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Geotextiles Exposed to Turbulent Water Conditions

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ABSTRACT
This Paper describes a new EN-ISO test method for determining the soil passing through a geotextile when exposed to turbulent water flow conditions. The test method is based on a procedure used in Germany for over twenty years for evaluating geotextiles in marine structures and beneath armourstones in navigable waterways. The paper presents test results for different soils and geotextiles under arrange of confinement and turbulent water flow conditions. The test apparatus comprises a multicell load-bearing steel frame with electric motor, control system, drive shafts fitted with turbulence-producing propellers, sample containers and collecting vessels. A geotextile specimen is placed in a sample container beneath the compacted test soil at a defined confinement load; the exposed geotextile is subjected to turbulent water flow. The filtration stability of the geotextile and soil system is determined by measuring the amount and rate of soil passing through the geotextile during the test. The rate at which soil passes through the geotextile indicates if the geotextile and soil will achieve the long-term stability required. Geotextile soil system is deemed to be stable filters, if the quantity of soil passing through the geotextile during the final test phase of the test compared with the quantity passing during the test as a whole does not exceed the specified limits. The test assigns an index value for geotextiles in erosion protection systems.

1. INTRODUCTION

The fluid dynamic distinguishes between turbulent and laminar flow. For geotextiles samples under water flow conditions exists several standard test methods like the standard DIN EN ISO 11058 for the determination of water permeability characteristics normal to the plane. By contrast, for geotextiles samples under defined turbulent water flow conditions no standard test method is currently available world-wide. For navigable waterways applications in Germany exists a guideline for the testing of geotextiles (RPG). This guideline describes among other test methods a test procedure which is used for over twenty years and simulates the exposure of geotextiles to turbulent conditions such as those that for example occur during the passage of a vessel due to propeller wash as shown in Figure 1.

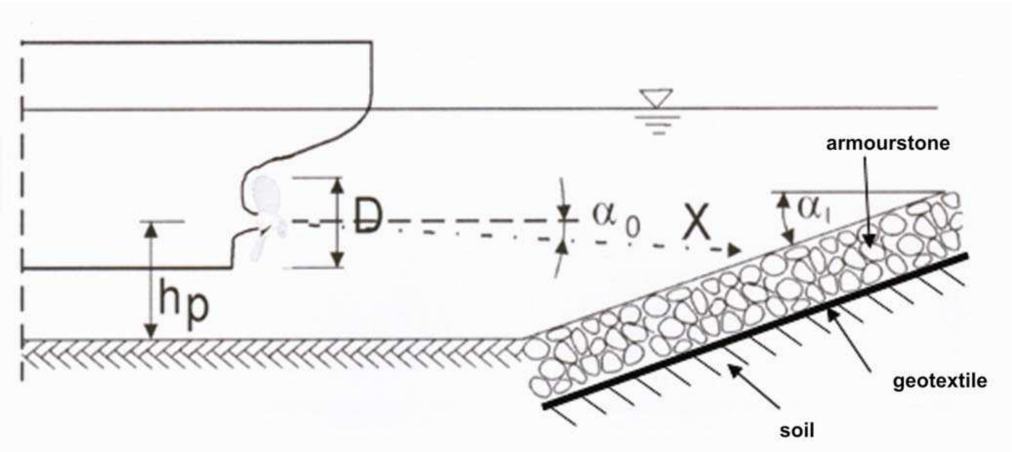


Figure 1. Navigable waterway with turbulent flow due to propeller wash.

Turbulent currents can cause erosion of the bottoms or banks of a canal or river in dependence on the particle size of the material present in the banks and beds. Highly turbulent currents occur for example in the tail water of weirs and the return flows due to shipping. Other possibilities for turbulent water flow conditions are the wave action on the embankment after the passage of a vessel as shown for example in Figures 2 and 3. But wave actions can also be caused by the operation of locks, weirs and hydroelectric power stations. Waves can also be generated by strong winds. Furthermore, due to high tide and low tide is a change of water level and turbulence a concomitant feature.

Figure 2. The road tunnel under the Ciel canal - the propellers of the vessel are producing a turbulent flow to the embankment.

Figure 3 shows the simultaneous geotextile installation on slope and bottom beneath a permeable layer of armour stones. The installation work is carried out during the passage of vessels due to the volume of ship traffic. Turbulence is here possible due to the propeller wash, the wave action and the return flow during the passage of vessels.

Figure 3. Geotextile installation in a navigable waterway during the passage of vessels.

Geotextiles are used as filter layers in erosion protection systems for navigable waterways in Germany as shown in Figure 4. According to the guidelines MAG (1993) and MAK (1993) the top layer D1 is a frequently used standard layer. Beneath a permeable layer of armour stones with the grading CP$_{90/250}$ there is a geotextile filter layer. The armourstone grading CP$_{90/250}$ is in accordance with the armour stone standard DIN EN 13383-1 and means stones within the sieve sizes 90 mm to 250 mm.

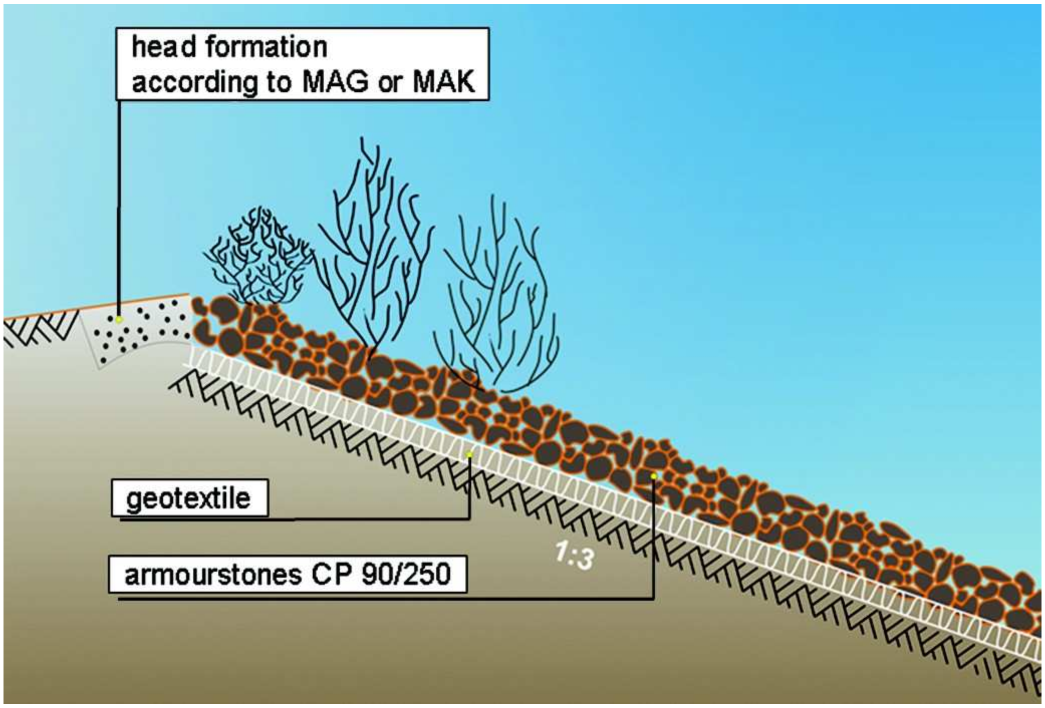


Figure 4. Standard top layer D1 for slope and bottom protection as used for navigable waterways.

Geotextiles as geo-bags filled with local soil or sand are a novel method for riverbank erosion protection. An example for such cost effective application with an enormous quantity of geotextiles has been reported by Oberhagemann (2004) for rivers in Bangladesh. Due to the variation of water levels during and the rapid recession at the end of the flood season an exposure of turbulent currents to the geo-bags is possible.

2. PRINCIPLE TEST METHOD

This test method is for the determination of the soil passing through a geotextile filter specimen in different test phases when exposed to turbulent external flow conditions. The test provides an index value for the comparison of geotextile products when a defined test soil is used. But it is also an appropriate performance test for the design of erosion protection layers in hydraulic engineering applications, if for the construction project the local soil is used as test soil. A key feature of the test method is the four bladed propeller for the simulation of turbulent water flow conditions such as those that occur during the wave action, passage of a ship, etc. The test results will also show by the comparison with the previous test phase whether the rate at which soil passes through the geotextile has stabilised as required by the client.

3. TEST METHOD

3.1 Description of the test apparatus

The test apparatus as described in RPG (1994) and shown in Figure 5 consists of three test containers with three specimen holders, a load-bearing steel frame with a flange-mounted electric motor (the drive), an electric control system, a v-belt drive and drive shafts fitted with turbulence-producing propellers. Further details of the test apparatus, which was designed to test three specimens simultaneously, are shown in Figures 6 and 7. A single specimen holder is shown in Figure 9. They are fastened firmly to the steel frame by means of the brass pipe bolted in the centre of the Perspex ® (plexiglass) lid. The pipes are also used to evacuate air from the specimen holders and equalize the pressure in them during the test phases.

Figure 5. Test apparatus, turbulent water flow.

Collecting vessels are used beneath the outlets for the water collection after each test phase as shown in Figure 6. The total height of the test apparatus is 1500 mm und the total length is 2210 mm, as shown in Figure 7.

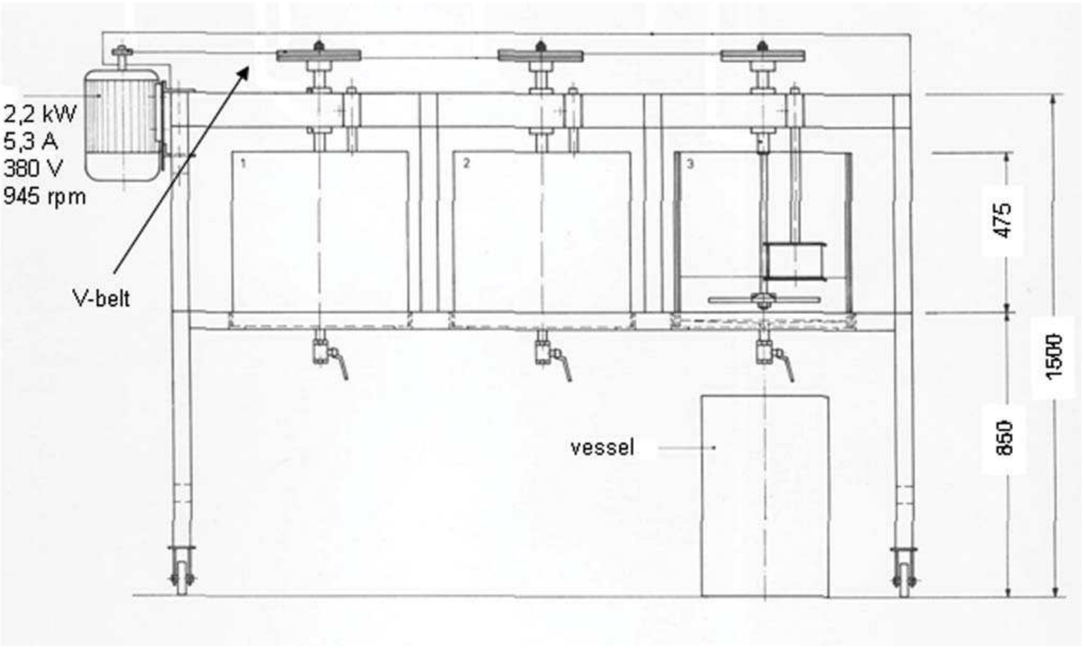


Figure 6. Drawing test apparatus with 3 test containers, lateral view.

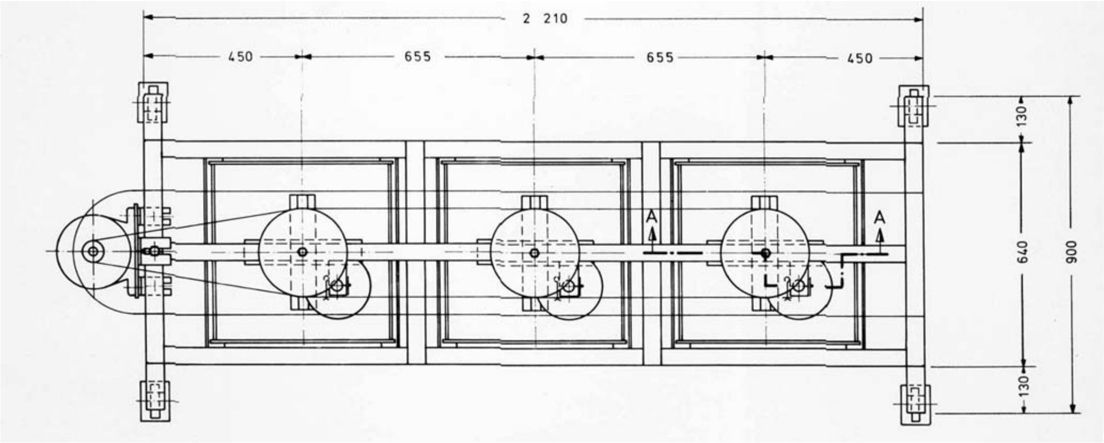


Figure 7. Drawing test apparatus with 3 test containers, top view.

Details of a single test container are shown in Figures 8. The water level in the test container is set by using a millimetre scale on the plexiglass window at the front of the tank. The rotor speed of the propeller depends on the fixed v-belt pulley ratios. A reliable means of measuring the speed could be required if a variable-speed motor is used. Each 4-bladed turbulence-producing propeller is rotating at 260 rpm and produces a turbulent flow that hits the filter (geotextile specimen as shown in Figure 9) at speeds between 70 and 90 cm/s. The passage of the propeller blades beneath the geotextile sample produces pressure pulsations with a frequency of 17.3 Hz.

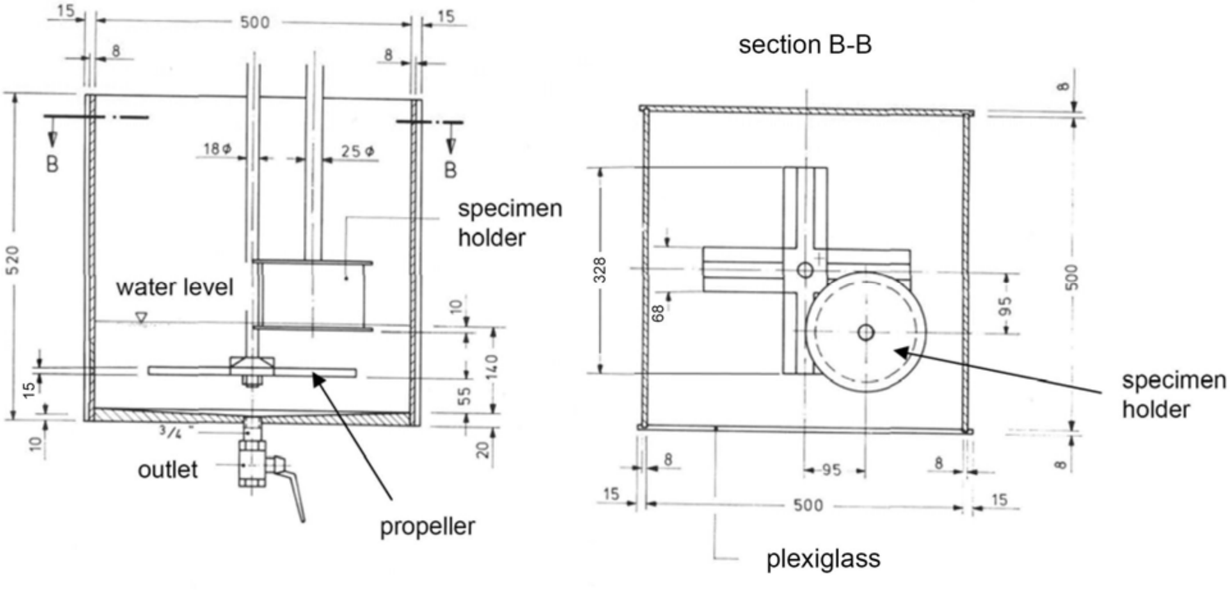


Figure 8. Drawing of a single test container, lateral and sectional view

Figure 9 shows the details of a single specimen holder. The framework of the specimen holder consists of a watertight plastic tube and a plexiglass lid. It is fixed with 6 screws. The geotextile specimen is beneath the test soil and above a stainless steel mesh. This mesh beneath the geotextile specimen is the open side for the water flow. Above the test soil is a second geotextile to prevent any soil loss at the annular gap between the brass disc and the tube during the test phases. The load to the geotextile is produced by the 1500 g of test soil and by a brass disc above the second geotextile with a mass of 2130 g.

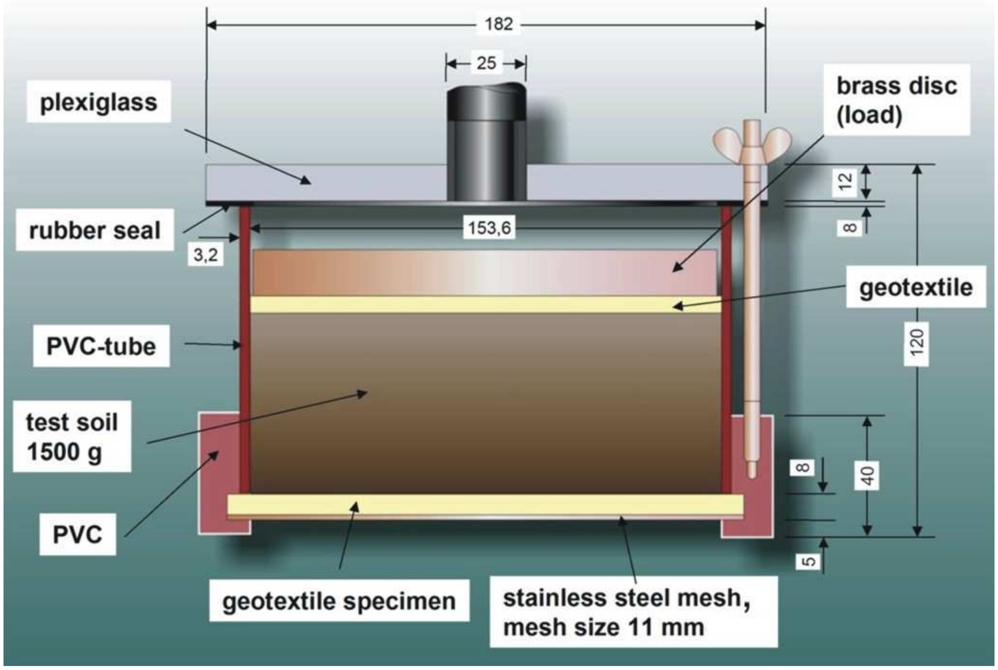


Figure 9. Drawing specimen holder with soil, sectional view.

A medium to coarse silt with a grading curve within the grading band shown in Figure 10 is normally used as test soil 4 (soil type name: ST4) in the original RPG (1994) test method. This soil type ST4 must also meet a plasticity index Ip ≤ 0.1 and cohesion of undrained soil u ≤ 1.5 kN/m². To point out the influence of test soil to the soil passing behaviour of geotextiles two further test soils, as also shown in Figure 10, are used for the testing within this paper. Test soil ST 2 (soil type name: ST2) is a medium sand with fine sand and is normally used for the determination of the mechanical filtration stability within the RPG (1994) flow trough method. The test soil O90 is the granular material from the standard DIN EN ISO 12956 for the determination of the characteristic opening size.

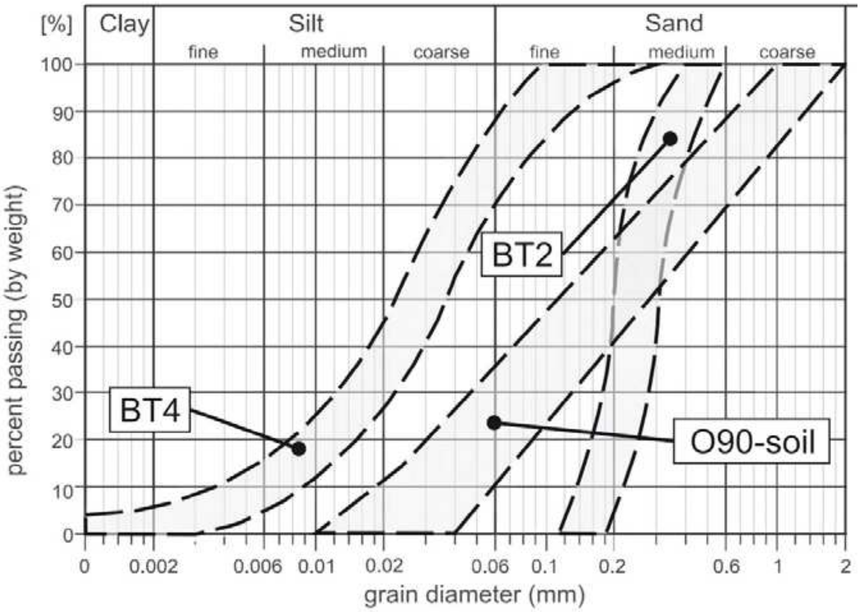


Figure 10. Grading curves for the test soils ST4, O90 and ST2

3.2 Procedure

Three geotextile specimens, each with a diameter of 168 mm, should be punched out of the laboratory sample in accordance with the standard DIN EN ISO 9862. Before installation the test soil is dried directly to constant mass at 105°C. After installation the test soil must be compacted by using a load which produces a surface pressure of 2 kPa on the geotextile specimen. The specimens are fastened on a vertically oscillating device for compaction. An appropriate vertically oscillating device is described in the standard DIN EN ISO 12956. A 5 mm plastic disc should be placed beneath the geotextile specimen to prevent a sagging during the compaction. The lid of the specimen holder is closed after a compaction time of 240 s. Before testing the specimen holder should be stored in drinking water with a temperature of 20 ± 5 °C for 16 hours until the specimen is saturated. The depth of the water should be 20 cm for the covering of the geotextile specimen. Furthermore the specimen holder should be immersed at an angle to prevent any air bubbles from being trapped under the surface of the geotextile.

Each test container should be filled with drinking water up to a depth of 20.5 cm. Before and after the several test phases is a measuring of the water temperature in each sample container necessary. Each specimen holder is to be placed in the test container by immersing it at an angle to prevent any air bubbles forming beneath the specimen surface. A adjusting of the height of each specimen holder by placing a spacer with a height of 3 cm between the lower edges of the specimen holders and the upper edges of the propellers is the last step before the test starts. The spacer is to be removed before testing. Beneath the test containers vessels must be placed for water collection.

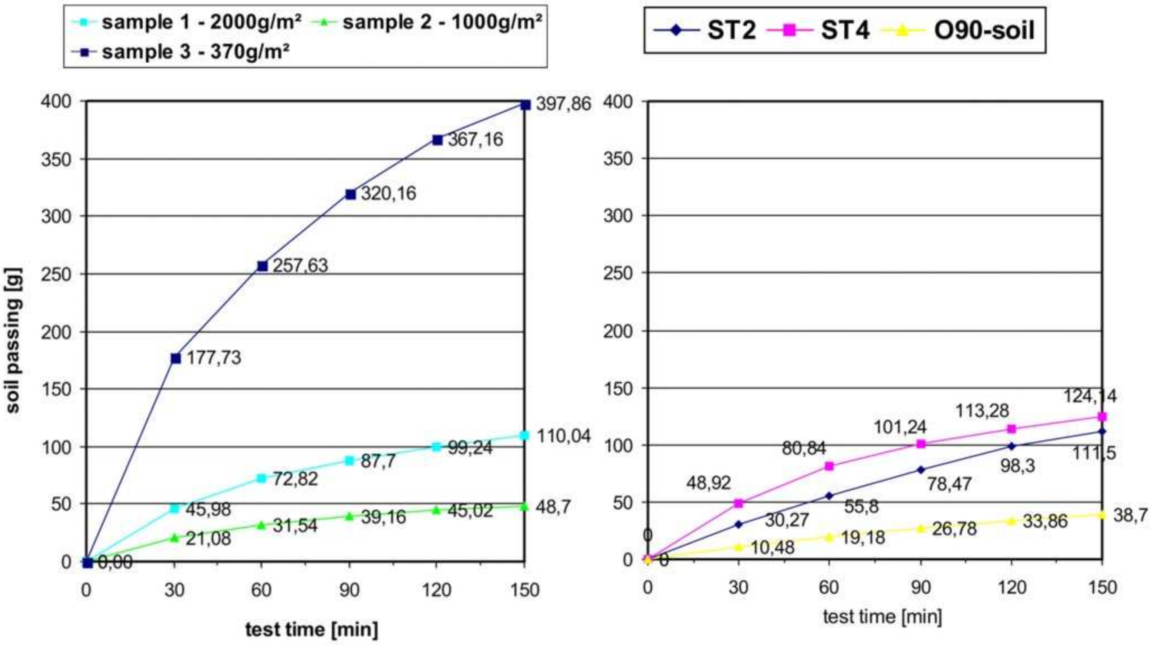
Each test phase should be terminated by a timer after 30 min. After each test phase each outlet is to be opened carefully for the water discharging. Each specimen holder and test container must be washed with fresh water to make sure that every passed soil is collected in the vessel. The quantity of soil passing through the specimens is determined from the collected water in the vessels by filtering, drying at 105°C and weighing. A hydrophilic cellulose fluted filter with a diameter of 500 mm and a grade of 7 to 10 µm is used for the water filtration.

This procedure should be repeated 5 times with fresh water to receive 5 test phases and a total testing time of 150 min for each geotextile specimen.

3.3 Evaluation and results for geotextile filters

For every test phase the mean value, standard deviation and coefficient of variation of the quantity of soil passing can be calculated. The test report should state information concerning the type of test soil, the quantity of soil passing through the filter during the final test phase (120 to 150 min) and the quantity passing during the whole test after 150 min in g to one decimal place. A cumulated curve can be obtained by plotting the mean value of soil passing for each test phase against the testing time.

A few examples for cumulative curves of non woven needled punched geotextiles are shown in Figure 11. The slope of the curve indicates, whether the filtration rate has stabilized. A possible increase of soil passing within the last test phase is a further important criterion for the evaluation of the mechanical filtration stability of geotextiles. If no stabilization of the filtration rate can be determined as shown for sample 2 and 3 in Figure 11 (a), it could prove to be very useful to prolong the testing time. Sample 1 and 2 are made of staple fibers. Sample 3 is made of continuous filament. The soil passing behavior of sample 3 is totally different to sample 1 and 2. By comparison sample 3 with a mass per unit area of 370 g/m² in accordance with the standard DIN EN ISO 9864 with sample 2 (1000 g/m²) and sample 1 (2000 g/m²) it is further recognizable that there is no link concerning soil passing and mass per unit area. Due to the slope of the cumulative curve and the soil passing quantity of sample 3 it is obvious that this geotextile product is not appropriate for a filter application. Figure 11 (b) shows the soil passing of a geotextile product with a mass per unit area of 650 g/m² and three different test soils. This none woven needled punched geotextile product is made of made of staple fibers. The cumulative curves of the test soils ST2 and ST4 are similar by contrast to the O90 soil.



(a) Soil passing with ST4 for several needle punched materials

(b) Influence of soil type for a 650 g/m² needle punched material

Figure 11. Soil passing diagrams for several non woven geotextiles

Requirements for soil passing limits are currently specified for German navigable waterways applications with the EU notified technical supply conditions TLG (2003). According to the TLG (2003) geotextiles are deemed to be stable filters for the soil type ST4, if the quantity of soil passing through the final test phase ≤ 30 g and the quantity of passing during the whole test ≤ 300 g.

The test method can also used to test the hydraulic filtration stability in accordance to TLG (2003). For this purpose the soil must be removed from the surface of the geotextile samples after the turbulent flow test phases. For the soil covered geotextile specimens the determination of water permeability normal to the plane without load are carried out in accordance with the standard DIN EN ISO 11058. The tests should be conducted with a hydraulic head of 50 mm and indicates the filter properties after the exposure of the turbulent water flow.

3.4 Testing of clay geosynthetic barriers under turbulent flow conditions

A few examples for reconstruction and improvement of dykes by using geosynthetic barriers (GBR-C) are been reported by Heerten (2003). The geosynthetic barriers are used as sealing elements on the water exposed side of dykes at rivers. A further application for the turbulent flow test method is to expose turbulent water flow conditions to GBR-C for the evaluation of the bentonite erosion stability.

The difference in the GBR-C procedure compared to the geotextile procedure is that instead of a test soil a basalt split aggregate with the grading 5 to 8 mm was used as load. To achieve the swelling of bentonite the specimen holder should be stored in drinking water with a temperature of 20 ± 5 °C for 48 hours. The exposition time is 96 hours and the coefficient of water permeability before and after the exposition is determined in accordance with the standard DIN 18130-1 and a cell pressure of 530 kPa and a back pressure of 500 kPa. Table 1 shows the results of three different GBR-C products and two different hydraulic gradients (i) which consider dykes and landfill applications. The determinations of the mass per unit area were carried out in accordance with the standard DIN EN ISO 9864. Product A and C are made of natural Na-bentonite. Product B is made of activated Na-bentonite. The mass of bentonite is determined by gravimetric analysis from punched out specimens with a diameter of 168 mm. The separated specimens were stored for 24 hours in a 200 ml beaker, washed out by hand and dried till constant mass at 60°C was achieved. As can be seen in Table 1, the mass of bentonite is different to the weighing at 20 ± 5 °C.

Due to the less passed granular material no cumulative curve is presentable. Furthermore no significant change of the permeability or rather the sealing behavior of the GBR-C after the exposure of turbulent water flow is observed.

Table 1. Permeability results of clay geosynthetic barriers (GBR-C)

product	mass per unit area [g/m²]	mass of bentonite [g/cm²]	soil passing in		Permeability per 1 cm bentonite layer [m/s²]			
			150min [g]	96h [g]	before		after	
					at i ≈ 50	at i ≈ 500	at i ≈ 50	at i ≈ 500
A	6400	0,51 ± 0,03	2,43[1.)]	1,21[1.)]	$5{,}0 \cdot 10^{-11}$	$3{,}5 \cdot 10^{-11}$	$7{,}5 \cdot 10^{-11}$	$5{,}0 \cdot 10^{-11}$
B	6000	0,54 ± 0,04	0,96[1.)]	1,12[1.)]	$3{,}5 \cdot 10^{-11}$	$3{,}5 \cdot 10^{-11}$	$3{,}5 \cdot 10^{-11}$	$3{,}0 \cdot 10^{-11}$
C	5200	0,42 ± 0,01	2,12[2.)]	1,46[2.)]	$2{,}5 \cdot 10^{-11}$	$2{,}0 \cdot 10^{-11}$	$3{,}5 \cdot 10^{-11}$	$2{,}0 \cdot 10^{-11}$

[1.)] Median of three samples

[2.)] Median of five samples

4. CONCLUSION

The key feature of the described test method is a propeller which produces turbulent water flow to geotextile specimens under specified conditions. For the comparison of geotextile products the soil passing through the filter specimen is to be determined after the test phases. This test method can be considered as index test, if a specified test soil is used. It is important to note that the described index test method could be used as a performance test for construction projects by using local soil as test soil. The test method can also be used for control testing. Test results and cumulative curves demonstrate the influence of test soil to the soil passing behavior of several non woven needled punched geotextiles. It could be shown that the type of test soil has a major influence on the soil passing behavior of geotextile filters. It must be noted that the described test method is based on a procedure which is used in Germany for over twenty years for evaluating geotextiles beneath armour stones standard layers in navigable waterways and in marine structures. The soil passing behavior under turbulence should be considered as an essential factor in selecting an appropriate geotextile filter for construction projects subjected to turbulent water conditions. The described test method for the exposition of turbulent water flow to geotextiles is now an EN-ISO work item and a first draft is under revision.

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