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Determination of long-term flow of geosynthetic drains

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Foreword

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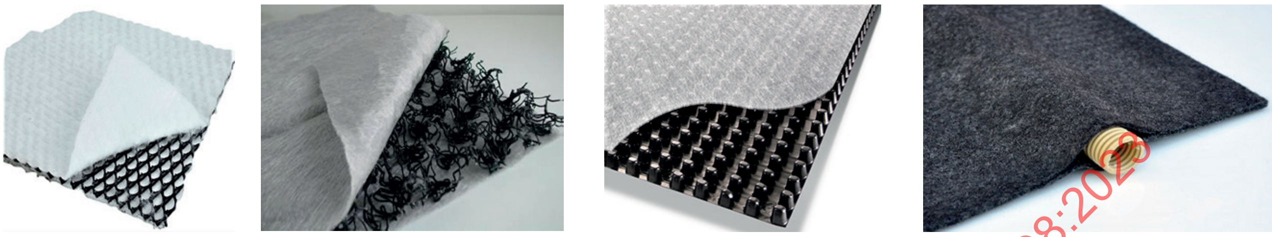
This document was prepared by Technical Committee ISO/TC 221, *Geosynthetics.*

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 most commonly used drainage geosynthetics are the geocomposites which are produced by laminating one or two geotextiles, with a filter function, onto a drainage core. Examples are included in Figure 1.



a) Geonet core b) Geomat core c) Cuspated core d) Perforated tube core

Figure 1 — Examples of drainage cores

The components generally have the following characteristics under operating conditions:

— filtering component:

  — adequate permeability to gases and liquids in the direction perpendicular to the filter plane;

  — retention capacity of the soil particles;

— drainage core:

  — adequate permeability to gases and liquids in the direction planar to the drainage structure;

  — adequate compressive strength and creep resistance for the loads to be applied.

The geocomposites are often defined by the drainage cores: geomats (GMA), geonets (GNT), geospacers (GSP), multi-linear drains.

Determination of long-term flow of geosynthetic drains

1 Scope

This document specifies methods of deriving reduction factors for geosynthetic drainage materials to account for intrusion of filter geotextiles, compression creep, and chemical and biological degradation. It is intended to provide a link between the test data and the codes for design with geosynthetic drains.

The geosynthetics covered include those whose primary purpose is planar drainage, such as geonets, cuspated cores only, or cuspated cores combined with laminated filter geotextiles, and drainage liners, where the drainage core is made from polypropylene and high-density polyethylene. The majority of geosynthetic drains are geocomposites with geotextiles laminated to a drainage core and it is important, where possible, to consider the drainage behaviour of the geocomposite as a whole rather than the behaviour of the component parts in isolation.

This document does not cover the strength of overlaps or joints between geosynthetic drains nor whether these might be more or less durable than the basic material. It does not apply to geomembranes, for example, in landfills. It does not cover the effects of dynamic loading nor any change in mechanical properties due to soil temperatures below 0 °C, or the effects of frozen soil. This document does not cover uncertainty in the design of the drainage structures, nor the human or economic consequences of failure. Design guidance for geosynthetic drains is found in ISO/TR 18228-4.

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 and definitions

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

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

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

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

4 Test equipment and procedures for determination of short-term in- plane water flow

4.1 Measurement of maximum hydraulic transmissivity and flow rate

The primary function of geosynthetic drains is to convey or transmit fluid within the flow direction(s) of a drainage layer. The discharge capacity can be given in terms of:

— Specific flow rate, which is the discharge per unit width in the geosynthetic drain, under a specified hydraulic gradient, as per Formula (1):

$$Q = q / B \quad (1)$$

Some users of flow tests desire to index the discharge rate per unit width to the applied hydraulic energy or hydraulic gradient at which flow is measured. In this case:

— Hydraulic transmissivity, which is the discharge per unit width of the geocomposite and per unit of hydraulic gradient, as per Formula (2):

$$\theta = (q\ /\ B)\ /\ i \tag{2}$$

The concepts of transmissivity and flow capacity were developed specifically to avoid consideration of the thickness as it is often difficult to specifically define the thickness of a geosynthetic drain in application.

Transmissivity is equal to flow rate only at a gradient of 1. Note also that the numerical value of transmissivity can be very different than the numerical value of the specific flow rate at small hydraulic gradients (e.g. at i = 0,1 transmissivity is 10 times the specific flow rate).

The discharge capacity test for a geosynthetic drain is performed in accordance with ISO 12958-1, ISO 12958-2 or ASTM D4716.

4.2 Test equipment

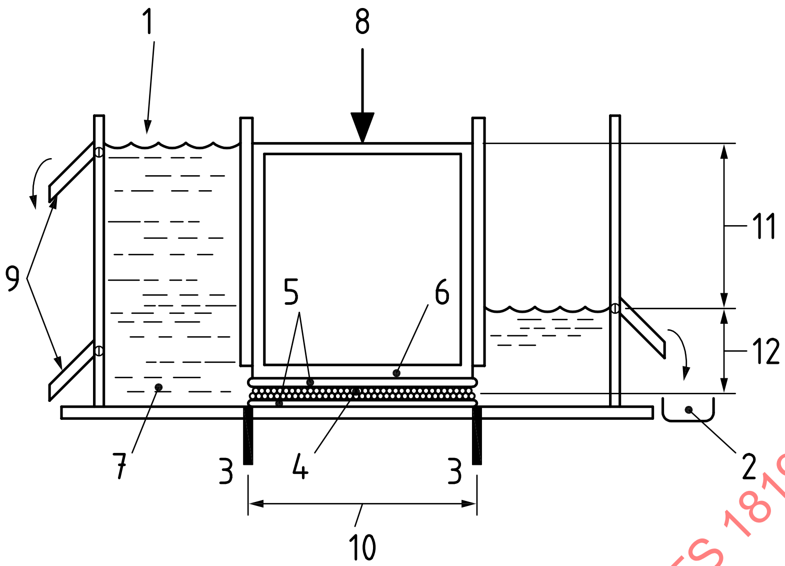
4.2.1 Unidirectional flow

The apparatus for these test methods are relatively simplistic in their design and ability to measure a discharge capacity or flow rate per unit width or transmissivity (Figure 2). By maintaining a constant head during the test, at a given normal stress, boundary conditions, and seating time, the flow rate Q of the geosynthetic drain can be determined using Formula (3):

$$Q_{\sigma,i,t,b} = \frac{q}{B} \cdot R_T \tag{3}$$

Where

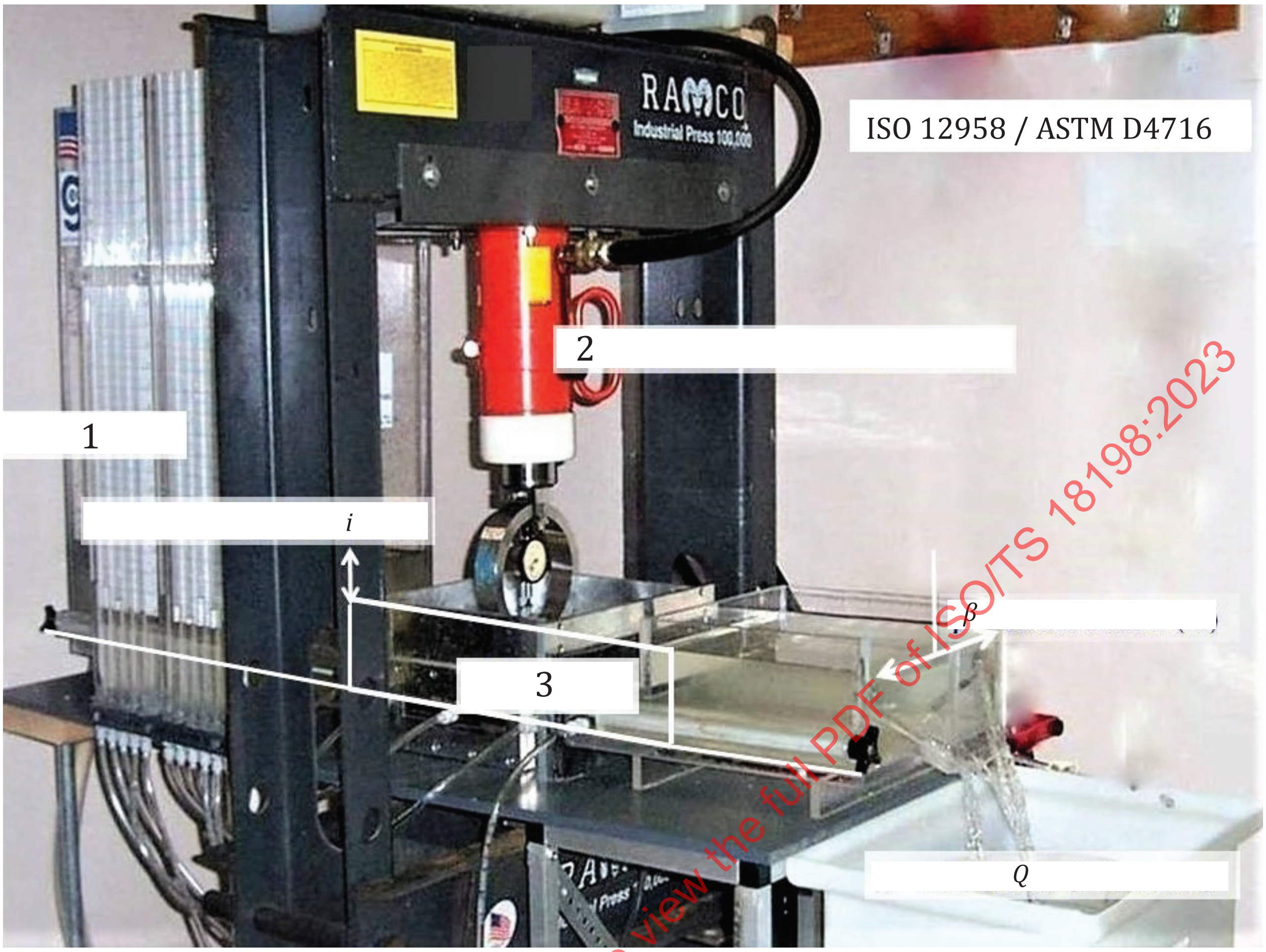
$Q_{\sigma,\mathrm{i,t,b}}$	is the numerical value of the in-plane water flow capacity per unit width at a defined stress σ, gradient i, seating time under load prior to flow measurement t and boundary conditions b, [l/(m·s)]
q	is the numerical value of the discharge capacity for a geosynthetic drain of width B measured in the test (l/s);
B	is the numerical value of width of flow (m)
R_T	is the numerical value of the correction factor converting to a test temperature of 20 °C.



Key

1	water supply
2	water collection
3	upstream water head manometers / piezometers
4	specimen
5	material used as boundary (e.g. soil)
6	loading platen
7	water reservoir
8	normal compressive load
9	overflow weirs
10	effective flow length (≥ 300 mm)
11	water head of discharge
12	downstream water head (≤ 100 mm)

Figure 2 — Example of test apparatus in horizontal test configuration



Key

1 manometers

2 normal compressive loading ram

3 test box

i *H*/*L* = Hydraulic gradient

β width of flow (m)

Q rate of flow (m^3/sec-m)

Figure 3 — Example of test equipment for water flow capacity of planar drainage geosynthetic

The test equipment shown in Figure 3 has the ability of constructing specific design cross-sections within the apparatus and then applying the required load(s) to the product, for which the geosynthetic drain shall perform in the proposed design. The normal load is applied vertically across the entire sample cross-section, typically by a pneumatic bladder or loading piston. The hydraulic gradient for the test is set by adjusting the hydraulic head *H* prior to the start of the test.

While sharing a number of common technical features for measuring flow, a specific flow capacity test as performed may differ slightly in testing details and prescribed procedural approaches. Depending on which manner a test is performed, the resulting data may be either of “index” type suitable for use in manufacturing quality control (see ISO 12958-1 or ASTM D4716), or of a “performance” type suitable for use in design and performance verification (see ISO 12958-2 or ASTM D4716). ISO 12958-1 prescribes flow measurements at predetermined hydraulic gradients and normal compressive stresses, as well as standardized superstratum and substratum (closed cell foam materials or rigid boundaries). The procedures in ISO 12958-2 and ASTM D4716, instead, invite the user of the test to determine all of the test parameters specific to the designed drainage application. For performance testing, as an example, the following test parameters or variables should be specified so as to represent anticipated or site-specific conditions such as: compressive load, hydraulic gradient, temperature, site-specific superstratum, site-specific substratum, and seating time prior to flow measurement.

4.2.2 Index and performance tests

Manufacturers typically quantify the relative capacity of their geosynthetic drainage products via index testing and document this performance on marketing documents and material data sheets. However, manufacturer's testing often reflects the flow rates of the product tested between two rigid plates, or standardized closed cell foam pads, under a specific load and gradient, and with a limited seating time (i.e. 15 min, 1 h, etc.). Thus, the manufacturer's data typically represents the short-term flow capacity for the product and serves to confirm production quality control.

To approach an understanding of the performance-related flow capacity of the geosynthetic drain it shall be tested using test parameters representative of field service conditions. Testing to provide an estimate of performance flow is described in ISO 12958-2 and ASTM D4716.

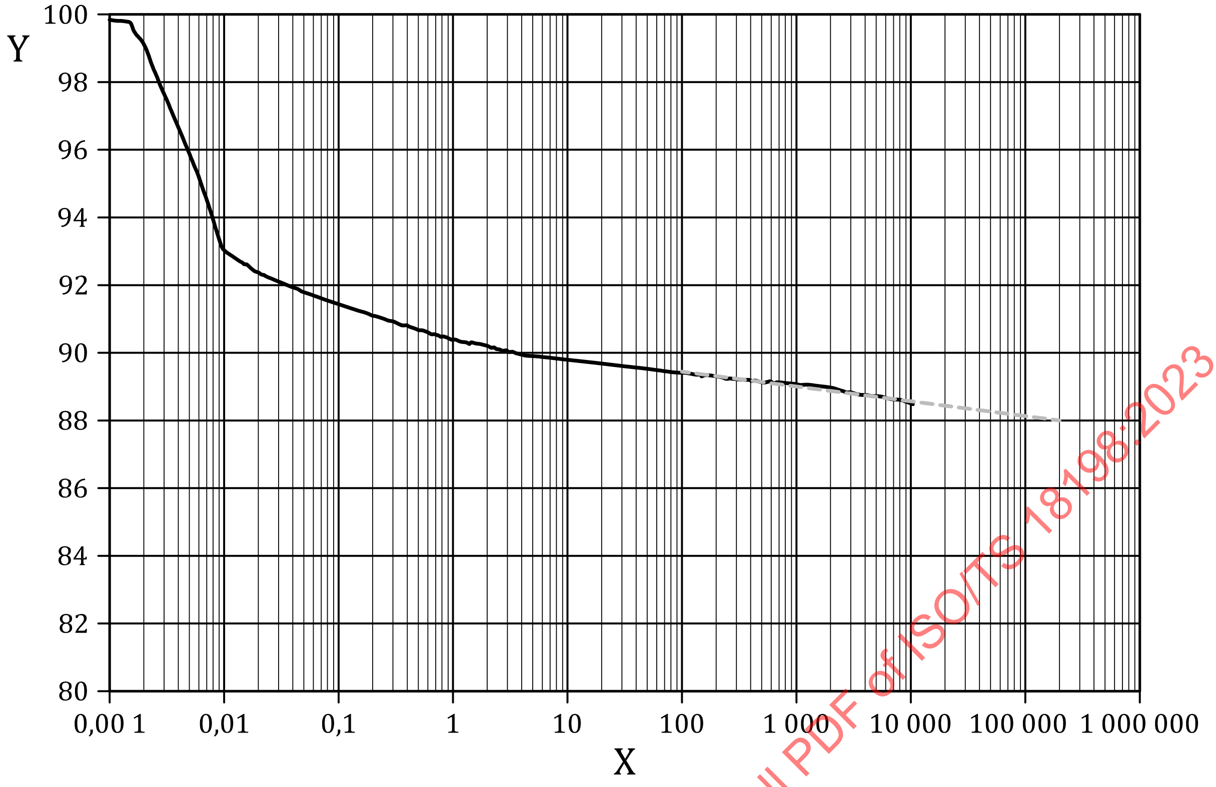
A performance flow test should allow materials above and below the geosynthetic drain to intrude into the void space of the product under compressive load to simulate real project conditions. Sand, for example, placed above the drain and loaded to design conditions will cause the upper filter geotextile to elongate and intrude into the space between each parallel strand of a geonet or the cusps of the cuspated core. The degree of intrusion has a direct relationship to the structural properties and bonding/no bonding and type of bonding (to the core) of the geotextile specified for the drain core and the amount of normal load applied to the design cross-section. Please note that the design engineer will need to supply the testing laboratory with a sufficient volume of representative soil sample to perform the number of required tests. The compaction requirements for the soil shall also be specified in order to set-up the test section to reflect the design conditions. If a geosynthetic clay liner is adjacent to the geosynthetic drain, the degree of saturation shall be specified along with the load at hydration, prior to placement of the normal load on the design cross-section test sample.

The ISO 12958-1 test procedure defines closed-cell foam materials meeting specific compressibility characteristics to simulate these field conditions. These "soft" superstratum and substratum materials assist in replicating test conditions and also avoiding contamination of test water with site-specific soils. Use of these standardized superstratum and substratum also enable manufacturers to publish like-data on their drainage products for product comparison while providing their own estimate of performance flow. ISO 12958-2 and ASTM D4716 allow use of site representative soils and other materials to more closely replicate field conditions.

4.3 Normal compressive loading and seating time

For performance testing, the normal stress used during testing should be equal to the maximum overburden pressure the material may experience during its service life. The practice of specifying a test pressure higher than anticipated field pressure is conservative when following the most common design procedures. Any uncertainties associated with long-term flow performance under load may be accounted through a factor of safety rather than a higher than expected normal pressure.

Most geosynthetic drains are constructed of polymeric material, which can deform under load and over time. This gradual deformation of the polymeric structure under a fixed load is known as "creep." The rate of ductile movement occurs rapidly initially (primary creep) and decreases overtime (secondary creep).



Key

X log time (h)

Y percent retained thickness

Figure 4 — Example of compressive creep curve for a drainage core

As compressive creep proceeds the thickness of the geosynthetic drain reduces; thereby reducing the porosity or available cavity through which the liquid can move through the product. The amount of thickness reduction is dependent on the compressive load placed on the product and the physical composition and structure of the geosynthetic drain, and time. Figure 4 illustrates the typical behaviour of a geosynthetic drain core, for which often (but not always), the majority of the creep will occur over the first 100 h after the design load is applied.

The requirement of the 100 h seating time can be a difficult burden for the geosynthetic testing community, requiring dedicated test apparatus for over four days prior to performing the test. Those requiring the 100 h seating time may allocate a sufficient testing period prior to the start of the construction project in order to obtain the conformance test results. The testing period for flow capacity verification might be significant for large projects where numerous conformance tests may be required.

4.4 Number of test specimens per sample per test

The ISO 12958-1 test requires flow measurements of three test specimens in both the machine and cross-machine direction be measured. ASTM D4716 requires the testing of two specimens per sample in the engineered flow direction to take account of manufacturing variation. Due to how a product is manufactured, this is an important requirement to obtain an acceptable representation for the reported test result. Processing parameters and manufacturing settings can have significant impact on drainage product flow rate capacity and how consistent this capacity is throughout the product structure. The test requirement for two or three specimens per sample attempts to average the variability in thickness and porosity of the product. While less of a concern for cuspated cores and prefabricated vertical drains, this variability should be captured in flow testing of all geosynthetic drains.

4.5 Hydraulic gradient

The flow rate of a geosynthetic drain is proportional to the hydraulic gradient *i* which is defined as in Formula (4):

$$i = \delta_h / L \qquad (4)$$

where

δ_h is the numerical value of the hydraulic head loss along the distance L for the fluid flow in the geosynthetic (m);

L is the numerical value of the distance between two points along the average direction of flow in the geosynthetic (m).

Performance oriented flow capacity tests of geosynthetic drains should be performed using a hydraulic gradient equal to or slightly smaller than sin β where β is equal to the slope angle of the geosynthetic drain with the horizontal. It is not conservative to test at higher gradients. Note that transmissivity or specific flow rate is a non-linear function of gradient because the flow regime with water in a geosynthetic drain is typically turbulent.

When performing an in-plane flow capacity test using a hydraulic gradient of 0,1 or less, it may be challenging to ensure the accuracy of the hydraulic gradient using open pipe manometers . These lower gradients are best established with the aid of accurate digital pressure gauges that enable confirmation of gradients as low as 0,01.

An alternative approach to measuring flow rates at very low gradients involves measuring flows at several higher gradients (for example gradients at 0,1, 0,25, 0,5 and 1) so as to develop an empirical relationship between flow rate and hydraulic gradient. The relationship between flow rate and gradient, at given applied pressure, boundary conditions and seating time, is usually as per Formula (5):

$$Q = a \cdot i^n \qquad (5)$$

where:

Q is the numerical value of the flow rate (m^2/sec);

a is the numerical value of the constant equal to the flow rate at unit gradient (m^2/sec);

i is the numerical value of the gradient (dimensionless); and

n is the numerical value of the constant (dimensionless).

Formula (5) has been verified by performing a number of tests on various materials under different test conditions. Constants *a* and *n* depend on type of geosynthetic drain, boundary conditions, normal stress, and test duration.

NOTE The use of this equation for very low gradients can be used with caution as other phenomenon can interfere with the actual field performance of the product, such as the contact angle between water and the polymer(s) used to manufacture the geosynthetic drain.

5 Determination of long-term flow performance

5.1 General

A design service lifetime, t_D, is defined for the drainage structure. For civil engineering structures such as roads and containment facilities, this service life is typically 50 years to 100 years. Some applications may require shorter service lives, such as sports fields (20 years to 50 years) or mining heap leach pad (5 years to 50 years). Additionally, some applications may have service lives lasting 1 year to 5 years.

All of these durations are too long for direct measurements to be made in advance of construction. There are, therefore, various considerations which may be modelled as reduction factors to short-term flow measurements which account for the time dependent changes in product performance likely to occur during service life.

Assessing the long-term flow performance of a geosynthetic drain consists in the comparison of the required flow rate q_{reqd}, determined by the application, and the allowable flow rate for the particular product used in a particular service environment for a defined service life Q_a. A factor of safety F_S can be determined as per Formula (6):

$$F_S = Q_a / q_{reqd} \tag{6}$$

The application of a series of reduction factors applied to the initial flow property of the geosynthetic drain incorporates the consideration of potential causes of reduction of the water flow. In this way an effort is made to ensure that the geosynthetic drain will always have a flow capacity equal to or in excess of the requirements associated to a particular application.

Because there are a variety of geosynthetic drain product types having a variety of different structures and compositions, the application of any specific reduction factor for the determination of long-term flow may be minimal in assigned magnitude, or inappropriate for the given application. For example, the time-dependent compressive creep resistance of a single nonwoven geotextile is negligible as ductile compression under compressive load generally happens readily and with little or no time-dependent resistance. Therefore, a reduction factor associated with time dependent creep may not be appropriately applied to a relatively long (e.g. 100 h) flow test.

On the other hand, the determination of long-term flow performance of a prefabricated vertical drain in a relatively short service life in a swamp wetland dewatering application would be wise to consider potential reductions of flow caused by biological clogging as applied to short terms flows measured in the crimped configuration.

ISO/TR 18228-4 provides precise guidance on how to establish q_{reqd}.

5.2 Reduction factors (R_F)

According to ISO/TR 18228-4, the allowable flow rate is given by Formula (7):

$$Q_a = Q_L / R_F \tag{7}$$

where:

$$R_F = R_{F,in} \cdot R_{F,cr\text{-}Q} \cdot R_{F,cc} \cdot R_{F,bc} \cdot R_{F,L} \tag{8}$$

Q_a is the numerical value of the available long-term flow rate for the geosynthetic drain (l/s/m or m^2/s). The long-term planar flow rate that will not result in failure of the geosynthetic drain during the required design life, calculated on a flow rate per unit of drain width basis;

Q_L is the numerical value of the short-term flow rate of the geosynthetic drain from hydraulic flow tests using site-specific test conditions, i.e. compressive stress, hydraulic gradient, seating time and boundary conditions l/s/m or m^2/s);

R_F is the numerical value of a combined reduction factor to account for potential long-term reduction of flow due to creep-induced thickness reduction, intrusion of adjacent materials (example: geotextile), and particulate, chemical and biological clogging;

$R_{F,in}$ is the numerical value of the reduction factor for the intrusion of filter geotextiles into the draining core due to tensile creep of the gtx, occurring after the short term test (dimensionless);

$R_{F,cr\text{-}Q}$ is the numerical value of the reduction factor for the compressive creep of the geocomposite (dimensionless);

$R_{F,cc}$ is the numerical value of the reduction factor for chemical clogging of the draining core (dimensionless);

$R_{F,bc}$ is the numerical value of the reduction factor for biological clogging of the draining core (dimensionless);

$R_{F,L}$ is the numerical value of the reduction factor for overall uncertainties on laboratory data and field conditions (dimensionless).

NOTE The designer can apply an additional reduction factor $R_{F,L}$ for overall uncertainties associated with laboratory testing and actual field conditions being simulated, or set $R_{F,L}$ = 1,0 and set a minimum value for the factor of safety F_S.

Note that, in Formulae (7) and (8), both $R_{F,in}$ and $R_{F,cr\text{-}Q}$ have to be evaluated starting from Q_L, that is from the short term flow rate obtained from laboratory tests with the appropriate boundary conditions.

The ASTM D7931 guide is applicable to all types of drainage geocomposites regardless of their core configuration or geotextile type. This guide is focused on determination of a q_{allow} value using the following Formula (9):

$$q_{allow} = q_{100}\left[\frac{1}{R_{F,CR} \times R_{F,CC} \times R_{F,BC} \times R_{F,GI}}\right] \qquad (9)$$

where:

q_{allow} is the numerical value of the allowable flow rate for a drainage geocomposite,

q_{100} is the numerical value of the initial flow rate determined under simulated conditions for 100 h duration,

$R_{F,CR}$ is the numerical value of the reduction factor for creep to account for long-term behaviour,

$R_{F,CC}$ is the numerical value of the reduction factor for chemical clogging,

$R_{F,BC}$ is the numerical value of the reduction factor for biological clogging, and

$R_{F,GI}$ is the numerical value of the reduction factor for geotextile intrusion past the initial 100-h seating time.

For a given drainage geocomposite product, one measures the 100 h duration flow rate according to ASTM D4716. This establishes the base value to which draining core creep beyond 100 h, and geotextile intrusion shall be accounted for. It is recognized that the default duration listed in Test Method D4716 is 15 min. The ASTM D7931 guide purposely requires that the test conditions be maintained for 100 h prior to measurement of flow, while simulating site-specific loading and boundary conditions.

5.3 Reduction factor for intrusion ($R_{F,in}$ and $R_{F,GI}$)

When the boundary conditions of the project are both rigid, intrusion cannot occur, neither at short term nor at long term: hence with both rigid boundary conditions, it shall be $R_{F,in} = R_{F,GI} = 1,0$.

When the short-term flow rate test is performed using site-specific boundary conditions, i.e. soil, $R_{F,in}$ or $R_{F,GI}$ is equal to 1,0 at short term. Intrusion can continue over time if one or both the boundaries are soft, i.e. soil, hence at long term it will be $R_{F,in} > 1,0$ and $R_{F,GI} > 1,0$.

Hence this reduction factor is intended to account for the effect on flow rate from the intrusion of flexible boundary materials into the voids of a particular geosynthetic drain, after the short term intrusion has already occurred during the flow rate test. $R_{F,in}$ and $R_{F,GI}$ depend primarily on the type of materials in contact with the two faces of the geosynthetic drain and the applied normal compressive load. Moreover, the intrusion depends on the structural and physical characteristics of the geotextiles and/or other material bonded or adjacent to the geosynthetic drainage core.

It is evident that a very rigid material (concrete walls, HDPE geomembrane in landfills, etc.) will compress the geocomposite very evenly, imparting a homogeneous decrease in its thickness but with very limited or no geotextile intrusion into the cavities of the draining core. Hence rigid materials produce negligible geotextile intrusion into the core. Conversely, a soft material (like a soil) in contact with the geocomposite will deform the geotextile, forcing the geotextile to intrude into the draining core with a resulting reduction in the cross-sectional area of the draining core and associated decrease of the flow capacity. Therefore, the reduction factor for geotextile intrusion will be a function of:

— thickness of the geocomposite;

— distance between the support points of the geotextile filter;

— pressure on the filter;

— strength, modulus and tensile creep of the geotextile filter;

— deformability of the material in contact with the geocomposite; and

— roughness of the geotextile filter.

Detailed guidance for the selection of appropriate intrusion reduction factors are found in ISO/TR 18228-4 for drainage. Site-specific factors may be determined where a performance test is carried out using the actual site-specific superstratum and substratum materials for a given application.

While the ASTM D7931 guide references a table of suggested $R_{F,GI}$ values via Koerner[13], ISO 12958-1:2020, Annex B presents a procedure that is used for evaluating the reduction factor for the intrusion of filter geotextiles into the draining core, where $R_{F,in}$ represents the effect on flow rate of geotextile intrusion after the initial intrusion in the short term flow rate test. It is recommended to fully evaluate $R_{F,in}$ according to ISO/TR 18228-4.

5.4 Reduction factor for creep ($R_{F,cr}$)

5.4.1 General

The reduction factor for flow rate reduction due to compressive creep of the geosynthetic drain depends on the type of product, the applied pressure and the service lifetime of the project. Compressive creep tests performed in accordance with ISO 25619-1 or ASTM D7406, determine the thickness reduction at an applied pressure and elapsed time. Hence compressive creep tests define the reduction factor for thickness $R_{F,cr\text{-}th}$ as per Formula (10):

$$R_{F,cr\text{-}th} = t_0 / t_{cr} \quad (10)$$

where

$R_{F,cr\text{-}th}$ is the numerical value of thickness-related creep reduction factor

t_0 is the numerical value of the thickness of the geosynthetic drain before load application;

t_{cr} is the numerical value of the thickness measured at a specified time (1 year, 10 years, ... 100 years) in compressive creep tests.

The relationship between thickness and flow rate is not linear for all products, hence $R_{F,cr\text{-}th}$ cannot be used directly to define $R_{F,cr\text{-}Q}$, which can be obtained by performing flow rate tests at defined thicknesses, corresponding to the reduced thicknesses, t_{cr}, obtained from the compressive creep tests. From these combined tests, the values of $R_{F,cr-Q}$ can be obtained for different values of the load duration, which should correspond to the selected design life of the geosynthetic drain for any specific project.

It was noted that some geosynthetic drains exhibit a majority of their thickness reduction and associated intrusion within the first 100 h of loading, i.e. approx. all the primary creep. As such, some determinations of allowable flow incorporate a 100 h flow, q_{100} (see ASTM D7931). In these cases, q_{100} serves to capture the plastic deformation of the geosynthetic drain (and associated intrusion over 100 h, when tested using soil as a boundary) while the creep reduction factor are now determined for a duration from 100 h to design life duration.

In order to establish the creep reduction factor, the compressive creep strain should be measured in accordance with ISO 25619*.* Test results may be plotted as strain against logarithimic time log(t). It may then be extrapolated to the design lifetime. Extrapolation may be by graphical or curve-fitting procedures, in which the formulae applied should be as simple as is necessary to provide a reasonable fit to the data, for example, power laws. The use of polynomial functions is discouraged since they can lead to unrealistic values when extrapolated.

Extrapolation of creep compression properties may be challenging and bring calculation-related uncertainties. To avoid such extrapolations, compressive creep properties may also be measured via an accelerated method, ASTM D 7361, also known as SIM testing, which is described in 5.4.2.

It is important to note that, in ASTM D7931, $R_{F,CR}$ should be obtained starting from q_{100}, that is starting from the flow rate obtained by testing after 100 h seating time, but during these 100 h the applied load remains constant, hence the thickness get reduced in the same way as in a compressive creep test after 100 h.

Therefore, for the same geosynthetic, $R_{F,CR}$ in Formula (9), evaluated after flow rate tests with 100 h seating time, has a different value than $R_{F,cr-Q}$ in Formula (8), evaluated after flow rate tests with zero seating time.

In any case, Q_a from ISO/TR 18228-4 and q_{allow} from ASTM D7931 represent the same property of the specific geocomposite under consideration, that is the same long-term flow rate at the same design life, hydraulic gradient, applied pressure, and boundary conditions. Hence, despite the different methods used, Q_a is equal to q_{allow}.

Given that we can assume $R_{F,in} = R_{F,GI}$, $R_{F,cc} = R_{F,CC}$, $R_{F,bc} = R_{F,BC}$, and assuming $R_{F,L}$ = 1,0, considering Formulae (4), (5) and (6), it can be easily demonstrated that:

$$\frac{Q_L}{R_{F,cr\text{-}Q}} = \frac{q_{100}}{R_{F,CR}} \tag{11}$$

Hence for evaluating Q_a according to ISO/TR 18228-4, or q_{allow}, according to ASTM D7931**,** it is equivalent to use the ratios $\frac{Q_L}{R_{F,cr\text{-}Q}}$ and $\frac{q_{100}}{R_{F,CR}}$.

5.4.2 Time-temperature superposition methods

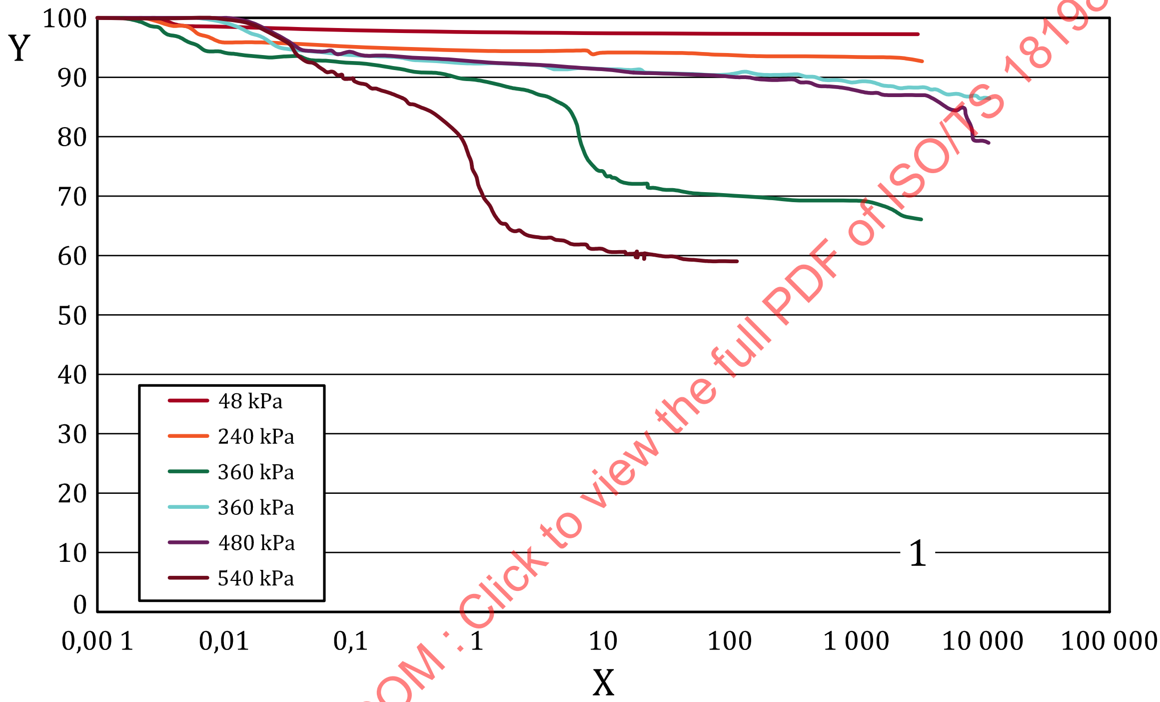
Time-temperature superposition methods may be used to assist with extending the creep curves, or in the case of stepped isothermal method (SIM), to rapidly estimate the creep curves.

In creep tests at constant temperature, creep curves are measured under the same load at different temperatures, with intervals generally not exceeding 10 °C, and plotted on the same diagram as strain against log *t*. The lowest temperature is taken as the reference temperature. The creep curves at the higher temperatures are then shifted along the time axis until they form one continuous “master” curve, i.e. the predicted long-term compressive creep curve for the reference temperature. The shift factors, i.e. the amounts (in units equivalent to log *t*) by which each curve is shifted, should be plotted against temperature where they should form a straight line or smooth curve. Experience has shown the strains on compression loading are variable. Since the increase in strain with time is small, this variability can lead to wide variability in time-temperature shifting (TTS).

The stepped isothermal method[15] avoids this problem by using a single specimen, increasing the temperature in steps, and then shifting the sections of creep curve measured at the various temperatures to form one continuous master curve.

If a more accurate measure of initial strain is required, five replicates are recommended at each load. Some of these can be of short duration (e.g. 1 000 s). At a series of loads, fewer replicates at each load will suffice if the data are pooled using regression techniques.

Regardless of the compressive creep measurement approach, it is key to perform thickness reduction monitoring throughout testing. This is important given that compressive collapse of the geosynthetic drain, if realized during testing, is often time dependent, as shown in Figure 5. This has been shown in many compressive creep experiments and is typically associated with a significant reduction of flow capacity. It is useful to design at loads that will not result in time-dependent collapse of the geosynthetic drain.



Key

X time (h)

Y thickness retained (%)

1 reference temperature 20 °C

Figure 5 — Example of time dependent collapse of a various biplanar geonet drains

5.5 Reduction factors for chemical clogging ($R_{F,CC}$) and biological clogging ($R_{F,BC}$)

There are two types of core clogging that might occur over a long time period. They are chemical clogging ($R_{F,cc}$) and biological clogging ($R_{F,bc}$), which are related to the chemical and biological content of the fluid to be drained.

$R_{F,cc}$ and $R_{F,pc}$ (reduction factor for particulate clogging) consider that the draining liquid might carry or precipitate particles, which may clog the drainage core, thus reducing the flow rate. High alkalinity groundwater will readily precipitate calcium and magnesium in this regard. Total suspended solids, or TSS, having values of greater than 5 000 mg/l require high reduction factors. Liquids high in microbial content, such as landfill leachates, agricultural wastewaters, and sewage biosolids, are all troublesome and result in high measured $R_{F,BC}$ values. Values of biochemical oxygen-demand (BOD) greater than 5 000 mg/l are considered high warranting concern.

While the clogging potential on the flow rate of the drainage core depends on the thickness, shape, and physical-chemical properties of the polymer of the draining core itself, at present there is no general practice or standardized test for evaluating the clogging potential for geosynthetic drains. This is due to the difficulty in developing a clogging test program the results of which can then be applied uniformly to the design process of a geosynthetic drain. Still, as shown in Figure 6, clogging of the drain is sometimes observed in application.

It is for this reason that most of the published literature on this topic is of qualitative nature as far as its utilization during the design process is concerned. Still, enough testing and field observation has been performed to enable researchers to recommend default reduction factors associated with clogging.

Figure 6 — Example of biological (root) clogging of a geosynthetic drain

As an example, Koerner[13] and others have recommended ranges of $R_{F,pc}$, $R_{F,cc}$ and $R_{F,bc}$ based on specific drainage applications. Giroud et. al[14] proposed ranges of values for $R_{F,cc}$ and $R_{F,bc}$ with ranges for $R_{F,cr}$ and $R_{F,int}$ as well.

A detailed discussion of clogging related reduction factors can be found in ISO/TR 18228-4:2022, B.2.

5.6 Additional considerations

5.6.1 Design life

A design lifetime, t_D, is defined for the geosynthetic drain. For civil engineering structures such as roads and containment facilities this is typically 50 years to 100 years. Other shorter-term applications may require the function of a geosynthetic drain for shorter periods of time, such as a sports field (20 years to 50 years) or mining heap leach pad (5 years to 50 years). All of these durations are too long for direct measurements to be made in advance of construction.

5.6.2 Design temperature

The design temperature should be defined for the application at hand. In the absence of a defined temperature or of site-specific in-soil temperature data, the design temperature should be taken as the temperature which is halfway between the average yearly air temperature and the normal daily air temperature for the hottest month at the site. If this information is not available, 20 °C should be used as the default value.

Many geosynthetic tests are performed at a standard temperature of (20 ± 2) °C. However, many geosynthetic drains are required to function at elevated temperatures such as bioreactor landfills and heap leach mining operations, where operations fluid temperatures may reach 50 °C to 80 °C.

Importantly, elevated temperatures may serve to increase the viscosity and flow rate of the draining fluid while simultaneously accelerating the compressive creep of the geosynthetic drain and reducing flow.[11], [12] A detailed discussion of the effect of viscosity on measured flow rate can be found in Rimoldi.[17] If the design temperature differs from (20 ± 2) °C, appropriate adjustments should be made to the measured properties.

The correction factor for temperature and viscosity is specifically included in ISO TR 18228-4.

5.6.3 Installation damage

For certain projects the nature of the fill material and the method of installation may be a consideration, and an additional reduction factor for installation damage, $R_{F,ID}$, may be considered as a cause of flow reduction. This may be investigated using a site specific installation damage exposure practice as described in ASTM D5818, which described site specific construction materials and procedures to evaluate installation damage.

When considering this potential “damage”, only installation damages affecting the flow capacity need to be considered. If installation damage produces a variation of the opening size of geotextiles, as example, the results would be an increased clogging of the draining core, which could be addressed by assuming higher values of $R_{F,cc}$ and/or $R_{F,bc}$.

5.6.4 Durability of the polymers

Durability of the polymers used to manufacture drainage geocomposites can be evaluated using techniques which are polymer-specific.

While it is obvious that the polymers used to manufacture geosynthetic drains shall have a durability at least equal to the design life of the project, durability is not the object of the present document. The manufacturer should be contacted to obtain polymer-specific information on durability.

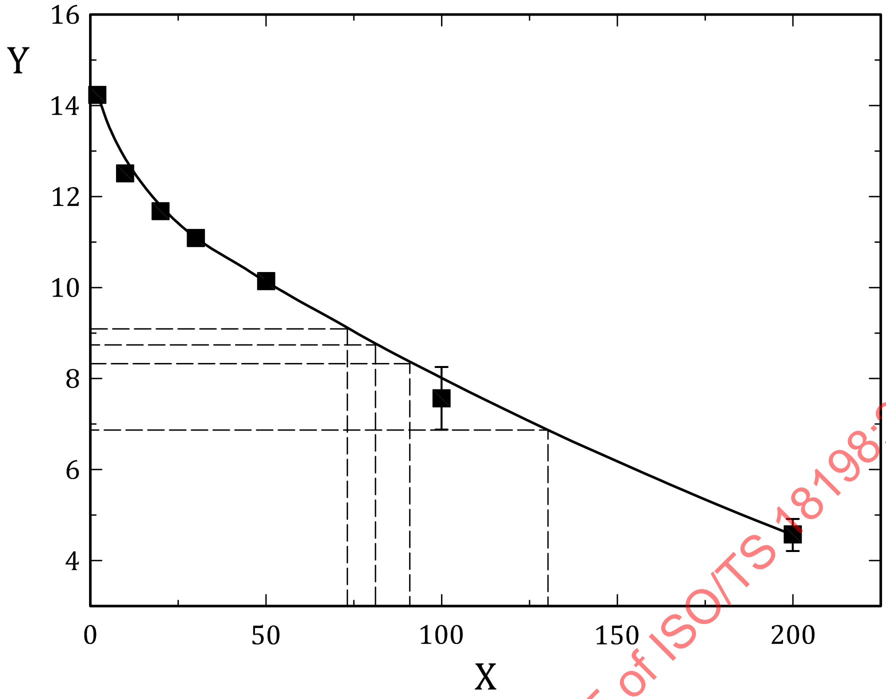
6 Alternative procedures to determine Q_a

6.1 General

Other procedures have been developed for the determination of Q_a. Instead of multiplying several individually determined reduction factors to predict long-term flow performance, fewer measurements are performed to incorporate flow reducing phenomenon. For example, the reduction factor for creep may be evaluated through long term or accelerated creep testing under normal and shear loads, followed by thickness-dependent flow capacity testing. The following procedures have employed use of long-term creep testing under normal and shear loads, followed by thickness-dependent flow testing as follows.

6.2 Long-term reduction of water flow capacity due to compressive creep by the BAM (Germany) method

As reported by Müller et al.,[16] thickness was measured with a rigid/rigid bedding condition as a function of normal pressure, p, as shown in Figure 7. Thereby the thickness as a function of pressure was obtained.



Key

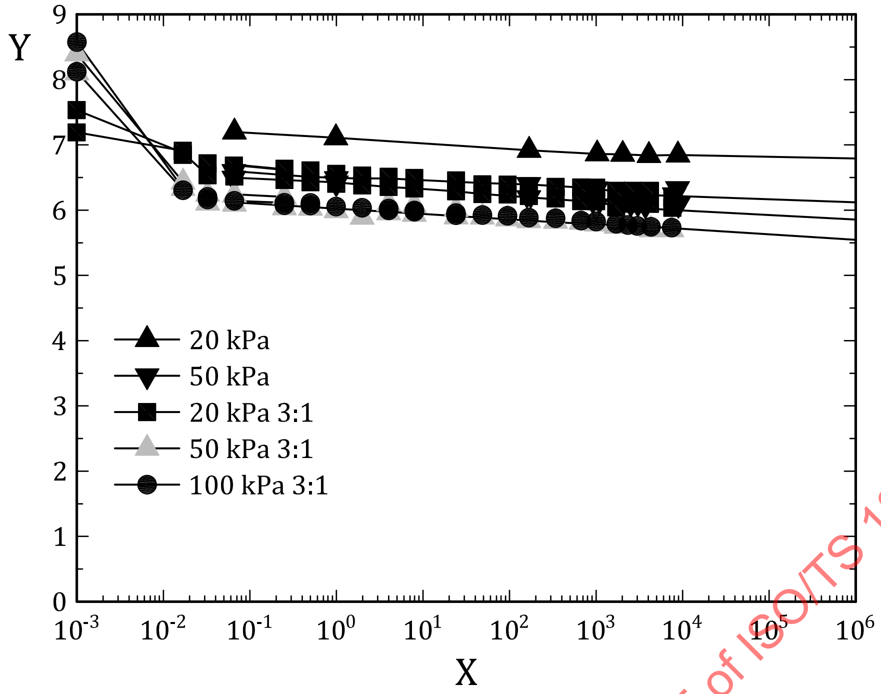
X compressive stress (kPa)

Y thickness (mm)

Figure 7 — Thickness of a GCO as a function of compressive stress at various hydraulic gradients for hard/hard bedding

Compressive creep was measured under various loading conditions (σ_1, S_1), (σ_2, S_2), etc., as shown in Figure 8, where σ is normal stress and S is the lateral slope producing shear stress. The residual thicknesses d_1, d_2, etc. were extrapolated for the relevant design life.

Then, the pressures p_1, p_2, etc., which corresponded to the respective residual thicknesses, were read from the pressure versus thickness curve of Figure 7.



Key

X time (h)

Y thickness (mm)

Figure 8 — Creep curve, i.e. thickness over time, for various mechanical stresses and hard/hard bedding of a GCO

Using these pressures, the water flow capacities were determined for the boundary conditions rigid/soft and soft/soft and were considered as the long-term water flow capacities relevant for the loading conditions (σ_1, S_1), (σ_2, S_2), etc. as shown in Figure 9.