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TESTING OF FILTER CHARACTERISTICS OF COMPOSITE MATERIALS
PRÜFUNG DER FILTEREIGENSCHAFTEN VON VERBUNDSTOFFEN
TEST DES PROPRIETES DE FILTRAGE DES GEOTEXTILES COMPOSITES

Hydraulic and filter characteristics were determined for mechanically bonded non-wovens in order to investigate how the individual layers influence the properties of the composite material. The influence of the number of layers, varying fibre thicknesses, and type of soil on the soil penetration, incorporation, and distribution over the filter thickness was shown by turbulence tests as developed by the FEDERAL INSTITUTE OF WATERWAYS ENGINEERING (BAW). Permeability values normal to the plane, k_v, determined by tests conducted at the FRANZIUS-INSTITUT FOR HYDRAULIC RESEARCH AND COASTAL ENGINEERING show the relationship between k_v-values of the single components and that of the composite material. Similar interrelationships were determined for the effective opening size, D_w. The influence of the needle-punching was also investigated. The tests also showed the influence of the roughness layer on the filter effectiveness of geotextiles.

Pour faire apparaître la manière dont interviennent les différentes particularités des différents composants du géotextile, on définit pour des géotextiles fixés mécaniquement, des nombres caractéristiques hydrauliques et de porosité. Dans les essais de turbulence, on montre l´influence de différentes unités de fibres et de la nature des sols sur la perméabilité du sol, l´ incorporation et la répartition des différentes couches sur la longueur de filtration. Dans les essais effectués sur la perméabilité perpendiculairement à la couche de géotextile, on montre la dépendance du k_v du géotextile composite et des valeurs de k_v des différents composants. La même remarque est valable pour les essais sur le diamètre efficace des pores. L´influence de la couture sans fil des géotextiles pourrait également être examinée. Par ailleurs, les essais montrent l´influence de la couche supplémentaire (couches de rugosité) sur l´effet de filtrage du géotextile.

1. INTRODUCTION

Geotextiles have come into increasing use in soils and hydraulic applications as a result of their technical and economic advantages over conventional construction methods.

At every location where a filter forms a substantial part of the construction (bank covering, revetment stabilization, groynes, scour prevention), the service life of these constructions depends upon the maintenance of the phase separation functions of the filter. Investigations of the long-term durability of the employed filter products have yielded positive results. Design and test criteria can only be developed after many years of experience, such as in the case of geotextile filter products, which have developed on the basis of a wide range of experience and the requirements arising therefrom. The latter course of development was from woven fabrics with a pore distribution in the horizontal plane only, via non-wovens with a pore distribution in both the horizontal and vertical planes, to finally composite materials with varying pore openings between individual layers.

On the basis of existing experience, composite materials have become increasingly popular over the past 10 years, e.g. in waterways engineering for highly durable canals. Composite materials are comprised of serveral layers of non-wovens of varying denier and thickness. By careful selection of the different non-woven layers (pore-opening distribution and thickness), they can improve, for example, the filter effectiveness especially for fine-grained and layered soils. For revetments ($m \geqslant 1 : 4$), composite materials placed directly on the soil are provided with a much more open non-woven layer - the so-called stabilization layer (roughness layer) - compared to the overlying filter layer.

As pointed out at the conferences in London (1984) and Dornbirn (1984), a number of cases of damage to the revetments have occurred as the result of soil displacement beneath the geotextile. A possible solution to this problem, which was developed in GERMANY and has received much attention, involves the use of geotextiles including a roughness layer for the prevention of soil movement and to stabilize surfaces susceptible to erosion.

In selecting a geotextile filter with a stabilization layer in contact with the soil on a revetment, the following requirements must be considered:

1. Solution of the filter problem, i.e. Determination of the pore-opening distribution in the actual overlying filter layer or filter layers, in order that the necessary filtration length can develop within the given overall layer thickness.
2. Solution of the boundary layer problem, i.e. Determination of the opening size of the stabilization layer, in order that soil particles migrate from the revetment into the roughness layer following an exceedance of the critical slope, thereby ensuring a state of equilibrium beyond the maximum expected pressure gradient.

The purpose of this paper is to describe the process in multiple-layer composite material systems in terms of characteristic values, taking into consideration the extremely complex interrelationsships between the geotextile, soil and moving water.

2. GEOTEXTILES USED

The hydraulic and filter characteristics were determined for mechanically bonded non-wovens, which were

GEOTEXTILE	MASS PER UNIT AREA g/m^2	THICK-NESS mm	D_W mm
Type A: 1 x 7 dtex	500	3,2	0,08
Type B: 1 x 17 dtex	500	4,0	0,13
Type C: Composite Mat.	1900	17,5	0,06
	820*	10,5*	0,58*
Type D: Composite Mat.	1800	21,3	-
	950*	13,3*	1,34*
Type E: Composite Mat.	1400	26,7	-
	560*	20,0*	≈ 6,0*

*of the Roughness Layer (Abb.: Stab.)

Table 1
Geotextiles Used

combined with one another in various ways, and for composite materials with a roughness (stabilization) layer in order to determine the influences of the characteristics of the individual components on the composite material. The influence of the needle-punching of the composite material could also be investigated by comparing the values of the composite material with those from the individual components loosely stacked upon one another (subsequently referred to as zero composite material).

Table 1 shows some values for basic estimates of the chosen products. Figure 1 shows the cross-section. of type D.

3. TEST PROCEDURES

Test equipment included a turbulence test according to BAW (FEDERAL INSTITUTE FOR WATERWAYS ENGINEERING, Karlsruhe), test equipment of the FRANZIUS-INSTITUT for the determination of the effective opening size and the permeability values normal to the plane of the geotextile, as well as equipment specially developed for these investigations.

3.1. Determination of the Effective Opening Size

The effective opening size, Dw, is determined by wet-sieving with a chosen test sand. During the test, the geotextile operates as a sieve, as shown in Figure 2.

The effective opening size is determined from the greatest grain-size fraction in which there is a defined percentage of sieved material from the test sand used. The value is determined by an interpolation between the individual fractions such that 10% of the total mass passes through the filter (geotextile).

3.2 Determination of the Permeability Normal to the Plane of the Geotextile

The permeability value normal to the plane of the geotextile, k_v, is a function of the applied load. It is determined by making use of DARCY'S law with a constant pressure head in the permeability cell acting on a packet consisting of several layers (see Fig. 3). In addition to this conventional set up, the permeability value was also determined from the samples removed from the turbulence tests and the corresponding zero tests (i.e. without soil incorporation) with loads of 2 kN/m^2.

3.3. Turbulence Test Procedure

The test container for the turbulence test according to BAW is positioned above a rotor, which generates turbu-

Fig. 1
Cross-Section of Geotextile Type D

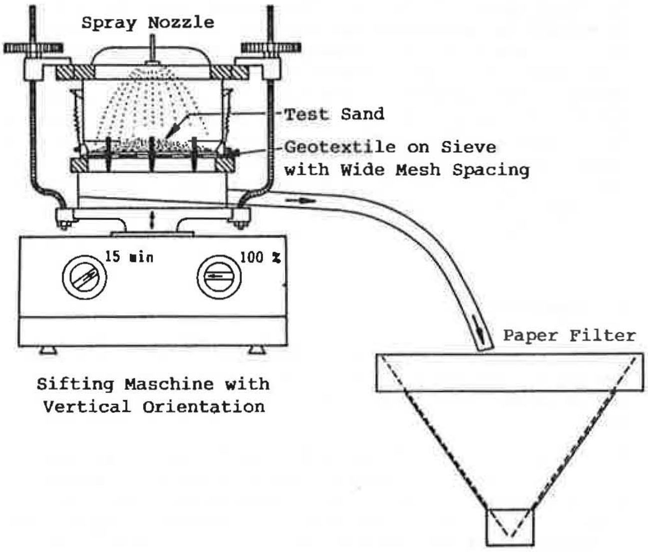

Fig. 2
Test Equipment for the Determination of the Effective Opening Size

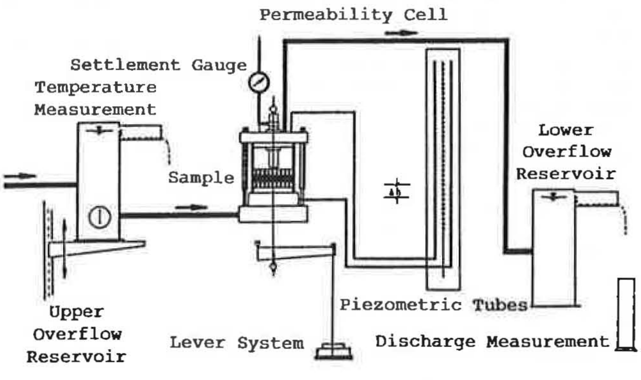

Fig. 3
Test Equipment for the Determination of the Permeability Normal to the Geotextile Plane

lent flow over the sample, such that the geotextile is about 1.0 cm below the surface of the water, as shown in Figure 4. The mass of soil material which passes through after a test of 150 min duration is determined. Soil mixtures were made using two of the soil types specified by BAW. Figure 5 shows the grain-size distributions of the soils used.

In order to eliminate the effect the force of gravity has on the passage of soil grains, an alternate arrangement was devised whereby the test container was placed at the same distance, but below, the rotor (Fig. 6).

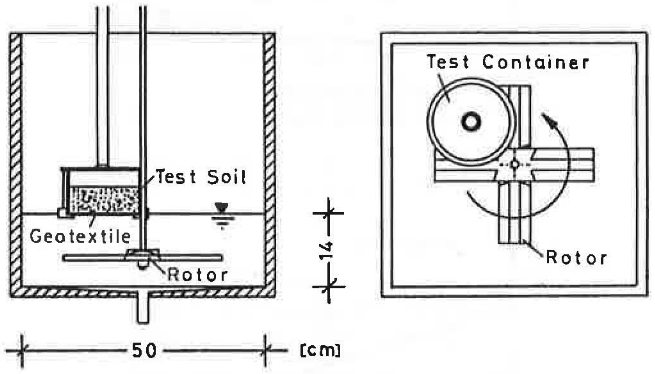

Fig. 4
Turbulence Test Set-up according to BAW

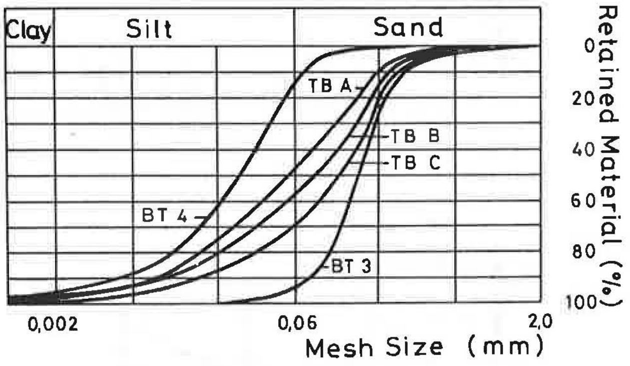

Fig. 5
Grain-Size Distribution of Soil Types Used

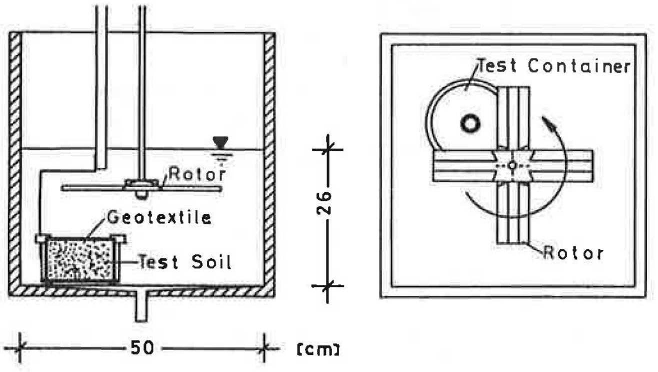

Fig. 6
Arrangement for Turbulence Test
Variant "Sample Below Rotor"

3.4 Test Equipment for the Investigation of Contact Surface Erosion

The test equipment shown in Figure 7 was developed by the FRANZIUS-INSTITUT in order to describe the penetration of soil particles in the roughness layer as well as the possible transport phenomena and process in the plane of the geotextile.

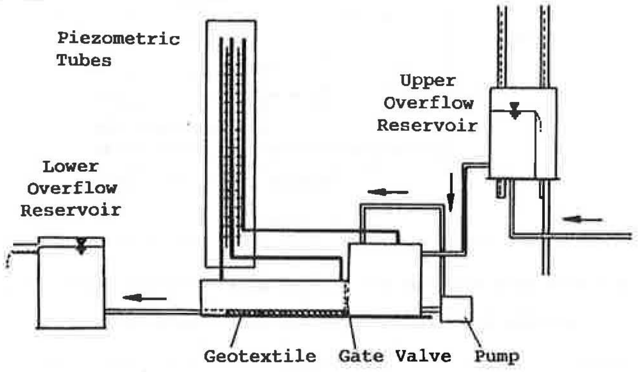

Fig. 7
Test Equipment for the Determination of Transport Phenomena

Water enters the rectangular container filled with soil from an overflow tank under constant hydraulic pressure head. A pump is attached to the container to provide mixing action. By opening a gate valve, the soil-water suspension enters the actual test chamber where the geotextile (50 cm x 10 cm) to be tested is installed. Water leaves the system by way of an overflow container.

4. DISCUSSION OF RESULTS

4.1 The Influence of the Filtration Length (Thickness) of Homogeneous Non-wovens on Soil Penetration

Several of the geotextiles were installed in the test equipment described above as zero composite materials in order to determine the filter penetration as a function of the thickness. As an example, Figure 8 shows the relationship between soil penetration (see Section 3.3) and the number of layers. A doubling of the number of layers considerably reduces soil penetration (test soil TB B). It must also be noted that thicker products are better at shielding the soil from the effects of turbulence by the rotor. The effective opening size (see Section 3.1) is insignificantly influenced by an increase in the number of layers.

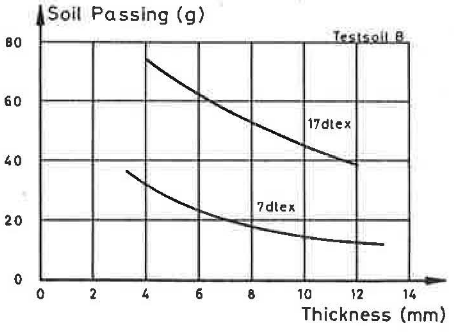

Fig. 8
Soil Penetration as a Function of Thickness

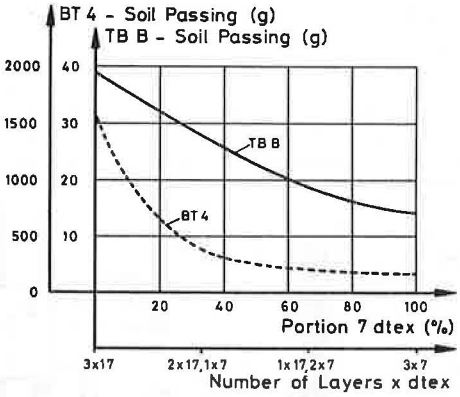

Fig. 9
Soil Penetration of Zero Composite Materials

4.2 Multiple-layered Non-Wovens with different Effective Opening Sizes for the Individual Components

Figure 9 shows the soil penetration for zero composite materials as a function of fibre thickness and soil type. A decrease in penetration with increasing fibre fineness is clearly evident. Figures 10 and 11 show the influence of the stabilization layer on the soil penetration. For all mixed soils (Test soils TB A, TB B and TB C), the soil penetration for the composite materials with a roughness layer is higher than for the pure non-wovens (Fig. 10). This may be explained by the increase in the fine-grained fraction in the soil penetration. The roughness layer operates like a sieve or pre-filter, which results in a retention of the coarse-grained fraction. An enhanced migration of finer particles is favoured owing to the absence of the coarse-grained fraction; blockage of individual pores does not take place. With an increase in the fine-grained particles (fractional increase of BT 4), the "sieve effect" becomes less important. For soil type BT 4, which has the highest mud fraction, the soil penetration of the non-woven is higher than that of the composite material.

By way of an additional pre-filter layer for the three-layered composite material, the soil penetration is reduced compared to that for a two-layered structure, especially for soil type BT 4. For example, Figure 11 shows this effect for the geotextile 7 dtex. For the geotextiles previously discussed, we are dealing with the production of pure fibre, i.e. no mixed fibre. A comparison with geotextiles as produced in practice is shown in Figure 12. Apart from minor differences in the fineness of the fibre, the composite materials C and D are constructed in exactly the same way as the composite materials 7 dtex (Type A), 17 dtex (Type B) and Stab. C (Stabilization layer C / Type C) and Stab. D (Stabilization layer D / Type D). The experimental results confirm a partial agreement. In contrast, the nature of the soil penetration for composite material E shows significant differences. Owing to the highly open structure of the roughness layer, a filter effect cannot be expected. The nature of the soil penetration is closely similar to that of a pure non-woven fabric (see Fig. 10).

The improvement of the mechanical filter effectiveness by means of a graded three-layered filter structure becomes evident from the tests described above, especially in the case of fine-grained soils. By comparing three-layered geotextiles with (e.g. 1 x 7, 1 x 17, Stab. C) and without (e.g. 1 x 7, 2 x 17) a stabilization layer, a tendency may also be established that the soil penetration of geotextiles with a roughness layer is reduced for soil type BT 4.

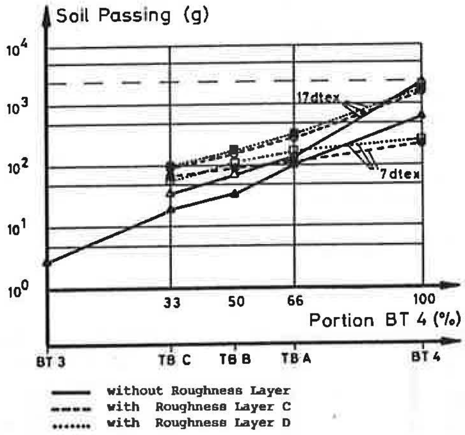

Fig. 10
Soil Penetration as a Function of Soil Type

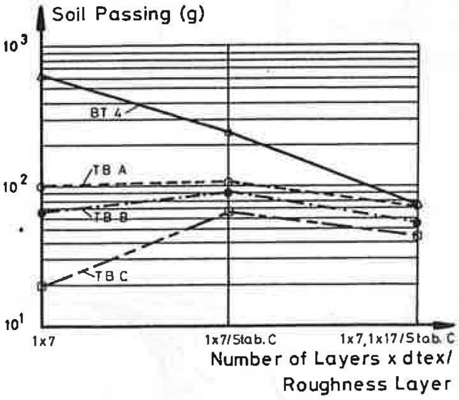

Fig. 11
Soil Penetration of the 7 dtex Non-Woven

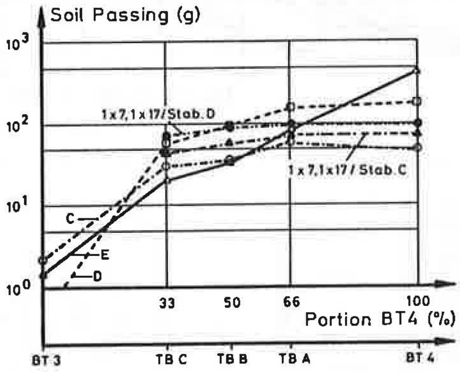

Fig. 12
Soil Penetration as a Function of Soil Type

Owing to the large effective opening size of the stabilization layers Stab. C and Stab. D (D_W = 0.58 mm and 1.34 mm, resp.) and the 17 dtex pre-filter layer (D_W = 0.13 mm), the enhanced retention of soil type BT 4 (d_{50} = 0.03 mm) affects the filtration length for graded pore structures. The soil penetration was reduced from 652 g (1 x 7 dtex) to 173 g (1 x 7, 2 x 17 dtex) and

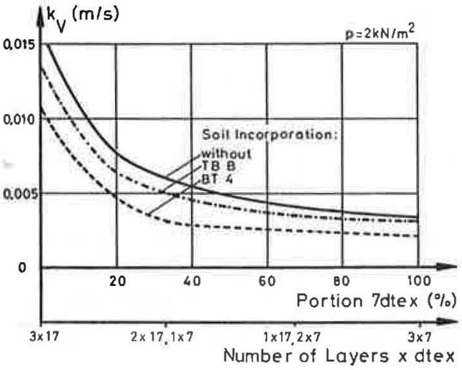

Fig. 13
Permeability Values for
Multiple-Layer Zero Composite Materials

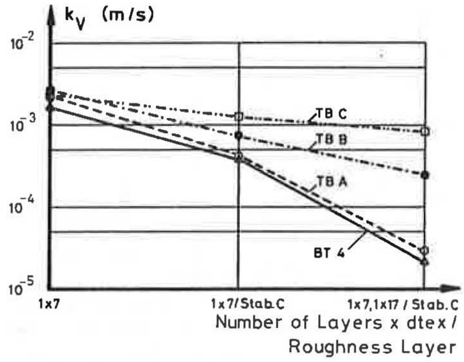

Fig. 14
Permeability of the 7 dtex Non-Woven

eventually down to 77 g (1 x 7, 1 x 17 dtex, Stab. C) by the interaction of these components. The mechanical filter effectiveness can only be improved, however, by correct gradation of the soil conditions.

The tests with the set-up "sample below rotor" (see Fig. 6) were carried out with soil type BT 4. The soil penetration lies generally in the order of 1 - 2 %, referred to the soil penetration for the standard test. Although the tendencies described above could be confirmed, the effects of a pre-filter layer for the three-layered structure could not be definitely shown owing to the comparison of small numbers and the shielding of turbulent flow effects.

Figure 13 shows the permeability of multiple-layer zero composite materials with various effective opening sizes from both new samples and those taken out of the containers from the turbulence tests. In comparison to a 3 x 17 dtex geotextile, the use of a 7 dtex layer will reduce the permeability by about 50%. The measured negligible reduction in permeability of soil-containing fabrics, determined using samples taken from the turbulence test, are not valid for use in the field.

The reduction in the permeability of geotextiles resting on soil compared to that of brand new material is due to soil incorporation, which is dependent upon the grain composition of the soil and the geotextile structure. It was thus observed, for example, that with an increase in fine soil particles incorporated within the 7 dtex geotextile (samples extracted from the turbulence container), a slight reduction in the water permeability occurs (Fig. 14).

Due to the roughness layer, coarse-grained fractions are retained within this layer. By virtue of the increased filtration length, it is also possible to retain grain fractions with comparatively small grain diameter (in the filter), and thus reduce the k_V-value. By incorporating a pre-filter layer, a large decrease in the water permeability compared to that for two-layered composite materials is observed, especially for soils with a high mud fraction (Fig. 14). The filter effectiveness of these products may be seen in relation to the results of the turbulence tests (significant reduction in the soil penetration compared to that for composite materials without a pre-filter layer).

The tendency of the k_V-value to reduce with a proportionate increase in soil type BT 4 is also confirmed for the mixed-fibre composite materials used in practice.

For composite materials without a stabilization layer (as tested here: 1 x 17, 2 x 7 and 2 x 17, 1 x 7 dtex) the k_V-values are virtually independent of the soil type, which is a positive sign with respect to the hydraulic filter effectiveness. In relation to the composition of a geotextile filter, however, the mechanical filter effectiveness must also be considered (see above). A multi-layered structure comprised of non-wovens with graded pore-opening and a roughness layer as a composite material is therefore preferable to a single non-woven layer.

The influence of the filtration length (see Section 4.1) of a non-woven material with a smaller D_W can be seen in Figure 15. A filter cake deposit is not found between two geotextile layers of the same fibre size in a zero composite material. A considerable soil build-up is found, however, on the surface of a zero composite material component which has a smaller effective opening size, D_W. Because of this, the results from zero composite materials with a single effective opening size cannot be directly compared with those with more than one effective opening size (multiple-layered non-woven with different effective opening sizes for the individual layer).

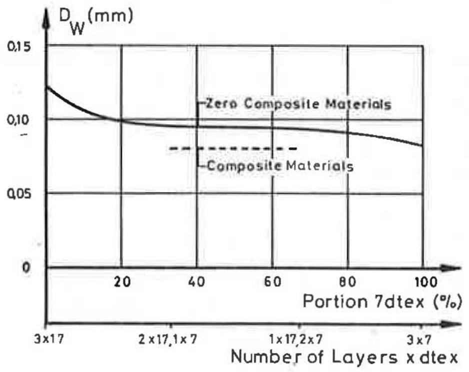

Fig. 15
Effective Opening Size D_W

4.3 Influence of Needle-Punching on Composite Materials

In the following, the influence of needle-punching on the values measured for zero composite materials, in comparison to those determined for non-wovens, is discussed.

Composite materials are thinner (in this case approx. 20-25 % as compared to zero composite materials) and stiffer, as well as having additional openings as the result of their being thoroughly needle-punched.

Needle-punching had only a small effect on the amount of soil passing in the turbulence test. Needle-punching

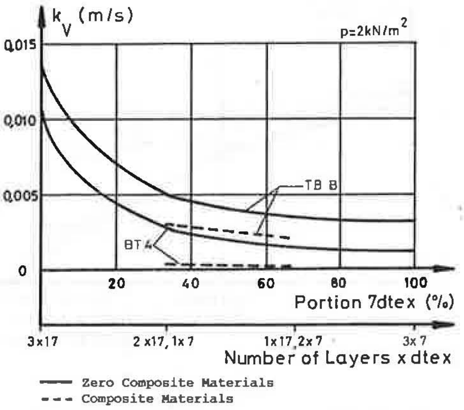

Fig. 16
Permeability of Multi-layered Non-wovens
with Soil-Incorporation

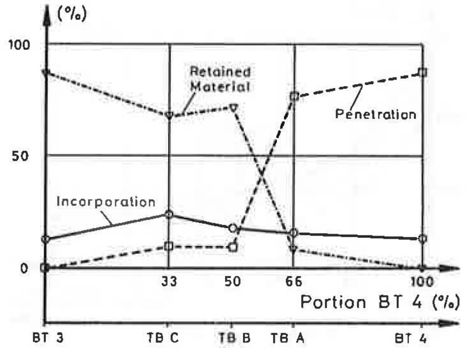

Fig. 17
Percentile Decomposition of the Test Soil
Mass for Composite Material D

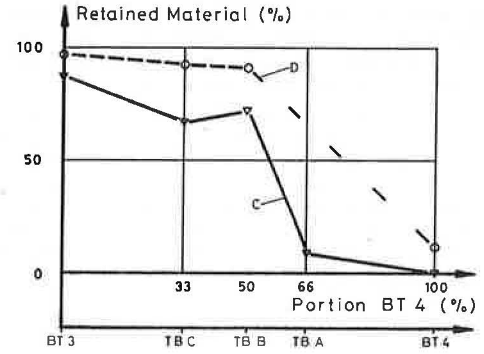

Fig. 18
Comparison of Soil Retentions

also resulted in a negligible reduction in the permeability values, k_V, of brand new non-wovens. The reduction in permeability values of composite materials, as compared to zero composite material samples, is shown in Figure 16 for soil-impregnated geotextiles taken from the turbulence test. A comparatively large decrease is evident for soil type BT 4. In terms of absolute values, a decrease of almost exactly an order of magnitude is evident for this soil type. In addition to the thorough needle-punching, one reason for the decrease in water permeability of composite materials is undoubtedly the increase in soil incorporation, which is roughly twice as large as for zero composite materials. The comparatively large decrease for the sample impregnated with soil type BT 4, as compared with test soil TB B, can be attributed to soil incorporation. Geotextiles taken from turbulence tests using soil type BT 4 showed up to 6 times greater soil incorporation values as samples from tests in which the test soil TB B was used.

Figure 15 clearly shows that in comparison to the individual components of zero composite materials, the effective opening size for composite materials is lower. This may be explained on the one hand by the soil incorporation already mentioned (composite materials exhibit almost twice the value of soil incorporation as corresponding zero composites), and on the other hand also by the reduced thickness aimed at during needle punching (larger fibre concentration). By comparing the values of the effective opening sizes for composite materials and for the zero composite material 3 x 7 dtex, it may be concluded from the close agreement between the three that it is not the repeated needle-punching which determines the D_W-value, but rather the individual component with the minimum effective opening size.

4.4 Transport and Boundary Surface Phenomena

For these investigations, the test equipment shown in Figure 7, as well as the composite materials C, D and E were available. As a parameter, an initial concentration of 500 g/l was selected.

For the case of test soils TB B, TB C and BT 3, the geotextiles C and D became impregnated with soil before the maximum specified test duration of 60 min. A series of tests with the geotextile E was not carried out because the soil was washed out of the roughness layer at even very low pressure head and no soil incorporation could be obtained. By way of example, Figure 17 shows the tendency of the soil penetration to increase for composite material D with percentage increase in the BT 4 fraction in the test soil. Through a visual inspection of the tests, it was clearly seen that the incorporation length of the soil particles also increases considerably with an increase in the fine-grained fraction of the test soil. The definitely smaller fractions of incorporated soil for geotextile C as compared with the composite material D is due to the smaller opening size of its roughness layer, which becomes more easily impregnated with soil during the tests, particularly for the case of large-grained soils. This also explains the larger soil retention and the smaller soil penetration compared with composite material type D (Stab. D: D_W = 1.34 mm) for the coarser soil types (Fig. 18).

5. CONCLUSIONS

The tests show that the multiple-layered structure of a geotextile filter as a composite material with a stabilization layer (roughness layer) provides a better filter effectiveness than that of a simple non-woven layer. Composite material with a three-layered non-woven structure has the advantage over a single non-woven fabric that a good filter effectiveness is provided over a wide range of grain sizes. Considering the difficult matching of the geotextile structure to the soil, this can provide an additional safeguard.

Under consideration of the factors mechanical and hydraulic filter effectiveness as well as stabilization of the soil, a multiple-layer, graded structure geotextile filter should be aimed at. A composition including a fine filter, pre-filter and roughness layer appears particularly meaningful, since the roughness layer, as well as providing stability, can also supplement the filtering function of the other layers.