Long Term Filter Function of Nonwovens : Large Scale Performance Test

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ABSTRACT: The long-term filter performance of 6 nonwovens differing in permittivity, thickness, mass per unit area and type of polymer was studied experimentally in a set of large permeameters. The geotextile samples of 500 mm diameter sandwiched between a sandy silt and a coarse gravel were submitted to steady-state seepage under a hydraulic gradient of i=3 for 18 months. The boundary conditions, such as the relevant properties of the test soils and the water, were well controlled throughout the test. So the continuously taken flow-rate measurements are a reliable basis for the evaluation of the time-dependent permeation behaviour of the system consisting of a fine-grained soil with very low cohesion. Such systems are problematic with respect to erosion in contact with coarse-grained drainage material and typical nonwoven geotextile filters. The test results enable a good comparison of the behaviour of different types of nonwoven geotextile filters under conditions which are encountered in practice in civil and geotechnical engineering. The paper presents the test set up, the measurements and a detailed description of the observations obtained during the long-term experiment. An investigation into the soil structure immediately above the geotextiles is given, and an interpretation of the test results with respect to the filter performance.

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. 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.

The Geotechnical Institute of the LGA has carried out an experimental investigation into the long-term filter performance of six different nonwoven geotextiles for one particular test soil under steady state flow of water.

2 TESTING PROGRAMME

2.1 Soil used for the performance tests

The fine-grained soil used for the long-term filtration test is a loess from a road construction site in the Central Hesse area, about 30 km north of Frankfurt/Main. The soil deposit appears to be very uniform and consequently the samples taken for the six permeameters and for soil mechanics testing show little scatter in their properties. A summary of the soil properties is given in table 1. Figure 2 shows the grain-size distribution of the loess soil. The grain size distribution of the loess is similar to the soil used by Lawson (1990) and Rollin et al. (1991).

According to the geotextile filter criteria currently applied in Germany (FGSV 1993) the loess falls within the gradation region of "problem soils". A soil is called "problem soil" with respect to 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.) $I_P < 15$ %

The soil used meets all three criteria (FGSV 1993).

2.2 Geotextiles

Six different nonwoven geotextiles were selected for the long-term performance test. They comprised needle-punched and heat-bonded nonwovens of various raw materials in a wide range of mass per unit area and thickness. Details of the selected geotextiles are given in table 2. 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.

Coefficient of uniformity	C_u	12.6
Content of grain sizes 0.02 mm < d < 0.1 mm		50 %
Liquid limit	w_l	29.8 %
Plastic limit	w_p	19.3 %
Plasticity index	I_p	10.5 %
Natural moisture content	w_n	14.0 %
Proctor density	ρ_{Pr}	1.78 g/cm^3
Optimum moisture content	w_{pr}	15.7 %
Lime content		12.2 %
Coefficient of permeability	k_v	1.18 x 10^{-8} m/s

Table 1: Summary of the properties of the soil

2.3 Permeameter circuit

The test equipment consists of 1 supply container and 6 permeameters arranged radially around the supply container. The permeameters were described previously by Kisskalt and Gartung (1990). They have a diameter of 50 cm and a height of 167.5 cm. In each of the permeameters a drainage gravel layer of grain size 16/32 mm is placed upon the conical bottom plate with a discharge opening at the centre. The geotextile sample is installed above the gravel and attached to the permeameter by a fixing ring. Then the soil layer of 20 cm thickness is placed on the geotextile. The test liquid (tap water) is supplied from a central container. It permeates uniformly through the samples under a hydraulic gradient of i=3 with respect to the soil layer above the geotextiles. The temperature of the test liquid is controlled during the test, it is kept at 20° Celsius ± 5° Celsius. The supply pumps are controlled automatically according to the required flow rate. The hydraulic conductivity of the soil / geotextile system is derived from discharge measurements at the bottom of the permeameter.

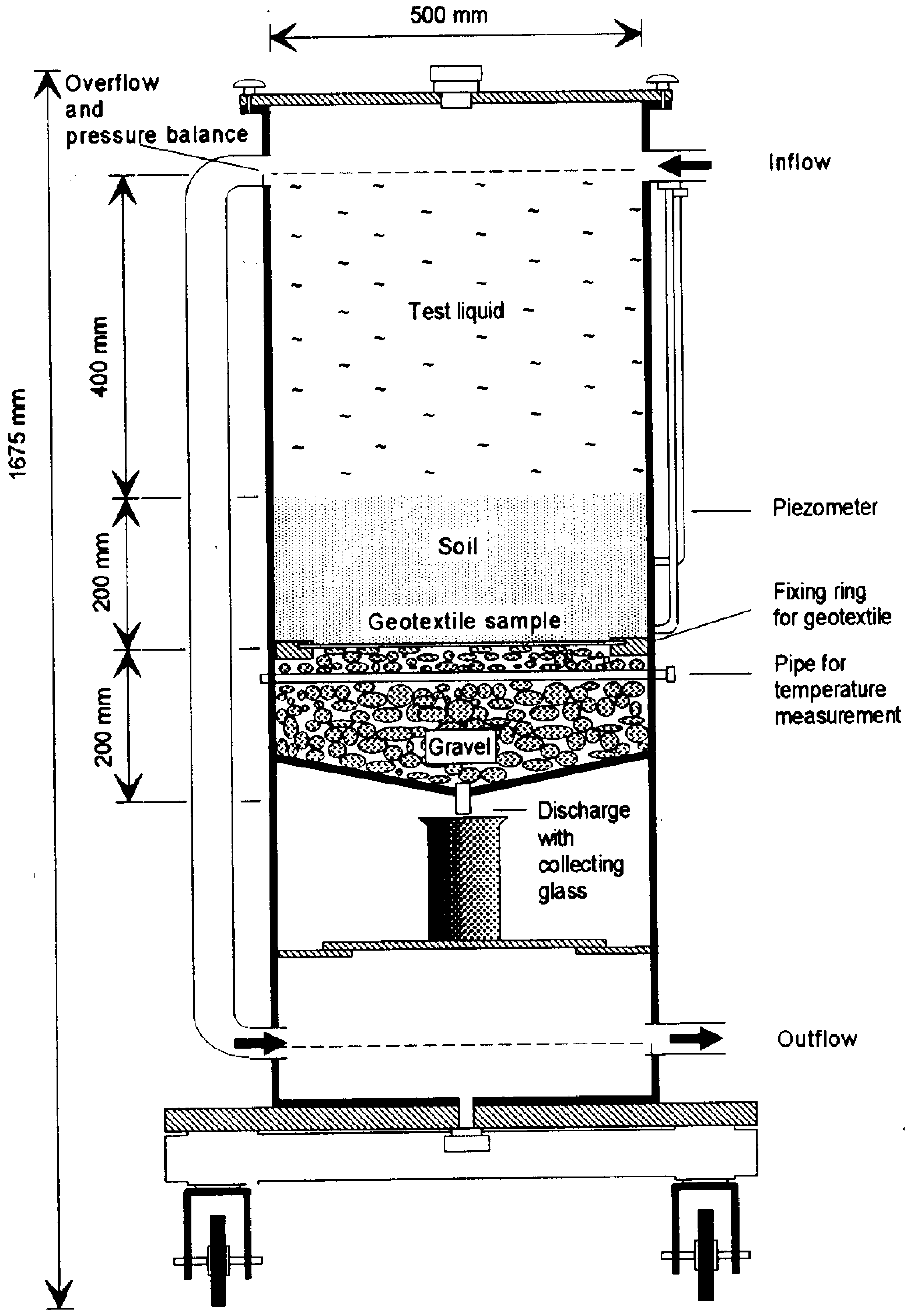

Figure 1: Permeameters used in the performance test

3 TEST RESULTS

3.1 Observations during the performance tests

During an initial period of approximately six weeks an increase in the permeability of the system was observed in all test containers. In spite of the increase in permeability, no soil particles were detected by the collecting glass. After about six weeks, the permeability of all permeameters began to decrease. With increasing test duration, the permeameters show only small differences in the system permeabilities.They follow the same trend towards constant values. The system permeabilities of the permeameters are given in figure 3. The behaviour of the system permeabilities is similar to the permeabilities described by Fillibeck, Heyer and Berkhout (1993). The coefficient of permeability of the loess soil tested by index test was about 1.2 x 10^{-8} m/s. The observed permeabilities of the system soil / geotextile never fell below this value, so the permeabilities of the geotextile filters were higher than that of the soil at all times.

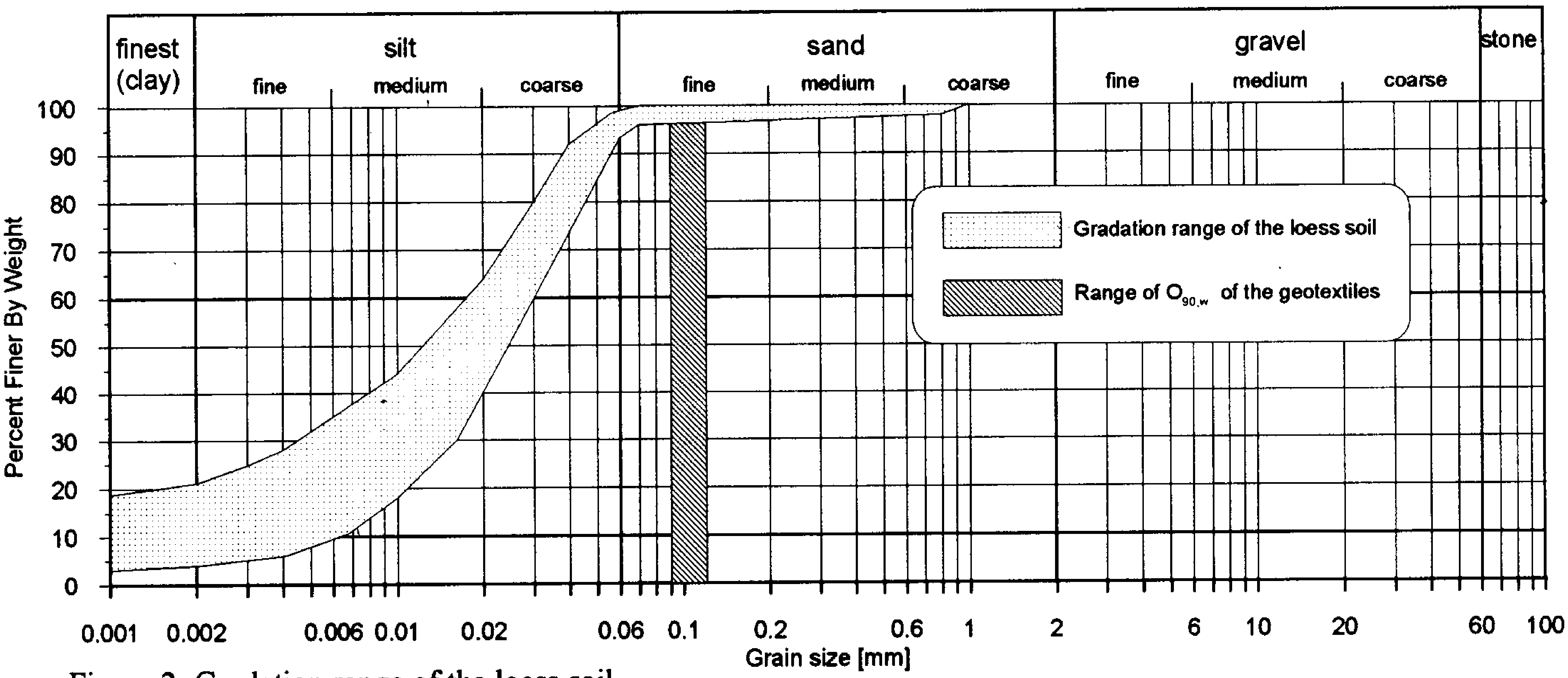

Figure 2: Gradation range of the loess soil

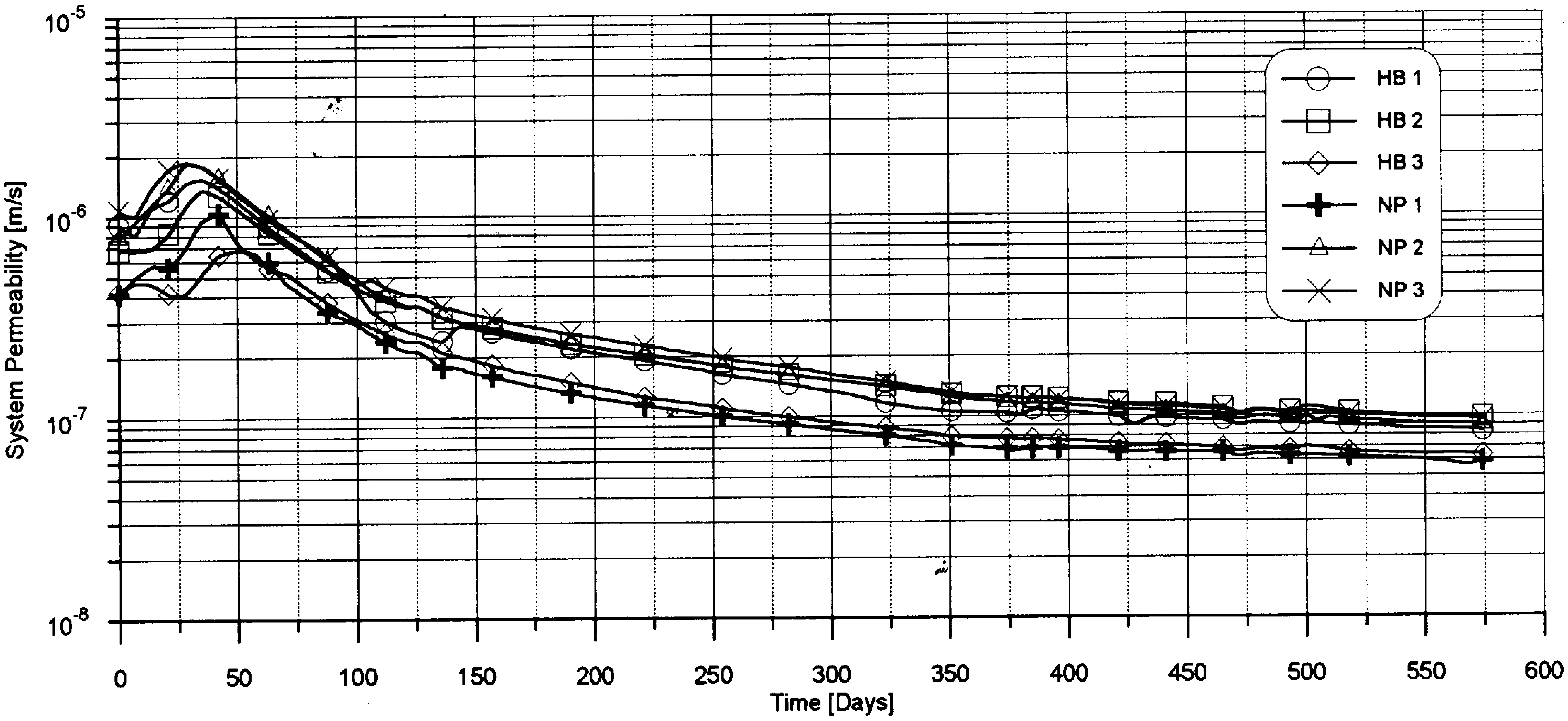

Figure 3: Permeabilities of the system soil / geotextile (related to 10° Celsius)

Property	HB 1 Heat-bonded nonwoven, PP / PE	HB 2 Heat-bonded nonwoven, PP / PE	HB 3 Heat-bonded nonwoven, PP / PE	NP 1 Needle-punched nonwoven, PET	NP 2 Needle-punched nonwoven, PET	NP 3 Needle-punched nonwoven, PP
Mass [g/m^2]	99	144	182	250	365	156
Thickness (2 kN/m^2) [mm]	0.66	1.03	1.18	2.97	4.02	1.47
$O_{90,w}$ [mm]	0.12	0.11	0.09	0.10	0.09	0.10
k_v (2 kN/m^2) [m/s]*	3.56×10^{-3}	4.72×10^{-3}	4.37×10^{-3}	3.84×10^{-3}	3.40×10^{-3}	9.95×10^{-3}
k_v (20 kN/m^2) [m/s]*	1.98×10^{-3}	1.71×10^{-3}	1.63×10^{-3}	2.20×10^{-3}	2.30×10^{-3}	3.39×10^{-3}
k_v (200 kN/m^2) [m/s]*	4.72×10^{-4}	8.59×10^{-4}	6.56×10^{-4}	7.21×10^{-4}	5.89×10^{-4}	9.11×10^{-4}
Ψ (2 kN/m^2) [s^{-1}]*	3.78	3.05	2.60	1.36	0.97	7.21
Ψ (20 kN/m^2) [s^{-1}]*	2.95	1.66	1.45	1.04	0.91	3.29
Ψ (200 kN/m^2) [s^{-1}]*	2.05	2.05	1.26	0.83	0.55	2.07

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

Table 2: Geotextiles used in the test

3.2 Properties of the geotextiles and the loess soil after the long-term test

After dismantling of the permeameters the mass per unit area and the permeabilities of the geotextiles were determined.

It is impossible to measure the permeabilities of the recovered geotextiles according to standard procedures (DIN 60500 : Part 4). The requirements of this method (submerging under water, de-aerating by vacuum prior to permeability testing) would cause loss of soil. Consequently the permeability of the geotextile samples was tested without de-aerating under a hydraulic gradient $i = 1$ with the moisture content of dismantling. That seems to be a good correlation to the conditions of the geotextiles inside the permeameter. The measured permeabilities were reduced by a factor of 10, but still they exceed the permeability of the loess soil by at least 10^3. The mass of the geotextiles was checked after the measurement of permeability to get the portion of soil which is tightly lodged into the geotextile. Some retention of fine soil particles was observed in all geotextiles. The amount of soil retained within the geotextiles varied between 232 % and 426 % of the weight of the clean geotextile. There was no clear correlation between the amount of soil retained by the geotextiles and thickness or mass per unit area.

Tests on grain size distributions of the loess layer a few millimeters above the geotextile indicate that no fines were washed out.

5 CONCLUSIONS

Although the six geotextiles employed in the large-scale, long-term filter experiment differed considerably in thickness, mass per unit area and type of construction their filter performance exhibited essentially the same characteristics. The apparent opening size of the six nonwovens which varied only in a small range of 0.09mm to 0.12 mm essentially controls the filter performance. Evidently, the thickness of the filtering nonwoven geotextile has no influence in the filter function under steady-state, low-hydraulic gradient water flow through a loess soil, which is a typical representative of the "critical" soils with respect to erosion resistance.

Although all six geotextile filters are not dimensioned with respect to the criteria of FGSV (region A and problem soil => $O_{90,w} < d_{90}$) they operated successfully. The permeabilities of the geotextiles remained greater than the permeability of the soil by about three orders of magnitude over a period of one and one half years. After an initial increase of the flow rate which lasted 30 to 50 days, the permeability of the soil / geotextile system decreased gradually towards a residual value of about 1×10^{-7} m/s which was approached after 500 days. The large scale, long-term performance test verifies the current practice of filter design under steady state flow conditions on the basis of the apparent opening size.

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