INVESTIGATION OF FILTRATION CHARACTERISTICS OF A NONWOVEN FABRIC FILTER

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The purpose of this study was to investigate the behavior of a nonwoven fabric filter in subdrainage applications. Experiments were restricted to a single fabric, Mirafi 140. Conventional aggregate filters were tested under compatible conditions to provide a basis of performance behavior. Experimental results indicate that the nonwoven fabric provides desirable performance under a relatively wide range of soil conditions. Hypotheses that relate to mechanisms controlling the behavior of the nonwoven fabric in subdrain applications are discussed. These mechanisms are, in turn, related to induced filtration and internal grading of the soil near the soil-fabric contact surface.

•MANY problems that occur both during and after construction are related to the flow of subsurface water or seepage. Hydrostatic pressures associated with seepage may produce instability within a soil mass. Unstable soil conditions may often be corrected or improved by subsurface drainage systems. Mechanisms involved in seepage and subsurface drainage are complex because they are related to both the physical and physicochemical characteristics of the soil.

Regardless of application, subsurface drainage systems must meet two divergent design criteria: (a) The subdrain must be sufficiently permeable so that seepage can be removed without buildup of excessive hydrostatic pressures, and (b) the subdrainage system must protect the soil against piping, i.e., the subsurface erosion of the soil mass. Consequently, subsurface drains or underdrains are often referred to as protective filters.

The basic criteria for the selection or design of fabric subdrainage systems must be the same as those for conventional filters. The primary difference arises because the gradation of the aggregate to be used as the filter is selected to provide the optimum of the two divergent criteria, whereas the filter criteria must be satisfied by the fabric structure and its effect on gradation of the soil immediately adjacent to the fabric.

LITERATURE REVIEW

Traditionally, the problems of seepage and subsurface drainage have been analyzed on the basis of empirical relationships. Although Darcy's law, formulated in 1856 (1), was based on a macroscopic investigation of the flow of water through fine-grained soils, the relationship was applicable to a majority of the seepage problems falling within the range of laminar flow.

Bertram (2) studied the filter design criteria suggested by Terzaghi. Experimental results indicated that, for an aggregate filter to provide sufficient permeability without development of excessive hydrostatic pressure, the 15 percent size of the aggregate must be four to five times the 15 percent size of the protected soil. Tests also revealed that the 15 percent size of an aggregate must not be greater than four to five times the

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85 percent size of the protected soil so that piping could be prevented. The work of Bertram was subsequently expanded by the U.S. Army Corps of Engineers (3) and the Bureau of Reclamation (4). These investigations substantiated the criteria for selection of aggregate gradation for use in subdrains; however, additional requirements have been suggested for gradation requirements. One such requirement recommended by both studies was that the aggregate filter gradation be as nearly parallel to the protected soil gradation curve as possible.

During the past decade, the availability of synthetic fabrics and filter cloths has produced increased interest in seepage control by subsurface drainage systems. Healy and Long (5) conducted laboratory and field tests on prefabricated subdrainage systems by using woven filter cloth. The subdrainage system was successful under several site conditions, one of which was the drainage of an unstable slope in glacial till where the installation of conventional aggregate drains would have been virtually impossible.

Because of the increasing interest and availability of fabric filter materials, the U.S. Army Corps of Engineers, through the Waterways Experiment Station, conducted an investigation to develop design criteria and acceptance specifications for fabric filter materials (6). Filtration tests and clogging tests were conducted to determine head losses across the fabric during filtration and soil loss through the fabric. A clogging ratio based on the hydraulic gradients measured across the fabric and across the system was used as a basis of comparison of performance. Flow measurements taken during the clogging tests were considered inconclusive; however, the clogging ratio did indicate the relative susceptibility of fabrics to clogging.

Barrett (7) has presented numerous examples of fabric use under a wide variety of field conditions. Although many of the applications of fabrics were in coastal structures, much information is presented about the ability of fabrics to prevent soil piping or clogging.

TEST PROCEDURES AND MATERIALS

Filtration tests were conducted in 1-ft (30.5-cm), square, plexiglass, constant-head permeameters equipped with a manometer to measure head losses at various points in the soil and across the fabric filter. The permeameters were constructed in two sections that bolted together after placement of conventional aggregate filters or fabric filter systems in the lower portion. For testing, 4 in. (10.2 cm) of soil were placed over the filter system. Flow measurements were obtained periodically as were head loss readings. Filtration tests were continued for 21 to 28 days or until the flow through the system became constant. All tests were conducted under a constant hydraulic gradient for the entire system of three.

The fabric filter system consisted of 8 in. (20.3 cm) of river gravel, which passed the U.S. standard ¾-in. (19.0-mm) sieve and was retained on the U.S. standard ½-in. (12.5-mm) sieve. This was overlaid with a single layer of Mirafi 140 fabric.

Conventional aggregate filter systems were designed according to the procedure recommended by the U.S. Army Corps of Engineers. Conventional 8-in. (20.3-cm) filters were used beneath the soil to be tested.

In this experimental investigation, 12 soils were tested. All soils were produced from a basic soil that was an alluvial deposit found in the floodplain of the Holston River near Knoxville, Tennessee. The base soil was produced by removing material finer than the No. 100 sieve.

Three groups or series of soils were produced by adding various fine fractions to the base soil. These groups were designated the S, K, and M series to indicate the addition of silt, kaolinite, and montmorillonite fractions respectively. A particular soil was identified by a series designation followed by a number representing the percent of the particular fines added to the base soil. Physical properties of the 12 soils tested are given in Table 1. Grain size distribution curves for the three series of soils tested are shown in Figures 1, 2, and 3.

The nonwoven fabric tested in filtration tests is produced by randomly distributing both monofilament and heterofilament fibers. The monofilament fiber is a polypro-

Table 1. Physical properties of soils tested.

Soil Type	Liquid Limit (percent)	Plastic Limit (percent)	Plasticity Index (percent)	Effective Grain Size, D_{10} (mm)	Uniformity Coefficient	Soil Classification	
						AASHTO	Unified
Natural	28.3	19.7	8.6	0.010	15.2	A-2-4(0)	SC
S-0	24.5	20.0	4.5	0.025	6.8	A-2-4(0)	SM
S-5	23.8	18.0	5.8	0.020	8.0	A-2-4(0)	SM
S-15	25.1	20.3	4.8	0.014	10.7	A-4(0)	ML
S-25	26.0	16.8	9.2	0.010	11.0	A-4(3)	ML-CL
S-35	28.4	19.6	8.8	0.007	12.2	A-4(5)	CL
S-50	29.7	20.6	9.1	0.007	8.6	A-4(6)	CL
K-0	22.75	21.05	1.70	0.059	4.2	A-2-4(0)	ML
K-10	23.50	18.45	5.05	0.0070	27.1	A-2-4(0)	ML-CL
K-20	26.25	20.60	5.65	0.00061	303.3	A-2-4(0)	ML-CL
K-30	27.8	17.2	10.6	0.00063	214.3	A-4(1)	CL
M-2	30.0	22.3	7.7	0.046	4.35	A-2-4(0)	CL
M-4	39.1	24.1	15.0	0.0175	11.1	A-2-4(0)	CL

Figure 1. Grain size distribution curves for S-series soils.

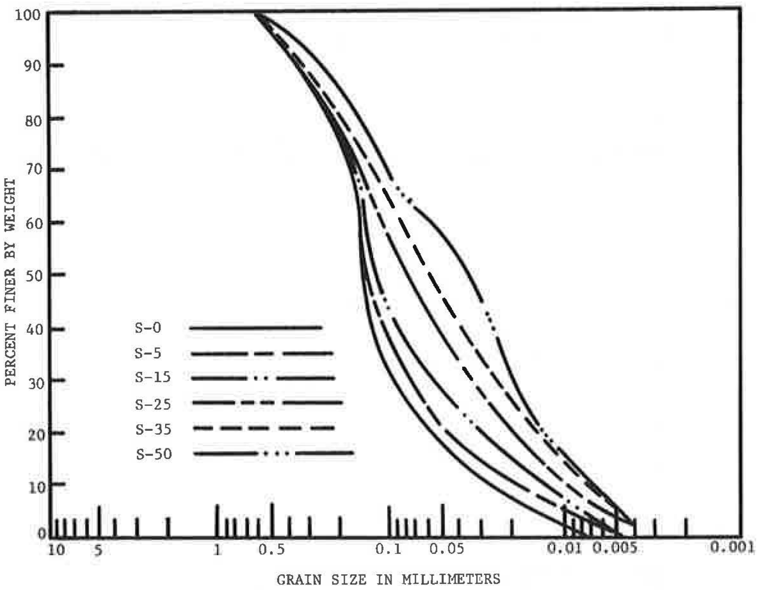


Figure 2. Grain size distribution curves for K-series soils.

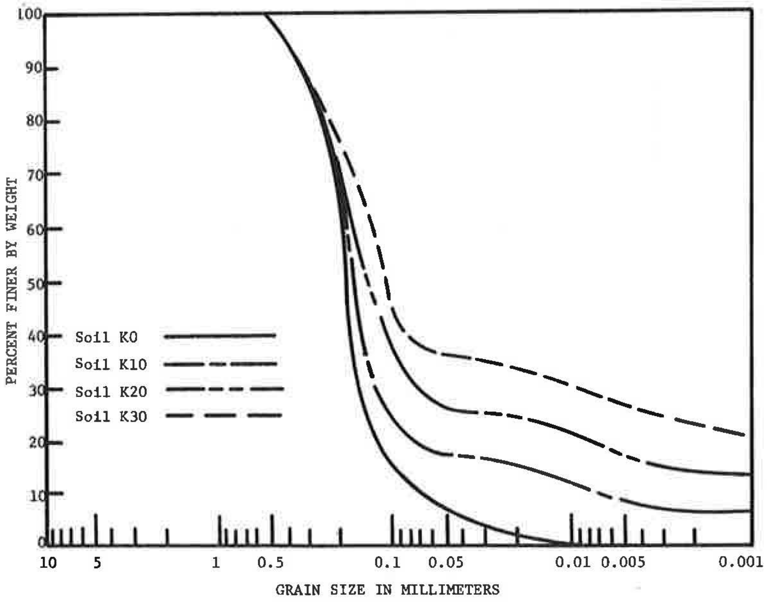


Figure 3. Grain size distribution curves for M-series soils.

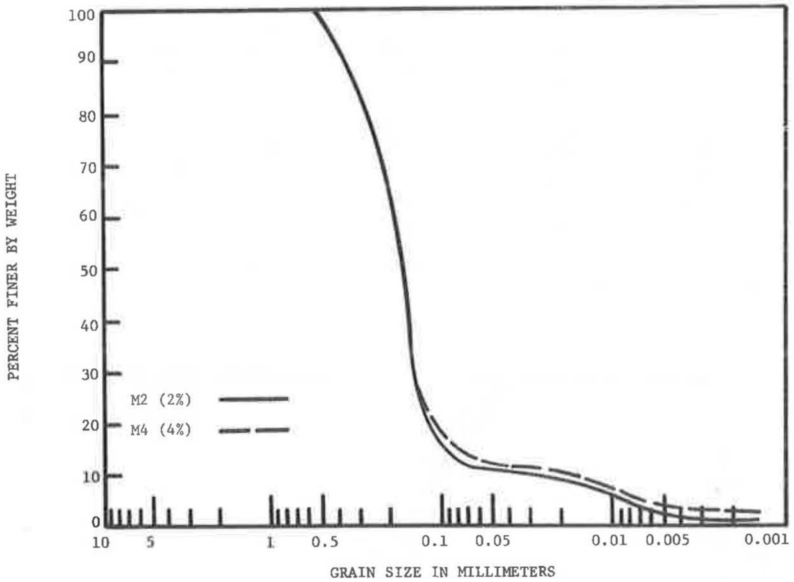
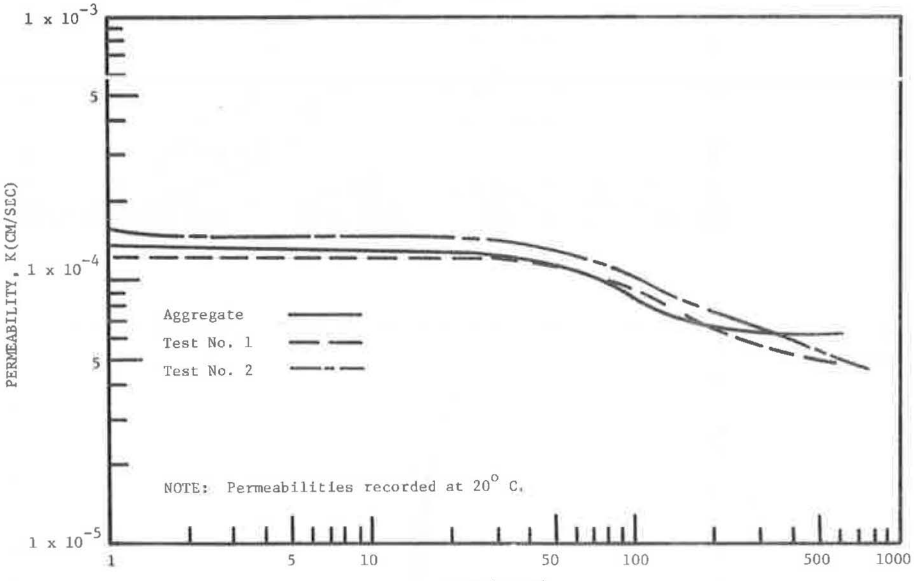


Figure 4. Permeability versus log-time curve for S-25 soil.



pylene, whereas the heterofilament fiber has a polypropylene core coated with nylon. Direct fusion at points of contact between the monofilaments and heterofilaments provides the nondirectional strength of the fabric structure. The average fiber diameter is 40 microns (40 μm) and has a fiber weight of 15 denure per fiber (DPF). One DPF is the weight in grams per 9000 m of fiber. The average mass/m^2 of the fabric was 140 g, and the fabric was approximately 20 mils (508 μm) thick.

DISCUSSION OF RESULTS

All soils tested with fabric filters exhibited a characteristic s-shaped permeability versus log-time curve. These curves indicated that, within the first few days of flow, the permeability of the system remained relatively constant; however, the log-time curves did not portray slight reductions in permeability during the first few minutes of flow, which were attributed to induced filtration and clogging of the fabric by particles immediately adjacent to the filter. These changes in permeability were insignificant relative to the overall behavior of the system.

After the initial period of flow, during which time the permeability of the system remained relatively constant, the permeability began to decrease to a minimum value after 2 to 3 weeks. This decrease in permeability was attributed to the formation of an internal filter cake within the soil immediately adjacent to the fabric. A typical permeability versus log-time curve is shown in Figure 4.

Analysis of the ratio of the hydraulic gradient across the fabric plus 2 in. (5.1 cm) of soil immediately above the fabric to the hydraulic gradient across the entire system substantiated the hypothesis of the formation of an internal filter cake immediately adjacent to the fabric. During the initial periods of flow, the ratio, which has been defined as the clogging ratio by other researchers (6), increased as a result of particles being piped through the fabric or clogging the fabric during induced filtration. The amount of increase in the clogging ratio varied with the percent fines contained in the soil. After the clogging ratio initially increased, the permeability and the ratio remained relatively constant for 2 to 3 days at which time the ratio again began to increase slightly as the permeability decreased. Analysis of data revealed that the relative decrease in permeability was closely related to relative increases in the hydraulic gradient ratio for various soil types. After this alteration in the hydraulic performance of the system, the permeability and clogging ratio again became constant. The clogging ratio versus log-time curve for various soils is an inverted image of the permeability versus log-time curve (Fig. 4).

So that the hypothesis about the formation of an internal filter cake could be substantiated, samples of the soil above the fabric filter were impregnated with an epoxy resin, EPO-TEK 301, to facilitate microscopic or pedographic analysis. Figure 5 shows a simplified model of the internal filter cake observed above the fabric. Those particles below the fabric are piped through the fabric during initial periods of induced filtration. The particles trapped in the fabric produce some clogging during the induced filtration period. The first stratum above the fabric contains particles remaining after induced filtration has removed the soil particles immediately adjacent to the fabric. The second stratum contains grain sizes that are trapped in the fabric in the event they are carried through the voids of the lower soil particle layer. The third soil stratum in the filter cake contains those particles that are piped through the fabric in the event they are carried through the voids of lower soil particle layers. Obviously, the schematic is somewhat idealized; however, visual examination of the cross section of impregnated samples has revealed that the individual strata of the internal filter cake can indeed be clearly distinguished.

As a result of this mechanism, most soil particles that are physically available to be trapped in the fabric and that produce clogging are those contained in a soil layer immediately adjacent to the fabric. This is because subsequent movement would be restricted by the soil voids remaining after these particles were removed. Similarly, the soil particles that are available for piping through the fabric are those contained in the first two soil strata previously described. Continued piping is restricted by the

Figure 5. Idealized internal filter gradation.

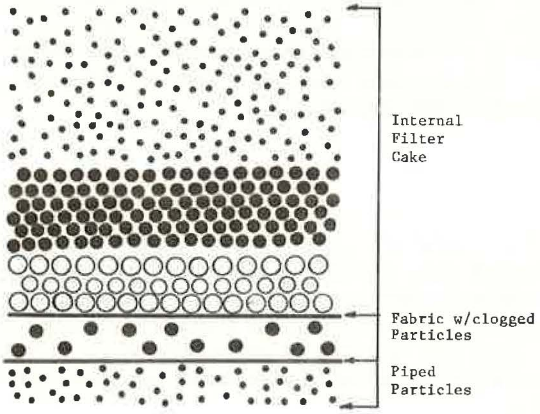
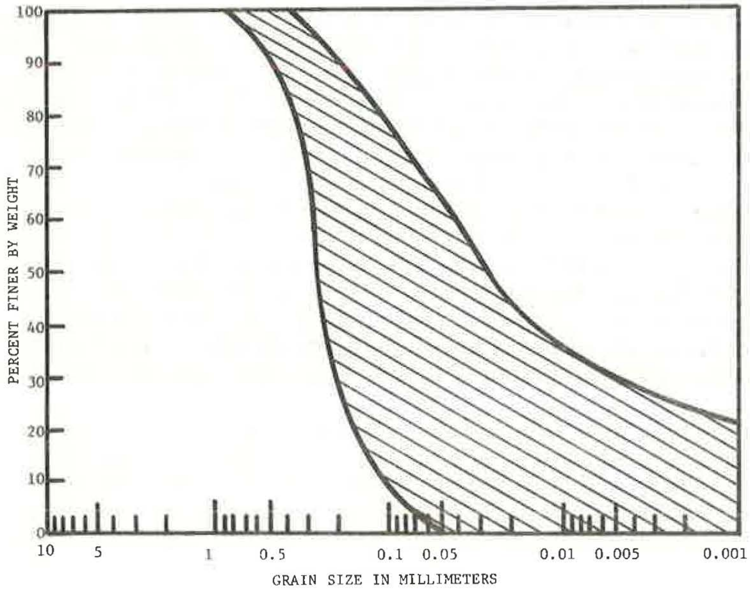


Table 2. Soil loss data.

Soil Type	Effective Grain Size, D_{10} (mm)	Uniformity Coefficient	Porosity (percent)	Piping (percent)	Clogging (percent)
S-0	0.025	6.8	54.2	3.0	0.05
S-5	0.020	8.0	53.1	2.0	0.04
S-15	0.014	10.7	53.0	1.6	0.05
S-25	0.010	11.0	53.0	2.0	0.04
S-35	0.007	12.2	53.2	1.8	0.04
S-50	0.007	8.6	53.0	1.4	0.05
K-0	0.059	4.2	52.7	1.2	0.03
K-10	0.007	27.1	54.1	1.1	0.04
K-20	0.0006	303.3	53.9	1.0	0.05
K-30	0.0006	214.3	53.9	1.5	0.04
M-2	0.046	4.4	54.3	1.3	0.03
M-4	0.0175	11.1	54.1	1.3	0.03

Figure 6. Range of grain size distribution for which fabric performed satisfactorily.



void spaces generated by the internal filter cake.

Obviously, the soil characteristics and fabric structure will be controlling parameters in the development of the internal filter cake formation. Inasmuch as only one fabric was used in this study, only the effect of soil characteristics could be analyzed. Table 2 gives clogging and piping data as a percentage of the total dry weight of the soil layer. As would be expected, the percentage of soil actually trapped in the fabric is quite small and does not vary significantly with soil type. The percentage of soil piped cannot be directly related to the grain size distribution of the soil type alone; however, the general trend indicates that less piping occurred with the more well graded soils, which possessed greater plasticity and cohesion.

SUMMARY AND CONCLUSIONS

The design criteria for fabric filter systems must be the same as those established for conventional aggregate filters: (a) to provide sufficient permeability so that seepage can be removed without the buildup of excessive hydrostatic pressures, and (b) to ensure that piping of soil particles does not occur during the drainage process.

Permeability and hydraulic gradient data collected during relatively long-term filtration tests were shown to be directly related to the formation of an internal soil-fabric filtration system. These data have been substantiated by visual examination of the soil-fabric filtration system that is produced under steady flow conditions.

As a result of this study, the nonwoven fabric used can be considered as effective in subdrainage applications for a relatively wide range of soil conditions. When consideration is given to grain size distribution alone, the range of soils for which the fabric is effective is shown in Figure 6.

ACKNOWLEDGMENT

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DISCUSSION

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Inasmuch as the conclusions of this study differ markedly from those of extensive earlier tests conducted by others, the authors were invited to publish this revised version of their paper in the interests of publicizing their research results. In that the amounts of fine-grained additives are not consistent from test series to test series, there may be some question about the applicability of the recommended filter system to the wide range of soils as suggested by the authors in Figure 6.

In the paper, it is emphasized that the design criteria for fabric filter systems must be the same as those established for conventional aggregate filters. Accordingly, the following two questions appear warranted:

1. What is the effective pore size of the fabric filter material?
2. What is the relationship between the reported clogging (Table 2) and the drop in hydraulic gradient across the clogged filter?

Finally, inasmuch as the fabric filter must withstand considerable abuse during some installations, it would be helpful for the designer to know the tensile strength of the material.