Third International Conference on Geotextiles,
1986, Vienna, Austria

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FILTRATION CAPABILITY OF GEOTEXTILES—TESTING AND PRACTICAL EXPERIENCE

FILTERWIRKSAMKEIT VON GEOTEXTILIEN — PRÜFUNG UND PRAXIS

CAPACITE FILTRANTE DES GEOTEXTILES — ESSAIS ET EXPERIENCES PRATIQUES

Based on existing investigations on the filter effect of geotextiles test series have been carried out to get more knowledge on the systeme soil-geotextile for creating design rules. Special mixtures of glas balls but also natural soils have been used. Tests have been carried out on two different systems:

1. Permeability cell with water flow in one direction. The amount of passing soil and change of hydraulic pressure versus time has been measured.
2. Test equipment for turbulent water flow to simulate slopes which are attacked by waves. The erosion of soil, also depending on the inclination of the slope, versus time has been investigated.

Additionally existing projects where geotextiles have been used, were examined to proof assumptions which hardly can be simulated by laboratory testing.

1. Introduction

While a number of papers have so far been published on the testing of the filtering performance of geotextiles, the application criteria derived from an interpretation of theses results show considerable variation. For the most part these differences are due to differences in the test soil and test equipment characteristics. Most of the failures reported to be due to inadequate opening sizes were accounted for by clogging or mechanical damage and only in a minority of cases by inadequate soil retention capacity. this suggests that the filter criteria used in erosion protection projects provide a high degree of safety.

1.1 Opening size of geotextiles

The appropriate opening size of geotextiles can be determined by a variety of test methods including screening, submersion and optical measurements. The question as to which of these methods is to be preferred is irrelvant as long as one and the same method is used for both defining and applying the filter criteria. At the same time it should be noted that the criteria apply only to products similar to those used in defining them.

2. Unidirectional flow studies

If the geotextile fabric clings firmly to the soil to be filtered it will give the particles added strength against dimensional changes as long as the particle configuration remains stable. The unidirectional water load results in an impaction of the soil particles on and between the fibres (arching). This prevents soil particles smaller than the opening size from being eroded. The acceptable ratio between soil particle size and geotextile opening size depends on a number of factors:

Soil characteristics (particle size, particle size distribution, cohesion)
Hydraulic gradient
Geotextile characteristics
External influences (mechanical stresses).

Some of the current filter criteria show a certain tendency for the soil particle/opening size ratio to increase with increasing soil uniformity C_u. Beyond C_u = 3 to 5 this ration tends to increase for some criteria and to decline for others. (Fig. 1)

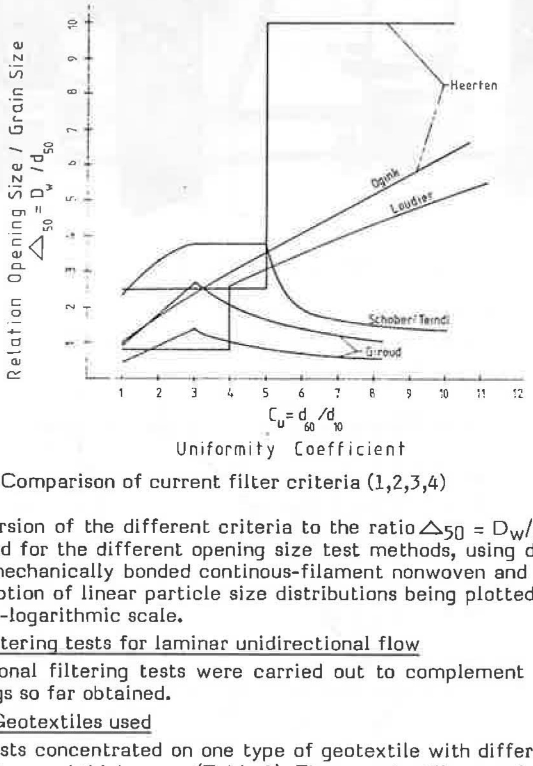

Fig. 1 Comparison of current filter criteria (1,2,3,4)

Conversion of the different criteria to the ratio $\triangle_{50} = D_w/d_{50}$ allowed for the different opening size test methods, using data of a mechanically bonded continous-filament nonwoven and the assumption of linear particle size distributions being plotted on a semi-logarithmic scale.

2.1 Filtering tests for laminar unidirectional flow

Additional filtering tests were carried out to complement the findings so far obtained.

2.1.1 Geotextiles used

The tests concentrated on one type of geotextile with different pore sizes and thicknesses (Table 1): These geotextiles consisted of continuous polypropylene fibres with diameters of 0.03 to 0.04 mm.
These randomly oriented fibres were bonded by entanglement (mechanically bonded).

Geotextile	A	B	C
Weight (g/m)	90	200	400
Thickness (mm)	1.1	2.0	3.1
Opening size D_w (mm) (acc. to Franzius Inst.)	0.12	0.11	0.08
Opening size O_{95} (mm) (acc. to CEMAGREF)	0.201	-	0.095
E.O.S. (mesh number)	40	70	120
Permeability coefficient k (cm/sec) (acc. to Franzius Inst.)	5.10^{-1}	5.10^{-1}	4.10^{-1}

Table 1

2.1.2 Testing equipment

The retention tests were performed in specially designed permeability chambers allowing for the installation of piezometers. The hydraulic head was set at 100, 200 or 300 mm. The geotextiles were placed on a ledge protruding into the chamber at its bottom. Sagging was prevented by a wire mesh (mesh width 10 mm). Lateral leakage was prevented by sealing. The piezometers were installed 10, 30, 50 and 75 mm above the geotextile. The open surface area of the chamber is 63,6 cm^2.

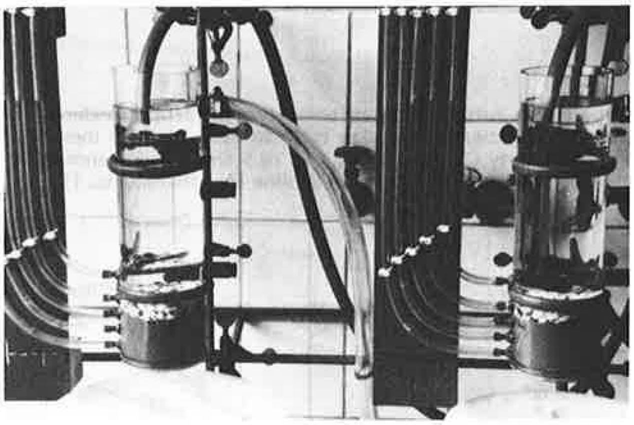

Fig. 2 Laminar flow filtering test chamber

2.1.3 Results

The test soils produced from different mixtures of glass beads were placed in the test chamber (Fig. 3).

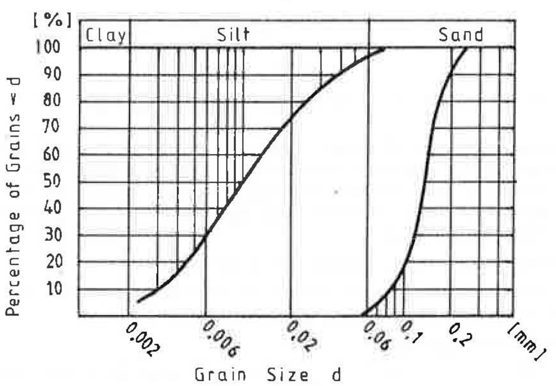

Fig. 3 Size range of test soils studied

Initially, the hydraulic gradient i was 2 and was subsequently increased to 4 and 6. In most cases the load was applied for at least 24 hours for each gradient. Both soil and water passage were measured.
The following consideration was made: In a drainage pipe with a diameter of 10 cm the maximum soil height must not exceed 1 cm. This corresponds to a soil weight of approx. 2000 g/m. In terms of the test chamber surface, this means approximately 12 g. Since the duration of the test rarely exceeded 72 hours, the maximumg permissible soil passage was fixed at 6 g on condition that it tended to decrease over time. Table 2 shows the results obtained so far.
These results show that the coefficient of uniformity affects filter stability (cf. test Nos. 18 and 56). Smaller particle sizes do not necessarily require smaller opening sizes, since the energy of flow is reduced to an extent preventing the transport of soil particles. This holds for $k < 10^{-5}$ cm/sec. Filter stability is also influenced by the hydraulic gradient, as is to be noted especially in test 18: While no soil passage is observed at i = 2, complete passage occurs at i = 6. This dependence of the filter stability on flow velocity indicates that higher permeability requires more stringent criteria. Clogging was not observed in our tests. In the case of those specimens showing a very low water passage, this was due to the low k value; no excessive pressure increase was observed on the piezometer mounted directly above the geotextile fabric.

3. Multidirectional flow studies

If the direction of water flow changes frequently (waves), impaction of soil particles is impossible. In order to ensure filter stability the opening size should be such that at least part of the soil to be conserved is retained. This will on the one hand prevent the finer particles from being eroded (except for those at the soil/geotextile interface) and, on the other, reduce the water energy that would erode the particles further inside the soil.
Some of the filter criteria applicable to this type of load indicate a ratio between opening size and a soil particle diameter critical for the criterion in question. As in the case of unidirectional flow, however, several parameters govern the choice of dimensions:

- Type of soil (particle size distribution, particle size, cohesion)
- Hydraulic load
- Geotextile/subsoil contact
- Type of geotextile

3.1 Turbulent flow studies

Stresses on the filter are highest where it is exposed to the action of waves, i.e. on sloping banks. Therefore, this aspect deserves special attention.

3.1.1 Geotextiles used

The materials were the same as those used for unidirectional flow studies.

3.1.2 Testing equipment

The test soil was placed in a square container with a depth of 5 cm. The geotextile was placed on top and fixed at the sides. To simulate the covering material an additonal load was applied in the form of a steel screen. To simulate different bank slopes the inclination of the surface may be varied. The made-up container was dipped into a water tank and withdrawn from it at a predetermined frequency. (Fig. 4)

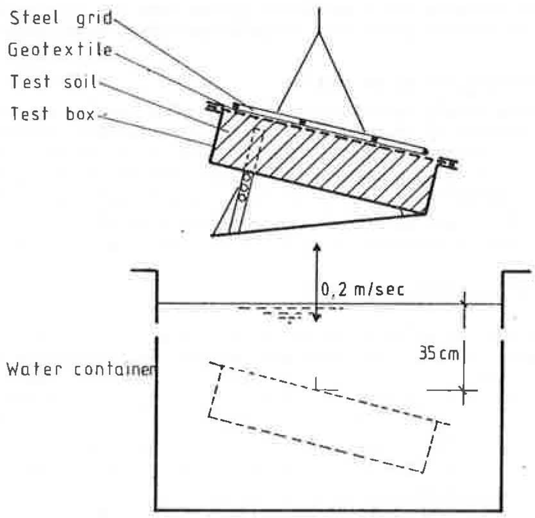

Fig. 4 Test equipment for turbulent flow studies

Geo-textile	Test No.	Test soil C_u	d_{50}	d_{85}	D_w/d_{50}	Soil passage(g) at hydraulic gradient i = 2	4	6	stable
A	18/1	1,7	0,039	0,052	3,1	0,0(24)	9,1(96)	43,1(4)	no
	18/2	1,7	0,039	0,052	3,1	0,0(24)	8,9(72)	18,0(24) 5,3(24) 13,1(120) 4,3(24)	no
	18/3	1,7	0,039	0,052	3,1	-	-	11,2(24) 37,2(72) 23,2(24)	no
	17	2,0	0,140	0,180	0,9	0,0(24)	0,0(24)	0,0(24)	yes
	53	2,1	0,043	0,087	2,8	0,8(24)	-	2,3(24) 0,0(18)	yes
	55	2,1	0,043	0,087	2,8	-	-	3,3(24) 1,6(72) 0,0(24)	yes
	52	3,7	0,072	0,170	1,7	0,5(16)	-	1,3(72) 0,0(24)	yes
	54	4,4	0,010	0,036	12,0	1,5(24)	-	18,6(24) 4,1(72)*	no
	60	4,3	0,035	0,055	3,4	11,8(24)	-	3,3(26) 0,0(26)	no
	56	4,5	0,033	0,051	3,6	3,0(4)	-	4,5(2) 2,8(120)	no
	58	5,1	0,041	0,130	2,9	0,0(24)	-	0,4(24) 1,5(24) 0,0(46)	yes
B	19/1	1,7	0,039	0,052	2,8	1,5(24)	3,7(24)	11,8(96)	no
	19/2	1,7	0,039	0,052	2,8	1,0(24)	1,9(24)	8,3(96)	no
	59	3,4	0,037	0,055	3,0	1,0(24)	-	1,2(24) 1,1(24) 0,0(70)	yes
	61	4,9	0,028	0,048	3,9	1,0(24)	-	2,6(26) 0,70(26) 0,85(24)	no
	51	41,0	0,145	0,370	0,8	0,0(24)	-	0,0(96)*	yes
C	20/1	1,7	0,039	0,052	2,1	1,2(24)	0,0(96)	3,9(552)	yes
	20/2	1,7	0,039	0,052	2,1	0,7(24)	0,0(96)	1,2(552)	yes
	57	4,3	0,013	0,044	6,2	0,0(4)	-	0,0(120)*	yes

Figures in parentheses indicate duration of test in hours
* minimal water passage

Table 2

3.1.3 Results

The container was dipped and withdrawn at a velocity of 0.2 m/sec at 10-second intervals. In the course of each test 11 000 dipping operations were performed. The average dipping depth was 35 cm. It as found that the soil stability to be achieved by the geotextile was negatively affected by settlements and/or erosion. Turbulences preventing the formation of a natural filter occurred in the clear space between the test soil and the geotextile, since the latter was attached to the rim of the container und was thus unable to remain in contact with the subsiding material. d_{95} of the soil passage corresponded to O_{95} of the geotextile (CEMAGREF test method), which was not surprising on account of the similarity of the test methods in regard to the hydraulic load. The different angles of slope of the test soil container affected soil passage. At larger angles of slope a larger soil area was pressed against the geotextile and the erodable surface was fairly small since the soil material tended to achieve a horizontal position. After some initial tests at different angles of slope further tests were performed at an inclination of 1 : 4. Upon completion of the test the surface of the cohesionless test soil showed a uniformely wavy pattern. (Fig. 5)

Cohesive soils, on the other hand, proved instable and showed erosion rills. Erosion tends to decrease with increasing plasticity. At a plasticity I_p = 30 % stability was achieved after inital erosion.

On condition that a certain amount of erosion is acceptable (settlements of a few centimetres usually do not affect bank stability) and that the geotextile is not entirely pressed against the underlying soil by the covering material (major interstices in the covering material), the opening size of the geotextile has to be such that part of the soil is safely retained. Soil retention depends on the heterogeneity of the soil: In choosing the ratio between opening size and d_{50} more stringent criteria have to be applied for highly homogeneous soils ($C_u < 3$) than for heterogeneous ones. In the former case even minor fluctuations of the parameters may impair stability, while in the latter case at all events a sufficient amount of soil will be retained. For sufficiently cohesive soils a geotextile with an opening size of $D_w < 0.11$ mm will be sufficient for loads corresponding to the test conditions. Further investigation will be necessary.

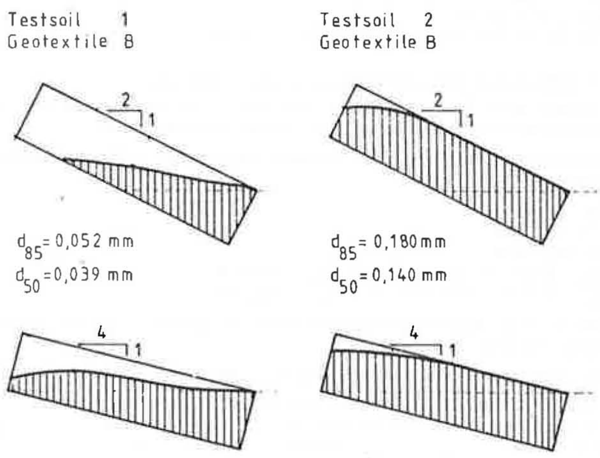

Fig. 5 Erosion of test soils under turbulent flow

4. Project executed

A number of practical examples will be given to demonstrate that in choosing the suitable geotextile opening size the particle size is less important in the case of cohesive soils than in the case of low-cohesion soils.

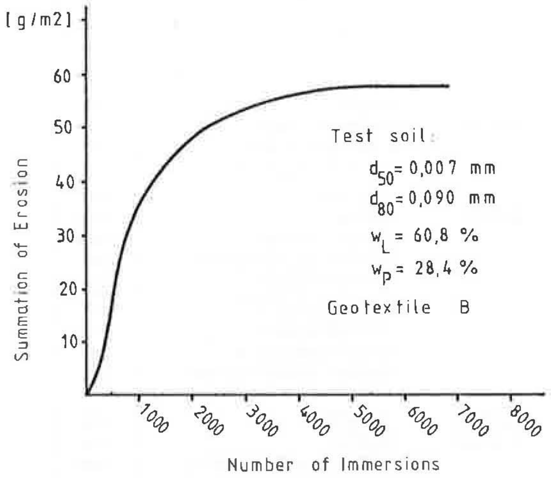

Fig. 6 Erosion of a cohesive soil under turbulent flow

4.1 Drainage canals in Kenya

Construction: The canals were lined with a geotextile and superimposed gabions. Canals not protected by geotextiles had formerly been rapidly destroyed.

Geotextile: Mechanically bonded non-woven (PP continuous filament)
D_W = 0.09 mm
t_G = 2.6 mm
Subsoil: laterite (cohesive)
d_{85} = 0.020 mm
d_{50} = 0.0016 mm
Result: No damage observed after 2 years.

4.2 Bank protection, Singapore River, Singapore

Construction: The geotextile was placed on the muddy subsoil and covered with riprap approximately 250 mm thick.

Geotextile: Mechanically bonded non-woven (PP continuous filament)
D_W = 0.11 mm
t_G = 2.1 mm
Subsoil: Mud
d_{85} = 0.08 - 1.10 mm w_L = 60.8 %
d_{50} = 0.0062 - 0.0220 mm w_P = 28.4 %
Result: No damage observed after 2 years. The geotextile fulfils its filter function.

4.3 Bank protection Kramnitzbach, Austria

Construction: The geotextile was placed on the slope. Up to the normal water level the geotextile was covered with rocks of up to 2 000 kg weight. Up to flood level, sods were placed on the geotextile.
Geotextile: Mechanically bonded non-woven (PP continuous filament)
D_W = 0.10 mm
t_G = 2.40 mm
Subsoil: Clay
d_{85} = 0.22 mm w_L = 32.2 %
d_{50} = 0.075 mm w_P = 26.7 %
Result: No damage observed after 9 years. The geotextile has fulfilled its filter function. At high-water level the geotextile has been fixed by the grass roots. Erosion damage has been observed in neighbouring areas not protected by geotextiles.

4.4 Bank protection, Rodl River, Austria

Construction: The geotextile was placed on the slope and fastened with pickets. Granite blocks with a weight of up to 2 000 kg were piled on top. Maximum flow velocity 3 m/sec.

Geotextile used: Mechanically bonded non-woven (PP continuous filament)
D_W = 0.08 mm
t_G = 3.0 mm
Subsoil: Highly variable, sand alternating with clay
d_{85} = 0.3 - 4.0 mm
d_{50} = 0.025 - 0.6 mm
Result: No damage observed after 12 years. The river banks are densely overgrown.

5. Summary

Filtering tests under multidirectional flow conditions revealed a certain relationship between geotextile opening sizes and the mean particle size d_{50} of the soil as well as soil uniformity. The tests were carried out under extreme conditions (glass beads, high gradient) so that the results can be considered fairly reliable. The ratio is lowest in the case of highly homogeneous soils and increases with soil heterogeneity. Over the range tested, between C_U = 2 and C_U = 5, a D_W/d_{50} ratio of 3 is permissible for thin non-woven fabrics (up to approximately 2 mm), for thicker fabrics it is higher. No clear-cut criteria have been derived for cohesive soils, the permeability of which was so low that no soil passage was observed: $D_W \approx 0.12$ mm.
For bank protection structures the suitable opening sizes depend on the covering material used. If the geotextile is not in contact with the subsoil over its entire surface the mesh size O_{95} is that opening size which retains soil particles of that size, thus being capable of building up a natural filter. This value has to be determined as a function of the permissible degree of erosion and the uniformity coefficient. For cohesive soils a plasticity I_P = 30 % is necessary to ensure stability under the test conditions described in cases of geotextile B being exposed to multidirectional flow. Practical applications have shown that no erosion occurred in the case of particle sizes $d_{85} \geq D_W$.
If the geotextile is in full contact with the subsoil over its entire surface the filter criteria are considerably less stringent. Under the conditions described a ratio of D_W/d_{85} = 1 is sufficient for non-cohesive soils.
These data apply of course only to geotextile similar in construction to the ones used in our tests. The influence of flow energy on design criteria remains to be studied.

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