
silty clay	woven slit film	0.8	180	.2
silty clay	nonwoven spunbonded	0.5	180	.2
mica silt	woven plain	24	75	≈0
mica silt	nonwoven spunbonded	20	150	≈0
mica silt	knit	13	75	≈0
mica silt	nonwoven needled	11	150	≈0

Notes:

1 - slope of initial portion of flow curve in units of cc/min/hr or q/t
2 - transition time in hours
3 - slope of long-term portion of flow curve in units of cc/min/hr or q/t

Bearing this long test time in mind, additional flow tests were performed using the gradient ratio concept originally proposed by the Corps of Engineers (6). See Figure 5 for the test configuration. Figure 6 shows the results of the silty clay soil in conjunction with the nonwoven needled polypropylene fabric for times up to 2500 hours. As with previous tests, piecewise linear behavior is noted on the flow curves with reasonable agreement to values listed in Table 3. Of interest here, however, is the lower part of Figure 6 which plots gradient ratio (the ratio of the hydraulic gradient through the fabric and 2.5 cm of soil above it, to the adjacent 5.0 cm of soil) versus time. During the initial soil compaction stage, the gradient ratio is seen to be quite constant. However, beyond the transition time it increases rapidly, indicating a non-equilibrium situation. The limiting behavior for the case shown is not yet established and the test is still ongoing. It should be noted, however, that a unique gradient ratio value does not seem to be present. Other gradient ratio tests (not shown) using the river silt and the plain woven polypropylene fabric show uniform behavior up to the transition time and then major oscillations of the gradient ratio (values fluctuated between 2.5 and 7.0) throughout the duration of the test.

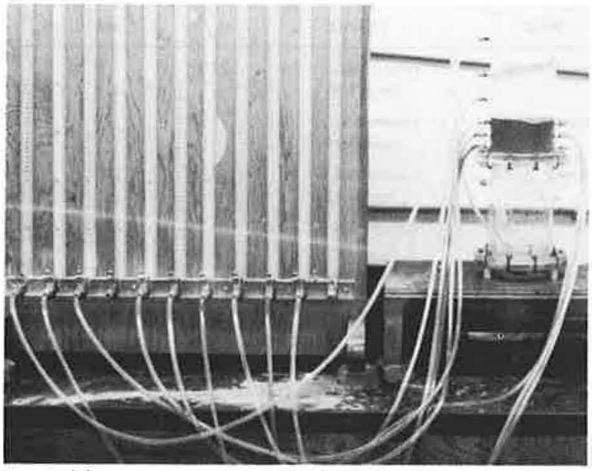

Fig. 5(a). - Photograph of Gradient Ratio Test Setup Where Hydraulic Heads are Monitored at Various Points Along the Soil Sample During a Constant Head Flow Test.

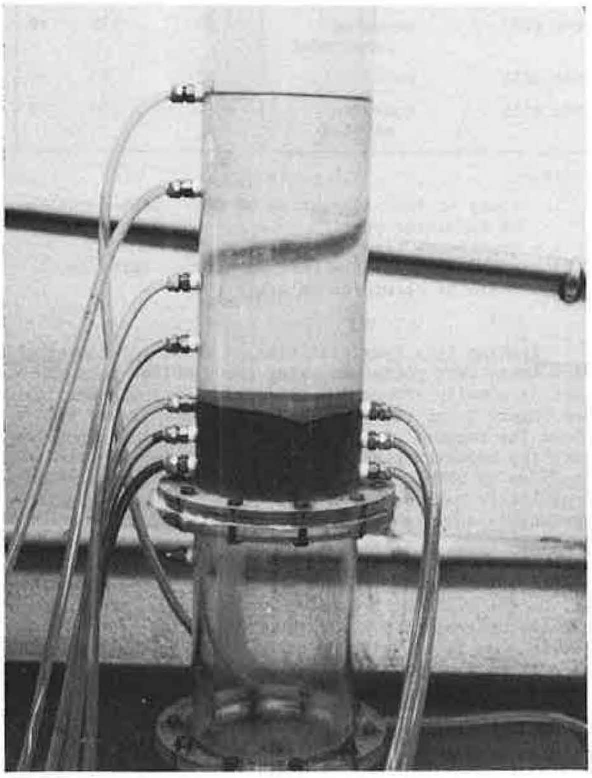

Fig. 5(b). - Closeup Photograph of Soil Sample During Constant Head Flow Test and Points Where Hydraulic Heads are Measured in Order to Calculate Gradient Ratio.

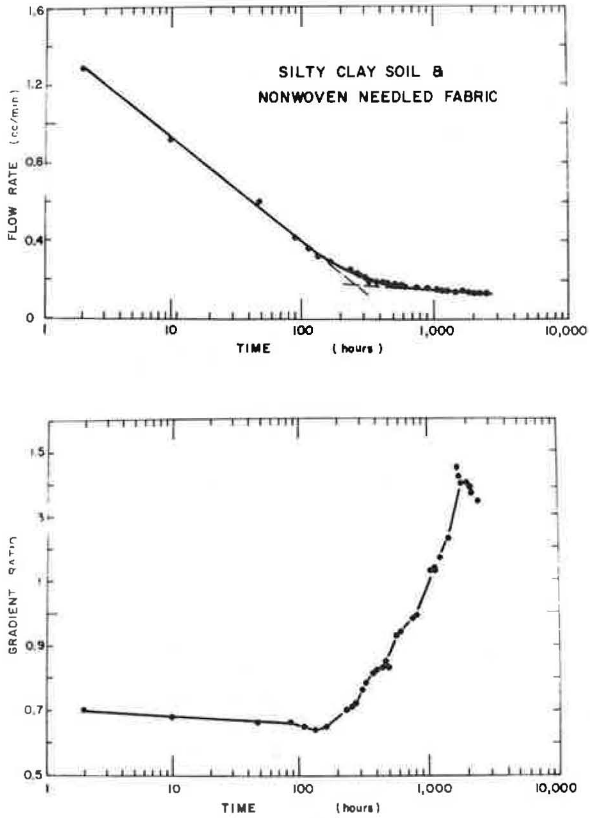

Fig. 6. - Long-Term Flow Curve of Silty Clay Soil and Nonwoven Needled Fabric (Upper) and Corresponding Values of Gradient Ratio (Lower).

SUMMARY AND CONCLUSIONS

Observation of the behavior of long-term flow tests through soil/fabric systems shows that the initial range is governed by the soil, and the final range is governed by soil/fabric interaction. It is this final range, as indicated by the slope of the flow curve, that is of primary interest. A zero, or nominal, slope is preferred over a large slope since it suggests equilibrium of the soil/fabric structure. This is perhaps explained by a stable soil filter structure at a finite distance upstream from the fabric (7), or by soil developing a stable arch over the fabric interstices at the soil/fabric interface (8). Numerous attempts (using grouts, image analyzers, etc.) at verifying these concepts were tried but with little success. A slope markedly greater than zero (as shown on these graphs all slopes are negative) indicates a nonequilibrium situation and suggests a blinding of the fabric's voids (8) or even a partial clogging of the fabric (8). These mechanisms are obviously not desirable and only with additional testing can they be further elaborated upon. In no case, however, was the flow from any of the fabrics tested, for any soil type, completely blocked off.

The idea of measuring hydraulic gradients and of using a gradient ratio (6) was also investigated. It was of interest to note that the gradient ratio began increasing at the same time that the transition between flow curve slopes occurred. However, no unique value of gradient ratio was observed.

The conclusion of the study at this point in time is that flow through soil/fabric systems is a complex phenomenon, governed by both the soil and fabric types and can only be definitively examined by long-term flow tests. The minimum time for such tests to be run varies from a few hours for sand soils, to slightly less than one hundred hours for silt soils, to approximately two hundred hours for soils with high clay content.

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