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Eurocode 7: Geotechnical design — Part 1: General rules

Eurocode 7: Entwurf, Berechnung und Bemessung in der Geotechnik — Teil 1: Allgemeine Regeln

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ICS:

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European foreword

This document (FprEN 1997-1) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

This document will partially supersede EN 1997-1:2004. Some content is migrated into prEN 1990-1:2024.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

In comparison with the previous edition, the following main changes have been made:

— the scope of EN 1997-1 has been extended to include the rock (the word “ground” is now used extensively to denote soil, rock, and fill);

— the Geotechnical Category has been redefined as a combination of the Consequence Class of the structure and the complexity of the ground (Geotechnical Complexity Class) (Clause 4 and Annex D);

— robustness, durability and sustainability have been introduced as new topics (Clause 4);

— the representative value of a ground property has been defined as either a nominal value (cautious estimate) or a characteristic value (based on statistical evaluation) (Clause 4 and Annex A);

— a new clause on the determination of groundwater levels and groundwater pressures has been added (Clause 6);

— a new procedure for verifying ultimate limit states using numerical models has been added (Clause 8);

— greater emphasis has been given to serviceability limit states, including ground movements and structural and hydraulic aspects (Clause 9);

— a new clause on the implementation of design (covering supervision, inspection, monitoring, and maintenance) has been added (Clause 10);

— a new clause on testing has been added, covering tests for determining ground properties, tests for measuring the resistance of geotechnical structures, product quality tests, and tests to determine geotechnical behaviour (Clause 11); and

— the clause on reporting has been revised to cover updated specification of the Ground Investigation and Geotechnical Design Reports and new requirements for Geotechnical Construction Records and geotechnical test reports (Clause 12 and Annex C).

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

— EN 1990, *Eurocode: Basis of structural and geotechnical design*

— EN 1991, *Eurocode 1: Actions on structures*

— EN 1992, *Eurocode 2: Design of concrete structures*

— EN 1993, *Eurocode 3: Design of steel structures*

— EN 1994, *Eurocode 4: Design of composite steel and concrete structures*

— EN 1995, *Eurocode 5: Design of timber structures*

— EN 1996, *Eurocode 6: Design of masonry structures*

— EN 1997, *Eurocode 7: Geotechnical design*

— EN 1998, *Eurocode 8: Design of structures for earthquake resistance*

— EN 1999, *Eurocode 9: Design of aluminium structures*

— New parts are under development, e.g. Eurocode for design of structural glass

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1997 (all parts)

EN 1997 consists of a number of parts:

— EN 1997-1, *Eurocode 7: Geotechnical design – Part 1: General rules*

— EN 1997-2, *Eurocode 7: Geotechnical design – Part 2: Ground properties*

— EN 1997-3, *Eurocode 7: Geotechnical design – Part 3: Geotechnical structures*

EN 1997 (all parts) establishes additional principles and requirements to those given in EN 1990 (all parts) for the safety, serviceability, robustness, and durability of geotechnical structures.

Design and verification in EN 1997 (all parts) are based on the partial factor method or other reliability-based methods, prescriptive rules, testing, or the Observational Method.

0.3 Introduction to FprEN 1997-1

FprEN 1997-1 establishes additional principles and requirements to those given in EN 1990 (all parts) for the safety, serviceability, robustness, and durability of geotechnical structures.

Design and verification in FprEN 1997-1 are based on the partial factor method or other reliability-based methods, prescriptive rules, testing, or the Observational Method.

0.4 Verbal forms used in the Eurocodes

The verb “shall" expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may" expresses a course of action permissible within the limits of the Eurocodes.

The verb “can" expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National annex for FprEN 1997-1

National choice is allowed in this standard where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing FprEN 1997-1 can have a National Annex containing all national choices to be used for the design of geotechnical structures to be constructed in the relevant country.

When no national choice is given, the default choice given in this standard is to be used.

When no national choice is made and no default is given in this standard, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

National choice is allowed in FprEN 1997-1 through notes to the following clauses:

4.1.2.2(1)	4.1.2.3(3)	4.1.3(1)	4.1.4(2)
4.1.5(1)	4.1.8(3)	4.2.3.2(2)	4.2.4(3)
4.3.2.3(2)	4.4.1.3(1) – (3 choices)	4.4.1.3(8) – (2 choices)	4.4.1.5(1) – (2 choices)
4.5(1)	4.5(4)	5.4(2)	5.5(2)
5.5(3)	7.1.1(7)	7.2(2)	8.1.4.2(3)
8.2(1) – (2 choices)	10.2(3)	12.1(4)	

National choice is allowed in FprEN 1997-1 on the application of the following informative annexes:

Annex A	Annex B	Annex C

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of FprEN 1997-1

(1) This document provides general rules for the design and verification of geotechnical structures.

(2) This document is applicable for the design and verification of geotechnical structures outside the scope of prEN 1997-3.

NOTE In this case, additional or amended provisions can be necessary.

1.2 Assumptions

(1) In addition to the assumptions given in prEN 1990-1, the provisions of prEN 1997 (all parts) assume that:

— ground investigations are planned by individuals or organisations with knowledge of potential ground and groundwater conditions;

— ground investigations are executed by individuals with appropriate skills and experience;

— the evaluation of test results and derivation of ground properties from the ground investigation are carried out by individuals with appropriate geotechnical experience and qualifications;

— the data required for design are collected, recorded, and interpreted by appropriately qualified and experienced individuals;

— geotechnical structures are designed and verified by individuals with appropriate qualifications and experience in geotechnical design;

— adequate continuity and communication exist between the individuals involved in data-collection, design, verification and execution.

(2) This document is intended to be used in conjunction with prEN 1990-1, which establishes principles and requirements for the safety, serviceability, robustness, and durability of structures, including geotechnical structures, and other construction works.

NOTE Additional or amended provisions can be necessary for assessment of existing structures, see prEN 1990-2.

(3) This document is intended to be used in conjunction with FprEN 1997-2, which gives provisions for determining ground properties from ground investigations.

(4) This document is intended to be used in conjunction with prEN 1997-3, which gives specific rules for the design and verification of certain types of geotechnical structures.

(5) This document is intended to be used in conjunction with other Eurocodes for the design of geotechnical structures, including temporary geotechnical structures.

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.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions (i.e. in 'may' clauses), possibilities (i.e. in 'can' clauses), and in notes.

EN 206, *Concrete - Specification, performance, production and conformity*

EN 1990-1[1], *Eurocode - Basis of structural and geotechnical design - Part 1: Design of new structures*

EN 1990-2, *Eurocode – Basis of structural and geotechnical design - Part 2: Assessment of existing structures*

EN 1991-2, *Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges and other civil engineering works*

EN 1991-1-1, *Eurocode 1: Actions on structures – Part 1-1: General actions – densities, self-weight, imposed loads for buildings*

EN 1992-1-1:2023 *Eurocode 2: Design of concrete structures - Part 1-1: General rules, rules for buildings, bridges and civil engineering structures*

EN 1993-1-1:2023, *Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings*

EN 1993-5, *Eurocode 3: Design of steel structures - Part 5: Piling*

EN 1995-1-1, *Eurocode 5: Design of timber structures - Part 1-1: General rules and rules for buildings*

EN 1996 (all parts), *Eurocode 6 Design of masonry structures*

EN 1997-2, *Eurocode 7: Geotechnical design - Part 2: Ground properties*

EN 1997-3, *Eurocode 7: Geotechnical design - Part 3: Geotechnical structures*

EN 1998-1-1 *Eurocode 8 - Design of structures for earthquake resistance - Part 1-1: General rules and seismic action*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in prEN 1990-1 and the following terms and definitions apply.

For the purpose of drafting common definitions, ISO 6707-1 has been used as source, as applicable.

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[1] As impacted by EN 1990:2023/prA1:2024

3.1.1 Terms relating to the ground

3.1.1.1
ground
soil, rock, and fill existing in place prior to execution of the construction works

Note 1 to entry: In this definition rock refers to the rock mass

[SOURCE: prEN 1990-1:2024, 3.1.1.5]

3.1.1.2
soil
aggregate of minerals and/or organic materials including fills which can be disaggregated by hand in water

[SOURCE: EN ISO 14688:2018-1, 3.17]

3.1.1.3
rock
naturally occurring assemblage or aggregate of mineral grains, crystals or mineral based particles compacted, cemented, or otherwise bound together and which cannot be disaggregated by hand in water

[SOURCE: EN ISO 14689:2018, 3.5]

3.1.1.4
rock mass
rock comprising the intact material together with the discontinuities and weathered zones

[SOURCE: EN ISO 14689:2018, 3.6]

3.1.1.5
rock material,
intact rock between the discontinuities

[SOURCE: EN ISO 14689:2018, 3.7]

3.1.1.6
weathered zone
distinctive layer of ground, differing physically, chemically, and/or mineralogically from the layers above and/or below due to the process of weathering

3.1.1.7
discontinuities
bedding planes, joints, fissures, faults and shear planes

[SOURCE: EN ISO 14688-1:2018, 3.4]

3.1.1.8
foliation
planar arrangements of constituents in any type of rock, especially the parallel structure that results from flattening, segregation and other processes undergone by the grains in a metamorphic rock

3.1.1.9
interface

surface between two geotechnical units in interact or surface where ground and structure interact

3.1.1.10
fill
made ground
ground that has been formed by using material to fill in a depression or to raise the level of a site

[SOURCE: ISO 6707-1:2017 3.4.4.9]

3.1.1.11
engineered fill
material placed in a controlled manner to ensure that its geotechnical properties conform to a predetermined specification

3.1.1.12
non-engineered fill
material placed with no compaction control and likely to have heterogeneous and anisotropic geotechnical properties within its mass

3.1.2 Terms relating to geotechnical reliability

3.1.2.1
desk study
analysis and presentation of information about the construction site from existing documentation

Note 1 to entry: A desk study includes, for example, the history of the site, observations of neighbouring structures, previous construction activities, information from aerial photographs, satellite observations, local experience in the area, and seismicity

Note 2 to entry: See also FprEN 1997-2:2024, Annex C

3.1.2.2
Geotechnical Complexity Class
classification of a geotechnical structure based on the complexity of the ground, groundwater and ground-structure interaction, taking account of prior knowledge

3.1.2.3
Geotechnical Category
classification system that combines the uncertainty and complexity of the ground including groundwater and ground-structure interaction with the consequence of failure of the structure

3.1.2.4
comparable experience
documented previous information about ground and structural behaviour that is considered relevant for design, as established by geological, geotechnical and structural similitude with the design situation

3.1.3 Terms relating to ground properties

3.1.3.1
ground property
physical, mechanical, geometrical, or chemical attribute of a ground material

3.1.3.2
derived value of a ground property
value of a ground property obtained by theory, correlation, or empiricism from test results or field measurements

3.1.3.3
nominal value of a ground property
cautious estimate of the value of a ground property that affects the occurrence of a limit state

Note 1 to entry: Further explanation of 'cautious estimate' is given in 4.3.2.

3.1.3.4
characteristic value of a ground property
statistical determination of the value of a ground property that affects the occurrence of a limit state having a prescribed probability of not being attained

Note 1 to entry: This value corresponds to a specified fractile (mean, superior or inferior) of the assumed statistical distribution of the particular property of the ground.

3.1.3.5
representative value of a ground property
nominal or characteristic value including the conversion factor

Note 1 to entry: Further explanation about the representative value is given in 4.3.2.

3.1.3.6
best estimate value of a ground property
estimate of the most probable value of a ground property

Note to entry: Further explanation about the best estimate value is given in 4.3.2.

3.1.3.7
indicative value of a ground property
value of a ground property determined from ground description or classification

3.1.4 Terms relating to actions and resistance

3.1.4.1
ground resistance
capacity of the ground, or part of it, to withstand actions without failure

3.1.4.2
ground strength
mechanical property of the ground indicating its ability to resist actions

3.1.4.3
overall stability
failure mechanism in the ground that encompasses the entire geotechnical structure

3.1.4.4
local stability
failure mechanism that encompasses only a part of the entire geotechnical structure without failure of the entire geotechnical structure

3.1.4.5
cyclic action
variable load that can induce significant stiffness and strength degradation, generation of excess pore pressure, liquefaction, or permanent settlements

3.1.4.6
creep
increase in strain at constant effective stress

3.1.5 Terms relating to verification methods

3.1.5.1
Observational Method
continuous, managed, integrated process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate

[SOURCE: CIRIA Report 185, 1999]

3.1.5.2
prescriptive rules
pre-determined, experienced-based, and suitably conservative rules for design

3.1.5.3
verification assisted by testing
testing of a structural element to verify design ground properties or resistance

Note 1 to entry: Verification assisted by testing includes the determination of shaft friction and end bearing of piles, pull-out strength of anchors, and shear strength of lime-cement columns, for example.

3.1.5.4
verification by testing
testing performed to verify that the performance of the geotechnical structure (or part of the structure) is within the limiting values

Note 1 to entry: Verification by testing includes full-scale or reduced-scale tests.

3.1.5.5
design variant
describes the anticipated behaviour of the geotechnical structure, given that the relevant ground properties lie in a predefined range

3.1.6 Terms relating to analysis and models

3.1.6.1
zone of influence
zone where construction works or the geotechnical structure can adversely affect the safety, serviceability, robustness, durability, or sustainability of the geotechnical structure, other structures, utilities, ground, or groundwater

3.1.6.2
geotechnical analysis
procedure or algorithm for determining effects of actions in and resistance of the ground

3.1.6.3
geotechnical system
term describing the ground, groundwater and the structure interacting with it

3.1.6.4
Geotechnical Design Model
conceptual representation of the site derived from the ground model for the verification of each appropriate design situation and limit state

Note 1 to entry: Guidance on the contents of a Geotechnical Design Model is given in Clause 12 and Annex B.

3.1.6.5
geotechnical unit
volume of ground that is defined as a single material

3.1.6.6
Ground Model
site specific outline of the disposition and character of the ground and groundwater based on the results of ground investigations and other available data

3.1.6.7
numerical models
calculation models involving numerical approximation to obtain solutions

Note 1 to entry: Numerical methods include, but are not limited to, finite-element, finite-difference, boundary-element, discrete-element and subgrade reaction methods.

3.1.6.8
validation
process of determining the degree to which a model and its input parameters represent a real design situation

3.1.6.9
robustness
ability of a structure to withstand unforeseen adverse events without being damaged to an extent disproportionate to the original cause

[SOURCE: prEN 1990-1:2024, 3.1.2.30]

Note 1 to entry: The aim of designing for robustness is either to prevent disproportionate consequences resulting from an adverse or unforeseen event or to provide some additional resistance to reduce the likelihood and extent of such an event.

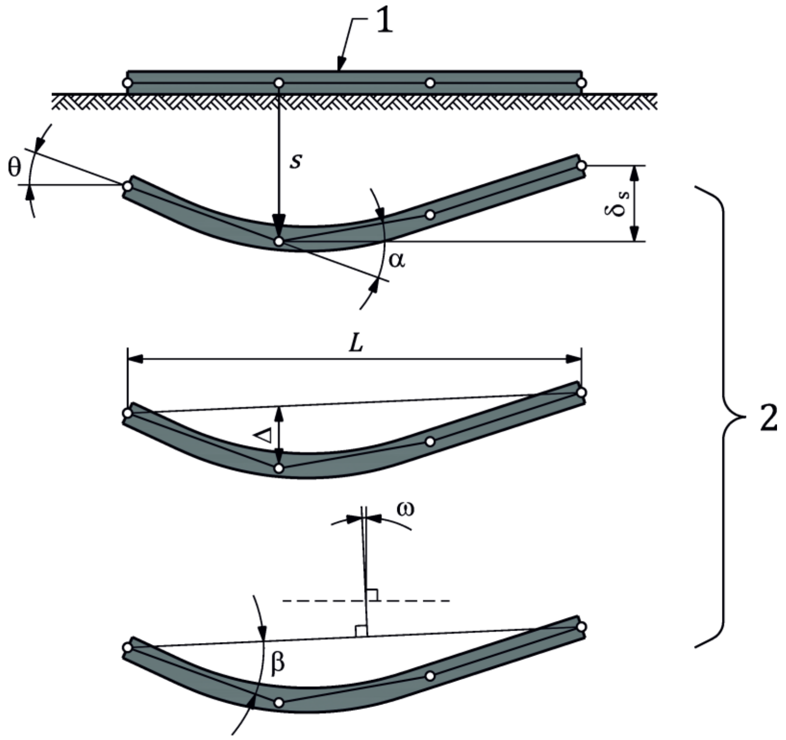
Note 2 to entry: There is a distinction between design for identified accidental actions and design for robustness. In design for accidental actions, a target level of reliability is expected to be achieved whereas design for robustness aims to increase the safety margin without aiming for a specified target reliability.

3.1.6.10
toppling
loss of static equilibrium due to rotation of the structure

3.1.6.11
overturning
rotation of the structure involving failure of the ground

3.1.7 Terms relating to structural deformation and ground movement

Definitions of some terms for foundation movement and deformation are given in Figure 3.1.



Key

s	settlement	Δ/L	deflection ratio
δ_s	differential settlement	ω	tilt
θ	rotation	β	angular distortion
α	angular strain	1	original position and shape
Δ	relative deflection	2	deformed position and shape

Figure 3.1 — Definitions of foundation movement

3.1.8 Terms relating to groundwater

3.1.8.1
groundwater
water held underground in the soil or in pores and discontinuities in rock

3.1.8.2
groundwater level
level of the water surface in the ground

3.1.8.3
piezometric level
level to which water would rise in a standpipe designed to detect the pressure of water at a point beneath the ground surface

3.1.8.4
surface water level
level of water above the ground surface

3.1.9 Terms relating to implementation of design

3.1.9.1
limiting values
value of the serviceability criteria

Note 1 to entry: Expressed, for example, as deformation, stress, strain, or vibration.

3.1.9.2
threshold value
value that, with an appropriate safety margin, defines the point at which contingency measures are applied to avoid exceeding the limiting value

3.1.9.3
acceptance criteria
acceptable variations of material, ground and geometrical properties expressed as tolerances to avoid exceeding the serviceability criteria or the ultimate limit state

3.1.9.4
supervision
measures or activities during execution to check that the construction work follows the process, including execution methods and construction stages, set by the execution specification

3.1.9.5
inspection
measures or activities during or after execution to check the compliance of the execution with the execution specification and the validity of the design assumptions in relation to encountered ground conditions at the site

3.1.9.6
monitoring
measurement or observation of the behaviour of the ground or structure to check compliance with the serviceability criteria and to check that the execution complies with the design assumptions and execution specifications

3.1.9.7
execution specification
set of documents comprising drawings, a description of the works, product choices, execution classes, tolerance classes, and other technical data and requirements necessary for the execution of the works

Note 1 to entry: An execution specification can include method statements, inspection plan, monitoring plan, maintenance plan, contingency plan, material specification, technical description etc. The information can be presented in text, drawings, models or databases, for example.

3.1.10 Terms relating to testing

3.1.10.1
investigation test
load test to establish the geotechnical ultimate load resistance of an anchor, soil nail, or rock bolt at the interface between the supporting element and the ground and to determine the behaviour of the element in the working load range

3.1.10.2
suitability test
load test to confirm that an particular anchor, soil nail, or rock bolt design will be adequate in particular ground conditions

3.1.10.3
acceptance test
load test to confirm that a individual anchor, soil nail, or rock bolt conforms with its acceptance criteria

3.1.10.4
control test
test used to check that a product meets its specifications and that its properties are consistent throughout the product

3.1.11 Terms relating to reporting

3.1.11.1
Ground Investigation Report
report (or reports) that compiles the results of ground investigation

Note 1 to entry: Details are given in FprEN 1997-2

3.1.11.2
Geotechnical Design Report
report (or reports) that compiles verification and design process of all construction phases and final design of the geotechnical structure

3.1.11.3
Geotechnical Construction Record
collection of documents of construction, supervision, monitoring and inspection of the final structure and each phase of execution

3.2 Symbols and abbreviations

For the purposes of this document, the following symbols and abbreviations apply.

NOTE 1 The symbols commonly used in all Eurocodes are defined in prEN 1990-1:2024.

NOTE 2 The notation of the symbols used is based on ISO 3898:1997.

3.2.1 Symbols

Latin upper-case letters

A_{wd} accidental component of groundwater pressure

E modulus of elasticity (Young's modulus)

E_d design value of action

$F_{w,rep}$ representative groundwater pressure

G shear modulus

G_{rep} representative value of any unfavourable permanent force (acting upwards) that is not caused by groundwater pressures

$G_{rep,fav}$ representative value of the favourable permanent force (acting downwards)

$G_{vd,dst}$ design value of any permanent destabilising force (upwards) not caused by groundwater pressure

$G_{vd,stb}$ design value of any stabilising (downward) force

G_w permanent component of groundwater pressure

G_{wk} characteristic value of G_w

$G_{wk,inf}$ lower (inferior) value of G_{wk}

$G_{wk,sup}$ upper (superior) value of G_{wk}

$G_{w,rep}$ representative value of groundwater pressure

K hydraulic conductivity

N_{95} parameter of the normal distribution, evaluated for a 95% confidence level and infinite degrees of freedom

N_{SPT} blow count measured in Standard Penetration Test

Q_{rep} representative value of any unfavourable variable force (acting upwards) that are not caused by groundwater pressures

$Q_{vd,dst}$ design value of any variable destabilising force (acting upwards) not caused by groundwater pressure

Q_w variable component of the groundwater pressure

$Q_{w,comb}$ combination value of Q_w

$Q_{w,freq}$ frequent value of Q_w

$Q_{w,k}$ characteristic value of Q_w

$Q_{w,qper}$ quasi-permanent value of Q_w

$Q_{w,rep}$ representative value of Q_w

R_d design value of resistance

T_{lf}	design service life
$U_{d,dst}$	design value of destabilising (uplift) force due to groundwater pressures
$U_{G,rep}$	representative value of the (unfavourable) uplift force due to permanent groundwater pressures
$U_{Q,rep}$	representative value of the (unfavourable) uplift forces due to variable groundwater pressures
V_X	coefficient of variation of the ground material property X
$V_{X,inh}$	coefficient of variation of a ground material property X due to inherent ground variability
$V_{X,quality}$	coefficient of variation of the measurement error
$V_{X,trans}$	coefficient of variation of the transformation error
X_d	design value of a ground property X
X_k	characteristic value of a ground property X
X_{mean}	mean value of a ground property X from test results
X_{nom}	nominal value of a ground property X
X_{rep}	representative value of X
Y_{mean}	mean value of the logarithmic values of a ground property Y from test results.

Latin lower-case letters

c'_p	peak effective cohesion
c'_r	residual effective cohesion
c_u	undrained shear strength of soil
c_h	coefficient of horizontal consolidation
c_v	coefficient of vertical consolidation
f_s	sleeve friction measured in a Cone Penetration Test
$h_{w,z}$	piezometric level at elevation z
$i_{c,d}$	design value of critical hydraulic gradient (when soil particles begin to move)
i_d	design value of the hydraulic gradient
k_n	coefficient that depends on the number of sample derived values (n) used to calculate X_{mean}
k_F	consequence factor applied to actions

k_M consequence factor applied to material properties

k_R consequence factor applied to resistance

k_{tr} reduction factor for a transient design situation

n number of sample test results, site-specific data, or derived values

p_l pressuremeter limit pressure

$p'_{v,rep}$ representative value of any effective vertical overburden at the ground surface

q_c cone resistance measured in a Cone Penetration Test

q_u unconfined compressive strength of soil or rock

s_x standard deviation of the sample derived values

$t_{95,n-1}$ student's *t*-factor, evaluated for a 95% confidence level and (n–1) degrees of freedom

u groundwater pressure at a point in the ground

u_0 groundwater pressure in the absence of flow (hydrostatic)

u_d design value of groundwater pressure at a point in the ground

$u_{d,dst}$ design value of destabilising (uplift) groundwater pressures

$u_{G,rep}$ representative value of the (unfavourable) uplift permanent groundwater pressures

$u_{Q,rep}$ representative value of the (unfavourable) uplift variable groundwater pressures

z vertical distance or the elevation where u is measured (positive upwards) vertical distance of the point in the ground below the ground surface

Greek upper-case letters

Δ relative deflection

Δ/L deflection ratio

Δu_d design excess groundwater pressure

Greek lower-case letters

β angular distortion

γ' buoyant weight density (effective density) of the ground

$\gamma_{c,x}$ partial factor on effective cohesion (where 'x' is replaced by 'p' for peak friction, 'cs' for critical state, 'r' for residual, or 'dis' for along a discontinuity)

γ_{cu} partial factor on shear strength in total stress analysis

γ_{E} partial factor applied to the effect of actions

γ_{F} partial factor on action

γ_{G} partial factor on an unfavourable permanent action

γ_{Gw} partial factor on a permanent water action

$\gamma_{G,fav}$ partial factor on a favourable permanent action

γ_{HYD} partial factor for hydraulic heave

γ_{M} partial factor on a material property

γ_{pv} partial factor for effective vertical overburden pressure

γ_{qu} partial factor on unconfined compressive strength

γ_{Q} partial factor on a variable action

γ_{Qw} partial factor on a variable water action

γ_{R} partial factor on resistance

γ_{rep} representative value of the weight density of the ground

$\gamma_{\tan\delta}$ partial factor on the coefficient of ground/structure interface friction

$\gamma_{\tan\varphi x}$ partial factor on tan φ_x (where 'x' is replaced by 'p' for peak friction, 'cs' for critical state, 'r' for residual, or 'dis' for along a discontinuity)

γ_{w} weight density of groundwater or porewater

$\gamma_{w,rep}$ representative weight density of groundwater

$\gamma_{\tau f}$ partial factor on the shear strength of soil in effective stress analysis

$\gamma_{\tau r}$ partial factor on the shear strength of rock and rock mass

$\gamma_{\tau dis}$ partial factor on the shear strength of rock discontinuities

δ ground/structure interface angle of friction

δ_{s} differential settlement

δ_{X} vertical scale of fluctuation of the property X

η conversion factor accounting for the effect of scale, moisture, temperature, ageing of materials, anisotropy, stress path or strain level.

τ_{f} shear strength in effective stress analysis

φ' effective angle of friction of the ground

$\sigma_{v,d}$ design value of the (stabilizing) vertical total stress at the base of the layer that is subject to uplift.

$\sigma_{v,rep}$ representative value of the (favourable) vertical total stress at the base of the layer that is subject to uplift

$\tan\delta$ coefficient of the ground/structure interface friction

$\tan\varphi'$ coefficient of effective friction

ω tilt

3.2.2 Abbreviations

CC Consequence Class

DCL Design Check Level

DQL Design Qualification (and experience) Level

EFA Effects Factoring Approach

GC Geotechnical Category

GCC Geotechnical Complexity Class

GCR Geotechnical Construction Record

GDM Geotechnical Design Model

GDR Geotechnical Design Report

GIR Ground Investigation Report

GM Ground Model

IL Inspection Level

MFA Material Factor Approach

NDP National Determined Parameter

OM Observational Method

RFA Resistance Factor Approach

VC Verification Case

4 Basis of design

4.1 General rules

4.1.1 Basic requirements

(1) The assumptions given in (1.2) of this document shall be verified.

(2) The design of geotechnical structures shall comply with prEN 1990-1 and EN 1997 (all parts).

(3) The following models shall be used to verify the requirements for safety, serviceability, robustness, and durability of geotechnical structures:

— Ground Model, as specified in FprEN 1997-2:2024, Clause 4;

— Geotechnical Design Model, as specified in 4.2.3.

NOTE Further guidance on reporting, including the Geotechnical Design Model, is given in Annex B.

4.1.2 Geotechnical reliability

4.1.2.1 Zone of influence

(1) The extent of the zone of influence shall be defined.

(2) When defining the extent of the zone of influence consideration should be given, as relevant, but not limited, to:

— the structure and its elements;

— any transient or persistent changes in ground conditions;

— all relevant ultimate limit states of surrounding ground;

— all relevant serviceability limit states;

— all relevant hydraulic or hydrogeological effects;

— topography and geomorphology;

— relevant redistribution of the in-situ stress states; and

— the influence of work undertaken during execution.

(3) The extents of the zone of influence should also take account of:

— environmental impact;

— pollution;

— vibrations; and

— noise.

(4) The extents of the zone of influence shall be estimated prior to the ground investigation.

(5) The extents of the zone of influence should be updated based on the results of the ground investigation and during the design process.

(6) The extent of potential failure surfaces and the potential occurrence of significant ground displacements shall be determined.

(7) In addition to (3), the zone of influence should include the extent of potential transient or persistent changes in the representative groundwater or piezometric levels.

4.1.2.2 Geotechnical Complexity Class

(1) The Geotechnical Complexity Class (GCC) shall be selected using engineering judgement, taking into account complexity and uncertainty in the ground, groundwater conditions and ground-structure interaction.

NOTE 1 General features to consider when selecting GCC are given in Table 4.1(NDP) unless the National Annex gives different features.

NOTE 2 Specific features to consider when selecting the GCC are given in Annex C.

Table 4.1 (NDP) — Selection of Geotechnical Complexity Class

Geotechnical Complexity Class	Complexity	General features
GCC 3	Higher	**Any** of the following apply: — considerable uncertainty regarding ground conditions — highly variable or difficult ground conditions — significant sensitivity to groundwater and surface water conditions — significant complexity of the ground structure interaction
GCC 2	Normal	GCC2 applies if GCC 1 and GCC3 are not applicable
GCC 1	Lower	**All** the following conditions apply: — negligible uncertainty regarding the ground conditions — uniform ground conditions — low sensitivity to groundwater and surface water conditions, — low complexity of the ground structure interaction
NOTE The terms 'considerable', 'significant', 'highly', etc. are relative to any comparable experience that exists for the particular geotechnical structure, design situation, and ground conditions.		

(2) A preliminary GCC should be selected as part of the desk study (see FprEN 1997-2:2024, 5.2.1).

(3) As an alternative to (2), a preliminary GCC may be selected based on a site inspection.

(4) The GCC shall be reviewed and, if appropriate, changed at each stage of design and execution.

(5) The GCC shall be assumed to be GCC3 unless a different class has been determined by the ground investigation.

4.1.2.3 Geotechnical Category

(1) Geotechnical structures shall be classified into a Geotechnical Category that combines the uncertainty and complexity of the ground and ground-structure interaction with the consequence of failure of the structure.

(2) Different parts of a geotechnical structure may be classified in different Geotechnical Categories if the geotechnical complexity or the consequence of failure differs between the parts.

(3) The Geotechnical Category should be determined from a combination of the Consequence Class of the structure and Geotechnical Complexity Class.

NOTE 1 The relationship between Geotechnical Category, Consequences Class, and Geotechnical Complexity Class is given in Table 4.2 (NDP) unless the National Annex gives a different relationship or specifies a direct determination of the Geotechnical Category.

NOTE 2 Guidance on classification of geotechnical structures in Consequence Classes is given in 4.1.3.

NOTE 3 The Consequence Class of the structure is defined by FprEN 1990-1:2024, Table 4.1.

Table 4.2 (NDP) — Relationship between Geotechnical Category, Consequences Class, and Geotechnical Complexity Class

Consequence Class (CC)	**Geotechnical Complexity Class (GCC)**		
	Lower (GCC1)	**Normal (GCC2)**	**Higher (GCC3)**
Higher (CC3)	GC2	GC3	GC3
Normal (CC2)	GC2	GC2	GC3
Lower (CC1)	GC1	GC2	GC2

(4) To ensure the appropriate level of reliability required by prEN 1990-1:2024, 4.2 is obtained, the Geotechnical Category shall be used to specify the extent and amount of the following measures:

— measures to achieve appropriate representation of parameters for design, including:

  — appropriate extent of ground investigation (FprEN 1997-2);

  — validation of available information from Ground investigations (4.2.4);

  — validation of the Geotechnical Design Model (4.2.3);

— measures to achieve accuracy of the calculation models used and the interpretation of their results, including:

  — validation of calculation models (7.1);

— measures to prevent errors in design and execution, and the occurrence of gross human errors, including:

  — designer qualifications and experience (4.1.8);

  — quality management measures (4.1.8);

  - amount and type of reporting (12);

- measures to ensure appropriate implementation of design according to procedures specified in the project documentation, including:

  - supervision (10.2);

  - inspection (10.3);

  - monitoring (10.4);

  - maintenance (10.5).

NOTE 1 Guidance on measures related to designer qualification and experience is given in prEN 1990-1:2024, Annex B.

NOTE 2 Guidance on amount and type of reporting is given in Annex B.

(5) If the measures in (4) are insufficient to obtain the appropriate level of reliability required by prEN 1990-1, additional measures should be taken.

4.1.3 Consequences of failure

(1) In addition to prEN 1990-1:2024, 4.3, the classification of the consequences of failure of a geotechnical structure should account for the potential effects on structures, utilities, and ground within the zone of influence.

NOTE 1 Table 4.3 (NDP) gives examples of geotechnical structures in Consequence Classes CC0 to CC4 unless the National Annex gives other examples.

NOTE 2 The provisions in EN 1997 (all parts) do not entirely cover design rules needed for geotechnical structures classified as CC4. For these structures, additional or amended provisions to those given in EN 1997 (all parts) can be needed.

Table 4.3 (NDP) — Examples of geotechnical structures in different Consequence Classes

Consequence class	Description of consequence	Examples
CC4	Highest	— Geotechnical structures whose integrity is of vital importance for civil protection[a]; — Geotechnical structures in areas with significant landslide hazards.
CC3	Higher	— Retaining walls and foundations supporting public buildings, with high exposure; — Man-made slopes and cuttings and retaining structures with high exposure; — Major road/railway embankments, bridge foundations that can cause severe interruption of service in emergency situations; — Geotechnical structures with a primary navigational function[b]; — Flood barrier protecting a large number of people; — Underground constructions with large occupancy.
CC2	Normal	All geotechnical structures not classified as CC0, CC1, CC3, or CC4
CC1	Lower	— Retaining walls and foundations supporting buildings with low occupancy; — Man-made slopes and cuttings, in areas where a failure will have low impact on society; — Minor road/railway embankments not vital for society; — Underground structures with occasional occupancy[c].
CC0	Lowest	Not applicable for geotechnical structures

[a] Examples of geotechnical structures whose integrity is of vital importance for civil protection are road/railway embankments with a fundamental role in the event of natural disasters, earth dams connected to aqueducts and energy plants, earth dams and tailing dams with extreme consequences upon failure, foundation of nuclear structures, and major harbour structures.

[b] Examples of geotechnical structures with primary navigational function are marking or protecting entrances of ports.

[c] Examples of underground structures with occasional occupancy are culverts not supporting main railway lines or major roads.

4.1.4 Robustness

(1) prEN 1990-1:2024, 4.4 shall apply.

NOTE 1 For most geotechnical structures, design in accordance with the Eurocodes provides an adequate level of robustness without the need for any additional design measures to enhance robustness.

NOTE 2 Appropriate prognosis of climate change affecting the geotechnical structure during its design service life is considered in 4.3.1.4.

(2) Measures to enhance robustness of a geotechnical structure should, as relevant, take into account:

— interaction between different structures or parts of structures;

— interaction between different failure modes affecting the geotechnical structure;

— potential progressive failures in the ground;

— ground conditions with specific issues that are not fully covered by normal design;

— impact on the geotechnical structure due to potential adverse events in the surroundings of the structure; and

— erosive influence of running water.

NOTE 1 Ground conditions with specific issues refer to local ground conditions known, by comparable experience, to be problematic (e.g. quick clay, swelling ground, liquefiable soils).

NOTE 2 Design measures to enhance robustness of geotechnical structure can be given in the National Annex.

(3) Potential strategies for designing geotechnical structures for robustness should provide:

— enough ductility and deformation capacity;

— redistribution of load within the geotechnical structure to avoid sudden collapse;

— increased resistance of critical elements identified within the geotechnical structure;

— addition of a margin to the execution tolerances;

— extra drainage capacity by appropriate design of drainage systems;

— measures to prevent scour leading to erosion of soil under and around a geotechnical structure; and

— restriction on future loads on the ground surface or the structure.

4.1.5 Design service life

(1) In addition to prEN 1990-1:2024, 4.5, the design service life T_{lf} of a geotechnical structure should be specified.

NOTE 1 The value of T_{lf} is given in Table 4.4 (NDP) for different categories of geotechnical structures, unless the National Annex gives different values or categories.

NOTE 2 The design service life of the supported structure is given in prEN 1990-1:2024, Annex A.

Table 4.4 (NDP) — Design service life categories of geotechnical structures

Category of geotechnical structures	Design service life T_{lf} years
Geotechnical structures that support other structures	At least that of the supported structure[a]
Geotechnical structures[b] supporting (or incorporated into) road or railway infrastructure Embankment dams for water defence	100
Geotechnical structures not covered by another category	50
Replaceable parts of geotechnical structure [c]	25
Temporary geotechnical structures	10
Temporary anchors[d]	2

[a] See prEN 1990-1:2024, Annex A

[b] For example, slopes, cuttings, embankments, retaining structures, reinforced fill or soil nailed structures, or ground improvement

[c] Replaceable parts of geotechnical structures (for example anchors)

[d] Durability requirements related to EN 1993-5

4.1.6 Durability

(1) The rules for durability given in prEN 1990-1:2024, 4.6 shall apply to geotechnical structures.

(2) In addition to (1) durability provisions for construction materials in contact with the ground and groundwater shall comply with relevant material and execution standards.

(3) To achieve adequate durability of the geotechnical structure, the design shall take into account the relevant environmental influences given in 4.3.1.4.

(4) Measures should be taken to provide adequate durability over the entire design service life of the geotechnical structure.

(5) If additional repair and strengthening measures are needed to achieve adequate durability of the geotechnical structure, they should be specified in a Maintenance Plan.

(6) As an alternative to (3), measures may be taken to limit the environmental influences.

NOTE Examples of provisions to limit the environmental influences include: insulation to avoid temperature variation, drainage or barriers to avoid seepage, or reduction of contamination in the ground.

4.1.7 Sustainability

(1) The rules for sustainability given in prEN 1990-1:2024, 4.7 shall apply to geotechnical structures.

(2) In addition to (1), specification of measures to enhance sustainability of a geotechnical structure and execution of geotechnical works, should, as relevant, take into account the:

- impact on non-renewable resources within the zone of influence;
- impact on structures, utilities, and ground within the zone of influence;
- impact on environment and economy during the life-cycle, from design stage to end of the structure's design service life; and
- potential re-use of structural elements or construction materials after the end of the structure's design service life.

(3) Potential strategies for designing geotechnical structures for enhanced sustainability should include:

- optimize quantities of materials used;
- utilisation of renewable material;
- inclusion of geothermal elements in the geotechnical structure;
- re-use of structural elements;
- re-use of excavated material within the construction site;
- consideration of the carbon footprint of the materials used and the applied construction procedure; and
- limitation on the use of construction materials that have the potential to cause pollution during execution or during the design service life of the structures.

4.1.8 Quality management

(1) The rules for quality management given in prEN 1990-1:2024, 4.8 shall apply to geotechnical structures.

(2) Quality controls should be implemented at all stages of ground investigation, design, preparation of execution specification, execution, use, and maintenance.

(3) If used, Design Qualification and Experience Levels (DQL), Design Check Level (DCL), and Inspection Levels (IL) should be related to Geotechnical Categories (GC).

NOTE 1 The definitions of DQL, DCL and IL are given in prEN 1990-1:2024, Annex B, together with guidance on the use.

NOTE 2 The relationship between Geotechnical Category (GC) and Design Qualification and Experience Levels (DQL), Design Check Levels (DCL), and Inspection Level (IL), is given in Table 4.5 (NDP) unless the National Annex gives a different relationship.

Table 4.5 (NDP) — Minimum Design Qualification and Experience, Design Check, and Inspection Levels for different Geotechnical Categories

Geotechnical Category	Minimum Design Qualification and Experience Level (DQL)	Minimum Design Check Level (DCL)	Minimum Inspection Level (IL)
GC3	DQL3	DCL3	IL3
GC2	DQL2	DCL2	IL2
GC1	DQL1	DCL1	IL1

4.2 Principles of limit state design

4.2.1 General

(1) The principles of limit state design given in prEN 1990-1:2024, Clause 5 shall apply to geotechnical structures.

(2) In addition to (1), limit states for geotechnical structures shall be verified by one or more of the following methods:

— calculation using the partial factor method (4.4) or other reliability-based methods;

— prescriptive rules (4.5);

— testing (4.6); or

— Observational Method (4.7).

(3) The verification of limit states by any of the methods given in (2) shall provide a level of reliability no less than that required by prEN 1990-1:2024.

(4) The result of the verification shall be compared with previous experience.

4.2.2 Design situations

(1) prEN 1990:2024, Clause 5 shall apply to geotechnical design situations.

(2) In addition to prEN 1990-1:2024, 5.2(1), the physical conditions that define geotechnical design situations shall include the following:

— geometrical properties of the site and the geotechnical structure;

— geometrical and material properties of the ground and groundwater; and

— environmental influences on the structure, ground, and groundwater.

NOTE Examples of changes in the ground or groundwater conditions and their geometrical properties are: adverse effects of excess groundwater pressures depending on the rate of construction, rapid drawdown of water level, propagating cracks in the ground, effects of scour, erosion or dredging on the ground geometry, effects of soluble, expansive or collapsible grounds on the geotechnical structure.

(3) Geotechnical design situations should also include:

— stages of execution, service life, repair, and maintenance;

— potential impact of execution methods on geometrical and ground properties;

— consideration of practicability and buildability;

— anticipated transient or permanent changes that will alter the ground or groundwater conditions, their geometrical properties, or the behaviour of the ground-structure interaction; and

— anticipated placement and removal of ground or storage of building material in the zone of influence.

4.2.3 Geotechnical Design Model

4.2.3.1 General

(1) A Geotechnical Design Model (GDM) shall be developed for each geotechnical design situation, with corresponding combinations of actions and associated relevant limit states.

NOTE The GDM can vary with the type of geotechnical structure; for one geotechnical structure various GDMs can be needed.

(2) The GDM shall be based on the Ground Model.

NOTE Guidance on Ground Model is given in FprEN 1997-2:2024, Clause 4.

(3) The GDM shall be developed after validating the information contained in the Ground Model, according to 4.2.4, regarding variability and uncertainty of the ground conditions.

(4) The GDM shall include representative values of ground properties for all the geotechnical units encountered in the zone of influence.

NOTE 1 Guidance on selection of representative values of ground properties is given in 4.3.2.

NOTE 2 For verification of limit states using the partial factor method, design values of ground properties are determined from representative values.

(5) The GDM shall identify any spatial trend in ground properties.

4.2.3.2 Validation of the Geotechnical Design Model

(1) Each GDM shall be validated to ensure that the level of reliability required by prEN 1990-1:2024 is obtained.

NOTE The validation of a GDM can be achieved by following the provisions given in (2) to (5)

(2) The measures taken to validate the GDM should be selected according to the Geotechnical Category.

NOTE Measures to validate the GDM are given in Table 4.6 (NDP) unless the National Annex gives different measures.

Table 4.6 (NDP) — Measures to validate the Geotechnical Design Model

Geotechnical Category	Measures
GC3	All the measures given for GC2 and GC1 and, in addition: — perform sensitivity analyses of key ground properties to identify any additional information needed to cover all anticipated design situations; — perform sensitivity analyses of key geometrical properties to identify any additional measures that are needed; — confirm that the information available is sufficient to determine the variability of the ground properties and groundwater conditions.
GC2	All the measures given for GC1 and, in addition: — compare derived values from different sources within each geotechnical unit to determine representative values of ground properties with an appropriate level of confidence; — confirm that the GDM includes all ground properties and groundwater conditions affecting the design situation; — confirm that the GDM is appropriate and compatible with the considered ultimate limit states (failure modes) and serviceability limit states; — confirm that the ground properties are determined for a time frame compatible with the considered limit states and design situation.
GC1	All the measures given below: — confirm that the assumed geotechnical units and geotechnical properties is consistent with available information from the desk study and comparable experience; — confirm that the GDM is consistent with information from site inspection.

(3) If the validation process in (1) and (2) indicates that confidence in the GDM is insufficient to obtain the level of reliability required by EN 1990-1, additional ground investigation shall be performed.

(4) As an alternative to (3), other measures may be used to improve confidence in the GDM, provided the measures are specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

(5) To account for any remaining uncertainty in the GDM, different design variants for the design situation, corresponding combinations of actions and associated limit states should be considered.

4.2.4 Validation of information from the Ground Investigation Report

(1) The information from the Ground Investigation Report shall be validated to ensure that the level of reliability required by EN 1990-1 is obtained.

NOTE The validation of information from the Ground Investigation Report can be achieved by following the provisions in (2) to (7).

(2) The quality, quantity, and appropriateness of the information obtained from the Ground Investigation Report (GIR) shall be validated for all relevant design situations, corresponding combinations of actions and associated limit states.

(3) The measures taken to validate the information from the GIR should be selected according to the Geotechnical Category.

NOTE Measures to validate the information in the GIR are given in Table 4.7 (NDP) unless the National Annex gives different measures.

(4) The exclusion of non-relevant information from the GDM should be documented and justified.

(5) In addition to (1), the level of detail and extent of the Ground Model shall be validated.

NOTE 1 Guidance on the Ground Model is given in FprEN 1997-2:2024, Clause 4.

Table 4.7 (NDP) — Measures to validate the information obtained from the GIR

Geotechnical Category	Measures
GC3	All measures given below for GC2 and GC1 and, in addition: — determine relevant quality[a] parameters based on the available data; — confirm that areas with low confidence in the determined geological, hydrogeological and geotechnical conditions do not have a significant influence on the design and verification of the limit state.
GC2	All measures given below for GC1 and, in addition: — compare the consistency of boundaries of the geotechnical units from different sources of information, to confirm that the used methods of interpolation have sufficiently captured the variations; — compare ground description, classification, and strength index test results to identify inconsistencies; — evaluate the performed testing to ensure that the test results are appropriate for the design situation considered, with respect to e.g. loading rate, strain level, stress path and boundary conditions; — confirm that, for the design situation considered, the derived values have been appropriately determined and correlations used within their respective limitations; — confirm that suitable in-situ techniques and laboratory tests have been used in relation to the design situation, ground property and sample quality class (see FprEN 1997-2:2024, 5.4.5).
GC1	All measures given below: — if field investigation and laboratory testing is performed, confirm that appropriate testing standards have been used; — compare derived values from different sources to identify inconsistencies and anomalies; — confirm that anomalies have been identified in the GIR, and — confirm that non-relevant information is not included in the GIR.
[a] Quality parameters include for example sample disturbance, zero-drift for CPT, measurement accuracy.	

(6) If the validation process in (1) and (4) indicates that the quantity, quality, or appropriateness of the information presented in the GIR is insufficient to achieve the level of reliability required by EN 1990-1, additional ground investigation shall be performed.

NOTE Guidance on the minimum amount of ground investigation is given in FprEN 1997-2:2024, Clause 5.

(7) As an alternative to (6), other measures may be used to obtain necessary information, provided they are specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

4.2.5 Impacts within the zone of influence

(1) Design situations shall include the impact of the new structure on existing structures, utilities, and the ground and groundwater within its zone of influence.

NOTE 1 Impacts include groundwater alteration, deformations, noise, vibrations and pollution.

NOTE 2 Additional guidance on design situation is given in 4.2.2.

(2) Design situations shall include the impact of existing structures, utilities, and the ground and groundwater on the new structure within their zones of influence.

(3) Strategies to limit adverse impact within the zone of influence may include:

— limitation of load close to sensitive structures or utilities;

— appropriate selection of installation methods in relation to ground conditions;

— inclusion of physical or chemical barriers to limit the zone of influence; and

— limitation of construction material with the potential to cause pollution during execution or during design service life the structure.

(4) In addition to prEN 1990-1:2024, 5.4, and 9.1 of this document, serviceability criteria for the new structure, existing structures, utilities, ground, and groundwater within the zone of influence should be defined.

(5) The Monitoring Plan shall include provisions that allow potential adverse impacts of the construction works on the behaviour of existing structures, utilities, and the ground and groundwater within the zone of influence, to be determined.

NOTE Guidance on the use of monitoring to limit the impact from execution and the geotechnical structure within the zone of influence and to ensure behaviour within the threshold values is given in 10.4.

(6) The anticipated behaviour during execution may be determined by prognosis (calculation with best-estimate-values) or engineering judgement, or both.

4.3 Basic variables

4.3.1 Actions and environmental influences

4.3.1.1 Classification and representative values of actions

(1) prEN 1990-1:2024, 6.1, shall apply to geotechnical structures.

4.3.1.2 Permanent and variable actions

(1) In addition to prEN 1990-1:2024, 6.1.2.2 and 6.1.2.3, the following potential actions should be included in relevant geotechnical design situations:

— the weight of the ground and groundwater;

— in situ ground stresses and pressures;

— groundwater pressures;

— ground movements and pressures arising from loads imposed on the ground directly or through other structural elements;

— ground movements and pressures caused by pre-existing stresses in the ground or changes thereof;

— ground movements and pressures caused by environmental influences;

— stress and stress changes due to construction and operation; and

— anticipated future structures.

(2) The design of geotechnical structures shall consider the effects of potential interaction between the structure and the ground.

(3) Variable actions arising from traffic loads shall comply with prEN 1991-2:2021, 6.9 and 8.10.

4.3.1.3 Cyclic and dynamic actions

(1) Variable actions that are applied repeatedly or vary systematically during the design service life of the geotechnical structure shall be considered as:

— cyclic actions:

  — when they induce significant ground strength or stiffness degradation, or densification, or generation of excess groundwater pressures, or permanent settlements or vibration in the surrounding ground;

— dynamic actions:

  — when they induce inertial effects on the geotechnical structures;

or

— cyclic and dynamic actions:

  — when the two previous conditions both hold.

NOTE 1 Examples of cyclic or dynamic actions include wind, waves, eccentrically rotating masses, traffic loads, vibrations due to wind turbines and machineries, including those used in geotechnical works.

NOTE 2 Dynamic actions are defined in EN 1990-1.

NOTE 3 Seismic actions are defined in EN 1998-1-1.

4.3.1.4 Environmental influences

(1) prEN 1990-1:2024, 6.1.4 shall apply.

(2) The adverse effects on actions of the following environmental influences shall be considered:

— climate conditions due to precipitation, temperature change, changes in surface water levels and water flow and wind;

— freezing and/or thawing of groundwater and surface water;

— mass displacement due to ground improvement, piling, or other installations in the ground;

— change in groundwater pressure due to construction work or other activities; and

— biological activity.

(3) The adverse effects on the design situation of the following environmental influences shall be considered:

— natural and man-made cavities and underground spaces;

— freezing and/or thawing of groundwater and surface water;

— pre-existing activities at regional scale (dewatering, oil or gas extraction, mining);

— climate change effects such as sea level rise, thawing of permafrost; and

— natural dissolution features.

(4) The adverse effects on the durability of the structure by degradation, corrosion, leaching and erosion, of the following environmental influences shall be considered:

— climate conditions due to precipitation, temperature and wind;

— mechanical damage during transportation, installation and execution;

— freezing and/or thawing of groundwater and surface water;

— electro-chemical composition of ground, groundwater, surface water and any fill;

— salinity of ground, groundwater and surface water;

— weathering effects due to ultra-violet (UV) radiation exposure for UV-sensitive materials;

— mineralogical composition of the ground;

— change of physical, chemical and/or mineralogical composition in the ground or groundwater;

— evaporation;

— any electrical current flowing in the ground;

— biological activity; and

— existing or potential contaminated ground, groundwater, or surface water.

(5) The adverse effects on strength and stiffness properties of ground including its groundwater, and construction material of the following environmental influences shall be considered:

— climate conditions due to precipitation, temperature and wind;

— mechanical damage during transportation, installation, and execution;

— evaporation;

— biological activity; and

— freezing and/or thawing including iteration effects.

(6) The potential adverse effects of environmental influences other than those given in (2) to (5) should be considered.

(7) If the geotechnical structure is in an area with temperatures below or around 0 °C, frost heave and thaw weakening shall be considered in ULS and SLS verifications.

NOTE Guidance on the determination of ground frost susceptibility is given in FprEN 1997-2.

4.3.2 Material and product properties

4.3.2.1 Representative values of ground properties

(1) Representative values of ground properties to be used in ultimate and serviceability limit state verifications shall be determined from derived values presented in the GIR.

NOTE 1 The representative value refers to a particular ground property of a single geotechnical unit.

NOTE 2 Guidance on the selection of representative values of structural material properties or product properties is given in other Eurocodes.

(2) The determination of representative values of ground properties shall take into account:

— pre-existing knowledge including geological information and data from previous projects;

— uncertainty due to the quantity and quality of site-specific data (4.2.4);

— uncertainty due to the spatial variability of the measured property; and

— the zone of influence of the structure at the limit state being considered, throughout the design service life.

(3) The representative value of a ground property shall be determined for each limit state, according to its sensitivity to spatial variability of the ground property in the volume of ground involved.

(4) If the limit state is insensitive to spatial variability of the ground, the representative value of the ground property shall be determined as an average value.

(5) If the limit state is sensitive to spatial variability of the ground, the representative value of the ground property shall be determined as an inferior or superior value.

(6) When available data are considered sufficient to establish the characteristic value of a ground property, the representative value (X_{rep}) should be determined from:

$$X_{\text{rep}} = X_{\text{k}} \tag{4.1}$$

where

X_k is the characteristic value of the ground property.

(7) When the available data are insufficient to establish the characteristic value of a ground property, the representative value (X_{rep}) should be determined from:

$$X_{\text{rep}} = X_{\text{nom}} \tag{4.2}$$

where

X_{nom} is the nominal value of the ground property.

(8) When appropriate, a conversion factor accounting for effects, among others, of scale, moisture, temperature, ageing of materials, anisotropy, stress path or strain level may be used to obtain the representative value of a ground material property by considering either:

$$X_{\text{rep}} = \eta X_{\text{k}} \tag{4.3}$$

or

$$X_{\text{rep}} = \eta X_{\text{nom}} \tag{4.4}$$

where, in addition to the symbols defined for Formula (4.1) and (4.2)

η is a conversion factor accounting for effects of scale, moisture, temperature, ageing of materials, anisotropy, stress path or strain level.

NOTE 1 The value of η is 1.0 for cases where effects of scale, moisture, temperature, ageing of materials, anisotropy, stress path and strain level are already included in selecting the nominal or determining the characteristic value.

NOTE 2 Ageing effects also include weathering effects as exposure to ultra-violet radiation.

NOTE 3 Environmental effects also include chemical effects related to ground pH, hydrolysis, oxidation and biological effects.

4.3.2.2 Characteristic values of ground properties

(1) In addition to prEN 1990-1:2024, 6.2 (2), when the verification of a geotechnical limit state is insensitive to the variability of a ground property, its characteristic value should be defined as an estimate of the mean value.

(2) When the verification of a geotechnical limit state is sensitive to the variability of a ground property, its characteristic value should be defined as an estimate of:

— the 5 % fractile value, where a low (inferior) value of the ground property is unfavourable; or

— the 95 % fractile value, where a high (superior) value of the ground property is unfavourable.

(3) The characteristic value of a ground property (X_{k}) should be determined from either a normal or a log-normal distribution, as appropriate.

NOTE The formula for a log-normal distribution is given in Annex A4.

(4) When a normal distribution is assumed, the characteristic value of a ground property (X_{k}) should be determined from:

$$X_{\text{k}} = X_{\text{mean}}[1 \mp k_{\text{n}} V_{\text{x}}] = X_{\text{mean}}\left[1 \mp \frac{k_{\text{n}} s_{\text{x}}}{X_{\text{mean}}}\right] \tag{4.5}$$

where

X_{mean} is the mean value of the ground property X from a number n of derived values;

V_X is the coefficient of variation of the ground property X;

n is the number of derived values used to determine X_{mean} and s_x;

k_n is a coefficient that depends on the number of sample derived values (n) used to calculate X_{mean};

$\mp$ denotes that $k_n V_X$ should be subtracted when a lower value of X_k is required and added when an upper value is required;

s_x is the standard deviation of the sample derived values.

NOTE 1 Annex A gives a procedure to evaluate the different terms in Formula (4.5) and provides indicative values of V_X for common ground properties and test parameters.

NOTE 2 Different expressions are used for other statistical distributions (see prEN 1990-1:2024, Annex C).

NOTE 3 Other procedures can be used to determine the characteristic values of a ground property varying with depth (e.g. using least squares with regression analysis) or the characteristic values of dependent properties (e.g. cohesion and friction angle).

(5) Other acceptable statistical procedures may be used.

NOTE Acceptable statistical procedures can be based, for example, on Bayesian statistics.

4.3.2.3 Nominal value of ground properties

(1) The nominal value of a ground property X_{nom} shall be selected as a cautious estimate of the (average, inferior, or superior) value affecting the occurrence of the limit state (based on the knowledge of the site and comparable experience).

(2) Indicative values may be used as nominal values provided they are specified by the relevant authority or, when not specified, agreed for a specific project by the relevant parties.

NOTE Indicative values can be given in the National Annex.

(3) Where an indicative value is used as a nominal value, it shall be selected as a very cautious estimate of the value affecting the occurrence of the limit state.

4.3.2.4 Best estimate value of ground properties

(1) The best-estimate value of a ground property, used for prognosis of the behaviour of the geotechnical structure, shall be determined from one of the following:

— most probable value of a sample of derived values of the considered ground property;

— mean, median or mode of a sample of derived values, whichever is most appropriate;

— most probable values obtained by back-analysis carried out to reproduce the performance of a geotechnical structure by monitoring.

4.3.3 Geometrical properties

(1) prEN 1990-1:2024, 6.3 and 8.3.7 or 8.4.6 , as appropriate for the limit state being verified, shall apply to geotechnical design.

(2) Ground surface, surface water level and groundwater levels, boundaries between geotechnical units, and the dimensions of geotechnical structures shall be regarded as geometrical properties.

NOTE Representative values of groundwater and surface water levels are defined in Clause 6.

(3) Geometrical properties of discontinuities in the ground shall include information on location, orientation, spacing, extent, voids or openings, and surface roughness.

(4) The geometrical properties of discontinuities within a geotechnical unit may be considered either:

— as properties of discretely defined discontinuities within the unit; or

— as equivalent ground properties of the unit, when modelled as a continuum.

NOTE Discontinuities and their properties are defined in FprEN 1997-2:2024, 6.2 and 8.1.5.

(5) In addition to prEN 1990-1:2024, 8.3.7, if the design is sensitive to the geometrical properties of the discontinuities, the uncertainty in their presence and properties shall be assessed before defining a_{nom} and Δa.

(6) The nominal value of geometrical properties for ground discontinuities may be determined by sensitivity analysis using a probabilistic approach.

4.4 Verification by the partial factor method

4.4.1 Verification of ultimate limit states

4.4.1.1 General

(1) In addition to prEN 1990-1:2024, 8.3, ultimate limit states that involve the ground should be verified using either:

— the material factor approach (MFA); or

— the resistance factor approach (RFA).

NOTE prEN 1997-3 specifies which approach or approaches can be used for specific geotechnical structures.

(2) When using MFA, partial factors γ_{M} should be applied to ground properties, using Formula (8.19) of prEN 1990-1:2024

NOTE This document gives values of γ_{M} for geotechnical structures.

(3) When using RFA, partial factors γ_{R} should be applied to ground resistance, using Formula (8.20) of prEN 1990-1:2024.

NOTE prEN 1997-3 gives values of γ_{R} for geotechnical structures.

(4) Partial factors should be applied to actions or their effects using either:

— Formula (8.4) of prEN 1990-1:2024, when applying γ_F to actions, or

— Formula (8.5) of prEN 1990-1:2024, when applying γ_E to effects of actions.

NOTE 1 Values of the partial factor γ_F for ultimate limit states are given in prEN 1990-1:2024.

NOTE 2 Values of the partial factor γ_E for ultimate limit states are given in prEN 1990-1:2024.

(5) The consequence of failure should be taken into account by use of a consequence factor, k_F, k_M or k_R.

(6) Only one of the consequence factors k_F, k_M and k_R shall be applied in a single verification.

NOTE 1 Values of k_F are given in prEN 1990-1:2024.

NOTE 2 Values of k_M and k_R for different consequence classes are given in 4.4.1.3 and 4.4.1.5.

(7) In addition to prEN 1990-1:2024, 5.5(3), the geotechnical structure shall be verified for all critical load cases in each relevant design situation.

(8) In addition to prEN 1990-1:2024, 5.1(2) the ultimate limit state may be verified implicitly without computing specific values of E_d and R_d.

4.4.1.2 Design values of the effects of actions

(1) prEN 1990-1:2024, 8.3.2. shall apply in geotechnical design.

(2) When design values of the effects of actions are calculated using Formula (8.4) of prEN 1990-1:2024, partial factors γ_F shall be applied to actions.

NOTE Values of the partial factor γ_F for ultimate limit states are given in prEN 1990-1:2024.

(3) When design values of the effects of actions are calculated using Formula (8.5) of prEN 1990-1:2024, partial factors γ_E shall be applied directly to effects of actions.

NOTE Values of the partial factor γ_E for ultimate limit states are given in prEN 1990-1:2024.

4.4.1.3 Design values of ground properties

(1) In addition to prEN 1990-1:2024, 8.3.5, when design values of geotechnical resistance are calculated using Formula (8.19) of prEN 1990-1:2024, partial factors γ_M should be applied to ground properties.

NOTE 1 Values of the partial factor γ_M for persistent and transient design situations are given in Table 4.8 (NDP) unless the National Annex gives different values.

NOTE 2 Values of the partial factors for resistance are given in prEN 1997-3:2022.

NOTE 3 The value of γ_M for an accidental design situation is equal to the square root of the value of γ_M for the corresponding persistent design situation, unless the National Annex gives a different value.

NOTE 4 Values of k_M for different consequence classes are given in Table 4.9 (NDP) unless the National Annex gives different values.

(2) The design value of a ground property may be determined directly, in accordance with prEN 1990-1:2024, 8.3.6(2).

Table 4.8 (NDP) — Partial factors on ground properties for persistent and transient design situations

Ground property	Symbol	M1[a]	M2[a]
Soil and fill			
Shear strength in effective stress analysis[b] (τ_f)	$\gamma_{\tau f}$	1,0	1,25 k_M
Coefficient of peak friction ($\tan \varphi'_p$)[d]	$\gamma_{\tan\varphi,p}$	1,0	1,25 k_M
Peak effective cohesion (c'_p)	$\gamma_{c,p}$	1,0	1,25 k_M
Coefficient of friction at critical state ($\tan \varphi'_{cs}$)[d]	$\gamma_{\tan\varphi,cs}$	1,0	1,1 k_M
Coefficient of residual friction ($\tan \varphi'_r$)[d]	$\gamma_{\tan\varphi,r}$	1,0	1,1 k_M
Residual effective cohesion (c'_r)	$\gamma_{c,r}$	1,0	1,1 k_M
Shear strength in total stress analysis[b] (c_u)	γ_{cu}	1,0	1,4 k_M
Unconfined compressive strength (q_u)	γ_{qu}	Same as γ_{cu}	
Rock material and rock mass[f]			
Shear strength (τ_r)	$\gamma_{\tau r}$	1,0	1,25 k_M
Unconfined compressive strength[c] (q_u)	γ_{qu}	1,0	1,4 k_M
Rock discontinuities			
Shear strength[e]	$\gamma_{\tau dis}$	1,0	1,25 k_M
Coefficient of residual friction[f] ($\tan \varphi'_{dis}$)	$\gamma_{\tan\varphi dis,r}$	1,0	1,1 k_M
Interface			
Coefficient of ground/structure interface friction ($\tan \delta$)	$\gamma_{\tan\delta}$	1,0	1,25 k_M

[a] M1 and M2 are alternative sets of material factors. prEN 1997-3:2022 specifies which set to use for specific geotechnical structures.

[b] Intended to be used for numerical models.

[c] Used for foundation purposes only.

[d] Partial factor is applied to $\tan\varphi$.

[e] Used when roughness component is neglected.

[f] Values of partial factors shown for soil and fill can be used for weak, highly fractures rock masses, in cases when soil mechanics concepts are found to apply.

Table 4.9 (NDP) — Consequence factors k_M

Consequence class (CC)	Description of consequences	Consequence factor k_M
CC3	Higher	1,1
CC2	Normal	1,0
CC1	Lower	0,9

(3) The inferior design value of a ground property $X_{d,inf}$ should be calculated from:

$$X_{d,inf} = \frac{X_{rep,inf}}{\gamma_M} \tag{4.6}$$

where

$X_{rep,inf}$ is the inferior representative value of the ground property X;

γ_M is a partial material factor.

NOTE 1 In most cases, the inferior design value of a ground property is used.

NOTE 2 Although the weight density of ground is not factored, actions arising from weight density can be factored.

(4) The superior design value of a ground property $X_{d,sup}$ should be obtained from:

$$X_{d,sup} = X_{rep,sup}\gamma_M \quad (4.7)$$

where

$X_{rep,sup}$ is the superior representative value of the ground property X;

γ_M is a partial material factor.

NOTE For example, a superior design value is needed to determine downdrag.

(5) Effective cohesion at the critical state shall be assumed to be zero.

NOTE Residual cohesion should be taken as zero, unless measured in an appropriate test.

(6) When design values of geotechnical resistance are calculated using Formula (8.19) of prEN 1990-1:2024 the partial material factor:

— $\gamma_{\tau f}$ may be applied directly to the effective shear strength of soil, τ_f;

— $\gamma_{\tau r}$ may be applied directly to the shear strength of rock material and rock mass, τ_r; and

— $\gamma_{\tau dis}$ may be applied directly to the shear strength of discontinuities, τ_{dis}.

(7) The value of γ_M for transient design situations may be multiplied by a reduction factor k_{tr}, provided that the product $k_{tr}\gamma_M$ is not less than 1,0.

(8) The value of k_{tr} may be ≤ 1,0, provided any constrains on its use is satisfied.

NOTE 1 The value of k_{tr} is 1,0 unless the National Annex gives a different value.

NOTE 2 Constrains on the use of k_{tr} < 1,0 can be given in the National Annex.

4.4.1.4 Design values of geometrical properties

(1) prEN 1990-1:2024, 8.3.7 shall apply in geotechnical design.

NOTE See also 4.3.3.

4.4.1.5 Design values of resistance

(1) When design values of geotechnical resistance are calculated using Formula (8.20) of prEN 1990-1:2024, partial factors γ_R should be applied directly to resistance.

NOTE 1 The value of γ_R for an accidental design situation is equal to the square root of the value of γ_R for the corresponding persistent design situation, unless the National Annex gives a different value.

NOTE 2 The values of the consequence factor k_R are given in Table 4.10 (NDP), unless the National Annex gives different values.

Table 4.10 (NDP) — Consequence factors k_R

Consequence class (CC)	Description of consequences	Consequence factor k_R
CC3	Higher	1,1
CC2	Normal	1,0
CC1	Lower	0,9

(2) The value of γ_R for transient design situations may be multiplied by a reduction factor k_{tr}, provided that the product $k_{tr}\gamma_R$ is not less than 1,0 and any constraints on its use are satisfied.

NOTE The value of k_{tr} and constraints on its use are given in 4.4.1.3(8).

4.4.1.6 Combination of actions

(1) prEN 1990-1:2024, 8.3.4 shall apply in geotechnical design.

4.4.2 Verification of serviceability limit states

(1) prEN 1990-1:2024, 8.4 shall apply in geotechnical design.

NOTE See also Clause 9.

4.5 Verification by prescriptive rules

(1) If prescriptive rules are used for verification of limit states involving geotechnical structures, they shall only be applied for their specified application and within their known limitations.

NOTE Prescriptive rules for verification of limit state can be used for verification of limit states unless the National Annex gives limitations for their applications.

(2) Prescriptive rules shall be suitably conservative and justified by comparable experience.

(3) Prescriptive rules shall specify the applications for which they can be used and their known limitations.

(4) Prescriptive rules shall be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

NOTE Prescriptive rules for geotechnical structures can be specified in the National Annex.

4.6 Verification by testing

(1) Prior to testing a geotechnical structure or structural element, the anticipated result of the test shall be determined.

(2) The verification shall include a range of different testing variants, covering all relevant foreseeable ground responses and ground-structure interactions.

NOTE Guidance on testing to verify limit state directly and evaluation of test results is given in Clause 11.

4.7 Verification by the Observational Method

(1) When using the Observational Method to verify limit states, a range of different design variants (including corresponding Geotechnical Design Models) shall be established, covering all foreseeable relevant ground responses and ground-structure interactions.

(2) If monitoring of the relevant ground responses and ground-structure interactions does not allow detection of incipient failures, the Observational Method shall not be used.

(3) A contingency plan shall be prepared that defines contingency measures to be applied when actual behaviour reaches acceptance criteria or threshold values.

NOTE Guidance on the content of the contingency plan for Observational Method is given in 10.6.

(4) Contingency measures shall include methods for preventing immediate failure and instructions for selecting a prepared design variant that covers the actual ground response and ground-structure interaction.

(5) Ultimate and serviceability limit states shall be verified for each design variant.

(6) Execution specifications shall be prepared for each design variant.

(7) There shall be sufficient design variants to allow replacement of the current design variant by one matching the observed behaviour of the structure when the threshold value is reached.

(8) An Inspection Plan and a Monitoring Plan shall be devised to check the assumptions against the specified acceptance criteria and threshold values for each design variant.

NOTE Guidance on implementation of design during execution using Observational Methods is given in 10.6.

(9) The design shall be adapted to the evaluated results in (8) by application of the contingency plan.

5 Materials

5.1 Ground

(1) Ground properties shall be determined according to FprEN 1997-2:2024.

5.2 Engineered fill

(1) The criteria for specifying material as suitable for use as engineered fill shall be based on achieving the required strength, stiffness, durability, permeability, and classification, after placing and compaction.

(2) The criteria for specifying material as suitable for use as engineered fill shall take account of the purpose of the engineered fill and the requirements of any structure that is placed on it.

(3) Engineered fill in earthworks should comply with EN 16907 (all parts).

(4) Measures shall be taken to ensure material placed as fill within the construction works does not cause contamination of the environment, ground, or groundwater.

5.3 Geosynthetics

(1) The properties of geosynthetics incorporated into geotechnical structures should comply with ENs 13249 to EN 13257 ,EN 13265 and 13738.

(2) Geosynthetic reinforcement shall comply with EN 14475.

(3) Vertical drainage in the ground shall comply with EN 15237.

5.4 Grout

(1) Grout for anchors shall comply with EN 1537.

(2) The properties of compounds of grout for rock bolts should comply with EN 206.

NOTE The National Annex can specify relevant standards giving additional rules for grout for rock bolts.

(3) Grout for soil nails shall comply with EN 14490.

(4) Grout for micropiles shall comply with EN 14199

(5) Grout placed in the ground shall comply with EN 12715.

(6) Grout used for jet-grouting shall comply with EN 12716.

(7) The choice of cement and water/cement ratio should take into account the aggressiveness of the environment, as specified in EN 206 or be based on comparable experience.

(8) Unless preliminary tests prove that grout or mortar is sufficient to resist the maximum proof load, its strength should be determined by comparable experience or testing.

(9) Grout placed in soil, should have a compressive strength equivalent to concrete class C25/30 according to EN 206, unless another value is specified in the Geotechnical Design Report.

NOTE Requirements for grout for a specific geotechnical structure are given in prEN 1997-3.

(10) Grout placed in rock mass, should have a compressive strength equivalent to concrete class C35/45 according to EN 206, unless another value is specified in the Geotechnical Design Report.

(11) The compressive and tensile strength of grout or mortar should be assessed from comparable experience or testing.

5.5 Plain and reinforced concrete

(1) Plain and reinforced concrete for geotechnical structures shall comply with EN 1992-1-1 and EN 206.

(2) Weldable reinforcing steel for reinforced concrete used for geotechnical structures should comply with EN 10080.

NOTE The National Annex can specify relevant standards giving additional rules for reinforcing elements.

(3) Steel reinforcement for wire, wire ropes, and link chains should comply with relevant standards for prestressing steel.

NOTE 1 The National Annex can specify relevant standards for prestressing steel.

NOTE 2 The harmonized product standard prEN 10138 for prestressing steel is currently under development.

NOTE 3 EN 10138-3 provides rules for prestressed steel bars.

(4) Tolerances for concrete spread foundations shall comply with EN 13670.

(5) Sprayed concrete incorporated into geotechnical structures shall comply with EN 14487 (all parts).

(6) The flexural strength and energy absorption capacity of fibre reinforced sprayed concrete should be determined in accordance with EN 14488 (all parts).

(7) The flexural strength of sprayed concrete without fibre reinforcement should be determined in accordance with EN 14651.

(8) The density of concrete and mortar shall comply with EN 1991-1-1.

NOTE Values of weight density are given in prEN 1991-1-1:2022, Table A.1

(9) The resistance to water penetration should be determined in accordance with EN 12390-5.

(10) The static modulus of elasticity in compression of hardened concrete should be determined in accordance with ISO 1920-10 and EN 1992-1-1.

5.6 Steel

(1) Steel for geotechnical structures and the values of steel parameters shall comply with EN 1993-1-10 and EN 1993-5.

(2) The effects of potentially deleterious stray currents should be investigated in accordance with EN 50162.

5.7 Timber

(1) Timber for geotechnical structures and the values of timber parameters shall comply with EN 1995-1-1.

(2) The minimum grade of timber should be SS for softwoods or HS for hardwoods conforming to EN 1912:2012, Tables 1 and 2.

5.8 Masonry

(1) Masonry incorporated into geotechnical structures shall comply with EN 1996 (all parts).

6 Groundwater

6.1 General

(1) The spatial and temporal variation of surface water and groundwater and the resulting piezometric levels, groundwater pressures, hydraulic gradients and seepage forces in the ground shall be determined.

NOTE 1 Guidance about hydrogeological conditions is given in FprEN 1997-2

NOTE 2 prEN 1997-3:2022, Clause 12 gives guidance about groundwater control techniques.

NOTE 3 For actions due to surface water on geotechnical structures, e.g. static pressure, scour and erosion, guidance is given in prEN 1990-1:2024, A.6; EN 1991-1-8; and CIRIA C731.

(2) The determination of piezometric levels, groundwater pressures, hydraulic gradients, and seepage forces should consider:

— their variation over time;

— spatial heterogeneity of the ground;

— aquifer and aquitard layers;

— anisotropy of the ground and hydraulic conductivity;

— construction works including effects on groundwater flow and drainage;

— supply of water by rain, flood, burst water mains or other means;

— zone of influence;

— potential changes of groundwater pressures due to the growth or removal of vegetation; and

— expected climatic changes.

(3) Groundwater pressure (u), shall be determined from:

$$u = \gamma_{\mathrm{w}}(h_{\mathrm{wz}} - z) \tag{6.1}$$

where

γ_{w} is the weight density of the pore water;

z is the elevation where u is measured (positive upwards); and

h_{wz} is the piezometric level at elevation z.

(4) Groundwater pressures arising from a common source of groundwater or surface water should be considered as a single action.

NOTE This rule is commonly known as the ‘single-source principle’ (prEN 1990-1:2024, 6.1.1).

(5) When a single source of groundwater action produces both favourable and unfavourable effects, the critical load cases involving upper and lower piezometric levels and the resulting groundwater pressures shall be identified and verified.

(6) Groundwater pressures should be determined by considering potential interactions between groundwater and the surface water.

(7) If the groundwater pressure is not hydrostatic, the variation of groundwater pressures in all directions should be determined in all geotechnical units identified in the Geotechnical Design Model.

(8) Groundwater pressures may be classified as accidental actions when:

— the annual probability of exceedance is less than that specified in prEN 1990-1:2024, 6.1.3.2(6);

— they are caused by extreme events with a probability of exceedance less than specified in 6.4(1);

— engineered systems fail owing to a deficiency; or

— the drainage system fails.

(9) Pore water suction shall only be considered for unsaturated ground conditions when the anticipated degree of saturation will be maintained throughout the design situation.

6.2 Properties of groundwater

(1) The effects of groundwater chemistry on the ground and on construction materials in contact with the ground shall be determined.

(2) The exposure classes for concrete or chemical environment for other materials (steel, timber, etc.) in contact with groundwater should comply with EN 206, EN 1992-1-1, EN 1993-1-1, or EN 1996-1-1.

(3) The presence, type, and amount of solutes in the groundwater should be determined.

(4) In the absence of significant quantities of solutes, the representative value of weight density of groundwater may be assumed to be 10 kN/m^3.

6.3 Measurements

(1) Surface water, groundwater, and piezometric levels (and associated groundwater pressures) shall be measured to determine the most critical design situation.

(2) Surface water, groundwater and piezometric levels, and groundwater pressures should be determined by direct measurements, taking into account the available historical data.

(3) In the absence of reliable direct measurements, surface water, groundwater, and piezometric levels may be determined from historical data alone.

(4) Representative values of piezometric levels should correspond to the annual probability of exceedance of the groundwater pressures that arise from them.

NOTE The annual probability of exceedance of the representative values of the groundwater pressures is given in 6.4.

6.4 Representative values of groundwater pressures

(1) If there is sufficient data to derive its value on the basis of the annual probability of exceedance, the representative value of groundwater pressure $F_{w,rep}$ should be selected as either:

— a single permanent value, equal to the characteristic upper $G_{wk,sup}$ or lower $G_{wk,inf}$ value of groundwater pressure (whichever is more adverse according to the considered limit state); or

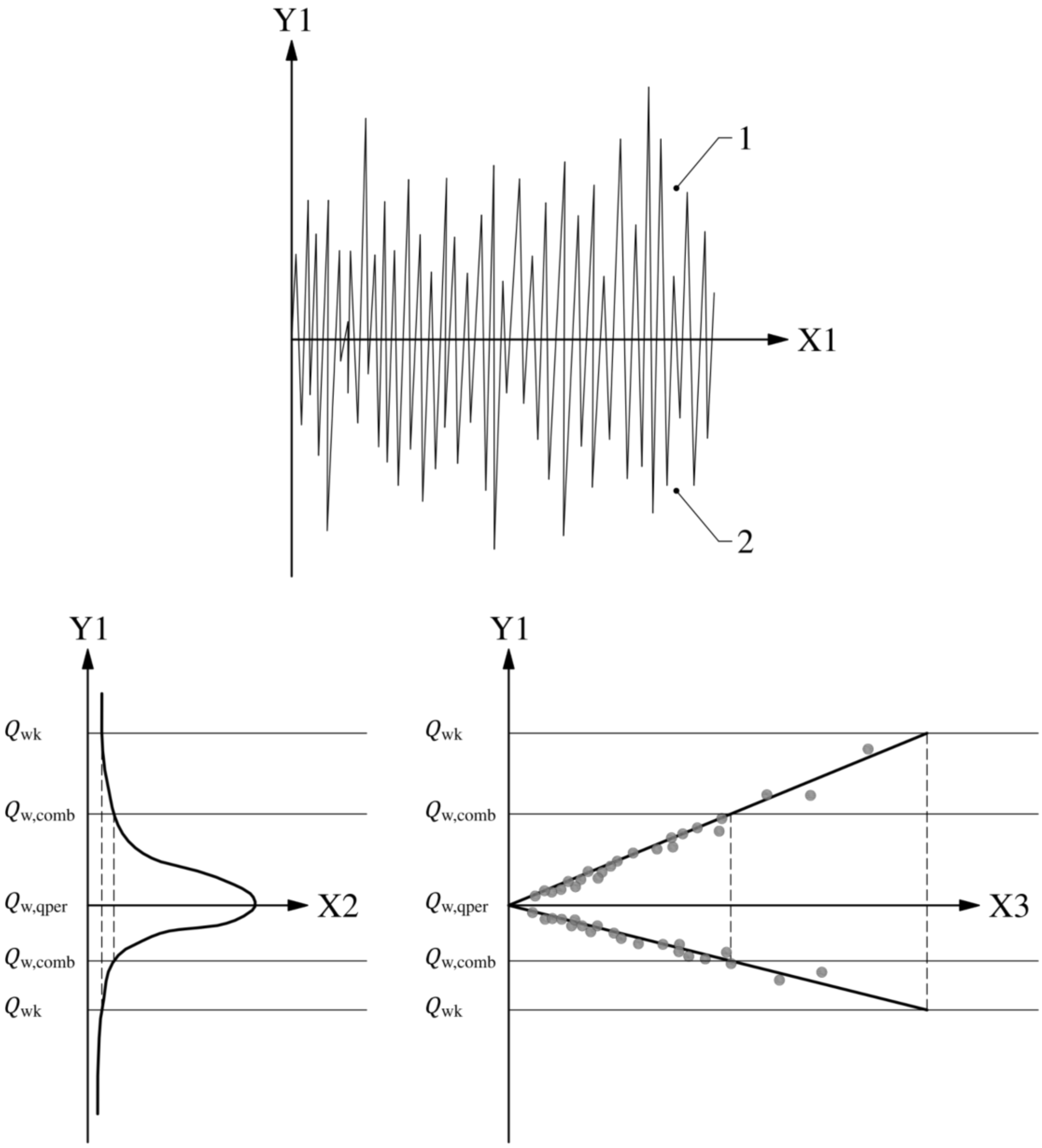
— the combination of:

  — a permanent value G_{wk}, equal to the mean value of groundwater pressure, and

  — a variable value, equal to the representative value $Q_{w,rep}$ of the variation in groundwater pressure.

NOTE 1 The values of $G_{wk,sup}$ and $G_{wk,inf}$ are based on an annual probability of exceedance of 2 %, as given in prEN 1990-1:2024, 6.1.3.2

NOTE 2 Figure 6.1 illustrates the different terms used to denote representative values of groundwater pressure, as defined in prEN 1990-1:2024, 6.1.3.2.



Key

X1	time	Y	groundwater pressures, Piezometric levels
X2	probability density (annual maximal)	1	higher values
X3	log *t* return period	2	lower values

Figure 6.1 — Representative values of groundwater pressures — illustration of characteristic, combination, frequent, and quasi-permanent values.

(2) If there is insufficient data to derive their values from statistics, $G_{wk,sup}$ and $G_{wk,inf}$ should be selected as cautious estimates of the most adverse values likely to occur during the design situation.

(3) The representative value $Q_{w,rep}$ of the amplitude of the variation in groundwater pressure shall be selected as one of the following, depending on the design situation:

— the characteristic value Q_{wk}; or

— the combination value $Q_{w,comb}$; or

— the frequent value $Q_{w,freq}$; or

— the quasi-permanent value $Q_{w,qper}$.

NOTE The values of Q_{wk}, $Q_{w,comb}$, $Q_{w,freq}$, and $Q_{w,qper}$ are based on the probabilities of exceedance given in prEN 1990-1:2024, 6.1.3.2.

(4) In persistent and transient design situations, $Q_{w,rep}$ shall be selected as:

— the characteristic value (Q_{wk}), when groundwater pressure is the leading variable action; or

— the combination value ($Q_{w,comb}$), when groundwater pressure is an accompanying variable action.

(5) For simplicity, the combination value ($Q_{w,comb}$) may be replaced by the more adverse characteristic value ($Q_{wk} \geq Q_{w,comb}$) for the superior value and ($Q_{wk} \leq Q_{w,comb}$) for the inferior value .

(6) If there is insufficient data to determine their values from statistics, Q_{wk} ,$Q_{w,comb}$ and $Q_{w,freq}$ should be selected as a cautious estimate of the most adverse value likely to occur during the design situation.

(7) If there is insufficient data to determine its value from statistics, the quasi-permanent value $Q_{w,qper}$ should be selected as a cautious estimate of the mean value likely to occur during the design situation.

(8) In accidental design situations, $Q_{w,rep}$ shall be selected as:

— the accidental value (A_{wd}) where groundwater pressure is the leading variable action; or

— the frequent value ($Q_{w,freq}$) or the quasi-permanent value ($Q_{w,qper}$) where groundwater pressure is an accompanying variable action.

NOTE The value of A_{wd} is based on the annual probability of exceedance given in prEN 1990-1:2024, 6.1.3.2.

6.5 Design values of groundwater pressures

6.5.1 Design values of groundwater pressures for ultimate limit state design

(1) Design values of groundwater pressures in the ultimate limit states shall be determined by one of the following methods:

— direct assessment; or

— applying a deviation to the representative piezometric level or to the representative groundwater pressure; or

— applying a partial factor to the representative groundwater pressures or to their action effects.

NOTE 1 Methods that involve direct assessment or application of a deviation are usually suitable in cases where groundwater pressures are used to calculate shear strength from effective stresses (e.g. overall stability analyses or retaining wall design). Application of a partial factor is usually suitable in cases where groundwater pressures are used to calculate forces and bending moments on structural elements.

NOTE 2 The value of the partial factor is given in prEN 1990-1:2024, Table A.1.8.

(2) When assessing design groundwater pressures directly or by applying a deviation to the representative piezometric level or groundwater pressure, design values of groundwater pressures for ultimate limit states shall have a probability of exceedance as specified in prEN 1990-1:2024.

(3) For accidental design situations, where the groundwater pressures are not the accidental action, design groundwater pressures may be taken equal to a combination of the representative permanent value G_{wk} and the frequent variable value $Q_{\mathrm{w,freq}}$.

NOTE For accidental design situations, the design value of the leading action is selected directly. The accompanying design actions are set equal to frequent values.

6.5.2 Design values of groundwater pressures for serviceability limit state design

(1) Design values of groundwater pressures in serviceability limit states shall be equal to the representative values defined in 6.4.

7 Geotechnical analysis

7.1 Calculation models

7.1.1 General

(1) Calculation models shall be validated to ensure that a level of reliability no less than that specified in prEN 1990-1:2024 is provided.

NOTE The validation of the calculation models can be achieved by following the provisions in (2) to (7).

(2) Calculation models shall be appropriate for the limit state being considered.

(3) The assumptions, including idealisations and limitations, of calculation models should be stated in the Geotechnical Design Report.

(4) Calculation models used to verify limit states should consider the following aspects as model inputs:

— model geometry including discretization and boundary conditions (mechanical, hydraulic and thermal);

— zones of heterogeneity and discontinuities;

— initial in-situ stress states;

— piezometric levels or groundwater pressures;

— ground properties and structural elements properties;

— effects of permanent, variable, cyclic and dynamic actions; and

— construction stages and loading rates.

(5) Parametric analyses may be performed to assess the effects of model inputs on the results of the calculation models and to refine their selection.

(6) Calculation models shall be validated to ensure that they are appropriate for the specific design situation and are applied within their limitations.

(7) The minimum level of validation of calculation models used in geotechnical design shall be determined according to the Geotechnical Category.

NOTE 1 The minimum level of validation of calculation models used in geotechnical design is given in Table 7.1 (NDP) unless the National Annex gives a different minimum level.

NOTE 2 Knowledge of the ground and workmanship control is to be considered as more significant in fulfilling the fundamental requirements than the precision in the calculation models.

Table 7.1 (NDP) — Measures to validate the calculation models

Geotechnical Category	Level of validation	Measures
GC3	High	All the measures given below for GC2 and, in addition: • calibrate the calculation model for all relevant design situations against another suitable calculation model or site observations.
GC2	Normal	All the measures given below: • confirm that the assumptions underlying the calculation model are relevant for all relevant design situations; • document the assumptions made in the calculation model; • document literature reference that the calculation model has been used for comparable design situations; and • confirm that any calculation model used falls within the limits of application stated in prEN 1997-3:2022.
GC1	Low	All the measures given below: • confirm that comparable experience exists showing that the calculation model is suitable for the local conditions; • confirm that any calculation model used falls within the limits of application stated in prEN 1997-3:2022.

7.1.2 Empirical models

(1) Empirical models may be used for the verification of limit states.

NOTE Empirical models are often intended for certain ground and site conditions. Therefore, they often have a narrow range of such conditions for which they are suitable.

7.1.3 Analytical models

(1) Analytical models may be used to verify limit states.

(2) Limit equilibrium analysis in ground with discontinuities (including rock mass and very stiff clay) should take into account the shear strength along the discontinuities that control the limit states.

(3) For the implicit verification of serviceability limit states, limit equilibrium and limit analysis models should only be used in accordance with 9.1(4).

7.1.4 Numerical models

(1) Numerical models may be used for the verification of limit states including the assessment of failure modes and ground movements.

(2) Numerical models shall be appropriate for the quality and quantity of data available for determining input parameters.

NOTE Simple models can provide more accurate results than complex models.

(3) The choice between continuum or discrete model shall be based on the problem being analysed taking into account the type of ground and the effects of discontinuities.

(4) The validation of the numerical model should be consistent with its complexity.

7.1.5 Calculation models for cyclic and dynamic actions

(1) Appropriate calculation models should be selected to determine the effects of cyclic and dynamic actions.

(2) Cyclic effects listed in 4.3.1.3(1) shall be determined for both the ultimate and serviceability limit states.

(3) When the expected effects of dynamic actions listed in 4.3.1.3(1) are significant, a full dynamic interaction analysis should be performed with modelling of the structure, its foundation, and the dynamic action.

NOTE The aim of design analyses of machine foundations is to ensure the prediction is within both ultimate and serviceability limit states. Serviceability limit state criteria are typically specified as peak velocity, maximum displacement, or acceleration amplitude during normal operation of the machinery.

(4) When dynamic actions are represented by quasi-static actions, ground properties should be selected appropriately for the frequency, the duration and the amplitude of the dynamic actions.

NOTE 1 Quasi-static actions are defined in prEN 1990-1:2024.

NOTE 2 FprEN 1997-2:2024, Clause 10, gives ground properties for verification of ultimate and serviceability limit states when cyclic or dynamic actions are involved.

7.2 Model factors

(1) Model factors should be used to adjust any significant bias and additional uncertainty in a calculation model compared with a reference model.

NOTE Suitable reference models include:

— comparable experience based on case histories;

— a full-scale monitored prototype of the geotechnical structure (for example, pile test, trial embankment);

— small-scale physical model that reproduces the limit states being considered (the validity of the model is ensured if its scale is such that the expected behaviour at the prototype scale is reproduced);

— theoretical model for which closed form or numerical solutions for the limit states being considered are available (for example, Prandtl's solution for shallow foundations, steady state seepage under a sheet pile wall, consolidation settlement in one dimension).

(2) The value of the model factor should not be less than 1,0.

NOTE 1 Model factors for the reference model already include an allowance for some bias and uncertainty.

NOTE 3 The value of the model factor is 1,0 unless the National Annex gives a different value for a specific calculation model.

NOTE 4 Guidance on suitable values for model factors for certain geotechnical structures is given in prEN 1997-3.

(3) Model factors should be used to ensure that calculation models are sufficiently accurate for their intended purpose and provide a level of reliability no less than that specified in prEN 1990-1:2024.

8 Ultimate limit states

8.1 Type of ultimate limit states

8.1.1 Failure by rupture

(1) In addition to the limit states given in prEN 1990-1:2024, 5.3(3), the following potential ultimate limit states caused by rupture of the ground shall be verified:

— rupture of the ground passing outside the geotechnical structure;

— translational and rotational failure of ground mass or rock blocks;

— loss of bearing capacity and sliding of foundations; and

— loss of geotechnical resistance of a structural element embedded in the ground.

NOTE Guidance on rupture of the ground for different geotechnical structures is given in prEN 1997-3.

(2) In addition to (1), other potential ultimate limit states caused by rupture of the ground should be verified.

8.1.2 Failure due to excessive deformation of the ground

(1) In addition to the limit states given in prEN 1990-:2024, 5.3(3), the following potential ultimate limit states of the structure or structural member caused by excessive deformation of the ground shall be verified:

— failure of a structural element owing to excessive deformation of the ground mass;

— failure of a structural element owing to excessive movements of its own foundation (without rupture of the ground); and

— failure of an existing structural element owing to the execution of another construction.

NOTE Examples of excessive deformation of the ground mass is down drag, swelling, shrinkage.

(2) In addition to (1), other potential ultimate limit states caused by excessive deformation of the ground should be verified.

8.1.3 Failure by loss of static equilibrium of the structure or ground

8.1.3.1 Loss of static equilibrium by rotation (toppling)

(1) Loss of static equilibrium due to the rotation of the structure or part of it shall be prevented by verifying that destabilizing design moments are less than or equal to the stabilizing design moments about the assumed point of rotation, with partial factors applied to actions using Verification Case 2 of prEN 1990-1:2024.

NOTE 1 See prEN 1990-1:2024, 8.3.3.1(5).

NOTE 2 Verification by comparison of stabilizing and destabilizing moments is only applicable if the point of rotation is known, which is the case only when the ground resistance is sufficiently high. For example, verification of toppling of a rigid body (such as a gravity retaining wall) founded on rock.

NOTE 3 Overturning, involving failure in the ground, is verified according to 8.1.1.

8.1.3.2 Loss of vertical equilibrium due to uplift

(1) Loss of static equilibrium due to uplift of an impermeable structure or a ground layer of low permeability shall be prevented by verifying that unfavourable design vertical forces are less than or equal to the favourable design vertical forces (including any resistance to uplift).

(2) If the structure or ground layer acts as a rigid body (Figure 8.1c, 8.1d and 8.1e), it shall be verified, using Verification Case 2 from prEN 1990-1:2024, that:

$$\gamma_{\mathrm{Gw}} U_{\mathrm{G,rep}} + \gamma_G G_{\mathrm{rep}} + \gamma_{\mathrm{Qw}} U_{\mathrm{Q,rep}} + \gamma_{\mathrm{Q}} Q_{\mathrm{rep}} - \gamma_{\mathrm{G,fav}} G_{\mathrm{rep,fav}} \leq R_{\mathrm{d}} \quad (8.1)$$

where

$U_{\mathrm{G,rep}}$	is the representative value of the (unfavourable) uplift force due to permanent groundwater pressures;
G_{rep}	Is the representative value of any unfavourable permanent force (acting upwards) that are not caused by groundwater pressures;
$U_{\mathrm{Q,rep}}$	is the representative value of the (unfavourable) uplift forces due to variable groundwater pressures;
Q_{rep}	is the representative value of any unfavourable variable force (acting upwards) that are not caused by groundwater pressures;
$G_{\mathrm{rep,fav}}$	is the representative value of the favourable permanent forces (acting downwards);
R_d	is design value of any resistance to uplift;
γ_{Gw}, $\gamma_{\mathrm{G,}}$, $\gamma_{\mathrm{Qw,}}$, $\gamma_{\mathrm{Q,}}$, $\gamma_{\mathrm{G,fav,}}$	are partial factors on action.

NOTE 1 The values of γ_{Gw}, $\gamma_{\mathrm{G,}}$, $\gamma_{\mathrm{Qw,}}$, $\gamma_{\mathrm{Q,}}$, $\gamma_{\mathrm{G,fav}}$ are given in prEN 1990-1:2024, Annex A

NOTE 2 The contribution of piles, anchors, etc. to R_{d} is determined according to prEN 1997-3.

(3) If the structure or ground layer does not act as a rigid body (Figure 8.1a and 8.1b), it shall be verified, using Verification Case 2 from prEN 1990-1:2024, that:

$$\gamma_{Gw} u_{\mathrm{G,rep}} + \gamma_{Qw} u_{Q,rep} - \gamma_{G,fav} \sigma_{\mathrm{v,rep}} \leq 0 \quad (8.2)$$

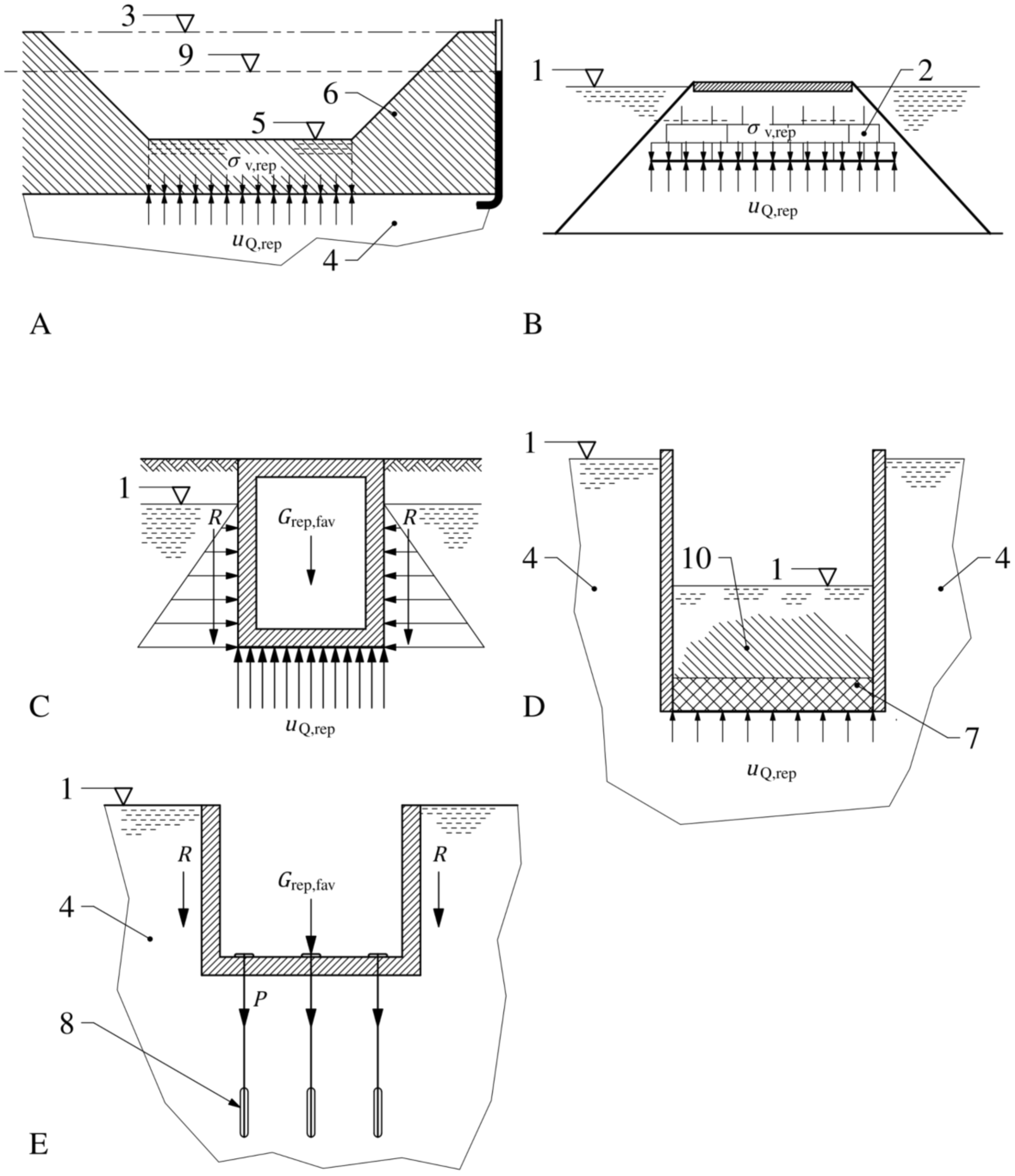
where

$u_{\mathrm{G,rep}}$	is the representative value of the (unfavourable) uplift permanent groundwater pressures;
$u_{\mathrm{Q,rep}}$	is the representative value of the (unfavourable) uplift variable groundwater pressures;
$\sigma_{\mathrm{v,rep}}$	is the representative value of the (favourable) vertical total stress at the base of the layer that is subject to uplift; and
γ_{Gw}, γ_{Qw}, $\gamma_{\mathrm{G,fav}}$	are partial factors on action.

NOTE 1 The values of γ_{Gw}, γ_{Qw}, and $\gamma_{\mathrm{G,fav}}$ are given in prEN 1990-1:2024, Annex A

NOTE 2 Representative values of groundwater pressures are determined according to 6.4.

NOTE 3 Figure 8.1 give examples of design situations where uplift might be critical.



Key

1	groundwater table	7	clay
2	light-weight material	8	injected sand
4	former ground surface	9	anchor
5	soil/sand	10	groundwater table in underlaying soil
6	dewatered level	11	sand/soil inside slab

NOTE Examples for non-rigid body in a and b. Examples for rigid body in c, d and e.

Figure 8.1 — Examples of design situations where uplift might be critical

(4) All supporting elements shall be verified separately according to 8.1.1 and 8.1.2.

8.1.4 Hydraulic failure

8.1.4.1 General

(1) In the presence of groundwater flow, the following ultimate limit states shall be verified for all ground conditions:

— hydraulic heave;

— internal erosion;

— piping.

(2) The assessment of groundwater seepage and groundwater pressures should take into account potential:

— anisotropy of hydraulic conductivity of ground layers;

— occurrence of confined aquifers.

8.1.4.2 Hydraulic heave

(1) To prevent a limit state of failure by hydraulic heave, vertical equilibrium shall be maintained in the ground by considering the ground's self-weight and the groundwater pressures.

NOTE For soils with significant cohesive strength or very low permeability, other failure mechanisms due to groundwater flow can lead to failure by uplift instead of heave.

(2) In cases of upward-flowing groundwater, it shall be verified that sufficient effective stress exists in the ground to support the self-weight of the ground and any supported structures, vehicles, and personnel.

(3) To prevent an ultimate limit state of hydraulic heave at any depth z (Figure 8.2), it shall be verified, that:

$$\Delta u_d \leq \gamma_{HYD} \left(\gamma_{rep} - \gamma_{w,rep}\right) z + \gamma_{pv} p'_{v,rep} \tag{8.3}$$

where

Δu_d is the design excess groundwater pressure = $u_d - u_0$;

u_d is the design groundwater pressure in the presence of flow;

u_0 is the groundwater pressure in the absence of flow (hydrostatic) = $\gamma_{w,rep}(z + h_w)$;

$\gamma_{w,rep}$ is the representative weight density of the groundwater;

z is the vertical distance of the point in the ground below the ground surface (not including any overlying fill);

γ_{rep} is the representative weight density of the ground;

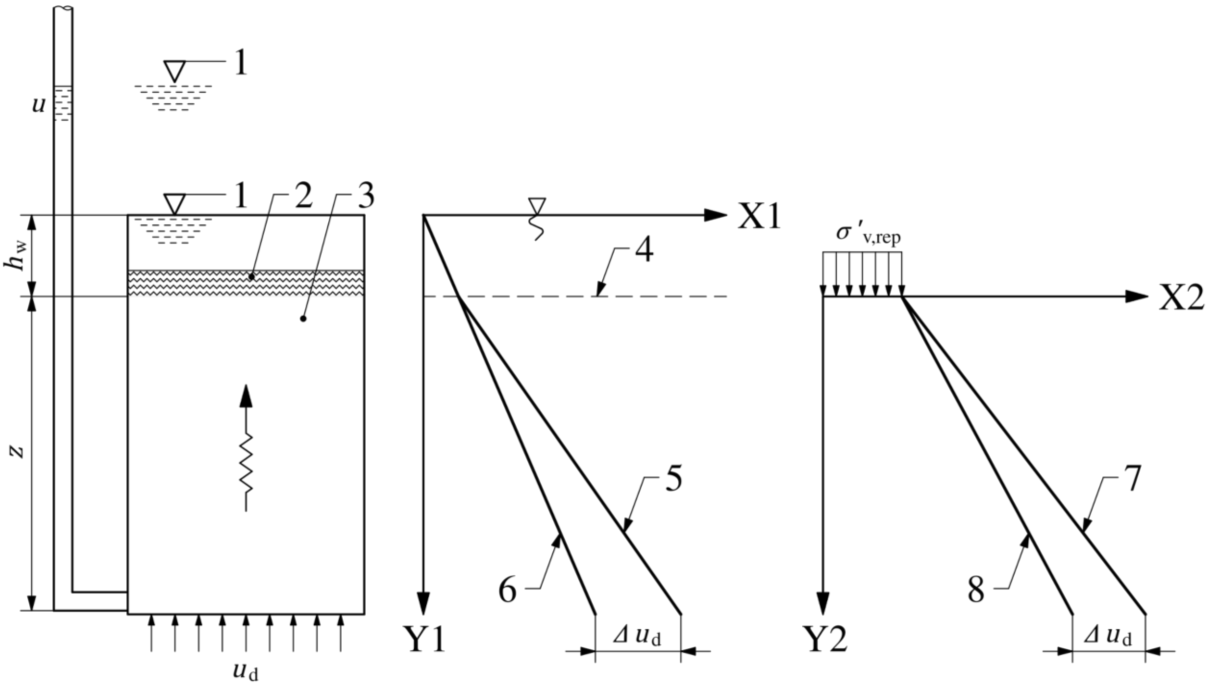
$p'_{v,rep}$ is the representative value of any effective overburden pressure at the ground surface;

γ_{HYD} is a partial factor for hydraulic heave;

γ_{pv} is a partial factor on the effective overburden pressure.

NOTE 1 The purpose of the factor γ_{HYD} is to ensure that the effective stress in the ground remains positive and to allow for local variations of stresses at a granular scale, relevant to hydraulic failures.

NOTE 2 The values of γ_{HYD} and γ_{pv} are both 0,67 unless the National Annex gives different values.



Key

1 water level

2 filter

3 ground

4 $\gamma_{gw,rep}$ h_w

5 u_d (in presence of flow)

6 u_0 (in absence of flow)

7 $\sigma'_{v,0}$ (in absence of flow)

8 $\sigma'_{v,d}$ (in presence of flow)

9 h_w vertical distance from the surface water level to the ground surface

X1 water pressure u

Y1 depth below surface water

X2 effective vertical stress σ'_v

Y2 depth

Figure 8.2 — One dimensional upward flow of water

(4) Formula (8.3) may be applied using an averaged value of Δu_d acting on the base of a soil block with a width of half of the depth of the block.

NOTE Further guidance is given in Terzaghi and Peck (1948)

(5) Exceedance of an ultimate limit state due to hydraulic heave should be prevented by measures including:

— increase in the length of the seepage path;

— reduction of the hydraulic gradient;

— increase of the effective overburden at the ground surface (filter thickness); or

— relief wells.

NOTE Guidance on measures for groundwater control is given in prEN 1997-3:2022, Clause 12.

8.1.4.3 Internal erosion and piping

(1) The design values of hydraulic gradients and seepage velocities shall be determined according to 6.5.

(2) Where seepage of groundwater occurs through coarse soil, as defined in EN ISO 14688 (all parts), ultimate limit state due to internal erosion or piping shall be verified.

(3) To prevent an ultimate limit state of internal erosion or piping, shall be verified:

$$i_d \leq i_{cd} \quad (8.4)$$

where

i_d is the design value of the hydraulic gradient;

i_{cd} is the design value of critical hydraulic gradient.

(4) The critical hydraulic gradient for internal erosion and piping should be determined taking into consideration:

— the direction of flow;

— the grain size distribution and shape of grains;

— layering of the ground.

NOTE 1 Values of i_{cd} depend on particle size and grading of the soil. Typical values are between 0,3 and 0,9.

NOTE 2 Methods to determine i_{cd} are given in The International Levee Handbook, CIRIA Report C731 (2013).

(5) Where seepage of groundwater occurs through thin layers of ground not subjected to internal erosion or piping (fine soils, grouted ground, etc.), hydraulic gradients greater than 1,0 may be accepted provided that the 8.1.4.2(3) is satisfied.

(6) Exceedance of an ultimate limit state due to internal erosion and piping should be prevented by measures including:

— filter protection at the free surface of the ground or at the end of any potential seepage path;

— increase in the length of the seepage path;

— reduction of the hydraulic gradient;

— sufficient safety against failure by heave in the case of a horizontal ground surface;

— sufficient stability of the surface layers in sloping ground (local slope stability).

(7) Filter protection should be provided by use of engineered fill that fulfils adequate design criteria for filter materials or by the use of geosynthetic filters that prevent transport of fines without clogging.

NOTE Design criteria for filter materials are given in The International Levee Handbook, CIRIA Report C731 (2013).

(8) When determining the outflow hydraulic conditions for the verification of failure by piping, account should be taken of joints and interfaces between the structure and the ground which can become preferred seepage paths.

(9) Where prevailing hydraulic and soil conditions can lead to the occurrence of piping and where piping endangers the stability or serviceability of the hydraulic structure, measures should be taken to prevent the onset of the piping process, either by the application of filters or by controlling or blocking groundwater flow.

8.1.5 Failure caused by time-dependent effects

(1) It shall be verified that potential failure in the ground or structural elements due to time-dependent effects cannot occur.

NOTE Examples of such time-dependent effects include degradation, weathering, and change of chemical composition.

8.1.6 Failure caused by the effect of cyclic actions

(1) Degradation of the ground resistance and accumulation of ground displacements, especially settlements, due to potential cyclic effects shall be considered.

(2) Liquefaction and generation of excess pore pressure should be considered for geotechnical structures located on saturated soils subjected to cyclic actions.

NOTE Guidance to include cyclic effects for verifications of specific geotechnical structures is given in prEN 1997-3:2022.

(3) When cyclic effects are significant, ultimate limit states shall be verified using the persistent combination of actions combined with cyclic effects.

8.2 Procedure for numerical models

(1) For geotechnical structures, verification of ultimate limit states by numerical models (Table 8.1) should be verified using both of the following factoring approaches:

— Input factoring, using:

  — factors on actions γ_F from Verification Case 3 and;

  — factors on material properties γ_M from Set M2;

— Output factoring, using:

  — factors on effects-of-actions γ_E from Verification Case 4 and;

— factors on material properties γ_M from Set M1.

NOTE 1 For input factoring, partial factors are not applied to resistance nor to effects of actions.

NOTE 2 For output factoring, partial factors are not applied to resistance nor to actions.

NOTE 3 The resistance of structural members is verified according to the other Eurocodes and prEN 1997-3.

NOTE 4 Values of γ_F and γ_E are given in prEN 1990-1:2024, Annex A.

NOTE 5 Values of γ_M are given in 4.4.1.3.

NOTE 6 The National Annex can specify cases where ultimate limit states can be verified by input or output factoring alone.

NOTE 7 The procedure for verification of ultimate limit states with numerical models is given in Table 8.1 (NDP) unless the National Annex gives a different procedure.

(2) As an alternative to (1), verification of ultimate limit states by numerical models may be performed using:

— factors on effect of actions γ_E from Verification Case 4; and

— resistance factors γ_R according to prEN 1997-3 for the geotechnical structure.

NOTE In this alternative, partial factors are not applied to material properties nor to actions.

(3) Verification of either of the approaches in (1) may be omitted when it is obvious that verification of the other approach is less favourable.

(4) Explicit verification of specific failure mechanisms may be omitted when using a numeral model that implicitly determines the most critical failure mechanism.

NOTE 1 Examples of specific failure mechanisms include sliding, overturning, bearing failure and overall stability.

NOTE 2 Input factoring uses partial factors that are not specific to a particular failure mechanism, whereas output factoring typically uses partial factors that are specific to the failure mechanism.

(5) The ground strength mobilized in numerical models should not exceed the design value.

NOTE The mobilized ground strength calculated by numerical models is influenced by the failure criterion as well as other input parameters, such as dilatancy and excess water pressure. When using effective stress analysis to predict undrained or partially drained ground strength, the mobilized ground strength can appear to exceed its design value.

(6) Strength reduction procedures should be used to verify that design values of ground strength properties are not exceeded.

NOTE 1 Different procedures are available to account for stress and strain changes caused by strength reduction and it is important that a suitable procedure is adopted in order to predict the most critical failure mechanisms accurately.

NOTE 2 Standard strength reduction procedures are not necessarily applicable to advanced constitutive models.

NOTE Strength reduction procedures normally starts from representative values.

(7) As an alternative to (6), design values of ground strength may be used as an input to numerical calculations (Table 8.1 – VC3+M2-alternative), provided that the effect of using design values throughout the calculation is considered when verifying the accuracy of simulations.

(8) Ground strength reduction may be combined with structural strength or resistance reduction to help identify potentially critical failure mechanisms of combined ground and structure failures.

(9) Design values of force effects in structures obtained by output factoring should be used to verify adequate resistance in addition to the input factoring.

NOTE 1 Examples of force effects are axial force, shear force and bending moment. The considered structures are e.g. piles, ground anchors, diaphragm walls and soil nails.

NOTE 2 In a variant of output factoring that enables utilisation of load redistribution capacities, action factors are initially applied to the resistance side of the equation, i.e., to the strength properties of the structure.

NOTE 3 Modification of the stiffness properties of the structure is an option to counteract possible stiffness reduction due to factoring of the strength parameters. The scope for load redistribution can be limited to the presence of brittle components of the system.

(10) Design values of outputs from geotechnical structure types other than those referred to in (9) may also be compared with geotechnical resistances to assess the reliability against particular failure mechanisms occurring.

(11) Geotechnical resistances may be calculated using numerical models by forcing geotechnical structures to fail by particular mechanisms.

NOTE 1 When geotechnical resistances are obtained by numerical models by simulating particular failure mechanism, usually a separate calculation is performed.

NOTE 2 For example, the vertical displacement of a rigid spread foundation can be increased until failure to obtain the bearing resistance from the output of force at failure.

Table 8.1 (NDP) — Procedure for verification of ultimate limit states with numerical models

			Factoring approach - See 8.2(1)		
			Output VC4 + M1	**Input VC3 + M2 (Recommended)**	**Input VC3 + M2 (Alternative)**
			See 8.2 (1), (9), (10)	**See 8.2 (1) and (6)**	**See 8.2 (1) and (7)**
Construction Stage 1 (CS1)			**Step 1[c] Representative Step**	**Step 1[c] Representative Step**	**Step 1[c] ---**
	Input	Piezometric level or groundwater pressure	Representative values		Not applicable Go directly to Step 2
		Ground properties	Representative Values		
		Structural element properties	Representative Values		
		External actions	Representative Values		
	Output	Movements	a		
		Structural forces	a		
			Step 2 ULS Verification Step	**Step 2 ULS Verification Step**	**Step 2 ULS Verification Step**
	Input	Piezometric level or groundwater pressure	Design level[b]	Design level [b]	Design level [b]
		Ground properties	Design values by M1 combination	Partial factors M2[d]	Design values by M2 combination
		Structural element properties	Representative values	Representative values	Representative values
		External actions	Design values by VC4 combination	Design values by VC3 combination	Design values by VC3 combination
	Output	Verification of ground failure	See 8.2(9) and (10)	ULS verified if equilibrium is attained in the ground with no failure of the structure	ULS verified if equilibrium is attained in the ground with no failure of the structure
		Verification of structural failure	Design values (E_d) obtained by applying γ_E to calculation results See 8.2(9) and (10)	Design values (E_d) obtained directly from calculation results See 8.2(8)	Design values (E_d) obtained directly from calculation results
CS2	Continue in the same way through any subsequent stage (CS2, CS3, etc.)				

a These output values can be used for SLS verifications

b "The design piezometric level" can be obtained by applying a deviation to the representative piezometric level as stated in 6.4.1 (1), second bullet

c The start of Step 1 of any given Construction Stage continues from the end of Step 1 of the preceding Construction Stage

d Usually in this step, the analysis performs a strength reduction and the ULS verification is checked, as set in 8.2 (6), If the analysis cannot perform strength reduction or apply different material factors to different geotechnical units, then Step 2 also continues from Step 1 of the preceding Construction Stage using design material properties determined with partial factors from Set M2

9 Serviceability limit states

9.1 General

(1) In addition to prEN 1990-1:2024, 5.4 and 8.4, the following potential serviceability limit states shall be verified:

— ground movements and structural aspects, including differential displacements, rotation, angular strain, relative deflection, deflection ratio, tilt, angular distortion, and resonance effects;

— hydraulic aspects including hydraulic conductivity, development of crack resulting in preferential drainage paths in the ground, and ingress or egress of water.

(2) In addition to prEN 1990-1:2024, 8.4, design values of ground properties for serviceability limit states shall be determined using a partial factor γ_M = 1,0.

(3) In addition to prEN 1990-1:2024, 5.4 and 8.4, verification of serviceability limit states should be based on calculation, testing, the Observational Method or on any combination of those.

NOTE Further guidance on monitoring and testing is given in Clauses 10 and 11.

(4) Verification of SLS may be based on a check of strength mobilization only if:

— a sufficiently low fraction of the ground strength is used as the mobilization limit;

— time dependent effects are taken into account; and

— established comparable experience exists with similar ground and structures.

(5) Long-term settlements and movements should be calculated using the quasi-permanent combination of actions given in prEN 1990-1:2024, 8.4.3.4, taking into account ground hydraulic conductivity and creep effects.

(6) In addition to 7.1.5(2), when cyclic effects are significant, they should be taken into account in the verification of serviceability limit states.

9.2 Serviceability criteria

(1) In addition to prEN 1990-1:2024, 5.4 the relevant serviceability criteria shall be determined with consideration of ground movement, structural aspects, and hydraulic aspects within the zone-of-influence.

NOTE Further guidance on serviceability criteria within the zone-of-influence is given in 4.2.5.

(2) In addition to (1), the serviceability criteria shall be selected to avoid any ultimate limit state in the new structure, existing structures, utilities, and ground within the zone of influence.

(3) The serviceability criteria may be defined in terms of limiting values and threshold values or in terms of acceptance criteria.

NOTE 1 The serviceability criteria can be defined in terms of e.g. deformation (differential displacement, rotation, settlement, tilt), stress, strain, groundwater level, groundwater pressure, groundwater flow, vibration, noise, environmental restrictions and temperature.

NOTE 2 The limiting value is the value of the relevant serviceability criterion.

NOTE 3 Guidance on limiting values of structural deformation and ground movements are given in prEN 1990-1:2024, Annex A.

NOTE 4 Guidance is given in 10.3 and 10.4 on the use of inspection and monitoring to limit the impact from execution of the geotechnical structure within the zone of influence and to ensure the behaviour satisfies the serviceability criteria.

(4) To limit the adverse impacts on existing structures, utilities, and ground and groundwater, serviceability criteria may be defined as a proportion of the limiting value of the deformation of the affected existing structures.

(5) If the serviceability criteria are defined according to (4), the proportion of the limiting value shall be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

9.3 Calculation of ground movements

(1) The determination of ground movement should take into account the following:

— loading distribution;

— effects of cyclic actions or dynamic actions (vibrations);

— construction method (including the sequence of loading);

— excavations, quarrying, tunnelling, and backfilling within the zone of influence of the geotechnical structure;

— consolidation and creep;

— changes in groundwater conditions and corresponding groundwater pressures;

— changes in groundwater chemistry;

— stiffness of the ground in relation to the expected rate of ground movements;

— degradation of the ground stiffness and the accumulation of permanent strains due to cyclic effects;

— stiffness of the structure during and after construction;

— volume loss due to soluble strata or oxidation of organic content; and

— mining (active or historical), gas extraction, or similar works.

(2) In the absence of reliable calculation models for determining ground movements, serviceability limit states may be verified by one or more of the following:

— limiting the mobilized shear strength to values specified in the design;

— using the Observational Method, observing the movements and specifying measures to reduce or stop them, as described in 4.7.

(3) When the structure can redistribute actions, ground-structure interaction analysis should be used to determine the amount of redistribution according to the relative stiffness of the ground and the structure.

9.4 Structural aspects

(1) Limiting foundation movements shall take account of the following:

— the confidence with which the acceptable value of the movement can be specified;

— the occurrence (or recurrence) and rate of ground movements;

— the effect of horizontal as well as vertical ground movements;

— the type, age and technical condition of the structure;

— the requirements of any plant or machinery (during both construction and the design service life of the structure) and the proposed use of the structure;

— the changing state of the structure during construction;

— the mode of deformation;

— relative movement between structures or parts of structures of different characteristics; and

— allowable movements of services entering the structure.

(2) In the absence of specified limiting values of structural deformations of the supported structure, the suggested values given in prEN 1990-1:2024, A1.8.4 shall be used.

9.5 Hydraulic aspects

(1) The limiting value of the serviceability criterion for hydraulic serviceability limit states shall be defined in terms of, but not limited to:

— hydraulic conductivity of the ground or certain parts of the ground;

— groundwater pressure;

— ingress of water or leakage into an excavation or defined space;

— egress of water from the surrounding environment; and

— groundwater level or changes to the groundwater level.

(2) In addition to (1), threshold values and related acceptance criteria should be defined.

10 Implementation of design

10.1 General

(1) To check that the implementation of the design during execution and during the design service life, provides a level of reliability no less than that required by EN 1990-1, The design of a geotechnical structure shall include the following:

— Supervision Plan;

— Inspection Plan;

— Monitoring Plan;

— Maintenance Plan.

(2) The type, level and amount of supervision, inspection, monitoring, and maintenance shall be related to the Geotechnical Category of the geotechnical structure, or the relevant part of it.

NOTE Guidance on appropriate levels is given in 4.1.8 and for inspection levels additional guidance is given in prEN 1990-1:2024, Annex B.

(3) The results of supervision, inspection, and monitoring shall be reviewed and used as an integral part to check that the execution complies with the design assumptions, execution specifications and maintenance requirements.

(4) The format of the Plans should be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

NOTE For example, the Plans can be single volume, multivolume, digital, paper copy, partly consist of drawings, part of a Building Information Model (BIM) or project specific databases.

(5) The objectives, type, extent, and level of supervision, inspection, monitoring, and maintenance shall comply with the specific requirements of prEN 1997-3:2022 and relevant execution standards.

(6) The Supervision, Inspection, Monitoring, and Maintenance Plans should be based on a review of the most unfavourable conditions that occur during execution or the design service life, with regard to:

— ground conditions;

— groundwater conditions;

— actions on the structure;

— environmental impacts and potential changes including landslides and rockfalls; and

— impact within the zone of influence (4.1.2.1).

NOTE 1 Guidance on specification of acceptance criteria for inspection is given in 10.3.

NOTE 2 Guidance on specification of limiting values and threshold values for monitoring is given in 10.4.

(7) Acceptance criteria may be established by sensitivity analyses or engineering judgement of acceptable variations.

(8) The Inspection, the Maintenance and Monitoring Plans should include measures that can be employed to prevent failure if the acceptance criteria or threshold values are reached.

(9) Before modifying the design or implementing additional contingency measures, the data should be checked for consistency.

(10) The design of geotechnical structures shall be checked for its practicability and feasibility for maintenance.

10.2 Supervision

(1) The execution of geotechnical structures shall be supervised.

NOTE This clause gives general provisions for supervision. Guidance on detailed provisions for supervision for a specific geotechnical structure is given in the corresponding execution standards.

(2) It shall be checked that the execution methods and construction stages used comply with the execution specification.

(3) The supervision of execution should ensure that all safety measures given in the execution specification for a safe working environment are implemented.

NOTE The National Annex can give further requirements in relation to safe working environment.

10.3 Inspection

(1) The Inspection Plan shall specify measures to check compliance with the design assumptions and the execution specification including:

— material and products are used according to the execution specification;

— execution is performed according to the work description and applicable method statement;

— the quality of structural element fulfils the assumed capacity according to the design;

— design revisions are adopted; and

— the probability of human errors occurrings is reduced during execution.

(2) In addition to (1), other relevant measures, should be included in the Inspection Plan to ensure compliance with the design assumptions and execution specification.

(3) Inspection may be performed by observation, measurement, or testing.

(4) The Inspection Plan shall specify acceptance criteria for:

— properties of construction material with tolerances;

— products and their quality specification;

— dimensions of products and structural elements with tolerances;

— improved ground properties;

— properties of engineered fill; and

— execution as specified by execution standard or method statements.

NOTE Guidance on tests to confirm resistance is given in 11.4 and to confirm product quality in 11.5.

(5) In addition to (4), other acceptance criteria should be included in the Inspection Plan.

(6) In addition to (1), the Inspection Plan shall specify provisions to check the ground conditions encountered at the site comply with the assumptions made in the Ground Model and the Geotechnical Design Model.

NOTE Guidance on appropriate testing to determine ground properties is given in 11.3.

(7) Indirect evidence of ground properties may be used to check encountered ground conditions.

NOTE Indirect evidence includes drilling records, pile driving records, back-analyses, etc.

(8) If acceptance criteria are exceeded during execution, the design and execution specification shall be reviewed and modified (if appropriate) or contingency measures taken to remedy the situation.

(9) If acceptance criteria are exceeded during the design service life, contingency measures shall be taken to remedy the situation.

10.4 Monitoring

(1) The objective of monitoring should be one or more of the following:

— during ground investigation, to obtain data of the ground behaviour;

— before execution, to establish reference conditions;

— during execution, to confirm the validity of the design and to identify the need for remedial measures, revision of the design, for switching to another design variant (if using the Observational Method), or alterations of the execution sequence or method; or

— after execution, to evaluate the long-term performance of the structure.

(2) If monitoring during execution or after execution is specified, a Monitoring Plan shall be prepared that specifies which aspects of the behaviour of the geotechnical structure shall be monitored to confirm compliance with the serviceability criteria.

(3) The Monitoring Plan should include, but is not limited to, provisions that:

— check the validity of the behaviour of all structures, ground, utilities within the zone of influence of the construction works;

— check the validity of the design assumptions compiled in the Geotechnical Design Model;

— reduce the probability of adverse environmental impact and damage to surroundings during execution;

— check that trends are consistent with the construction activities; and

— ensure that the structures continue to behave as required after execution.

(4) In addition to (3), other provisions should be included in the Monitoring Plan to monitor for successful performance of the structure.

(5) The Monitoring Plan shall specify threshold and limiting values for the following:

— behaviour of geotechnical structure at relevant construction stages;

— behaviour of structures, ground and utilities within the zone of influence (4.1.2.1);

— variation in groundwater conditions within the zone of influence; and

— environmental impact, including noise, vibration, and pollution within the zone of influence.

(6) In addition to (5), other threshold and limiting values should, as relevant, be included in the Monitoring Plan.

(7) If threshold values are exceeded during monitoring, the Monitoring Plan shall be reviewed and modified (if appropriate), or contingency measures taken to remedy the situation.

(8) If the Observational Method is applied and the threshold values are exceeded during monitoring, an alternative design variant shall be applied.

(9) The Monitoring Plan should include duration, type and frequency of monitoring, and locations of monitoring points.

(10) It shall be verified that the behaviour of the geotechnical structure, other structures, utilities, and ground in the zone of influence complies with the serviceability criteria as defined in 4.2.5.

(11) Monitoring may be performed using observations or measurements (including geotechnical and geodetical monitoring).

NOTE Monitoring can include observations made without measurement (e.g. visual observations).

(12) Effects of noise, vibration, and temperature on selected monitoring and monitoring equipment shall be accounted for.

(13) Geotechnical monitoring should comply with EN 18674 (all parts).

(14) If the verification of a limit state is sensitive to a specific ground property, the Monitoring Plan should include measures to verify the design assumptions made for the specific ground properties.

(15) The response time of instruments shall be rapid enough to capture potential changes in ground-structure behaviour.

(16) The management and communication procedures for analysing results shall be fast enough to ensure that adverse outcomes are prevented.

10.5 Maintenance

(1) A Maintenance Plan shall be prepared that records the activities needed to ensure the safety, serviceability, and durability of the geotechnical structure during its design service life.

NOTE Guidance on use of maintenance to ensure adequate durability is given in 4.1.6 (1).

(2) The Maintenance Plan shall specify the objectives, types, and frequency of activities required to ensure that the structure, and any part of it, can be used for its intended purpose without major repair during its design service life.

NOTE Maintenance activities for geotechnical structures include, e.g. cleaning of drainage systems, adjustment of erosion protection, replacement of specific part of the structural element, adjustment of the surface level of embankment.

(3) The Maintenance Plan shall include the supervision, inspection, and monitoring activities as specified in 10.1 to 10.4, as far as applicable for the design service life.

(4) The Maintenance Plan should specify:

— critical parts of the geotechnical structure that need post-execution inspection;

— the objective, type and frequency of post-execution inspection;

— acceptance criteria related to the intended inspection;

— threshold and limiting values related to the intended monitoring; and

— maintenance activities if acceptance criteria and/or threshold values are violated.

NOTE 1 Post-execution monitoring can include measurement of groundwater variations, displacements, rotations, pressure, anchor force and visual inspections.

NOTE 2 Post-execution inspection can include checking of clogging of dewatering systems, effects of erosion and signs of degradation of construction material.

(5) In addition to (4), other information should be included in the Maintenance Plan to check that the structure functions as intended during its design service life.

(6) If acceptance criteria are exceeded during the design service life, the Maintenance Plan shall be reviewed and modified (if appropriate) or contingency measures taken to remedy the situation.

10.6 Application of the Observational Method

(1) In addition to 10.1 to 10.4, when using the Observational Method to verify limit states, the Contingency Plan shall address foreseeable ground responses and ground-structure interactions and give contingency measures appropriate for each design variant.

(2) The Contingency Plan shall be activated if threshold values or acceptance criteria for the current design variant are exceeded.

11 Testing

11.1 General

11.1.1 Use of testing

(1) Testing may be used to determine ground properties, determine parameters for use in design, verify capacity of a structural element, check quality of construction material or product, and to understand the behaviour of the geotechnical structure or part of it.

NOTE Guidance on design assisted by testing is given in prEN 1990-1:2024, 7.3 and Annex D.

(2) Testing may be used as part of ground investigation or as part of verification by calculation, testing, prescriptive rules or the Observational Method.

(3) Tests may be carried out either on a sample of the actual geotechnical structure, on a supporting element, or on full scale or reduced scale models.

11.1.2 Test planning

(1) Test requirements, including test method and the number of tests, should be related to the Geotechnical Category of the relevant part of the geotechnical structure.

(2) Prior to carrying out tests, a Test Plan should be compiled that includes, as relevant, but is not limited to:

- test objectives and scope;
- specifications of sample preparation;
- loading specifications;
- testing arrangements;
- period of time from execution of the geotechnical structure to the performance of the test;
- test duration and time planning;
- test equipment (characteristics, maintenance and calibration requirements);
- measurement plan and frequency;
- prediction of test results;
- method for test evaluation;
- method for reporting;
- content of the test report; and
- requirements from comparable experience.

NOTE 1 Acceptance criteria are specified in the related Inspection Plan and limiting values are specified in the related Monitoring Plan.

NOTE 2 Guidance on content of test reports is given in 12.5.

11.1.3 Test evaluation

(1) Test evaluation shall include determination of the accuracy of each test.

(2) Test evaluation shall include a check of the validity of the test results by comparison with prognosis of the test results or with comparable experience.

(3) When significant deviations from prognosis or comparable experience occur, the reasons shall be determined, evaluated and documented.

(4) In case of unexpected deviations, the test should be repeated or an alternative test method should be used.

(5) The following aspects, amongst others, should be considered in the evaluation of the test:

— differences in ground properties between the test and the actual site of the geotechnical structure;

— effects of time, scale, stress levels, temperature and particle size.

11.2 Testing to determine ground properties

(1) Testing may be used to obtain ground properties using specified testing procedures during the ground investigation.

NOTE Guidance on relevant field investigation and laboratory testing for specific ground properties are given in FprEN 1997-2.

11.3 Testing to determine parameters for use in design

(1) Testing may be used to determine ground properties and other parameters used in the design.

NOTE Other parameters include, for example, ground-structure interface properties, bearing capacity of the ground etc.

(2) Investigation tests on supporting elements that are not incorporated in the final structure may be used to determine the ultimate resistance of the elements at the ground-structure interface and to determine their stiffness properties under serviceability conditions.

NOTE Guidance on the applicability of investigation tests for piles, anchors, soil nails, and rock bolts is given in prEN 1997-3.

(3) Tests on laboratory specimens of improved ground may be used to determine their strength and stiffness properties.

NOTE Guidance on applicability of tests for ground improvement are given in prEN 1997-3.

(4) Suitability tests may be used to confirm that a specific design and construction methodology is suitable for the present ground conditions.

NOTE Guidance on the applicability of suitability tests for piles, anchors, soil nails, rock bolts, and ground improvement is given in prEN 1997-3.

11.4 Testing to verify resistance

(1) Testing may be used to verify that a geotechnical structure fulfils its specified design requirements without exceeding a limit state.

(2) Acceptance tests may be used to verify that the specified acceptance criteria are fulfilled.

11.5 Testing to control quality

(1) Control tests should be used to check the identity or quality of delivered products or the consistency of production characteristics.

NOTE Example of control tests are tests to check the identity or quality of delivered products (for instance geosynthetics) or the consistency of production characteristics (for instance lime-cement columns).

(2) Control tests should be used to check the compaction of engineered fill, using compaction control.

11.6 Testing to determine geotechnical behaviour

(1) Testing may be used to determine the behaviour of the geotechnical structure (or part of it).

NOTE Guidance on acceptable limits of behaviour for geotechnical structures is given in 4.2.5 and 9.2.

12 Reporting

12.1 General

(1) The geotechnical aspects of the design and execution of geotechnical structures and other works shall be reported.

(2) The extent and details of the reporting shall be adequate for an independent technical review.

(3) Reporting shall include information specified for the Ground Investigation Report (12.2), Geotechnical Design Report (12.3), Geotechnical Construction Record (12.4), and any geotechnical test reports (12.5).

NOTE 1 Guidance on the content of the reports is given in Annex B.

NOTE 2 The format of the reports is not specified in this document. The reports can be e.g. single volume, multivolume, digital, paper copy, partly consist of drawings, or part of a Building Information Model (BIM).

(4) The extent and details of the reporting should be appropriate for the type of geotechnical structure and the Geotechnical Category.

NOTE 1 Guidance on specific reporting for different geotechnical structures is given in prEN 1997-3.

NOTE 2 The minimum extent and level of detail of reporting is given in Table 12.1 (NDP) unless the National Annex gives a different minimum extent and level of detail.

Table 12.1 (NDP) — Extent and level of detail of reporting appropriate for each Geotechnical Category

Geotechnical Category	Extent and level of detail
GC3	All the items given below for GC2 and, in addition: — more extensive documentation should be included, covering all aspects of the design as outlined in Annex B; — the extent of the documentation and the degree of detail should make it possible for a third party to obtain similar results from check analyses of the design.
GC2	All the items given below for GC1 and, in addition: — the documentation should cover all critical aspects of the design; — the extent of the documentation for items that are not critical may be reduced or excluded provided justification is given.
GC1	— the documentation should cover the main design assumptions with justification; — the extent of the documentation for each heading, as outlined in Annex B, may be reduced to a record with bullet-points of what has been done.
NOTE An example of a reduced GDR for GC1 is given in C.4.4	

(5) The responsibility for reporting and keeping the records should be specified by the relevant authority or, where not specified, agreed for a specific project, by the relevant parties.

12.2 Ground Investigation Report

(1) The results of ground investigation shall be compiled in a Ground Investigation Report (GIR).

NOTE Guidance on the contents of the GIR is given in FprEN 1997-2:2024, Annex A.

NOTE The format of GIR is not specified in EN 1997 (all parts). The GIR can be presented in a single or in multiple volumes; developed at different stages of the ground investigation, or cover different geographical areas.

(2) The GIR shall, for each stage of the ground investigation, consist of a factual account of site information and all results from the in-situ and laboratory testing as detailed in FprEN 1997-2:2024, Clause 13.

(3) The GIR should present a Ground Model, unless one is presented in the GDR.

(4) The GIR shall include derived values, if available.

(5) The GIR shall state limitations of the results from field investigation and laboratory testing.

(6) The GIR shall include an evaluation of the geotechnical data included in the report, stating any assumptions made in the interpretation of test results.

(7) For sites located in seismic regions, the GIR shall include information necessary to establish seismic properties required by EN 1998-1-1.

12.3 Geotechnical Design Report

12.3.1 General

(1) Documentation of the verification and design process of all construction phases and the final design shall be compiled in a Geotechnical Design Report (GDR).

NOTE Guidance on the content of the GDR is given in B.4.

NOTE The format of the GDR is not specified in EN 1997 (all parts). The GDR can be presented in a single or in multiple volumes; developed at different stages of the design process; or cover different parts of the geotechnical structure.

(2) The GDR shall give a description of the site and the planned geotechnical structure, including the zone-of-influence.

(3) The GDR may present a Ground Model, unless presented in the GIR.

(4) The GDR shall record the Consequence Class, Geotechnical Complexity Class, and Geotechnical Category.

(5) Compliance with the assumptions in 1.2 shall be recorded in the GDR.

(6) The extent and details of the reporting for design situations and design assumptions which do not govern the design may be reduced.

12.3.2 Ground properties and Geotechnical Design Model

(1) The GDR shall document the Geotechnical Design Model (GDM) for the verification of each relevant design situation and limit state.

(2) The GDM should include representative values of the ground properties of the geotechnical units, geometric specification, and groundwater conditions.

(3) The data sources used to determine the representative value of a ground property shall be stated in the GDM.

NOTE Further guidance on content of the Geotechnical Design Model is given in B4.2.

(4) The exclusion of non-relevant information from the GDM should be documented and justified.

(5) The GDR shall record the results of validating information in the GIR according to 4.2.4.

(6) The GDR shall record changes to the Ground Model that occur on receipt of additional information about the ground conditions.

(7) The GDR shall record the results of validating the GDM according to 4.2.3.

12.3.3 Properties

(1) The GDR shall record the evaluation of nominal values of geometrical properties.

(2) The GDR should record the evaluation of representative values of actions and resistances.

(3) The GDR shall record the evaluation of the representative and design values of material properties.

12.3.4 Verification of limit states

(1) The GDR shall describe the design situations considered (4.2.2).

(2) The GDR shall record the verification of limit states (4.2.1).

12.3.5 Implementation of design

(1) The GDR shall include the Inspection (10.3), Monitoring (10.4), and Maintenance (10.5) Plans.

(2) The GDR shall include specification of supervision.

(3) The GDR shall identify any important modifications of the design implemented to account for results from supervision, inspection, monitoring, or maintenance.

(4) The GDR shall identify contingency measures, with corresponding acceptance criteria or threshold values, to be implemented based on results from supervision, inspection, monitoring, or maintenance.

(5) If the Observational Method is applied, the GDR shall include a Contingency Plan as specified in 10.6.

12.4 Geotechnical Construction Record

(1) A Geotechnical Construction Record (GCR) shall be prepared that documents construction, supervision, monitoring, and inspection of the final structure and each phase of execution.

NOTE 1 Guidance on the content of the GCR is given in B.5.

NOTE 2 The aim of the GCR is to assist with future maintenance, design of additional works and decommissioning of the works.

(2) In addition to (1), for verification of limit states using the Observational Method, the GCR shall include a record of scenarios encountered during construction and the contingency measures implemented, with justification.

12.5 Geotechnical test reports

(1) The results of testing, of the performance of a geotechnical structure or the ground, or part thereof, for design, supervision, inspection, or monitoring shall be compiled in a geotechnical test report.

NOTE 1 Guidance on use of testing is given in Clause 11.

NOTE 2 Geotechnical test reports can be part of the GIR, GDR, or GCR.

(2) If standard test methods are used, the documentation shall be presented and reported according to the requirements defined in applicable test standards.

(3) Geotechnical test reports shall state any limitations of the results.

Annex A
(informative)

Characteristic value determination procedure

A.1 Use of this annex

(1) This Informative Annex provides complementary guidance to 4.3.2 on characteristic values of ground properties.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

A.2 Scope and field of application

(1) This Informative Annex covers procedures to determine the characteristic value of ground properties.

A.3 Background

(1) Different sources of uncertainty should be related to the observed value variability through:

$$\mathrm{V}_x = \sqrt{\mathrm{V}_{x,inh}^2 + \mathrm{V}_{\mathrm{x,quality}}^2 + \mathrm{V}_{\mathrm{x,trans}}^2} \qquad \text{(A.1)}$$

where

V_{x} is the coefficient of variation of the observed property value;

$V_{\mathrm{x,inh}}$ is the coefficient of variation of the property due to inherent ground variability;

$V_{\mathrm{x,quality}}$ is the coefficient of variation of the measurement error;

$V_{\mathrm{x,trans}}$ is the coefficient of variation of the transformation error.

NOTE 1 There are several sources of uncertainty that affect the evaluation of ground properties.

NOTE 2 These sources include inherent variability, measurement error, statistical uncertainty, and transformation uncertainty, as well as sampling quality.

NOTE 3 Statistical uncertainty describes the errors associated with estimating parameters (e.g. mean) of a population based on a limited number of samples. Larger number of samples leads to smaller statistical uncertainties.

NOTE 4 Transformation uncertainty is only relevant if the property is not measured directly but inferred from a separate measurement.

NOTE 5 An example of transformation uncertainty is undrained shear strength from Standard Penetration Test blow count.

NOTE 6 Only inherent variability is a site property, the rest are design dependent.

A.4 Description of the determination procedure

(1) The determination procedure described in this Annex should be used to calculate the characteristic value of a ground property by statistical methods.

(2) The derived values of the ground property presented in the Ground Investigation Report, should be used for the determination of the characteristic value of the ground property.

(3) The procedure described in this Annex may be applicable for the determination of the characteristic value of a ground property, considered as an estimate of either:

— the mean value [Type A]; or

— the inferior (5 % fractile) or superior (95 % fractile) value [Type B].

NOTE 1 The ratio of the scale of fluctuation to the extent of the failure surface can be used in the determination of the characteristic values.

NOTE 2 Alternative determination procedures can be given in the National Annex.

(4) The procedure in this Annex shall be used to evaluate the different terms in the following formula [repeated from Formula 4.3]:

$$X_{\mathrm{k}} = X_{\mathrm{mean}}[1 \mp k_{\mathrm{n}} V_{\mathrm{x}}] \tag{A.2}$$

where

X_{k} is the characteristic value of the ground property X;

X_{mean} is the mean of the ground property X from a number (n) of sample derived values;

k_{n} is a coefficient that depends on the number of sample derived values (n) used to calculate X_{mean};

V_{X} is the coefficient of variation of the ground property X [V_{X} = (standard deviation)/(mean value)];

$\mp$ denotes that $k_{\mathrm{n}}V_{\mathrm{X}}$ should be subtracted when a lower value of X_{k} is critical and added when an upper value is critical.

NOTE Formula A.2 is based on the following assumptions: the ground property values follow either a normal or a log-normal distribution; and there is no prior knowledge about the mean value.

(5) The determination procedure may be applied for three different cases:

— Case 1 “V_{X} known”;

— Case 2 “V_{X} unknown”; and

— Case 3 “V_{X} assumed".

(6) Case 1 should be used when the coefficient of variation of the ground property being determined is known from prior knowledge.

NOTE Prior knowledge can come from the evaluation of previous tests in comparable situations. Engineering judgement is used to determine what can be considered as “comparable”.

(7) Case 2 should be applied when the coefficient of variation of the ground property being determined is unknown ab initio.

(8) Case 3 should be applied when indicative values are used for ground properties, or for test parameters.

NOTE 1 Indicative values for ground properties are given in Table A.1 (NDP) and for test parameters in Table A.2 (NDP) unless the National Annex gives different values.

NOTE 2 In practice, it is often preferable to use Case 3 together with a conservative upper estimate of V_X, rather than to apply the rules given for Case 2 .

Table A.1 (NDP) — Indicative values of coefficient of variation for different ground properties

Soil / Rock Type	**Ground property**	**Symbol**	**Coefficient of variation Vx (%)**
All soils and rocks	Weight density	γ	5-10
Fine-grained soils	Shear strength in total stress analysis	c_u	30-50
All soils and rocks	Peak or residual effective cohesion	c'_p or c'_r	30-50
All soils and rocks	Coefficient of friction	tan φ	5-15
All soils and rocks	Shear strength at failure	τ_f	15-25
All soils and rocks	Unconfined compressive strength	q_u	20-80
All soils	Modulus of deformability[a]	E or G	20-70
Fine-grained soils	Vertical or horizontal consolidation coefficient	c_v or c_h	30-70
All soils	Hydraulic conductivity[b]	K	70-250

[a] This refers to the different moduli of deformation whose symbols appear FprEN 1997-2:2024; 3.2.1.

[b] Given the high value of the coefficient of variation for the hydraulic conductivity, this procedure should not be used.

Table A.2 (NDP) — Indicative values of coefficient of variation for different test parameters

Soil/Rock Type	Test parameter	Symbol	Coefficient of variation V_X (%)
Coarse soils	SPT blowcount	N_{SPT}	15-45
All soils	Pressuremeter limit pressure	p_l	5-15
All soils	Cone resistance	q_c	5-15
All soils	Sleeve friction	f_s	5-15

(9) The value of X_{mean} should be calculated from:

$$X_{\text{mean}} = \frac{\sum_{i=1}^{n} X_i}{n} \quad \text{(A.3)}$$

where

X_i is the value of the i-sample derived value;

n is the number of sample derived values used for the evaluation of X_{mean}.

(10) The value of k_n should be obtained from Table A.3 which presents Formulae for Cases 1 to 3 as defined in (6), (7) and (8).

Table A.3 — Values of k_n for different cases and type of estimate

	A	B	C
1	**V_x CASES**	**Estimate of the mean value**	**Estimate of the inferior or superior value (5 or 95 % fractile)**
2	Case 1: "V_X known" & Case 3 "V_X assumed"	$k_n = N_{95}\sqrt{\frac{1}{n}}$	$k_n = N_{95}\sqrt{1+\frac{1}{n}}$
3	Case 2: "V_X unknown"	$k_n = t_{95,n-1}\sqrt{\frac{1}{n}}$	$k_n = t_{95,n-1}\sqrt{1+\frac{1}{n}}$

where

N_{95} parameters of the normal distribution, evaluated for a 95% confidence level and infinite degrees of freedom;

$t_{95,n-1}$ Student's t-factor, evaluated for a 95% confidence level and (n–1) degrees of freedom, with n being as defined in (9).

(11) For Case 2, the value of V_X should be calculated by:

$$V_X = \frac{s_X}{X_{\text{mean}}} \; ; \; s_X = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_{\text{mean}})^2}{n-1}} \tag{A.4}$$

where

s_X is the standard deviation of the sample derived values.

NOTE 1 Tables A.4 to A.7 collates the values of normal and Student's t factor (N_{95} *or* $t_{95,n-1}$) and resulting k_n for the different combinations of V_x and type of estimation, according to Formula in Table A.3 Cells B2, B3, C2 and C3.

NOTE 2 For Case 3, indicative values of V_x may be taken from Table A.1, for ground properties, or from Table A.2, for test parameters, unless the National Annex gives different values.

Table A.4 — Selected values of N_{95} and k_n to estimate the characteristic value as the mean value according to the Formula in Table A.3, Cell B2

n	2	3	4	5	6	7	8	9	10	12
N_{95}	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
k_n	1,16	0,95	0,82	0,74	0,67	0,62	0,58	0,55	0,52	0,47
n	**14**	**16**	**18**	**20**	**25**	**30**	**35**	**40**	**50**	**100**
N_{95}	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
k_n	0,44	0,41	0,39	0,37	0,33	0,30	0,28	0,26	0,23	0,16

Table A.5 — Selected values of $t_{95,n-1}$ and k_n to estimate the characteristic value as the mean value according to the Formula in Table A.3, Cell B3

n	2	3	4	5	6	7	8	9	10	12
$t_{95,n-1}$	6,31	2,92	2,35	2,13	2,02	1,94	1,89	1,86	1,83	1,80
k_n	4,46	1,69	1,18	0,95	0,82	0,73	0,67	0,62	0,58	0,52
n	**14**	**16**	**18**	**20**	**25**	**30**	**35**	**40**	**50**	**100**
$t_{95,n-1}$	1,77	1,75	1,74	1,73	1,71	1,70	1,69	1,68	1,68	1,66
k_n	0,47	0,44	0,41	0,39	0,34	0,31	0,29	0,27	0,24	0,17

Table A.6 — Selected values of N_{95} and k_n to estimate the characteristic value as the inferior or superior value (5 or 95% fractile) according to the Formula in Table A.3, Cell C2

n	2	3	4	5	6	7	8	9	10	12
N_{95}	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
k_n	2,01	1,90	1,84	1,80	1,78	1,76	1,74	1,73	1,73	1,71
n	**14**	**16**	**18**	**20**	**25**	**30**	**35**	**40**	**50**	**100**
N_{95}	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
k_n	1,70	1,70	1,69	1,69	1,68	1,67	1,67	1,67	1,66	1,65

Table A.7 — Selected values of $t_{95,n-1}$ and k_n to estimate the characteristic value as the inferior or superior value (5 or 95% fractile) according to the Formula in Table A.3, Cell C3

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**
$t_{95,n-1}$	6,31	2,92	2,35	2,13	2,02	1,94	1,89	1,86	1,83	1,80
k_n	7,73	3,37	2,63	2,34	2,18	2,08	2,01	1,96	1,92	1,87
n	**14**	**16**	**18**	**20**	**25**	**30**	**35**	**40**	**50**	**100**
$t_{95,n-1}$	1,77	1,75	1,74	1,73	1,71	1,70	1,69	1,68	1,68	1,68
k_n	1,83	1,81	1,79	1,77	1,74	1,73	1,71	1,71	1,69	1,67

NOTE 1 When the ground property is considered to follow a log-normal distribution, Formulae A.2, A.3 and A.4 become:

$$X_k = e^{Y_{mean}(1 \pm k_n V_Y)} \tag{A.5}$$

where

X_k is the characteristic value of the ground property ***X***;

Y_{mean} is the mean from a number (n) of sample derived log values, as defined in Formula A.10;

k_n is a coefficient that depends on the number of sample derived values (n) used to calculate Y_{mean} (Table A.1);

V_Y is the coefficient of variation of the log values of the ground property X [$V_Y = s_Y / Y_{mean}$], where s_y is the standard deviation of the sample derived log values (Formula A.11);

-/+ denotes that $k_n V_Y$ should be subtracted when a lower value of X_k is critical and added when an upper value is critical.

$$Y_{mean} = \frac{\sum_{i=1}^{n} lnX_i}{n} \tag{A.6}$$

where

X_i is the value of the i-sample derived value;

n is the number of sample derived values used for the evaluation of Y_{mean}.

$$s_Y = \sqrt{\frac{\sum_{i=1}^{n}(lnX_i - Y_{mean})^2}{n-1}} \tag{A.7}$$

NOTE 2 Adopting a log-normal distribution has the advantage that no negative values can occur as, for example, for geometrical and resistance variables.

NOTE 3 There are determination procedures, different from the one described in this Annex, that can be used to determine the characteristic relation line, (for example least squares using regression analysis) of the values of a ground property that varies with depth (z) or the characteristic values of dependent properties (e.g. cohesion and friction angle).

Annex B
(informative)

Contents of reports

B.1 Use of this Informative Annex

(1) This Informative Annex provides additional requirements and recommendations to those given in Clause 12, concerning the content and extent of reporting.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

B.2 Scope and field of application

(1) This Informative Annex covers documentation of the design process from initial desk study and ground investigation to implementation of the design through execution.

(2) This Informative Annex is intended to be used in conjunction with other European standards that give complementary requirements on documentation for specific phases in the design process, as illustrated in Figure B.1.

NOTE The process of geotechnical design and execution generally comprises a number of successive phases. The guidelines for documentation are defined in different standards for these phases, as presented in Figure B.1.

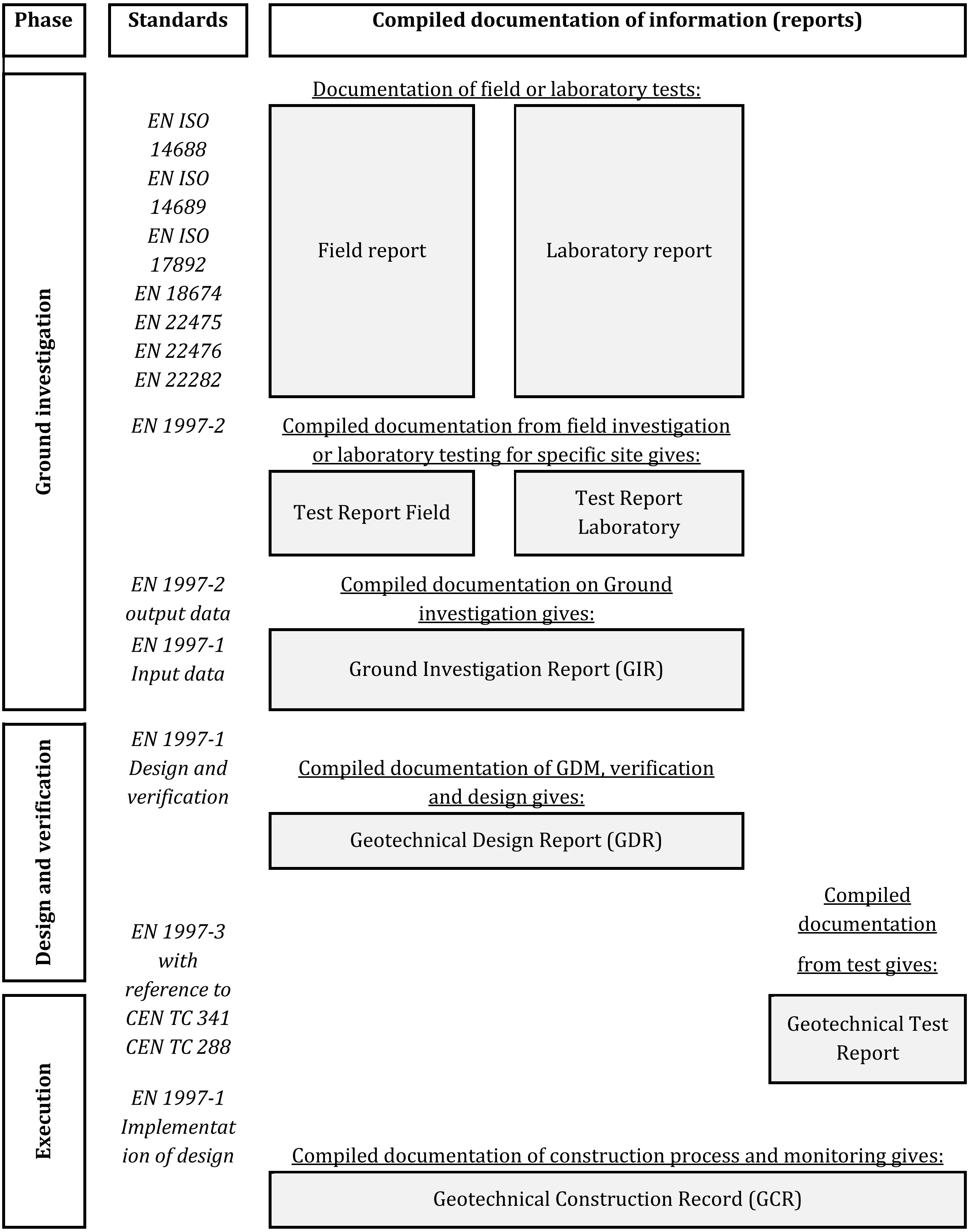


Figure C.1 — Illustration of interaction between documentation in EN 1997 (all parts) and complementary European standards.

B.3 Ground Investigation Report

(1) FprEN 1997-2:2024, Annex A shall apply.

B.4 Geotechnical Design Report

B.4.1 General content

(1) The Geotechnical Design Report should include, but is not limited to, the following information:

1. Project information
    a. Project name;
    b. Proposed structure and its use and location (coordinates and reference system);
    c. Normative references;
    d. Reference to the GIR, Ground Model, and other sources of information.
2. Evaluation of available information
    a. Desk study;
    b. Site inspection;
    c. In-situ and laboratory testing;
    d. Other relevant investigations and studies;
    e. Validation of information obtained from GIR (4.2.4).
3. List/sketch geotechnical structures for evaluation
    a. Geotechnical structures for consideration;
    b. Evaluation of the alternatives;
    c. Choice of main alternatives, and motive for abandoning the other.
4. Basis of design
    a. Design situations (4.2.2);
    b. Limit states considered (8, 9);
    c. Actions and combinations of actions (4.3.1);
    d. Geotechnical reliability, Consequence Class (GCC, GC) (4.1.2.2, 4.1.2.3);
    e. Ground Model (see FprEN 1997-2:2024, Clause 4);
    f. Geotechnical Design Model, including evaluation of representative values (4.3.2) and validation of GDM (4.2.3);
    g. Impact within the zone of influence (4.2.5);
    h. Aspects in relation with robustness (4.1.4), design service life (4.1.5), durability ((1)) and sustainability (4.1.7);
    i. Any restrictions (loading, vibration, deformation, etc.);
    j. Any assumptions or simplifications;
    k. Verification method with corresponding selections and justification:
        i. For verification by calculation
            – Applicable design case and partial factors;
            – Validation of chosen calculation model (7.1).
        ii. For verification by testing
            – Reference to performed and planed testing.
        iii. For verification by prescriptive rules
            – Reference to selected prescriptive rules.
        iv. For verification by Observational Method
            – Selection of design variants for analyses.
5. Geotechnical Analyses
    a. Estimate of the expected range of results;
    b. Documentation of analyses;
    c. Sensitivity analyses;
    d. Evaluation of results;

    e. Analyses of execution phases.

6. Implementation of design (contribution to execution specification)
    a. Specification of materials (dimensions, tolerances, quality);
    b. If needed, drawings;
    c. Requirements on the execution process and description of each execution phase.
    d. Supervision Plan (10.2);
    e. Inspection Plan (10.3);
    f. Monitoring Plan (10.4);
    g. Maintenance Plan (10.5).

(2) Additional information to that given in (1) should be included to give proper documentation.

B.4.2 Specification of the Geotechnical Design Model

(1) A Geotechnical Design Model shall include specification of design situations (physical conditions and timeframe), corresponding combinations of actions and associated relevant limit states.

(2) The description of the ground conditions compiled in the Geotechnical Design Model should include, but is not limited to:

— the results of the field investigation and laboratory tests evaluated according to FprEN 1997-2;

— a statement about the data that is excluded from evaluation with justification;

— a statement about any limitations of the investigation results;

— the choice of Geotechnical Category, with justification;

— a review of the results of the site inspection, desk study, field investigation and laboratory tests;

— a review of topographical data;

— a review of the derived values of ground properties.

(3) The description of geotechnical units should include, but is not limited to:

— a description and classification of the ground included within each geotechnical unit;

— a designation of the material properties relevant for design;

— a identification of the data that was used in the selection of representative values of ground properties.

NOTE Guidance on the specification of geotechnical units is given in FprEN 1997-2.

(4) The geometrical specification should include, but is not limited to:

— the location of boundaries between different geotechnical units;

— the location of discontinuities within a geotechnical unit;

— the spatial trends in the variation of ground properties, particularly with depth.

NOTE Guidance on the geometric specification is given in FprEN 1997-2.

(5) The specification of groundwater and surface water conditions at a site should include, but is not limited to:

— identification of any low permeability materials;

— specification of water tables, groundwater pressures, and flows relevant to the design;

— identification of saturation conditions for all materials in the model;

— chemical properties of groundwater;

— a statement about the likely drainage response of each permeable saturated material present in the model.

NOTE Guidance on the specification of groundwater conditions is given in FprEN 1997-2.

(6) The documentation should include, but is not limited to:

— tabulation and graphical presentation of the results of field investigation and laboratory testing;

— cross-sections of the ground showing relevant geotechnical units and their boundaries including the groundwater table;

— the process of compiling the Geotechnical Design Model considering the groundwater table, ground type, ground investigation techniques, transport, handling, specimen preparation, local experience, and other sources of information.

B.4.3 Verification of limit states

(1) Documentation of verification by prescriptive rules (4.5) should include, but is not limited to:

— a reference to the prescriptive rules specified by the relevant authority or agreed for the specific project by the relevant parties;

— an evaluation of the applicability of the prescriptive rules for the considered design situation, limit state and Geotechnical Design Model.

(2) Documentation of verification by testing (4.6) should include, but is not limited to:

— a reference to the appropriate geotechnical test report;

— an evaluation of the test results and their limitations.

(3) Documentation of verification by the calculation, including verification by partial factor method (4.4) should include, but is not limited to:

— validation of the calculation model for the used Geotechnical Category;

— the design values of ground parameters, including justification;

— the design cases applied; and

— the geotechnical design calculations and drawings.

(4) In addition to (3) documentation of verification by the Observational Method (4.7) should include, but is not limited to:

— justification of the applicability of the Observational Method for the design situation, and Geotechnical Category;

— the design variant used at the outset of execution; and

— the design variants including threshold and limiting values and acceptance criteria with associated contingency measures.

(5) In addition to (3) or (4), documentation of design by calculation using numerical methods should include, but is not limited to:

— justification of the applicability of the numerical model used for specific design situations;

— statement about the boundary conditions of the model.

B.4.4 Simplification for Geotechnical Category 1

(1) For Geotechnical Category 1, the lists above may be reduced to the following information, as applicable:

1. Project information
   a. Project name;
   b. Proposed structure and its use;
   c. Reference to the GIR and other sources of information.
2. Evaluation and validation of available information, summarised in a simplified Geotechnical Design Model that is validated.
3. Basis of design
   a. Geotechnical Reliability (GCC, GC) and Consequence class (CC);
   b. Restrictions (loading, vibration, deformation, etc.);
   c. Limit states;
   d. Any assumptions and simplifications.
4. Geotechnical Analyses, one or more of the following:
   a. Prescriptive rules with justification;
   b. Documentation of calculation model used (with justification of its validation Table 7.1)
5. Specification of the geotechnical structure
   a. Specification of materials and dimensions;
   b. Requirements on the execution process and description of each execution phase.
6. Implementation of design during execution and service life
   a. Supervision Plan (10.2);
   b. Inspection Plan (10.3).

B.5 Geotechnical Construction Record

B.5.1 General content

(1) The Geotechnical Construction Record should include, but is not limited to, the following:

1. Project information
   a. Project name;
   b. Completed structure, its intended use and location (coordinates and reference system);
   c. Any relevant normative references;
   d. Reference to the GIR and GDR and to construction drawings and specifications.
2. Construction record
   a. Sequence of construction operations assumed in the design including any deviations from it during construction;
   b. Encountered deviations from the design basis including the Geotechnical Design Model;
   c. Measures applied;
   d. Deviations from construction specification and structure specification made during construction including justifications;
   e. Temporary works;
   f. Requirement for on-going monitoring;
   g. As-built drawings.
3. Inspection record
   a. Evaluation of inspection reports, including testing of structure and complementary ground investigation;
   b. Revision of the Ground Model and Geotechnical Design Model;
   c. Measures applied;
   d. Deviations from the plan.
4. Supervision record
   a. Evaluation of results from supervision;
   b. Measures applied;
   c. Deviations from the plan.
5. Monitoring record
   a. Evaluation of monitoring results;
   b. Measures applied;
   c. Deviations from the plan.
6. Consideration for future maintenance
   a. Summary of observation made during the construction;
   b. Record of items with special consideration for future maintenance.

(2) Test reports, inspection records, and drawings may be added to the GCR.

(3) A Building Information Model may be used to compile part of the GCR.

B.5.2 Record of construction

(1) The record of construction should include, but is not limited to:

— a general description of the works, including ground and groundwater conditions encountered;

— instability problems, unusual ground conditions, and groundwater problems, including measures to overcome them;

— contaminated and hazardous material encountered on site and the location of disposal, both on and off site;

— temporary works and foundation treatment, including drainage measures and treatment of soft areas and their effectiveness;

— types of imported and site-won materials and their use;

— any aspect of the specification or standards used that should be reviewed in light of problems encountered on site;

— any unexpected ground conditions that required changes to the design; and

— problems not envisaged in the Geotechnical Design Report and the solutions to them.

(2) For geotechnical structures in Geotechnical Category 1, a formal construction schedule may be omitted from the Geotechnical Construction record.

B.5.3 Record of supervision, monitoring and inspection

(1) The record of supervision, monitoring, and inspection should include, but is not limited to:

— evaluation of results from measurements, observations and tests on the geotechnical structure or parts of it;

— the impact of the results on the execution and built structure;

— evaluation of results from complementary geotechnical investigations;

— the impact of such investigation on the execution and built structure;

— alteration of the Geotechnical Design Model;

— deviations from the Supervision, Monitoring, and Inspection Plans;

— details of aspects that during the execution phase differed from the assumptions made during the design and an assessment of their impact; and

— summary of observations made during supervision, monitoring, and inspection.

B.6 Geotechnical test report

(1) The factual account in a geotechnical test report should include, but is not limited to:

1. Project information
    a. Project name;
    b. Purpose of testing;
    c. List of tests performed and their locations (coordinates);
    d. Any relevant normative reference;
    e. Date and time of tests;
    f. Environmental conditions on site during testing;
    g. Name of field personnel;
    h. Equipment used;
    i. Documentation of calibration and certification documents;
    j. Test methodology.
2. Details of structural parts tested
    a. Type of ground, structure and/or structural parts;

   b. Locations (drawing and/or coordinates);
   c. Dates of installation.
3. Test results
   a. Measured values;
   b. Derived values (with any correlations used, including justification);
   c. Remarks on specific test results.
4. Review of testing and results
   a. Problems encountered during the test that could affect the results;
   b. Known limitations of the results.

Annex C
(informative)

Guideline on selection of Geotechnical Complexity Class

C.1 Use of this Informative Annex

(1) This Informative Annex provides complementary guidance to Clause 4 for selection of appropriate Geotechnical Complexity Class.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

C.2 Scope and field of application

(1) This Informative Annex covers guidelines on selection of appropriate Geotechnical Complexity Class.

C.3 Specific features to consider

(1) The Geotechnical Complexity Class should be selected based on an evaluation of the degree of severity for the design situation of these general features;

— uncertainty of the ground conditions;

— variability and difficulty of the ground;

— sensitivity of the geotechnical structure to groundwater and surface water conditions;

— complexity of the ground-structure interaction.

(2) The evaluation of the severity should be based on engineering judgement, with a scale from significant, considerable, high at one end to negligible, uniform, low at the other end of the scale.

(3) If the evaluation in (1) results in a high severity for any of the general features, the GCC should be selected as GCC 3.

NOTE Specific features to include in the evaluation of the severity of the general features is given in Table C.1 (NDP) unless the National Annex gives different specific features.

(4) If the evaluation in (1) results in a low severity for all the general features, the GCC should be selected as GCC 1.

NOTE Guideline on specific features to be fulfilled for GCC1 is given in Table C.2 (NDP) unless the National Annex gives different specific features.

Table C.1 (NDP) — Examples of specific features to account for in selection of the Geotechnical Complexity Class

General features	Specific feature
Uncertainty in ground condition	— evaluation of uncertainty from the available results from ground investigations; — evaluation of completeness of available results and relevance of ground investigation method with respect to best possible knowledge of the ground conditions; — ground conditions are with high certainty expected to be as interpreted from the ground investigations.
Variability or difficulty of ground condition	— ground with weak layers or zones; — unfavourable discontinuity patterns; — potential pre-existing failure surfaces; — occurrence of ground conditions where geotechnical structure design or execution need detailed assessment. E.g. fine soil sensitive to disturbance, aggressive soil, highly compressible soil, organic soil, creep soil, swelling soil.
Sensitivity to groundwater and surface water conditions	— existence of hydraulic gradient and seepage forces; — exposure to erosion, scour or piping; — potential for water flow; — high groundwater level; — excavation below groundwater level; — variability in water level.
Complexity of the ground-structure interaction	— ongoing ground movements (settlement and/or slope movement); — potential unstable ground; — progressive failure of natural or improved ground; — potentially sensitive adjacent structure or complex interaction with adjacent structures; — sensitivity of the structure to movements and differential movements; — structure subjected to dynamic, cyclic or seismic actions; — highly concentrated loading on part of the geotechnical structure; — complexity of the structure itself including geometry, variation in plane and depth; — lack of documented comparable experience for the considered geotechnical structure and execution of it in similar conditions.

Table C.2 (NDP) — Examples of specific features to select Geotechnical Complexity Class 1

General features	Specific feature
Uncertainty in Ground condition	— documented comparable experience of the ground conditions, — no known information that indicate uncertainty in the ground conditions.
Variability or difficulty of ground condition	— available results from Ground investigations validate simple and uniform ground conditions; — no known weak layers or unfavourable discontinuities; — ground considered as suitable for the specific application without further improvement.
Sensitivity to groundwater and surface water conditions	— no excavation below the ground water level, without comparable experience; — no exposure to erosion, scour or piping or any other water induced transport of soil particles; — minimal potential of water flow through the structure; — low influence from groundwater and/or surface water.
Complexity of the ground-structure interaction	— No records of significant ground movements (settlement and or slope movement); — geotechnical structure insensitive to movements; — horizontal o slightly inclined ground surface; — limited excavation depth; ○ e.g. 2 m in fine soil and 3 m in coarse soil — absence of sensitive structures within the zone of influence; — simple loading conditions ○ no dynamic, cyclic or seismic actions. ○ no concentrated loading. ○ permanent loading is restricted to a limited fraction of anticipated bearing capacity of the ground

Bibliography

References given in recommendations (i.e. "should" clauses)

The following documents are referred to in the text in such a way that some or all of their content constitutes highly recommended choices or course of action of this document. Subject to national regulation and/or any relevant contractual provisions, alternative documents could be used/adopted where technically justified. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1537, *Execution of special geotechnical works - Ground anchors*

EN 1912:2012, *Structural Timber - Strength classes - Assignment of visual grades and species*

EN 10080, *Steel for the reinforcement of concrete - Weldable reinforcing steel - General*

prEN 10138[2], *Prestressing steels*

EN 12390-5, *Testing hardened concrete - Part 5: Flexural strength of test specimens*

EN 12715, *Execution of special geotechnical work - Grouting*

EN 12716, *Execution of special geotechnical work - Jet grouting*

EN 13249, *Geotextiles and geotextile-related products - Characteristics required for use in the construction of roads and other trafficked areas (excluding railways and asphalt inclusion)*

EN 13250, *Geotextiles and geotextile-related products - Characteristics required for use in the construction of railways*

EN 13251, *Geotextiles and geotextile-related products - Characteristics required for use in earthworks, foundations and retaining structures*

EN 13252, *Geotextiles and geotextile-related products - Characteristics required for use in drainage systems*

EN 13253, *Geotextiles and geotextile-related products - Characteristics required for use in erosion control works (coastal protection, bank revetments)*

EN 13254, *Geotextiles and geotextile-related products - Characteristics required for the use in the construction of reservoirs and dams*

EN 13255, *Geotextiles and geotextile-related products - Characteristics required for use in the construction of canals*

EN 13256, *Geotextiles and geotextile-related products - Characteristics required for use in the construction of tunnels and underground structures*

[2] Under development.

EN 13257, *Geotextiles and geotextile-related products - Characteristics required for use in solid waste disposals*

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EN 14651, *Test method for metallic fibered concrete - Measuring the flexural tensile strength (limit or proportionality (LOP), residual)*

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EN 16907 (all parts), *Earthworks*

EN 50162, *Protection against corrosion by stray current from direct current systems*

EN ISO 14688 (all parts), *Geotechnical investigation and testing - Identification and classification of soil*

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EN ISO 17892 (all parts), *Geotechnical investigation and testing - Laboratory testing of soil*

EN ISO 18674 (all parts), Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation

EN ISO 22475 (all parts), *Geotechnical investigation and testing - Sampling and groundwater measurements*

EN ISO 22476 (all parts), *Geotechnical investigation and testing - Field testing*

EN ISO 22282 (all parts), *Geotechnical investigation and testing - Geohydraulic testing*

ISO 1920-10, *Testing of concrete - Part 10: Determination of static modulus of elasticity in compression*

ISO 6707-1, *Buildings and civil engineering works - Vocabulary - Part 1: General terms*

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