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FUNCTIONAL DESIGN OF FILTERS USING GEOTEXTILES
PROBLEMORIENTIERTE FILTERBEMESSUNG FÜR GEOTEXTILIEN
DIMENSIONNEMENT FONCTIONEL DE FILTRES UTILISANT DES GEOTEXTILES

Opening size of the goetextile, grain diameter, uniformity and sometimes degree of compaction of the existing soil for the assessment of the mechanical filter efficiency (soil tightness) and a comparison of the water permeability coefficients of the soil and geotextile (comparison of the k-value) represent common parameters for the filter design of geotextiles. Following the recommendations of WG 14 GSSMFE indications are given on different load conditions and filter technical problem soils as well as filter rules are presented. For embankment protection recommendations are formulated for structure and thickness of geotextiles to avoid migration of soil particles beneath the fabric downslope.

1. Introduction

Opening size of the geotextile, grain diameter, uniformity and sometimes degree of compaction of the existing soil for the assessment of the mechanical filter efficiency (soil tightness) and a comparison of the water permeability coefficients of the soil and geotextile (comparison of the k-value) represent common parameters for the filter design of geotextiles. Parallel to experiences with the dimensioning of mineral filters conclusions increase that pore diameter and water permeability coefficient do not lead in all cases to satisfactory filter designs , but a third design-criteria has to be used in analogy with the filtration length for mineral filters indicating a minimum thickness. Furthermore problem orientated analyses of the existing soil and the given loads can give valuable indications for the choice of a geotextile filter in correspondence with the requirements. This contribution treats some aspects of the a. m. problems taking into account the recommendations for the use of synthetic materials in soil and hydraulic engineering of the working group 14 of the German Society for Soil Mechanics and Foundation Engineering (WG 14 GSSMFE).

2. Filter technical assessment of soils

The Swiss standard SN 670125a "filter materials" for the application field drain pipes, drain trench, wall backfills and boundary (crossing) layers includes the diagram Fig. 1 for the filter technical assessment of soils.

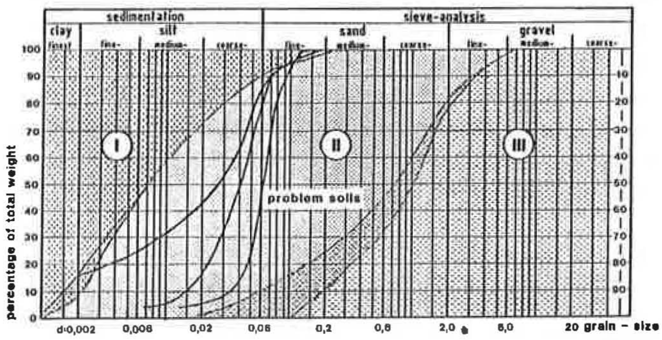


Fig. 1: Soil types for drainage systems according to the Swiss standard SN 670125a. The grain sizes shown in Zone II represent examples for problem soils.

Zone I is characterized by an efficient cohesion and therefore a comparably more open filter dimensioning is possible. The hydraulic efficiency of the filter is less important due to the small permeability of the soils of zone I. But the cohesion has to be preserved at long-term under operation condition of the drainage system and possibly concentrated water outflows in stratifications have to be taken into account for the hydraulic design.

The soils of zone II and especially silts and fine sands require an extremely careful filter dimensioning. Corresponding experiences are documentated in the grain distribution curve of problem soils shown in zone II of Fig. 1. Dug-out samples of these soils show an increased tendency of silting up (soil wash-outs into the drain pipes (5)).

In addition to Fig. 1 the recommendations of WG 14 GSSMFE contain the following criterias which refer to filter technical problem soils with an increased mobility of fine soil particles (tendency to scouring, erosion and silting up).

1. Grain fractions < 0,06 mm silt contained in soil and more:
   Coefficient of uniformity $Cu = \frac{d_{60}}{d_{10}} < 15$
2. Quantity part of soil in the section
   $0{,}02\ \text{mm} < d < 0{,}1\ \text{mm} > 50\%$
3. Plasticity index $I_p < 0{,}15$ (15%)

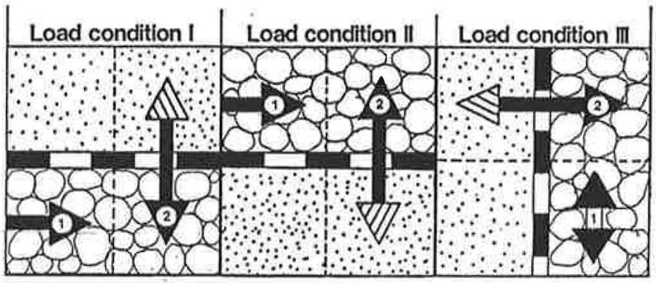
Note: If the plasticity index is unknown f. ex. in the planning phase the clay - silt proportion has auxiliarily to be taken into account in order to recognize a filter technical problem soil. This subsidiary criterion is expressed in:

$$\frac{\text{Quantity of clay}}{\text{Quantity of silt}} < 0{,}5$$

According to SN 670125a the soils of zone III can normally be drained without additional filter layers, but with correspondingly dimensionated pipes. In this connection it must be noted that d_{85} of the soil to be filtered is to be greater than the smallest opening of the drainage pipe (d_{85} > smallest dimensions of the openings in the filtration pipe).

3. Load conditions for hydraulic filter loads

In the recommendations of WG 14 GSSMFE three often occuring load conditions for hydraulic filter loads of geotextiles are represented. The situation of the soil/geotextile boundary and the direction of flow have to be distinguished (Fig. 2). All soil/geotextile contact areas can also be inclined, with a corresponding influence on the effect direction of the acceleration due to gravity. The acceleration due to gravity can influence decisively the establishment of a secondary filter as more stable grain-grain-bridgings are built in direction of the acceleration due to gravity. In case that the current load is effective against the direction of the acceleration due to gravity, instabilities may occur if the current load just compensates the acceleration due to gravity.



(1) current load parallel to geotextile
(2) current load vertical to geotextile

Fig. 2: Schematic representation of hydraulic filter loads

Current loads vertical to the geotextile can in case of overpassing critical gradients of $i_{crit} = 0{,}6 \div 1{,}1$ produce contact erosions, whereas for current load parallel to the geotextile contact erosions can already occur with critical gradients of $i_{crit} = 0{,}05 - 0{,}15$. Due to this, parallel flows to the geotextile are considerably more critical for a soil-filter system than vertical current loads to the geotextile. These foundamental flow directions can in practice still be eclipsed by hydraulic dynamic components. Depending on sub-soil and covering layer the thickness and pore structure of a geotextile can decisively influence the stability of the interface. With increasing stresses a bigger total thickness is necessary. Mühring and Saathoff give indications for tests in laboratories of the interface stability with parallel flows (7).

4 Filter rules

4.1 Mechanical filter efficiency (soil tightness) according to WG 14 GSSMFE

When setting up filter rules for the mechanical efficiency of filtering, three different grain sections (A,B,C) are distinguished.

Note: In the recommendations of WG 14 GSSMFE the filter rules refer to the effective opening size D_w. D_w is determinated by the wet sieving analysis of the Federal Institute for Hydraulic Research and Coastal Engineering (6). This testing method is also laid down in a Swiss standard (SN 640550), however, the effective opening size designated O_w. The effective opening size D_w corresponds to undersize amounting to 10% of test soil and 90% oversize. Therefore, according to the declarations for symbols and dimensions of this conference, $D_w = O_w = O_{90}$. But it must strictly be noted that the defined O_{90} resulting from the wet sieving test of the Franzius Institute for Hydraulic Research and Coastal Engineering cannot be treated as equivalent to O_{90}-values resulting from other test methods. Each O_{90}-value has its specific test definition. The following filter rules can therefore only be applied with O_{90}-values resulting from the mentioned wet sieving method or otherwise a O_{90}/O_{90} relationship for different test methods has to be considered.

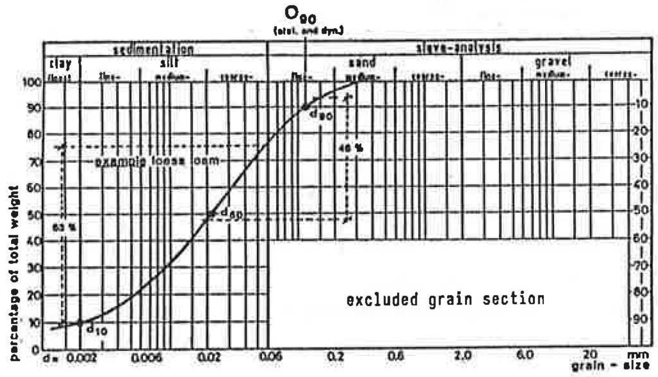


Fig. 3: Soils of grain section A with a silt quantity > 40% (fine-grained soil according to DIN 18196) with the example loess loam

Filter rules for the mechanical filter stability of the geotextile in grain section A

a) static load condition $O_{90} < 10 \cdot d_{50}$
- for problem soils according to paragraph 2 in addition

  $O_{90} < d_{90}$
- for soils with a stable cohesion at long-term

  $O_{90} < 2 \cdot d_{90}$

b) dynamic load condition $O_{90} < d_{90}$

Note: The formulation $O_{90} < 2 \cdot d_{90}$ for a more open filter dimensioning under static load can only be applied if the cohesive properties of the soil to be filtered are absolutely preserved even under loads. In case of dynamic load it is in addition recommendable to choose $O_{90} < 0,3$ mm in order to ensure a sufficient retention function to fine grain quantities.

For the example "loess loam" (problem soil according to criterion 3 clay/silt relationship) the following opening sizes turn out:

a) static load $O_{90} < 0,12$ mm
b) dynamic load $O_{90} < 0,12$ mm

In case of a laboratory proof of a plasticity index $I_p > 15\%$, $O_{90} < 2 \cdot d_{90} = 0,24$ mm could be used under static load.

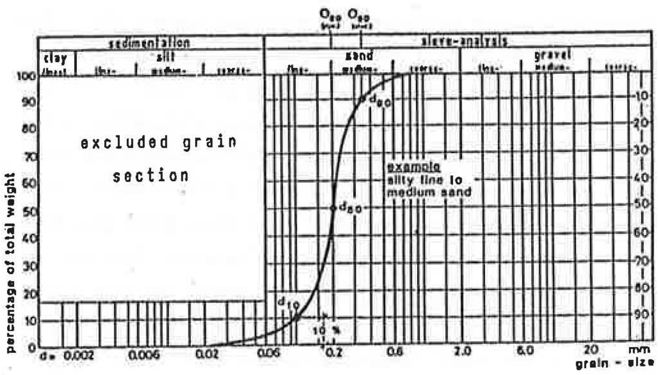


Fig. 4: Soils of grain section B with a silty grain quantity < 15% with the example "silty fine to medium sand"

Filter rules for the mechanical filter stability of the geotextile in grain section B

a) static load

   $O_{90} < 5 \cdot d_{10} \sqrt{Cu}$ and $O_{90} < 2\ d_{90}$

   as well as $O_{90} < d_{90}$ for problem soils according to paragraph 2

b) dynamic load

   $O_{90} < 1,5 \cdot d_{10} \sqrt{Cu}$ and $O_{90} < d_{50}$

Note: In case of dynamic load it is in addition recommendable to choose $O_{90} < 0,5$ mm in order to ensure a sufficient retention function to fine grain quantities.

For the example "silty fine to medium sand" (problem soil according to criterion 1) the following pore sizes turn out:

a) static load $O_{90} < 0,34$ mm
b) dynamic load $O_{90} < 0,20$ mm

For grain section C with mixed grained soils (sedimentation quantity between 15% and 40%) the filter rules of grain section B are applied. But the WG 14 GSSMFE has mentioned additional notes for the filter technical assessment of this soil group in its recommendations and has pointed out the known advantages of the application of nonwoven fabrics (multilayer filter fabrics) when it is the question of ensuring a high mechanical and hydraulic filter efficiency.

4.2 Hydraulic filter efficiency

After the installation of the filter (filter stabilization phase) in the interface geotextile/soil the water permeability of a geotextile vertical to the plane has to remain the same or become greater than the water permeability of the existing soil in order to ensure the highest possible pressureless drainage. During the filter stabilization phase a reduction of the permeability of the virgin geotextile - as with mineral filters - is inevitably produced by soil contact (deep filtration, clogging, cake filtration, blocking). For consideration of this influence mineral filters receive with common filter design a "permeability reserve" of 1 to 2 tenth powers. A corresponding behaviour can also be seen by thick nonwovens and composite materials with which the hydraulic filtering efficiency can generally be regarded as fulfilled if the water permeability measured on the virgin product with a load of 2 kN/m² exceeds the permeability coefficient of the soil by 50 times (3). The reduction of the water permeability of certain geotextile types (f.ex. woven fabrics with open sieve structure) can attain 3 to 4 tenth powers. Fundamentally the reduction of water permeability depends on pore structure and thickness of the geotextile as well as grain structure of the sourrounding soil. Taking account of the hydraulic filter stability the upper limits of the opening size, which are permitted with guarantee of the mechanical filter stability, should be used - an open thick pore structure is superior to a thinn dense with regard to filter efficiency.

5. Requirements for geotextiles regarding bank protection

In addition to the normal filter technical design as well as the requirements f.ex. for push-through, abrasion, tensile strength and elongation the geotextile and the soil/geotextile friction behaviour as part of a revetment for bank protection have to be designed in a way that migrations of soil particles down the slope underneath the geotextile are safely avoided. A typical revetment damage caused by soil movements unterneath the geotextile is shown in Fig. 5.

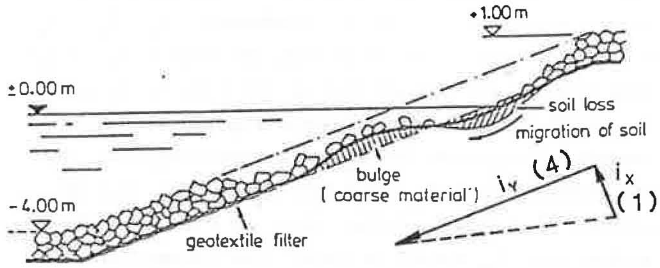


Fig. 5: Migration of soil particles beneath the geotextile and effective hydraulic gradients according to measurements at the Hartel Canal (1)

Field measurements at the Hartel Canal in The Netherlands have shown that hydraulic gradients i_y parallel to the slope can be 3 to 4 times as great as the gradients vertical to the slope i_x. Furthermore it has revealed that a mineral filter layer between covering layer and geotextile can considerably reduce the gradients underneath the geotextile with a corresponding reduction of the ground water flow in direction of the revetment toe ( ).

For more than 10 years thick composite materials consisting of filter and coarse roughness layers have successfully been installed directly beneath the covering layer in revetment construction on German Waterways in order to avoid migrations of soil particles downslope. Two different solutions for the prevention of migration of soil particles downslope are indicated:

- reduction of the effective hydraulic gradients by the installation of a mineral filter layer on top of the geotextile (grain size and thickness suited to the covering layer giving a uniform stable load on the geotextile to avoid vibrations).
- stabilization of the soil horizont beneath the goetextile by coarse roughness layers with the following requirements according to the recommendations of WG 14 GSSMFE:

Table 1: requirements for stabilization layers

	grain section A	grain section B
effective opening size O_{90}	0,3 mm < O_{90} < 1,5 mm	0,5 mm < O_{90} < 2,0 mm
Thickness T (with 2 kN/m²)	7,5 mm < T < 15 mm	7,5 mm < T < 20 mm

Based on these different proposals the requirements illustrated in Fig. 6 for thickness and composition of different layers of the geotextiles can be formulated in revetment construction for bank protection. These requirements are necessary in addition to the normal filter technical design and other construction properties of the geotextile to be required for slope inclations between 1:2,5 and 1:5. In case of flater slopes the requirements can possibly be reduced whereas they have to be extended for steeper slopes.

Fig. 7 documentates which fatal consequences migration of soil particles beneath the geotextile can involve. This figure shows three different concrete block systems on a geotextile filter in test sections of each 60 m long at the Rim Canal of the Lake Okeechobee in Florida/USA

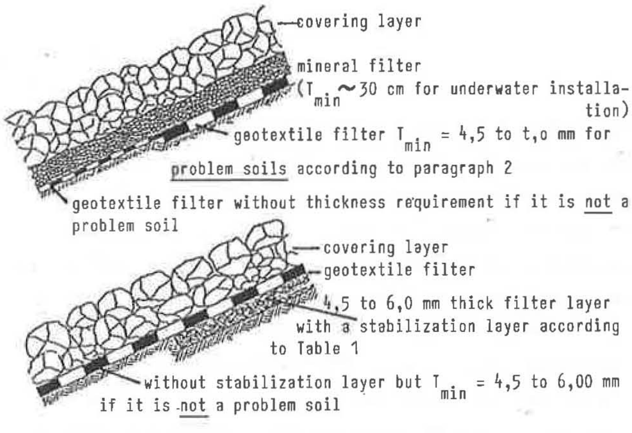
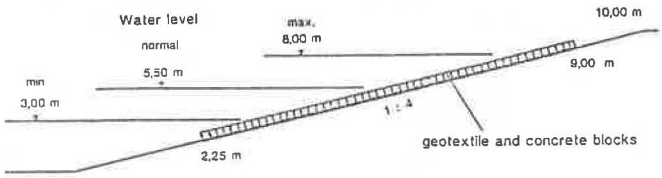


Fig. 6
Requirements for thickness and composition of different layers of geotextiles in revetments for bank protection with inclinations of 1:2,5 to 1:5



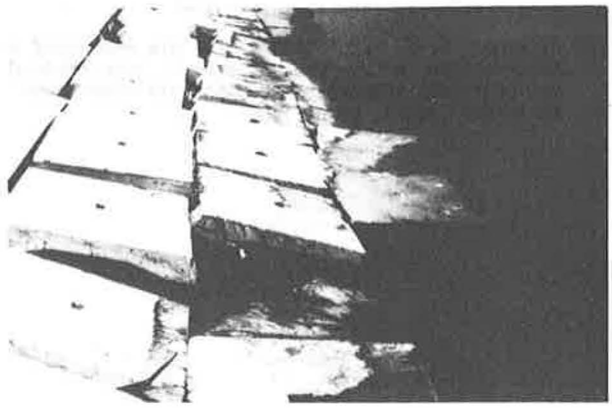
technical datas of the Lake Okeechobee test section

current velocity - neglectable

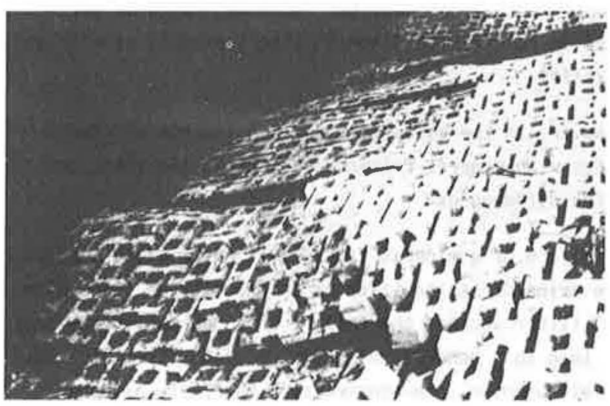
max. wave height by boating - 1,5 m

Cross-section of the Rim Canal Lake Okeechobee

A Terrafix revetment system



B Armormat revetment system



C Armorlock revetment system

Fig. 7: Revetment test sections at the Rim Canal Lake Okeechobee, Florida/USA. Cross-section and condition of the three test sections approx. 6 months after installation

only 6 months after their installation. The choice of the geotextile for the filtering purposes towards the existing sand (10% coarse silt < 0,06 mm, 45% fine sand < 0,2 mm, 25% medium sand < 0,6 mm as well as coarse sand < 2,0 mm and gravel < 10 mm each 10%) has been left to the offerer or the producer of the revetment system. For the revetment systems B and C woven fabrics have been applied which perfectly carry out the soil tightness towards the existing sandy soil, but which could not avoid soil movements beneath the geotextile downslope. This was attained, however, with the needlepunched nonwoven fabric applied under the system A . The applied fabric was approx. 4,0 mm thick and had a weight per unit area of about 400 g/m². By that, system A fulfils and confirms the requirements formulated in Fig. 6 (covering layer directly on the geotextile, no problem soil according to the criterias of paragraph 2--> 4,5 to 6,0 mm thick geotextiles). In the author's opinion the needlepunched nonwoven applied by system A already comes up to the lower justifiable limit and could only be recommended against the background of an inclined slope of 1:4 and the relatively unimportant stress by pleasure boat traffic.

Final remarks

It is not to be amazed that the complex filter problem cannot always be controlled by rules of thumb. This applies in a figurative sense also for mineral filters. However, these are normally - due to the conditions of soil engineering - installed in considerably thicker layers than necessary from the filter technical point of view (T_{min} 25 d_{50}) and by this they can include corresponding reserves. Filter technical failures will reveal in future with mineral filters as well as with geotextiles.

However, in the assessment and consequence of damage cases with mineral filters and geotextiles there are often differences:

A failure of a mineral filter will never cause a doubt on the principle suitability of a correctly designed mineral filter whereas the failure of a geotextile can easily lead to a general rejection of geotextiles as a relatively unknown, new construction material, although finally also just a design mistake has been done or the wrong product has been chosen. In such cases it would be important to recognize that an unsuitable product has been chosen or that the consultancy was insufficient but to be sure that there are geotextiles which would have fulfilled this filtering task. In case of doubt it should never be forgotten that the needlepunched fabric - singlelayer or multilayer - shows due to its thickness the greatest affinity to a mineral filter and that higher expenses for a superior geotextile filter can generally always be justified taking into account possible expenses resulting from a damage or failure.

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