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Design using geosynthetics —

Part 3: **Filtration**

Design pour géosynthétiques —

Partie 3: Filtration

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 221, *Geosynthetics*.

A list of all parts in the ISO/TR 18228 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The ISO/TR 18228 series provides guidance for designs using geosynthetics for soils and below ground structures in contact with natural soils, fills and asphalt. The series contains parts which cover designs using geosynthetics, including guidance for characterization of the materials to be used and other factors affecting the design and performance of the systems which are particular to each part, with ISO/TR 18228-1 providing general guidance relevant to the subsequent parts of the series.

The series is generally written in a limit state format and guidelines are provided in terms of partial material factors and load factors for various applications and design lives, where appropriate.

This document includes information relating to the filtration function. Details of design methodology adopted in a number of regions are provided. The characteristics of the geosynthetics and the test methods normally used to quantify the properties of the geosynthetics are described. Some regional specific rules and regulations that normally apply to designs using geosynthetics in these regions are also provided.

Design using geosynthetics —

Part 3:
Filtration

1 Scope

This document provides general considerations to support the design guidance to geotechnical and civil engineers involved in the design of structures in which a geotextile is used as a filter. The key potential failure mechanisms are described, and guidance is proposed to select engineering properties.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10318-1, *Geosynthetics — Part 1: Terms and definitions*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10318-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.2 Symbols

B, B_1, B_2	factors function of the application, soil properties and hydraulic conditions, used for the verification of the retention criteria of the soil skeleton
C	constant, used for the verification of the non-retention criteria of fines in suspension
C_u	coefficient of uniformity of the soil, defined as $C_\mathrm{u} = d_{60} / d_{10}$
d_{85}, d_{60}, d_{50}, d_{30} or d_{10}	diameters of particles for which 85 %, 60 %, 50 %, 30 % or 10 % of all soil particles are smaller (e.g. d_{85} = 200 μm means that 85 % of the soil particles are smaller than 200 μm)
d_I	indicative diameter of the soil, for retention criteria
d_J	indicative diameter of the soil, for non-retention criteria of fines in suspension
ΔH	water head used to measure the indicative velocity in the laboratory test, i.e. ΔH = 0,05 m

E constant, used for the verification of the permeability criteria

i_G hydraulic gradient prevailing immediately upstream of the geotextile (0 to 0,025 m away from the geotextile as in ASTM D5101)

i_s hydraulic gradient prevailing in the soil, in the vicinity of the geotextile filter

k_s permeability of the soil

m number of constrictions

V_F is the indicative velocity of the water passing through the filter, which is the flow rate divided by the total area of passage (apparent area) at a water head of ΔH = 0,05 m

Ψ permittivity, represents the volumetric flow rate of water per unit cross sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile

3.3 Abbreviated terms

BOD biological oxygen demand

COD chemical oxygen demand

COS characteristic opening size of a geotextile

PI plasticity index

POA percent open area

PVD prefabricated vertical drain

UV ultra-violet

4 Concepts and fundamental principles

4.1 General

Soils are porous media containing 20 % to 40 % voids in between soil particles, which are typically filled with gas such as air, liquid such as water, or both. Displacement of water within the voids of the soil generates a dragging force on each of the grains of the soil. When the grains are supported, e.g. by other grains, they stay in place and the water moves without disturbing the soil structure. However, if the grains of soil are not in contact with a solid that can offer a resisting force, internal erosion can develop: soil particles are dragged by the water until they reach an obstacle, or until they exit the soil structure.

Soil structures often include configurations where the water has to flow away from the soil, e.g. into a drain. To prevent internal erosion, a filter media can be installed, in order to offer a resisting force to the largest particles of the soil, called the soil skeleton, and to prevent it from being dragged away by the water. However, this filter media should not restrain the flow of water, in particular to avoid pore pressure build-up, which could also adversely affect the stability of the soil structure.

In geosynthetics, the filtration function is to stabilize the soil by maintaining in place the soil skeleton in contact with the geotextile surface and restrain uncontrolled passage of soil, while allowing the passage of water or other fluids and some of the finest particles transported in suspension across the filter. The geotextile filter can be thought of as a catalyst to create a natural granular filter in the thin soil layer in contact.

Filters may be installed at the interface with a water-transport media, e.g. soil with high permeability, drainage pipe, edge drain, drainboard, PVDs. They may also be installed between soil and rip-rap, gabions or product with the same function, for example for coastal protection, banks protections, in dams.

When the geotextiles are not covered with soil and laid alone, e.g. as silt fences, etc., the filtration behaviour is different: there is no soil skeleton to stabilize, the geotextile is intended to trap or screen all moving particles.

The performance of a filter may be qualified by its ability to fulfil the two contradictory functions required for filtration:

— prevent damages caused by the transport of an excessive quantity of particles from one side of the filter to the other (piping), such as internal erosion of the soil being filtered which could modify in its engineering properties, formation of cavities on the upstream side of the filter. Such damages also include excessive contamination of the structure located downstream by particles piped through the filter, e.g. blocking of a drainage pipe;

— minimize restriction to the flow of water passing through the filter, to avoid pore pressure build-up on the upstream side of the filter.

4.2 The filtration function of geotextiles

Long term performance of geotextile filters can be endangered by the blocking of the surface (blinding) or of the pores (clogging) of a soil or geotextile filter. These mechanisms can be caused by the accumulation of fine particles and development of a “cake” on the surface of the geotextile (blinding), or inside the geotextile structure (clogging), resulting in a drastic reduction of the permittivity of the filter.

In some cases, reduction of the capacity of the geotextile filter to let water pass across its plane might also be caused by the precipitation of chemicals, e.g. iron ochre, calcium, or the development of a biological activity. Evidences of clogging caused by the presence of air pockets trapped into, or in the vicinity of, the filter have also been observed.

These mechanisms suggest that the best performance for a filter is obtained when using a material which openings are small enough to stabilize the largest particles in contact (soil skeleton) but large enough to let pass the finest particles in suspension and to avoid internal erosion of the soil, and piping.

For both piping and clogging mechanisms, the parameter controlling the performance of a filter is the size of the voids through which particles of the soil are likely to travel at the surface or inside the geotextile. The filtration characteristics of a geotextile filter, such as opening size or permeability, are therefore crucial to its design. These properties need to be selected with consideration to the properties of the soil to be filtered and hydraulic conditions prevailing on a particular site.

Other parameters characterizing the structure of a geotextile have also been investigated, such as the pore size distribution (determined using ASTM D6767) or the number of constriction (determined using ASTM D7138). However, although there is a consensus regarding the fact these parameters can influence the filtration performance of a filter, they are still being investigated by the research community. Design guidance was still not available at the time this document was prepared.

Depending on their structure, some geotextiles can be compressed under load. Consequently, their permeability might decrease when compared to the property measured without load. This phenomenon was investigated. Some reliability issues were identified with the testing techniques and the impact of normal load found to be difficult to quantify. There is no consensus at the time this document was prepared regarding the need, nor the value, that should be used as a safety factor to be applied on the values of permeability without load to address this issue.

In some cases, account also needs to be taken of potential loading mechanisms, presence of iron ochre, potential biological activity, and mineralogy of the soil, which can all affect the long-term performance of the filter. For extreme situations, it might be necessary to use alternatives to geotextiles.

4.3 Filter selection fundamentals

A geotextile filter should be selected considering the following parameters:

- filtration performance: ability to retain the soil skeleton and to let the water pass perpendicularly to its plane, depending on the soil properties, i.e. grain size distribution, cohesion and permeability of the adjacent soils, and taking into account the type of pore water flow (turbulent, laminar);
- suspended solids concentration of the water to be filtered, property of the suspended particles when applicable;
- survivability, or capacity to resist the stress caused by installation and subsequent construction works;
- capacity to resist mechanical stresses encountered during its service, when applicable;
- durability, which includes resistance to the chemical environment in which it is installed; resistance to UV oxidation during construction or in service when applicable; and long-term durability;
- penetration of roots, anchorage of an overlying structure, or any other alien material likely to affect its continuity or its properties;
- location of the geotextile filter within the soil structure.

Most applications involve the seepage of water in a single direction, typically perpendicular to the plane of the geotextile filter. However, some applications involve bi-directional flow, cyclic flows, which involve significantly different hydraulic and/or mechanical stresses which are likely to affect the filtration performance of a geotextile.

Mechanical stress prevailing on the soil/geotextile interface might vary from one application to another. While many drainage and filtration applications involve static, constant loads, others such as bank protection can experience dynamic loading, which can affect the stability of the filter. For many roadway applications, the repetitive passage of trucks on a road generates dynamic stresses which are likely to affect the stability of the soil structure in the vicinity of the filter.

Geotextile filters are typically used to drain water but may also be used with leachate or other liquids from adjacent soils, waste, or other solid porous media, such as in landfill leachate collection systems. They are occasionally used to filter gases in soils, e.g. gas collection layers in landfills, or gas drainage layers installed beneath building basements.

5 Typical applications

5.1 General considerations

There are two key types of application of geotextile filters, which involve different filtration mechanisms, thus different approaches to design:

- filtration of soils, where the geotextile is in intimate contact with the soil. The water then moves within the soil matrix, and might drag the finest particles away depending on the equilibrium of each particle in contact at the geotextile surface;
- filtration of slurries or suspended particles, where each particle reaching the geotextile (or soil accumulated on the geotextile) is suspended in water.

Designing using one or the other approach might lead to the recommendation of different properties for the geotextile filter. Consequently, the long-term performance of the geotextile filter is first determined by the correct identification of the filtration mechanism actually involved. One impact might be the recommendation of preventive measures to ensure that a geotextile designed for soil filtration is not exposed to slurry filtration (i.e. include a requirement to backfill immediately after installation).

5.2 Soil filtration

Soil filtration typically involves the filtration/retention of compacted soils exposed to a flow of water, where an intimate contact between the soil and the geotextile is assumed. Examples of such situations include:

— drainage systems (buildings, agriculture, etc.);

— dams;

— PVDs;

— roadways;

— rail track bed;

— waterways/canals;

— coastal protection;

— landfills – leachate collection systems.

Soil filtration can also involve the separation/retention of soils exposed to the flow of gases, for example:

— protection against the intrusion in buildings of radon and other subsurface gases;

— gases collection layers in landfills.

5.3 Slurry filtration

Typical applications where the geotextile is designed to separate water from solid particles, where there is little or no particle-to-particle contact, include:

— filtration of slurries and dewatering applications;

— geocontainers;

— silt fences.

6 Materials

Geotextiles intended to perform as a filter for permanent applications are usually manufactured with polypropylene, polyester or polyethylene fibres. They may be woven, non-woven or knitted. Typical ranges of properties are given in this Clause, however, there are products on the market offering characteristics beyond the proposed limits, intended for use in specific applications. Manufacturers should be contacted for further details on their products.

Woven geotextiles may be either slit-films (Figure 1), monofilaments, multi-filaments or a combination thereof (Figure 2). They offer opening sizes varying between 0,05 mm and 2,0 mm, POA from 0,5 % and 40 %, and velocity index from 0,001 m/s to 1 m/s. Their construction may include multifilament polyester yarns, polypropylene or polyethylene tapes or strands.

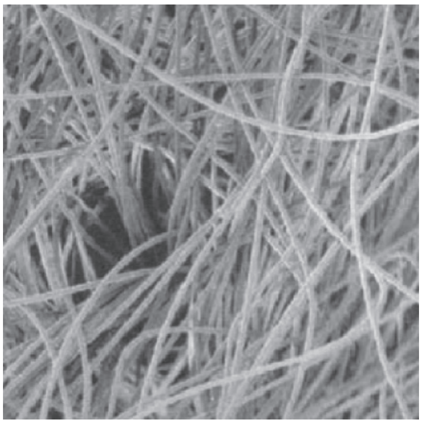
SOURCE: Reproduced with permission from Kaytech[31].

Figure 1 — Structure of a woven slit film geotextile

SOURCE: Reproduced with permission from CTT Group / Sageos[29].

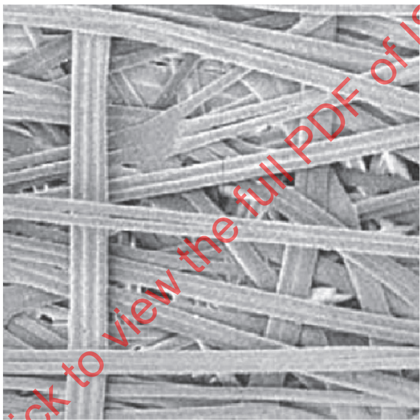
Figure 2 — Structure of a woven geotextile combining a tape and a monofilament

Non-woven geotextiles may be continuous filaments or staple fibres, with opening sizes varying between 0,05 mm and 0,5 mm, numbers of constrictions from 5 to 50, and velocity index from 0,005 m/s to 0,5 m/s. They are typically polypropylene or polyester fibres. They can be needle-punched (Figure 3) or heat-bonded (Figure 4).



SOURCE: Reproduced with permission from Kaytech[31].

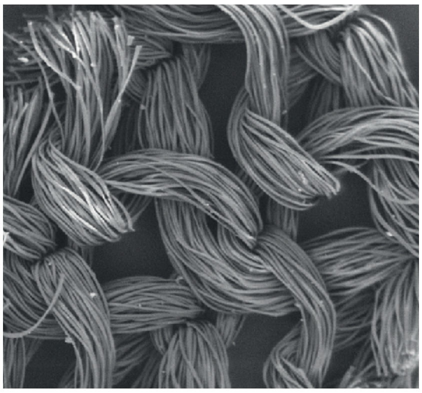
Figure 3 — Structure of a non-woven, needle-punched geotextile



SOURCE: Reproduced with permission from Kaytech[31].

Figure 4 — Structure of a non-woven, heat-bonded geotextile

Knitted geotextiles (Figure 5) are typically constructed using multifilament polyester yarns, to form a structure with opening size varying between 0,15 mm and 0,5 mm and velocity index from 0,05 m/s to 1 m/s.



SOURCE: Reproduced with permission from Geofabrics[30].

Figure 5 — Structure of a knitted geotextile

Woven and non-woven geotextiles are offered in rolls with widths varying typically between 1 m and 6 m or more. Knitted geotextiles are typically manufactured in a seam-free, tubular fashion, and are typically used as filters to envelope drainage pipes, up to 1,2 m in diameter, used in subsurface drainage applications.

Some manufacturers use lubricants in their manufacturing process. Traces of these lubricants might be found in the product. These lubricants can be hydrophobic or hydrophilic, which might affect the resistance to water penetration of the geotextile. These traces are typically washed out over time, but might affect positively or negatively the behaviour of geotextiles immediately after their installation. However, geotextiles are usually deep enough into the soil to keep a permanent moisture content, and this issue is typically no longer relevant once the geotextile has been installed and the flow of water initiated.

A variety of composite materials include geotextiles as a filter component. This includes:

— geogrid-geotextile components, where the geotextile is bonded on a geogrid to offer both a separation and a stabilization layer;

— drainage geocomposites, where a filter is bonded or otherwise attached to or around a drainage core, to offer a product capable of collecting and removing water from the soil.

In some cases, bonding of the geotextile filter on a core involves heating of both the core (e.g. a geonet or a dimpled sheet) and the geotextile to a temperature sufficient to achieve welding. This operation might affect the filtration properties of the geotextile.

Biological or chemical activity is known to affect the clogging potential of geotextiles, especially in environments which are prone to clogging, such as landfills. Some materials are treated to minimize the potential for biomass growth within their body, through the use of biocide treatments, such as with the use of silver nanoparticles, either as a secondary treatment, applied on the finished geotextile, or within the fibre itself.

7 Functional properties relevant to design

7.1 Characteristic opening size

The characteristic opening size of a geotextile is typically compared to a characteristic diameter of the soil to be filtered to assess the ability of the geotextile to perform well as a filter.

The characteristic opening size is typically measured using ISO 12956 (wet sieving) or ASTM D4751 (dry sieving). Other standards such as CGSB 148.1 no. 10 (hydrodynamic sieving) or ASTM D6767 (pore size distribution) may also be used. Results obtained with different standards might not compare, with differences as high as 100 % of the value assessed as the characteristic opening size in some cases. In case of discrepancies, the referee value should be the one obtained using ISO 12956.

Significant work is ongoing to improve the understanding of the bubble point/pore size distribution technique described in ASTM D6767, which develops a full pore size distribution of a geotextile instead of a single "characteristic" value. Better understanding of the influence of pore size distribution of the geotextile might change the approach to geotextile filter design in the future.

7.2 Velocity index and permittivity (permeability)

Permeability characteristics of a geotextile, i.e. velocity index or permittivity, are measured without load using ISO 11058 or ASTM D4491. Both techniques use a similar water head of 0,05 m to perform the measurement.

The velocity index of a geotextile, measured using ISO 11058, is the velocity of the water flowing through the geotextile under the prescribed water head of 0,05 m.

The permittivity is determined by dividing the velocity of the water by the water head, 0,05 m when evaluated using ASTM D4491. In contrast with the permeability of a soil, the permittivity describes the property of the full layer of the material, disregarding its thickness.

7.3 Resistance to water penetration

Resistance to water penetration is measured using ISO 811 or EN 13562. This property determines the water head needed to initiate a flow of water through a geotextile filter. The filtration function of a geotextile usually requires a resistance to water penetration as low as possible, typically zero, or less than 0,005 m or 0,01 m. However, a high resistance to water penetration is sometimes useful (e.g. for capillary breaks).

7.4 Number of constrictions

The number of constrictions "*m*" of a geotextile describes the theoretical number of obstacles that a particle can cross while travelling through the thickness of a non-woven geotextile filter. This property is measured using ASTM D7178.

According to the theory developed by J.P. Giroud[28], this property may be used to explain differences in filtration behaviour between two geotextiles exhibiting an identical characteristic opening size. According to this theory, the higher the number of constrictions, the higher the chances of piping; the lower the number of constrictions, the higher the chances of clogging inside the geotextile. However, there is currently no consensus on threshold values which could be considered for "*m*", nor on how this property actually affects the filtration behaviour of geotextile filters.

At least two issues limit the acceptance of this property. Firstly, it is assumed that the volumetric distribution of the fibres is uniform across the surface and thickness of the non-woven structure, which is typically not the case (see Figure 1 to Figure 5). Secondly, it is determined according to the precise number of fibres used (and distribution of fibres, when multiple types of fibre are used). This measurement can be very challenging for a non-woven geotextile, and even impossible for some structures, especially when the manufacturing details are unknown.

Although the influence of the number of constrictions on the filtration performance of geotextiles has been demonstrated by some researchers for particular applications[23],[27], other studies are questioning its relevance[25]. More research is needed to establish design criteria based on "*m*".

7.5 Percent open area

The POA is a property which can only be used to characterize woven geotextiles. It describes the percentage of their surface that is a "void", e.g. that is not a fibre, compared to the total surface. It is an optical method, where the surface of light passing through the openings is compared to the total surface using a microscope and image analysis software.

Although commonly used in the industry, the measurement of POA was not a registered test method at the time this document was prepared. The typical reference used for its determination is US Corps of engineers specification CW-02215[21].

Besides selection of characteristics which are directly related to the function of a geotextile filter, other characteristics should be specified to prevent damage during installation, for example the tensile strength and elongation, the resistance to abrasion, and the resistance to UV degradation.

8 Principles of design

8.1 General considerations

The various environmental conditions that might prevail during the service life of the geotextile as well as during its installation are considered in geotextile filtration design.

To perform as expected during the design, the soil in contact with the geotextile should be the soil considered in the design, and the properties of the geotextile should be those considered at the time the product was selected. To ensure this is the case, the geotextile should not present any physical damage at the time of installation and be backfilled as soon as possible, typically within two weeks, and before any environmental condition affects the soil and/or the geotextile properties. Typical examples of situations leading to an unexpected performance of a geotextile include:

— Water can run on the surface of a soil and erode it from its finer particles. These fine particles are carried in a suspension to the geotextile filter and might then be retained either inside its thickness or on its surface to develop a “cake” of very fine particles. This layer of very fine soil can affect the performance of a filter, up to the point where it could create an impervious layer on the surface of the filter.

— Bad contact between the geotextile surface and the soil to be filtered (e.g. folds) can create erosive water flow channels.

— Extended exposure of the geotextile filter to solar radiation or heat could oxidize the filter up to the point where its engineering property could be modified, e.g. its resistance to water penetration. Geotextiles filters which have been exposed for extended periods of time to UV or heat should not be used unless their performance has been assessed taking into account their condition at the time of installation.

— Some installation or operating conditions might damage the geotextile by abrasion, puncture or tearing, which are likely to modify the filtration properties of the geotextile or even to create open holes, which would result in the local absence of filter. This can eventually lead to situations where the filtration function would not be provided, with consequences to be assessed by the designer, e.g. internal erosion, contamination of the materials, and excessive piping in the drainage media.

Some environmental conditions are likely to generate clogging of the geotextile, as they would for any other filter material. These include:

— Presence of ferrous iron Fe^{2+} or manganese oxide (MnO_2) in the soil. These metals are likely to precipitate in the geotextile, and/or to be digested by bacteria such as Gallionella, Leptothrix, and Sphaerotilus among others, favour their growth. When the population of bacteria is large enough, they form a biofilm that is likely to clog the geotextile filter. There are no known, universal methods available to mitigate clogging of filters exposed to highly Ferrous environments. Researches and white papers were published suggesting maximum Fe^{2+} concentrations in the range of 3 ppm to 12 ppm, depending on the pH of the water.

— Presence of organic matter that can enhance microbiological activity and production of complexes and precipitates.

— Presence of high concentration of minerals in the water, likely to crystallize in the geotextile because of the evaporation of the water, a change in chemical environment in this location, or any other condition likely to favour crystallization of dissolved minerals.

Other environmental factors likely to affect the performance of a geotextile filter include:

— biological activity such as leachate collection layers in landfills. It is generally well accepted that geotextiles used in leachate collection systems will eventually clog, in particular because of their very small pore sizes which are likely to be clogged by organic material developing in the geotextile. It is generally well accepted that woven geotextiles exhibiting a high POA are likely to perform longer in these specific applications;

  NOTE When designing geotextile filters for landfill applications, the time over which the geotextile actually needs to perform well as a filtering media is considered. Factors influencing this can include the way the landfill is operated, i.e. how long will the cell be left exposed to rain without waste, thickness of the waste versus anticipated rainfalls, volumes of leachate generated, leachate recirculation, etc.

— suspended solids concentration of the water. When water exhibiting high solid contents is flowing through a geotextile, the suspended particles might end up being retained in the structure of the geotextile and reduce its permeability.

Many if not most applications of geotextiles involve relatively simple environmental conditions, where the concerns presented in the preceding list are not critical or can easily be handled. For these, the criteria presented below can be followed.

a) Step 1: Identification of the environmental conditions.

   1) Confirm that the geotextile is not exposed to any of the following:

      — biological activity, e.g. leachate filtration;

      — ferrous iron Fe^{2+} in excess of 3 ppm in the water;

      — high concentration of dissolved minerals in the water;

      — high concentration of suspended solids in the water;

      — installation and operating conditions are not likely to alter the properties of the geotextile filter on its entire surface.

      Designing with any of the above conditions is beyond the scope of this document. If any of these conditions not be met, the design method proposed herein may not apply. Consultation of a specialist (manufacturer, specialized consultant or laboratory) is strongly recommended.

   2) Assess if there will be intimate contact between the soil and the geotextile immediately after its installation and over its entire service life and no suspended particles can be carried by a liquid toward its surface:

      — yes: an intimate contact is ensured on the upstream side of the geotextile and no suspended particles can be transported by a liquid toward the geotextile: design the geotextile filter for soil filtration;

      — no: the geotextile filter is used for the filtration of a slurry or for the retention of suspended particles: design the geotextile filter for slurries filtration.

   3) Identify the soil properties:

      — particle size distribution: d_{85}, d_{60}, d_{50}, d_{30}, d_{10}. Calculate C_u as d_{60} divided by d_{10}. Assess whether the grain size distribution curve is gap graded;

      — for soil filtration: plasticity index (PI);

— for clay soil filtration: dispersivity.

b) Step 2: Designing the geotextile.

1) Retention criteria of the soil skeleton, use Formula 1:

$$\mathrm{COS} \leq B \times d_I \qquad (1)$$

where

COS is the characteristic opening size;

B is a factor function of the application, soil properties, and hydraulic conditions;

d_I is the indicative diameter of the soil, for retention criteria.

2) Non-retention criteria of fines in suspension, use Formula 2:

$$\mathrm{COS} \geq C \times d_J \qquad (2)$$

where

COS is the characteristic opening size;

C is a constant;

d_J is the indicative diameter of the soil, for non-retention criteria of fines in suspension.

3) Permeability criteria, use Formula 3:

$$V_F \geq E \times k_s \times i_s \qquad (3)$$

where

V_F is the indicative velocity of the water passing through the filter, which is the flow rate divided by the total area of passage (apparent area) at a water head of ΔH = 0,05 m;

E is a constant;

k_s is the permeability of the soil;

i_s is the hydraulic gradient prevailing in the soil, in the vicinity of the geotextile filter.

The permeability criteria may also be expressed considering the permittivity of the geotextile, which is defined by Formula 4:

$$\psi = V_F / \Delta H \qquad (4)$$

where

ψ is the permittivity, in s^{-1};

V_F is the indicative velocity of the water passing through the filter, in m/s;

ΔH is the water head used to measure the indicative velocity in the laboratory test, i.e. ΔH= 0,05 m.

The methods used for determining COS and d_I (and d_J) can vary depending on local construction or building codes and practices, and the value of COS is not the same if it is measured in accordance with ISO 12956, ASTM D4751, ASTM D6767 or another technique. Local experiences and practices might also influence the design parameters. As a consequence, the values associated with the criteria presented in the following sections are proposed as indications and should be confirmed with local authorities. They are based on the Canadian Foundation Manual[20].

c) Step 3: Additional properties.

The specification of a geotextile may be completed by additional properties such as resistance to water penetration and POA for woven geotextiles.

Specification of the number of constrictions is not common practice, as this property remains relatively controversial and its significance is only moderately supported by experimental data.

8.2 Designing geotextiles for soil filtration

8.2.1 General

These criteria apply to situations where there is always intimate contact between the upstream soil and the geotextile, such as in most buried drainage applications. The values B, C and E in Formulae 1, 2 and 3 are defined in the following sections.

NOTE These criteria are mostly based on the proposition of the Canadian Foundation Engineering Manual (CFEM) with some additions and further precision. Heibaum has also proposed an in-depth analysis of existing filtration criteria and proposes an approach that is similar to the CFEM. A characteristic opening size is defined based on the d_{50} of the simplified grain size distribution of the soil as well as the C_u.

The COS is typically the O_{90} of the geotextile, determined using ISO 12956.

8.2.2 Retention criteria of the soil skeleton

For steady state conditions with soils exhibiting less than 50 % of silt (d_{50} > 75 µm):

For Cu < 2	$B = 1$	and	$dI = d85$
For 2 ≤ Cu < 4	$B = 0{,}5 \times Cu$	and	$dI = d85$
For 4 ≤ Cu ≤ 8	$B = 8 / Cu$	and	$dI = d85$
For Cu > 8, and linearly graded soils:	$B = 1$	and	$dI = d50$
For Cu > 8, and concave upward gradation curves:	$B = 1$	and	$dI = d30$
For Cu > 8, and gap-graded gradation curves where DG is the minimum gap size	$B = 1$	and	$dI = dG$

For steady state conditions with soils exhibiting more than 50 % of silt (d_{50} < 75 µm)

For PI ≤ 5	$B = 1$	and	$dI = d85$,	and	COS ≤ 300 µm
For PI > 5 and a dispersivity ≥ 50 %	$B = 1$	and	$dI = d85$		
For PI > 5 and a dispersivity < 50 %	COS ≤ 80 µm				

The factor B may also be adjusted depending on hydraulic gradient, soil density and boundary conditions:

$$B = B_1 \times B_2$$

— B_1 = 0,6 in case of bidirectional flow;

— B_1 = 0,8 in case of hydraulic gradient $i > 5$;

— B_1 = 1 in case of hydraulic gradient $i \leq 5$;

— B_2 = 0,8 in case of unconfined soils;

— B_2 = 1,25 in case of dense and confined soils.

In the particular case of woven geotextile filtration of silty sands and silts, a maximum POA value of 8 % was proposed by Austin et al[22].

For turbulent or bidirectional flow conditions where a stable, self-filtering structure of the soil might not be able to develop (e.g. shore protection), d_{50} should be used instead of d_{85}.

8.2.3 Non-retention criteria of fines in suspension

For well-graded soils with $C_u > 3$:

For steady state conditions and low hydraulic gradients: $C = 3$ and $d_J = d_{15}$ (Formula 2).

The following exceptions apply.

When $d_{15} \geq 20$ µm, particles are less likely to be in suspension: COS ≥ 63 µm.

For dynamic/turbulent flow, the COS should be greater than 63 µm.

For $C_u \leq 3$, the risks of clogging are not significant. The COS should be selected according to the retention and permeability criteria only. The COS should remain relatively close to the value defined using the retention criteria.

In the particular case of woven geotextile filtration, minimum values of POA were proposed by Austin et al[22] as follows:

— coarse sands: POA > 4 %;

— fine, poorly graded sands: POA > 1,6 %;

— silty sands: POA > 0,5 %.

8.2.4 Permeability criteria

The value of E should be determined according to the risks and associated consequences of a pressure building up on the upstream side of the geotextile. The permeability of the geotextile should always be greater than the permeability of the soil.

— For high risks (e.g. dams): $E \geq 1000$.

— For low risks (e.g. low-rise geotechnical structures): $E \geq 100$.

— For very low risks (delaying the flow of water does not have any quantifiable impact on the stability of the structure): $E \geq 10$.

NOTE 1 There is no consensus on the need to address the impact of compressive stress on the permeability of a geotextile with an additional safety factor.

NOTE 2 As indicated in 7.1a), biological and chemical clogging are not addressed in this criteria.

8.3 Designing geotextiles for slurry and suspended solids filtration

This subclause addresses situations where solid particles, e.g. grains of soil, reach the geotextile in a suspended form, by design. This includes geocontainers, silt fences, sludges, and tailings filtration. Situations where the filtration of suspension is accidental are out of the scope of this subclause, e.g. particles eroded by water running on the surface of a naked soil, and accidentally reaching a geotextile filter which is part of a drainage system.

Filtration of suspended particles is usually associated with dewatering applications. The geotextile controls the velocity of water flowing through the slurry/geotextile system at the beginning of the process, when no particles are retained yet. As it starts to retain particles, a layer of densified slurry develops on the upstream side of the geotextile, which restrains the velocity of water. The performance of geotextiles in slurry filtration applications thus closely depends on the permeability of the densified slurry, e.g. its particle size distribution, and on the kinetic of the clogging and/or blinding mechanism.

To maximize the long term performance of a slurry filtration system, common strategies are either to use techniques to increase the “apparent” diameter of the particle, such as adding flocculent in very fine grained slurries (e.g. tailings), and/or to periodically clean the surface of the geotextile to reduce the thickness of the cake that builds up on its upstream side. Efficiency of these techniques is always product- and application-specific. It is strongly recommended that specialist advice be obtained, e.g. from a manufacturer, specialized consultant or laboratory.

Geotextile filters for dewatering applications are usually designed using an experimental approach, with performance testing. This may include the “hanging bag” test (ASTM D7701), the closed bag test (ASTM D7780), or other performance tests as recommended by the manufacturer of the geotextile being used.

9 Testing the soil/geotextile filtration compatibility

9.1 General

There are several tests available to evaluate the compatibility of a geotextile with a given soil in given sets of conditions. These are described in this clause.

9.2 Soil/geotextile compatibility

9.2.1 Gradient ratio

The “gradient ratio” test (ASTM D5101) was designed to evaluate the compatibility of geotextiles with sandy soils. A 0,1 m thick specimen of the soil is installed on top of a geotextile candidate. Hydraulic gradients of 1, 5 and 10 are applied on the soil/geotextile system. Water heads are recorded over time at a distance of 0,025 m and 0,075 m as well as above and below the tested system. The permeability of the system is also recorded over time. As an option, the quantity of soil passing through the geotextile during installation, or after some flow has occurred, can also be observed.

The “gradient ratio” is determined by dividing two hydraulic gradients: i_G, the hydraulic gradient prevailing immediately upstream of the geotextile (0 to 0,025 m away from the geotextile as in ASTM D5101), and i_S, measured in the soil without influence of the geotextile, at a distance of 0,025 m to 0,075 m away from the geotextile. If the geotextile has no impact at all on the soil structure in the vicinity of the geotextile, then i_G should be similar to i_S. However, if the geotextile becomes clogged or blinded, pore pressure can develop next to the geotextile. The gradient i_G thus increases, while i_S decreases. The value of gradient ratio thus increases. A maximum value of 3,0 has historically been considered acceptable for gradient ratio. The observed tendency (upward or downward) may also be used to assess the system behaviour, especially if the type of soil tested is likely to influence the initial distribution of the hydraulic gradients, thus the value of gradient ratio, disregarding the filtration behaviour of the soil/geotextile system.

The evolution of permeability of the system is observed. If clogging occurs, the permeability decreases.

When measured, the mass of soil passing through the geotextile may be used to evaluate the piping potential.

Modified versions of ASTM D5101 were developed by Fannin [26] as well as Daqoune [24], to observe the behaviour of soil/geotextile systems exposed to cyclic flows and/or dynamic loading.

9.2.2 Hydraulic conductivity ratio

The hydraulic conductivity ratio (ASTM D5567) is intended to evaluate the compatibility of fine-grained soils with geotextiles. The test is conducted in a flexible wall permeameter.

The soil/geotextile system is saturated and consolidated. The hydraulic conductivity of the soil/geotextile specimen is then recorded as a function of time and of volume of water passing through the specimen.

The hydraulic conductivity ratio is the ratio between the hydraulic conductivity measured at any time during the test versus the initial conductivity. Clogging of a soil/geotextile system can be detected by a significant decrease of hydraulic conductivity ratio.

9.2.3 Retention performance of geotextiles exposed to turbulent flow conditions

ISO 10772 simulates the exposure of geotextiles to turbulent conditions such as those occurring during the wave action, passage of a ship, etc. in coastal applications. The filtration stability of the geotextile is determined by measuring the amount and rate of soil passing through the geotextile during the test.

9.3 Evaluation of slurry/geotextile behaviour

The tests described in this subclause are typically used for the design of geocontainers. These products are typically used for the dewatering of sludges and might not apply to other applications where geotextiles are used for the filtration of slurries or water containing suspended particles, e.g. filtration dikes.

These test methods may be used to assess the quantity of fine-grained dredged material sediment that might pass through the geotextile container into the environment. They are intended for evaluation of a specific material, as the result depends on the specific high water content slurry and geotextile evaluated and the location of the geotextile container below or above water.

The hanging bag test (ASTM D7701) is used to determine the flow rate of water and suspended solids through a geosynthetic permeable bag used to contain high water content slurry such as dredged material. The results for the water and sediment that pass through the geotextile bag are shown as litres of water per time period, and the percent total suspended solids in milligrams per litre or parts per million. The flow rate is the average rate of passage of a quantity of solids and water through the bag over a specific time period.

The closed bag test (ASTM D7880) is used to determine the flow rate of water and suspended solids through a geosynthetic permeable closed bag used to contain high water content slurry such as dredged material. The results for the water and sediment that pass through the geotextile bag are shown as litres of water per time period, and the percent total suspended solids in milligrams per litre or parts per million. The flow rate is the average rate of passage of a quantity of solids and water through the bag over a specific time period.

9.4 Biological or chemical clogging potential

The resistance of a particular geotextile to biological clogging in presence of a particular liquid (e.g. leachate) may be assessed using ASTM D1987. This test has predominantly been used to assess the behaviour of geotextiles in presence of leachates generated by municipal solid wastes.

A sample of geotextile is installed in a column and the candidate liquid is circulated through it. Flow rate under a given set of conditions is measured periodically to observe the evolution of the flow capability of the candidate geotextile with time and/or volume of liquid percolated.

This test may also be used to assess the performance of cleaning or back-flushing techniques.

The conditions prevailing in the service life of the geotextile should be well defined and precisely modelled in the test. Such test conditions include temperature, aerobic/anaerobic environment, nature of the mineral layer, BOD and COD of the liquid, etc. These should be as representative as possible of the

