CEN/TC 250/SC 7
Eurocode 7 - Geotechnical design

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Eurocode 7: Geotechnical design — Part 1: General rules

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Eurocode 7: Calcul géotechnique — — Partie 1 : Règles générales

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Contents

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Drafting foreword by PT6

This document (prEN 1997-1:20xx) has been prepared by project team M515.SC7.T6.

This document is a working document, which was delivered to NEN on 2020-10-31.

<Drafting note: This Drafting foreword will be deleted during the enquiry stage.>

Question that TG A2 need to further discuss:

- The content and status of Annex B, Limiting values of structural deformation and ground movement.
  - There are proposals to delete the annex, revise it or keep it as it is.
- The status of Annex C, Additional guidance on reporting
  - PT6 suggest a coherent approach for all reporting. Hence, the status of Annex C in EN 1997-1 should be the same as the status of Annex A in EN 1997-2.
- The inclusion of Annex D, Qualification and professional experience
  - This is mainly a TC250 decision whether this Annex may be included or not.
- The inclusion of Annex F, Traffic load on geotechnical structures
  - This is mainly a TC250 decision whether this Annex in its' current format may be included or not.

European foreword

[DRAFTING NOTE: this version of the foreword is relevant to EN Eurocode Parts for enquiry stage]

This document (EN 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.

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.

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 recognise 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.

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>

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.

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 Eurocode 7

Eurocode 7 is intended to be used in conjunction with EN 1990 (all parts), which establishes principles and requirements for the safety, serviceability, robustness, and durability of structures, including geotechnical structures, and other construction works.

Eurocode 7 establishes additional principles and requirements for the safety, serviceability, robustness, and durability of geotechnical structures.

Eurocode 7 is intended to be used in conjunction with the other Eurocodes for the design of geotechnical structures, including temporary geotechnical structures.

Design and verification in Eurocode 7 are based on the partial factor method or other reliability-based methods, prescriptive rules, testing, or the observational method.

Eurocode 7 consists of a number of parts:

- EN 1997-1, *Geotechnical design – Part 1: General rules*
- EN 1997-2, *Geotechnical design – Part 2: Ground properties*
- EN 1997-3, *Geotechnical design – Part 3: Geotechnical structures*

0.3 Introduction to EN 1997-1

EN 1997-1 establishes additional principles and requirements for the safety, serviceability, robustness, and durability of geotechnical structures.

EN 1997-1 is intended to be used in conjunction with the other Eurocodes for the design of geotechnical structures, including temporary geotechnical structures.

Design and verification in EN 1997 are based on the partial factor method, 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 EN 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 EN 1997-1 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works 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 EN 1997-1 through the following clauses:

3.1	Table 3.1	4.1.2.2	Table 4.1
4.1.2.3	Table 4.2	4.1.3	Table 4.3
4.1.8	Table 4.4	4.2.3	Table 4.5
4.2.4	Table 4.6	4.4.3	Table 4.7
4.4.3	Table 4.8	7.1.2	Table 7.1
8.2	Table 8.1	12.1	Table 12.1
A.4	Table A.2	A.4	Table A.3
D.3	Table D.1	E.3	Table E.1

E.3	Table E.2

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

Annex A	Annex B	Annex D
Annex E	Annex F	

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 EN 1997-1

(1) EN 1997-1 provides general rules for the design and verification of geotechnical structures.

(2) EN 1997-1 is applicable for the design and verification of geotechnical structures outside the scope of EN 1997-3.

NOTE 1. In this case additional or amended provisions can be necessary.

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

1.2 Assumptions

(1) The assumptions of EN 1990-1, 1.2, apply.

(2) In addition to (1), the provisions of EN 1997 (all parts) assume that:

- data required for design are collected, recorded, and interpreted by appropriately qualified and experienced personnel;
- geotechnical structures are designed and verified by personnel with appropriate qualifications and experience in geotechnical design;
- adequate continuity and communication exist between the personnel involved in data-collection, design, verification and execution.

(3) EN 1997-1 will be used in conjunction with EN 1997-2, which provides provisions rules for determining ground properties from ground investigations.

(4) EN 1997-1 will be used in conjunction with EN 1997-3, which provides specific rules for the design and verification of certain types of geotechnical structures.

(5) EN 1997-1 will be used in conjunction with the other Eurocodes for the structural 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 1990 (all parts), *Eurocode: Basis of structural and geotechnical design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1992 (all parts), *Eurocode 2: Design of concrete structures*

EN 1993 (all parts), *Eurocode 3: Design of steel structures*

EN 1994 (all parts), *Eurocode 4: Design of composite steel and concrete structures*

EN 1995 (all parts), *Eurocode 5: Design of timber structures*

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 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

EN 1999 (all parts), *Eurocode 9: Design of aluminium structures*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this document, the definitions given in EN 1990-1 and the following definitions apply.

NOTE Table 3.1 lists the terms defined hereafter in alphabetical order with reference to the number hereafter where they are defined (different table for each language).

<Drafting note: this table will be updated before the final PT6 submission. Kept for the drafting process, the table will be deleted in final version depending on the drafting rules.>

Table 3.1 (NDP) Terms in alphabetical order with reference to numbers for definition

Term	Reference
acceptance criteria	3.1.9.3
alarm value	3.1.9.2
best estimate value of a ground property	3.1.3.6
characteristic value of a ground property	3.1.3.4
comparable experience	3.1.2.3
cyclic actions	3.1.4.5
derived value of a ground property	3.1.3.2
desk study	3.1.2.1
discontinuities	3.1.1.7
engineered fill	3.1.1.12
execution specification	3.1.9.7
Fill (made ground, US)	3.1.1.12
foliation	3.1.1.8
geotechnical analysis	3.1.6.2
Geotechnical Complexity Class	3.1.2.2
Geotechnical Construction Record	3.10.1.3
Geotechnical Design Report	3.10.3.2
Geotechnical Design Model	3.1.6.4
geotechnical system	3.1.6.3
geotechnical unit	3.1.6.5
ground	3.1.1.1
ground properties	3.1.3.1
Ground investigation report	3.1.10.1
Ground Model	3.1.6.6
ground resistance	3.1.4.1
ground strength	3.1.4.2
groundwater level	3.1.8.1
infill	3.1.1.10
inspection	3.1.9.5
interface	3.1.1.9
limit value	3.1.9.1
local stability	3.1.4.4
monitoring	3.1.9.6
nominal value of a ground property	3.1.3.3

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

[SOURCE: EN 1990-1]

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]

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]

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

[SOURCE: EN ISO 14689]

3.1.1.5
rock material (intact rock)
intact rock between the discontinuities

[SOURCE: EN ISO 14689]

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

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

[SOURCE: EN ISO 14688]

3.1.1.8
foliation
planar arrangements of constituents such as crystals in any type of rock (3.5), especially the parallel structure that results from flattening, segregation and other processes undergone by the grains in a metamorphic rock in geology refers to repetitive layering in metamorphic rocks

[SOURCE: EN ISO 14689]

3.1.1.9
interface
surface where two systems of ground interact or surface where ground and structure interact

3.1.1.10
infill
material that fills or is used to fill a space, hole or discontinuity

3.1.1.12
fill (or made ground)
ground that has been formed by using material to fill in a depression or to raise the level of a site

[SOURCE: EN ISO 14689]

3.1.1.12
engineered fill
material placed in a controlled manner to ensure that its geotechnical properties conform to a predetermined specification

3.1.1.13
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 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 EN 1997-2, Annex B

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

3.1.2.3
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

[SOURCE: modified from ISO 6707-1]

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. 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 on 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 1 to entry: further explanation on best estimate values is given in 4.3.2

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 certain part of the entire geotechnical structure without failure of the entire geotechnical structure.

3.1.4.5
cyclic actions
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 during sustained load

[SOURCE: ISO 6707-1]

3.1.5 Terms relating to verification methods

3.1.5.1
Observational Method (to check)
limit state verification method that comprises a continuous, managed, integrated process of design; construction control, monitoring and review included in a contingency plan that enables previously defined modifications to be incorporated during or after construction as appropriate.

[SOURCE: modified from 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, for example, the determination of skin friction and end bearing of piles; the pull-out strength of anchors; and the shear strength of lime-cement columns

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

3.1.6 Terms relating to analysis and models

3.1.6.1
zone of influence
zone where construction works or the geotechnical structure can induce adversely affects in terms of safety, serviceability, robustness, durability or sustainability on the geotechnical structure itself, 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 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: Guidelines on the contents of a Geotechnical Design Model are given in Clause 12 and Annex C

3.1.6.5
geotechnical unit
volume of ground or ground layer that is defined as a single material in a Geotechnical Design Model

3.1.6.6
Ground Model
site specific outline of the disposition and character of the ground and groundwater based on results from 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 calculation 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: EN 1990-1]

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

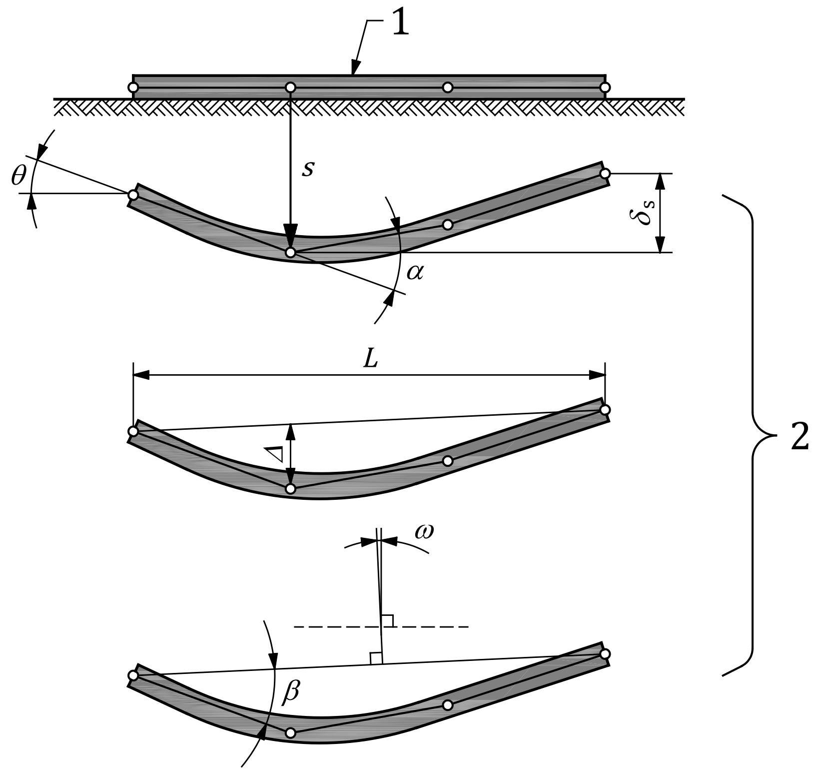
Note 2 to entry: There is a distinction between design for identified accidental actions and design for robustness. In design for accidental actions, a target level of reliability is expected to be achieved whereas design for robustness aims to increase the safety margin without aiming for a specified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

3.1.8.2
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

3.1.8.3
surface water level
level of water above the ground surface

3.1.9 Terms relating to implementation of design

3.1.9.1
limiting value
value of the serviceability criteria

Note 1 to entry: expressed as e.g. deformation, stress, strain, vibration,

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

3.1.9.3
acceptance criteria
acceptable variation of material properties, ground properties 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 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
measuring/observation of the behaviour of the ground and/or structure, to check compliance with the serviceability criteria.

3.1.9.7
execution specification
Is the synthesis of the requirements on material, products, dimensions, execution methods, control and construction stages from the Geotechnical Design Report.

Note 1 to entry: A execution specification can include method statements, supervision plan, inspection plan, monitoring plan, maintenance plan, contingency plan, material specification, technical description etc. The information can e.g. be presented in text, drawings, models, databases.

3.1.10 Terms relating to reporting

3.1.10.1
Ground Investigation Report
factual report that compiles the results of ground investigation

3.1.10.2
Geotechnical Design Report
report that complies verification and design process of all construction phases and final design of the geotechnical structure

3.1.10.3
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 apply.

NOTE 1 The symbols commonly used in all Eurocodes are defined in EN 1990-1

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

<Drafting note: Symbols marked with "grey" is known conflicts, there symbol is used for multiple purposes. Further improvement needed>

3.2.1 Latin upper-case letters

$A_{w,d}$	Accidental component of groundwater pressure
E	modulus of elasticity (Young's Modulus)
G	shear modulus
$G_{d,dst}$	design value of any permanent destabilising force not caused by groundwater pressures
$G_{d,stb}$	design value of any stabilising (downward) force
G_{w}	permanent component of groundwater pressure
G_{wk}	characteristic value of G_w
$G_{wk,inf}$	characteristic lower value of G_w
$G_{wk,sup}$	characteristic upper value of G_w
$G_{w,rep}$	representative value of groundwater pressure
h_w	piezometric level

K hydraulic conductivity

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

N_{SPT} blow count measured in Standard Penetration Test

$Q_{d,dst}$ design value of any variable destabilising force (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

$U_{d,dst}$ design value of destabilising (uplift) force due to 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

$V_{X,tran}$ coefficient of variation of the transformation error

X ground material property

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 for a number (n) of sample derived log values

3.2.2 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 in a CPT

$h_{w,z}$ piezometric level at elevation z

i_{d} design value of the hydraulic gradient

$i_{c,d}$ design value of critical hydraulic gradient (when soil particles begin to move)

k_{n} coefficient that depends on n used to determine X_{k}

n number of sample test results or of site-specific data

n degrees of freedom for the Student law

p_{l} pressuremeter limit pressure

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

q_{c} cone resistance in a CPT

$q_{k,rail}$ characteristic uniformly distributed vertical static loads applied to the entire trafficked area for railway traffic

$q_{k,road}$ characteristic uniformly distributed vertical static loads applied to the entire trafficked area for road traffic

q_{u} unconfined compressive strength of soil or rock (for foundation purposes)

s_{x} standard deviation of the sample derived values

t_{95} 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

u_{d} design groundwater pressure at a point in the ground

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

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

3.2.3 Greek upper-case letters

Δ relative deflection

Δ/L deflection ratio

Δu_d design excess groundwater pressure

3.2.4 Greek lower-case letters

β angular distortion

δ ground/structure interface angle of friction

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

$\gamma_{c,x}$ partial factor on effective cohesion (x=p for peak, x=r for residual)

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

γ_{E} partial factor on effect-of-actions

γ_{F} partial factor on action

γ_{HYD} partial factor for hydraulic heave

γ_{M} partial factor on material, applied to ground properties

γ_{pv} partial factor for effective vertical overburden pressure

γ_{qu} partial factor on unconfined compressive strength

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

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

$\gamma_{\tan\varphi,x}$ partial factor on coefficient x [x = p, peak friction, x = cs, critical state, x = dis, along discontinuity]

γ_{w} weight density of groundwater

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

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

δ ground/structure interface angle of friction

δ_s differential settlement

δ_X vertical scale of fluctuation of the property

η conversion factor

τ_f shear strength of soil 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.

σ_x standard deviation of a ground property X.

τ_f shear strength at failure

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

$\tan\varphi'$ coefficient of effective friction

ω tilt

3.2.5 Abbreviations

CC Consequence Class

DC Design Case

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

OCR Over Consolidation Ratio

OM Observational Method

RC Reliability Class

RFA Resistance Factor Approach

4 Basis of design

4.1 General rules

4.1.1 Basic requirements

(1) <REQ> The assumptions given in this document (1.2) shall be verified.

(2) <REQ> The design of geotechnical structures shall comply with EN 1990-1, EN 1997-1, EN 1997-2 and relevant clauses of EN 1997-3.

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

– Ground Model, as specified in EN 1997-2, 4;
– Geotechnical Design Model, as specified in 4.2.3 and Annex C.

4.1.2 Geotechnical reliability

4.1.2.1 Zone of influence

(1) <REQ> The extents of the zone of influence shall be defined.

(2) <REQ> The extents of the zone of influence shall be estimated prior to the ground investigation.

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

(4) <REQ> The extent of potential failure surfaces and the potential occurrence of significant ground displacements shall be determined.

(5) <REQ> In addition to (4), the extents of the zone of influence shall be determined from the extent of any transient or persistent changes in the representative groundwater or piezometric levels.

(6) <RCM> When defining the extent of the zone of influence consideration should include, but not be 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;
– relevant redistribution of the in-situ stress states; and
– the influence of work undertaken during execution.

(7) <RCM> The extents of the zone of influence should also take account of:

– environmental impact;
– pollution;
– vibrations; and
– noise.

4.1.2.2 Geotechnical Complexity Class

(1) <REQ> 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 E.

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 features of 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) <REQ> A preliminary GCC shall be selected as part of the desk study (EN 1997-2, 5.2.1).

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

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

(5) <REQ> EN 1997-2, 5.2.1(6) shall apply, in absence of a selected GCC.

4.1.2.3 Geotechnical Category

(1) <REQ> 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) <RCM> The Geotechnical Category (GC) should be determined from a combination of the Consequence Class of the structure (CC) and Geotechnical Complexity Class (GCC).

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 Class is given in 4.1.3.

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

(3) <REQ> In addition to EN 1990-1, 4.2the Geotechnical Category shall be used to specify the extent and amount of the following measures, to ensure the appropriate level of reliability required by EN 1990-1 is achieved:

- measures to achieve appropriate representation of parameters for design, including:
  - appropriate extent of ground investigation (EN 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 (4.1.8and Annex D);
  - quality management measures (4.1.8);
  - amount and type of reporting (12 and Annex C).
- 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).

(4) <RCM> If the measures in (3) are insufficient to achieve the appropriate level of reliability required by EN 1990-1, additional measures should be taken.

4.1.3 Consequences of failure

(1) <RCM> In addition to EN 1990-1, 4.3 the classification of the consequences of failure of a geotechnical structure should account for 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	– Critical infrastructures; – Geotechnical structures whose integrity is of vital importance for civil protection; – Areas with significant landslide hazards.
CC3	Higher	– Retaining walls and foundations supporting public buildings, with high exposure; – Man-made slopes and cuts, retaining structures with high exposure; – Major road/railway embankments, bridge foundations that can cause server interruption of service in emergency situations; – Geotechnical structures with a primary navigational function; – Underground constructions with large occupancy.
CC2	Normal	All geotechnical structures not classified as CC1, CC3, or CC4
CC1	Lower	– Retaining walls and foundations supporting buildings with low occupancy; – Man-made slopes and cuts, in areas where a failure will have low impact on the society; – Minor road/railway embankments not vital for the society; – Underground constructions with occasional occupancy.
CC0	Lowest	Not applicable for geotechnical structures

NOTE 1 Examples of Geotechnical structures whose integrity is of vital importance for civil protection is road/railway embankments with fundamental role in the event of natural disasters, earth dams connected to aqueducts and energy plants, levees, tailing dams and earth dams with extreme consequences upon failure, foundation of nuclear structures, and major harbour structures.

NOTE 2 Examples of Geotechnical structures with primary navigational function is marking or protecting entrances of ports.

NOTE 3 Examples of Geotechnical structures with occasional occupancy is culverts not supporting main railway lines or major roads.

4.1.4 Robustness

NOTE 1 See EN 1990-1, 4.4

NOTE 2 For most geotechnical structures, design in accordance with the Eurocodes provides an adequate level of robustness without the need for any additional measures to enhance robustness.

NOTE 3 Appropriate prognosis of climate change affecting the geotechnical structure during its design service life is considered in 4.3.1.5.

(1) <RCM> Measures to enhance robustness of a geotechnical structure should 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;
- erosive influence of running water.

NOTE 1 Ground conditions with specific issues refer to local ground conditions known by comparable experience, to be difficult to handle and with huge consequences e.g. quick clay, swelling ground, liquefiable soils.

NOTE 2 Specification of criteria for application of measures to enhance robustness of geotechnical structure, in addition to design according to Eurocode, can be given in the National Annex.

(2) <RCM> Strategies for designing geotechnical structures for robustness should include providing:

- enough ductility and deformation capacity;
- redistribution of load within the geotechnical structure to avoid sudden collapse;
- increased resistance of identified critical elements within the geotechnical structure;
- larger acceptable excavation 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;
- restriction on future loads on the ground surface or the structure.

4.1.5 Design service life

NOTE 1. See EN 1990-1, 4.5

4.1.6 Durability

(1) <REQ> In addition to EN 1990-1, 4.5 durability provisions for construction materials in contact with the ground and groundwater shall comply with relevant material and execution standards.

(2) <REQ> To achieve adequate durability of the geotechnical structure, the design shall take into account the relevant environmental influences given in 4.3.1.5.

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

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

(5) <PER> As an alternative to (3), measures may be taken to limit the environmental influences.

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

4.1.7 Sustainability

(1) <RCM> In addition to EN 1990-1, 4.7, specification of measures to enhance sustainability of a geotechnical structure and execution of geotechnical works, should 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 structures design life;
- potential re-use of structural elements or construction materials after the structures design service life.

(2) <RCM> 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;
- limitation of construction material with potential to cause pollution during execution and the structures design service life.

4.1.8 Quality management

NOTE See EN 1990-1, 4.8

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

NOTE Definition and guideline on use of Inspection Levels (IL), Design Check Levels (DCL) and Design Qualification and Experience Levels (DQL), as appropriate quality management measures, are given in EN 1990-1, Annex B.

(2) <RCM> If used, Design Check Levels (DCLs), Design Qualification and Experience Levels (DQLs), and Inspection Levels (IL) should be related to Geotechnical Categories (GC).

NOTE 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 4.4(NDP) unless the National Annex gives a different relationship.

Table 4.4(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) <REQ> In addition to EN 1990-1, 5, 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);
- Observational Method (4.7).

(2) <RCM> When the uncertainty in ground properties is too large to ensure the level of reliability required by EN 1990-1, limit states for geotechnical structures should not be verified using the partial factor method alone.

(3) <REQ> The verification of limit states by any of the methods given in 1) shall provide a level of reliability no less than that required by EN 1990-1.

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

4.2.2 Design situations

(1) <REQ> In addition to EN 1990-1, 5.2(1), the physical conditions that define the 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, the ground, and groundwater.

(2) <RCM> In addition to (1), design situations should include:

- stages of execution, service life, repair, and maintenance;
- potential impact of execution methods on geometrical and ground properties;
- consideration of the 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;
- anticipated placement and removal of ground or storage of building material in the zone of influence.

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.

4.2.3 Geotechnical Design Model

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

(2) <REQ> The Geotechnical Design Model shall be based on the Ground Model.

NOTE Guidance on Ground Model is given in EN 1997-2, 4

(3) <REQ> Information contained in the Ground Model regarding variability and uncertainty of the ground conditions shall be validated according to 4.2.4 before the Geotechnical Design Model is developed.

(4) <REQ>The Geotechnical Design Model 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 clause 4.3.2.

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

(5) <REQ> Any spatial trend in ground properties shall be identified in the Geotechnical Design Model.

(6) <REQ> The confidence of each Geotechnical Design Model shall be validated to ensure that the level of reliability required by EN 1990-1 is achieved.

(7) <RCM> The measures taken to validate the Geotechnical Design Model should be selected according to the Geotechnical Category.

NOTE Measures to validate the GDM are given in Table 4.5(NDP) unless the National Annex gives different measures.

Table 4.5(NDP) – Measures to validate the Geotechnical Design Model

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

(8) <REQ> If the validation process in (6) and (7) indicates that confidence in the Geotechnical Design Model is insufficient to achieve the level of reliability required by the EN 1990-1, additional ground investigation shall be performed.

(9) <PER> As an alternative to (8), other measures may be used to improve the confidence, provided the measures are specified by the relevant authority or, where not specified, agreed for a specific project by relevant parties.

(10)<RCM> To account for any remaining uncertainty in the Geotechnical Design Model, 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) <REQ> The quality and quantity of the information obtained from the Ground Investigation Report, GIR, and its appropriateness for the considered design situations, corresponding combinations of actions and associated limit states shall be validated.

(2) <RCM> The measures taken to validate the information from the GIR should be selected according to the Geotechnical Category.

NOTE Measures for validation are given in Table 4.6(NDP) unless the National Annex gives different measures.

(3) <RCM> Information identified as non-relevant for inclusion in the GDM should be documented and justified.

(4) <REQ> In addition to (1), the appropriate level of detail and extent of the Ground Model shall be validated.

NOTE 1. Guidance on Ground Model is given in EN 1997-2, 4

Table 4.6(NDP) – Measures to validate the information obtained from the GIR

Geotechnical Category	Measures
GC3	All items given below for GC2 and, in addition: – determine relevant quality[a] parameters based on the available data; – check 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 items given below for GC1 and, in addition: – comparison of the consistency of boundaries of the geotechnical units from different sources of information, to confirm that used methods of interpolation has sufficiently captured the variations; – comparison of ground description, classification, and strength index test results to identify inconsistencies; – evaluation of the performed testing to ensure that the test results are appropriate for design situation considered, with respect to e.g. loading rate, strain level, stress path and boundary conditions; – check that, for the design situation considered, the derived values have been appropriately determined and correlation used within their respective limitations; – check the confidence of the different sources of information with consideration of the in-situ techniques and laboratory tests suitability for the considered design situation and possible level of confidence (see EN 1997-2).
GC1	All items given below: – if field investigation and laboratory testing is performed, check that appropriate testing standards have been used; – comparison of derived values from different sources to identify inconsistencies and anomalies; – check of anomalies identified in the GIR, and exclusion of non-relevant information.
[a] Quality parameters include e.g. sample disturbance, zero-drift for CPT, measurement accuracy.	

(5) <REQ> 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 the Eurocodes, additional ground investigation shall be performed.

NOTE Guidance on minimum amount of ground investigation is given in EN 1997-2, 5.

(6) <PER> As an alternative to (5), 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) <REQ> 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, settlement, noise, vibrations and pollution.

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

(2) <REQ> In addition to (1), 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) <RCM> Strategies to limit the adverse impact within the zone of influence should 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 zone of influence;
- limitation of construction material with potential to cause pollution during execution and the structure design service life.

(4) <RCM> In addition to EN 1990-1, 5.4, and 9.1 serviceability criteria for the new structure, existing structures, utilities, and the ground and groundwater within the zone of influence should be defined.

(5) <REQ> In addition to (4) the serviceability criteria shall be selected to avoid any ultimate limit state in the new structure, existing structures, utilities and ground.

(6) <PER> The serviceability criteria may be defined by limiting values or in terms of acceptance criteria.

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

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

(8) <REQ> If the serviceability criteria are defined according to (7), 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) <RCM> If the construction works are likely to have adverse impacts on the behaviour of existing structures, utilities, and the ground and groundwater within the zone of influence, their anticipated behaviour during execution should be checked against provisions included in the Monitoring Plan.

(10) <PER> In addition to (9), the anticipated behaviour may be determined by prognosis (calculation) or engineering judgement.

4.3 Basic variables

4.3.1 Actions and environmental influences

4.3.1.1 Classification and representative values of actions

NOTE See EN 1990-1, 6.1.1 – 6.1.3

4.3.1.2 Permanent and variable actions

(1) <REQ> In addition to actions from the supported structure, the following potential actions shall be included in relevant 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;
- anticipated future structures.

(2) <RCM> Actions other than those given in (1) should be included as necessary to ensure that all actions affecting the limit states are accounted for.

(3) <REQ> The design of geotechnical structures shall consider the effects of interaction between the structure and the ground.

(4) <RCM> Variable actions arising from traffic loads should be modelled as uniformly distributed loads or as line loads.

NOTE Traffic loads models complying with EN 1991-2 are given in Annex F.

4.3.1.3 Cyclic and dynamic actions

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

- cyclic actions
  - when they induce significant ground strength degradation, or ground stiffness degradation, or densification, or generation of excess groundwater pressures, or permanent settlements or vibration in the surroundings;
- 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.

(2) <RCM> Actions other than those given in (1) should be considered as cyclic and dynamic actions, where present.

4.3.1.4 Accidental actions

NOTE See EN 1990-1, 8.3.3.4.

4.3.1.5 Environmental influences

NOTE See EN 1990-1, 6.1.4.

(1) <REQ> The adverse effects on actions of the following environmental influences shall be considered:

- existing and future climate conditions such as precipitation, temperature and wind;
- freezing and/or thawing of groundwater and surface water;
- mass displacement due to ground improvement, piling, or other installation in the ground;
- increase in groundwater pressure due to construction work or other activities;
- biological activity.

(2) <REQ> In addition to (1), the adverse effects on the design situation of the following environmental influences shall be considered:

- natural and man-made cavities and underground spaces;
- pre-existing activities at regional scale (dewatering, oil or gas extraction, mining);
- climate change effects such as sea level rise;
- natural dissolution features.

(3) <REQ>The adverse effects on the durability of the structure, of the following environmental influences on degradation, corrosion, leaching and erosion shall be considered:

- existing and future climate conditions due to precipitation, temperature and wind;
- 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;
- mineralogical composition of the ground;
- change of physical, chemical and/or mineralogical composition in the ground;
- evaporation;
- any electrical current flowing in the ground;
- biological activity;
- existing or potential contaminated ground, groundwater, or surface water.

(4) <REQ> The adverse effects on strength and stiffness properties of ground and construction material of the following environmental influences shall be considered:

- existing and future climate conditions due to precipitation, temperature and wind;
- evaporation;
- biological activity;
- freezing and/or thawing of groundwater and surface water.

(5) <RCM> The adverse effects of environmental influences other than those given in (2), (3), (4) and (5) should be considered where present.

4.3.2 Material and product properties

4.3.2.1 Representative values of ground properties

(1) <REQ> Representative values of ground properties to be used in ULS and SLS verifications shall be based on the derived values collected in 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) <REQ> 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.

(3) <REQ> The representative value of a ground property shall be the value affecting the occurrence of the limit state, corresponding to one of the following:

– An average value of the ground property in the volume involved in the limit state, when the occurrence of the limit state in study is insensitive to the spatial variability of the ground property in the volume of the ground involved in the limit state; or
– an inferior or superior value of the ground property in the volume involved in the limit state, when the occurrence of the limit state in study is sensitive to the spatial variability of the ground property in the volume of the ground involved in the limit state.

(4) <REQ> The representative value of a ground property X_{rep} shall be determined from either Formula (4.1) or Formula (4.2):

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

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

where

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

X_{k} is the characteristic value of the ground property.

(5) <PER> 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 Formula (4.3) or Formula (4.4):

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

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

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

4.3.2.2 Characteristic values of ground properties

(1) The characteristic value of a ground property X_k shall be determined by statistical methods such that the probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%, taking into account statistical uncertainty, as follows:

- when an average value is to be used: an estimate of the mean value of the ground property;
- when an inferior value is to be used: an estimate of the 5% fractile of the distribution of the ground property; or
- when a superior value is to be used: an estimate of the 95 % fractile of the distribution of the ground property.

(2) <RCM> In addition to EN 1990-1, 6.2, the characteristic value of a ground property (X_k) should be determined taking account of the number of derived values that are available from Formula (4.5):

$$X_{\mathrm{k}} = X_{\mathrm{mean}}[1 \mp k_{\mathrm{n}}V_{\mathrm{x}}] = X_{\mathrm{mean}}\left[1 \mp \frac{k_{\mathrm{n}}\sigma_{\mathrm{x}}}{X_{\mathrm{mean}}}\right] \qquad (4.5)$$

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 X;

k_n is a coefficient that depends on n;

$\mp$ 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;

σ_x is the standard deviation of X.

NOTE 1 Formula (4.5) assumes_that the values X follows a normal distribution. Different expressions are used for other statistical distributions (see EN 1990-1, Annex C).

NOTE 2 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 3 Other procedures can be used to determine the characteristic values of a ground property increasing with depth (z) (e.g. for example using least squares with regression analysis) or the characteristic values of dependent parameters (e.g cohesion and friction angle)

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

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

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

4.3.2.4 Best estimate value of ground properties

(1) <REQ> The determination of best-estimate value of a ground property, used for prognosis of the behaviour of the geotechnical structure, shall be determined as:

- the most probable value of a sample of derived values of the considered ground property;
- the mean or the median or the mode of a sample of derived values, whichever it is considered more appropriate;
- the most probable values obtained by back-analysis carried out to reproduce the performance of a geotechnical structure known by monitoring.

NOTE The best-estimate refer to a particular ground property of a single geotechnical unit.

4.3.3 Geometrical properties

NOTE See EN 1990-1, 6.3 and 8.3.7.

(1) <REQ> Ground surface, surface water and groundwater levels, boundaries between geotechnical units, and the dimensions of the geotechnical structure shall be regarded as geometrical properties.

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

(2) <REQ> Geometrical properties of discontinuities in the ground shall include information on location, orientation, length, and presence of voids or openings.

NOTE Orientation can be described in terms of dip and direction

(3) <RCM> Values of the geometrical properties given in (2) should normally be nominal values.

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

- accounted for as properties of discretely defined discontinuities within the unit; or
- taken into account when defining equivalent ground properties for the unit.

NOTE Discontinuities and their properties are defined in EN 1997-2, 6.2 and 8.1.5.

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

(6) <PER> The nominal value of geometrical properties for ground discontinuities may be determined by sensitivity analysis using a probabilistic approach considering location, orientation, and length of the discontinuities.

4.4 Verification by the partial factor method

4.4.1 Verification of ultimate limit states

4.4.1.1 General

(1) <RCM> In addition to EN 1990-1, 8.3, ultimate limit states that involve the ground should be verified using either the:

- material factor approach (MFA); or

– resistance factor approach (RFA)

NOTE 1 EN 1997-3 specifies which approach can be used for specific geotechnical structures.

NOTE 2 Where EN 1997-3 allows either MFA or RFA to be used, unless the National Annex gives a specific choice, the approach to be used is as specified by the relevant authority or, where not specified, as agreed for a specific project by the relevant parties.

(2) <RCM> When using MFA, partial factors should be applied as follows:

– γ_M applied to ground properties, using Formula (8.19) of EN 1990-1; and
– either:
  – γ_F applied to actions, using Formulae (8.4) of EN 1990-1, or
  – γ_E to effects-of-actions, using Formula (8.5).

NOTE 1 EN 1997-3 specifies which factors to apply for specific geotechnical structures.

NOTE 2 Using γ_E to effects-of-actions is known as EFA (Effect-of-actions Factoring Approach)

(3) <RCM> When using RFA, factors should be applied as follows:

– γ_R applied to ground resistance, using Formula (8.20) of EN 1990-1; and
– either:
  – γ_F applied to actions, using Formulae (8.4) of EN 1990-1, or
  – γ_E to effects-of-actions, using Formula (8.5).

NOTE 1 EN 1997-3 specifies which factors to apply for specific geotechnical structures.

NOTE 2 Using γ_E to effects-of-actions is known as EFA (Effect-of-actions Factoring Approach)

4.4.1.2 Design values of the effects of actions

NOTE See EN 1990-1, 8.3.2.

(1) <RCM> When design values of the effects of actions are calculated using Formula (8.4) of EN 1990-1, partial factors γ_F should be applied to actions.

NOTE Values of the partial factor γ_F for ultimate limit states are given in Annex A of EN 1990-1.

(2) <RCM> When design values of the effects of actions are calculated using Formula (8.5) of EN 1990-1, partial factors γ_E should be applied directly to effects of actions.

NOTE Values of the partial factor γ_E for ultimate limit states are given in Annex A of EN 1990-1.

4.4.1.3 Design values of ground properties

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

NOTE 1 Values of the partial factor γ_M for persistent, transient and accidental design situations are given in Table 4.7(NDP) unless the National Annex gives different values.

NOTE 2 Partial factors for resistance are given in EN 1997-3.

NOTE 3 Design values obtained by other means, such as indices and unitless parameters are not factored using the partial factor γ_M.

Table 4.7(NDP) – Partial factors on ground properties for persistent, transient, and accidental design situations

Ground property	Symbol	M1[1]	M2[1]	
		Persistent Transient Accidental	Persistent Transient	Accidental
Soil and Fill parameters				
Shear strength in effective stress analysis[2] (τ_f)	$\gamma_{\tau f}$	1,0	1,25 K_M	1,1
Coefficient of peak friction (tan φ'_p)[4]	$\gamma_{\tan\varphi,p}$	1,0	1,25 K_M	1,1
Peak effective cohesion (c'_p)	$\gamma_{c,p}$	1,0	1,25 K_M	1,1
Coefficient of friction at critical state (tan φ'_{cs})[4]	$\gamma_{\tan\varphi,cs}$	1,0	1,1 K_M	1,0
Coefficient of residual friction (tan φ'_r)[4]	$\gamma_{\tan\varphi,r}$	1,0	1,1 K_M	1,0
Residual effective cohesion (c'_r)	$\gamma_{c,r}$	1,0	1,1 K_M	1,0
Shear strength in total stress analysis[2] (c_u)	γ_{cu}	1,0	1,4 K_M	1,2
Unconfined compressive strength (q_u)	γ_{qu}	Same as γ_{cu}		
Rock parameters				
Shear strength[2] (τ_r)	$\gamma_{\tau r}$	1,0	1,4 K_M	1,2
Coefficient friction along discontinuity (tan φ'_{dis})[4]	$\gamma_{\tan\varphi dis}$	1,0	1,4 K_M	1,2
Unconfined compressive strength[3](q_u)	γ_{qu}	1,0	1,4 K_M	1,2
Interface parameters				
Coefficient of ground/structure interface friction (tan δ)	$\gamma_{\tan\delta}$	1,0	1,25 K_M	1,1

[1] M1, and M2 are alternative sets of material factors. EN 1997-3 specifies which set to use for specific geotechnical structures.
[2] Intended to be used for numerical models and non-Mohr-Coulomb strength criteria.
[3] Used for foundation purposes only.
[4] the partial factor is applied to the tanφ

(2) <RCM> Except as given in (4) below, the design value of a ground property X_d should be calculated from Formula (4.6):

$$X_{\mathrm{d}} = \frac{X_{\mathrm{rep}}}{\gamma_{\mathrm{M}}} \tag{4.6}$$

where

X_{rep} is the representative value of the ground property;

γ_{M} is a partial material factor.

NOTE 1 The weight density of ground is not factored although actions arising from weight density can be factored.

NOTE 2 In specific cases, such as downdrag, the design values of ground properties are obtained by increasing the representative values with partial material factors in order to obtain superior values.

(3) <REQ> Effective cohesion at critical state shall be zero.

(4) <PER> When design values of geotechnical resistance are calculated using Formula (8.19) of EN 1990, partial factors $\gamma_{\tau\text{f}}$ may be applied directly on effective shear strength of soil (τ_{f}) and on shear strength of rock (τ_{f}), respectively.

(5) <PER> Design values of ground parameters may be assessed directly.

(6) <REQ> Only one of the consequence factors K_{M}, K_{F} and K_{R} shall be applied in a single verification.

NOTE 1 Values of K_{F} are given in EN 1990-1 Annex A.

NOTE 2 The value of K_{R} is 1.0 unless the National Annex gives a different value.

NOTE 3 Values of K_{M} for different consequence classes are given in Table 4.8(NDP) unless the National Annex gives different values.

(7) <PER> Provided (6) is satisfied and that the resulting partial factor is not less than 1,0, the value of γ_{M} may be adjusted according to the consequences of failure, by multiplying the partial factor with the consequence factor K_{M}.

Table 4.8(NDP) – Consequence factors K_{M} for ground properties

Consequence class (CC)	Description of consequences	Consequence factor K_{M}
CC3	Higher	1,1
CC2	Normal	1,0
CC1	Lower	0,9

(8) <PER>Provided (9) is satisfied, the value of γ_{M} for transient design situations may be multiplied by a reduction factor $K_{\text{tr}} \leq 1{,}0$, provided that the product $K_{\text{tr}}\gamma_{\text{M}}$ is not less than 1,0.

NOTE The value of the reduction factor K_{tr} is 1.0 unless the National Annex gives a different value.

(9) <RCM> The reduction factor K_{tr} should only be applied if:

- the geotechnical structure behaviour is ductile;
- contingencies measures are available to deal with any arising problems that would affect the safety of the works;

– the consequences of failure for adjacent structures or for the general public are limited.

4.4.1.4 Design values of geometrical properties

NOTE See EN 1990-1, 8.3.7 and EN 1997-1, 4.3.3.

4.4.1.5 Design values of resistance

(1) <RCM> When design values of geotechnical resistance are calculated using Formula (8.20) of EN 1990-1, partial factors γ_R should be applied directly to the resistance.

4.4.1.6 Combination of actions

NOTE See EN 1990-1, 8.3.4.

4.4.2 Verification of serviceability limit states

(1) <REQ>In addition to EN 1990-1, 8.4, provisions in 9 shall apply.

4.5 Verification by prescriptive rules

(1) <REQ> 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 1. 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) <REQ> Prescriptive rules shall be suitably conservative and justified by comparable experience.

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

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

4.6 Verification by testing

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

(2) <REQ> 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 corresponding evaluation of test results is given in 11.

4.7 Verification by the Observational Method

(1) <REQ> 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.

NOTE 1 A design variant, describing the anticipated behaviour of the geotechnical structure, comprises a design situation with the Geotechnical Design Model and associated failure mode.

NOTE 2 A design variant describes the anticipated behaviour of the geotechnical structure, given that the relevant ground properties lie in a predefined range.

(2) <REQ> In addition to (1), a contingency plan shall define contingency measures, to be applied when actual behaviour violates acceptance criteria or threshold values.

(3) <REQ> Contingency measures shall consist of instructions on any immediate failure-prohibiting measures for direct application, followed by selection of a prepared design variant that covers the actual ground response and ground-structure interaction.

(4) <REQ> Ultimate and serviceability limit states shall be verified for each design variant.

(5) <REQ> It shall be shown that there is an acceptable probability to fulfil the serviceability criterion.

NOTE Guidance on determination of serviceability criterion is given in 4.2.5 and 9.

(6) <REQ> Execution specifications shall be specified for each design variant.

(7) <REQ> Contingency measures shall be sufficiently rapid to apply to avoid attaining the limit state.

(8) <REQ> The number of design variants and the difference between them shall be sufficient to allow rapid replacement of a design variant by one matching the observed behaviour.

(9) <REQ> 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.

(10) <REQ> The design shall be adapted to the evaluated results in (9) by application of the contingency plan.

5 Materials

5.1 Ground

(1) <REQ> Ground properties shall be determined according to EN 1997-2.

(2) <RCM> The effects of ground and groundwater on concrete structure incorporated into the ground should be determined using the exposure classes defined in EN 206.

5.2 Engineered fill

(1) <REQ> 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.

(2) <REQ> 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) <RCM> Engineered fill for earthworks should comply with EN 16907 (all parts).

(4) <REQ> 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) <RCM> Geosynthetics incorporated into geotechnical structures should comply with ENs 13249 to 13257 and 13265.

(2) <RCM> Geosynthetic reinforcement should comply with EN 14475.

(3) <RCM> Vertical drainage in the ground should comply with EN 15237.

5.4 Grout

(1) <RCM> Grout for anchors should comply with EN 1537.

(2) <RCM> Grout for rock bolts should comply with EN 197-1.

(3) <RCM> Grout placed in the ground should comply with EN 12715.

(4) <RCM> Grout used for jet-grouting should comply with EN 12716.

(5) <RCM> Grout and mortar should comply with the rules given for concrete in EN 445, EN 447, and EN 14199.

NOTE EN 445 describes the test methods for grout specified in EN 447.

(6) <RCM> 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.

(7) <RCM> Unless preliminary tests prove that grout is sufficient to resist the maximum proof load, grout strength should be determined by comparable experience or grout testing.

(8) <RCM> For soil, unless another value is specified in the Geotechnical Design Report, the value of the compressive strength should be equivalent to concrete class C25/30 according to EN 206.

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

(9) <RCM> For rock, in order to avoid the occurrence of failure mechanisms into the grout, unless another value is specified in the Geotechnical Design Report, the value of the compressive strength should be equivalent to concrete class C35/45 according to EN 206.

(10) <RCM> The compressive and tensile strength of grout or mortar should be assessed from comparable experience or testing.

5.5 Plain and reinforced concrete

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

(2) <RCM> For the design of concrete incorporated in geotechnical structures, the minimum concrete cover value should be based on $C_{min,dur}$ as defined in EN 19972-1-1.

(3) <RCM> Weldable reinforcing steel for reinforced concrete used for geotechnical structures should comply with EN 10080.

(4) <RCM> Steel reinforcement for wire, wire ropes, and link chains should comply with EN 10138.

(5) <RCM> Tolerances for concrete spread foundations should comply with EN 13670.

(6) <RCM> Sprayed concrete incorporated into geotechnical structures should comply with EN 14487.

(7) <RCM> For fibre reinforced sprayed concrete, the flexural strength and the energy absorption capacity should be determined in accordance with EN 14488.

NOTE Annex JA of EN 1992-1 give information about the design of fibre reinforced sprayed concrete

(8) <RCM> For sprayed concrete without fibre reinforcement the flexural strength should be determined in accordance with ISO 1920-10.

(9) <RCM> The density of hardened concrete should be determined in accordance with EN 12390.

(10) <RCM> The resistance to water penetration should be determined in accordance with EN 12390.

(11) <RCM> 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) <REQ> Steel for geotechnical structures and the values of steel parameters shall comply with EN 1993-1-1 and EN 1993-5.

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

5.7 Cast iron

(1) <RCM> Cast iron for piles or piled foundations and the values of cast iron properties should comply with EN 1563.

NOTE EN1993 does not cover cast iron. In that case, specifications are given by the relevant authorities.

5.8 Timber

(1) <REQ> Timber for geotechnical structures and the values of timber parameters shall be determined in accordance with EN 1995-1-1.

(2) <RCM> Timber grading for pile foundations should comply with the general requirements of EN 14081-1.

(3) <RCM> The minimum grade of timber should be SS for softwoods or HS for hardwoods conforming to EN 1912 Tables 1 and 2.

(4) <PER> Timber piles without preservative treatment may be used provided the piles are installed below the groundwater table and remain fully submerged throughout their service life.

5.9 Masonry

(1) <REQ> Masonry incorporated into geotechnical structures shall comply with EN 1996.

6 Groundwater

6.1 General

(1) <REQ> 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 Guidelines about hydrogeological conditions are presented in EN 1997-2.

NOTE 2 Clause 12 of EN 1997-3 is about groundwater control techniques.

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

– variation over time;
– spatial heterogeneity of 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;
– potential changes of groundwater pressures due to the growth or removal of vegetation
– expected climate changes.

(3) <REQ> The Groundwater pressure u, the elevation (z) at which u applies and the piezometric level ($h_{w,z}$) shall be considered according as in Formula (6.1):

$$u = \gamma_w (h_{w,z} - z) \tag{6.1}$$

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) <RCM> 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' (EN 1990-1, 6.1.1).

(5) <REQ> 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) <RCM> The groundwater pressures should be determined by considering the potential interactions between the groundwater and the surface water.

(7) <RCM> 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) <PER> Groundwater pressures may be classified as accidental actions when:

- the annual probability of exceedance is less than that specified in EN 1990-1, 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 deficiency in sealing or dam;
- drainage system fails.

(9) <REQ> Ground 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) <REQ> The effects of groundwater chemistry on the ground and on construction materials in contact with the ground shall be determined.

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

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

(4) <PER> 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) <REQ> Surface water, groundwater, and piezometric levels (and associated groundwater pressures) shall be measured in order to give the most critical design situation.

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

(3) <PER> When direct measurements are not reliable enough for the design service life of the structure, surface water, groundwater, and piezometric levels may be determined only from historical data.

(4) <RCM> 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.

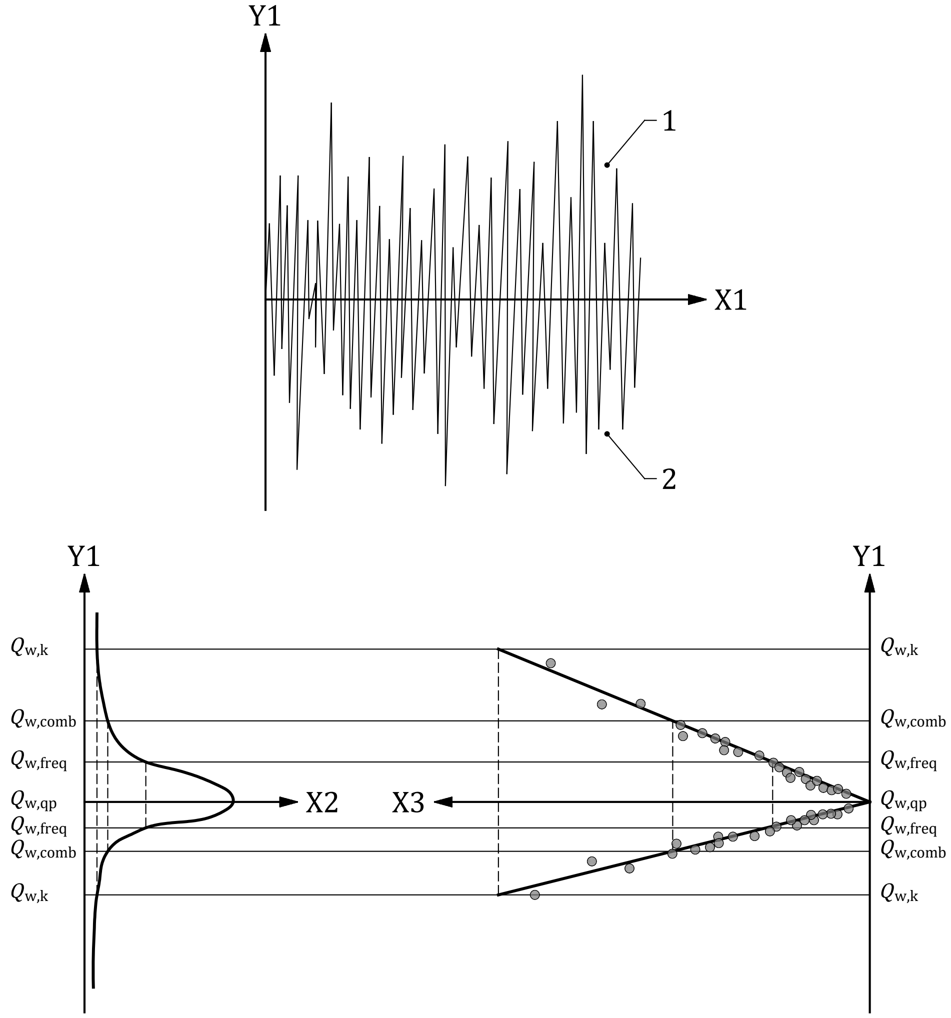
6.4 Representative values of groundwater pressures

(1) <RCM> The representative value of groundwater pressure $G_{w,rep}$ 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);
- 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 The values of $G_{wk,sup}$ and $G_{wk,inf}$ are based on an annual probability of exceedance of 2 % (which corresponds to a return period of 50 years), unless the National Annex gives a different value.

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



Key

X1 t

X2 Probability density (annual maximal)

X3 log t return period

Y Groundwater pressures, Piezometric levels

1 Higher values

2 Lower values

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

(2) <RCM> If there is insufficient data to derive their values on the basis of the annual probability of exceedance, $G_{wk,sup}$ and $G_{wk,inf}$ should be selected as cautious estimates of the most adverse values likely to occur during the design situation.

(3) <REQ> 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 specified in EN 1990, 6.1.3.2.

(4) <REQ> 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) <PER> For simplicity, the combination value ($Q_{w,comb}$) may be replaced by the (more adverse) characteristic value ($Q_{wk} \geq Q_{w,comb}$).

(6) <RCM> If there is insufficient data to determine their values on the basis of annual probability of exceedance, the characteristic value Q_{wk} and the combination value $Q_{w,comb}$ should be selected as a cautious estimate of the most adverse value likely to occur during the design situation.

(7) <REQ> In accidental design situations, $Q_{w,rep}$ shall be selected as:

– the accidental value ($A_{w,d}$) 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 $A_{w,d}$ is based on the annual probability of exceedance specified in EN 1990-1, 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) <REQ> Design values of groundwater pressures in 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 specified in EN 1990-1 (see Table A.1.8).

(2) <REQ> 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 EN 1990-1.

(3) <PER> 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 $Q_{w,freq}$.

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) <REQ> Design values of groundwater pressures in serviceability limit states shall be equal to the representative values defined in 6.4.

6.6 Groundwater in freezing conditions

(1) <REQ> If all of the following apply, the design shall consider the effect of groundwater in freezing conditions:

- there is groundwater or sufficient moisture available;
- the geotechnical structure is in an area with temperatures below zero; and
- the ground is frost-susceptible.

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

(2) <RCM> If freezing of moist soil is possible during the design service life, the following should be considered:

- frost heave;
- thaw weakening;
- deformations and ultimate limit state due to frost and subsequent thaw;
- change of material properties due to frost and its effect on frost heave;
- change of material properties due to thaw and its effect on thaw weakening;
- change of material properties with temperature in general;
- iteration effects of freeze thaw occurrences.

7 Geotechnical analysis

7.1 Calculation models

7.1.1 General

(1) <REQ> Calculation models shall be appropriate for the limit state under consideration.

(2) <REQ> Calculation models shall provide a level of reliability no less than that specified in EN 1990-1.

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

(4) <RCM> 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 non-homogeneities 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;
- construction stages and loading rates.

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

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

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

NOTE 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.

Table 7.1 (NDP) — Level of validation of calculation models

Geotechnical Category	Measures
GC3	All the measures given below for GC2 and, in addition: • Calibration of the calculation model for the specific site against another suitable calculation model or site observations.
GC2	All the measures given below for GC1 and, in addition: • Literature reference that the calculation model has been used for similar conditions; • documentation showing that the assumptions for the calculation model used are relevant for the specific site and structure.
GC1	All the measures given below: • Local experience shows that the calculation model is suitable for the local conditions; • When using calculation models contained in EN 1997-3, confirmation that the design falls within the limits of application stated in EN 1997-3.

NOTE 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.

7.1.2 Empirical models

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

(2) <RCM> 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) <RCM> For the verification of serviceability limit states, limit equilibrium and limit analysis models should only be used in accordance with 9.1(5).

7.1.4 Numerical models

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

(2) <REQ> The complexity of a numerical model shall be appropriate for the quality and quantity of data available for determining input parameters.

NOTE The reliability of a numerical model does not only depend on its complexity but on the quality of the input data. Simple models can provide more reliable results than complex models.

(3) <REQ> The choice between continuum or discrete model shall be based on the type of ground, especially on the presence and the effects of discontinuities.

(4) <RCM> The validation of the numerical model should be consistent with the complexity of the numerical model.

7.1.5 Calculation models for cyclic and dynamic actions

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

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

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

NOTE For machine foundations design analyses aim at predicting their response to ensure that both ultimate limit states and serviceability limit states are verified. Serviceability limit states are typically specified in terms of peak velocity or displacement or of acceleration amplitudes during normal operation of the machinery.

(4) <RCM> 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 Quasi-static actions are defined in EN 1990-1.

NOTE EN 1997-2, 10, provides ground properties for verification of ultimate and serviceability limit states when cyclic or dynamic actions are involved.

7.2 Model factors

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

NOTE 1 The reference model can be:

- Comparable experience based on case histories;
- a full-scale instrumented and 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).

NOTE 2 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 are given in EN 1997-3.

(2) <RCM> 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 EN 1990-1.

8 Ultimate limit states

8.1 Type of ultimate limit states

8.1.1 Failure by rupture

(1) <REQ> In addition to EN 1990-1, 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;
– loss of geotechnical resistance of a structural element embedded in the ground.

NOTE 1. Guidance on rupture of the ground for different geotechnical structures is given in EN 1997-3.

(2) <RCM> 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) <REQ> In addition to EN 1990-1, 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);
– 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) <RCM> 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 rotational equilibrium

NOTE See EN 1990-1, 8.3.3.1(5)

(1) <REQ> Loss of static equilibrium due to the rotation of the structure 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 Design Case 2 of EN 1990-1.

NOTE 1 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.

NOTE 2 Overturning is verified according to EN 1997-3, 5 involving failure in the ground.

8.1.3.2 Loss of vertical equilibrium due to uplift

NOTE See EN 1990-1, 8.3.3.1(5).

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

NOTE The effects of all actions are compared with the resistances. Therefore, the actions consist of destabilising (permanent and variable) actions of groundwater pressures and other forces and the stabilising actions due to the weight of the structure. Resistance can be provided by anchors, piles or shear strength of the ground along the sides of the structure.

NOTE This verification can also be applied for other fluids than water.

(2) <REQ> If the structure or ground layer acts as a rigid body (Figure 8.1a), the inequality given by Formula (8.1) shall be verified:

$$U_{\mathrm{d,dst}} + G_{\mathrm{d,dst}} + Q_{\mathrm{d,dst}} - G_{\mathrm{d,stb}} \leq R_d \tag{8.1}$$

where

$U_{\mathrm{d,dst}}$ is the design value of destabilising (uplift) force due to groundwater pressures;

$G_{\mathrm{d,dst}}$ is the design value of any permanent destabilizing force (upwards) not caused by groundwater pressures;

$Q_{\mathrm{d,dst}}$ is the design value of any variable destabilizing force (upwards) not caused by groundwater pressures;

$G_{\mathrm{d,stb}}$ is the design value of the stabilizing (downward) forces;

R_d is design value of any resistance to uplift.

NOTE 1 Partial factors for actions are given in EN 1990-1, Annex A; for ground properties in Table 4.7(NDP); and for resistances in EN 1997-3.

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

(3) <REQ> If the structure or ground layer does not act as a rigid body (Figure 8.1b), the inequality given by Formula (8.2) shall be verified:

$$u_{d;dst} - \sigma_{v;d} \leq 0 \tag{8.2}$$

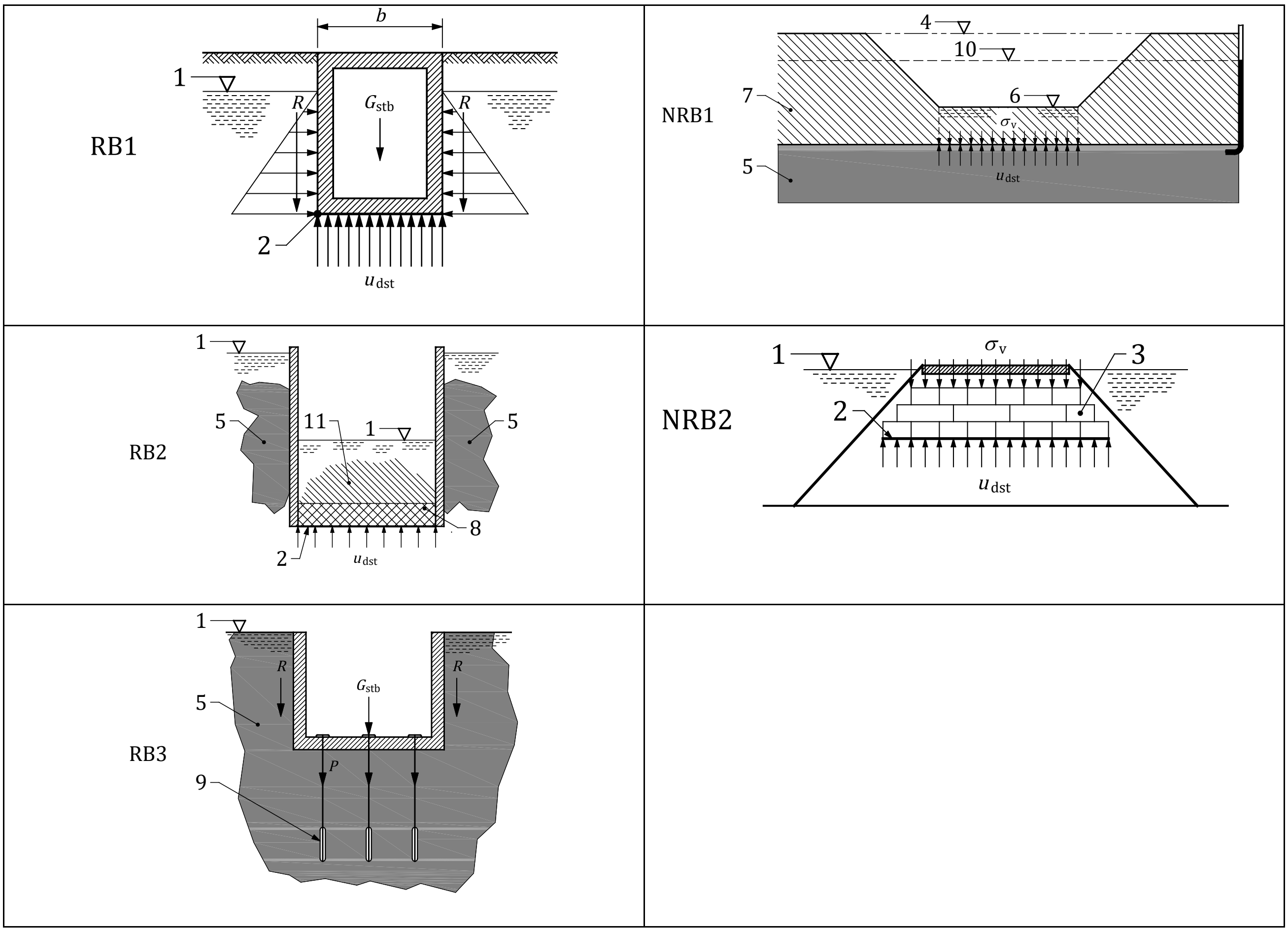
where

$u_{\mathrm{d,dst}}$ is the design value of destabilizing (uplift) groundwater pressures;

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

NOTE Design values of groundwater pressures are determined according to 6.5.

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



Key

Rigid body

1 Groundwater table

2 Water tight surface

5 Sand

8 Injected sand

9 Anchor

11 Sand

Non-rigid body

1 Groundwater table

2 Water tight surface

3 Light-weight material

4 Former ground surface

5 Gravel

6 Groundwater table bottom excavtion

7 Clay

10 Groundwater table in gravel

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

(4) <REQ> When additional structural verifications are necessary, they shall comply with 8.1.1 and 8.1.2.

8.1.4 Hydraulic failure

8.1.4.1 General

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

- hydraulic heave;
- internal erosion and piping.

(2) <RCM> The anisotropy of hydraulic conductivity of ground layers and of the ground stratigraphy should be considered in the assessment of groundwater seepage and groundwater pressures, together with the potential occurrence of confined aquifers.

8.1.4.2 Hydraulic heave

(1) <REQ> In order 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 shear resistance and the groundwater pressures.

(2) <RCM> Components of shear resistance that are affected by groundwater pressure should be treated with special caution.

(3) <REQ> 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.

(4) <REQ> To prevent an ultimate limit state of hydraulic heave (Figure 8.2), the inequality given in Formula (8.3) shall be verified:

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

where

Δu_{d} is the design excess groundwater pressure = $u_{\mathrm{d}} - u_0$;

u_{d} is the design groundwater pressure in the presence of flow;

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

$\gamma_{\mathrm{w,rep}}$ 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);

h_{w} is the vertical distance from the surface water level to the ground surface;

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

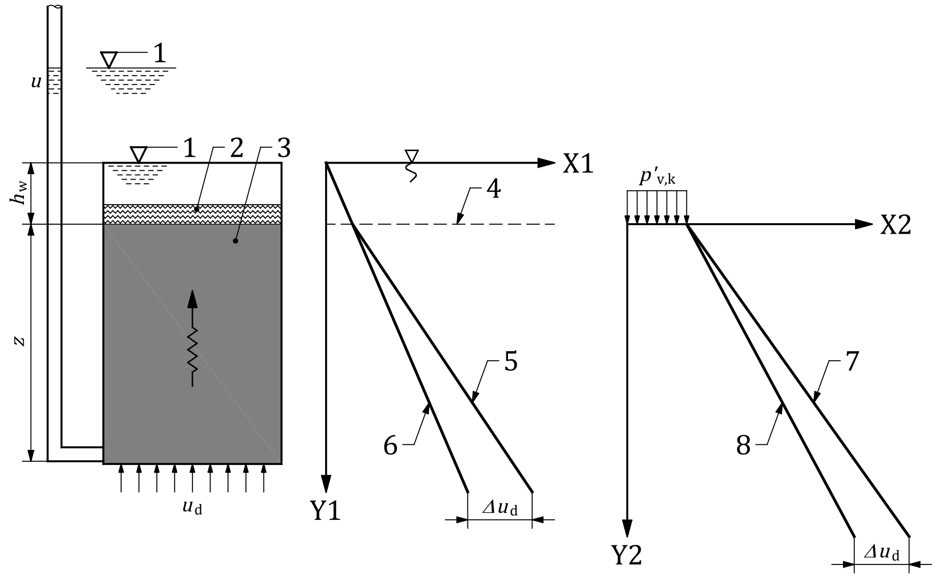
$p'_{\mathrm{v,rep}}$ is the representative value of any effective vertical overburden pressure at the ground surface;

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

γ_{pv} is a partial factor for effective vertical 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 γ_{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 prescende of flow)

Figure 8.2 – One dimensional upward flow of water

8.1.4.3 Internal erosion and piping

(1) <REQ> The design values of hydraulic gradients and seepage velocities shall be determined as specified in 6.3.3.

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

(3) <REQ> To prevent an ultimate limit state of internal erosion or piping, the inequality given in Formula (8.4) shall be verified:

$$i_d \leq i_{cd} \tag{8.4}$$

where

i_d is the design value of the hydraulic gradient;

i_{cd} is the design value of critical hydraulic gradient (when soil particles begin to move).

(4) <RCM> 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) <PER> 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(4) is satisfied.

(6) <RCM> 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 of the length of the seepage path;
- reducing the hydraulic gradient;
- sufficient safety against failure by heave in case of a horizontal ground surface;
- sufficient stability of the surface layers in sloping ground (local slope stability).

(7) <RCM> Filter protection should be provided by use of soil 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) <RCM> 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) <RCM> 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) <REQ> 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) <REQ> Degradation of the ground resistance and accumulation of ground displacements, especially settlements, due to cyclic effects shall be considered.

(2) <REQ> 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 EN 1997-3.

(3) <RCM> 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) <RCM> For geotechnical structures, verification of ultimate limit states by numerical models (Table 8.1) should be based when relevant on the less favourable outcomes given by the:

- Material Factor Approach (MFA), using:
  - factors on actions γ_F from Design Case 3 and;
  - factors on material properties γ_M from Set M2;
- Effect Factor Approach (EFA), using:
  - factors on effects-of-actions γ_E from Design Case 4 and;
  - factors on material properties γ_M from Set M1.

NOTE 1 Values of γ_F and γ_E are given in EN 1990-1, Annex A.

NOTE 2 Values of γ_M are given in 4.4.1.3.

NOTE 3 The Material Factor Approach (MFA) often determines the limiting ground resistance, whereas the Effects Factoring Approach (EFA) often determines the limiting structural resistance.

NOTE 4 In MFA, all possible geotechnical ultimate limit states are verified by demonstrating that equilibrium can still be obtained with design values of input parameters, without excessive deformation or a failure mechanism being activated either in the ground or in structural elements.

NOTE 5 Unless the national Annex gives a specific choice, the choice between MFA or/and EFA to be used is as specified by the relevant authority or where not specified, as agreed for a specific project by the relevant parties.

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

(3) <RCM> 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, for example, it is possible for the mobilized ground strength to exceed its design value.

(4) <RCM> Strength reduction should be used to verify that design values of ground strength parameters are not exceeded.

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

(5) <PER> As an alternative to (4), design values of ground strength may be used as input to numerical calculation (Table 8.1 – DC3+M2-alternative), provided that the effect of using design values throughout the calculation is considered when verifying the accuracy of simulations.

NOTE The use of design values from the start of a numerical model calculation can be detrimental to the intended degree of conservatism. The effect can be conservative or non-conservative and can increase with successive stages of the analysis.

(6) <PER> Ground strength reduction may be combined with structural strength or resistance reduction to help identify potentially critical collapse mechanisms of combined ground and structure failures.

NOTE Reducing structural material strength or resistance reduces the effective stiffness of structures. Therefore, structural forces can be underestimated.

NOTE Design values of forces into structural elements depend on the constitutive law used. When elastic behaviour is considered, design values can become infinite and lead to inappropriate results. When elasto-plastic behaviour is considered, design values are limited to the ultimate resistance of the structural elements.

(7) <RCM>Design values of force output in structures obtained by EFA should be used to verify adequate resistance in addition to the MFA verification.

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

NOTE 2 The resistance of structures such as piles, diaphragm walls, ground anchors and soil nails are highly dependent on the properties of the interface and disturbed ground immediately around such structures. Consequently, factoring the undisturbed ground strength alone cannot provide a sufficiently reliable means of verifying the ultimate limit state of such structures.

(8) <PER> Design values of outputs from geotechnical structure types other than those referred to in (7) above may also be compared with geotechnical resistances to assess the reliability against particular failure mechanisms occurring.

NOTE MFA allows the most critical geotechnical ultimate limit state to be verified but does not necessarily provide the degree of safety against particular failure mechanisms occurring. If this is required, it can sometimes be obtained in this way (e.g. comparing the design value of spread foundation lateral load with its corresponding value of sliding resistance). The resistance value can be obtained from a separate calculation or by numerical models in accordance with (9) below.

(9) <PER> Geotechnical resistances may be calculated by 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 forms, usually a separate calculation is performed.

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

NOTE 3 The procedure for verification of ultimate limit states with numerical models is given in Table 8.1(NDP) unless the National Annex gives different procedure.

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

<table>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Factoring approach - See 8.2(1)</td></tr>
<tr><td>EFA
DC4 + M1</td><td>MFA
DC3 + M2
(Recommended)</td><td>MFA
DC3 + M2
(Alternative)</td></tr>
<tr><td>See 8.2(2), (7) and (8)</td><td>See 8.2(2),(3) (4) and (6)</td><td>See 8.2(2), (5) and (6)</td></tr>
<tr><td rowspan="14">Construction Stage 1 (CS1)</td><td colspan="2"></td><td>Step 1
Representative Step</td><td>Step 1
Representative Step</td><td>Step 1
---</td></tr>
<tr><td rowspan="4">Input</td><td>Piezometric level or groundwater pressure</td><td colspan="2">Representative values</td><td rowspan="6">Not applicable
Go directly to Step 2</td></tr>
<tr><td>Ground properties</td><td colspan="2">Representative Values</td></tr>
<tr><td>Structural element properties</td><td colspan="2">Representative Values</td></tr>
<tr><td>External actions</td><td colspan="2">Representative Values</td></tr>
<tr><td rowspan="2">Output</td><td>Movements</td><td colspan="2">[1]</td></tr>
<tr><td>Structural forces</td><td colspan="2">[1]</td></tr>
<tr><td colspan="2"></td><td>Step 2
ULS Verification Step</td><td>Step 2
ULS Verification Step</td><td>Step 2
ULS Verification Step</td></tr>
<tr><td rowspan="4">Input</td><td>Piezometric level or groundwater pressure</td><td>Design level [2]</td><td>Design level [2]</td><td>Design level [2]</td></tr>
<tr><td>Ground properties</td><td>Design values by M1 combination</td><td>Partial factors M2 (to obtain Design values by “Strength reduction” procedure)</td><td>Design values by M2 combination</td></tr>
<tr><td>Structural element properties</td><td>Representative values</td><td>Representative values</td><td>Representative values</td></tr>
<tr><td>External actions</td><td>Design values by DC4 combination</td><td>Design values by DC3 combination</td><td>Design values by DC3 combination</td></tr>
<tr><td rowspan="2">Output</td><td>Verification of ground failure</td><td>See 8.2(7) and 8.2 (8)</td><td>ULS verified if equilibrium is attained in the ground with no failure of the structure</td><td>ULS verified if equilibrium is attained in the ground with no failure of the structure</td></tr>
<tr><td>Verification of structural failure</td><td>Design values (E_d) obtained by applying γ_E to calculation results
See 8.2(7) and (8)</td><td>Design values (E_d) obtained directly from calculation results
See 8.2(6)</td><td>Design values (E_d) obtained directly from calculation results</td></tr>
<tr><td>CS2</td><td colspan="5">Continue in the same way through any subsequent stage (CS2, CS3, etc.)</td></tr>
<tr><td colspan="6">[1] These output values can be used for SLS verifications
[2] 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.</td></tr>
</table>

9 Serviceability limit states

9.1 General

(1) <REQ> In addition to EN 1990-1, 5.4 and 8.4, the following specific serviceability limit states shall be verified:

- ground movements and structural aspects, including differential displacements, rotation, angular strain, relative deflection, deflection ratio, tilt, and angular distortion (see Annex B);
- hydraulic aspects including hydraulic conductivity, ingress or egress or water.

(2) <REQ> In addition to EN 1990-1, 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.

(3) <REQ> In addition to (2) the serviceability criteria shall be determined as the limit that, if exceeded, will cause one or more of the following:

- adverse effects on the function, durability or appearance of the structure;
- limit the functional effectiveness of the structure; or
- effect the comfort of the users.

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

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

(4) <REQ> In addition to EN 1990-1, 8.4, design values of ground properties for serviceability limit states shall be determined using a partial factor $\gamma_M = 1.0$.

(5) <RCM> In addition to EN 1990-1, 5.4 and 8.4, verification of serviceability limit states should be based on calculation, monitoring and testing.

NOTE 1. Further guidance on monitoring and testing is given in Clause 10 and Clause 11.

(6) <PER> Verification of SLS may be based on the check of strength mobilisation only if:

- a sufficiently low fraction of the ground strength is used as mobilisation limit;
- time dependent effects are taken into account; and
- established comparable experience exists with similar ground, structures.

(7) <RCM> Long-term settlements and movements should be calculated using the quasi-permanent combination of actions specified in EN 1990-1, 8.4.3.4 taking into account ground hydraulic conductivity and creep effects.

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

9.2 Calculation of ground movements

(1) <RCM> 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;
- mining (active or historical), gas extraction, or similar works.

(2) <PER> 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 mobilised shear strength to values specified in the design;
- observing the movements and specifying measures to reduce or stop them, as described in 4.7.

(3) <RCM> 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.

9.3 Structural aspects

(1) <REQ> Limiting foundation movements shall take account of the following, where relevant:

- 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 and age of 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 buildings or parts of buildings of different characteristics;
- allowable movements of services entering the structure.

(2) <REQ> In the absence of specified limiting values of structural deformations of the supported structure, the suggested values given in EN 1990-1, A1.7.4 shall be used.

NOTE Further guidance on the choice of the limiting values of structural deformation is given in Annex B.

9.4 Hydraulic aspects

(1) <RCM> The determination of the hydraulic serviceability limit states should be related to its purpose for the geotechnical structure.

NOTE 1. EN 1997-3 provides requirements for the specific geotechnical structures.

(2) <REQ> The limiting value of the serviceability criterion for hydraulic serviceability limit states shall be defined as, but are 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;
- groundwater level or changes to the groundwater level.

(3) <RCM> In addition to (2) threshold values and related acceptance criteria should be defined.

10 Implementation of design

10.1 General

(1) <REQ> The design of a geotechnical structure shall include specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.

NOTE The specifications are prepared at an appropriate stage during the design.

(2) <REQ> 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 1 Guidance on appropriate levels is given in 4.1.8 and EN 1990-1, B.

NOTE 2 Unless the national Annex gives a specific choice, type, level and amount of supervision, inspection, monitoring and maintenance, is as specified by the relevant authority or where not specified, as agreed for a specific project by the relevant parties.

NOTE 3 The format of the Plans is not specified in this standard. The Plans can be for example single volume, multivolume, digital, paper copy, partly consist of drawings, part of a Building Information Model (BIM) or project specific databases.

(3) <REQ> 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 and execution specifications.

(4) <REQ> If (3) give any incompatibility, contingency measures shall be specified and implemented.

(5) <REQ> The Plans of supervision, inspection, monitoring, and maintenance shall ensure that the execution of geotechnical structures provides a level of reliability no less than that required by EN 1990-1.

(6) <REQ> The objectives, type, extent, and level of supervision, inspection, monitoring, and maintenance shall comply with the specific requirements of EN 1997-3 and relevant execution standards.

(7) <RCM> The Plans of supervision, inspection, and monitoring should be based on a review of the most unfavourable conditions that occur during execution, with regards to:

- ground conditions;
- groundwater conditions;
- actions on the structure;
- environmental impacts and potential changes including landslides and rockfalls;
- impact within the zone of influence (4.1.2.1).

(8) <REQ> An Inspection Plan shall be prepared that specifies acceptance criteria for:

- properties of construction material with tolerances;
- products and their quality specification;
- dimensions of products and structural elements with tolerances;
- 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.

(9) <RCM> In addition to (8), other acceptance criteria should be included in the Inspection Plan.

(10)<REQ> A Monitoring Plan shall be prepared that specifies threshold and limiting values for the:

- 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;
- environmental impact, including noise, vibration, and pollution within the zone of influence.

(11)<RCM> In addition to (10), other threshold and limiting values should be included in the Monitoring Plan.

(12)<RCM> If acceptance criteria or threshold values are violated, the data should be checked for consistency before modifying the design or implementing additional contingencies measures.

(13)<REQ> If acceptance criteria or threshold values are violated, the design and execution specification shall be reviewed and modified appropriately.

(14)<RCM> The Inspection Plan and Monitoring Plan should include failure-prohibiting measures to be directly activated if the acceptance criteria or threshold values are violated.

(15)<REQ> Design of geotechnical structures shall be checked for their practicability and maintenance.

10.2 Supervision of execution

(1) <REQ> The execution of geotechnical structures shall be supervised.

(2) <REQ>It shall be checked that the construction works complies with the execution specification with regards to execution methods and construction stages.

(3) <REQ> Supervision shall be undertaken during the execution to ensure that all safety measures required to ensure a safe working environment are implemented.

10.3 Inspection

(1) <REQ> The Inspection Plan shall specify measures to check compliance with the design and the execution specification including, but not limited to:

- 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;
- the probability of human errors during execution is reduced.

(2) <RCM> In addition to (1), other measures should be included in the Inspection Plan to ensure compliance with the design and execution specification.

(3) <PER> Inspection may be performed by observation, measurement, or testing.

(4) <REQ> In addition to (1), the Inspection Plan shall specify provisions to check that the Ground Model and the Geotechnical Design Model are both in compliance with the encountered ground conditions at the site.

NOTE Guidance on appropriate testing to assess ground properties is given in 11.3.

(5) <PER> 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.

(6) <RCM> The extent and details of the Inspection Plan should be linked to the Inspection Level (and hence the Geotechnical Category) given in 4.1.8.

(7) <PER> Acceptance criteria may be established by sensitivity analyses or engineering judgement of acceptable variations.

10.4 Monitoring

(1) <RCM> Monitoring should be undertaken:

- during ground investigation, to obtain data of the ground behaviour;
- before execution, to establish reference conditions;
- during execution, 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;
- after execution, to evaluate the long-term performance of the structure.

(2) <REQ> If monitoring is specified, a Monitoring Plan shall be prepared that specifies which aspects of the behaviour of the geotechnical structure shall be monitored to verify compliance with the serviceability criteria.

(3) <RCM> 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 coherent with the construction activities;
- ensure that the structures continue to behave as required after execution.

(4) <RCM> In addition to (2), other provisions should be included in the Monitoring Plan to monitor for successful performance of the structure.

(5) <RCM> The Monitoring Plan should include duration, type and frequency of monitoring, and locations of monitoring points.

(6) <REQ> 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.

(7) <PER> Monitoring may be performed using observations or measurements (including geotechnical and geodetical monitoring).

NOTE Monitoring includes visual observation.

(8) <RCM> Effects of noise, vibration, and temperature on selected monitoring and monitoring equipment shall be accounted for.

(9) <RCM> Geotechnical monitoring should comply with EN 18674 (all parts).

(10) <RCM> 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 these ground properties.

(11) <REQ> The response time of instruments shall be rapid enough to capture potential changes in ground-structure behaviour.

(12) <REQ> In addition to (10), the management and communication procedures for analysing results shall be sufficiently fast to allow adverse outcomes to be prevented.

10.5 Maintenance

(1) <REQ> 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 1. Guidance on use of maintenance to ensure adequate durability is given in 4.1.6.

(2) <REQ> 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 1. 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) <REQ> The Maintenance Plan shall include the supervision, inspection, and monitoring activities specified in 10.1 to 10.4.

(4) <RCM> 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;
- 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, anchors 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) <RCM> 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.

10.6 Application of Observational Method

(1) <REQ> In addition to 10.1 to 10.4, when using the Observational Method to verify limit states, the Contingency Plan shall specify contingency measures appropriate for all design variants.

(2) <REQ> Violation of threshold values or acceptance criteria for the current design variant shall trigger the activation of the Contingency Plan.

11 Testing

11.1 General

11.1.1 Use of testing

(1) <PER> Testing may be used to determine ground properties, determine parameters for use in design, verify capacity of structural element, check quality of construction material or product, and to understand the behaviour of the geotechnical structure or part of it.

(2) <PER> Testing may be used as part of ground investigation, verification by calculation, verification by testing, verification by prescriptive rules and verification by the Observational method.

(3) <PER> Tests may be carried out either on a sample of the actual geotechnical structure or supporting element or on full scale or reduced scale models.

11.1.2 Test planning

(1) <RCM> Test requirements, such as test method, number of tests, should be related to the Geotechnical Category of the geotechnical structure or, the relevant part of it.

(2) <RCM> Prior to carrying out tests, a Test Plan should be compiled that includes, but is not limited to:

- test objectives and scope;
- specifications of sample preparation, as required;
- loading specifications;
- testing arrangements;
- period of time from execution to test, where relevant;
- test equipment (characteristics, maintenance and calibration requirements);
- measurement plan and frequency;
- prediction of test results;
- method for test evaluation and reporting;
- acceptance criteria;
- requirements from comparable experience, if any.

(3) <RCM> In addition to (2), other items should be included in the Test Plan needed to give a successful execution of the test.

11.1.3 Test evaluation

(1) <REQ> Test evaluation shall include a check of the validity of the test results by comparison with prognosis of test results or comparable experiences.

(2) <RCM> When significant deviations from prognosis or comparable experience occur, the reasons should be established and documented.

(3) <RCM> In case of unexpected deviations, the test should be repeated, or an alternative test method should be performed.

(4) <RCM> The following aspects should be considered in the evaluation of the test:

- differences in the ground properties between the test and the actual site of the geotechnical structure;

– effects of time, scale, stress levels and particle size.

(5) <RCM> In addition to (4), other aspects should be included in the test evaluation as necessary to ensure an appropriate result.

11.2 Testing to determine ground properties

(1) <PER> 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 EN 1997-2.

11.3 Testing to determine parameters for use in design

(1) <PER> Testing may be used to determine values of parameters others than ground properties for use in the design.

NOTE Parameters for use in the design and verification of limit states can refer to, ground-structure interface properties or bearing capacity of the ground.

(2) <PER> 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 characteristics in the working load range.

NOTE Guidance on the applicability of investigation tests for piles, anchors, soil nails, and rock bolts, and is given in EN 1997-3.

(3) <PER> Investigation tests on laboratory specimens of improved ground may be used to determine shear strength and deformation characteristics in the working load range.

NOTE Guidance on applicability of investigation tests for ground improvement is given in EN 1997-3.

(4) <PER> 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 EN 1997-3.

11.4 Testing to verify resistance

(1) <PER> Testing may be used to verify that a geotechnical structure fulfils its specified design requirements without exceeding a limit state.

(2) <PER> Acceptance tests may be used to verify that the specified acceptance criteria are fulfilled in order to verify the limit states.

11.5 Testing to control quality

(1) <RCM> Control tests should be used to check the identity or quality of delivered products or the consistency of production characteristic.

NOTE Example of control test are tests to check the identity or quality of delivered products (for instance geosynthetics) or the consistency of production characteristic (for instance lime-cement columns).

(2) <RCM> Control tests should be used to check the compaction of engineered fill, using compaction control,

11.6 Testing to determine behaviour

(1) <PER> 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 are given in 4.2.5.

12 Reporting

12.1 General

(1) <REQ> The geotechnical aspects of the design of geotechnical structures and other works shall be reported.

(2) <REQ> The extent and details of the reporting shall be adequate for an independent technical review.

(3) <REQ> 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 The format of the reports is not specified in this standard. 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) <REQ> The content of the reporting shall include the information specified in Annex C.

(5) <RCM> 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 EN 1997-3.

NOTE 1. The minimum extent and level of detail of reporting is given in Table 12.1(NDP) unless the National Annex gives different a minimum extent and level of detail.

Table 12.1(NDP) –Extent and level of detail of reporting appropriate for GC

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 defined in Annex C; – 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 defined in Annex C, may be reduced to a record with bullet-points of what has been done.
NOTE: An example of a reduced GDR for GC1 is presented in C.4.4	

(6) <RCM> 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) <REQ> The results of ground investigation shall be compiled in a Ground Investigation Report (GIR).

(2) <REQ> The Ground Investigation Report 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 testings as detailed in EN 1997-2 Clause 13.

(3) <REQ>The Ground Investigation Report shall document the Ground Model.

(4) <REQ> The Ground Investigation Report shall include derived values, where available.

(5) <REQ> The Ground Investigation Report shall state limitations of the results from field investigation and laboratory testing.

NOTE Unless the National Annex gives a different requirement, the GIR needs to include the depth to conventional bedrock H800 for all projects located within seismic regions in accordance with EN 1998-1

12.3 Geotechnical Design Report

12.3.1 General

(1) <REQ> Documentation of the verification and design process of all construction phases and the final design shall be compiled in a Geotechnical Design Report (GDR).

(2) <REQ> The contents of the Geotechnical Design Report shall comply with Annex C.4.

(3) <REQ> The Geotechnical Design Report shall give a description of the site and the planned geotechnical structure, including the zone-of-influence.

(4) <REQ> The Geotechnical Design Report shall record the Consequence Class, Geotechnical Complexity Class, and Geotechnical Category.

(5) <REQ> Compliance with the assumptions in 1.2 shall be recorded in the Geotechnical Design Report.

(6) <PER> 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) <REQ> The Geotechnical Design Report shall document the Geotechnical Design Model.

(2) <RCM> The Geotechnical Design Model should include representative values of the ground properties of the geotechnical units, geometric specification, and groundwater conditions.

(3) <REQ> The data sources used to determine the representative value of a ground property shall be stated in the Geotechnical Design Model.

NOTE Further guidance on content of the Geotechnical Design Model is given in Annex C.

(4) <REQ> The Geotechnical Design Report shall record the results of validating information in the GIR according to 4.2.4.

(5) <REQ> The Geotechnical Design Report shall record changes to the Ground Model that occur on receipt of additional information about the ground conditions.

(6) <REQ> The Geotechnical Design Report shall record the results of validating the Geotechnical Design Model according to 4.2.3.

12.3.3 Properties

(1) <REQ> The Geotechnical Design Report shall record the evaluation of nominal value of geometrical properties.

(2) <RCM> The Geotechnical Design Report should record the evaluation of representative values of actions and resistances.

(3) <REQ> The Geotechnical Design Report shall record the evaluation of the representative and design values of material properties.

12.3.4 Verification of limit states

(1) <REQ> The Geotechnical Design Report shall describe the design situations considered (4.2.2).

(2) <REQ> The Geotechnical Design Report shall record the verification of limit states (4.2.1).

12.3.5 Implementation of design

(1) <REQ> The Geotechnical Design Report shall include the Inspection (10.3), Monitoring (10.4), and Maintenance (10.5) Plans.

(2) <REQ> The Geotechnical Design Report shall include specification of supervision.

(3) <REQ> The Geotechnical Design Report shall identify any important modifications of the design implemented to account for results from supervision, inspection, monitoring, or maintenance.

(4) <REQ> The Geotechnical Design Report shall identify contingency measures, with corresponding acceptance criteria or threshold values, to be implemented based on results from supervision, inspection, monitoring, or maintenance.

(5) <REQ> If the Observational Method is applied (10.6), a Contingency Plan shall address foreseeable ground responses and ground-structure interactions and give required contingency measures for each design variants.

12.4 Geotechnical Construction Record

(1) <REQ> A Geotechnical Construction Record (GCR) shall be prepared that documents construction, supervision, monitoring, and inspection of the final structure and each phase of execution.

(2) <REQ> The contents of the Geotechnical Construction Record shall comply with Annex C.5.

NOTE The aim of the GCR is to assist with future maintenance, design of additional works and decommissioning of the works.

(3) <REQ> In addition to (1), for verification of limit states using the Observational Method, the Geotechnical Construction record shall include a record of encountered scenarios at site and the contingency actions implemented, with justification of any implemented contingency measure.

12.5 Geotechnical test reports

(1) <REQ> 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 Guidance on use of testing is given in 11.

(2) <REQ> If standard test methods are used, the documentation shall be presented and reported according to the requirements defined in applicable test standards.

(3) <REQ> Geotechnical test reports shall state any limitations of the results.

NOTE Geotechnical test reports can be part of the GIR, GDR, or GCR.

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 1. 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

(2) This Informative annex covers procedures to determine the characteristic value of ground properties.

A.3 Background

(1) There are several sources of uncertainty that affect the evaluation of ground properties.

(2) These sources include inherent variability, measurement error, statistical uncertainty, and transformation uncertainty, as well as sampling quality.

NOTE 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.

(3) Transformation uncertainty is only relevant if the property is not measured directly but inferred from a separate measurement.

NOTE Examples of transformation uncertainty is undrained shear strength from Standard Penetration Test blow count.

(4) Only inherent variability is a site property, the rest are design-dependent.

(5) For the purposes of this Annex, it is assumed that the different sources of uncertainty are related to the observed variability value through Formula (A. 1):

$$\mathrm{V}_x = \sqrt{\mathrm{V}_{x,inh}^2 + \mathrm{V}_{x,quality}^2 + \mathrm{V}_{x,trans}^2} \qquad \text{(A. 1)}$$

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;

$V_{x,trans}$ is the coefficient of variation of the transformation error.

A.4 Description of the determination procedure

(1) <RCM> The determination procedure described should be used to calcualte the characteristic value of a ground property by statistical methods.

(2) <RCM> 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) <PER> 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 [Case A]; or
- the inferior (5% fractile) or superior (95% fractile) value [Case B].

NOTE Alternative assessment procedures can be given in the National Annex.

(4) <REQ> The procedure in this Annex shall be used to evaluate the different terms in Formula $(A.2)$ [repeated from Formula 4.3]:

$$X_k = X_{mean}[1 \mp k_n V_x] \qquad (A.2)$$

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 $k_n V_X$ 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; there is no prior knowledge about the mean value.

(5) <PER> The determination procedure may be applied for three different cases: Case 1 "V_X known", Case 2 "V_X assumed" and Case 3 "V_X unknown.

(6) <RCM> Case 1 "V_X known" should be used when the coefficient of variation of the ground property being determined is known from prior knowledge.

(7) <RCM> Case 2 "V_X assumed" should be used when the designer decides to use the indicative values in Table A.2, for ground parameters, or Table A.3, for test parameters.

(8) <RCM> Case 3 "V_X unknown" should be used when the coefficient of variation of the ground property being determined is unknown ab initio.

NOTE 1 Prior knowledge might come from the evaluation of previous tests in comparable situations. Engineering judgement may be used to determine what can be considered as "comparable".

NOTE 2 In practice, it is often preferable to use Case 2 "V_X assumed" together with a conservative upper estimate of V_X, rather than to apply the rules given for Case 3 "V_X unknown".

(9) <RCM> The value of X_{mean} should be calculated by Formula ($A.3$).

$$X_{mean} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad (A.3)$$

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)<RCM> The value of k_n should be obtained from Table A.1 which collates Formulas (A.4) to (A.7) for the Cases defined above.

Table A.1 —Values of k_n for different cases and type of estimations

CASES	Case 1: "V_X known & Case 2: "V_X assumed"	Case 3 "V_X unknown"
Case A: Estimate of the mean value	$k_n = N_{95}\sqrt{\frac{1}{n}}$ (A.4)	$k_n = t_{95,n-1}\sqrt{\frac{1}{n}}$ (A.5)
Case B: Estimate of the inferior or superior value (5 or 95 % fractile)	$k_n = N_{95}\sqrt{1+\frac{1}{n}}$ (A.6)	$k_n = t_{95,n-1}\sqrt{1+\frac{1}{n}}$ (A.7)

where:

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

$t_{95,n-1}$ represents the Student's *t* distribution, evaluated for a 95% confidence level and n–1 degrees of freedom, being n as defined above.

(11)<PER> For Case 2 "*V*x assumed", indicative values of V_x may be taken from Table A.2, for ground parameters, or Table A.3, for test parameters, unless the National Annex gives different values.

Table A.2 (NDP) — Indicative values of coefficient of variation for different ground properties

Soil / Rock Type	Ground property	Symbol	Coefficient of variation *V*x (%)
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 redisdual effective cohesion	c'_p c'_r	30-50
All soils and rocks	Angle of friction	φ	5-15
All soils and rocks	Shear strength at failure	τ_f	15-25

Soil / Rock Type	**Ground property**	**Symbol**	**Coefficient of variation** ***V*x (%)**
All soils and rocks	Unconfined compressive strength	q_u	20-80
All soils	Modulus of deformability[(1)]	E or G	20-70
Fine-grained soils	Vertical or horizontal consolidation coefficient	c_v or c_h	30-70
All soils	Hydraulic conductivity[(2)]	k	70-250
[1]It refers to the different modulus of deformation whose symbols appear in 3.2.1. & 3.2.7/EN 1997-2. [2]Given the high value of the coefficient of variation for the hydraulic conductivity, this procedure should not be used.			

Table A.3 (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	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

(12)<RCM> For Case 3 "*V*x unknown", the value of V_X should be calculated by Formula ($A.8$):

$$V_X = \frac{s_x}{X_{mean}} \ ; \ s_x = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_{mean})^2}{n-1}} \qquad (A.8)$$

where:

s_x is the standard deviation of the sample derived values.

NOTE 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 Cases and type of estimation, according to Formulas (A.4) to (A.7)

Table A.4 — Selected values of N_{95} and k_n to estimate the characteristic value as the mean value [Case A1 & A2], according to Formula (A.4)

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 [Case A3], according to Formula (A.5)

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) [Case B1 & B2], according to Formula (A6)

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) [Case B3], according to Formula (A.7)

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 When the ground property is considered to follow a log-normal distribution, Formulas $(A.2)$, $(A.3)$ and $(A.8)$becomes:

$$X_k = e^{Y_{mean}(1+/-k_n V_Y)} \qquad (A.2 - log)$$

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.3-log;

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 [$V_Y = s_Y / Y_{mean}$], being s_x the standard deviation of the sample derived log values (Formula A.8-log);

-/+ 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.

$$Y_{mean} = \frac{\sum_{i=1}^{n} lnX_i}{n} \qquad (A.3 - log)$$

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}.

$$s_Y = \sqrt{\frac{\sum_{i=1}^{n}(lnX_i - Y_{mean})^2}{n-1}} \qquad (A.4 - log)$$

NOTE 1 Adopting a log-normal distribution has the advantage that no negative values can occur as, for example, for geometrical and resistance variables.

NOTE 2 There are determination procedures, different from the one described in this Annex, to determine the characteristic relation (line, for example least squares with regression analysis) of the values of a ground property with depth (z) or the characteristic values of dependent parameters (e.g cohesion and friction angle).

Annex B
(informative)

Limiting values of structural deformation and ground movement

B.1 Use of this Annex

(1) This Informative Annex provides complementary guidance to that given in clause 9 regarding limiting design values of structural deformation and ground movement.

(2) 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 provides guidance on limiting design values for serviceability criterion related to ground movement and structural aspects.

(2) The limiting design values of deformations in this Annex do not apply to buildings or structures which are out of the ordinary or for which the loading intensity is markedly non-uniform.

B.3 General

(1) The components of geotechnical structure movement to consider can include settlement, relative (or differential) settlement, rotation, tilt, relative deflection, angular distortion, deflection ratio, horizontal displacement and vibration amplitude.

(2) The damage criteria shown in Table B.1 is a guide to set limiting design value of the serviceability criteria for walls based on ease of repair.

NOTE 1 The boundary between Damage Classes 2 and 3 typically forms a serviceability limit state while Damage Class 5 is typically considered an ultimate limit state.

NOTE 2 For further information om limiting design value of serviceability criterion see EN 1990-1, 8.4.1.

(3) Based on the damage criteria in Table B.1, Figures B.1 to B.3 provide an example of the derivation of allowable deflection ratio for visual damage to walls in bending with different levels of horizontal strain.

NOTE 1 The derivation of the values in Table B-1, Figure B.1 to B.3 is described in Burland (1997) and Burland et al (1977).

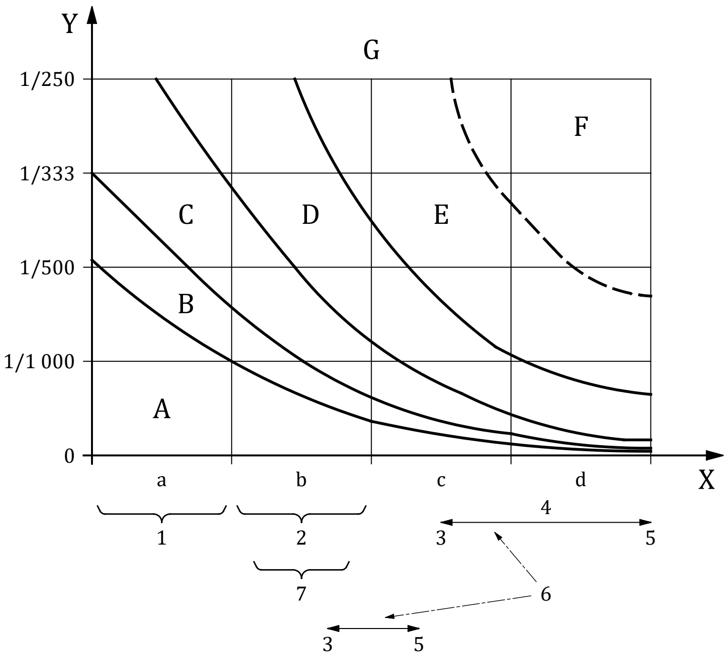
NOTE 2 The damage criteria shown in Table B.1 is a guide to setting serviceability limi state damage criteria to walls for masonry buildings based on ease of repair.

(4) In the absence of specified limiting values of structural deformations of the supported structure, the values of structural deformation given below is a guide:

- Suggested limit on tilt of tall structures (height H) for visual appearance:
  - $\omega = 1/250$ (H<24m);
  - $\omega = 1/330$ (24m<H<60m);

- ω=1/500 (60m<H<100m);
- ω=1/1000 (H>100m).
- Other suggested serviceability limits:
  - Leakage of steel fluid storage tanks β=1/300 to 1/500;
  - Flexible utility connections s=150mm;
  - Crane operation on rails β=1/300;
  - Drainage of floors β=1/50 to 1/100;
  - Stacking of goods ω=1/100;
  - Operation of machinery β=1/300 to 1/5000 depending on machinery type, 1/750 typical;

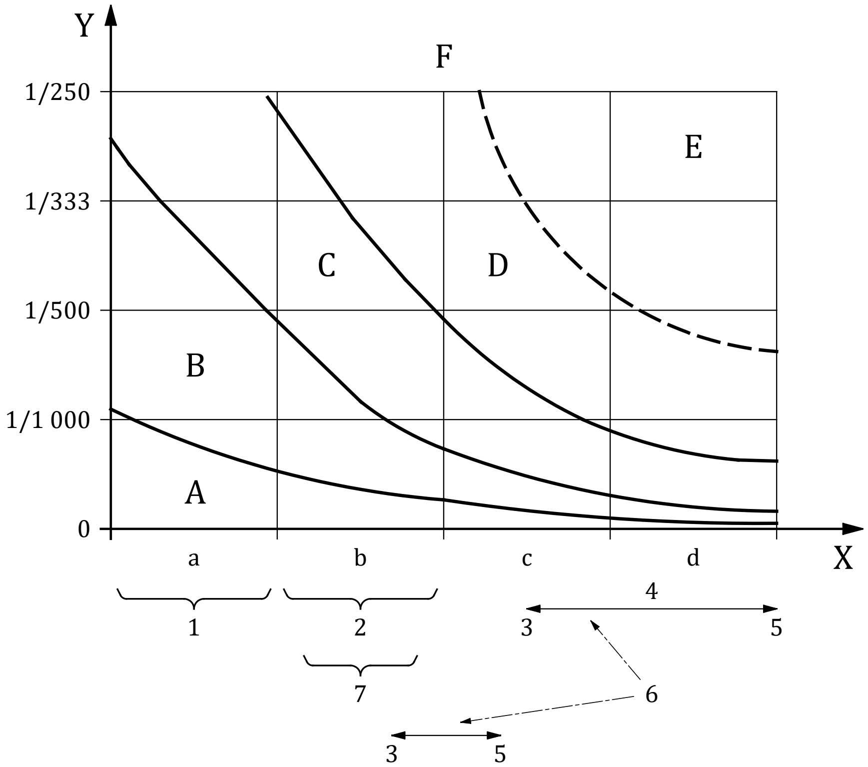
Lift and escalator operation ω=1/1200 to 1/2000



Key

X	/L	1	Flexible structures
Y	Sensitivity to wall damage	2	Load-bearing reinforced blockwork / masonry walls
A	Negligible	3	L/ H ca. 6
B	Very slight	4	Hogging
C	Slight	5	L/H ca. 1
D	Moderate	6	Load-bearing unreinforced blockwork / masonry walls
E	Severe	7	Structural frames
F	Very severe [ULS]	a	Low
G	Visual damage	b	Medium
		c	High
		d	Very high

Figure B.1 — Example determination of deflection ratio limits for walls in bending (zero horizontal strain)

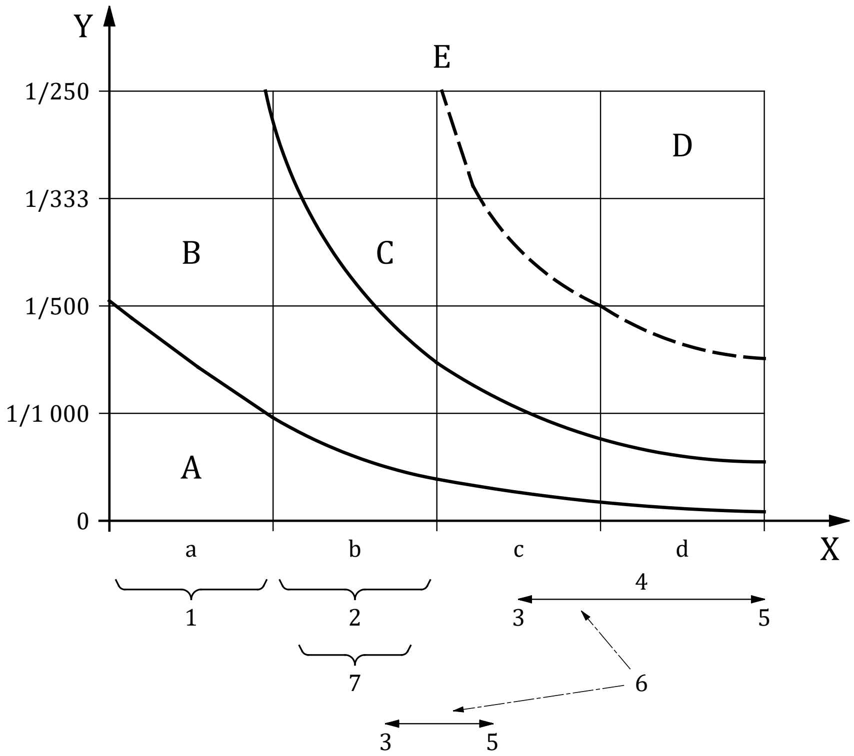


Key

X	/L
Y	Sensitivity to wall damage
A	Very slight
B	Slight
C	Moderate
D	Severe
E	Very severe [ULS]
F	Visual damage
a	Low
b	Medium
c	High
d	Very high

1	Flexible structures
2	Load-bearing reinforced blockwork / masonry walls
3	L/ H ca. 6
4	Hogging
5	L/H ca. 1
6	Load-bearing unreinforced blockwork / masonry walls
7	Structural frames

Figure B.2 — Example determination of deflection ratio limits for walls in bending (0.05% horizontal strain)



ey

X	/L	1	Flexible structures
Y	Sensitivity to wall damage	2	Load-bearing reinforced blockwork / masonry walls
A	Slight	3	L/ H ca. 6
B	Moderate	4	Hogging
C	Severe	5	L/H ca. 1
D	Very severe [ULS]	6	Load-bearing unreinforced blockwork / masonry walls
E	Visual damage	7	Structural frames
a	Low		
b	Medium		
c	High		
d	Very high		

Figure B.3 — Example determination of deflection ratio limits for walls in bending (0.1% horizontal strain)

- .

Table B-1 — Damage criteria for walls

Damage class	Normal degree of sensitivity	Limiting tensile strain (%)	Description	Typical crack widths (mm)	Ease of repair
0	Negligible	0-0.05	Hairline cracks	< 0.1	
1	Very slight	0.05-0.075	Damage generally restricted to internal wall finishes. Close inspection may reveal some cracks in external brickwork or masonry	≤ 1	Fine cracks that are easily treated during normal redecoration
2	Slight	0.075-0.15	Cracks may be visible externally; doors and windows may stick slightly	2-3	Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. Some repointing may be required to ensure water-tightness
3	Moderate	0.15-0.3	Doors and windows sticking; service pipes may fracture; weather-tightness often impaired	Up to 5 locally	Cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork may be replaced
4	Severe	> 0.3	Windows and door frames distorted; floor sloping noticeably; walls leaning or bulging noticeably; some loss of bearing in beams; service pipes disrupted	5-15	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows
5	Very severe		Beams lose bearing; walls lean badly and require shoring; windows broken with distortion; danger of instability	Several closely spaced > 3	Requires a major repair job involving partial or complete rebuilding

Annex C
(normative)

Additional requirements and recommendations for reporting

C.1 Use of this Normative Annex

(1) This Normative Annex provides additional requirements and recommendations to those given in clause 12, concerning the content and extent of reporting.

C.2 Scope and field of application

(1) This Normative Annex covers documentation of the design process from initial desk study and ground investigation to implementation of the design in execution.

(2) This Normative 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 C1.

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 C1.

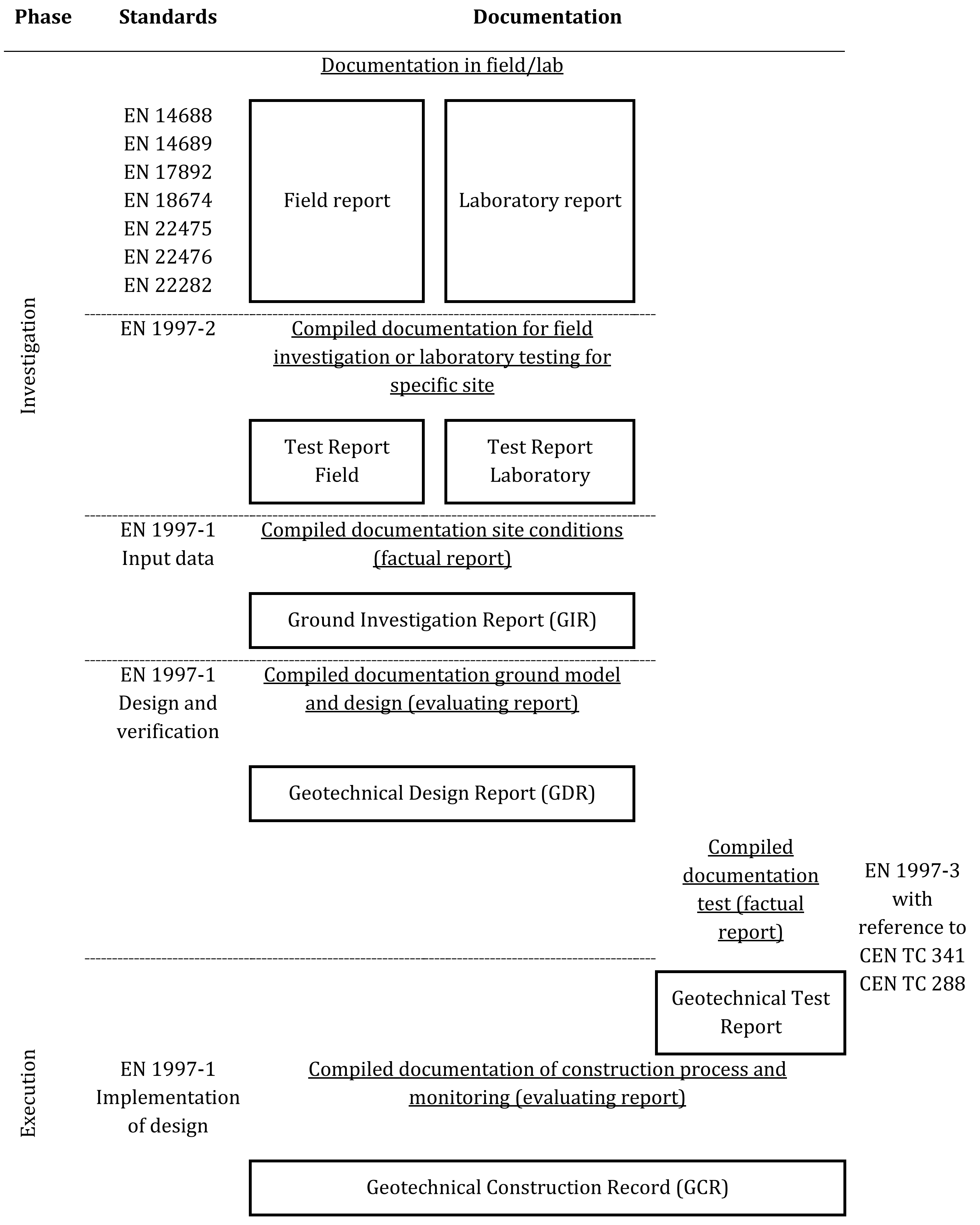


Figure C.1 Illustration of interaction between documentation in EN 1997 and complementary European standards.

C.3 Ground Investigation Report

(1) <REQ> EN 1997-2, Annex A shall apply.

C.4 Geotechnical Design Report

C.4.1 General content

(1) <RCM> 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. Bases 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. Geotechnical Design Model, including evaluation of representative values (4.3.2) and validation of GDM (4.2.3);
    f. Impact within the zone of influence (4.2.5);
    g. Aspects in relation with robustness (4.1.4), design service life (4.1.5), durability (4.1.6) and sustainability (4.1.7);
    h. Any restrictions (loading, vibration, deformation, etc.);
    i. Any assumptions or simplifications;
    j. 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. Execution specification for the geotechnical structure
   a. Specification of materials (dimensions, tolerances, quality);
   b. If needed, drawings;
   c. Requirements on the execution process and description of each execution phase.
7. Implementation of design
   a. Specification of supervision (10.2);
   b. Inspection Plan (10.3);
   c. Monitoring Plan (10.4);
   d. Maintenance Plan (10.5).

(2) <RCM> Additional information than given in (1) should be included to give proper documentation.

C.4.2 Specification of the Geotechnical Design Model

(1) <REQ> A Geotechnical Design Model shall include specification of design situations (physical conditions and timeframe), corresponding combinations of actions and associated relevant limit states.

(2) <RCM> 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 EN 1997-2;
– statement about data that is excluded from evaluation with justification;
– statement about any limitations of the investigation results;
– 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) <RCM> The description of geotechnical units should include, but is not limited to:

- description and classification of ground included within each geotechnical unit;
- designation of the material parameters relevant for design;
- 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 EN 1997-2.

(4) <RCM> The geometrical specification should include, but is not limited to:

- location of boundaries between different geotechnical units;
- location of discontinuities within a geotechnical unit;
- spatial trends in the variation of ground properties, particularly with depth.

NOTE Guidance on the geometric specification is given in EN 1997-2.

(5) <RCM> 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 EN 1997-2.

(6) <RCM> The documentation should include, but is not limited to:

a. tabulation and graphical presentation of the results of field investigation and laboratory testing;
b. cross-sections of the ground showing relevant geotechnical units and their boundaries including the groundwater table;
c. 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.

C.4.3 Verification of limit states

(1) <RCM> Documentation of verification by prescriptive rules (4.5) should include, but is not limited to:

– reference to the prescriptive rules specified by the relevant authority or agreed for the specific project by relevant parties;
– evaluation of the applicability of the prescriptive rules for the considered design situation, limit state and Geotechnical Design Model.

(2) <RCM> Documentation of verification by testing (4.6) should include, but is not limited to:

– reference to the appropriate geotechnical test report;
– evaluation of the test results and their limitations.

(3) <RCM> 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;
– design values of ground parameters, including justification;
– design cases applied;
– geotechnical design calculations and drawings.

(4) <RCM> 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;
– design variant used at the outset of execution;
– design variants including threshold and limit values and acceptance criteria with associated contingency measures.

(5) <RCM> 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.

C.4.4 Simplification for Geotechnical Category 1

(1) <PER>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. Bases 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 it's 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. Specification of supervision (10.2);
   b. Inspection Plan (10.3).

C.5 Geotechnical Construction Record

C.5.1 General content

(1) <RCM> 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 base including Geotechnical Design Model;
   c. Measures applied;
   d. Deviations from construction specification and structure specification made during construction including justifications;
   e. Temporary work;
   f. Requirements 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) <PER> Test reports, inspection records, and drawings may be added to the GCR.

(3) <PER> A Building Information Model may be used to compile part of the GCR.

C.5.2 Record of construction

(1) <RCM> 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 view of problems encountered on site;
- any unexpected ground conditions that required changes to design;
- problems not envisaged in the Geotechnical Design Report and the solutions to them.

(2) <PER> For geotechnical structures in Geotechnical Category 1, a formal construction schedule may be omitted from the Geotechnical Construction record

C.5.3 Record of supervision, monitoring and inspection

(1) <RCM> 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;
- elaborate aspects which in execution phase differ from assumptions in design and assess its impact;
- summary of observations made during supervision, monitoring, and inspection.

C.6 Geotechnical test report

(1) <RCM>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 tested structural parts
    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 D
(Informative)
Qualification and professional experience

<Drafting note: TC250 will decide on whether this annex may be included or not.>

D.1 Use of this Annex

(1) This Informative Annex provides complementary guidance to 1.2 Assumptions and 4.1.8.

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.

D.2 Scope and field of application

(1) This Informative Annex covers one potential approach to verify the assumption that the design and collection of information is performed by competent persons, as stated in (4.1.1).

(2) This Informative Annex provides guidelines on requirements for competence of persons responsible for either geotechnical design or ground investigation process.

(3) This Informative Annex is intended to be used in conjunction with national legislation that specifies requirements on competence.

D.3 Guideline

(1) <RCM> The persons responsible for Ground Investigation and Geotechnical Design should have appropriate qualifications and experience within their respective field that includes:

- A diploma demonstrating successful completion of tertiary studies in a relevant field;
- Professional experience in ground engineering;
- Continuous Professional Development (CPD) in ground engineering;
- Membership of a relevant Professional Register, if available or required in individual countries.

NOTE 1 The recommended minimum requirements for qualifications and experience are given in Table D-1 (NDP) unless the National Annex gives different requirements. Examples of current and proposed requirements for countries can be found in JRP X[1]

NOTE 2 European Commission Directive 2005/36/EC on mutual recognition of professional qualifications acknowledges that engineers are organised differently in various EU member states.

NOTE 3 The minimum requirements in Table D-1 are applicable for geotechnical structures that fall within Geotechnical Category 2.

NOTE 4 The National Annex can stipulate which professional titles or levels of registration meet the minimum requirements in Table D-1.

Table D.1. (NDP) Minimum requirements for qualifications and professional experience to fulfil the assumptions of clause 1.2 for Geotechnical Category 2 structures [a]

(1)	(2)	(3)	(4)	(5)
Educational qualification (ECTS credit points)	**Professional experience**	**Continuous Professional Development (CPD)**	**Professional Competence**	**Remarks Registration** **Professional qualifications and application**
NOTE A	**NOTE B**	**NOTE C**	**NOTE D and E**	
B Sc / B Eng (180 – 240) Dipl. Ing. / M Sc / M Eng (300)	B Sc / B Eng 5 years – GC 2 Dipl. Ing. / M Sc / M Eng 3 years – GC 2 and demonstrated appropriate competence	≥ 20 hours /year	General requirements are defined in Note 5.	National requirements for registration may be enforced by private or public law. Applications for professional registration should be documented, subject to independent assessment and include a statement of professional competency and curriculum vitae.

[a] This table is an NDP and the NSB can clarify the following for its application.
- Additional requirements for Geotechnical Category 3 structures
- Additional acceptable academic qualification and associated professional experience
- Specification of criteria for CPD
- Additional general requirements on professional competence
- Specific requirements on professional competence for different technical areas

NOTE A Core subjects such as soil / rock mechanics, foundation engineering and engineering geology are required as part of university studies.

NOTE B The professional experience is measured in number of years demonstrating appropriate competence in the application of the relevant clauses of EN 1997.

NOTE C The criteria for valid CPD hours varies nationally. Learned Societies can give input to the specification.

NOTE D The required professional competence, including level of competence, depends on which clauses of EN 1997 a person will apply. Specific requirements for different technical areas can vary. Examples of relevant technical areas include planning of field and laboratory investigation, evaluation of ground investigation results, pile design, ground reinforcement, numerical methods. The professional competence also includes general professional competence related to documentation, project management, risk management, and communication.

NOTE E The General requirements are defined in the following statement. *"Competence is the ability to carry out a task to an effective standard. To achieve competence requires the right level of knowledge, understanding and skill, and a professional attitude. Competence is developed by a combination of formal and informal learning, and training and experience, generally known as initial professional development. However, these elements are not necessarily separate or sequential and they may not always be formally structured. There are five generic areas of competence and commitment for all ground engineering professionals, broadly covering: A) Knowledge and understanding; B) Design and development of ground engineering processes, systems, services and products; C) Responsibility, management or leadership; D) Communication and inter-personal skills; E) Professional commitment.*

NOTE [1] JPR x is a planned paper that will give more guideline. JRP X is expected to be largely based on a publication by Buggy et al (2018) "Registration of Ground Engineering Professionals – a European Perspective", 13th IAEG Congress, San Francisco, Ca. USA 15 – 23 September 2018 [To be updated]

Annex E
(Informative)
Guideline on selection of GCC

E.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.

E.2 Scope and field of application

(1) This Informative Annex covers guidelines on selection of appropriate Geotechnical Complexity Class.

E.3 Specific features to consider

(1) <RCM> 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) <RCM> 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) <RCM>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 E.1 (NDP) unless the National Annex gives different specific features.

(4) <RCM> 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 E.2 (NDP) unless the National Annex gives different specific features.

Table E.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 judged 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 soil that has potential to cause additional needs for the geotechnical structure or execution. 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 of 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 nonstable ground; – progressive failure of natural or improved ground; – potential sensitive adjacent structure or complex interaction with adjacent structures; – 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 E.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	– Restrictions on excavation below the ground water level; – no exposure to erosion, scour or piping; – minimal potential of water flow through the structure; – low influence from groundwater and/or surface water.
Complexity of the ground-structure interaction	– No known ground movements (settlement and our slope movement); – restrictions on ground surface inclination; – restrictions on maximum excavation depth; o e.g. 2 m in fine soil and 3 m in coarse soil – absence of sensitive structures within the zone of influence; – restriction on loading o No dynamic, cyclic or seismic actions. o No concentrated loading. o permanent loading is restricted to a limited fraction of anticipated bearing capacity of the ground

Annex F
(Informative)
Traffic load on geotechnical structures

F.1 Use of this Informative Annex

(1) This Informative Annex provides complementary guidance to that given in Clause 4 regarding loading of embankments, retaining structures and reinforced structures due to traffic loading.

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.

F.2 Scope and field of application

(1) This Annex provides:

- application rules concerning the traffic load models LM1 and LM71 of EN 1991-2 as applied in 2 dimensional analyses to geotechnical structures;
- characteristic values of static actions on geotechnical structures for verification of ultimate and serviceability limit states in 2-dimensional situations.

NOTE 1 For the SW/2 rail traffic load model, it is referred to EN 1991-2.

NOTE 2 Characteristic values of traffic loads are combined with other actions in accordance with EN 1990-1.

NOTE 3 Dynamic effects are included in these static actions.

F.3 General rules

(1) <REQ>The loads defined in EN 1991-2 shall be used for the design of bridges, including piers, abutments, upstand walls, wing walls and flank walls, noise barriers and their foundations.

NOTE EN 1991-2 presents imposed loads on bridge structures associated with road traffic, pedestrian actions and rail traffic, including, when relevant, dynamic effects and centrifugal, braking and acceleration actions and actions for accidental design situations.

(2) <REQ> When the design action is based on a load configuration that, which is not presented in EN1991-2, relevant global and local effects of the action shall be considered in the calculation model.

NOTE Load configuration not presented in EN 1991-2 comprise for example, geotechnical structures supporting light rail or pedestrian lanes.

F.4 Road traffic load on embankments and slopes

(1) <PER> As an alternative to EN 1991-2, 6.9, load model LM1, for embankments and slopes may be replaced by a characteristic uniformly distributed vertical static loads ($q_{k,road1}$) applied to the entire trafficked area.

NOTE The value of $q_{k,road1}$ is 12 kPa on the trafficked area and for areas only accessed for maintenance a value of $q_{k,road1}$ 5 kPa is applied, unless the National Annex gives different values

(2) <PER> As an alternative to EN 1991-2, 6.9, the load model for local loads effects on embankment and slopes may be replaced, by a characteristic uniformly distributed load ($q_{k,local}$).

NOTE 1 Local load effects represent specific situations like low embankments on soils with low shear strength or concentrated loads in a plane strain model.

NOTE 2 Guidance on application of $q_{k,local}$ can be specified in the National Annex.

NOTE 3 The value of $q_{k,road1}$ is 20 kPa on one lane of width 3 m with 9 kPa on other lanes, unless the National Annex gives different values.

(3) <REQ> For local load effects, the heaviest loaded lane shall be selected to provide the most onerous effect on the design situation.

F.5 Road traffic load on trafficked areas adjacent to retaining structures

(1) <PER> As an alternative to EN 1991-2, 6.9 load model LM1, for retaining structures may be replaced by a uniformly distributed vertical static loads ($q_{k,road2}$) applied to the entire trafficked area.

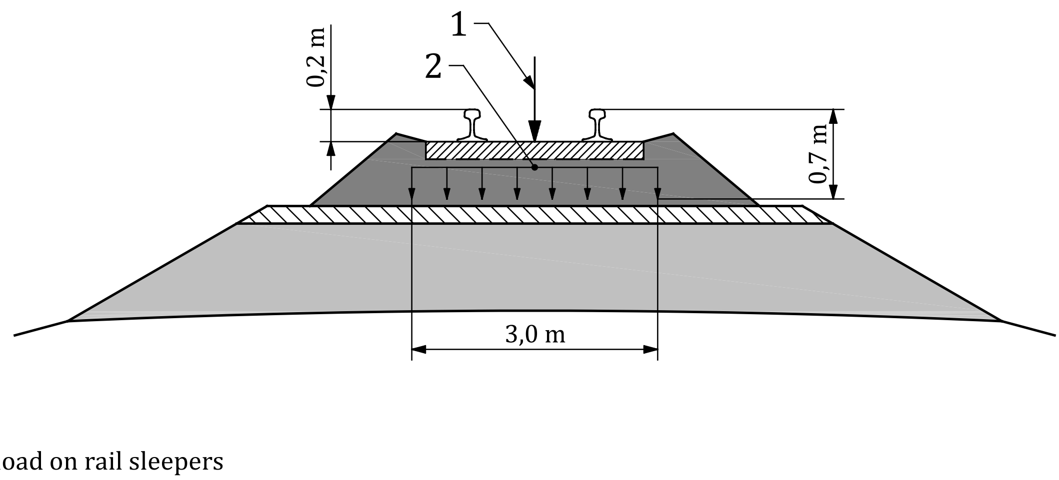
NOTE The value of $q_{k,road2}$ is 20 kPa on one lane of width 3 m with 9 kPa on all other lanes combined with a $q_{k,road2}$ 5kPa on areas only accessed for maintenance, unless the National Annex gives different values.

(2) <REQ> The heaviest loaded lane shall be selected to provide the most onerous effect on the design situation.

F.6 Railway traffic load on embankments and slopes

(1) <PER> As an alternative to EN 1991-2, 8.10, the load model for embankments and slopes may be replaced by one of the following loads:

- a characteristic uniformly distributed load ($q_{k,rail1}$) of a width 3.0 m acting at 0.7 m below the running surface of the rails.
- a characteristic line load $Q_{k,rail1}$ at 0.2 m below the running surface of the rails acting on rail sleepers.



Key

1 `Line load on rail sleepers

2 UDL (Uniformly Distributed Load)

Figure F.1 — Railway traffic load acting (a) as a line load, $Q_{k,rail1}$ on rail sleepers or (b) as uniformly distributed load $q_{k,rail1}$ at depth of 0,70 m from the running surface of the rails.

NOTE 1 The value of $q_{k,rail1}$ is 52 kPa , unless the National Annex gives a different value

NOTE 2 For plane strain conditions, the value of $Q_{k,rail1}$ is 100 kN/m (with load classification factor α equal to 1.0), unless the National Annex gives a different value

NOTE 3 The values of $q_{k,rail1}$ and $Q_{k,rail1}$ are equivalent to the load intensity given by LM71's point loads with a load classification factor α equal to 1.0. These loads include the anticipated local load effects on embankments and slopes.

(2) <RCM> In addition to (1), the values of $q_{k,rail1}$ and $Q_{k,rail1}$ should be multiplied by the load classification factor α given in EN1991-2.

F.7 Railway traffic load on trafficked areas adjacent to retaining structures

(1) <PER> As an alternative to EN 1991-2, 8, for retaining structures load model LM71 may be replaced by the following loads:

- a characteristic uniformly distributed load ($q_{k,rail2}$) of width 3.0 m at 0.7 m below the running surface of the rails;
- a characteristic line load ($Q_{k,rail2}$) at 0.2 m below the running surface of the rails acting on the rail sleepers.

NOTE 1 The value of $q_{k,rail2}$ is 52 kPa, unless the National Annex gives a different value.

NOTE 2 The global analyses under plane strain conditions, the value of $Q_{k,rail2}$ is 100 kN/m (with load classification factor, α equal to 1.0), unless the National Annex gives a different value.

NOTE 3 The values of $q_{k,rail,2}$ and $Q_{k,rail,2}$ are equivalent to the load intensity given by LM71's point loads with α equal to 1.0. These loads include the anticipated local load effects on retaining structures.

(2) <RCM> In addition to (1), the values of $q_{k,rail,2}$ and $Q_{k,rail,2}$ should be multiplied by a load classification factor α according to EN1991-2.

Annex G
(Informative)
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 197-1, *Composition, specifications and conformity criteria for common cements*

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

EN 445, *Grout for prestressing tendons – Test methods*

EN 447, *Grout for prestressing tendons – Basic requirements*

EN 1563, *Founding – Spheroidal graphite cast irons*

EN 1537, *Execution of special geotechnical works - Ground anchors*

EN 1912, *Structural Timber – Strength classes – Assignment of visual grades and species*

EN 10080, *Steel for the reinforcement of concrete – Weldable reinforcing steel - General*

EN 10138, *Prestressing Steels*

EN 12390, *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*

EN 13257, *Geotextiles and geotextile-related products - Characteristics required for use in solid waste disposals*

EN 13265, *Geotextiles and geotextile-related products - Characteristics required for use in liquid waste containment projects*

EN 14081-1, *Timber structures - Strength graded structural timber with rectangular cross section - Part 1: General requirements*

EN 14199, *Execution of special geotechnical works - Micropiles*

EN 14475, *Execution of special geotechnical works - Reinforced fill*

EN 14487 (all parts), *Sprayed concrete*

EN 14488 (all parts), *Testing sprayed concrete*

EN 15237, *Execution of special geotechnical works - Vertical drainage*

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*

EN ISO 14689, *Geotechnical investigation and testing - Identification, description and classification of rock*

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. General terms*

References given in permissions (i.e. "may" clauses)

The following documents are referred to in the text in such a way that some or all of their content expresses a course of action permissible within the limits of the Eurocodes. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

none

References given in possibilities (i.e. "can" clauses) and notes

The following documents are cited informatively in the document, for example in "can" clauses and in notes.

CIRIA R185 (1999), *Observational method in ground engineering: principles and applications*, CIRIA, London.

CIRIA C731 (2013). *The International Levee Handbook*. CIRIA, Ministère de l'Ecologie, du Développement Durable et de l'Energie, and the US Army Corps of Engineers. CIRIA, London.

Burland, J.B. and Wroth, C.P. (1974). *Settlement of buildings and associated damage*. SOA Review. Conf. Settlement of Structures, Cambridge, Pentech Press, London, pp 611-654