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Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

Lignes directrices pour la détermination de la résistance à long terme des géosynthétiques pour le renforcement du sol

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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.

ISO/TR 20432 was prepared by Technical Committee ISO/TC 221, *Geosynthetics*.

Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

1 Scope

This Technical Report provides guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement.

This Technical Report describes a method of deriving reduction factors for geosynthetic soil-reinforcement materials to account for creep and creep rupture, installation damage and weathering, and chemical and biological degradation. It is intended to provide a link between the test data and the codes for construction with reinforced soil.

The geosynthetics covered in this Technical Report include those whose primary purpose is reinforcement, such as geogrids, woven geotextiles and strips, where the reinforcing component is made from polyester (polyethylene terephthalate), polypropylene, high density polyethylene, polyvinyl alcohol, aramids and polyamides 6 and 6,6. This Technical Report does not cover the strength of joints or welds between geosynthetics, nor whether these might be more or less durable than the basic material. Nor does it apply to geomembranes, for example, in landfills. It does not cover the effects of dynamic loading. It does not consider any change in mechanical properties due to soil temperatures below 0 °C, nor the effect of frozen soil. The Technical Report does not cover uncertainty in the design of the reinforced soil structure, nor the human or economic consequences of failure.

Any prediction is not a complete assurance of durability.

2 Normative references

The following referenced documents are indispensable for the application 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, *Geosynthetics — Terms and definitions*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

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

3.1.1
long-term strength
load which, if applied continuously to the geosynthetic during the service lifetime, is predicted to lead to rupture at the end of that lifetime

3.1.2
long-term strain
total strain predicted in the geosynthetic during the service lifetime as a result of the applied load

3.1.3
reduction factor
factor (⩾ 1) by which the tensile strength is divided to take into account particular service conditions in order to derive the long-term strength

NOTE In Europe, the term 'partial factor' is used.

3.1.4
characteristic strength
95 % (two-sided) lower confidence limit for the tensile strength of the geosynthetic, approximately equal to the mean strength less two standard deviations

NOTE This should be assured by the manufacturer's own quality assurance scheme or by independent assessment.

3.1.5
block shifting
procedure by which a set of data relating applied load to the logarithm of time to rupture, all measured at a single temperature, are shifted along the log time axis by a single factor to coincide with a second set measured at a second temperature

3.1.6
product line
series of products manufactured using the same polymer, in which the polymer for all products in the line comes from the same source, the manufacturing process is the same for all products in the line, and the only difference is in the product mass per area or number of fibres contained in each reinforcement element

3.2 Abbreviated terms

CEG carboxyl end group

DSC differential scanning calorimetry

HALS hindered amine light stabilizers

HDPE high density polyethylene

HPOIT high pressure oxidation induction time

LCL lower confidence limit

MARV minimum average roll value

OIT oxidation induction time

PA polyamide

PET polyethylene terephthalate

PP polypropylene

PTFE polytetrafluorethylene

PVA polyvinyl alcohol

RF_{CH} reduction factor to allow for chemical and biological effects

RF_{CR} reduction factor to allow for the effect of sustained static load

RF_{ID} reduction factor to allow for the effect of mechanical damage

RF_{W} reduction factor to allow for weathering

SIM stepped isothermal method

TTS time-temperature shifting

3.3 Symbols

A_i	time-temperature shift factor
b_a	gradient of Arrhenius graph
d_{50}	mean granular size of fill
d_{90}	granular size of fill for 90 % pass (10 % retention)
f_s	factor of safety
G, H	parameters used in the validation of temperature shift linearity (see 7.4)
m	gradient of line fitted to creep rupture points (log time against load); inverse of gradient of conventional plot of load against log time.
M_n	number averaged molecular weight
n	number of creep rupture or Arrhenius points
P	applied load
R_1	ratio representing the uncertainty due to extrapolation
R_2	ratio representing the uncertainty in strength derived from Arrhenius testing
S_{sq}	sum of squares of difference of log (time to rupture) and straight line fit
S_{xx}, S_{xy}, S_{yy}	sums of squares as defined in derivation of regression lines in 9.4.3
σ_0	standard deviation used in calculation of LCL
t	time, expressed in hours
t_{90}	time to 90 % retained strength
t_D	design life
t_{deg}	degradation time during oxidation
t_{ind}	induction time during oxidation
t_{LCL}	LCL of time to a defined retained strength at the service temperature
t_{max}	longest observed time to creep rupture, expressed in hours
t_{n-2}	Student's t for $n - 2$ degrees of freedom and a stated probability
t_R	time to rupture, expressed in hours
t_s	time to a defined retained strength at the service temperature
T	load per width
T_B	batch tensile strength (per width)
T_{char}	characteristic strength (per width) (see 6.1)
T_x	unfactored long-term strength (see 9.4.3)

T_D	long-term strength per width (including factor of safety)
T_{DR}	residual strength
θ_j	temperature of accelerated creep test
θ_K	temperature
T_{LCL}	LCL of T_{char} due to chemical degradation
θ_s	service temperature
x	abscissa: on a creep rupture graph the logarithm of time, in hours
$\bar{x}$	mean value of x
x_i	abscissa of an individual creep rupture point
x_p	predicted time to rupture
y	ordinate: on a creep rupture graph, applied load expressed as a percentage of tensile strength, or a function of applied load
y_0	value of y at 1 h (log t = 0)
$\bar{y}$	mean value of y
y_i	ordinate of an individual creep rupture point
y_0	value of y at time 0, derived from the line fitted to creep rupture points

4 Design procedure

4.1 Introduction

The design of reinforced soil structures generally requires consideration of the following two issues:

a) the maximum strain in the reinforcement during the design lifetime;

b) the minimum strength of the reinforcement that could lead to rupture during the design lifetime.

In civil engineering design, these two issues are referred to as the serviceability and ultimate limit state respectively. Both factors depend on time and can be degraded by the environment to which the reinforcement is exposed.

4.2 Design lifetime

A design lifetime, t_D, is defined for the reinforced soil structure. For civil engineering structures this is typically 50 to 100 years. These durations are too long for direct measurements to be made in advance of construction. Reduction factors have therefore to be determined by extrapolation of short-term data aided, where necessary, by tests at elevated temperatures to accelerate the processes of creep or degradation.

4.3 Causes of degradation

Strain and strength may be changed due to the effects of the following:

— mechanical damage caused during installation;

— sustained static (or dynamic) load;

— elevated temperature;

— weathering while the material is exposed to light;

— chemical effects of natural or contaminated soil.

4.4 Design temperature

The design temperature should have been defined for the application in 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. If the design temperature differs, appropriate adjustments should be made to the measured properties.

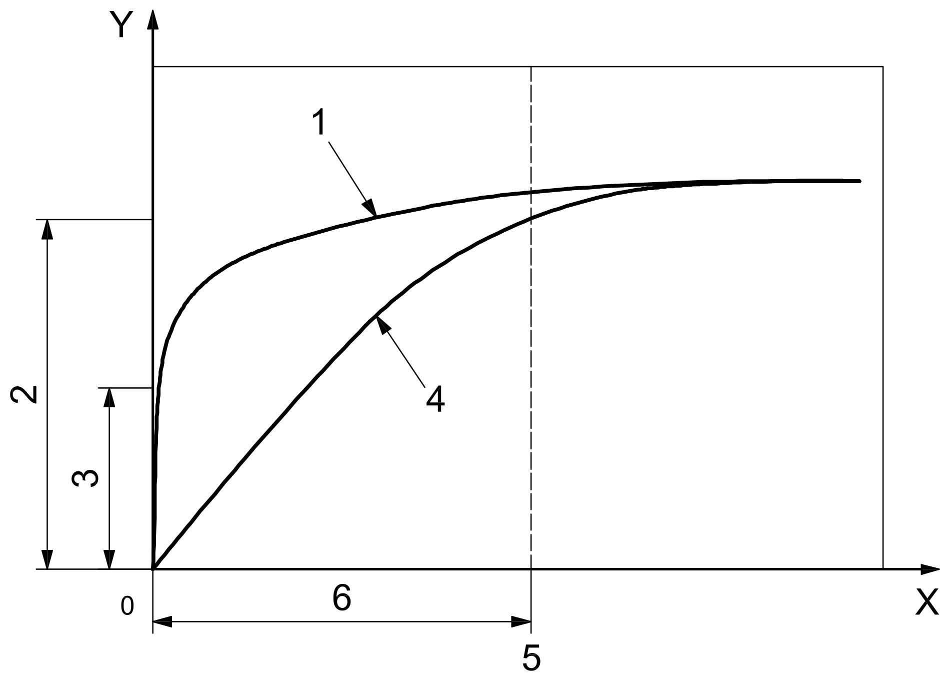
This Technical Report does not cover the effects of temperatures below 0 °C (see Clause 1).

5 Determination of long-term (creep) strain

5.1 Introduction

The design specification may set a limit on the total strain over the lifetime of the geosynthetic, or on the strain generated between the end of construction and the service lifetime. In the second case, the time at “end of construction” should be defined, as shown in Figure 1. When plotted against log t, even a one-year construction period should have negligible influence on the creep strain curve beyond 10 years.

Levels of creep strain encountered in the primary creep regime (creep rate decreasing with time) are thought not to adversely affect strength properties of geosynthetic reinforcement materials.



Key

1 Laboratory creep test
2 Load ramp period on wall
3 Load ramp period in creep test
4 Loading and creep of reinforcement in wall
5 New time = 0 for post construction creep
6 Wall construction time
X Time
Y Strain

Figure 1 — Conceptual illustration for comparing the creep measured in walls to laboratory creep data

5.2 Extrapolation

Creep strain should be measured according to ISO 13431 and plotted as strain against the 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.

5.3 Time-temperature superposition methods

Time-temperature superposition methods may be used to assist with extending the creep curves. 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 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. The cautions given in 7.6 should be noted.

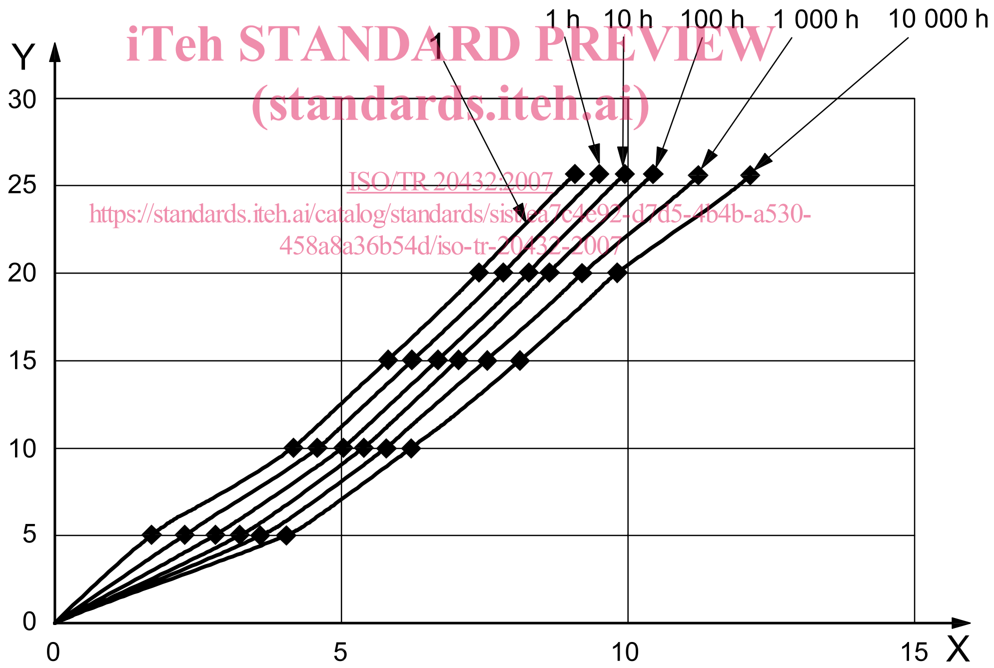
Experience has shown the strains on loading are variable. Since the increase in strain with time is small, this variability can lead to wide variability in time-temperature shifting (TTS). The stepped isothermal method (SIM) described in 7.5 avoids this problem by using a single specimen, increasing 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. One approach is to use regression analysis to develop an isochronous load versus strain curve at 0,1 h. The creep curve should then be shifted vertically to pass through the mean strain measured after 0,1 h.

If the lowest test temperature is below the design temperature, the shift factor corresponding to the design temperature should be read off the plot of shift factor against temperature. The time-scale of the master curve should then be adjusted by this factor.

5.4 Isochronous curves

From the creep curve corresponding to each load, read off the strains for specified durations, typically 1 h, 10 h, 100 h, etc., and including the design lifetime. Set up a diagram of load against strain. For each duration, plot the points of load against strain for the corresponding durations (see Figure 2). These are called isochronous curves. Where a maximum strain is permitted over the design lifetime, or between the end of construction (e.g. 100 h) and the design lifetime, it is possible to read off the corresponding loads from these curves. Where the strain is measured from zero, note that in geosynthetics strains are measured from a set preload (defined in ISO 10319 and ISO 13431 as 1 % of the tensile strength) and that some woven and particularly non-woven materials may exhibit considerable irreversible strains below this initial loading. See [2] in the Bibliography for additional details on creep strain characterization.



Key

X Strain

Y Load

Figure 2 — Isochronous diagram

5.5 Weathering, chemical and biological effects

Creep strain is generally insensitive to limited weathering, chemical and biological effects. In addition, creep strains are in general not affected by installation damage, unless the damage is severe, or unless the load level applied is very near the creep limit of the undamaged material. In most cases, the load level applied is well below the creep limit of the material. See [3] in the Bibliography for additional details on this issue. Thus, no further adjustment is generally required beyond the effect of temperature.

Note, however, that artificially contaminated soils may contain chemicals, such as organic fuels and solvents, which can affect the creep of geosynthetics. If necessary, perform a short-term creep test according to ISO 13431 on a sample of geosynthetic that is immersed in the chemical or has just been removed from it. If the creep strain is significantly different, do not use this geosynthetic in this soil.

6 Determination of long-term strength

6.1 Tensile strength

The characteristic strength, T_{char}, is taken as the basis for the long-term strength. T_{char} is typically a statistical value generated from the mean strength of production material less two standard deviations sometimes referred to as the minimum average roll value (MARV), unless otherwise defined.

6.2 Reduction factors

T_{char} can then be divided by the following four reduction factors, each of which represents a loss of strength determined in accordance with this Technical Report, to arrive at the long-term strength T_D:

— RF_{CR} is a reduction factor to allow for the effect of sustained static load at the service temperature;

NOTE The effect of dynamic loads is not included.

— RF_{ID} is a reduction factor to allow for the effect of mechanical damage;

— RF_W is a reduction factor to allow for weathering during exposure prior to installation or of permanently exposed material;

— RF_{CH} is a reduction factor to allow for reductions in strength due to chemical and biological effects at the design temperature (see 4.4).

In addition to the reduction factors, a factor of safety, f_s, takes into account the statistical variation in the reduction factors calculated (see 6.1). It does not consider the uncertainties related to the soil structure and the calculation of loads.

6.3 Modes of degradation

Degradation of strength can be divided into three Modes according to the manner in which they take place with time:

— Mode 1: Immediate reduction in strength, insignificant further reduction with time;

— Mode 2: Gradual, though not necessarily constant, reduction in strength;

— Mode 3: No reduction in strength for a long period; after a certain period, onset of rapid degradation.

For Mode 1, of which installation damage is an example, it is appropriate to reduce the tensile strength by an appropriate time-independent reduction factor. For Mode 2, where there is a progressive reduction in strength, the tensile strength will be reduced by a time-dependent reduction factor. For Mode 3, it is not appropriate to apply a reduction factor to the tensile strength but rather to restrict the service lifetime.