Filter design for external erosion control on the basis of a reversing-turbulent-flow test

H.-U. Abromeit
Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany

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ABSTRACT: Opening size is generally regarded to be the decisive index value for the soil-retaining capacity of a geotextile used as a filter. Recent comparative tests carried out at the BAW have shown that opening size is an insufficient parameter in this respect. This became obvious when determining the masses of soil passing through different products of identical opening size exposed to external turbulent flow impact. The result: geotextile design on the basis of opening size may lead to unjustified exclusion of a product although its soil-retaining capacity is extremely high. None of the existing design methods yields an idea of the mass of soil which may pass through a geotextile during its lifetime. But the soil-retaining behaviour of a geotextile in relation to the subsoil is decisive for possible settlements of a hydraulic structure and thus for its long-term serviceability. First of all information on the hydrodynamic test method used is given and some remarkable test results are presented. Finally an alternative, more reliable method of geotextile design for external erosion control in hydraulic structures on the basis of initial type testing the soil mass passing is presented for discussion.

1 REVERSING-TURBULENT-FLOW TEST METHOD

1.1 *History*

In 1977 the BAW presented the principle of a hydrodynamic test apparatus - the reversing-turbulent-flow-test apparatus - suitable for determining the real soil masses passing through a geotextile under specific hydrodynamic loads depending on loading time and thus allowing assessment of the long-term soil retaining behaviour of a product (List 1977).

The reversing-turbulent-flow-test method of that time has been improved little by little and when delivering reproducible results finally became a BAW standard index test in 1994. This test method is used especially for initial type testing of a new product which is designed for external erosion control according to the soil-type design procedure of the BAW described later in this paper (MAG 1993).

1.2 *Test principle*

Reversing turbulent flow conditions as they can prevail under wave attack or be caused by highly turbulent natural or ship induced currents in hydraulic structures are simulated in the test apparatus. The geotextile specimen in contact with an optional test soil (standard or in-situ soil) and charged with a defined normal stress excluding liquefaction of test soil is exposed on its surface during 5 load cycles to defined pulsating external turbulent current actions. The soil mass washed out through the geotextile per cycle is determined. Test result: total mass of soil passing and in addition, it is recognisable if the desirable and very important effect of reduction of soil mass passed through per cycle has occurred. With respect to maximum hydraulic loads caused e.g. by shipping the testing time represents a traffic period of about 15 years.

1.3 *Test specimens*

3 circular specimens are used for testing, exposed diameter 153 mm.

1.4 *Apparatus*

The BAW apparatus comprises the following essential details (Fig. 1):
- water container, bottom dimensions 0,50 x 0,50 m
- 4-armed rotor (up to ca. 275 revs/min) to generate the required pulsating current loads
- a cylindrical receptacle, internal diameter 153 mm, containing specimen, test soil and loading disk
- drying oven suitable for temperatures up to 110°C
- balance to determine the mass of the dry test soil to an accuracy of 0.01 g.

The driving mechanism of the rotor allows the hydrodynamic loads to be set to different levels.The hydraulic load parameters of the test apparatus (mean velocity and degree of turbulence) should comply with the loads measured or with the expected on site/in hydraulic structure.

The BAW standard test is performed with the maximum level of mean pulsating velocities measured in armourstone revetments of waterways or in coastal areas, i.e. $v_m \approx 0{,}8$ m/s. The amount of test soil is about 1500 g and the normal pressure on the specimen caused by test soil and loading disk is 2 kPa.

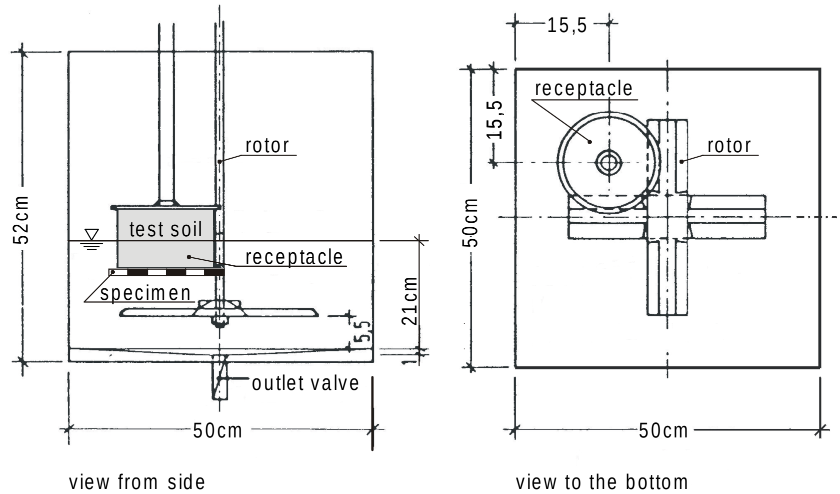

Figure 1. Reversing-turbulent-flow test apparatus at the BAW

1.5 *Procedure*

The specimen is placed on the support grid of the receptacle and after this the receptacle is charged with the test soil. Finally a loading disk is placed on top of the soil. Afterwards the soil is compacted on a sieving machine in a defined manner. The container is filled up with water and the specimen receptacle is installed to saturate for at least 16 hours (RPG 1994).

After these preliminaries water level and specimen receptacle are adjusted to the positions necessary to obtain the required turbulent-flow level close to the specimen‘s surface (Fig. 1). The first of 5 load cycles is started. When the rotor is in action the specimen is completely immersed. The rotor is left in action for 30 minutes.

Soil mass washed out through the specimen during the first load cycle is determined by removing the water from the container and filtering the water, drying the residue at 105°C and weighing it.

A further 4 cycles are conducted according to the first cycle, i.e. the total load duration is 150 minutes. The time needed to carry out the full load scale on three specimens can be shortened when testing 3 specimens simultaneously.

Afterwards permeability of the soil filled specimens is determined on the basis of EN ISO 11058 (falling head method).

1.6 *Calculation and presentation of results*

The summarised soil-masses passing through during 5 load cycles are plotted against time for each specimen. Additionally a collective plot is given. Figure 2 shows as an example the collective plot of test results obtained with a test soil 3 and a test soil 4 (Fig. 4).

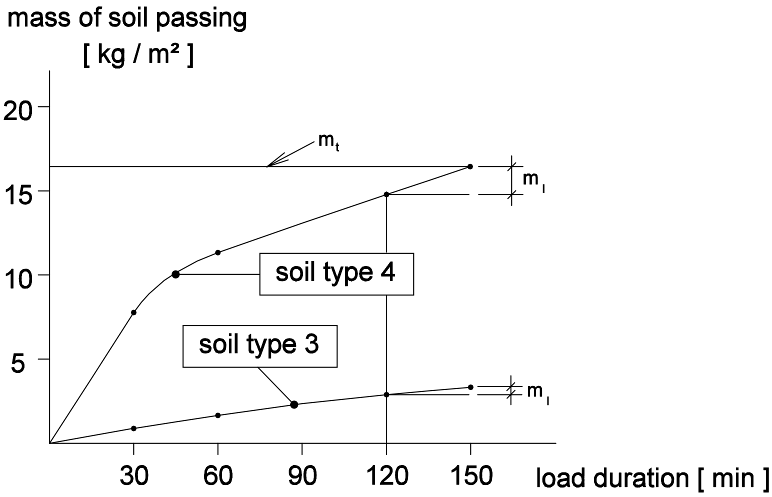

Figure 2. Example of a collective plot of test results and relevant threshold values (m_t, m_l) of a filtration specification (see 3.4.3)

2 RESULTS OF THE REVERSING-TURBULENT-FLOW TEST IN COMPARISON TO OPENING SIZE INDEX VALUE

Due to many doubts about the significance of the opening size on the soil-retaining capacity of a geotextile the BAW has carried out a lot of standard reversing-turbulent-flow tests (see 1.4) using a defined well graded fine non-cohesive test soil (sandy silt) and nonwoven products of different bonding (needle-punched, thermally bonded).

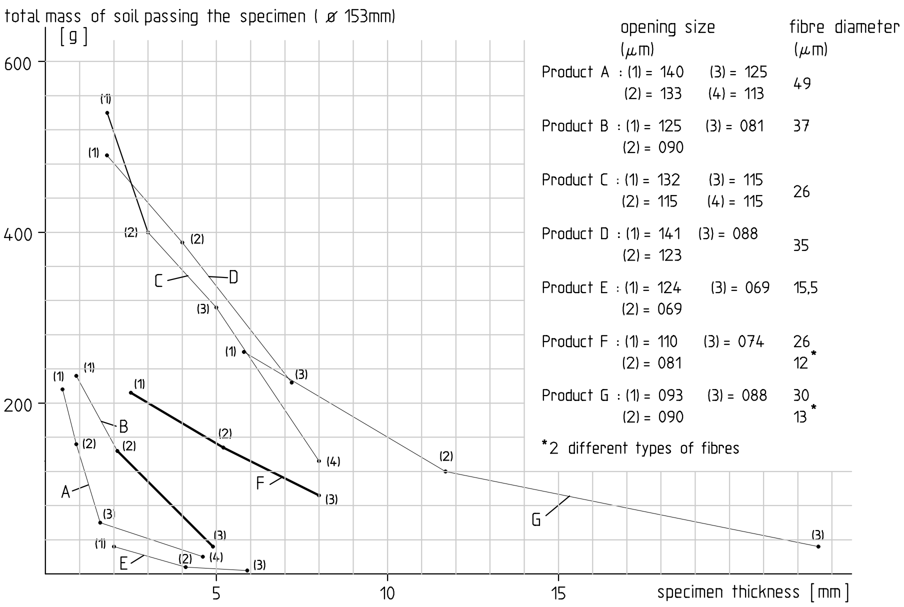

Figure 3. Test results of different products obtained with sandy silt and relevant opening size and fibre diameter(s)

The objective was to ascertain, whether opening size is really the decisive parameter for the filtration design of a geotextile.

It has been self-evident, that in the case of identical opening size and same type of structure and of bonding, layer thickness too must be a decisive parameter for the soil-retaining behaviour. Hence specimen thickness of a product has been enhanced in the tests by multi-layer installation.

Some remarkable examples of test results are shown (Fig. 3). It can be seen that the total mass of soil passing through different products of nearly identical O_{90} may differ by up to 1000% (e.g. products C and E). It can be assumed that the soil-retaining behaviour of a specific product will be of the same tendency when using different test soils.

Soil mass passing through a specific type of product seems to be nearly linearly proportional to thickness.

3 EXTERNAL EROSION CONTROL DESIGN

3.1 *General*

A geotextile used for external erosion control may be designed on the basis of
- specific characteristic opening size or
- filtration tests for the determination of soil mass passing through under specific hydraulic impact conditions.

3.2 *Design on the basis of a characteristic opening size*

It is most common to design a geotextile filter on the basis of a specific characteristic opening size. World-wide a large number of design methods exists, in which different characteristic opening size index values are used (e.g. O_{90}, O_{95}, O_{98}, D_w), derived from quite different national test methods. With the coming into force of EN ISO 12956 in 1999 the decisive index value of characteristic opening size is now O_{90}.

3.3 *Discussion of importance of an opening size index value*

Filtration tests at the BAW have shown that the soil-retaining capacity of different geotextile products of identical characteristic opening size O_{90} may differ by up to 1000% with regard to the total mass of test soil passed through (Fig. 3), i.e. filtration property cannot be a function of a characteristic opening size index value only and must be dependent on some further parameters such as

(a) hydrodynamic load level (flow velocity, degree of turbulence)
(b) type of geotextile (woven, nonwoven, composite)
(c) external structure (woven)
(d) internal structure/fibre diameter(s) (nonwoven)
(e) type of bonding (e.g. needle punched, thermally bonded)
(f) position of openings related to current direction (affects action of external hydraulic loads on subsoil surface)
(g) geotextile thickness (affects action of external hydraulic loads on subsoil surface)
(h) number of openings per unit area corresponding to the characteristic opening size
(i) possible change of opening sizes due to strain caused by surcharge
(j) possible change of opening sizes due to fibre shifting caused by soil particle action
(k) liquefaction of subsoil particles due to excess pore-water-pressure (in the reversing-turbulent-flow test procedure excluded by specimen surcharge).

With the exception of thickness none of these parameters has been determined by any existing national test procedure and thus cannot be considered in any existing geotextile design rule. Thus the question must be asked whether the prevalent practice of filtration design on the basis of a characteristic opening size index value should be maintained.

3.4 *Presentation of a design method on the basis of initial filtration testing*

3.4.1 *Preliminary remarks*

Recognising the shortcoming of geotextile design on the basis of a characteristic opening size index value, an alternative design procedure (soil-type design procedure) for evaluating the suitability of a geotextile product used as a filter layer in hydraulic structures is presented. The design procedure applies to hydrodynamic flow conditions only.

The soil-type design procedure encompasses the whole range of non-cohesive and slightly cohesive soils from medium silt to coarse gravel and is applicable to cohesive soils too.

3.4.2 *Principle of soil-type design procedure*

The field of non-cohesive soils has been subdivided into 4 soil-type ranges (MAG 1993). Each soil-type range is characterized by a grading band close to the fine-grained border. A grading of this band is used as a test soil to determine the soil-retaining capacity of a geotextile according to the reversing-turbulent-flow standard test method (see 1.4-1.6).

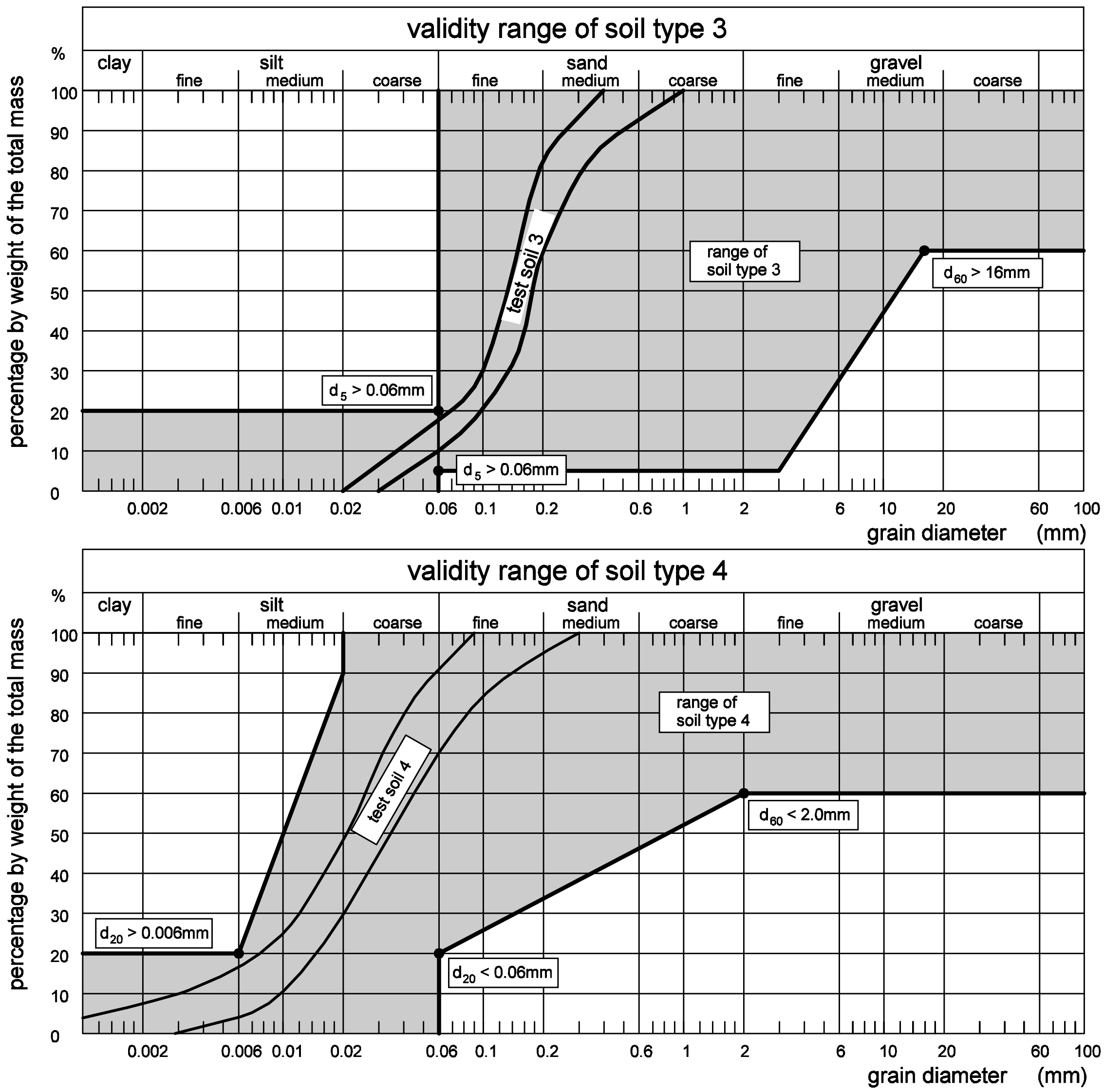

Figure 4. Soil-type ranges 3 and 4 and band of recommended relevant test soils for initial type testing

Gradings of the recommended test-soil band yield the most unfavourable soil masses which may pass through a product in relation to the specific soil-type range.

A geotextile is suitable as a filter layer upon any grading of a specific soil-type range if the required filtration specification of the soil-type range is met, i.e. soil masses passing and permeability of the soil filled geotextile. This must be proved by the manufacturer for a geotextile which shall be designed for external erosion control by initial type testing performed with a relevant test soil of the specific soil-type range. Initial type testing should be carried out at least for the most problematical soil types 3 (silty sand) and 4 (sandy silt), Figure 4.

For the evaluation of filtration suitability of a geotextile in the particular application only the grading curves of the finest and of the coarsest soil forming the subgrade are needed. If the subsoil is of cohesive nature c_u and I_p should be known too.

The designer must check to which of the 4 soil-type ranges the finest and the coarsest of the subsoils to be filtered can be assigned. The soil-type which encloses in its validity range the grain fractions $d_5 - d_{60}$ of the finest subsoil is decisive for the soil-retaining specification, the soil-type which encloses in its validity range the grain fractions $d_5 - d_{60}$ of the coarsest subsoil is decisive for the permeability specification of a geotextile used as a filter in a hydraulic structure.

3.4.3 *Filtration specification*

The designer has to establish the soil-type range only (or if necessary the soil-type ranges in the case of a broad grading band) and the level of the filtration specification.

An offered product is appropriate to the intended use if its initial type testing values meet the required filtration specification.

The following standard specification has been set up by the BAW and is recommended for hydrodynamic environment as e.g. on waterways or in coastal engineering (TLG 1993):

a) requirements upon non-cohesive soils (soil-type ranges 1 – 4)
   - (1) admissible total soil mass passing: $m_t \leq 16.3$ kg/m^2
   - (2) admissible soil mass passing during the last test cycle: $m_l \leq 0.1\ m_t$ (see Figure 2)
   - (3) permeability of the soil-filled geotextile: must be greater than permeability of the coarsest subsoil present on site
   - (4) thickness of filter layer:
     soil-type ranges 1-3: $t \geq 4.5$ mm
     soil-type range 4: $t \geq 6.0$ mm
     (required only in the case of subsoil gradings, which may lead to reduction of permeability due to clogging or blocking)

b) requirements upon cohesive subsoils (Abromeit 1991)
   - (1) when $c_u \geq 10$ kN/m^2 and $I_P \geq 0.15$: soil-type range optional, depending on other site conditions
   - (2) when $c_u < 10$ kN/m^2 <u>or</u> $I_P < 0.15$: admissible masses passing as soil-type range 4

   Where c_u and I_P are unknown, all requirements on soil-type range 4 apply.

The total-mass-passing value (m_t) is equivalent to settlements of about 1 cm. The last-cycle-mass-passing value (m_l) is an index of adequate reduction of soil loss during this test period.

Of course, the above-mentioned specification can be established at another level depending on sensitivity of a hydraulic structure to settlements.

3.4.4 *Production control and filtration properties*

To ensure that the soil masses passing do not exceed the measured values obtained in initial type testing of a product, it is sufficient for production control if the following geotextile index parameters are checked, which may be determined very easily and in a short time:

- mass per unit area
- thickness
- velocity index (according to EN ISO 11058, falling head method)

If the values actually tested are only slightly below the respective initial type testing mean values then proved through experiments and empirical observation a significant increase in soil-mass passing can be excluded.

4 CONCLUSIONS AND OUTLOOK

Filtration tests at the BAW, which will be extended to further types of products, have shown that the masses of soil which may pass under specific hydraulic loads are not a function of a specific characteristic opening size index value only but also of external or internal structure and of thickness of a product (nonwoven), and additionally certainly also of some other product parameters.

BAW test results (see 2) lead to the following conclusions with respect to geotextiles used in external erosion control:

<u>Conclusion 1:</u> A design procedure based on opening size index value may be valid for a specific type of geotextile only, i.e. each type of geotextile structure needs its own design rule.

<u>Conclusion 2:</u> The soil-retaining capacity of a specific geotextile structure (nonwoven) increases nearly linearly with increasing thickness of a product.

<u>Conclusion 3:</u> geotextile design on the basis of an opening size index value may lead to the exclusion of a product which is absolutely appropriate for filtration purposes when considering the mass of soil which may pass through in relation to the hydrodynamic load level.

<u>Conclusion 4:</u> In the case of alternating subsoils, geotextile design on the basis of opening size may lead to the unnecessary installation of different geotextile products.

Most existing design procedures consider only a characteristic opening size index value. A few combine layer thickness with opening size (e.g. DVWK 1992), but remaining insufficient too with respect to the real filtration behaviour of a geotextile.

More realistic and very simple filter design is possible according to the soil-type design procedure which is based on initial type testing of a new product by determining the soil masses passing under defined hydrodynamic loads.

The presented BAW reversing-turbulent-flow-test method is suitable as an index test of the manufacturer for the initial type testing of a new product. The test results allow the designing engineer the evaluation of possible settlements of a structure on the basis of soil masses which may pass through a geotextile during its lifetime under required specific hydrodynamic loads.

The test can be modified, if desired, at any other hydrodynamic impact level. It can be used also as a performance test when applying the subsoil present on site and thus leading to a more economic construction. The test method has been proposed as a CEN-Report.

Filtration test method and design procedure presented are up for discussion.

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