Evaluation of soil/geotextile compatibility

L'évaluation de la compatibilité sol-géotextile

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SYNOPSIS: Existing filter criteria for geotextiles, which are based on in-isolation characteristics, do not address the long-term behaviour of soil/geotextile systems. This paper describes an investigation to evaluate soil/geotextile compatibility and the long-term behaviour of these materials. Laboratory flow tests were performed on 85 soil/geotextile combinations and a road subsurface drainage installation was monitored over a period of two and a half years. The results of the investigation showed that in-isolation parameters cannot be used to predict the long term behaviour of geotextiles as filters.

1 INTRODUCTION

Geotextiles are used fairly widely in road subsurface drainage installations in South Africa. In a typical side drain application, wrapped around crushed rock which contains a perforated pipe, they serve as filters. Although these synthetic filters are accepted by most road authorities, there is a certain amount of concern regarding their long-term performance, owing to a lack of proven design criteria and indications of permeability reduction or clogging. The Division for Roads and Transport Technology of the Council for Scientific and Industrial Research (CSIR) has, for the past three years, conducted a research project to investigate the long-term behaviour of geotextiles, evaluate soil/geotextile compatibility and, ultimately, to recommend standard tests and design criteria.

PREVIOUS RESEARCH AND EXISTING CRITERIA

Existing filter criteria are based largely on in-isolation tests of geotextiles and soils, and do not take into account soil/geotextile compatibility or the long-term behaviour of these materials. The most widely used parameters for quantifying geotextiles are indicative pore sizes and normal permeability (permittivity). Pore sizes are determined by the method of inverse sieving, where glass beads of known sizes are sieved through the geotextile to obtain a distribution curve of opening sizes. The opening sizes thus obtained are used in the various criteria, in relation to nominal grain sizes of the base soil, to restrict piping. In some cases these parameters are also used for the permeability criterion, whereas in others the normal permeability of the geotextile is used for that purpose. Some examples of existing criteria are shown in Table 1, indicating the opening sizes, grain sizes and other parameters used.

Table 1: Examples of parameters used in various filter criteria.

Reference	Geotextile* opening size	Soil $ grain size	Other parameters
Calhoun (1972)	050(EOS)	D85	% open area
Zitscher (1975)	050	D50	
ICI (1978)	050	D15,D85	
Ogink (1975)	090	D90	
Giroud (1982)	095	D50	U,K #
Heerten (1982)	090	D10,D50	U,K
Ragutzki (1973)	090	D50	
Schober & Teindl (1979)	090	D50	

* 050 is the diameter of an opening in a geotextile where 50 % of all other openings are smaller.

$ D50 is the diameter of a particle of soil where 50 % of all other particles are smaller.

\# U = uniformity coefficient = D60/D10.
K = permeability coefficient (geotextile and soil).

There is some reluctance to use these criteria, for the following reasons (Legge and Van der Merwe, 1987):

- the criteria differ widely and very little information is available on long-term geotextile performance to guide the designer in choosing a set of criteria;
- the inverse sieving tests on which the criteria are based have many shortcomings, the most important being that specific equipment and procedures have not been standardised. Wates and Wittstock (1986) showed that opening

sizes can vary by more than 100 % if the test method is changed, and

- most criteria were derived from theoretical analyses without actual laboratory tests to evaluate the long-term behaviour. In general, the criteria address piping and permeability without considering clogging potential.

Long-term flow tests have been used by a number of researchers to evaluate soil/geotextile compatibility in the laboratory. In these investigations, a soil sample is placed on top of a geotextile in a permeameter and water is allowed to flow through the system. The flow rate is monitored, over time, thus obtaining an indication of long-term behaviour. Figure 1 shows a summary of results obtained in this way by various researchers. The results show the change in permeability coefficient K, of the soil/geotextile system, with time. These tests were performed in different laboratories using different test apparatus and methods but certain aspects of the results were similar, thus allowing some general conclusions:

- typically, there was an initial decrease in permeability, followed by a relatively constant flow. This is ascribed to the forming of a filter zone upstream of the geotextile as follows (Rankilor, 1981): At the beginning of the test, the original soil structure is intact up to the soil/geotextile interface. The permeability is then that of the soil. As the test continues, water washes the fine particles out of the zone adjacent to the geotextile, resulting in a certain amount of piping. At the same time particles build up in a zone just above (upstream of) the first zone, thus forming a filter zone. The decrease in permeability continues until the forming of the filter zone has been completed, after which the permeability remains constant;
- the magnitude of decrease in permeability was typically with a factor of 10, but varied in some cases, indicating some clogging with certain soil/geotextile combinations;
- the final permeability was usually less than that of the soil or the geotextile and was a function of the filter zone permeability, rather than the geotextile permeability;
- the filtration function was performed by the filter zone in the soil and not by the geotextile. The exact pore sizes of the geotextile were therefore not important;
- continuous piping only occurred where opening sizes were 2 mm or larger;
- where natural (granular) filters were tested, their performance was similar to that of geotextiles, and
- the flow through a soil/geotextile system is a complex phenomenon, and can only be evaluated by long-term flow tests.

Based on the knowledge gained from previous research as described above, and guided by the need to establish standard tests and design criteria, the following tests were performed in the investigation reported here:

- long-term flow tests in the laboratory using permeameters;
- in-isolation tests (opening size, geotextile permeability, etc.) to determine if any correlations existed between these and long term results, and
- monitoring of an installed subsurface drainage system in order to gain some perspective on the laboratory tests.

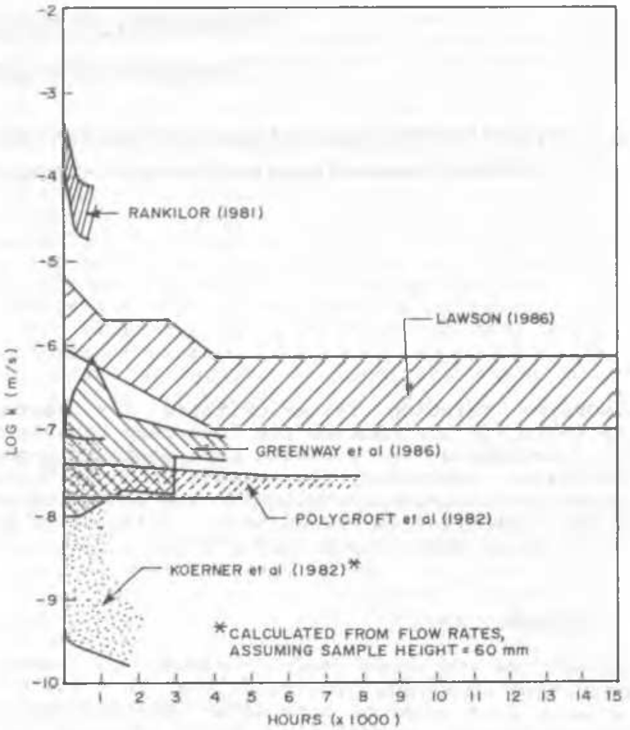

Figure 1. Summary of long-term flow tests by other researchers.

2 LABORATORY FLOW TESTS

Details of the permeameters used in the laboratory are shown in Figure 2.

Thirty permeameters were mounted in a stand with a constant-head water tank of which the height could be adjusted. Each permeameter was supplied with a valve at the inlet and could therefore be used independently. In the tests borehole water was used which, although not demineralised, was relatively free of any salt or other chemicals. The repeatability of the test method and the influence of factors such as support meshes, soil protection, initial soil moisture content, soil compaction and hydraulic gradient were evaluated. For this purpose a variety of tests was performed using one soil (a medium-grained sand) and one geotextile (nonwoven needle-punched, medium grade) and by varying the factors mentioned above. Selected results from these tests are shown in Figures 3 to 6. Illustrated in these figures is the change in permeability coefficient, K, with time. Permeability was calculated from the flow rate, height of the soil sample and water head, each of which was measured at regular intervals. The water head was kept at 1 000 ± 25 mm above the geotextile. The value K400, shown with the results, is the permeability coefficient after 400 of hours testing, as a percentage of the initial permeability coefficient at the beginning of the test. This parameter was used to quantify clogging potential. The reasons for using this parameter are discussed in Section 4.

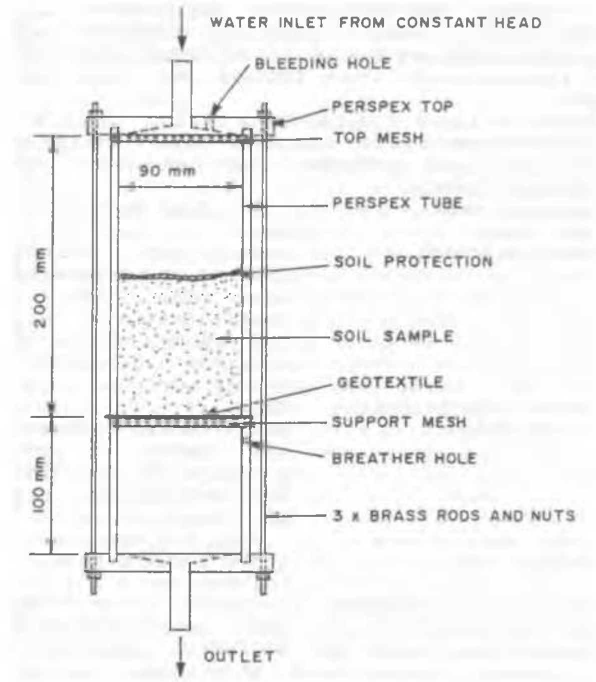

Figure 2. Permeameter for laboratory flow tests.

An indication of repeatability can be obtained from the results shown in Figure 3. The various parameters were identical for the three tests shown. The variation in K400 resulted in a coefficient of variance (CoV) of 4,6 %. Three other identical tests (results not shown) gave a CoV of 11,7 % for K400.

In these tests the geotextile was supported by a brass mesh with relatively small openings. In a subsurface drainage installation, the downstream side of the geotextile is usually supported by gravel or rock. For this reason it was important to investigate the influence of the support system. Figure 4 shows the results obtained from tests where all parameters, except mesh size, were kept constant. It is evident that there was some difference in the initial behaviour of the system. After 400 hours the difference was less marked and after 1 200 hours there was virtually no difference between the three tests. The increase in permeability after 300 hours obtained with the 3,0 mm mesh was typical of all permeameters where a 3,0 mm mesh was used. This can probably be ascribed to fines being washed through the geotextile at that point, resulting in a higher flow.

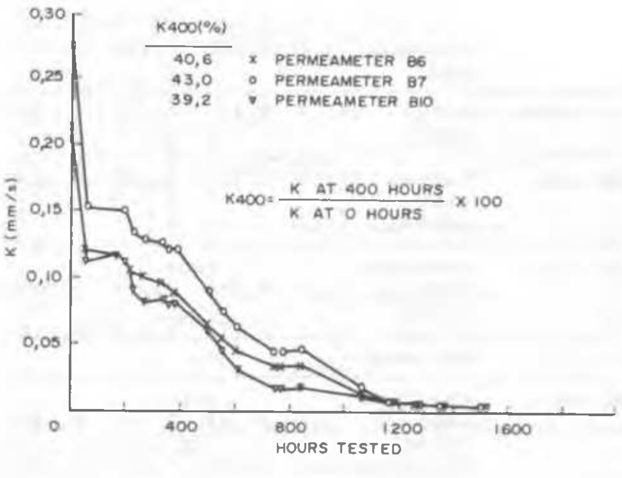

Figure 3. Laboratory flow tests: Repeatability.

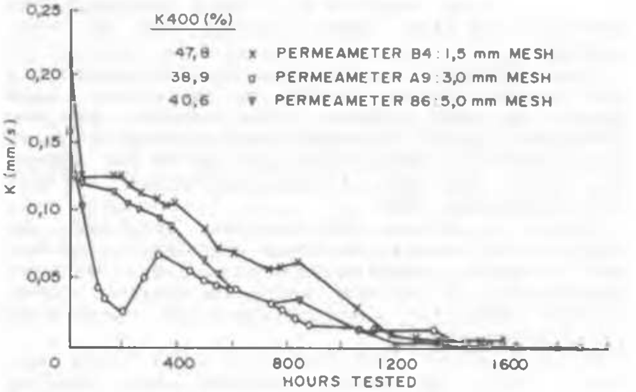

Figure 4. Laboratory flow tests: Influence of support mesh size.

In some tests a mesh was placed at the top of the permeameter to ensure an even flow of water in order not to disturb the surface of the soil sample. The mesh alone did not ensure a smooth sample surface and a small circular plate of galvanised iron was placed directly beneath the brass mesh. This resulted in a deposit forming on the surface of the soil sample, probably resulting from an electrolytic reaction between the brass and the galvanised iron. The result obtained from one of these permeameters (permeameter B9) is shown in Figure 5. The whole system was virtually clogged after 200

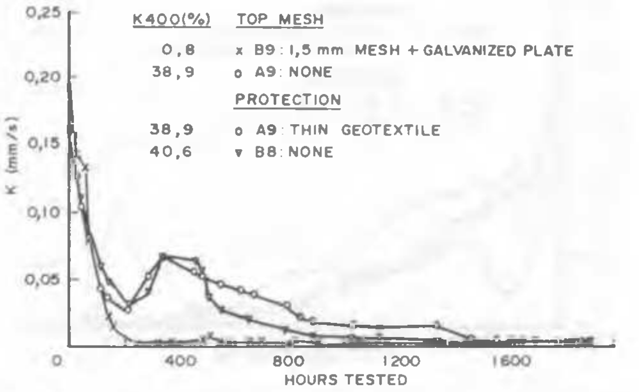

Figure 5. Laboratory flow tests: Influence of top mesh and soil protection.

hours and K400 was 0,8 %. This was true for each of the five tests carried out in this manner.

In an attempt to keep the surface smooth, a thin geotextile was placed on top of the soil sample in some tests. The results of two identical tests, one with and the other without the geotextile protection are shown in Figure 5. There was very little difference evident throughout the test.

Figure 6 shows the results obtained by varying the initial moisture and density of the soil samples. Samples were placed dry without compaction, at optimum moisture content (OMC) without compaction, and at OMC with compaction (87 % Mod AASHTO).

It is evident from Figure 6 that there was very little difference between the results obtained from the compacted and uncompacted samples. It was noted visually that in the test without initial moisture (A9), more fine material was washed through at the beginning of the test than was the case with the two moist samples. K400 was again similar for all three tests.

In a subsequent series of tests using a heavy clay (86 % passing the 0,075 mm sieve; PI = 64), it was observed that initial compaction of the sample had a fairly significant influence on the results. With all other soils tested, the water head was sufficient to compact the soil to at least 80 % Mod AASHTO. With the heavy clay, however, additional compaction was needed since the pressure exerted by the water resulted in only 60 % Mod AASHTO. Flow tests with this low density soil sample resulted in a much lower rate of permeability reduction.

The influence of the hydraulic gradient was also investigated. The gradient was decreased by increasing the height of the soil sample (a larger soil sample). This resulted in a lower rate of permeability reduction (see Figure 6). For a hydraulic gradient i = 5,7, the resultant K400 was 53,6 % as opposed to 38,9 % for i = 10,0.

From the investigation described above, the following conclusions were drawn:

- the repeatability of the test method was good when all parameters were the same, and
- factors that influenced the results most significantly were hydraulic gradient and chemical clogging due to electrolytic reaction. The influence of other factors was relatively small.

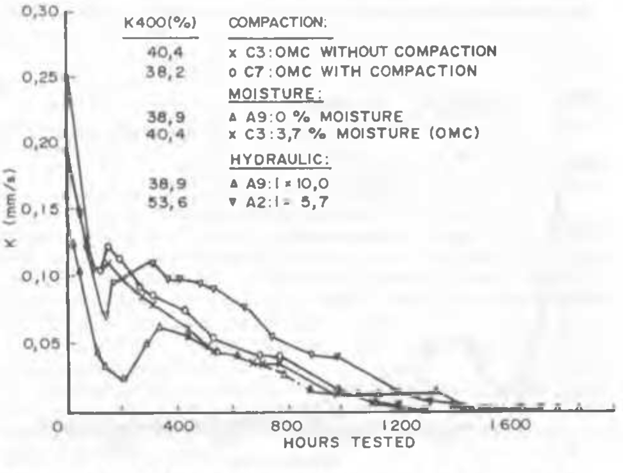

Figure 6. Laboratory flow tests: Influence of moisture, compaction and hydraulic gradient.

Based on these findings and taking practical considerations into account, the following procedure was adopted as standard for subsequent tests:

Support mesh	:	3 mm brass mesh.
Top mesh	:	None.
Soil protection	:	None, but initial filling of permeameter was done with a small-diameter pipe and spray nozzle to minimise disturbance of the surface.
Initial moisture	:	OMC.
Compaction	:	None, unless compaction under water pressure was less than 80 % Mod AASHTO, e.g. with heavy clays.
Soil sample size	:	1,0 kg dry mass.
Water head	:	1 000 ± 25 mm above geotextile.

Using this standard procedure, flow tests were performed on 85 soil/geotextile combinations, using 30 different geotextiles and 19 soil types, 14 of which were gradings made up in the laboratory by mixing different proportions of grain sizes. A summary of the soils used is given in Table 2.

Table 2: Summary of soils used in laboratory investigation

Soil	Description	U = D60/ D10	D85 (mm)	D50 (mm)	D10 (mm)
Warmbaths	Medium-grained sand	3,1	0,405	0,260	0,096
Stocks	Washed river sand	8,4	2,971	0,995	0,160
Du Plessis	Building sand	8,6	0,599	0,256	0,037
Silverton	Silty sand	302,8	0,411	0,095	0,0007
Montana	Medium clay (P1=32)	141,8	0,311	0,060	0,0005
S1 - S5	Gradings made up using Silverton sand	from 3,0 to 377,4	0,370 0,610	0,027 0,303	0,0005 0,118
W1 -W8	Gradings made up using Warmbaths soil	from 2,8 to 4,1	0,385 0,520	0,184 0,282	0,067 0,100

Geotextiles used were different grades of nonwoven needle-punched, nonwoven spunbonded, woven multifilament and woven monofilament.

3 FIELD TESTS

Field tests consisted of the monitoring of an installed subsurface drainage system. The system was a side drain alongside a newly constructed road. It was installed to act as a cut-off drain in a perched water table area. The site was chosen for two main reasons: firstly, it could be monitored from the beginning of its life and, secondly, it was seen to be a fairly critical application. In South Africa the average water table is usually well below the surface (10 m or more) and high water tables only occur in isolated areas. The vast majority of side drains are installed in cuts to remove ground water after a rain storm. The side drain that was monitored has had a continuous flow of water for the past three years and any design criteria based on the investigation will be conservative for road subsurface drainage.

Figure 7 shows a typical cross section of the road and side drain. The total length of the side drain is 840 m. Observation wells were placed across the road to obtain the position of the water table as indicated in Figure 7. This was repeated at six positions along the length of the installation. The height of the water table in each observation well, as well as the total amount of water flowing out of the system at the drain outlet, was measured at regular intervals. The permeability coefficient of the whole system was calculated as follows:

$K = Q/iA$ (Darcy equation)
where Q = total flow at the drain outlet
i = hydraulic gradient using h and ℓ as indicated on Figure 7
A = total area through which the water flowed (calculated for full length of the side drain)

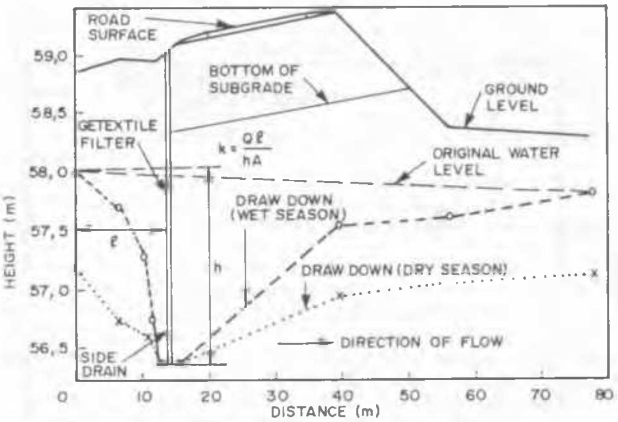

Figure 7. Typical cross section through road and side drain.

4 RESULTS

The change in permeability coefficient of the field installation over a period of two and a half years is shown in Figure 8. The permeability reduction in the laboratory tests, using the same soil/geotextile combination as in the field, is shown in Figure 9 (Geotextile A). It is evident that in both the field and the laboratory there was a reduction in permeability. To determine the relation between field and laboratory results, the total amount of water that flowed through the system per unit area of geotextile was calculated for both field and laboratory results.

In the field, a total of 24 000 m^3 of water flowed through an average area of 371 m^2, or 64,5 m^3/m^2, over a period of 22 500 hours. In the laboratory, the same volume of water per unit area (i.e. 64,5 m^3/m^2) passed through the system after 10,7 hours of testing. The laboratory test was therefore an accelerated

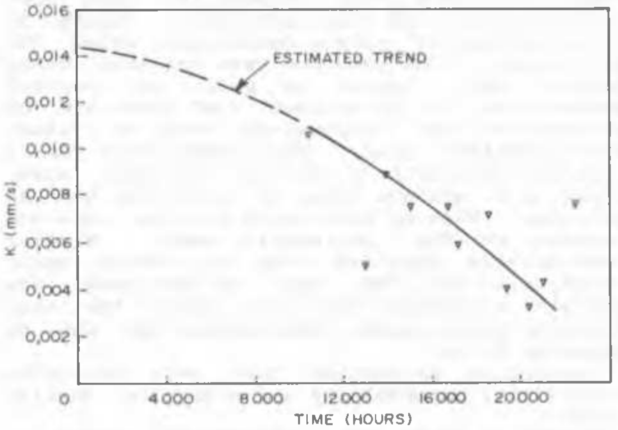

Figure 8. Permeability reduction of field installation.

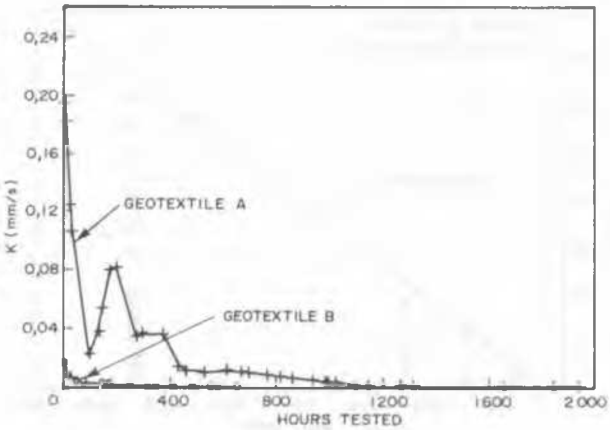

Figure 9. Laboratory permeability reduction of two geotextiles.

test, if compared with the field installation that was monitored. In the laboratory the flow rate per unit area was 2 100 times higher than the average rate in the field. (The hydraulic gradient used in the laboratory was 100 times greater than that encountered in the field.) If these values are extrapolated for the field situation, 400 hours of laboratory testing are equivalent to almost 100 years in the field. Although no road has a life expectancy of 100 years, a large safety factor is desirable to counteract all the unknown factors, assumptions and varying field conditions.

In the laboratory tests, the point at which equilibrium was most probably reached, i.e. where the rate of reduction decreased considerably resulting in the flat portion of the curve, was invariably around 400 hours. For these reasons, it was decided to use 400 hours as a criterion and hence the value of K400 as defined earlier.

Using the value of K400, the laboratory long-term flow tests were evaluated to determine how soil types and geotextile factors influenced the results.

To evaluate the influence of the soil, comparisons were made between the flow test results (K400) and soil parameters. Figure 10 is an example of such a comparison, using D50 of the soil. The results were obtained using various soil types as well as various geotextiles. It is evident that there was no correlation, but an envelope could be fitted giving maximum values. This means that for a specific soil with a certain D50 grain size, there is a maximum value of K400 that can be obtained. Whether this value will be obtained depends on the geotextile used. Similar results were obtained with all other grain sizes, i.e. D10, D90, etc. In each case, the results suggested that the finer the soil (smaller grain sizes), the smaller K400 can be expected to be.

Geotextile parameters that were evaluated were normal permeability and effective opening sizes.

Figure 9 shows the permeability reduction curves for two geotextiles using the same soil. The normal permeability of geotextile A was higher than the permeability of the soil, and that of geotextile B was lower than that of the soil. The results of geotextile B and all similar results, were discarded for the purpose of evaluating long-term flow test results.

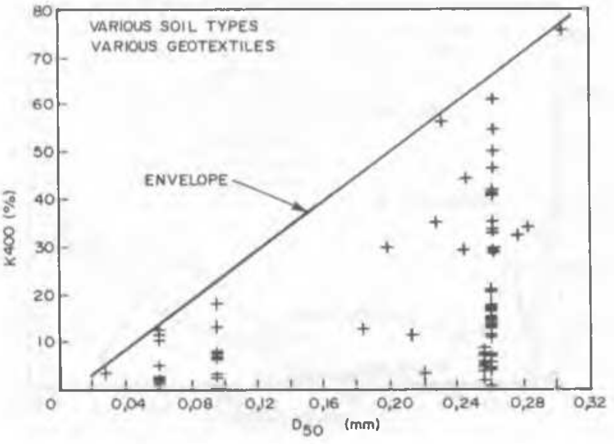

Figure 10. Influence of soil grain size on permeability reduction.

The influence of normal permeability on K400 is illustrated in Figure 11. These results represent tests using various geotextiles but only one soil type (a medium-grained sand). In each case, the initial permeability of the geotextile was higher than that of the soil, as discussed above. Once again an envelope can be fitted, indicating that a certain geotextile permeability will result in at least a certain value of K400, but a lower permeability will not necessarily result in a lower K400.

The results shown in Figure 12 compare opening sizes of the geotextile (O50) to K400 obtained. These are also results from tests using various geotextiles and one soil type (medium-grained sand). Here no correlation or envelope is evident. The results were similar for all other opening sizes (O10, O90, etc.).

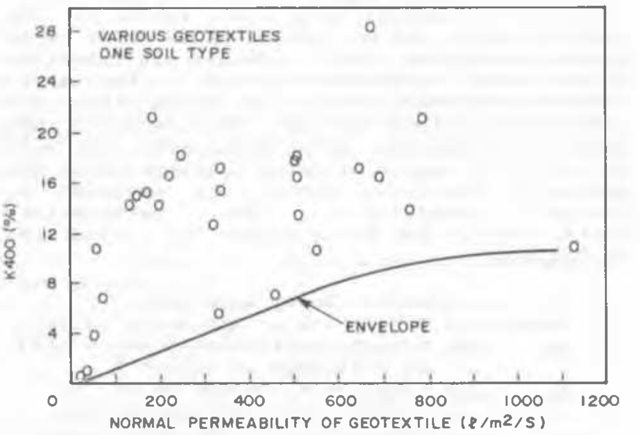

Figure 11. Influence of geotextile permeability on permeability reduction.

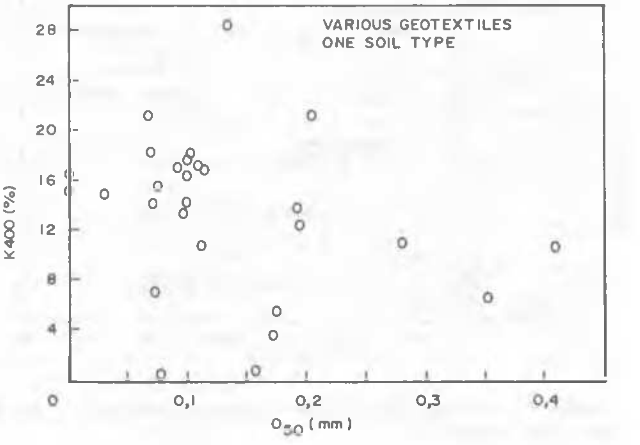

Figure 12. Influence of geotextile opening size on permeability reduction.

5 CONCLUSIONS

(1) The trends observed by other researchers using long-term flow tests were confirmed.
(2) The repeatability of the permeameter flow tests was found to be adequate. The apparatus and test method were standardised.
(3) Laboratory flow tests were related to field observations, which indicated the laboratory tests to be accelerated, with 400 hours in the laboratory representing 100 years in a fairly critical field application. Using the field/laboratory relation, a parameter was quantified to evaluate laboratory flow tests.
(4) No correlations were evident between in-isolation parameters of the soil and geotextiles (opening sizes, etc.) and the results obtained with long-term flow tests.
(5) It is recommended that, in addition to piping and permeability criteria, long-term flow tests be used to evaluate geotextile filters.

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