Performance of Geotextiles on Clay and Fine Sand in Bed and Bank Protection

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ABSTRACT: Erosion control is traditionally achieved by geometrical sandtight geotextiles, with openings smaller than the grains of the subsoil to be protected. Performance tests are described in the present paper, supporting the theory that in many cases it is possible to apply geotextiles that do not meet the geometric criteria. Preliminary criteria for hydrodynamical sandtight geotextiles are derived in this paper on the bases of the test results. However some contradictory results make further research necessary.

1 INTRODUCTION

Geotextiles, usually covered with rock or gravel, are frequently used to prevent the erosion of sand, silt or clay subsoils. The geotextile can be either a part of a bank or dike protection structure, or of a bottom protection. Examples of these are given in Figure 1 and 2.

Up to now the retention criterion for geotextiles applied in bed and bank protection is based mainly on geometric sandtightness. This implies that the openings of the geotextiles must be smaller than the underlying soil particles. No consideration of the hydrodynamic forces or cohesion is included in this criterion. Many such criteria have been published in the past: e.g. Ogink (1975) and Heerten (1982). The criteria of Heerten are given below:

a) Static load conditions, non-cohesive soils:
$O_{90}/d_{90} \leq 1.0$ and $O_{90}/d_{50} < 10$ (if $d_{60}/d_{10} \geq 5$)
$O_{90}/d_{90} \leq 1.0$ and $O_{90}/d_{50} < 2.5$ (if $d_{60}/d_{10} < 5$)
b) Dynamic load conditions, non-cohesive soils:
$O_{90}/d_{50} < 1.0$
c) Cohesive soils, all load conditions:
$O_{90}/d_{90} \leq 1.0$ and $O_{90}/d_{50} < 10$ and $O_{90} \leq 0.1$ mm

with: O_{90} = average diameter of the standardized sand fraction, of which 90% remains on the geotextile after a sieve test under defined conditions (m)
d_x = grain size of subsoil corresponding to x% by weight of finer particles (m)

In the case of clay, silt or fine sand, however, it can be very difficult to meet these requirements. A more advanced requirement is based on hydrodynamic sandtightness, viz. the internal flow must not be capable of washing out the subsoil material (even though the openings of the geotextile are much larger than the subsoil grains). This arises from:

- the hydrodynamic forces on the subsoil are greatly reduced by the geotextile,
- the cohesion forces of the particles do not allow small particles to be washed away.

The hydrodynamical sandtightness criteria can be applied in the majority of structures because hydraulic loads usually are low in the vicinity of the geotextile (see Figure 2). Only in some cases, in which the geotextile is very close to the surface of the structure and, provided the hydraulic loads are heavy (for example breaking waves), the geotextiles should be geometrically sandtight (see Figure 1).

It is also advised to apply geometrical sandtight geotextiles where a geotextile is used in the foundation of a structure (such as a bridge pier or a lock).

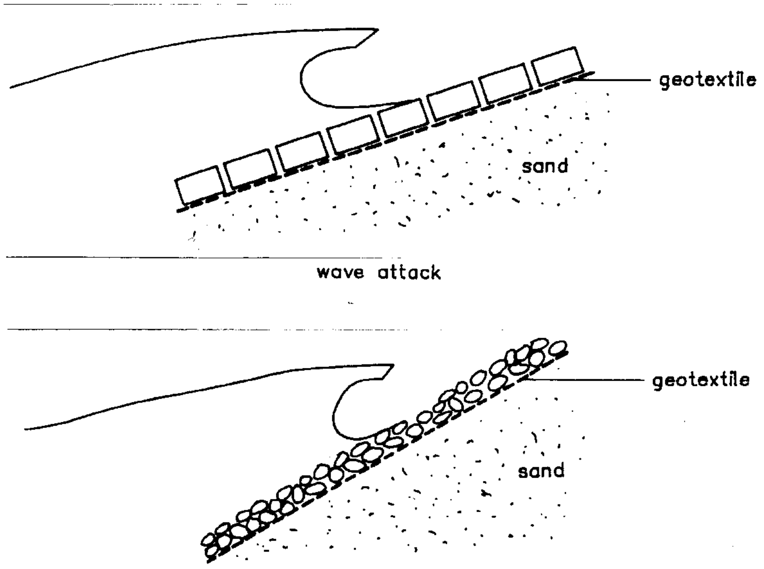

Fig. 1 Examples of structures in which geometrically sandtight geotextiles are necessary

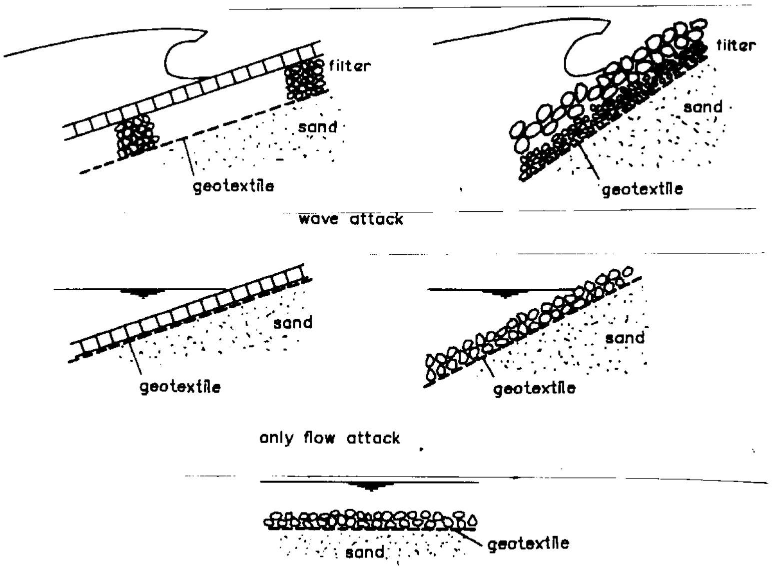

Fig. 2 Examples of structures in which hydrodynamically sandtight geotextiles can be applied

The present paper considers the structures in which the hydraulic loads are small, which offers the possibility of applying hydrodynamically sandtight geotextiles. Discussed are the physical processes involved in the transport process of the subsoil, the performed model investigations, and the test results.

2 THEORETICAL BACKGROUND

Hydrodynamically sandtight geotextiles prevent the erosion of the subsoil up to a certain hydraulic load, described by the (pressure potential) gradient, i_{cr}, or the filter velocity q_{cr} (discharge per unit flow area), in the rock protection on top of the geotextile.

To describe the physical processes involved in the behaviour of the subsoil under a geotextile, we consider a horizontal geotextile on a subsoil of sand (non-cohesive) and under a layer of rock (granular filter):

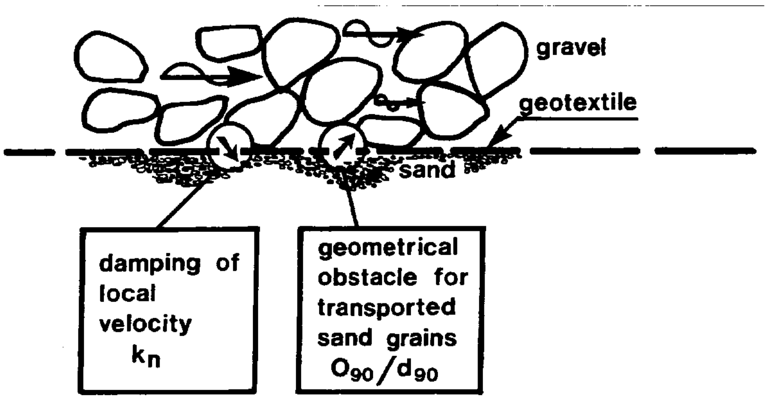

Fig. 3 Erosion mechanism

The mean main flow in the rock layer is assumed to be parallel to the geotextile. In spite of this, the local flow has a component in the vertical direction caused by the presence of the rock because the water flows around these obstacles. This is also the case near the geotextile, where the water flows through the geotextile, picks up sand grains and transports them into the rock layer. We assume there are small "channels" under the geotextile, caused by an imperfect contact between the geotextile and the subsoil. This transport mechanism can only take place if both the hydrodynamic forces on the sand grains allow the initial transport and if the openings of the geotextile are large enough to let the particles pass. The following scheme visualizes the transport mechanism and also shows the aspects influencing the transport:

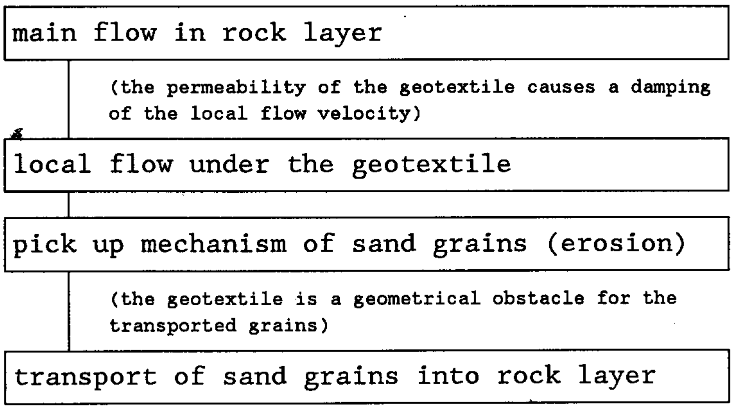

Fig. 4 Various stages in transport mechanism

The described mechanism indicates that the geotextile decreases the hydraulic load on the sand interface. For a subsoil of clay there is a second mechanism that plays an important role. Individual clay-particles, being small enough to pass the geotextile openings, are clustered together into clay clods due to cohesion. These clods, having diameters of more than a millimetre, cannot pass through the openings. On the other hand, large gradients are capable of eroding the clods, leading eventually (after months or years of exposure) to considerable loss of material.

For a practical case (Helmond-lock project in the Netherlands) it has been shown that a woven geotextile on silt with opening size grain size ratio of $O_{90}/d_{90} = 5$ can be used (Klein Breteler and Verhey, 1990).

3 PERFORMANCE TESTS

Performance tests were carried out to test the theory described in the previous paragraph and to find criteria for hydrodynamic geotextiles on sand and clay. For these tests, a protective structure consisting of a subsoil, geotextile and a cover layer, were installed in the Oscillating Water Tunnel at DELFT HYDRAULICS. This simulates a bed or bank protection with water flowing parallel to the geotextile as shown in Figure 5.

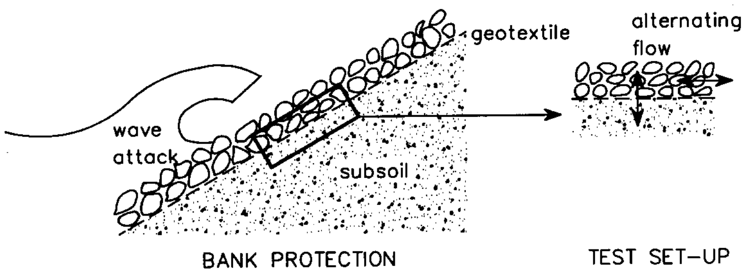

Fig. 5 Simulation of bank protection in test set-up

From tests on the interface between sand subsoil and a granular filter we know that the slope angle has a negligible influence on the critical gradient, provided the slope is less than 1:3 (Bezuyen, Klein Breteler and Bakker, 1987).

A typical cross section of the model set-up is given in Figure 6.

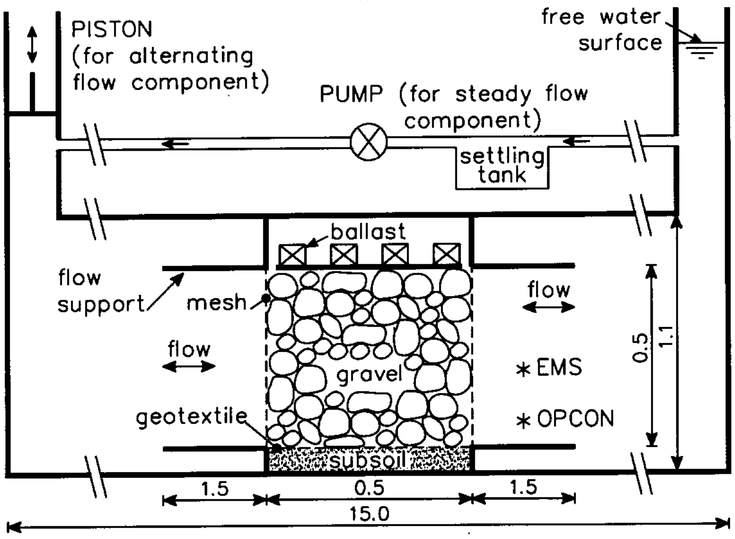

Fig. 6 Vertical cross section of model set up (schematised, not to scale, lenghts in m)

The Oscillating Water Tunnel is capable of generating an alternating pressure amplitude of up to 20 kPa across the test section (2 m water column), in combination with a steady flow component. The wave period can be varied between 0.5 s and 20 s, but a 4s period was selected for all tests since this is frequently encountered at bank protection structures exposed by wind waves.

In each test, the gradient along the geotextile was increased step by step, while the erosion rate was measured (migration of the subsoil particles). The output of the tests was the critical gradient, i_{cr}, and critical filter velocity, q_{cr}, at which the erosion of the subsoil was initiated.

The erosion rate was measured with an optical concentration meter (OPCON) in combination with an electromagnetic flow velocity meter (EMS). The product of concentration and net velocity yields the resulting transport. For this purpose a net flow of 0.02 m/s was used. Because of this net flow, the suspended particles were transported out of the test section to the OPCON and EMS, where the magnitude of the transport was measured.

With this test set up we could detect an erosion rate of the subsoil surface as small as 0.1 mm/hour. The erosion rate is defined as the average lowering in time of the subsoil surface as a result of the removal of the subsoil particles.

The tests were performed with a subsoil of 'good' clay, 'medium' clay, 'poor' clay and fine sand, covered by various types of woven and non-woven geotextiles. All details of the tests, including the results, are presented in Table 1.

The geotextiles P6014, NF180, NH625 and R425 are woven multi-filament tape fabrics, the others are non-wovens. Geotextile FF3S, S201 and PHB3 are needle punched, non-woven geotextiles and T3407 is a thermal bound non-woven.

All tests were performed with a gravel layer on top of the geotextile having grain size between 60 mm and 100 mm (D_{15} = 55 mm). From tests on granular filters we know that the filter velocity near the subsoil is the decisive hydraulic load. Varying the grain size of the filter will result in only a minor variation in the critical filter velocity, but will give a very large variation in critical gradient. Previous tests on geotextiles on a sand subsoil have confirmed this hypothesis.

Table 1 Test programme and results

subsoil	geotextile	$O_{90,d}$ (μm)	t_{GT} (mm)	k_n (mm/s)	test	i_{cr} (%)	q_{cr} (m/s)
good clay <2 μm: 39% d_{50} = 9 μm d_{90} = 80 μm	P6014	185	1.5	0.9	1	450	0.54
	NF180	185	0.7	1.5	2	>300	>0.5
	NH625	209	2.1	0.7	3	300	0.47
	none	-	-	-	4	10	0.06
medium clay <2 μm: 22% d_{50} = 42 μm d_{90} = 100 μm	P6014	185	1.5	0.9	5	220	0.40
					6	150	0.32
	NF180	185	0.7	1.5	7	150	0.32
	NH625	209	2.1	0.7	8	110	0.27
	FF3S	105	1.6	2.1	9	130	0.30
	S201	161	3.3	5.1	10	190	0.37
	PHB3	144	1.3	4.2	11	280	0.46
					12	150	0.32
			4		13	120	0.28
poor clay <2 μm: 20% d_{50} = 130 μm d_{90} = 400 μm	P6014	185	1.5	0.9	14	140	0.31
	NH625	209	2.1	0.7	15	120	0.28
	S201	161	3.3	5.1	16	110	0.27
			10		17	380	0.54
	PHB3	144	1.3	4.2	18	120	0.28
	T3407	144	0.5	1.1	19	150	0.32
fine sand d_{10} = 65 μm d_{50} = 90 μm d_{90} = 105 μm	NF180	185	0.7	1.5	20	8	0.05
	R425	297	1.3	2.1	21	12	0.07
	PHB3	144	1.3	4.2	22	10	0.06

$O_{90,d}$ = O_{90} determined with dry sieving test (m)
q_{cr} = filter velocity in the rock layer, parallel to the geotextile, at which the subsoil starts to wash out (m/s)
i_{cr} = (pressure potential) gradient in the rock layer, parallel to the geotextile, at which the subsoil starts to wash out (-)
t_{GT} = geotextile thickness (m)
k_n = permeability of geotextile: $k_n = (\phi_t/T_g)^m/q_t$ (m/s)
ϕ_t = pressure potential over geotextile during permeability test (m)
q_t = filter velocity through geotextile during permeability test (m/s)

Therefore we believe that the critical filter velocity is the most relevant parameter for describing the critical hydraulic load (primary output of the tests), although we still have to verify this for clay subsoils. The influence of the grain size on the critical filter velocity is for the present assumed to be negligible.

For the test 6 and 12 the filter material was placed on the geotextile by exerting a large force on the individual stones, thereby pressing them firmly into the subsoil and stretching the geotextile. Compared to the tests 5 and 11 where the filter stones were not placed with force, this procedure resulted in a considerable lower critical filter velocity.

Test 13 and 17 were performed to find the influence of the geotextile thickness. In both tests we had 3 layers non-woven geotextiles, stacked upon each other to compare with test 11 and 16 with only one layer of the same geotextile. For the S201 geotextile (test 16 and 17) on poor clay, we see a result that we could expect: 3 layers gives a better performance (higher critical filter velocity) than 1 layer. But tests 11 and 13 give the opposite result! Since there is no rational explanation for this phenomenon we can only conclude that these tests have to be repeated, also for other types of geotextiles.

4 ANALYSIS OF TEST RESULTS

The test results for good clay show that the application of a geotextile with relatively large openings gives an enormous increase in the critical filter velocity. In test 4, without a geotextile, we saw several clods of clay being washed away at very low filter velocities, but in test 1, 2 and 3 these clods were kept in place by the geotextile. Individual clay particles can not wash away because of the large cohesion forces.

An interesting result from the tests on poor clay is that the critical filter velocity is not very large (appro. 0.3 m/s), although the opening size of the geotextile is smaller than the d_{90} of the subsoil, suggesting geometrical sand tightness. Probably the small particles can wash out between the large particles, leading to considerable erosion. It is still unknown if this erosion process will stop or slow down in time.

The critical filter velocity for medium clay turns out to be of the same order of magnitude as that for poor clay ($q_{cr} \approx 0.3$ to 0.4 m/s), although the grain size distribution and cohesion was very different. The only resemblance is the colloid content (percentage by weight of grains smaller than 2 μm), which was 22% and 20%. This might be an important parameter to characterise the type of clay.

Because of the unexpected results with the 3 layers of stacked geotextiles, and the still unproven hypothesis concerning the lack of influence of the filter grain size on the critical filter velocity, we can only derive global conclusions from the test results:

- Good clay (colloid content = 39%; $d_{50} = 9\ \mu m$; $d_{90} = 80\ \mu m$):
  $q_{cr} > 0.45$ m/s
- Medium and poor clay (colloid content = 20%; $42\ \mu m < d_{50} < 130\ \mu m$; $100\ \mu m < d_{90} < 400\ \mu m$):
  $q_{cr} > 0.25$ m/s
- Fine sand ($d_{50} = 90\ \mu m$; $d_{90} = 130\ \mu m$):
  $q_{cr} > 0.05$ m/s

Using a permeability formula for turbulent flow yields the following criteria for the applicability of geotextiles with O_{90} between 100 and 300 μm on clay or sand:

- Good clay (colloid content = 39%; $d_{50} = 9\ \mu m$; $d_{90} = 80\ \mu m$):

$$i_{cr} = \frac{0.03}{n^2 D_{15}}$$

- Medium and poor clay (colloid content = 20%; $42\ \mu m < d_{50} < 130\ \mu m$; $100\ \mu m < d_{90} < 400\ \mu m$):

$$i_{cr} = \frac{0.01}{n^2 D_{15}}$$

- Fine sand ($d_{50} = 90\ \mu m$; $d_{90} = 130\ \mu m$):

$$i_{cr} = \frac{0.001}{n^2 D_{15}}$$

Where n is the porosity of the filter layer (usually $0.3 < n < 0.4$) and D_{15} is the grain size of the granular material on the geotextile (m).

If gradients larger than i_{cr} can be expected (structures like in Figure 1), than geometrically sandtight geotextiles are recommended. If the gradients will be smaller (structures in Figure 2), than geotextiles with $O_{90} < 300\ \mu m$ will prevent erosion.

5 DISCUSSION

The preliminary performance tests, carried out in the Oscillating Water Tunnel at Delft Hydraulics, with geotextiles covered with gravel (simulating a bank protection) have proven that geotextiles with a relatively large opening size can prevent erosion up to a certain applied gradient. Based on the test results preliminary criteria are derived.

But the test results also have generated important questions. Further research should be focused on the following subjects:

- Reproducibility of the tests.
- Influence of individual geotextile properties, such as opening size, thickness and permeability.
- Influence of subsoil properties, such as colloid content and cohesion.
- Influence of grain size of the granular material on the geotextile.
- Influence of duration of the loading on the erosion rate, especially for poor clay.

Further research on these topics is scheduled for autumn 1994.

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