Large-scale Performance Tests to Evaluate Filtration Processes

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ABSTRACT: The long-term filter performance of 5 geotextiles differing in permittivity, thickness, mass per unit area and type of polymer was studied experimentally in large permeameters supplied with three different soils. In three test series, the geotextile samples of 500 mm diameter were submitted to steady state seepage under different hydraulic gradients for 6 to 24 months. In the first two performance tests, the water flow was in the direction of gravity. The third test series simulated the case of upward water flow. Although the geotextiles differed in their parameters, their filter performance exhibited very similar characteristics and satisfied the requirements for stable filter performance. A detailed microscopic investigation into the soil structure directly above the geotextiles confirmed that the geotextiles formed an internal soil filter with a bridging network.

KEYWORDS: Long-Term Filtration, Clogging tests, Performance Evaluation, Microstructure

1 INTRODUCTION

Geotextile filters function adequately when they retain a majority of the soil particles at the interface between a finer and a coarser soil and permit the flow of water through the pores of the soils and the geotextile filter without any water pressure build up upstream of the filter. Many investigations were carried out to obtain reliable criteria for the design of geotextile filters, but it is difficult to predict the long-term filter behaviour. The long-term performance of geotextile filters depends primarily on the following factors:

- the properties of the filter,
- the properties of the soils,
- the type of water flow.

Since these major factors are variable, it is not possible at the present time to predict the long-term filter performance of different geotextiles quantitatively on a theoretical basis. The long-term filter performance can only be evaluated correctly on the basis of either field experience or large scale performance tests under well defined boundary conditions which can be related to the in-situ situation.

2 TESTING PROGRAMME

2.1 Soils used for the performance tests

According to the geotextile filter criteria currently applied in Germany (FGSV 1994), a soil is called a "problem soil" regarding the geotextile filtration, if any one of the following criteria applies:

a) $C_u = d_{60}/d_{10} < 15$ and the soil contains some fines < 0.06 mm
b) > 50 % content of the grain size fraction 0.02 mm $< d < 0.1$ mm
c) $I_P < 15$ % (if not available: content of clay / content of silt < 0.5)

The fine-grained silt used for long-term filtration test was a loess from a road construction site in the Central Hesse area, about 30 km north of Frankfurt/Main.

The soils A and B were blended from different quartz fractions. Thus, it was possible to design cohesionless soils with gradation curves which met the above-mentioned criteria for a "problem soil" with respect to geotextile filtration.

The soils used in the permeation tests fully satisfied all criteria for a "problem soil". The grain size distributions are shown on Figure 1. Details of the soil parameters used in the tests are given by Kossendey et al. (1996b).

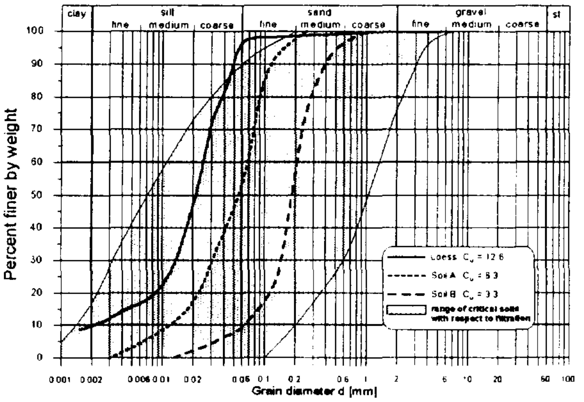

Figure 1. Grain size distributions of the soils used in the long-term permeation tests

2.2 Geotextiles

5 different nonwovens (3 heat-bonded, PP and 2 needle-punched, PET) geotextiles were selected for the long-term performance tests. They comprised geotextiles of various polymers and different manufacturing technologies in a wide range of their properties. Details of the selected geotextiles are given in table 1. Their properties were determined by index tests at the laboratory of the LGA-Geotechnical Institute. The results of these tests served as reference data for the evaluation of changes in the geotextile properties after the long-term permeation.

2.3 Permeameter circuit

The test equipment used in these test series consists of 3 supply containers and 4 permeameters per circuit arranged radially around the supply container. They have a diameter of 50 cm and a height of 167.5 cm. A detailed description of the permeameters was given previously by Gartung et al. (1994) and Kossendey et al. (1996b).

2.4 Test conditions

In total, three long-term filtration test series differing in their boundary conditions were carried out. For the first two test series, a mesh was placed upon the conical bottom plate with a discharge opening at the centre in each of the permeameters. The geotextile sample was installed above the mesh and attached to the permeameter by a fixing ring. The soil layer was placed on the geotextile. The first long-term test series was carried out under a hydraulic gradient of i=3 regarding the soil layer above the geotextiles. This hydraulic gradient falls into the range of typical hydraulic gradients for drainage applications under steady-state flow conditions, as noted by Davindenkoff (1976) and Luettich et al. (1992). During the second test series the hydraulic gradient was selected as i = 12 to observe the permeation behaviour under higher hydraulic gradients. The permeation of the tests was in direction of gravity. In order to examine the filtration behaviour of a system geotextile/soil under conditions of upward permeation against the direction of gravity, a third test series was implemented with a hydraulic gradient i = 2,5 (figure 2). The soil layers of each test implementation were only slightly compacted to test the filtration behaviour for the worst case.

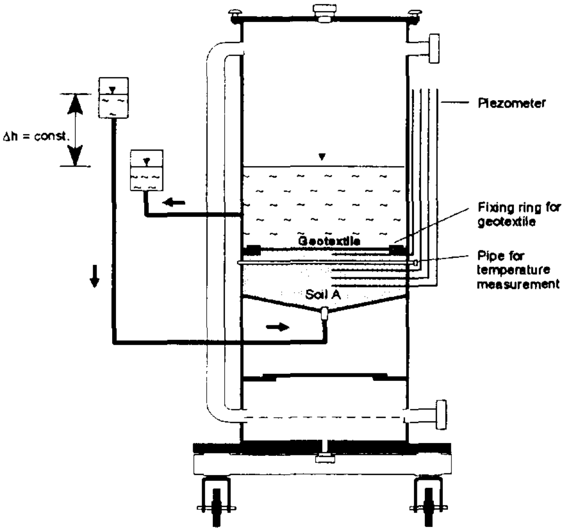

Figure 2. Schematic sketch of the test with upward permeation

The test liquid (tap water) permeated uniformly through the system geotextile/soil. The determined values of dissolved oxygen in the different circuits were between 4.2 ppm and 5.5 ppm. Following the definition of de-aired water (maximum at 6 ppm), the criterion for the oxygen content of de-aired water was met in the filtration tests.

2.5 Analysis of the microstructure

In order to analyse the microstructure at the interface geotextile/soil influenced by the interaction between geotextile and soil, microscopic sections were prepared. The undisturbed soil samples taken after the end of the tests were saturated by a resin in the same way as by water in the filtration tests to prevent the soil samples from any disturbance. The viscosity of the resin was similar the water that permeated the system geotextile/ soil.

3 TEST RESULTS

3.1 Performance tests with a hydraulic gradient i = 3

During an initial period of approximately four weeks, an increase in the system permeability of the permeameters with the loess soil was observed. In spite of the increase in permeability, no soil particles were detected by the collecting glass. After about four weeks, the permeability of all permeameters began to decrease. With increasing test duration, the permeameters showed only small differences in the system permeabilities. They followed the same trend towards constant values. The system permeabilities of the permeameters are given in Figure 3. The coefficient of permeability of the loess soil tested by small scale index test was $1.2 \cdot 10^{-8}$ m/s. The observed permeabilities of the large scale system geotextile/soil never fell below this value, so the permeabilities of the system soil / geotextile were higher than that of the small soil sample at all times. The reason for the discrepancy may be local variations in the density of the large permeameter sample, and associated inhomogeneities in the distributions of the coefficient of hydraulic conductivity.

The behaviour of the system permeabilities in the permeameters with soil A and soil B are similar to the results of the tests described by Kossendey et al. (1996a, 1996b). In permeameter with geotextile NP1 an additional load of 20 kPa was applied. The system permeabilities began to increase in all permeameters. In contrast to the test with the loess soil, the initial period of increasing permeabilities lasted only a few days.

Except for a slight cloudiness of the test liquid which could not be quantified, no particle migration was observed in the test circuit with soil A at the beginning of the tests. Although the geotextile HB1 was not dimensioned with respect to the criteria of FGSV, it satisfied the requirements for a sufficient filter performance. The greatest amount of migrated soil particles of NP1 was detected during the first 2 hours. With increasing test duration, the geotextile showed a stabilization like in the other permeameters. The reason for the higher amount might be details in the filling procedure of the permeameter. The cumulative amount of the migrated soil particles is given in table 1.

Table 1. Cumulative amount of migrated soil

Geotextile	Amount of migrated soil [g/m^2]	Soil
HB 1	19.02	A
HB 2	14.80	A
HB 3	5.97	A
NP 1*	78.38	A
HB 1	24.27	B
HB 2	9.15	B

* with 20 kPa load

After that initial period, the flow rates became consistent and the various permeameters showed only very small differences. As a result of higher compaction of the soil layer, the measured permeabilities in the permeameters with geotextiles NP1 and HB2 (soil A) were lower. The system permeabilities of the permeameters with soils A and B stabilized to equilibrium conditions after 100 days, and then they varied only in a very small range for the remainder of the test period. Like in the test with the loess soil, there were no discernible differences in the performance between the types of geotextile. The system permeabilities are given also on figure 3.

The permeameters which were filled with soil B and the permeameter with the geotextile HB 1 and soil A showed a slight decrease in their permeabilities after 300 days, while all of the other permeameters were constant in their permeabilities. After the monthly addition of a disinfectant against microbiological growth, an immediate increase in the permeabilities of the treated permeameters was observed. Although a biofilm of algae was not observed at the surface of the soil layer, probably a microbial growth within the pores of the soil had to lead to a reduction of the system permeabilities. The measured permeabilities of the dismantled geotextiles were smaller than those of the virgin geotextiles by a factor of 10 at maximum, but they never fell below the permeability of the test soils.

3.2 Performance test with a hydraulic gradient i = 12

Two heat-bonded and two needle-punched nonwovens were selected for a second test series to evaluate the filter performance under a hydraulic gradient of i = 12. In a first step, a layer of soil A with 5 cm thickness installed without compaction in the permeameters was permeated.

The development of the permeabilities of both tests under the hydraulic gradient i = 12 was similar to the results of the first test series. After an initial period of increase, the permeabilities began to decrease slightly. The measured amount of migrated soil was higher than in the test with a hydraulic gradient i = 3, but after 2 hours permeation no measurable amounts of soil were detected. After a test duration of 85 days, the soil layer in the permeameters was brought into suspension to simulate the extreme case of the destruction of the internal soil filter. Like in the first test, there were no discernible differences in the performance between the geotextile types. The measured amounts of migrated soil were higher than the results before the disturbance, but piping of the soil stopped within 3 hours. A distinct trend of a better performance of thicker products regarding the retention of particles was not observed. The system permeabilities and the cumulative amount of migrated soil particles are given on Figures 4 and 5.

3.3 Performance tests with upward permeation

Four nonwovens (two heat-bonded and two needle-punched) were selected for a third test series to evaluate the filter performance with upward permeation under a hydraulic gradient i = 2.5. The behaviour of the permeabilities was similar to the results of the two test series mentioned above. During an initial period of about 10 days, the permeabilities showed a nonuniform permeation behaviour. After that initial period, the permeabilities in all permeameters adjusted to constant flow rates. In order to simulate the frequent case of interrupted water flow in a subsurface drainage system, the upward permeation of the test system was stopped after 40 days. After the renewed start of the permeation, following an initial period of instability, the system permeabilities remained again relatively constant with time. The system permeabilities are given on Figure 6.

Table 2. Geosynthetics used in the long-term permeation tests

	Geotextile	Polymer	Mass per unit area [g/m^2]	Thickness (2 kPa) [mm]	$O_{90,w}$ [mm]^1	k_v (20 kPa) [m/s] ^{2}	Permittivity (20 kPa) [s^{-1}] ^{2}
heat-bonded	HB 1	PP	113	0.44	0.18	$4.0 \cdot 10^{-4}$	1.34
	HB 2	PP	195	0.56	0.13	$2.4 \cdot 10^{-4}$	0.55
	HB 3	PP	300	0.82	0.09	$3.2 \cdot 10^{-4}$	0.42
needle-punched	NP 1	PET	250	2.97	0.10	$2.2 \cdot 10^{-3}$	0.83
	NP 2	PET	365	4.02	0.09	$2.3 \cdot 10^{-3}$	0.55

1 measured by wet sieving (draftDIN 60500-6)

2 related to 10° Celsius and 1 geotextile layer, surcharge loads are given in brackets

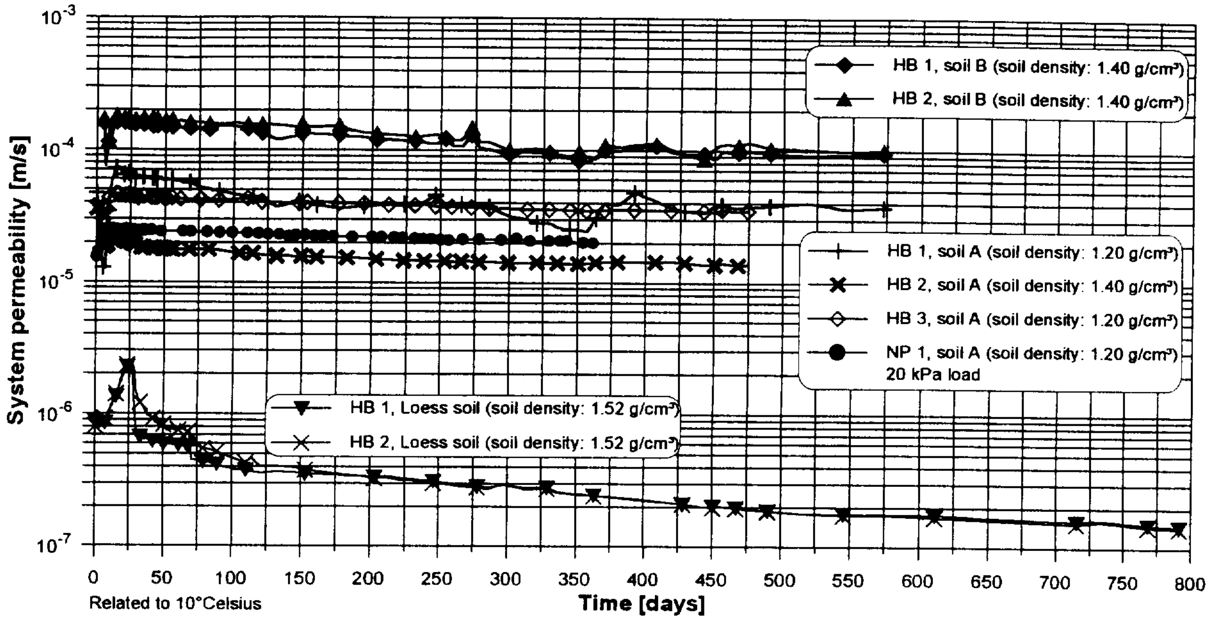

Figure 3. Permeabilities of the different systems of geotextile/soil (downward permeation, hydraulic gradient i=3)

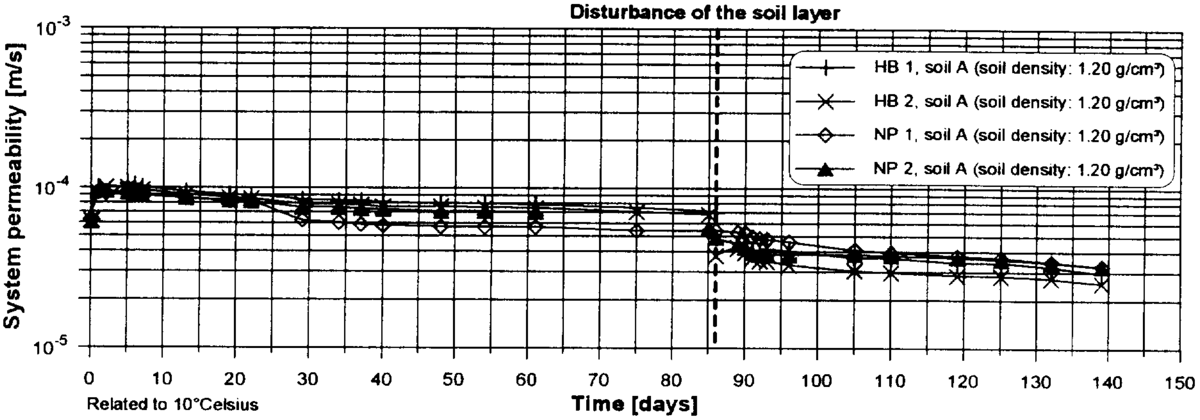

Figure 4. Permeabilities of the system of geotextile/soil A (downward permeation, hydraulic gradient i=12)

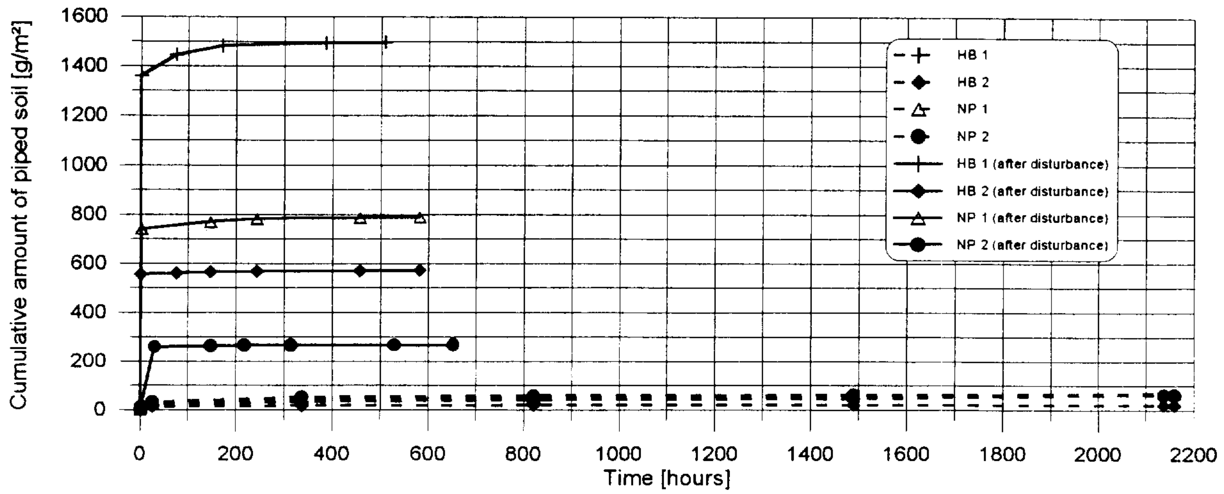

Figure 5. Cumulative amounts of piped soil (hydraulic gradient i=12)

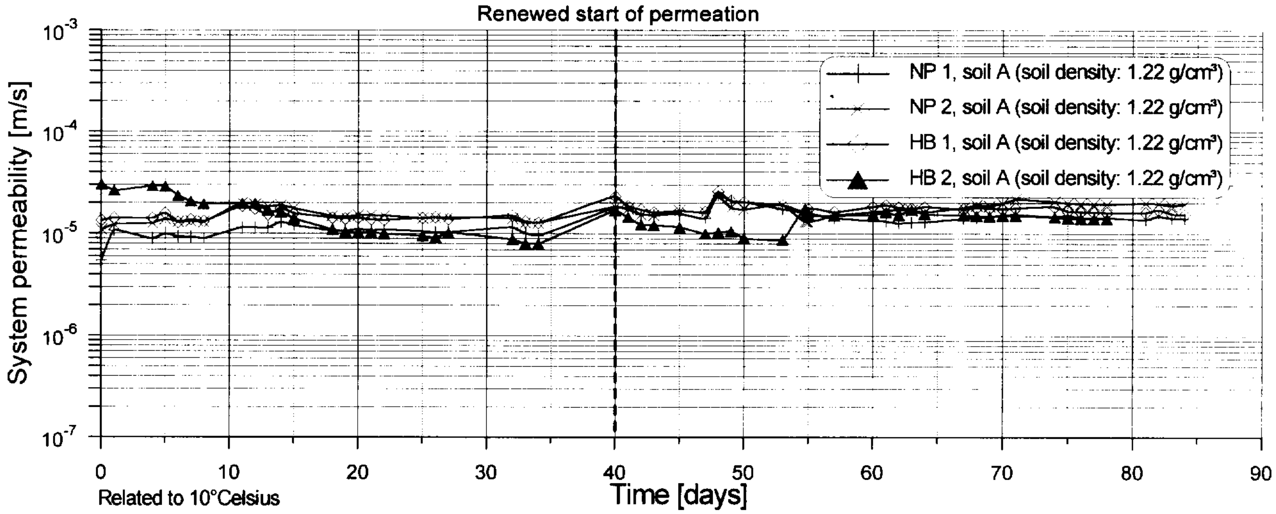

Figure 6. Permeabilities of the system of geotextile/soil A (upward permeation, hydraulic gradient i=2.5)

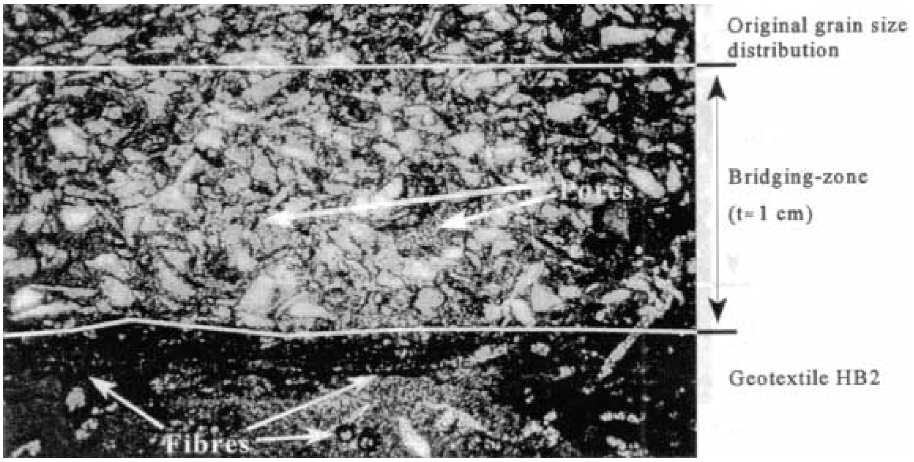

Figure 7. Microstructure at the interface Geotextile HB2/ Soil A (2^{nd} Test series; hydraulic gradient i=12)

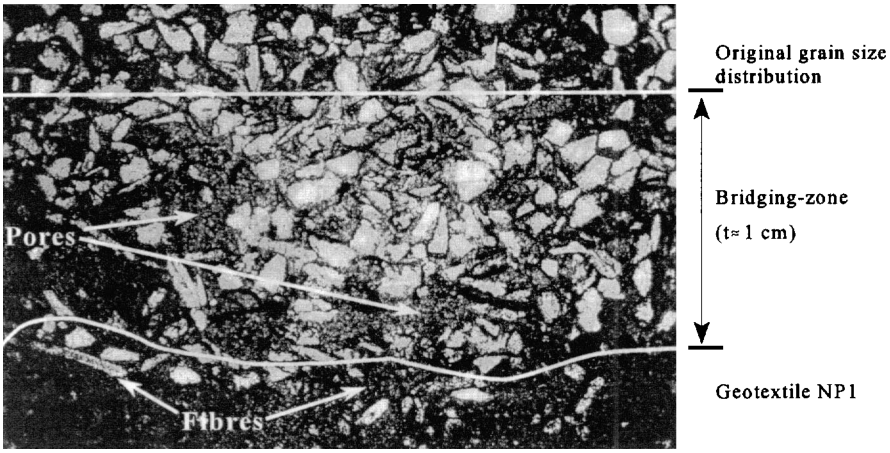

Figure 8. Microstructure at the interface Geotextile NP1/ Soil A (2^{nd} Test series; hydraulic gradient i=12)

4 MICROSTRUCTURAL ANALYSES

During the dismantling of permeameters of the test series permeated downward, undisturbed geotextile/soil samples were prepared for microscopic analyses. In all analysed microscopic sections, it was observed that soil particles formed an internal soil filter in the form of a bridging network above the geotextiles. The geotextile filter layers acted as a catalyst for the formation of this internal filter system of the soil. The thickness of the bridging-zone was dependent on the hydraulic gradient. The thickness of the bridging-zone observed in the tests under the hydraulic gradient i = 3 was 5 mm at maximum and about 1 cm in the tests under a hydraulic gradient i = 12. A trapping of finer soil particles by the filter layer was noticed only in tests with the needle-punched geotextiles. However, the penetration was about 0.5 mm, so that the phenomena of deep filtration discussed by Heerten (1993) was not observed. The microstructures of soil A and the geotextiles HB2 and NP1 are given on figures 7 and 8.

5 CONCLUSION

Although the tested geotextiles differed in their material parameters, their filter performance exhibited essentially the same characteristics. They satisfied the requirements of stable permeation conditions. A review of the test results published by Kisskalt (1992), by Gartung et al. (1994) and by Kossendey et al. (1996a, 1996b), revealed that this observation applies to the geotextiles and test soils studied by Kisskalt and by Kossendey et al. as well. The test duration of up to 800 days and the large scale of the test equipment admit the application of these findings to conditions which are encountered in engineering practice (steady-state-flow conditions and lower hydraulic gradients). The opening size $O_{90,w}$ (measured by the wet sieving method) of most of the recently obtainable nonwovens falls into the region from 0.07 to 0.13 mm. Following the obtained test results, it has to be assumed that geotextiles which meet the retention criterion based on $O_{90,w}$, will perform successfully under these boundary conditions.

Along with the results of previous research investigations (Kisskalt 1992 and Kossendey et al., 1996a, 1996b), the findings of these long-term studies in filtration with 25 different geotextiles and 6 critical soils regarding filtration are a wide basis for the assessment of the long-term filter performance. All results confirmed that the thickness of a geotextile layer is not a relevant criterion for filtration under steady-state-flow conditions and the retention criterion based on $O_{90,w}$, has proved to be a reliable basis for the dimensioning of geotextile filter layers. Field examinations of geotextiles installed up to 15 years ago (Rollin et al.,1994 and Mylnarek et al., 1994) confirm the results with respect to the long-term performance.

The test results of the long-term test series reported in the present paper and compared to results of previous test series carried out at the LGA-Geotechnical Institute can be summarized as follows:

- all permeameters showed the same flow behaviour with increasing test duration
- stable flow conditions were obtained in all permeameters
- the system permeability was independent of the type of geotextile
- the thickness of a geotextile filter layer had definitely not any influence on the filtration behaviour under test conditions described above
- the microscopic analyses indicated that the geotextile filter acts as a catalyst for the formation of an internal soil filter based on a bridging network
- the phenomenon of deep filtration was not observed
- no measurable migration of soil particles occurred after 48 h, stable hydraulic conditions were obtained in all permeameters
- even relatively openly designed geotextiles performed successfully
- no failure of the geotextile filter by clogging was found during the performance tests

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