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Eurocode 7 — Geotechnical design — Part 2: Ground properties

***Eurocode 7 - Entwurf, Berechnung und Bemessung in der Geotechnik — Teil 2
Bodeneigenschaften***

Eurocode 7 - Calcul géotechnique — Partie 2: Propriétés des terrains

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European foreword

This document (FprEN 1997-2) 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 supersede EN 1997-2:2007.

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

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

- the scope of EN 1997-2 has been completely revised to assist the determination of ground parameters for design rather than provide a synopsis of ground investigation techniques;
- the concept of a Ground Model has been introduced to represent a site specific outline of the disposition and character of the ground and groundwater (Clause 4);
- the ground investigation process has been set out more clearly under the topics desk study (Annex C), site inspection (Annex C), preliminary and design investigations, and monitoring (Clause 5);
- rules for the minimum extent and spacing of ground investigation locations have been added (Clause 5 and Annex H);
- the description and classification of soil and rock (including discontinuities) have been described, mainly by reference to separate EN ISO standards (Clause 6);
- a new clause covering state, physical and chemical properties of the ground has been added (Clause 7);
- a new clause covering strength and stiffness parameters of the ground has been added, together with correlations linked to test data (Clauses 8 and 9 and Annexes E and F);
- a new clause covering cyclic, dynamic and seismic ground properties has been added together with correlations linked to test data (Clause 10 and Annex G);
- new clauses covering groundwater and geohydraulic properties and thermal properties have been added (Clauses 11 and 12); and
- the rules for reporting of ground investigations in the Ground Investigation Report have been revised (Annex A).

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

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

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

0 Introduction

0.1 Introduction to the Eurocodes

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

- EN 1990, *Eurocode: Basis of structural and geotechnical design*
- EN 1991, *Eurocode 1: Actions on structures*
- EN 1992, *Eurocode 2: Design of concrete structures*
- EN 1993, *Eurocode 3: Design of steel structures*
- EN 1994, *Eurocode 4: Design of composite steel and concrete structures*
- EN 1995, *Eurocode 5: Design of timber structures*
- EN 1996, *Eurocode 6: Design of masonry structures*
- EN 1997, *Eurocode 7: Geotechnical design*
- EN 1998, *Eurocode 8: Design of structures for earthquake resistance*
- EN 1999, *Eurocode 9: Design of aluminium structures*
- New parts are under development, e.g. Eurocode for design of structural glass

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

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

0.2 Introduction to EN 1997 (all parts)

EN 1997 consists of a number of parts:

- EN 1997-1, *Eurocode 7: Geotechnical design – Part 1: General rules*
- EN 1997-2, *Eurocode 7: Geotechnical design – Part 2: Ground properties*
- EN 1997-3, *Eurocode 7: Geotechnical design – Part 3: Geotechnical structures*

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

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

FprEN 1997-2:2023.TC250(E)**0.3 Introduction to FprEN 1997-2**

FprEN 1997-2 establishes rules for obtaining information about the ground at a site, as needed for the design and execution of geotechnical structures, including temporary geotechnical structures.

0.4 Verbal forms used in the Eurocodes

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

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

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

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

0.5 National annex for FprEN 1997-2

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

The national standard implementing FprEN 1997-2 can have a National Annex containing all national choices to be used for the design of geotechnical structures to be constructed in the relevant country.

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

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

National choice is allowed in FprEN 1997-2 through notes to the following clauses:

None (this document contains no national choices given in notes).

National choice is allowed in FprEN 1997-2 on the application of the following informative annexes:

Annex A	Annex B	Annex C	Annex D
Annex E	Annex F	Annex G	Annex H

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

1 Scope

1.1 Scope of FprEN 1997-2

- (1) This document provides rules for determining ground properties for the design and verification of geotechnical structures.
- (2) This document covers guidance for planning ground investigations, collecting information about ground properties and groundwater conditions, and preparation of the Ground Model.
- (3) This document covers guidance for the selection of field investigation and laboratory test methods to obtain derived values of ground properties.
- (4) This document covers guidance on the presentation of the results of ground investigation, including derived values of ground properties, in the Ground Investigation Report.

1.2 Assumptions

- (1) The provisions in FprEN 1997-2 are based on the assumptions given in prEN 1990-1 and FprEN 1997-1.
- (2) This document is intended to be used in conjunction with FprEN 1997-1, which provides general rules for design and verification of all geotechnical structures.
- (3) This document is intended to be used in conjunction with prEN 1997-3, which provides specific rules for design and verification of certain types of geotechnical structures.
- (4) This document is intended to be used in conjunction with EN 1998-1-1 which provides the requirements for the ground properties needed to define the seismic action.
- (5) This document is intended to be used in conjunction with EN 1998-5 which provides rules for the design of geotechnical structures in seismic regions.

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 ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1990-1¹:2024, *Eurocode - Basis of structural and geotechnical design – Part 1: Design of new structures*

EN 1997-1:2024, *Eurocode 7 - Geotechnical design - Part 1: General rules*

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

EN 1998-5, *Eurocode 8 - Design of structures for earthquake resistance - Part 5: Geotechnical aspects, foundations, retaining and underground structures*

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

FprEN 1997-2:2023.TC250(E)

EN ISO 14688, (all parts), *Geotechnical investigation and testing – Identification and classification of soil (ISO 14688)*

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

EN ISO 22475-1, *Geotechnical investigation and testing - Sampling methods and groundwater measurements - Part 1: Technical principles for the sampling of soil, rock and groundwater (ISO 22475-1)*

3 Terms, definitions, and symbols

For the purposes of this document, the terms and definitions given in prEN 1990-1, FprEN 1997-1 and the following terms and definitions apply.

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

3.1 Terms and definitions

3.1.1 Common terms used in EN 1997-2

3.1.1.1

site

surface area or underground space where construction work or other development is undertaken

3.1.1.2

anthropogenic ground

materials placed by human activity

3.1.1.3

rockhead

boundary between materials that behave as soil and those that behave as rock

3.1.2 Terms relating to the Ground Model and derived values

3.1.2.1

state property

ground property that can change over time, such as mass density, water content and saturation, density index, or stress state

3.1.2.2

measured value of a ground property

value of a ground property recorded during a test

3.1.3 Terms relating to the content of ground investigation

3.1.3.1

ground investigation

use of non-intrusive and intrusive methods to investigate the ground and groundwater conditions beneath or around the site or zone of influence

3.1.3.2

ground investigation location

location (point, line, or area) on the site where the ground is examined and investigated by intrusive or non-intrusive methods

3.1.3.3**low-rise structure**

warehouse sheds, factory buildings, or residential buildings up to three storeys high

3.1.3.4**high-rise structure**

buildings and structures greater than three storeys high, including chimneys and towers

3.1.3.5**site inspection**

observation and recording of features relevant to the surface and sub-surface conditions and any exposures of the ground, existing infrastructure or environment

Note 1 to entry: The inspection normally extends beyond the site boundaries.

3.1.3.6**sample**

defined amount of rock, soil, or groundwater recovered from a recorded depth

3.1.3.7**specimen**

part of the sample taken for laboratory testing

3.1.3.8**sample quality class**

quality class of the sample based on its degree of disturbance according to sampling technique

Note 1 to entry: Quality class for soil samples with related sampling categories is given in Table 5.4

Note 2 to entry: Quality class for rock samples with related sampling categories is given in Table 5.5

3.1.3.9**disturbance factor**

disturbance of the rock mass

3.1.3.10**mapping**

process of physically going out into the field and recording information from the ground at the surface or from excavations and exposures

3.1.3.11**geological mapping**

mapping to record and describe geological information and features observed in the field

Note 1 to entry: Description covers features such as morphology, lithology, hydrogeology, weathering, and any visible geological structure.

3.1.3.12**geotechnical mapping**

geological mapping adapted for engineering purposes, with the addition of ground classification or geometrical features

Note 1 to entry: Geometrical features include joint sets and deformation patterns.

FprEN 1997-2:2023.TC250(E)**3.1.4 Terms relating to chemical, physical, and state properties****3.1.4.1****classification**

definition of material groups and classes and assigning of materials to groups and classes with similar properties

[SOURCE: EN 16907-2:2018, 3.1.2, modified – deleted “for earthworks”.]

3.1.4.2**very coarse soil**

soil with particle sizes larger than 63 mm

[SOURCE: EN ISO 14688-1:2018, 5.1.1]

3.1.4.3**coarse soil**

soil with particle sizes between 0,063 and 63 mm

[SOURCE: EN ISO 14688-1:2018, 5.1.1]

3.1.4.4**fine soil**

soil with particle sizes smaller than 0,063 mm

[SOURCE: EN ISO 14688-1:2018, 5.1.1]

3.1.4.5**density index**

ratio of the difference between the maximum void ratio and the observed void ratio to the difference between maximum and minimum void ratios

3.1.4.6**relative density**

synonym for ‘density index’

3.1.4.7**consistency (Atterberg) limits**

collective name for liquid, plastic, and shrinkage limits of soil

3.1.4.8**liquid limit**

water content of soil at which a fine soil passes from the liquid to the plastic condition, as determined by the liquid limit test

[SOURCE: EN ISO 14688-2:2018, 3.7]

3.1.4.9**plastic limit**

water content of soil at which a fine soil passes from the plastic to the semi-solid condition, as determined by the plastic limit test

[SOURCE: EN ISO 14688-2:2018, 3.9]

3.1.4.10**shrinkage limit**

water content of soil below which loss of water does not result in volume reduction

3.1.4.11**activity index**

ratio of the plasticity index and the clay fraction content

3.1.5 Terms relating to strength**3.1.5.1****shear strength envelope**

expression that defines the boundary to failure in the material under shearing in a stress space

3.1.5.2**shear strength parameters**

material parameters appearing in the expression of shear strength envelopes

3.1.5.3**shear strength in effective stresses**

shear strength obtained from an envelope defined in terms of effective stress

3.1.5.4**peak shear strength**

upper limit of the shear strength observed in a test

3.1.5.5**critical state shear strength**

shear strength at the critical state corresponding to a state at which a soil continues to deform at constant stress and constant void ratio

3.1.5.6**residual shear strength**

lower limit of the shear strength of a fine soil reached after extensive shearing and particle re-orientation or lower limit of the shear strength reached after extensive shearing of discontinuities

3.1.5.7**undrained shear strength**

shear strength of water saturated soils obtained from an envelope defined in terms of total stress

3.1.5.8**peak undrained shear strength**

upper limit of the undrained shear strength

3.1.5.9**remoulded undrained shear strength**

undrained shear strength for totally remoulded soil

3.1.5.10**sensitivity**

ratio between peak and remoulded undrained shear strengths

FprEN 1997-2:2023.TC250(E)**3.1.5.11****Geological Strength Index**

index used for rock mass classification and estimation of mechanical properties

3.1.5.12**Joint Roughness Coefficient**

number characterizing the roughness of discontinuities

3.1.5.13**joint wall compressive strength**

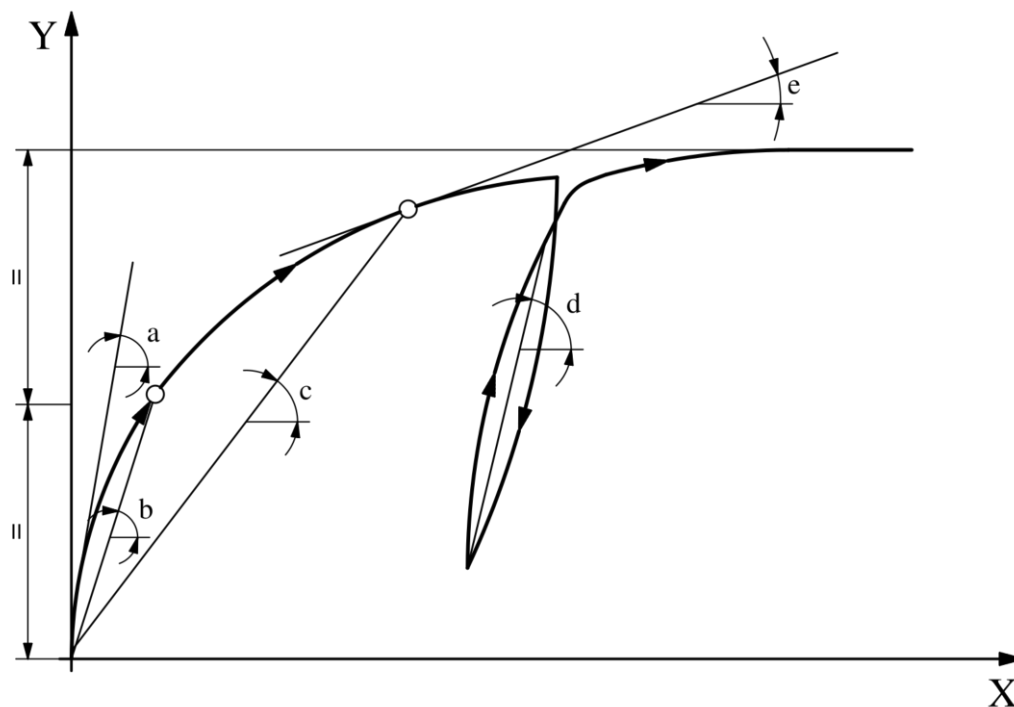
compressive strength of a discontinuity adjusted for weathering, size, width, infill and scale

3.1.5.14**rock mass strength**

strength resulting from the combination of the structural and material properties of the rock mass

3.1.6 Terms relating to stiffness and consolidation**3.1.6.1****elastic modulus**

ratio of stress increase to the corresponding increase in strain in the stress-strain relationship as shown in Figure 3.1

**Key for Modulus of Elasticity**

X	axial strain	c	E_{sec}
Y	axial stress	d	E_{cyc}
a	E_0	e	E_{tan}
b	E_{50}	II	50% of the maximum axial stress

Key for Shear Modulus

X	shear strain	c	G_{sec}
Y	shear stress	d	G_{cyc}

a	G_0	e	G_{tan}
b	G_{50}		50% of the maximum shear stress

Figure 3.1 — Definition of modulus on a stress-strain curve**3.1.6.2****bulk modulus**

ratio between mean stress increase to a corresponding decrease in volumetric strain

3.1.6.3**shear modulus**

ratio of shear stress increase to a corresponding increase in shear strain, as shown in Figure 3.1

3.1.6.4**secant modulus**

ratio between stress and the corresponding strain accumulated from an initial reference state, as defined by Figure 3.1

3.1.6.5**tangent modulus**

ratio between small increments of stress and strain from a given reference state, as shown in Figure 3.1

3.1.6.6**very small strain elastic modulus**

value of the elastic modulus at strains $< 10^{-5}$

3.1.6.7**very small strain Poisson's ratio**

value of Poisson's ratio at strains $< 10^{-5}$

3.1.6.8**oedometer (one dimensional) modulus**

ratio of the variation of a principal stress by the linear strain obtained in the same direction, with the other principal strains equal to zero

Note 1 to entry: Also known as the 'constrained modulus'.

3.1.6.9**swelling**

ground volume expansion caused by physicochemical processes or by the ingress of water

3.1.6.10**undrained modulus**

elastic modulus for undrained conditions

3.1.7 Terms relating to cyclic, dynamic, and seismic properties**3.1.7.1****compressional wave velocity**

velocity of propagation of a compressional (primary) wave in a medium

FprEN 1997-2:2023.TC250(E)**3.1.7.2****cyclic liquefaction**

transition of soil behaviour from solid-like to liquid-like due to cyclic or seismic actions

3.1.7.3**cyclic modulus**

slope of the line connecting the two points of reversal in cyclic loading as shown in Figure 3.1

3.1.7.4**cyclic shear strength**

maximum value of cyclic shear stress that can be sustained for a given number of cycles without exceeding a given strain threshold

3.1.7.5**cyclic undrained shear strength**

shear stress required to develop a specified residual axial strain in a given number of load cycles

Note 1 to entry: The specified residual axial strain is normally taken as 10 %

3.1.7.5**cyclic strain**

maximum strain attained or imposed during the application of cyclic actions

3.1.7.6**cyclic stress**

maximum stress attained or imposed during the application of cyclic actions

3.1.7.7**damping ratio**

ratio between the energy dissipated in a cyclically loaded system and the corresponding elastic energy of deformation based on hysteresis loops of stress vs strain

3.1.7.8**cyclic degradation**

deterioration of ground properties due to repeated load cycles (similar to fatigue in structural members)

3.1.7.9**fundamental frequency**

lowest value of the frequency associated with relative maximum amplification of the seismic ground motion

3.1.7.10**post-cyclic strength**

available strength after the application of a given number of stress cycles

3.1.7.11**post-cyclic creep**

deformation associated with average constant loads after the application of a given number of stress cycles

3.1.7.12**seismic bedrock**

reference formation identified by a shear wave velocity greater than 800 m/s

3.1.7.13**shear wave velocity**

velocity of propagation of a shear (secondary) wave in a medium

3.1.8 Terms relating to groundwater and geohydraulic properties**3.1.8.1****aquitard**

confining layer that retards, but does not prevent, the flow of water to or from an adjacent aquifer

3.1.8.2**aquifer**

body of permeable rock or soil mass suitable for containing and transmitting groundwater

[SOURCE: EN ISO 18674-4:2020, 3.10]

3.1.8.3**aquiclude**

body of soil or rock with extremely low transmissivity, which effectively prevents the flow of water through the ground

[SOURCE: EN ISO 18674-4:2020, 3.14]

3.1.8.4**joint water pressure**

pressure of the water in the joints or discontinuities of ground

3.1.8.5**pressure head**

ratio of the pore water/joint water pressure and the weight density of water above a point

[SOURCE: EN ISO 18674-4:2020, 3.3]

3.1.8.6**piezometer**

field instrument system for measuring pore or joint water pressure or piezometric level, at the measuring point

Note 1 to entry: The system is either an open or closed piezometric system.

[SOURCE: EN ISO 18674-4:2020, 3.1, modified]

3.1.8.7**open system**

field instrument system in which the fluid is in direct contact with the atmosphere and the piezometric level at the measuring point is measured

Note 1 to entry: Also known as an 'open piezometric system'.

[SOURCE: EN ISO 18674-4:2020, 3.6]

FprEN 1997-2:2023.TC250(E)**3.1.8.8****closed system**

measuring system in which the reservoir is not in direct contact with the atmosphere and in which the pressure in the fluid is measured by a pressure measuring device

Note 1 to entry: Also known as a 'closed piezometric system'.

[SOURCE: EN ISO 18674-4:2020, 3.7]

3.1.8.9**hydraulic conductivity**

ratio of the average velocity of a fluid through a cross-sectional area (Darcy's velocity) to the applied hydraulic gradient

Note 1 to entry: Hydraulic conductivity can vary in the vertical and horizontal directions.

3.1.8.10**absolute permeability**

property that quantifies the ability of porous ground to permit the flow of fluids through its pore spaces

Note 1 to entry: Also known as intrinsic permeability or specific permeability. The terms 'hydraulic conductivity' and 'absolute permeability' are interchangeable if the ground is fully saturated.

3.1.8.11**transmissivity**

rate at which water passes through a unit width of an aquifer under unit hydraulic gradient

3.1.9 Terms relating to thermal properties of the ground**3.1.9.1****thermal conductivity**

ratio of the thermal flux through a cross-sectional area (Fourier's law) to the applied thermal gradient

3.1.9.2**heat capacity or specific heat capacity**

capacity of a material to store thermal energy

3.1.9.3**thermal diffusivity**

ratio of the thermal conductivity to the specific heat capacity

3.2 Symbols and abbreviations

For the purposes of this document, the symbols given in FprEN 1997-1 and the following symbols and abbreviations apply.

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

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

3.2.1 Latin upper case letters

<i>B</i>	pore water pressure coefficient
<i>C</i>	thermal capacity per unit volume

C_c	compression index
$C_{C,PSD}$	coefficient of curvature
C_g	swelling coefficient
C_i	non-dimensional coefficient of correlation
C_{sw}	swelling index
$C_{U,PSD}$	uniformity coefficient
C_α	coefficient of secondary compression
D	disturbance factor for rock mass
D_n	particle size that n % by weight are smaller than
D_0	small strain damping ratio
D_{50}	median grain size
E'	drained modulus of elasticity
E_u	undrained modulus of elasticity
E_{BJT}	modulus of elasticity from a borehole jack test according to EN ISO 22476-7
E_{cyc}	cyclic modulus of elasticity
E_{DMT}	modulus of elasticity from a flat dilatometer test according to EN ISO 22476-11
E_{FDP}	modulus of elasticity from a full displacement pressuremeter test according to EN ISO 22476-8
E_{FDT}	modulus of elasticity from a Flexible Dilatometer test according to EN ISO 22476-5
E_i	modulus of elasticity of intact rock
E_M	modulus of elasticity from a Ménard pressuremeter test according to EN ISO 22476-4
E_{OED}	modulus of elasticity from an oedometer test according to EN ISO 17892-5
E_{PBP}	modulus of elasticity from a pre-bored pressuremeter test according to EN ISO 22476-5
E_{PLT}	modulus of elasticity from a plate loading test
E_{rm}	modulus of elasticity of rock mass
E_s	modulus of elasticity of soil
E_{SBP}	modulus of elasticity from a self-boring pressuremeter test according to EN ISO 22476-6
E_{sec}	secant modulus of elasticity
E_{tan}	tangent modulus of elasticity
E_u	undrained modulus of elasticity
G_0	shear modulus at very small strain
G_{cyc}	shear modulus from a CTxT
G_{FDT}	shear modulus from a Flexible Dilatometer test according to EN ISO 22476-5
G_M	shear modulus from a Ménard pre-bored pressuremeter test according to EN ISO 22476-4
G_{PBP}	shear modulus from a Pre-Bored Pressuremeter test according to EN ISO 22476-5
G_{SBP}	shear modulus from a Self-Boring Pressuremeter test according to EN ISO 22476-6

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G_{sec}	shear modulus from a DSS
H_{800}	depth of the bedrock formation identified by a shear wave velocity vs greater than 800 m/s
I_A	activity index
I_c	soil behaviour type index
I_D	density index of coarse soil
I_{DMT}	DMT material index according to EN ISO 22476-11
I_f	fracture spacing
I_L	liquidity index of fine soil according to EN ISO 17892-12
I_P	plasticity index of fine soil according to EN ISO 17892-12
K	hydraulic conductivity
K_{bulk}	bulk modulus
K_D	DMT horizontal stress index as per EN ISO 22476-11
K_0	at-rest earth pressure coefficient
K_{PMT}	calibration factor for PMT test results
L	length of test section in the thickness of aquifer
M_{DMT}	DMT modulus according to EN ISO 22476-11
N	number of blows to drive the penetrometer over a defined distance as per EN ISO 22476-2
N	number of cycles
N_{kt}	a cone factor as per EN ISO 22476-1
N_{min}	minimum number of field investigations
N_{WST1}	number of half rotations per 1 m penetration as per EN ISO 22476-10
N_{60}	SPT blow count normalized for energy as per EN ISO 22476-3
$(N_1)_{60}$	SPT blow count normalized for overburden pressure and energy as per EN ISO 22476-3
OCR	Over consolidation ratio
Q	coefficient that depends on the crushability of the material
R_f	friction ratio
T	transmissivity
$V_{s,H800}$	equivalent value of the shear wave velocity of the soil column above the depth of the bedrock formation
X_{max}	maximum distance between two field investigations

3.2.2 Latin lower case letters

a	non-dimensional material parameter in the Hoek-Brown strength envelope
c_{dis}	apparent cohesion of the discontinuity
$c'_{X,Y}$	effective cohesion measured at a condition X (p for peak, cs for critical state, r for residual) by a specific test Y (UCT, UU, TX, FVT, etc.)
c_h	coefficient of horizontal consolidation

$c_{u,X,Y}$	shear strength in total stress analysis measured at a condition X (p for peak, cs for critical state, r for residual, rmd for remoulded) by a specific test Y (DST, TXT, CU, CD, FVT etc.)
c_v	coefficient of consolidation
c_{fv}	peak shear strength of soil, derived from the maximum torque measured by field vane test as per EN ISO 22476-9
d_{min}	minimum depth of field investigation
e	void ratio of soil
e_{max}	maximum void ratio of soil
e_{min}	minimum void ratio of soil
e_0	void ratio of the prepared specimen
f	frequency of the load in Hz
f_0	fundamental frequency of a soil deposit
f_1	soil property function defining the relationship between shear strength and soil suction
f_s	sleeve resistance
h_w	pressure head
k	absolute permeability
m	coefficient that depends on the relevant shear mode to failure
m_b	non-dimensional material parameter in the Hoek-Brown strength envelope
m_i	non-dimensional material parameter in the Hoek-Brown strength envelope
m_v	one dimensional compressibility
p'	mean principal effective stress
p_1	corrected pressure at the origin of the pressuremeter modulus pressure range (see EN ISO 22476-4)
p_a	atmospheric air pressure
p_{LM}	limit pressure from Ménard pressuremeter test according to EN ISO 22476-4
p_{ref}	reference pressure usually equal to 100 kPa
q_c	cone tip resistance measured as per EN ISO 22476-1
q_n	net cone resistance ($= q_t - \sigma_{v0}$)
q_t	corrected cone resistance as per EN ISO 22476-1
s	non-dimensional material parameter in the Hoek-Brown strength envelope
u	groundwater pressure
u_a	pore air pressure
v_p	compressional wave velocity
v_s	shear wave velocity
w	water content
w_L	liquid limit of soil
w_P	plastic limit of soil

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w_s shrinkage limit of soil

3.2.3 Greek upper case letters

Δu_2 excess pore water pressure measured at the gap between cone tip and friction sleeve as per EN ISO 22476-1

Δe change in void ratio

3.2.4 Greek lower case letters

γ shear strain

γ weight density of the fluid.

γ_{cyc} cyclic shear strain

γ_e elastic threshold strain beyond which shear modulus falls below its maximum value

γ_{ref} reference value of engineering shear strain (at which $G_{sec}/G_0 = 0,5$)

γ_w weight density of groundwater

δ_x horizontal incremental displacement of a specimen in direct shear

δ_z vertical incremental displacement of a specimen in direct shear

ε strain

ε_g swelling amplitude

ε_{vol} volumetric strain ($= \Delta V/V_0$) from reconsolidation to $(\sigma'_{v0}, \sigma'_{h0})$

η dynamic viscosity of a fluid

κ thermal diffusivity

λ thermal conductivity

ν Poisson's ratio

ν_0 Poisson's ratio at very small strain

ρ bulk mass density

$\rho_{d,max}$ reference density at optimal water content (Proctor)

σ normal stress

σ' effective normal stress

σ_0 In-situ total stress

σ_{ci} uniaxial compressive strength

σ'_{h0} in-situ horizontal effective stress

σ_n normal stress acting on a discontinuity

σ'_p pre-consolidation pressure

σ_t tensile strength of soil or rock

σ_v total vertical stress

σ_{v0} in-situ vertical total stress

σ'_{v0} in-situ vertical effective stress

σ_1	major principal stress
σ_3	minor principal stress
τ	shear stress
τ_{dis}	shear stress at failure along a discontinuity;
τ_p	peak shear strength of discontinuity
φ	angle of friction
φ'	effective angle of friction
φ_b	base angle of friction of a rock surface
$\varphi'_{x,Y}$	effective angle of friction measured at a condition X (p for peak, cs for critical state, r for residual) by a specific test Y (DST, CU, CD, TXT, etc.)

3.2.5 Abbreviations

BDP	Borehole Dynamic Penetration (test)
BE	Bender Element
BJT	Borehole Jack Test
BST	Borehole Shear Test
CBR	California Bearing Ratio
CDSS	Cyclic Direct Simple Shear
CD	Consolidated Drained (Triaxial Test)
CPT	Cone Penetration Test
CPTU	Cone Penetration Test with pore water pressure measurement (piezocone test)
CRS	Constant Rate of Strain
CTS	Cyclic Torsional Shear
CTxT	Cyclic Triaxial Test
CU	Consolidated Undrained (Triaxial Test)
DMT	Flat Dilatometer Test (also known as Marchetti Dilatometer Test)
DP	Dynamic Penetration (Test)
DSS	Direct Simple Shear
DST	Direct Shear Test
FDP	Full Displacement Pressuremeter
FDT	Flexible Dilatometer Test
FVT	Field Vane Test
GIR	Ground Investigation Report
GSI	Geological Strength Index
IL	Incremental loading oedometer test
IST	Interface Shear Test
JCS	Joint Compressive Strength of a discontinuity

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JRC	Joint Roughness Coefficient
MBV	Methylene Blue Value
MPM	Ménard Pressuremeter (Test)
MQC	Minimum Quality Class of sample suitable for a test (see 5.4.5)
MR	Modulus Ratio
MWD	Measuring While Drilling
OCR	Over-Consolidation Ratio
OED	Oedometer (Test)
OMC	Organic Matter Content
PBP	Pre-Bored Pressuremeter (Test)
PLT	Plate Loading Test
PMT	Pressuremeter Test
RC	Resonant Column (Test)
RQD	Rock Quality Designation
SBP	Self-Boring Pressuremeter (Test)
SCPT	Seismic Cone Penetration Test
SCR	Solid Core Recovery
SDMT	Seismic Dilatometer Test
SPT	Standard Penetration Test
TCR	Total Core Recovery
TxT	Triaxial Test
UCS	Unaxial Compressive Strength
UCT	Unconfined Compression Test
UU	Unconsolidated Undrained (Triaxial Test)
WST	Weight Sounding Test

4 Ground Model and derived values**4.1 Ground Model**

- (1) A Ground Model shall comprise the geological, hydrogeological, and geotechnical conditions at the site, based on the ground investigation results.

NOTE 1 Geological conditions include, for example, the description of the site geomorphology, the lithology of the geotechnical units, the potential presence and level of a rockhead, geometrical and geotechnical properties of discontinuities and weathered zones.

NOTE 2 Hydrogeological conditions address surface, groundwater, and piezometric levels, including their potential variation with time, potential water flows and the presence of other fluids or gases affecting the site.

NOTE 3 Geotechnical conditions include, for example, the disposition of the geotechnical units and the mechanical behaviour of the ground described by the properties of the geotechnical units.

- (2) Variability and uncertainty of geological, hydrogeological and geotechnical conditions and properties shall be included in the Ground Model.
- (3) The detail and the extent of the Ground Model shall be consistent with the Geotechnical Category and the zone of influence.

NOTE Guidance on Geotechnical Category and zone of influence is given in FprEN 1997-1:2024, 4.1.2.

- (4) The Ground Model shall be progressively developed and updated based on potential new information.

NOTE The Ground Model and the Ground Investigation Report are the main output of the Ground Investigation and form the basis for the development of the Geotechnical Design Model (see FprEN 1997-1:2024, 4.2.3).

- (5) The Ground Model shall reference the derived values of ground properties for encountered geotechnical units.

NOTE Guidance on derived values is given in 4.2.

- (6) The Ground Model should be documented in the Ground Investigation Report.
- (7) As an alternative to (6), the Ground Model may be documented in the Geotechnical Design Report.

4.2 Derived values

- (1) Derived values of the properties of a geotechnical unit shall be established from data gathered during the desk study, site inspection, preliminary and design investigations, and monitoring of the ground and structures.
- (2) Empirical correlations and theories used to obtain the derived values shall be documented in the Ground Investigation Report.
- (3) The Ground Investigation Report shall record whether empirical correlations and theories used in parameter derivation are intended to provide average, superior, or inferior values.
- (4) The information given for each correlation should specify either directly or through reference:
 - the materials to which they apply, specified by their description according to EN ISO 14688-1 and classification according to EN ISOs 14688-2 and 14689, or their intrinsic and chemical properties;
 - the database that supports the correlation; and
 - the estimated transformation errors.
- (5) Site-specific data should be used to support generic correlations.

NOTE Site specific data generally results in smaller transformations errors.

- (6) Derived values of ground mass properties that are determined from test results on samples should be adjusted for scale effects.

5 Ground investigation

5.1 General

- (1) The ground investigation shall be planned so that it collects the information needed to define the geotechnical units that influence the anticipated design situations.

NOTE 1 Guidance on suitable ground investigation techniques is given in Annex B.

NOTE 2 The geotechnical units include soil layers, rock masses and any fill in place prior to the investigation works.

- (2) The ground investigation should determine potential obstacles, hidden objects, and locally adverse properties in the ground, that could influence the geotechnical structure and its execution.

NOTE Examples are existing underground infrastructure, cables, pipes, cavities, unexploded devices, historical, archaeological, and cultural objects, local absence or presence of critical layers or zones.

- (3) The scope, level of detail, and accuracy of the ground properties to be obtained during the ground investigation shall be defined before the start of the investigation.

NOTE 1 The extent of ground investigation and the required sample quality classes affect the precision of the determined ground properties.

NOTE 2 Guidance on the confidence levels of the results from different tests is given in Annex B.

- (4) The ground investigation should be carried out in phases to progressively increase knowledge and reduce uncertainty of the information about the ground.

- (5) The ground investigation shall identify the ground materials and groundwater conditions within the zone of influence.

- (6) The ground investigation should determine potential obstacles for the execution of the geotechnical structure, including but not limited to:

- obstructions to drilling and boring;
- drivability of the ground;
- abrasivity;
- borehole stability;
- potential flow of groundwater in or out of a borehole;
- geometrical properties of discontinuities and weakness zones;
- borehole axis deviations; and
- potential loss of grout from the borehole.

- (7) The ground investigation should identify rockhead, transition zones between geotechnical units and weathered zones where present.

NOTE A distinct rockhead can be difficult to define in cases with transition or weathered zones between soil and rock materials.

- (8) The minimum amount of ground investigation should be specified according to the Geotechnical Category, as given in Table 5.1.

Table 5.1 — Criteria for ground investigation for different Geotechnical Categories

Geotechnical Category	Criteria for ground investigation
GC3 ^a	<p>The items given below for GC2 and, in addition:</p> <ul style="list-style-type: none"> — sufficient ground investigations to capture the relevant variabilities of the ground; — sufficient ground investigations to capture the properties for relevant geotechnical units using more than one ground investigation method; — sufficient ground investigations to capture the scatter of the relevant properties of each geotechnical unit.
GC2	<p>The items given below for GC1 and, in addition:</p> <ul style="list-style-type: none"> — sufficient ground investigations to identify relevant geotechnical units in the zone of influence; — determination of relevant ground properties by field and laboratory testing and by monitoring.
GC1	<p>All items given below:</p> <ul style="list-style-type: none"> — desk study of the site, review of comparable experience; — site inspection; — design investigation, if necessary.
<p>^a GC3 is assumed unless a different category has been determined by the desk study or by preliminary or design investigation.</p>	

- (9) If there is sufficient information from the desk study and site inspection to justify classification as GC1, additional design investigation may be omitted.

NOTE Guidance on the content of a Desk Study is given in 5.2.2.

- (10) Ground investigations may also include other laboratory or field investigation tests than are specified in this document, using methods adapted to the local conditions.

- (11) The results of the ground investigation should be presented together with statements on any limitations, discrepancies, uncertainties, or gaps in the data, as well as if any deviation has been made from standard procedures for the investigation.

5.2 Contents of ground investigation

5.2.1 General

- (1) Ground investigation shall include:

- a desk study (5.2.2);
- site inspection (5.2.3); and

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- for GC2 and GC3 design investigations (5.2.5).
- (2) Ground investigation for GC2 and GC3 should also include:
 - preliminary investigation (5.2.4);
 - monitoring (5.2.6).

NOTE Guidance on information to be obtained from the ground investigation is given in Annex D.

5.2.2 Desk study

- (1) A desk study shall be carried out.

NOTE Guidance on the desk study is given in Annex C.

- (2) A desk study should include factual information of the site details, site history, and site geology, including any previous GIR in the vicinity of the site and previous experience related to the site.
- (3) The desk study should be carried out at an early stage of the ground investigation.
- (4) The desk study should identify potential hazards in the ground.
- (5) The desk study should identify the presence of any existing structure that can influence or can be affected by the new structure.

NOTE This includes hidden structures, e.g. foundations, cables, pipes, tunnels, and potential archaeological finds.

- (6) The desk study shall determine a preliminary zone of influence.

5.2.3 Site inspection

- (1) The site shall be visited and inspected before preliminary or design investigations are conducted.

NOTE 1 Guidance on site inspection is given in Annex C.

NOTE 2 See FprEN 1997-1:2024, 10.3, for inspection during execution and FprEN 1997-1:2024, 10.6, for inspection as part of the Observational Method.

- (2) The findings of the site inspection should be confirmed by comparison with the information gathered by the desk study.
- (3) The site inspection should cover the entire surface area of the zone of influence.
- (4) Inspection and geotechnical mapping of visible ground surfaces should be included in the site inspection.
- (5) The findings of the site inspection shall be recorded in the Ground Investigation Report.

5.2.4 Preliminary investigation

- (1) Preliminary investigations should be performed to identify key issues that need to be addressed by design investigation.

NOTE 1 Geophysical investigations can be performed in the preliminary investigation to identify these key issues.

NOTE 2 Further guidance on the Ground investigation is given in Annex D, including geotechnical hazards.

NOTE 3 Light footprint screening techniques can be used to optimize subsequent phases of ground investigation and the resulting ground and geotechnical models.

(2) Preliminary investigations should enable determination of:

- groundwater conditions, including aquifers, aquitards, or aquicludes;
- geotechnical hazards present at the site, including landslide and seismic hazards;
- valuable or historical constructions;
- suitable positioning of the structure;
- preliminary design of the geotechnical and related structures;
- stability of any excavations or underground openings;
- potential impacts of the proposed construction on the surroundings, including neighbouring buildings, structures, and sites;
- potential need for and suitability of different ground improvement methods; and
- sources of construction materials.

(3) Preliminary investigation should provide information concerning:

- material types and their disposition;
- rockhead within the zone of influence;
- discontinuities and their geometry;
- piezometric levels and groundwater pressures;
- preliminary values of the strength and stiffness properties of the geotechnical units; and
- potential occurrence of natural or anthropogenic contamination in the ground or groundwater.

5.2.5 Design investigation

- (1) Design investigations shall provide values of ground properties needed to verify all limit states in any applicable design situations.
- (2) Design investigations should identify ground and groundwater conditions that could influence the behaviour and execution of the structure or adversely affect its durability.
- (3) In addition to (1) and (2), design investigations should provide, as relevant:
 - data for a description and classification of the geotechnical units;

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- values of state, physical and chemical ground and groundwater properties;
- values of strength properties of the ground;
- values of stiffness, compressibility and consolidation properties of the ground;
- values of cyclic, dynamic, and seismic properties of ground;
- groundwater conditions and ground hydraulic properties; and
- values of thermal properties of the ground.

(4) The information on groundwater conditions should include, as relevant:

- the depth, thickness, and extent of water-bearing geotechnical units in the ground;
- the groundwater pressure distribution;
- piezometric levels and their variation over time;
- the hydraulic conductivity and its possible anisotropy for each geotechnical unit; and
- the chemical composition and temperature of groundwater.

5.2.6 Monitoring

(1) Monitoring should be used to obtain information on ground behaviour and on groundwater conditions for design.

NOTE See FprEN 1997-1:2024, 10.4.

5.3 Ground investigation techniques**5.3.1 Site inspection techniques**

(1) Site inspection should be performed using one or more of the following techniques:

- visual observation;
- topographic mapping;
- photogrammetric mapping;
- airborne and on-ground video tools;
- geological mapping; and
- geotechnical mapping.

5.3.2 Preliminary or design investigation techniques**5.3.2.1 Exploratory holes and openings**

(1) Ground and groundwater conditions should be determined using one or more of the following techniques:

- test pits, shafts, and exploratory headings;
- percussive and rotary boreholes;
- logging of borehole walls, excavations, and exposures; and
- probing.

(2) Exploratory activities should include sampling and groundwater measurements.

5.3.2.2 Field investigation techniques

(1) Field investigation tests should be performed in accordance with the standards given in Table 5.2.

Table 5.2 — Field investigation tests and corresponding standards

Type of test	Test standard
Field testing	EN ISO 22476 (all parts)
Geophysical testing	See Note ^a
Geohydraulic testing	EN ISO 22282 (all parts)
Geothermal testing	EN ISO 17628 (all parts)
Testing of geotechnical structures	EN ISO 22477 (all parts)
In-situ stress measurements	ISRM Suggested Methods (all parts)
^a ISO TC182/WG12 is preparing a standard. Information is also available in ISO 19901-10:2021	

(2) Field investigation tests other than those given in Table 5.2 may also be carried out, provided the test standard used is recorded in the Ground Investigation Report.

(3) Geophysical tests should be used to identify:

- ground conditions (including stratification and any lateral variations, weathered or fractured zones, faulting, presence of cavities);
- buried objects (including utilities, services, existing foundations and basement structures, artefacts, archaeological structures and unexploded ordnance) that could interfere with the construction works;
- groundwater conditions; and
- parameters for the estimation of porosity, hydraulic conductivity and stiffness.

NOTE Guidance on utilisation of geophysical methods in site characterisation can be found in Medhus, A.B. and Klinkby, L. (2022).

(4) Disposition of geotechnical units identified using geophysical testing shall be compared with the results of direct ground investigation techniques and adjusted accordingly.

NOTE Geophysical testing can be carried out ahead of intrusive investigation to optimize the scope of the investigation.

5.3.2.3 Laboratory testing

- (1) Laboratory tests should be performed in accordance with the standards given in Table 5.3.

Table 5.3 — Laboratory test standards

Type of test	Test standard
Laboratory testing of soil	EN ISO 17892 (all parts)
Laboratory testing of rock	ISRM Suggested Methods

- (2) Laboratory tests other than those given in Table 5.3 may also be carried out, provided the test standard used is recorded in the Ground Investigation Report.

- (3) Laboratory testing should be carried out shortly after sampling.

NOTE This is particularly important when stiffness properties are to be determined.

- (4) Preservation and storage of samples for laboratory testing should comply with EN ISO 22475-1.

5.3.3 Instrumentation for monitoring

- (1) Geotechnical monitoring by field instrumentation should comply with EN ISO 18674 (all parts).
- (2) Instruments shall be maintained throughout the period identified in the Monitoring Plan specified in FprEN 1997-1:2024, 10.4.

5.3.4 Back analysis

- (1) Monitoring results may be obtained during execution or from existing, trial, or failed geotechnical structures.
- (2) Information on the behaviour of the ground may be gathered from back-analysis of monitoring results.
- (3) Best estimate values of parameters for calculation models may be determined from back-analysis of monitoring results.

5.4 Planning of preliminary and design investigations

5.4.1 General

- (1) The planning of preliminary and design investigations shall be appropriate for the purpose of the investigation and the anticipated geotechnical units.
- (2) The planning of preliminary and design investigations shall provide:
- positioning and depth of field investigation and sampling locations;
 - field investigation techniques to be used at each location;
 - required sample quality and therefore the samplers to be used (see Clauses 7 to 10 and EN ISO 22475-1);
 - laboratory testing to be carried out;

- measurements of groundwater pressures and piezometric levels to be made;
 - details of instrumentation to be installed; and
 - standards to be applied to all aspects of the works.
- (3) The type and extent of the techniques to be used in the investigation shall be based on the results of the desk study, the site inspection, previous knowledge of the geotechnical structure to be designed, the Geotechnical Category, and the zone of influence.
- (4) The extent of investigations shall cover the:
- zone of influence of the structure;
 - zone of influence of temporary works elements;
 - depth of effect of any dewatering works on groundwater conditions;
 - depth for calculation of the seismic response as specified in prEN 1998-1, Clause 5 and prEN 1998-5, Clause 6 when prescribed; and
 - presence of any destabilising features in the ground on or around the site.

NOTE The zone of influence under cyclic, dynamic or seismic actions can be different from that under static loading.

5.4.2 Number of investigation locations and laboratory tests

- (1) The number of investigation locations and laboratory tests in a geotechnical unit shall be determined from:
- the variability of the ground;
 - previous documented experience in ground with the same variability; and
 - the Geotechnical Category.
- (2) The number of investigation locations and laboratory tests should be appropriate for the ground investigation techniques used and typical uncertainty levels of the test results.

NOTE 1 The use of more than one ground investigation technique can reduce uncertainty in derived values.

NOTE 2 Guidance on the suitability and applicability of different ground investigation techniques is given in Annex B.

- (3) The number and type of samples for laboratory tests should be appropriate for the material to be sampled and potential sample disturbance.

5.4.3 Minimum extent of field investigation and spacing of investigation locations

- (1) The depth and horizontal extent of the field investigation shall be sufficient to determine the ground conditions within the zone of influence.

NOTE Guidance on the minimum depth d_{\min} of field investigation is given in prEN 1997-3 for specific structures.

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- (2) Groundwater and piezometric levels shall be determined to assess whether they could influence the stability or displacements or drainage of the geotechnical structure or any adjacent structures or utilities or their execution.
- (3) The value of d_{\min} should be increased in the case of unfavourable ground conditions.
- (4) The value of d_{\min} may be reduced in competent ground if sufficient comparable experience exists to allow its properties to be predicted throughout the zone of influence.

NOTE Depending on the level of loading, examples of competent ground include medium strong rock masses or stronger, very dense coarse soil and fine soil with very high shear strength.

- (5) The spacing of investigation locations shall be appropriate for the:

- variation of the ground conditions;
- variation of the geotechnical units;
- variation of the groundwater conditions;
- critical elements of the structure; and
- the geotechnical category.

- (6) The spacing of investigation locations on plan should be no greater than X_{\max} .

NOTE Guidance on X_{\max} is given in Annex H.

- (7) The number of investigation locations should be no less than N_{\min} .

NOTE Guidance on N_{\min} is given in Annex H.

- (8) For structures in Geotechnical Category 3, the maximum spacing of investigation locations should be less than X_{\max} and the minimum number of investigation locations should be greater than N_{\min} .
- (9) Where documented previous knowledge, local experience, or the results of preliminary investigations indicate that ground properties are highly variable, closer spacing and more investigation locations than given in (6) and (7) should be used.

NOTE 1 Further guidance on the extent of ground investigation for specific geotechnical structures is given in prEN 1997-3.

NOTE 2 Geophysical techniques can supplement the information between intrusive investigation locations.

- (10) In cases where more than one type of investigation technique is planned, the investigation locations shall be separated by sufficient distance to avoid any interference.
- (11) For structures in Geotechnical Category 1, the maximum spacing of investigation locations may be greater than X_{\max} and the minimum number of investigation locations may be less than N_{\min} .
- (12) Where documented previous knowledge, local experience or the results of preliminary investigations indicate that ground properties are sufficiently uniform across the site, a wider spacing or fewer investigation locations than given in (6) and (7) may be used, provided the reduced intensity is justified in the Ground Investigation Report.

5.4.4 Positioning of investigation locations

- (1) The depth and positioning of investigation locations shall be sufficient to identify the disposition of geotechnical units and their properties within the zone of influence.

NOTE The zone of influence for the different geotechnical structures is specified in prEN 1997-3.

- (2) The positioning of investigation locations should be based on the results of the desk study, site inspection and results of any preliminary investigations and according to the:
 - presence of critical locations relative to the shape, structural behaviour, and expected load distribution of the structure;
 - stability of slopes or cuttings and steps in the ground;
 - necessity of investigation locations outside the site so that the stability of the slopes or cuttings can be assessed;
 - preventing hazards to the structure, its execution, or the surroundings;
 - requirements for groundwater and monitoring instruments; and
 - potential monitoring during and after execution.
- (3) The position and elevation of investigation locations shall be recorded in the Ground Investigation Report, together with details of the grid reference system and geodetic reference datum used.

5.4.5 Sampling and laboratory testing

- (1) Samples should be taken from all geotechnical units.
- (2) Sampling shall comply with EN ISO 22475-1.
- (3) Groundwater measurements should comply with EN ISO 18674-4.
- (4) Planning of the sampling and selection of the equipment for taking each sample shall be appropriate for the:
 - parameters to be measured;
 - tests to be carried out;
 - minimum sample quality class;
 - material to be sampled;
 - required diameter and mass of the sample; and
 - chosen sampler.
- (5) A specific sampling category, defined according to EN 22475-1, shall be selected according to Tables 5.4 and 5.5 to obtain a required minimum quality class (MQC).

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- (6) Samples of lower quality class may be used for testing, if the design acknowledges that test results and resulting design parameters have a larger uncertainty and not necessarily accurately reflect in situ conditions/behaviour.

NOTE An example is water content in cohesion material that can be determined from quality class 4 instead of 3 if the increased uncertainty is accounted for in the design parameters.

Table 5.4 — Quality classes of soil samples and sampling categories

Soil properties	Quality classes of soil samples for laboratory testing				
	1	2	3	4	5
Unchanged soil properties					
soil type	*	*	*	*	*
particle size	*	*	*	*	
water content	*	*	*		
density, density index, hydraulic conductivity	*	*			
compressibility, shear strength, stiffness	*				
Properties that can be determined					
sequence of layers	*	*	*	*	*
boundaries of strata – broad	*	*	*	*	
boundaries of strata – fine	*	*			
Atterberg limits, particle density, organic content	*	*	*	*	
water content	*	*	*		
density, density index, porosity, hydraulic conductivity	*	*			
compressibility, shear strength, stiffness	*				
Sampling categories	A				
		B			
			C		
				D	
					E

Table 5.5 — Quality classes of rock samples and sampling categories

Rock properties	Quality classes of rock samples for laboratory testing				
	1	2	3	4	5
Unchanged properties					
identification of rock type	*	*	*	*	*
particle shape and mineralogy	*	*	*	*	*
dimensions of all particles	*	*	*	*	
texture	*	*			
particle size	*	*	*	*	
density, porosity, hydraulic conductivity	*	*			
strength and deformation	*				
Properties that can be determined					
boundaries of strata – coarse definition	*	*	*	*	*
boundaries of strata- fine definition	*	*	*	*	
weathering	*	*	*		
discontinuity description	*	*	*		
discontinuity properties	*	*			
overall fracture state (including RQD)	*	*			
atterberg limits, particle density, organic content	*	*	*	*	
water content	*	*	*		
sensity, porosity, hydraulic conductivity	*	*			
strength, deformation, stiffness	*				
Sampling categories	A				
		B			
			C		
				D	
					E

(7) Before taking specimens for testing, the quality of recovered samples should be reported in the Ground Investigation Report.

NOTE See Table F.1 for guidance on verifying sample quality for low to medium OCR clays.

(8) Soil samples obtained using Category A samplers (as defined in EN ISO 22475-1) shall be handled to avoid deformation, desaturation, or swelling of samples during transport and storage.

(9) Reconstituted or reconsolidated specimens may be used to determine ground properties.

(10) Reconstituted specimens of coarse soils should have approximately the same composition, bulk mass density, and water content as the in-situ material.

(11) The procedure used to reconstitute soil specimens shall be reported in the Ground Investigation Report.

(12) Planning of laboratory testing shall consider:

- the selection of test samples;
- the conditions of storage before testing;

- maximum allowed time between sampling and laboratory testing;
- whether desiccated samples are to be re-saturated and by which technique;
- the number of tests required per geotechnical unit; and
- whether parallel tests are to be run on the same geotechnical unit.

6 Description and classification of the ground

6.1 General

- (1) Natural exposures, artificial exposures created as part of the investigation and all samples recovered in the investigation shall be inspected and described.
- (2) The description and classification of soils shall comply with EN ISO 14688 (all parts).
- (3) The description and classification of rock and its weathered profile shall comply with EN ISO 14689.

NOTE Particular care is needed in describing the transition between soil and rock at rockhead.

- (4) Rock mass classification systems may be used for placing a rock mass into groups or classes and assigning unique descriptions (or values) on the basis of similar properties or characteristics.
- (5) Rock mass classification systems may be used to determine the rock mass strength parameters in accordance with 8.1.
- (6) Rock mass classification systems may be used to estimate the rock mass stiffness in accordance with 9.1.
- (7) Classification of a site for seismic purposes shall comply with EN 1998-1-1.
- (8) Classification of materials and fill for earthworks should comply with EN 16907-2.
- (9) The classification of materials should be adjusted in accordance with results from different test types and comparable experience.

NOTE Indirect classification or an indication of ground type can be derived from field tests.

- (10) Anisotropy of the ground and corresponding properties should be described.

6.2 Discontinuities and weathered zones

- (1) Potential foliation of rock and of hard soils should be identified.
- (2) Discontinuities and weathered zones shall be defined by geometrical and geotechnical properties.
- (3) Geotechnical properties of discontinuities and weathered zones shall include, but not be limited to, state and physical properties.

NOTE Examples of state and physical properties are apertures, interlocking, infill, thickness, roughness, smoothness, weathering, and alteration.

- (4) State and physical properties affecting strength of the discontinuities and weathered zones shall be defined and described as specified in Clauses 7 and 8.

- (5) Discontinuities may be grouped into sets that have similar dip and strike (or dip direction).
- (6) The presence of groundwater in discontinuities and possible freeze-thaw conditions shall be determined.
- (7) Groundwater pressures in discontinuities should be determined according to Clause 11 and FprEN 1997-1:2024, Clause 6.
- (8) The properties of any infill and hydraulic conductivity in discontinuities and weathered zones shall be determined according to Clauses 7 and 11.

NOTE 1 Typical infill properties of discontinuities are organic matter content, swelling potential and presence of crushed material.

NOTE 2 See E.6 for guidance on determining the Geological Strength Index.

7 State, physical, and chemical properties

7.1 State properties

7.1.1 General

- (1) State properties should be determined according to one or more of the standards given in Table 7.1.

NOTE Table B.5 gives examples of applicable national standards, in the absence of EN and ISO standards.

- (2) State properties should be determined on specimens representing each soil or rock type in the sample.

Table 7.1 — Field and laboratory tests to determine state properties

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Bulk mass density (ρ)	Linear measurement method; immersion in fluid method; fluid displacement method	EN ISO 17892-2	2	Testing method used considering soil type and possible sample disturbance Density of a coarse soil is generally only approximate
	Water absorption coefficient by capillarity	EN 1925	2	-
	Immersion in fluid method; fluid displacement method	EN 1936	2	Determination of real density and apparent density, and of total and open porosity
	Sand replacement method	ISO 11272	-	In situ test
	Loose bulk density and voids	EN 1097-3	3	Suitable for coarse soils and aggregates
	Nuclear gauge	See Note ^a	-	Presence of nuclear source as a hazard
	Electrical density method	See Note ^a	-	-
	Dynamic probing Cone penetration test Flat dilatometer test	EN ISO 22476-2 EN ISO 22476-1 EN ISO 22476-11	-	Use correlations
Water content (w)	Oven drying	EN ISO 17892-1	3	Check storage method of samples Standard oven-drying method. For gypsum, organic soil and soil with closed pores filled with water; precautions are needed Report presence of gypsum, organic soil
	Water content	See Note ^a	2	For rock
	Oven drying in a ventilated oven	EN 1097-5	3	Suitable for aggregates
	Neutron depth probe method	ISO 10573	-	Determination of water content in the unsaturated zone
Porosity	Mercury intrusion porosimetry for soil	See Note ^a	2	Use of mercury in the laboratory depends on local regulation
	Porosity of rock by saturation and caliper	See Note ^a	-	Determination of porosity and density of rock
	Porosity of rock by saturation and buoyancy	See Note ^a	-	Determination of porosity and density of rock

	Water method	EN 1936	3	Determination of real density and apparent density, and of total and open porosity
Saturation		See Note ^a		Determination of saturation is based on water content, bulk mass density and particle density values
Density index	-	EN 14688-2	4	Applicable to coarse soils
	Cone Penetration Test	EN ISO 22476-1	-	Use correlation
	Dynamic Penetration Test	EN ISO 22476-2	-	Use correlation
	Standard Penetration Test	EN ISO 22476-3	-	Use correlation
	Ménard Pressuremeter Test	EN ISO 22476-4	-	Use correlation
	Weight Sounding Test	EN ISO 22476-10	-	Use correlation
	Borehole dynamic probing	EN ISO 22476-14	-	Use correlation
^a There is currently no EN or ISO standard for this test.				

7.1.2 Bulk mass density

- (1) The bulk mass density of soil and rock should be determined according to one or more of the standards given in Table 7.1.
- (2) A distinction shall be made between the bulk mass density of rock in-place and the bulk mass density of excavated or blasted rock.

NOTE A given mass of rock in place can occupy up to 40 % greater volume after excavation or blasting.

- (3) Bulk mass density of soil shall be determined using a specimen prepared from a sample with at least Quality Class 2.
- (4) The evaluation of the test results shall be adjusted for potential specimen disturbance.
- (5) The standard procedure used for such adjustment shall be defined and recorded in the Ground Investigation Report.

NOTE Guidance on evaluation of specimen disturbance is given in F.3

- (6) Additional tests should be performed if test results fall outside the typical range of values, taking into account mineralogy and organic matter content.

7.1.3 Water content

- (1) Water content of soil and rock should be determined according to one or more of the standards given in Table 7.1.
- (2) Water content of soil specimens should be determined according to EN ISO 17892-1.
- (3) The water content of rock material should be determined according to the ISRM suggested method.

NOTE See ISRM (2007), Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-Durability Index Properties.

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- (4) Water content shall be determined using a specimen prepared from a sample with at least Quality Class 3.
- (5) The extent to which the water content measured in the laboratory on a soil sample is representative of the in-situ value should be recorded in the Ground Investigation Report.
- (6) Water content may be determined indirectly using field tests provided the testing, reporting, and interpretation procedures are recorded in the Ground Investigation Report.

NOTE See ASTM D6780/D6780M-12 for the Time Domain Reflectometry technique.

7.1.4 Porosity

- (1) The porosity and pore size distribution of soil samples should be determined according to one or more of the standards given in Table 7.1.
- (2) The porosity of rock samples should be determined according to the appropriate ISRM Suggested Method.

NOTE See ISRM (2007), Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-Durability Index Properties.

7.1.5 Saturation

- (1) The degree of saturation of an unsaturated specimen should be determined according to one of the standards given in Table 7.1.
- (2) When specimens are not fully saturated, suctions present in the specimen shall be measured when relevant for the design situation.

NOTE 1 Further information on the determination of the volume of water is given in EN ISO 17892-1 and of the volume of voids in EN ISO 17892-2 and 17892-3.

NOTE 2 Further information on the determination of the volume of water is given in ASTM D-5298-03.

NOTE 3 Further information on the determination of water suction height in aggregates is given in EN 1097-10.

7.1.6 Density index

- (1) The density index of coarse soils should be determined according to one or more of the standards given in Table 7.1.

NOTE Guidance on determination of density index from field tests is given in E.3.

7.1.7 In-situ stress state

- (1) The in-situ stress state of soils and rock mass should be determined according to one or more of the standards given in Table 7.2.

NOTE Table B.5 give examples of applicable national standards in the absence of EN and ISO standards.

Table 7.2 — Field and laboratory tests to determine in-situ stress parameters

Parameter	Test	Test standard	MQC	Comments on suitability and interpretation
In-situ stress state: horizontal total stress (σ_0 , K_0)	Self-boring pressuremeter	EN ISO 22476-6	-	Expansion test. Specific procedure
	Ménard pressuremeter	EN ISO 22476-4	-	-
	Pre-bored pressuremeter	EN ISO 22476-5	-	Pre-bored expansion test Specific procedure
	Full displacement pressuremeter	EN ISO 22476-8	-	Insertion by full displacement specific procedure is used
	Flat dilatometer	EN ISO 22476-11	-	Insertion by full displacement Choice of correlation depending on soil type
	Total pressure cells	EN ISO 18674-5	-	Insertion by full displacement
At-rest earth pressure coefficient (K_0)	Triaxial test	EN 17892-9	1	Specific procedure and local measurement needed
	Oedometer test	EN 17892-5	1	Specific procedure and local measurement needed
In-situ stress state component	Flat jack	See Note ^a	-	Measured stress component in a rock mass surface
In-situ stress state: minimum/maximum horizontal stresses and orientation/components of the stress tensor	Hydraulic fracturing in a borehole/ hydraulic tests on pre-existing joints	See Note ^a	-	Vertical axis often considered as one principal direction and vertical stress magnitude equals the weight of the overburden
In-situ stress state in rock mass: independent components of the stress tensor	Over-coring in a borehole	See Note ^a	-	Elastic parameters of the rock required
Initial groundwater pressure	Piezometers	EN ISO 18674-4	-	-
Pre-consolidation pressures (σ'_p), over-consolidation ratio (OCR)	Incremental loading oedometer test	EN 17892-5	1	For unsaturated soils, specific procedures are used

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Parameter	Test	Test standard	MQC	Comments on suitability and interpretation
	Constant rate of strain oedometer test	See Note ^a	1	-
	Flat dilatometer test	EN 22476-11	-	Use correlation
^a There is currently no EN or ISO standard for this test.				

(2) In-situ stress state in soils may be assessed by geophysical testing.

(3) Determination of in-situ vertical total stress shall be based on the bulk mass densities of the geotechnical units.

(4) The in-situ stress state of soils may be determined using, results from pressuremeter tests.

NOTE 1 Pressuremeter tests give more reliable measurements of the in-situ stress state of soil than laboratory tests.

NOTE 2 Results from self-boring pressuremeter tests are more reliable than those from displacement and pre-bored pressuremeter, particularly in clayey soils.

(5) The stress in the ground may be determined using tests other than those given in Table 7.2 provided the testing, reporting, and interpretation procedures are recorded in the Ground Investigation Report.

(6) In the absence of reliable test results for soils, the coefficient of earth pressure at rest K_0 may be estimated from Formula (7.1):

$$K_0 = [1 - \sin\varphi'] \cdot OCR^{0.5} \quad (7.1)$$

where

K_0 is the at-rest earth pressure coefficient;

φ' is the effective angle of friction;

OCR is the over-consolidation ratio.

NOTE See Mayne and Kulhawy (1982) for further information.

7.2 Physical properties

7.2.1 Particle size distribution

(1) The particle size distribution of soil shall be determined using particle size analysis.

(2) The particle size distribution of soils should be determined according to one or more of the standards given in Table 7.3.

Table 7.3 — Laboratory tests to determine particle size properties

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Grain size distribution curve Uniformity Coefficient ($C_{U,PSD}$) Coefficient of curvature ($C_{C,PSD}$)	Sieve method	EN ISO 17892-4	4	For particles larger than 0,063 mm (or closest sieve size available)
	Sedimentation method	EN ISO 17892-4	4	For particles smaller than 0,063 mm (or closest sieve size available) Carbonates and organic matter can influence test results
	Laser diffraction	ISO 13320	4	For particle sizes from about 0,000 1 to 3 mm May be extended with modification
	X-Ray gravitational	ISO 13317-3		For particle sizes from about 0,000 5 to 100 mm Influence by the chemical composition of particles.

(3) Tests other than those given in Table 7.3 may be used to measure particle size provided they incorporate detection systems using density measurements or particle counters or they are calibrated against the sieve or sedimentation methods given in Table 7.3.

7.2.2 Consistency (Atterberg) limits

(1) The consistency (liquid and plastic) limits of fine soils should be determined according to one or more of the standards given in Table 7.4.

NOTE Table B.5 gives examples of applicable national standards in the absence of EN and ISO standards.

(2) The shrinkage limit of fine soils should be determined according to one or more of the standards given in Table 7.4.

NOTE The shrinkage limit can be useful for determining swelling behaviour or to evaluate the volume change of soils in unsaturated conditions.

Table 7.4 — Laboratory tests to determine consistency limits

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Plastic limit (w_p) ^b	Thread method	EN ISO 17892-12	4	Organic matter influences test results
Liquid limit (w_L)	Fall cone	EN ISO 17892-12	4	Strongly sensitive to pore fluid salinity for $w_L > 100$ %
	Casagrande method	EN ISO 17892-12	4	Strongly sensitive to pore fluid salinity for $w_L > 100$ % Results may not be reliable for thixotropic soil
Methylene blue value (MBV)	Methylene blue test	EN 933-9 EN 17542-3	4	For fine soils
Shrinkage limit (w_s)	Volumetric or linear method	See Note ^a	2	For fine soils

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- a There is currently no EN or ISO standard for this test.
- b When significant clay content is present in an organic sample, the classification is assisted by plotting a Casagrande diagram complying with ISO 14688-2 and determining soil particle density.

- (3) Consistency limits should be determined using a specimen prepared from a sample with at least Quality Class 4.

7.2.3 Particle density

- (1) Density of solid soil particles should be determined according to EN ISO 17892-3 for soils and EN 1097-6 for aggregates.
- (2) Particle density should be determined using specimens prepared from a sample with at least Quality Class 4.
- (3) The mineralogy of the soil, its organic matter, and its geological origin should be confirmed by further testing if, for a particular geotechnical unit, the measured values of the particle density are outside the range 2,5 to 3,0 Mg/m³.

7.2.4 Maximum and minimum void ratios

- (1) Determination of maximum and minimum void ratios and density at loosest and densest packing of coarse soils should be carried out as specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

NOTE If the values of minimum and maximum void ratios are decisive for the design, a series of methods can be used to map them as the values vary with the applied method.

- (2) If the minimum or maximum void ratios of a coarse soil are not within the range 0,35 to 0,9, the particle size distribution should be checked.
- (3) Maximum and minimum void ratios may be determined indirectly using field tests provided the testing, reporting, and interpretation procedures are recorded in the Ground Investigation Report.

7.2.5 Particle and rock block shape

- (1) Descriptive and quantitative representation of particle shape and morphology shall comply with EN ISO 14688-1 and ISO 9276-6 for coarse and very coarse soils.
- (2) Particle shape should be characterized by three dimensionless ratios: sphericity (cf. eccentricity or plainness), roundness (cf. angularity) and smoothness (cf. roughness).
- (3) Digital image analysis may be used to facilitate the evaluation of mathematical descriptors of particle shape including Fourier analysis, fractal analysis and other hybrid techniques.
- (4) Descriptive and quantitative representation of rock block shape and morphology shall comply with EN ISO 14689.

7.2.6 Rock weathering and alteration, abrasivity, and degradation

- (1) The state of weathering and alteration of rock material and discontinuities shall be investigated and recorded in the Ground Investigation Report.
- (2) Rock weathering and alteration, abrasivity, and degradation should be determined in accordance with one or more of the standards given in Table 7.5.

NOTE Table B.5 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 7.5 — Laboratory tests to determine rock physical properties

Property	Test standard
Weathering and alteration	EN ISO 14689
Abrasivity	See Note ^a
Degradation	EN ISO 14689
^a There is currently no EN or ISO standard for this test.	

7.2.7 Water density

(1) Determination of the density of water samples may be performed.

NOTE 1 There is currently no EN or ISO standard for this test. Table B.5 gives examples of applicable national standards.

NOTE 2 The density of fresh water is typically 1 Mg/m³. The density of sea water is typically 1,02 to 1,03 Mg/m³.

7.2.8 Soil dispersibility, erosion, and rock degradation

(1) The dispersive and erodible characteristics of clayey soil and stability of rock when immersed in water should be identified according to one of the standards given in Table 7.6.

NOTE 1 Usual tests for classifying soil for engineering purposes do not identify the dispersive characteristics of a soil.

NOTE 2 Tests for dispersibility are carried out on clayey soil, primarily in connection with earth embankments, mineral sealings and other geotechnical structures in contact with water.

NOTE 3 Table B.5 give examples of applicable national standards in the absence of EN and ISO standards.

Table 7.6 — Field and laboratory tests to determine stability, dispersibility and erodibility properties

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Stability	Immersion in water	EN ISO 14689	1	Compares the disintegration of a rock specimen in plain water with a conventional description
Dispersibility	Double Hydrometer Test	See Note ^a	4	Compares the dispersion of clay particles in plain water without mechanical stirring with that obtained using a dispersant solution and mechanical stirring Qualitative evaluation
	Crumb Test	See Note ^a	2	Stability of soil aggregates subjected to the action of water Qualitative evaluation
	Pinhole test	See Note ^a	2	Need to consider specifying different compaction conditions for specimens Avoid drying of the specimen before testing Qualitative evaluation of internal erosion
	Chemical	See Note ^a	-	Determination of the exchangeable sodium percentage with respect to the four basic cations Ca, Mg, Na and K all expressed in meg/100gr of dry soil.
Critical stress and erosion coefficient	Hole erosion test	See Note ^a	2	Internal erosion on undisturbed or reconstituted specimens Hydraulic gradient should be specified according to the structure
	Jet erosion test	See Note ^a	2	In-situ or laboratory on small surface Representativeness External erosion

^a There is currently no EN or ISO standard for this test.

(2) The following shall be specified:

- the storage of samples such that their water content is preserved;
- testing procedures to be applied; and
- the specimen preparation method.

(3) Particle size distribution and consistency limits of the sample shall be recorded in the Ground Investigation Report.

(4) Dispersibility and erodibility tests should not be used for soil with clay content of less than 10 % and with a plasticity index less than or equal to 4 %.

(5) For the hole erosion and pinhole test, the compaction conditions of the soil specimens, wet or dry of optimum, and the mixing water (distilled versus reservoir water) should be specified.

- (6) For the double hydrometer test, a third hydrometer test should be specified if it appears necessary to study the effect of reservoir water on the soil in suspension.
- (7) The sensitivity of rocks that contain magnesium or calcium carbonate to dissolution and chemical weathering should be analysed and recorded in the Ground Investigation Report.
- (8) The sensitivity to disintegration of rocks that are liable to break up or crumble away when subject to moisture, heat, frost, air, or internal chemical reaction of the component parts of rocks should be analysed and reported.

7.2.9 Compactibility

- (1) Soil compaction tests (Proctor and vibration tests) shall be used to determine the relationship between dry density and water content for a given compactive effort.

NOTE 1 EN 16907 (all parts) covers the design of earthworks materials, execution, monitoring, and checking of earthworks construction processes to ensure that the completed earth-structure satisfies the geotechnical design.

NOTE 2 The laboratory determination of compaction can miss the macro structure due to scale effects.

- (2) The California Bearing Ratio (CBR) test may be used to evaluate the subgrade strength of roads and pavements.
- (3) The degree of compaction of soils should be determined using one or more of the tests given in Table 7.7.

NOTE Table B.5 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 7.7 — Laboratory tests to determine compaction properties

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Reference density and water content ($\rho_{d,max}$, w_{opt})	Proctor compaction	EN 13286-2	4	Unbound and hydraulically bound mixtures Limited in particle dimension to 20 mm
	Vibrating hammer Vibrating table	EN 13286-4 EN 13286-5	4	Suitable for coarse soils and aggregates
California bearing ratio (CBR) immediate bearing index and linear swelling	CBR test	EN 13286-47	4	Unbound and hydraulically bound mixtures Limited in particle dimension to 20 mm
Fragmentability and degradability	Evolution of particle size distribution after dynamic compaction or humidification drying of soil	See Note ^a	4	for aggregates
^a There is currently no EN or ISO standard for this test.				

(4) Proctor compaction and CBR tests may be combined.

(5) Proctor, modified Proctor, and vibration tests may be used to define the optimal water content to obtain the higher dry density during the compaction process.

(6) Fragmentability and degradability index may be determined to characterize the evolution of gravels during compaction, as specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

7.3 Chemical properties

7.3.1 General

(1) The chemical properties and aggressiveness of the ground and groundwater shall be determined during the ground investigation.

(2) The chemical properties of ground should be determined according to one or more of the standards given in Table 7.8.

NOTE 1 Table B.5 gives examples of applicable national standards in the absence of EN and ISO standards.

NOTE 2 There are other chemical components that can cause an environment to be very aggressive to steel and concrete, for example magnesium and ammonium. The corresponding chemical testing is not covered in this standard.

Table 7.8 — Laboratory tests to determine chemical properties of ground

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Mineralogy	X-Ray diffraction	EN13925-1	3	
	Petrographic description	EN 12407	3	For natural stones
	Simplified petrographic description	EN 932-3	3	For aggregates
	Normal and UV light microscopy	-	3	For μm thin sections of rock specimens
Carbonate content	Loss in dry weight after reaction with hydrochloric acid	See Note ^a	3	-
	Volumetric method	EN ISO 10693	3	
Organic matter content (OMC)	Hydrogen peroxide reagents and dry weight after reaction	ISO 10694	4	Commonly used in geotechnical laboratories
	Determination of loss on ignition	EN 15935	4	Only suitable for estimating organic matter content for peats and organic sands
	Dry combustion	EN 15936 ISO 10694	4	Methods given are combustion or acid dissolution. Test not usually achievable in a geotechnical laboratory
	Chemical analysis	EN 1744-1	4	For aggregates Unsuitable for soil due to high oven temperatures
Sulphate and sulphide content	Determination of sulphide content of rock	ISO 11048 EN196-2 EN1744-1	3	
Hydrogen potential pH	Electrometric methods (acidity and alkalinity)	EN ISO 10390 ISO 4316	3	
Chloride and other salt content	Mohr's method for water-soluble chlorides; Volhard's method for acid-soluble or water-soluble chlorides; electrochemical procedures.	EN 1744-5 EN 1744-1	3	For aggregates; similar test methods are also suitable for soils
Radioactivity	Geiger counter /measurement of radioactivity Gamma emitting radionuclides	ISO 19581	-	For radon content in rock

^a There is currently no EN or ISO standard for this test.

(3) The corrosiveness of steel constructions in ground may be determined according to EN 12501-1.

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- (4) Chemical tests should be used to classify the ground and to assess the detrimental effect of chemicals in the ground and groundwater on concrete, steel, timber, material of other structural elements and on the ground itself.

NOTE The tests are not intended for environmentally related purposes.

- (5) Chemical characterization of water should include, as a minimum, carbonate and carbon dioxide content, sulphate content, pH value, and magnesium content.

- (6) The chemical properties of water should be determined according to one or more of the standards given in Table 7.9.

NOTE Table B.5 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 7.9 — Laboratory tests to determine chemical properties of groundwater

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Carbonate content	-	See Note ^a	-	-
Chloride content	-	EN ISO 10304-1	-	-
Carbon dioxide content	-	EN 13577	-	Aggressive CO ₂ content Total CO ₂ content
Sulphate and sulphide content	-		-	-
Dissolved magnesium content	Flame atomic absorption spectrometry	EN ISO 7980	-	Magnesium content of up to 5 mg/l
Calcium content		EN ISO 7980 EN ISO 14911	-	-
Conductivity	Specific electrical conductivity	EN 27888 ISO 7888	-	-
Dissolved oxygen		EN ISO 25813	-	-
Hydrogen potential (pH)	Electrometric methods (acidity and alkalinity)	EN ISO 10523 EN ISO 9963-1	-	Within the range pH 2 to pH 12 with an ionic strength below $I = 0,3 \text{ mol/kg}$ (conductivity: $\gamma_{25 \text{ °C}} < 2000 \text{ mS/m}$) solvent and in the temperature range 0 °C to 50 °C
^a There is currently no EN or ISO standard for this test.				

- (7) Disturbed soil samples may be used for the chemical tests, provided particle size and water content are representative of in situ conditions (Quality Classes 1 to 3).

7.3.2 Mineralogy

- (1) The mineralogical composition and petrographic description should be determined according to one or more of the standards given in Table 7.8.
- (2) The mineral type should be determined according to one or more of the standards given in Table 7.8.
- (3) Mineralogical identification and description should be carried out on all samples received in the laboratory, regardless of rock homogeneity, as the identification and description constitute the framework for all testing and evaluations.
- (4) The clay content and dominant clay minerals of swelling soils or rock should be determined according to 9.2.4.

7.3.3 Carbonate content

- (1) Carbonate content should be determined according to one or more of the standards given in Table 7.8.
- (2) Carbonate content shall be calculated from the content of carbon dioxide measured on treatment of the soil with HCl to classify natural carbonate ground or as an index to indicate the degree of cementation.

NOTE Measurement of the carbonate content depends on the reaction with hydrochloric acid (HCl) which liberates carbon dioxide. It is usually assumed that the only carbonate present is calcium carbonate (CaCO₃).

- (3) Large samples of soils and rocks with non-homogenous carbonate distribution may be riffled and crushed to provide representative test specimens.
- (4) Alternative test methods should be used in the presence of carbonates that do not dissolve using the standard solution of hydrochloric acid or during the specified time.

7.3.4 Organic matter content

- (1) The organic matter content of soils should be determined according to one or more of the standards given in Table 7.8.
- (2) The organic matter content of organic soil with less than 2 % clay and carbonate content shall be determined from the loss on ignition at a controlled temperature as specified in the relevant standard.
- (3) The organic matter content of organic soils with more than 2 % clay content shall be derived from the loss on ignition at a controlled temperature as low as possible but not less than 480°C.
- (4) The organic matter content as a percentage of original dry matter, also giving the method of determination, shall be recorded in Ground Investigation Report.
- (5) In addition to (4), if the carbonate content is significant the temperature should not exceed 600 °C.

7.3.5 Sulfate and sulphide content

- (1) The sulfate and sulphide content of ground and groundwater shall be determined and classified to allow suitable precautionary measures to be taken to prevent potential detrimental effects on concrete, steel, and timber and potential swelling of the ground.

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- (2) Sulfate content should be determined according to one or more of the standards given in Table 7.8.
- (3) The acid-soluble sulfate content should be reported as the total sulphate content.
- (4) Large samples of heterogeneous ground containing visible crystals of anhydrite or gypsum shall be crushed, mixed, and riffled to provide representative test specimens and the method of preparation shall be selected visually.

7.3.6 Acidity and alkalinity

- (1) The pH value of groundwater and solutions of ground in water shall be determined to assess potential of excess acidity or alkalinity.
- (2) Acidity and alkalinity should be determined according to EN 16502.
- (3) The following shall be specified for each test or group of tests, in addition to the general requirements for chemical testing:
 - whether or not the soil shall be dried; and
 - the water content.
- (4) The pH value of the ground suspensions and groundwater and the test method used shall be recorded in the Ground Investigation Report.
- (5) The evaluation of pH should take into account the potential influence of oxidation.

7.3.7 Radioactivity

- (1) The presence of radioactivity should be determined according to ISO 19581.

7.3.8 Chloride content

- (1) The salinity of ground and groundwater shall be assessed to determine the water-soluble or acid-soluble chloride content.
- (2) The source of the chloride content from sea water or other sources should be determined.
- (3) The following shall be specified for each test or group of tests:
 - whether water-soluble or acid-soluble chlorides shall be determined; and
 - whether or not the soil shall be dried.

7.3.9 Other chemical content

- (1) The presence of ammonium should be determined according to ISO 7150-1.
- (2) The presence of carbon dioxide in water should be determined according to EN 13577.
- (3) The presence of magnesium cation should be determined according to EN ISO 7980.

8 Strength

8.1 Strength envelopes and parameters for soils and rocks

8.1.1 General

- (1) Ground strength may be described in terms of total or effective stress using strength envelopes.
- (2) The applicable stress and strain range of each strength envelope shall be recorded in the Ground Investigation Report.
- (3) The applicable strength condition (peak, critical state, or residual) of each strength envelope shall be recorded in the Ground Investigation Report.
- (4) The stress and strain range of each stress envelope should be selected according to the expected design conditions.

8.1.2 Strength envelopes for saturated soils and rock

- (1) The shear stress at failure τ_f of saturated soils and rock may be determined from the Mohr-Coulomb envelope given in terms of effective stresses from:

$$\tau_f = c' + (\sigma - u) \tan \varphi' \quad (8.1)$$

where

- c' is the effective cohesion;
- σ is the normal total stress on the failure plane;
- u is the groundwater pressure;
- φ' is the effective angle of friction.

NOTE The effective cohesion and the angle of effective friction are mutually dependent parameters and cannot be determined independently.

- (2) In drained strength envelopes describing critical state conditions, effective cohesion shall be assumed to be zero ($c' = 0$).
- (3) As an alternative to (1), for soil and weak rock masses, where soil mechanics concepts are found to apply, the shear stress at failure τ_f may be determined from a Mohr-Coulomb envelope given in terms of total stresses by:

$$\tau_f = \frac{(\sigma_1 - \sigma_3)_f}{2} \quad (8.2)$$

where

σ_1 and σ_3 are the major and minor total principal stresses, respectively.

- (4) Undrained and drained shear strength may be determined from different types of tests considering:
 - the deformation modes applied in the tests;
 - the rates of shearing in the tests; and
 - potential anisotropic ground behaviour.

8.1.3 Strength envelopes for unsaturated soils

- (1) The shear stress at failure τ_f of unsaturated soils may be determined from the Mohr-Coulomb envelope given in terms of effective stresses from:

$$\tau_f = c' + (\sigma - u) \tan \varphi' + (u_a - u) f_1 \quad (8.3)$$

where

c' is the effective cohesion;

σ' is the normal total stress on the failure plane;

u_a is the pore air pressure;

φ' is the effective angle of friction;

u is the pore water pressure;

f_1 is a function defining the relationship between shear strength and soil suction.

NOTE Methods to evaluate the parameters in Formula (8.3) are given in Fredlund (2006).

- (2) Total strength envelopes may be defined for unsaturated conditions with friction angle and cohesion depending directly or indirectly on the degree of saturation.

8.1.4 Strength envelopes for rock material and rock mass

- (1) For both rock material and rock mass, shear strength may be described using the Hoek-Brown strength envelope given by:

$$\sigma_1 = \sigma_3 + \sigma_{ci} \left(m_b \frac{\sigma_3}{\sigma_{ci}} + s \right)^a \quad (8.4)$$

where

σ_1 and σ_3 are the major and minor principal stresses, respectively;

σ_{ci} is the uniaxial compressive strength of the intact rock;

m_b , s , and a are non-dimensional material parameters.

NOTE 1 For intact rock, the values in Formula (8.4) are $a = 0.5$ and $s = 1$.

NOTE 2 For intact rock, m_i replaces m_b in Formula (8.4).

NOTE 3 The value of m_b is determined as given in 8.3.3.

NOTE 4 See Hoek and Brown (2019) for further information.

- (2) As an alternative to (1), the shear strength of rock material and rock mass may be described using a Mohr-Coulomb envelope.
- (3) When the Hoek-Brown strength envelope is approximated by a linear relationship, the procedure used and its applicable stress range shall be recorded in the Ground Investigation Report.

8.1.5 Strength envelopes for rock discontinuities**8.1.5.1 General**

- (1) Determination of the shear strength of discontinuities shall consider whether there is contact at shear between the rock surfaces or not.
- (2) The shear strength of discontinuities shall be determined using effective normal stress.
- (3) Scale effects should be considered.

8.1.5.2 Discontinuities with rock-to-rock surface contact

- (1) The discontinuity roughness shall be considered when assessing the shear strength.
- (2) The shear stress at failure τ_{dis} along discontinuities with rock-to-rock surface contact should be determined, using linear or non-linear strength envelopes, and their applicable normal stress range recorded in the Ground Investigation Report.
- (3) The value of τ_{dis} along discontinuities with rock-to-rock surface contact may be described by the linear Mohr-Coulomb strength envelope given by:

$$\tau_{dis} = c_{dis} + (\sigma_n - u) \tan \varphi_{dis} \quad (8.5)$$

where

- τ_{dis} is the shear stress at failure along a discontinuity;
- σ_n is the normal stress acting on the discontinuity;
- u is the water pressure in the discontinuity;
- c_{dis} is the apparent cohesion of the discontinuity;
- φ_{dis} is the effective angle of friction of the discontinuity.

NOTE 1 The apparent cohesion c_{dis} is the intercept at zero normal stress of the linear Mohr-Coulomb envelope.

NOTE 2 Special care is needed when extrapolating the envelope to low normal stresses to avoid overestimating the strength of the discontinuity.

- (4) The value of τ_{dis} along discontinuities with rock-to-rock surface contact may be described by the non-linear Barton-Bandis strength envelope given by:

$$\tau_{dis} = (\sigma_n - u) \tan \left[JRC \log_{10} \frac{JCS}{(\sigma_n - u)} + \varphi_{dis,r} \right] \quad (8.6)$$

where

- JRC is the joint roughness coefficient;
- JCS is the joint wall compressive strength;
- φ_r is the residual angle of friction of the discontinuity.

NOTE Methods to evaluate the parameters in Formula (8.5) are given in ISRM (2004).

- (5) The Barton-Bandis strength envelope shall only be used for closed discontinuities with rock surface contact.

- (6) When the Barton-Bandis strength envelope is approximated by a linear relationship, the procedure used and its applicable stress range shall be recorded in the Ground Investigation Report.

8.1.5.3 Infilled rock discontinuities without rock-to-rock surface contact

- (1) Aperture and filling shall be considered when determining the shear strength of the discontinuities.
- (2) The value of the shear stress at failure τ_{dis} along infilled rock discontinuities without rock-to-rock surface contact may be described by the Mohr-Coulomb strength envelope using Formula (8.1).

NOTE 1 For infilled discontinuities without rock-to-rock surface contact, cohesion is normally taken as $c' = 0$.

NOTE 2 For infilled discontinuities, the value of φ' is normally taken as the effective angle of friction of the infill or as the angle of interface friction between the infill and the rock surface.

8.1.6 Other strength envelopes

- (1) As an alternative to 8.1.2, 8.1.4, and 8.1.5, other strength envelopes may be used.

NOTE More elaborate descriptions of the effect of intermediate principal stress on shear strength than those provided by Mohr-Coulomb and Hoek-Brown models are sometimes necessary.

- (2) Strength envelopes shall be considered as calculation models and validated according to FprEN 1997-1:2024, 7.1.1.
- (3) If models including implicitly defined strength envelopes are used, it shall be shown that these models reproduce the strength of the material under simple stress conditions relevant for design.

NOTE Simple stress conditions that are typically relevant include triaxial compression, triaxial extension and simple shear.

8.2 Soil strength

8.2.1 Direct determination of soil strength

- (1) The shear strength of soils should be determined directly using one or more of the tests given in Table 8.1.

NOTE Table B.6 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 8.1 — Direct determination of soil strength properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
Peak effective cohesion and friction angle (c'_p, ϕ'_p)	Consolidated triaxial compression	EN ISO 17892-9	1	See 8.2.1 (4) to (10)
	Direct shear	EN ISO 17892-10	1	
	Direct simple shear	See Note ^a	1	
	Borehole shear test	EN 22476-16	-	
Effective friction angle at critical state (ϕ'_{cs})	Consolidated triaxial compression	EN ISO 17892-9	1-4	See 8.2.1 (5) to (9)
	Direct shear	EN ISO 17892-10	1-4	See 8.2.1 (4) to (9)
	Direct simple shear	See Note ^a	1-4	
Residual effective cohesion and friction angle (c'_r, ϕ'_r)	Direct shear	EN ISO 17892-10	1	
	Ring shear	EN ISO 17892-10	1	
Peak shear strength in total stress analysis ($c_{u,p}$)	Unconfined compression test	EN ISO 17892-7	1	See 8.2.1 (4), (8), and (11) In the triaxial tests, compression is undrained
	Unconsolidated undrained triaxial compression	EN ISO 17892-8	1	
	Consolidated triaxial compression	EN ISO 17892-9	1	
	Laboratory vane	See Note ^a	1	
	Field vane	EN ISO 22476-9	-	See 8.2.1 (11)
	Direct simple shear	See Note ^a	1	
Remoulded shear strength in total stress analysis $c_{u,rm}$	Laboratory vane	See Note ^a	1	
	Field vane	EN ISO 22476-9	-	
^a There are currently no EN or ISO standards for this test.				

(2) The shear strength of soils may be determined directly using tests not given in Table 8.1 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

(3) For laboratory tests not listed in Table 8.1, the following shall be specified and reported in a test report:

- specimen preparation method;
- orientation of specimen;

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- type of test;
- classification tests that need to be done;
- consolidation stresses;
- time for consolidation increments;
- criteria applied to end consolidation;
- shearing rate;
- strain at which parameters are determined
- criteria for terminating tests;
- acceptability criteria; and
- accuracy of measurements.

NOTE 1 Examples of acceptability criteria are degree of saturation during test and scatter in results.

NOTE 2 Guidance on test reports is given in FprEN 1997-1:2024, 12.5 and C.6.

- (4) The peak shear strength of clays, silts, and organic soils shall be determined using a specimen prepared from a sample in Quality Class 1.
- (5) The critical state and residual shear strengths of clays, silts, and organic soils may be determined using a reconstituted specimen from a sample in Quality Class 4 or above.
- (6) The shear strength of coarse soils should be determined from a reconstituted specimen from a sample in Quality Class 4 or above.
- (7) If reconstituted specimens are employed to determine shear strength, the method employed for specimen formation as well as the composition and state (stress, density, saturation) of the specimen shall be specified before testing and reported with the test results.
- (8) Specimens should be reconstituted at state conditions close to those existing in-situ.

NOTE Methods of preparing reconstituted specimens are given in EN ISO 17892-9.

- (9) Differences in saturation between specimens at testing and conditions in-situ at appropriate design situations should be taken into account when deriving strength parameters.

NOTE Effective cohesion can arise from fitting a linear envelope to a non-linear response that is also relevant in the field, but it also may arise from specimen conditions not relevant in design, e.g. partial saturation.

- (10) Non-uniform failure modes in triaxial specimens should be avoided when determining critical state shear strength.

NOTE Special procedures (e.g. lubricated end platens) not covered by EN ISO 17892-9 are sometimes needed to avoid non-uniformities in triaxial specimens.

- (11) Dilatancy effects on shear strength should be considered when determining strength parameters.

- (12) Undrained shear strength values derived from any field or laboratory vane test should not be employed in design if partial drainage is suspected during testing.

8.2.2 Indirect determination of soil strength

- (1) The shear strength of soils may be determined indirectly using any of the tests listed in Table 8.2.

Table 8.2 — Indirect determination of soil strength properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
peak effective angle of friction (ϕ'_p)	Cone Penetration Test	EN ISO 22476-1	-	See Annex E for correlations (with I_D) for coarse soils
	Standard Penetration Test	EN ISO 22476-3	-	
	Menard Pressuremeter Test	EN ISO 22476-4	-	-
	Flexible Dilatometer Test	EN ISO 22476-5	-	-
	Flat Dilatometer Test	EN ISO 22476-11	-	-
Angle of friction critical state (ϕ'_{cs})	Consistency limits	EN ISO 17892-12	4	-
Residual shear strength (ϕ'_r)	Consistency limits	EN ISO 17892-12	4	-
Peak cohesion in total stress analyses ($c_{u,p}$)	Cone Penetration Test	EN ISO 22476-1	-	See Annex E for correlations for fine soils
	Standard Penetration Test	EN ISO 22476-3	-	
	Menard Pressuremeter Test	EN ISO 22476-4	-	
	Flexible Dilatometer Test	EN ISO 22476-5	-	
	Flat Dilatometer Test	EN ISO 22476-11	-	-
	Fall cone	EN ISO 17892-6	1	
Remoulded cohesion in total stress analyses $c_{u,rm}$	Cone Penetration Test	EN ISO 22476-1	-	Correlations (with sensitivity) exist for fine soils
	Fall cone	EN ISO 17892-6	-	Indicative method

- (2) The shear strength of soils may be determined indirectly using tests not given in Table 8.2 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

- (3) For tests not listed in Table 8.2, the following shall be specified and recorded in the test report:

- the testing procedure (reference shall be given to the relevant standard, if available);
- the test equipment (reference shall be given to the relevant standard, if available);
- the test results to be employed in interpretation; and

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— an estimate of measurement error.

NOTE Guidance on test reports is given in FprEN 1997-1:2024, 12.5 and C.6.

- (4) All correlations used for indirect determination of shear strength shall comply with 4.2.
- (5) Peak undrained cohesion may be derived from DMT results using the relationship between DMT results and overconsolidation ratio.

NOTE See E.3 for an example relationship.

8.3 Rock strength**8.3.1 Rock material strength**

- (1) Strength parameters for rock material (intact rock) should be determined using one or more of the laboratory tests given in Table 8.3.

NOTE Table B.6 gives examples of applicable national standards in absence the of EN and ISO standards.

Table 8.3 — Determination of rock material strength properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
Uniaxial compressive strength (σ_{ci})	Unconfined compression test (UCT)	See Note ^a	-	See (2)
	Triaxial test (TxT)	See Note ^a	-	See (2)
	Point load test	See Note ^a	-	See (2)
	Schmidt hammer test	See Note ^a	-	See (2)
Parameter (m_i)	Triaxial test (TxT)	See Note ^a	-	See (2)
Tensile strength (σ_t)	Direct tensile tests	See Note ^a	-	See (2)
	Brazilian test (diametral compression test)	See Note ^a	-	See (2)
^a There are currently no EN or ISO standards for this test				

- (2) The effect of specimen size should be taken into account.

NOTE Small specimens normally give less representative results than large ones.

8.3.2 Strength of rock discontinuities

- (1) The properties affecting the strength of the discontinuities shall be recorded in the Ground Investigation Report.

NOTE See 6.2 and FprEN 1997-1:2024, 4.3.3.

- (2) The shear strength of rock discontinuities should be determined using one or more of the laboratory tests given in Table 8.4.

NOTE Table B.6 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 8.4 — Determination of strength properties for rock discontinuities

Property	Test	Standard	MQC	Comments on suitability and interpretation
Peak shear strength along discontinuity ($c'_{\text{dis,p}}, \varphi'_{\text{dis,p}}$)	Direct shear test of rock discontinuities	See Note ^a	-	See 8.1.5 Only derived for a certain range at a particular value of σ_n
	Triaxial test or rock discontinuities (TX)	See Note ^a	-	Only derived for a certain range at a particular value of σ_n
Joint Roughness Coefficient (JRC)	Direct shear test of rock discontinuities	See Note ^a	-	See 8.1.5.2
	Tilt or pull test of rock discontinuities	See Note ^a	-	See 8.1.5.2
Joint-wall Compressive Strength	Schmidt Hammer test	See Note ^a	-	See 8.1.5.2
Residual shear strength of discontinuity (φ_r)	Tilt or pull test of rock discontinuities and Schmidt hammer test	See Note ^a	-	See 8.1.5.2
^a There are currently no EN or ISO standards for this test				

(3) Scale effects should be accounted for when extrapolating the results of laboratory discontinuity strength measurements to larger scales.

(4) Inputs for the strength evaluation of rock discontinuities may be obtained from descriptive procedures given in EN ISO 14689.

8.3.3 Rock mass strength

(1) The strength of the rock mass may be determined using:

- estimation from field investigation and laboratory test results in combination with rock mass characteristics;
- rock mass classifications;
- back-analysis; or
- a combination of the above.

(2) Rock mass strength values should be reduced in the presence of discontinuities unfavourably oriented with respect to the excavation face.

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- (3) Rock mass strength values should be reduced in the case of weathered discontinuity surfaces.
- (4) The strength of rock mass shall be determined accounting for the influence of:
 - rock material strength;
 - rock mass structure;
 - discontinuity geometry;
 - surface conditions of discontinuities;
 - groundwater presence;
 - stress state to which the rock mass will be subject;
 - the scale of project in relation to the scale of rock properties; and
 - type and applicability of investigation methods.
- (5) The strength of a rock mass may be quantified by the following:
 - Hoek-Brown strength parameters;
 - Mohr-Coulomb strength parameters.
- (6) Hoek-Brown and Mohr-Coulomb envelopes for rock mass strength shall be used only for those cases when the limit state is not controlled by discontinuities or other discrete geological features.
- (7) The values of the Hoek-Brown strength parameters for a rock mass (m_b , a , and s) may be determined using empirical formulations that take as inputs the:
 - values of Hoek-Brown strength parameters for the rock material (intact rock); and
 - values obtained from rock mass classification systems.

NOTE See Annex E.6 regarding the use of rock mass classification systems.

- (8) The application of rock mass classification systems shall be in accordance with comparable experience.

8.4 Interface strengths

- (1) The strength of interfaces between the ground and other materials may be determined by suitably adapted laboratory direct or ring shear tests or by field pull-out or direct shear tests.

NOTE Examples of other materials include steel, concrete and plastics.

- (2) When measuring interface strengths, the roughness of the material surface shall be recorded in the Ground Investigation Report.

9 Stiffness, compressibility and consolidation

9.1 Ground stiffness

9.1.1 General

- (1) Ground stiffness should be described by a stress-strain curve over the expected stress and strain ranges for the anticipated design situation.
- (2) Ground stiffness may be approximated by one or more values of elastic moduli, provided each modulus is limited to a particular stress or strain range.

NOTE Guidance is given in Annex F.

- (3) Ground stiffness properties should be determined directly (from test results), according to 9.1.2.

NOTE The effects of cyclic and dynamic actions on ground stiffness are given in Clause 10.

- (4) Tests carried out to measure ground stiffness should follow the anticipated stress path for the relevant design situation.

NOTE Ground zones around a geotechnical structure can follow different stress paths.

- (5) The following factors shall be considered when selecting the test method and the procedure to determine stiffness:

- scale of specimens according to ground mass;
- discontinuity pattern in the ground, especially in rock masses and stiff clays;
- strain level and strain rate compared to the ones expected in the ground;
- in-situ stress state;
- stress history;
- foliation; and
- anisotropy of the ground.

- (6) The loading rate and drainage conditions shall be chosen accordingly when determining undrained or drained moduli.
- (7) Time effects should be determined for swelling (9.2.4), creep (9.2.2), and crushing behaviour of rock mass.
- (8) Techniques based on propagation of shear waves or other dynamic methods may be used to determine the very small strain modulus of ground.
- (9) The stiffness decay curve should be determined using the results from a range of tests including seismic, laboratory, and field investigation tests.

NOTE Guidance is given in Annex F.

- (10) The minimum resolution of the test procedure shall be recorded in the Ground Investigation Report.

FprEN 1997-2:2023.TC250(E)**9.1.2 Direct determination of ground stiffness****9.1.2.1 By field investigation**

(1) Field measurements of stiffness should be obtained using one or more of the tests given in Table 9.1.

NOTE Table B.7 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 9.1 — Direct determination of ground stiffness properties from field investigation

Property	Test	Strain level	Standard	Comments on suitability and interpretation
G_0	Seismic Flat Dilatometer Test (sDMT) Seismic Cone Penetration Test (sCPT) Geophysical seismic tests	$< 5 \times 10^{-6}$	See Note ^a	One-value obtained
G_{PBP}, E_{PBP} E_{FDT}	Prebored Pressuremeter Test (PBP) Flexible Dilatometer Test (FDT)	$> 10^{-4}$	EN ISO 22476-5	Several values / full curve obtained
E_{BJT}	Borehole Jacking Test (BJT)	$> 10^{-4}$	EN ISO 22476-7	Several values obtained
E_{PLT}	Plate Loading Test (PLT) with local measurement	$> 10^{-4}$	See Note ^a	-
	Flexible Plate Loading method		See Note ^a	-
	Plate Loading Test (PLT)	$> 10^{-2}$	See Note ^a	One value obtained
E_{rm}	Radial jacking test ^b	$< 10^{-5}$	See Note ^a	-
	Large flat jack tests ^b	$< 10^{-5}$	See Note ^a	-
G_{SBP}, E_{SBP}	Self-Boring Pressuremeter Test (SBP)	$> 10^{-4}$	EN ISO 22476-6	Full curve obtained
G_M, E_M	Ménard Pressuremeter Test (MPM)	$> 10^{-3}$	EN ISO 22476-4	Several values/full curve obtained
E_{DMT}	Flat Dilatometer Test (DMT)	$> 10^{-2}$	EN ISO 22476-11	One value obtained
E_{FDP}	Full Displacement Pressuremeter Test (FDP)	10^{-2} to 10^{-1}	EN ISO 22476-8	Full curve obtained
-	Drill hole deformation gauges	10^{-2} to 10^{-1}	See Note ^a	Full curve obtained
^a There are currently no EN or ISO standards for this test.				
^b The geophysical seismic tests from which very small strain modulus can be derived are given in 10.4.				

(2) Field measurements of stiffness may be obtained using tests not listed in Table 9.1 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

NOTE Geophysical methods or specific logging techniques not listed in Table 10.2 can also provide information on stiffness parameters: micro-seismic in borehole; full wave sounding in borehole and seismic refraction.

(3) In rock mass, optical or acoustic imaging of borehole walls may be used to determine a suitable test interval.

(4) Rock creep should be determined by using unconfined or triaxial compression tests.

9.1.2.2 By laboratory testing

(1) Laboratory measurements of stiffness should be obtained using one or more of the tests given in Table 9.2.

NOTE Table B.7 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 9.2 — Direct determination of ground stiffness properties from laboratory tests

Property	Test	Strain level	Standard	Comments on suitability and interpretation
G_0	Bender elements (S-wave)	$< 10^{-5}$	See Note ^a	
G_0	Resonant column tests	10^{-5} - 10^{-2}	See Note ^a	Several values/full curve obtained
K_p	P-wave pulsar elements	$< 5 \times 10^{-6}$	EN 14579 EN 14146	
G, G_{cyc}, G_{sec}	Consolidated Undrained Direct Simple Shear Testing (DSS)	10^{-5} - 10^{-2}	See Note ^a	Several values/full curve obtained
G, E	Consolidated triaxial compression tests on water saturated soils (with local strains measurement)	$> 10^{-5}$	EN ISO 17892-9	(Partially applicable) Several value/full curve obtained
	Triaxial tests for rock specimens (with global or local strain measurement)		See Note ^a	-
	Direct shear test for discontinuities (for normal and tangential stiffness)		See Note ^a	
E	Unconfined compression test (UCT) for soil	10^{-5} - 10^{-1}	EN ISO 17892-7 EN 14580	(Partially applicable) Several values obtained
G, E	Unconfined compression test (for rocks)	$> 10^{-1}$	See Note ^a	-
G_{cyc}, E_{cyc}	Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus (CTxT)	$> 10^{-4}$	See Note ^a	Several values/full curve obtained
G_{RC}	Modulus and Damping of Soils by Fixed-Base Resonant Column Devices (RC)	10^{-5} - 10^{-2}	See Note ^a	(Partially applicable) Several values/full curve obtained
E_{OED}	Incremental loading oedometer test (OED)	$> 10^{-2}$	EN ISO 17892-5	Several values obtained
E_{OED}	Constant Rate of strain test (CRS)	10^{-2} to 10^{-1}	See Note ^a	Full curve obtained
G, E	Triaxial tests for rock specimens (with global or local strain measurement)	$> 10^{-2}$	See Note ^a	
G, E	Direct shear test for discontinuities (for normal and tangential stiffness)	$> 10^{-2}$	See Note ^a	
K_s, K_n	Direct shear test for discontinuities (for normal and tangential stiffness)	10^{-2} to 10^{-1}	See Note ^a	-

^a There are currently no EN or ISO standards for this test

(2) The choice of laboratory test shall be consistent with the strain level expected in the anticipated design situations.

- (3) Laboratory measurements of stiffness may be obtained using tests not listed in Table 9.2 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.
- (4) Bulk modulus may be determined by following appropriate stress paths in triaxial tests.
- (5) The Poisson's ratio (ν) of the ground may be determined in uniaxial or triaxial compression tests in the elastic range.
- (6) In the absence of direct measurement, the Poisson's ratio of soil may be assumed to be $\nu = 0,3$ in drained conditions and $\nu_u = 0,5$ in undrained conditions.
- (7) Soil specimen used for laboratory measurement of stiffness shall be obtained from a sample of Quality Class 1.

NOTE 1 Annex F gives indicators of specimen quality that can be used to ensure a minimum quality class.

NOTE 2 Small strain moduli of soil (e.g. moduli at less than 1 % strain for soft to medium clays) are very sensitive to all perturbations during sampling. Specific sampling equipment and methods can be used, for example block sampling or stationary piston sampling or any other method known to give the most accurate results for the soil to be tested.

9.1.3 Indirect determination of ground stiffness

- (1) Stiffness parameters of ground may be determined indirectly from one or more of the tests or procedures given in Table 9.3.

Table 9.3 — Indirect determination of ground stiffness

Property	Test or procedure	Standard	Comments on suitability and interpretation
Shear modulus (G)	Cone Penetration Test	EN ISO 22476-1	Correlations are strain level dependent
	Standard Penetration Test	EN ISO 22476-3	For coarse grained soils only
	Back analysis	FprEN 1997-1:2024, 4.3.2 EN ISO 18674 (all parts)	-
Drained modulus of elasticity (E') and undrained modulus of elasticity (E_u)	Cone Penetration Test	EN ISO 22476-1	Correlations are strain level dependent
	Dynamic Penetration Test	EN ISO 22476-2	-
	Ménard pressuremeter test and Flexible dilatometer test	EN ISO 22476-4 and -5	-
	Back analysis	FprEN 1997-1:2024, 4.3.2 EN ISO 18674 (all parts)	-
Oedometer modulus (E_{OED})	Ménard pressuremeter test and Flexible dilatometer test	EN ISO 22476-4 and -5	
	Flat dilatometer test	EN ISO 22476-11	
	Cone Penetration Test	EN ISO 22476-1	Correlations are strain level dependent
	Standard Penetration Test	EN ISO 22476-3	For coarse grained soils only
	Back analysis	FprEN 1997-1:2024, 4.3.2 EN ISO 18674 (all parts)	-

(2) Indirect measurements of stiffness may be obtained using tests or procedures not listed in Table 9.3 provided that the test procedure and reporting requirements are as specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

(3) Back analysis may be used to determine ground stiffness according to 5.3.4.

9.2 Ground compressibility and consolidation

9.2.1 General

- (1) Ground compressibility should be described by a load-compression curve over the expected stress and strain ranges, including loading-unloading conditions, for the anticipated design situation.
- (2) Ground compressibility should be approximated by one or more compression parameters, each parameter limited to a particular stress or strain range and time period.

NOTE Relevant parameters include the compression index (C_c), recompression index (C_r), coefficient of secondary compression (C_α) and pre-consolidation pressure (σ'_p).

- (3) Compressibility parameters and the coefficient of consolidation (c_v) should be determined directly according to 9.2.2.
- (4) When swelling or viscous (time dependent) behaviour is encountered in the ground, the testing program should be adapted with longer test duration (see 9.2.4).
- (5) Compressibility parameters for soils in an unsaturated state may be determined to evaluate the additional compression upon inundation due to structural collapse of the soil as specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

9.2.2 Direct determination of compression and consolidation properties

- (1) Laboratory measurements of ground compressibility and consolidation parameters should be obtained using one or more of the tests given in Table 9.4.

NOTE 1 Additional loading procedure stages to those reported in the standards listed in Table 9.4 can be used.

NOTE 2 Table B.8 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 9.4 — Direct determination of compression and consolidation properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
Compression index (C_c)	Incremental loading oedometer	EN ISO 17892-5	1	1-dimensional value
	Constant rate of strain	See Note ^a	1	1-dimensional value
	Consolidated triaxial compression on water saturated soils	EN ISO 17892-9	1	Isotropic or anisotropic value
Recompression index (C_r)	Incremental loading oedometer	EN ISO 17892-5	1	For any loading cycle
	Constant rate of strain	See Note ^a	1	Single value
One-dimensional compressibility (m_v)	See Table 9.2 ($m_v = 1/E_{OED}$)			
Pre-consolidation pressure (σ'_p)	Incremental loading oedometer	EN ISO 17892-5	1	1-dimensional value
	Constant rate of strain	See Note ^a	1	1-dimensional value
	Consolidated triaxial compression on water saturated soils	EN ISO 17892-9	1	Isotropic or anisotropic value
	Flat dilatometer test	EN ISO 22476-11	-	
Coefficient of vertical consolidation (c_v)	Incremental loading oedometer	EN ISO 17892-5	1	At any loading or unloading step
	Constant rate of strain (CRS)	See Note ^a	1	At any set of readings
Coefficient of horizontal consolidation (c_h)	Cone Penetration Test (CPTU)	EN ISO 22476-1	-	-
	Radial consolidation test	See Note ^a	1	At any loading or unloading step
	Flexible Dilatometer Test	EN ISO 22476-5	-	-
	Self-boring Pressuremeter Test	EN ISO 22476-6	-	-
	Flat Dilatometer Test	EN ISO 22476-11	-	-
Coefficient of secondary compression (C_α)	Incremental loading oedometer	EN ISO 17892-5	1	Several values
^a There are currently no EN or ISO standards for this test.				

9.2.3 Indirect determination of compression and consolidation properties

- (1) Compression and consolidation properties for soils may be determined indirectly from one or more of the tests given in Table 9.5.

Table 9.5 — Indirect determination of compression and consolidation properties

Property	Test	Standard
Compression index (C_c)	Liquid limit	EN ISO 17892-12
Recompression index (C_r)	Compression index	EN ISO 17892-5
Coefficient of consolidation (c_v)	Liquid limit	EN ISO 17892-12
Coefficient of secondary compression (C_α)	Compression index	EN ISO 17892-5

- (2) Indirect measurements of ground compression or recompression parameters may be obtained using tests not listed in Table 9.5 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.
- (3) The formula used to obtain the ground compression or consolidation parameters shall be recorded in the Ground Investigation Report, together with all parameters used.

9.2.4 Swelling properties

- (1) Swelling parameters of ground should be determined directly from one or more of the tests given in Table 9.6.

NOTE Table B.8 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 9.6 — Direct determination of swelling properties from laboratory tests

Property	Test	Test standard	MQC	Comments on suitability and interpretation
Swelling pressure (σ_g)	One specimen with axial surcharge Huder Amberg method	See Note ^a	1	σ'_{vo} deduced from the Ground Model should be provided
	under zero volume change	See Note ^a	1	Specific to stress path
	Several specimens with axial surcharge	See Note ^a	-	-
Swelling amplitude (ε_g)	Free swelling	See Note ^a	1	Specific to stress path
	Linear swelling	EN 13286-47	-	Unbound and hydraulically bound mixtures
Swelling coefficient (C_g)	Several specimens with axial surcharge; one-Dimensional Swell or Settlement Potential	See Note ^a	1	Pressures should be specified
	Huder Amberg method	See Note ^a		
Swelling index (C_{sw})	Incremental loading oedometer test (unloading)	EN ISO 17892-5	1	Several conventional values
	Constant rate of strain test	See Note ^a		-
^a There are currently no EN or ISO standards for this test.				

- (2) Laboratory measurements of swelling may be obtained using tests not listed in Table 9.6 provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.
- (3) Swelling tests should be performed on specimens taken from undisturbed samples of Quality Class 1.
- (4) Where the sample is too weak or too broken to allow preparation, swelling index tests may be carried out on remoulded and re-compacted specimens provided the procedures used are recorded in the Ground Investigation Report.

10 Cyclic, dynamic, and seismic properties

10.1 General

- (1) Investigations of the mechanical response of ground to cyclic and dynamic action shall provide the relevant information for:
- Design for cyclic and dynamic actions; and
 - seismic design (see EN 1998-1-1 and EN 1998-5).
- (2) Ground investigations should provide relevant information on:
- stress-strain response to cyclic actions, including small strain stiffness;

- energy dissipation properties;
 - development of excess pore water pressures under cyclic actions;
 - shear strength under cyclic actions;
 - post cyclic behaviour in terms of post-cyclic shear strength, dissipation of cyclic-induced pore water pressure, and other associated deformations; and
 - cyclic undrained shear strength for liquefaction assessment (see EN 1998-5).
- (3) The following factors, which affect the measurement of mechanical response of the ground to cyclic and dynamic actions, shall be considered when selecting a test method:
- intrinsic and state properties;
 - size of the specimen;
 - discontinuity pattern in the ground specially in rock masses;
 - strain level compared to the one expected in the ground for the specific design situation;
 - expected cyclic and average stresses for the specific design situation;
 - anisotropy;
 - foliation; and
 - stress history.
- (4) The pre-failure stress-strain response to cyclic actions may be described in terms of variation of the secant elastic modulus and damping ratio versus cyclic shear strain.

10.2 Measurement of cyclic response

- (1) The response to cyclic and dynamic actions should be investigated in the laboratory using one or more of the laboratory tests given in Table 10.1.

NOTE Table B.9 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 10.1 — Laboratory tests for measuring response to cyclic and dynamic actions

	Laboratory test (and associated test standards)					
Test	Cyclic torsional shear	Cyclic direct simple shear	Cyclic triaxial for soil	Resonant column	Bender elements	Cyclic triaxial for rock
Standard	See Note ^a					
Strain level						
Very small ($< 10^{-5}$)	(full)	-	-	full	one	(full)
Small (10^{-5} - 10^{-3})	full	(full)	(full)	(full)	-	full
Medium (10^{-3} - 10^{-1})	-	full	full	-	-	-
- = not applicable; 'one' = one conventional value; 'full' = the full stress-strain curve can be obtained; () = partially applicable						
^a There are currently no EN or ISO standards for these tests.						

- (2) The range of cyclic strains investigated in laboratory test shall be consistent with the strain levels for the anticipated design situation.
- (3) Cyclic shearing shall be initiated from the effective stress state relevant for the design situation.
- (4) The response to cyclic actions should be investigated on specimens obtained from samples of Quality Class 1.
- (5) When undisturbed sampling is not feasible, tests may be performed on reconstituted samples that reproduce the state properties of the in-situ ground.
- (6) The method of preparing reconstituted specimens shall be specified before testing commences and recorded with the test results.

NOTE Methods of preparing reconstituted specimens are given in EN ISO 17892-9.

- (7) Reconstitution of the sample should reproduce the stress history of the soil before application of the cyclic test stresses.
- (8) Specimens of soil to be used as fill shall be reconstituted from bulk or disturbed samples by simulating the anticipated compaction procedure.

10.3 Secant modulus and damping ratio curves

10.3.1 General

- (1) The variation of secant shear modulus and damping ratio against cyclic shear strain should be investigated in laboratory tests.
- (2) The variation of shear modulus versus cyclic shear strain should be normalized by the value of shear modulus at very small strains ($\gamma < 10^{-5}$) as measured during the test.
- (3) In the absence of suitable laboratory test results the normalised secant shear modulus and the damping ratio curves may be determined indirectly using empirical relationships that take into account physical parameters and soil classification indices.

NOTE Examples of indirect methods are given in Annex G.

(4) The indirect methods should take explicit account of the influence of:

- grain size distribution;
- plasticity index;
- in-situ state of stress;
- density index for coarse soils or void ratio for fine soils;
- over-consolidation ratio; and
- number of equivalent cycles.

10.3.2 Measured values

- (1) The measurements shall cover the relevant stress or strain regime anticipated for the design situation.
- (2) The degradation of soil response over repeated cycles should be quantified in cyclic tests by assessing the degradation of the normalized shear modulus and the increase of damping ratio as a function of the number of applied cycles.

10.4 Very small strain moduli and wave velocities

10.4.1 General

- (1) The very small strain shear modulus G_0 may be estimated using laboratory and in situ geophysical measurements of the velocity of propagation of shear waves using Formula (10.1):

NOTE See also prEN 1998-5:2021, 6.4.

$$G_0 = \rho v_s^2 \quad (10.1)$$

where

ρ is the bulk mass density; and

v_s is the shear wave velocity.

- (2) Wave propagation velocities determined on laboratory specimens may be used to assess disturbance of the material with respect to its in-situ state.
- (3) Measurement of vertically and horizontally polarised shear waves may be used to investigate the anisotropy of ground response.

10.4.2 Direct determination of wave velocities

- (1) Shear and compressional wave velocities should be determined directly using any of the geophysical tests given in Table 10.2.

NOTE Table B.10 gives examples of applicable national standards in the absence of EN and ISO standards.

Table 10.2 — Geophysical tests to determine shear and compressional wave velocities

Parameter	Test	Standard
Shear wave velocity (v_s)	Cross-Hole Test	See Note ^a
	Down-Hole Test	See Note ^a
	P-S suspension logging test	-
	Seismic Refraction	See Note ^a
	Seismic Reflection	See Note ^a
	Seismic Cone Penetration Test	-
	Seismic Flat Dilatometer Test	-
	Sonic logging	-
	Ultrasonic pulse velocity test	-
	Ultrasonic Wave Propagation	-
	Surface Wave Methods ^b	-
Compressional wave velocity (v_p)	Cross-Hole Test	See Note ^a
	Down-Hole Test	See Note ^a
	P-S suspension logging test	-
	Seismic Refraction	See Note ^a
	Seismic Reflection	See Note ^a
	Sonic logging	-
	Ultrasonic Wave Propagation	-

^a There are currently no EN or ISO standards for these tests.

^b Surface wave methods include all the geophysical methods which are based on the spectral analysis of the propagation of surface waves (Rayleigh, Love, or Stoneley) such as Ambient Noise Tomography (ANT), Spectral Analysis of Surface Waves (SASW), Multichannel Analysis of Surface Waves (MASW and interferometric variants), Continuous Source Surface Waves (CSSW), Ambient Vibration Analysis (AVA), H/V Microzonation and Refraction Microtremor (ReMi).

- (2) Other geophysical methods may be used provided that they guarantee an adequate spatial resolution and accuracy with respect to the design situation and that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.
- (3) Cross-hole tests should be used whenever a very high resolution and accuracy is necessary for the specific design situation.
- (4) The interpretation of cross-hole tests should account for critical refraction at the interface between different layers especially when a sequence of thin layers with a marked change of velocity is expected.
- (5) P-S suspension logging should only be used to obtain measurement more than 5 m deep.
- (6) When using surface wave methods or seismic refraction surveys, uncertainties associated with solution non-uniqueness should be quantified.

- (7) The seismic refraction survey shall only be used whenever the stratigraphic conditions ensure that a reduction of velocity with depth is excluded.

NOTE In situ velocity and stiffness contrasts can be used for the detection and characterisation of thin layers (less than a few metres) at large depth (more than 20 m).

10.4.3 Indirect determination of shear wave velocity

- (1) The shear wave velocity may be determined indirectly using correlations with any of the tests listed in Table 10.3.

NOTE Example correlations are given in Annex G.

Table 10.3 — Tests for indirect determination of shear wave velocity

Parameter	Test	Test Standard
Shear wave velocity (v_s)	Cone Penetration Test	EN ISO 22476-1
	Standard Penetration Test	EN ISO 22476-3
	Ménard Pressuremeter Test	EN ISO 22476-4
	Flexible Dilatometer Test	EN ISO 22476-8
	Pre-bored Pressuremeter Test	EN ISO 22476-5
	Self-Boring Pressuremeter Test	EN ISO 22476-6
	Flat Dilatometer Test	EN ISO 22476-11

- (2) Indirect determination using tests other than those listed in Table 10.3 may be used provided that the test procedure and reporting requirements have been specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

- (3) Correlations used for the indirect derivation of the shear wave velocity shall comply with 4.2.

- (4) Correlations used for standard and cone penetration tests (SPTs and CPTs) shall include the influence of:

- type of soil or grain size distribution; and
- in-situ state of stress or depth at which the measurement is taken.

- (5) Correlations used for SPTs and CPTs should also include the influence of the geological history of the soil deposit (age, stress history, and diagenesis).

NOTE The uncertainty in the estimate of shear wave velocity is usually evaluated taking into account the uncertainty associated with the measured value in the test and random error and bias inherent in the correlation used.

10.5 Excess pore water pressure

- (1) The development of excess pore water pressure during cyclic loading should be investigated in the laboratory, according to 10.2 using any of the following tests:

- Cyclic Torsional Shear Test (CTS); or
- Cyclic Direct Simple Shear Test (CDSS); or

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- Cyclic Triaxial Test (CTxT).
- (2) In absence of suitable laboratory tests results, the excess pore water pressure may be determined indirectly by empirical correlations.
- (3) Empirical correlations used to determine excess pore water pressure shall account for:
 - type of material;
 - plasticity index and over-consolidation ratio for clays or the density index for sands;
 - effective confining pressure;
 - expected level of shear strains in the soil; and
 - expected number of equivalent cycles.

10.6 Cyclic undrained shear strength**10.6.1 General**

- (1) Cyclic undrained shear strength should be expressed as a relationship between the number of cycles required to attain a cyclic strength limit and the corresponding average shear stress and shear stress amplitude.
- (2) Cyclic strength limits shall be associated with either a maximum threshold strain level or an excess pore water pressure equal to the effective stress.
- (3) Threshold strain levels may be defined in terms of accumulated average shear strains (permanent) or cyclic shear strain.
- (4) The cyclic undrained shear strength should be determined using medium strain level cyclic tests given in Table 10.1.
- (5) Potential effects of the load frequency should be considered when selecting the testing frequency and interpreting the results.

10.6.2 Cyclic undrained shear strength of coarse soils

- (1) For assessing the response of foundations subject to cyclic actions, the effects of installation and preloading should be taken into account by applying appropriate static or cyclic preloading sequences.

NOTE As an example, installation effects for a driven pile may be simulated by DSS interface shear tests.

- (2) Cyclic tests for testing the cyclic undrained shear strength shall be conducted in undrained conditions.
- (3) Each cyclic test should be defined by a value of the average (permanent) shear stress, a cyclic shear stress amplitude and shear stress frequency.
- (4) The cyclic test program should include a sufficient number of tests to reproduce the full response of the soil under cyclic loading.

NOTE Depending on the nature of the cyclic event and of the stress paths in the ground, both one-way and two-way cyclic tests can be necessary.

- (5) Empirical correlations based on the results from field tests may be used, for Geotechnical Category 1 structures and when cyclic liquefaction cannot be determined by laboratory tests.

NOTE Correlations are given in prEN 1998-5:2021, 7.3.3

- (6) Empirical correlations based on results from field tests shall comply with 4.2 and account for effective confining pressure and fines content.

10.6.3 Cyclic undrained shear strength for fine soils

- (1) The potential degradation of the cyclic undrained shear strength during cyclic loading should be investigated with cyclic laboratory tests on specimens obtained from samples of Quality Class 1.
- (2) The influence of the strain rate should be investigated.
- (3) The potential increase of cyclic undrained shear strength with rate of loading may be taken into account on the basis of laboratory data.
- (4) In total stress analysis, for assessing the response of foundations subject to cyclic loading, the effects of installation and preloading on the undrained shear strength should be taken into account by applying appropriate static or cyclic preloading sequences.
- (5) The mode of deformation imposed during the test should reproduce the expected cyclic loading conditions, either in compression, extension, or simple shear.
- (6) Each cyclic test should be defined by a value of the average shear stress, shear stress frequency and a cyclic shear stress amplitude.

NOTE Excess pore pressure criteria cannot be applied to fine soils because excess pore pressures are not homogeneous within the sample.

- (7) The cyclic test program should include a sufficient number of tests to reproduce the full response of the soil under cyclic loading.

NOTE Depending on the nature of the cyclic event and of the stress paths in the ground, both one-way and two-way cyclic tests can be relevant.

- (8) The value of cyclic undrained shear strength derived from monotonic conditions may be used for dynamic or cyclic analyses when shear strength degradation due to the number of cycles and shear strength increase due to rate of loading compensate each other.

10.6.4 Cyclic shear strength on discontinuities

- (1) Laboratory cyclic direct shear tests should be carried out on natural discontinuities to estimate the shear strength decrease.

10.7 Additional parameters for seismic site response evaluation

10.7.1 Depth to seismic bedrock

- (1) The position of the seismic bedrock should be determined with the geophysical tests given in 10.4.2 for the measurement of shear wave velocity profile.

- (2) Tests for the indirect determination of the shear wave velocity may be used to evaluate the position of the seismic bedrock if they are accompanied by a direct inspection of ground samples retrieved from the bedrock layer.
- (3) The position of the seismic bedrock may be determined from the measurement of compressional wave velocity, with a seismic refraction survey or a seismic reflection survey, if a suitable contrast in compressional wave velocity is observed between the bedrock and the overburden soil.

10.7.2 Fundamental frequency of soil deposits

- (1) When used as an additional parameter for site categorization according to EN 1998-1-1, the fundamental frequency of soil deposits may be determined directly from a single-station horizontal-to-vertical spectral ratio survey, accounting for uncertainties and limitations of the method.

11 Groundwater and geohydraulic properties

11.1 General

- (1) Geohydraulic measurements and testing should comply with EN ISO 18674-4, EN ISO 22282 (all parts) and EN ISO 17892-11.
- (2) The evaluation of geohydraulic measurements shall consider the influence of:
 - geological and geotechnical conditions of the site;
 - accuracy of individual measurements;
 - natural fluctuations of pore and joint water pressures with time;
 - duration of the observation period;
 - frequency of readings;
 - nearby surface water;
 - the density and temperature of groundwater; and
 - climate and hydrological conditions.
- (3) The level of surface water within the zone of influence should be recorded during the period of groundwater measurements.
- (4) Measurement of the fluctuations in groundwater pressure should also be made outside the zone of influence.

11.2 Groundwater pressure and pressure head

11.2.1 General

- (1) Groundwater pressure should be determined according to EN ISO 18674-4.
- (2) The selection of equipment for piezometric measurements and for design of observation wells shall be based on the:
 - method of installation;

- anticipated hydraulic conductivity of the ground;
- purpose of the measurements;
- required observation period;
- expected groundwater fluctuations; and
- required accuracy.

(3) In aquicludes and ground with low hydraulic conductivity, measurements should be made using a closed system.

NOTE 1 Ground with low hydraulic conductivity includes, for example, fine soils and lightly jointed rock mass.

NOTE 2 For guidance on selection of open or closed system, see EN ISO 22282-1

(4) The number and frequency of readings and the length of the measuring period shall be planned according to the purpose of the measurements and the period needed for groundwater pressures to come into equilibrium.

(5) The piezometric level $h_{w,z}$ at an elevation z may be determined from:

$$h_{w,z} = \frac{u}{\gamma_w} + z \quad (11.1)$$

where

u is the groundwater pressure;

γ_w is the weight density of pore water;

u/γ_w is the pressure head;

z is the elevation where u is measured (positive upwards).

(6) The weight density of groundwater should be measured according to 7.2.7.

(7) In the absence of a measured value, the weight density of fresh groundwater may be assumed to be 10 kN/m³.

NOTE The weight density of groundwater depends on its mineral content, salinity, and temperature.

(8) The response time of the measuring system should be less than the anticipated rate of variation of the groundwater pressure.

(9) When the rate of variation is high, continuous recording systems should be used.

NOTE Continuous recording includes the use of transducers and data loggers.

(10) The reading interval should be adjusted after an initial period to account for the measured variations of the readings.

11.2.2 Test results

(1) Correction due to atmospheric pressure shall be made when deriving the pressure head from measurements with a pressure probe.

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- (2) To assess groundwater pressure fluctuations, measurements should be taken at intervals appropriate to the frequency of the fluctuations.
- (3) Measurements should be performed through at least two cycles of long-term variation in groundwater pressure.
- (4) The water level in wells, the occurrence of springs, and artesian groundwater shall be recorded in the Ground Investigation Report.
- (5) At seaside and offshore locations, the tidal water level shall be recorded in the Ground Investigation Report.
- (6) The accuracy of measurements shall be evaluated, based upon the method of reading, the system components, and the uncertainty in the water density.

11.2.3 Direct determination**11.2.3.1 Open systems**

- (1) Installation, measurements, and monitoring in open standpipes should comply with EN ISO 18674-4 and EN ISO 22282 (all parts).
- (2) Open standpipes installed in pre-drilled boreholes should be sealed off from layers above and below their filters.

11.2.3.2 Closed system

- (1) In closed systems tests installation, measurements and monitoring should comply with EN ISO 18674-4.

11.2.3.3 Cone penetration tests with pore water pressure measurement

- (1) Cone penetration tests with pore water pressure measurement should comply with EN ISO 22476-1.

NOTE Cone penetration tests with pore water pressure measurement are also known as piezocone tests.

- (2) Measurements in a geotechnical unit during sounding should be performed over a length longer than 2 m.

NOTE Derivation of pressure head over a length shorter than 2 m is only indicative.

- (3) Measurements may also be made by pausing the sounding and allowing equilibration.
- (4) For equilibration, it shall be verified that the hydraulic response is drained and the pore water pressure hydrostatic over the measured length.
- (5) During soundings, the pressure head in a geotechnical unit may be evaluated assuming a hydrostatic pressure gradient of 10 kPa/m.

NOTE A more accurate method is a cone penetration test with pore water pressure measuring, see EN ISO 22476-1.

- (6) Derived values should be reported together with the depth over which the hydrostatic pore water pressure is recorded.

11.3 Geohydraulic properties

11.3.1 General

- (1) Hydraulic conductivity should be determined according to EN ISO 22282 (all parts).
- (2) The following items shall be considered when determining the hydraulic conductivity of a geotechnical unit through field tests in boreholes or laboratory testing:
 - preferred test type for conductivity determination;
 - orientation of the test and the specimen;
 - evaluation of the representativeness of a soil specimen for a geotechnical unit, considering heterogeneities and changes in soil-structure during sampling;
 - anisotropy; and
 - the need for additional classification tests.

NOTE Further information on the procedure for, presentation of, and determination of hydraulic conductivity can be found in EN ISO 17892-11.

- (3) The following shall be specified for deriving hydraulic conductivity in the laboratory, depending on the conditions where the test results will be used:
 - in fine and organic soil:
 - stress conditions under which the specimen is to be tested;
 - criteria for achieving and maintaining the steady-state flow condition;
 - direction of flow through the specimen;
 - hydraulic gradient and the need for back pressure, under which the specimen is to be tested;
 - required degree of saturation; and
 - chemistry of percolating water;
 - in coarse soil:
 - density index to which the specimen is to be prepared;
 - hydraulic gradient under which the specimen is to be tested;
 - direction of flow;
 - need for back pressure; and
 - required degree of saturation.
- (4) The relationship between transmissivity (T), hydraulic conductivity (K), and absolute permeability (k) should be determined from:

$$T = KL = kL \frac{\gamma}{\eta} \quad (11.2)$$

$$K = \frac{T}{L} = k \frac{\gamma}{\eta} \quad (11.3)$$

$$k = \frac{T \eta}{L \gamma} = K \frac{\eta}{\gamma} \quad (11.4)$$

where

L length of test section in borehole;

η dynamic viscosity of the fluid; and

γ weight density of the fluid.

(5) The weight density of groundwater should be measured according to 7.2.6.

11.3.2 Test results

- (1) When deriving the hydraulic conductivity from test results, it shall be verified that the flow is laminar and obeys Darcy's law.
- (2) The determination of hydraulic conductivity should take into account:
 - extent to which the boundary conditions (degree of saturation, the direction of flow, hydraulic gradient, stress conditions, density and layering, side leakage and head loss in filter and tubing) affect the test results;
 - effect of scale (field tests and specimen size vs the size of geotechnical unit); and
 - how well these conditions match the situation in the field, especially temperature and dynamic viscosity.

11.3.3 Applicability

- (1) The specimens used for laboratory hydraulic conductivity tests on fine or organic soil should be taken from samples in Quality Class 1.
- (2) The specimens used for laboratory hydraulic conductivity tests on coarse soils may be taken from samples in Quality Class 2 or higher or reconstituted soil.

11.3.4 Direct determination of hydraulic conductivity

11.3.4.1 Hydraulic conductivity tests by constant and falling head

- (1) Hydraulic conductivity by constant and falling head tests in the laboratory should be determined according to EN ISO 17892-11.

11.3.4.2 Hydraulic conductivity tests in a borehole using open systems

- (1) Determination of hydraulic conductivity in a borehole using open systems should be determined according to EN ISO 22282-2.

11.3.4.3 Water pressure tests in rock mass

- (1) Field water pressure test should comply with EN ISO 22282-3.

NOTE 1 Lugeon water tests are a variant of water pressure test often used in rock engineering.

NOTE 2 The Lugeon unit of permeability equals 1 litre of water taken per metre of test length, per minute, at 10 bars pressure (see EN ISO 22282-3).

11.3.4.4 Pumping tests

- (1) Field pumping tests should comply with EN ISO 22282-4.

11.3.4.5 Infiltrometer tests

- (1) Field ring infiltrometer tests should comply with EN ISO 22282-5.

11.3.4.6 Hydraulic conductivity tests in a borehole using closed systems

- (1) Hydraulic conductivity in a borehole using closed systems should be determined according to EN ISO 22282-6.

11.3.5 Indirect determination of hydraulic conductivity

- (1) Indirect determination of hydraulic conductivity using cone penetration tests with pore water pressure dissipation should be according to EN ISO 22476-1.
- (2) The accuracy of the test results should be evaluated depending on the cone used according to EN ISO 22476-1.
- (3) Dissipation test results shall be reported together with the results of CPTU soundings.
- (4) For coarse and very coarse soils, derivation of hydraulic conductivity may be based on the grain size distribution and density index.
- (5) For fine soils, derivation of hydraulic conductivity may be based on the overall content of fines.

12 Thermal properties of the ground

12.1 General

- (1) The method to be used for measurements of geothermal properties shall be selected according to:
 - the type and expected thermal conductivity of the ground;
 - the purpose of the measurements;
 - the required observation period;
 - the expected temperature fluctuations; and
 - the response time of the equipment and ground.
- (2) The determination of geothermal properties shall consider the influence of:
 - geological, hydrogeological and geotechnical conditions of the site;
 - the source, duration and extent of thermal loading affecting the ground

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- accuracy of individual measurements;
 - initial and anticipated natural variation of temperature in the tested volume;
 - natural fluctuations of pore water pressures with time;
 - chemistry of groundwater;
 - permeability and groundwater flow;
 - duration of the observation period;
 - season of measurements; and
 - climatic conditions during and before the testing.
- (3) Thermal expansion and contraction should be considered when determining the strength and stiffness properties of ground that is sensitive to thermomechanical changes.

12.2 Frost susceptibility

- (1) The susceptibility of a soil to frost heave may be determined directly from laboratory tests on natural, recompacted and reconsolidated, specimens or on reconstituted specimens.
- (2) As an alternative to (1), susceptibility to frost heave may be determined indirectly from correlation with soil classification properties (particle size distribution, the height of capillary rise, or fines content).

NOTE 1 The height of capillary rise is defined in EN 1097-10.

NOTE 2 The frost susceptibility of soil materials plays an essential role in the design of foundations placed above the freezing front in frost susceptible soil.

NOTE 3 Roads, airport runways, railways, buildings on spread foundations, buried pipelines, dams and other structures can be subject to frost heave due to freezing of a frost-susceptible soil having access to water. Frost-susceptible soil can be used in its natural state or as a constructed base for structures.

- (3) For soil in which (2) does not clearly indicate the absence of frost heave susceptibility, tests in the laboratory should be conducted.

NOTE Examples of soil types indicating the need for laboratory tests in addition to correlations to classification properties include organic soils, peat, saline soils, artificial soils, and coarse soils with a wide range of grain size.

- (4) Frost susceptibility of soil in its natural state should be determined from a specimen taken from intact samples of Quality Class 2 or higher.
- (5) Frost susceptibility of a constructed fill may be determined by frost heave tests carried out on recompacted and reconsolidated specimens or on reconstituted specimens.
- (6) If the risk of thaw weakening is to be tested, a California Bearing Ratio (or equivalent) test should be carried out after subjecting the recompacted or reconstituted specimen to one or more freeze-thaw cycles.

NOTE Interpretation of the results of frost susceptibility tests depends on the type of construction work, rules used in the design, available comparable experience, and potential consequences of frost effects.

12.3 Thermal conductivity

- (1) The determination of thermal conductivity by a Geothermal Response Test in a borehole in ground should use a borehole heat exchanger complying with EN ISO 17628.
- (2) Thermal conductivity may be determined in soil and soft rock by thermal needle probe method according to ASTM D5334.

NOTE 1 ASTM D5334 presents a procedure for determining the thermal conductivity of soil and soft rock using a transient heat method.

NOTE 2 ASTM D5334 is applicable for both intact and reconstituted soil specimens and soft rock specimens and only suitable for homogeneous materials.

12.4 Heat capacity

- (1) The specific heat capacity of the ground may be determined according to ASTM D4611.

NOTE 1 The value of specific heat depends upon chemical or mineralogical composition and temperature.

NOTE 2 The rate of temperature diffusion through a material, thermal diffusivity, is a function of specific heat; therefore, specific heat is an essential property of rock and soil when these materials are used under conditions of unsteady or transient heat flow.

12.5 Thermal diffusivity

- (1) The thermal diffusivity of the ground may be determined according to ASTM D4612, provided the bulk mass density, thermal conductivity, and specific heat are determined under as near identical specimen conditions as possible.

12.6 Thermal linear expansion

- (1) The thermal linear expansion coefficient of rock may be determined using laboratory tests complying with ASTM D4535.

12.7 Direct determination of geothermal properties

- (1) Geothermal properties should be determined by any of the methods given in Table 12.1.

NOTE Table B.11 give examples of applicable national standards in the absence of EN and ISO standards.

Table 12.1 — Direct determination of geothermal properties

Property	Method	Standard	Applicable to			Comment
			Soil	Rock	Fluid	
Thermal conductivity	Multi-probe method	See Note ^a	Yes	Yes		Transient field and lab. method
	Single-probe method (needle-probe)		Yes	Yes	Yes	Transient field and lab. method
	Divided-bar method			Yes		Stationary laboratory method
	Transient plane source (TPS)		Yes	Yes	Yes	Transient laboratory method
Thermal diffusivity	Multi-probe method	See Note ^a	Yes	Yes		Transient field and lab. Method
	Single-probe method (needle-probe)		Yes	Yes	Yes	Transient field and lab. Method
	Transient plane source (TPS)		Yes	Yes	Yes	Transient laboratory method
^a There are currently no EN or ISO standards for this test.						

(2) Geothermal properties may be determined by theoretical calculation from the knowledge of rock and soil mineral content, porosity and water content.

13 Reporting

13.1 Ground Investigation Report

(1) The results of a ground investigation shall be compiled in a Ground Investigation Report.

NOTE Guidance on the content of the Ground Investigation Report is given in Annex A.

(2) FprEN 1997-1:2024, Clause 12, shall apply.

Annex A **(informative)**

Ground Investigation Report

A.1 Use of this Informative Annex

- (1) This Informative Annex contains additional provisions to Clause 13 for preparing the Ground Investigation Report.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

A.2 Scope and field of application

- (1) This Informative Annex covers contents of the Ground Investigation Report.

A.3 Contents of the Ground Investigation Report

- (1) The Ground Investigation Report (GIR) should include, but is not limited to, the following information:

1. Project name
2. Proposed structure stage of execution relevant for GIR, scope of investigation
3. Normative references
4. List of information used to plan the ground investigation
5. Geotechnical Category (selection for ground investigation purposes)
6. Site overview
 - a. For land-based projects: topography, existing structures, vegetation, nearby open water
 - b. For near shore projects: current tidal levels and bathymetry
7. Location (coordinates)
8. Desk study
9. Site inspection
10. Geological and hydrogeological studies
11. Geophysical surveys or measurements
12. Field investigations
 - a. Dates of fieldwork

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- b. Names and qualifications of field personnel
- c. Type of equipment
- d. Calibration certificates and documents
- e. List of performed investigations and locations
- f. Environmental conditions during field investigation;
- g. Geodetic position and level of samples and tests performed;
- h. Geodetic position and level of the monitoring probes;
- i. Handling of samples
- j. Main site observations during the investigation

13. Laboratory testing

- a. List of investigations performed and on which samples
- b. Dates tests performed
- c. Names and qualifications of laboratory personnel
- d. Calibration certificates and documents
- e. Main observations during testing (quality, sample content)

14. Groundwater investigations

- a. List of field investigation performed and their locations (short and long term)
- b. Time period of investigation
- c. Names and qualification of field personnel
- d. Calibration certificates and documents
- e. Handling of samples
- f. Main observations during the investigation

15. Presentation and review of monitoring results**16. Back analysis****17. Derived values of ground properties**

- a. State, physical, and chemical properties
- b. Strength properties
- c. Stiffness and compressibility properties

- d. Cyclic, dynamic, and seismic properties
 - e. Groundwater and geohydraulic properties
 - f. Geothermal properties
 - g. Other relevant properties
 - h. Information referred in 4.2 (4)
18. Ground Model (see Clause 4)
19. Review of results
- a. Any limitations, discrepancies, uncertainties, or gaps in the data
 - b. Any deviation from the standard procedures for field and laboratory testing
- (2) Additional information than given in (1) should be included as appropriate:
- a. Significant variations of consistency of the ground (weaker or stronger)
 - b. Apparently anomalous or outlier results for a ground property
 - c. Geometrical irregularities including cavities and zones of discontinuous material
 - d. Important observations from the field and laboratory testing and from the monitoring
- (3) The following should be added to the GIR as referenced reports:
- Field reports;
 - Laboratory test reports;
 - Field investigation and monitoring reports;
 - Desk studies; and
 - Geological and hydrogeological studies.
- (4) The following should be added to the GIR as separate annexes:
- Tabulation and graphical presentation of the field investigation and laboratory test results;
 - Field reconnaissance reports;
 - Evaluated soundings with derived values;
 - Graphical presentations of derived value; and
 - Estimates of the coefficients of variation of ground properties.
- (5) Plans, sections, and profiles with investigation locations should be added to the GIR.

Annex B (informative)

Suitability and applicability of test methods

B.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clauses 4 to 6 for suitable methods of test in investigation.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

B.2 Scope and field of application

- (1) This informative Annex covers identification of the suitability and applicability of test methods given in this document.

B.3 Suitability of test methods

- (1) Specification of the scope of a ground investigation should consider the relationship between the proposed structure, the necessary geotechnical information and the appropriate methods of ground investigation that can be deployed.

NOTE 1 An indication of the suitability of the test methods covered is given in Table B.1.

NOTE 2 Guidance for use of Table B.1 for a proposed geotechnical structure or works (left hand column in top half of table) the ground information needed is identified and ranked in the top row. To obtain the information follow the ground information needed column down to the lower half of the table and thereby identify appropriate methods of investigation (left hand column in lower half of table).

NOTE 3 An illustration is highlighted and arrowed where for spread foundations, information on the disposition and nature of geotechnical units is of High Relevance and, following down, this might be found by, amongst other methods, where Sampling and Laboratory testing is of High Applicability.

Table B.1 — Guidance on appropriate methods of ground investigation

		Ground information needed (FprEN 1997-2 clauses) H = High relevance M = Medium relevance L = Low relevance C= compulsory				5.2.1 Desk Study - history and past uses of site	5.2.2 Site Inspection - ground features and geomorphology	5.2.3 Disposition and nature of geotechnical units	5.2.4 Groundwater conditions	5.2.4 Geohydraulic properties	5.2.5 Geotechnical monitoring	6 Description and classification of ground	7.1 and 7.2 Physical properties	7.3 Chemical properties	8 Strength properties	9 Stiffness properties	10 Cyclic response and seismic properties	11 Groundwater and geohydraulic properties	12 Geothermal properties	Presence of voids (natural or man-made)	Properties of material for reuse	Contaminated ground	Aggressive ground
Proposed structures and engineering works	Structures (prEN 1997-3)	4 Excavations, cuttings	C	C	H	H	H	H	H	H	H	H	H	M	H	M	M	H	L	M	M	L	L
		4 Embankments	C	C	H	H	M	H	H	H	H	H	H	M	H	H	M	H	L	M	M	M	L
		5 Spread foundations ->	C	C	H	H	H	M	H	H	M	H	H	M	H	H	M	H	L	H	L	H	H
		6 Piled foundations	C	C	H	H	H	M	H	H	M	H	H	H	H	H	M	H	M	H	L	H	H
		7 Retaining structures	C	C	H	H	H	H	H	H	H	H	H	H	H	H	M	H	L	M	H	M	M
		8 Anchors	C	C	H	H	M	M	H	H	M	H	H	H	H	H	M	H	L	M	L	M	H
		9 Reinforced fill structures	C	C	H	H	H	M	M	H	M	H	H	H	H	H	M	H	L	M	M	M	H
		10 Ground reinforcing elements	C	C		H	M	M	H	H	M	H	H	H	H	M	M	H		M	L	M	H
		11 Ground improvement	C	C	H	H	M	M	M	H	M	H	H	M	H	M	M	M	L	L	L	M	H
		12 Groundwater control	C	C	H	H	H	H	H	H	M	M	H	M	M	M	M	H	L	H	L	H	M
	Miscellaneous works	Linear - roads	C	C	H	H	M	M	H	H	M	H	H	M	H	H	M	H	L	H	H	H	H
		Linear - pipelines	C	C	H	H	H	M	H	H	M	H	H	H	H	H	M	H	L	M	H	H	H
		Linear – tunnels	C	C	H	H	H	H	H	H	M	H	H	L	H	H	M	H	L	H	H	M	M
		Underground openings	C	C	H	H	H	M	H	H	M	H	H	L	H	H	M	H	L	H	M	M	M
		Dams and barriers	C	C	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	L	M
		Construction materials	C	C	H	H	L	M	H	H	M	H	H	H	H	H	L	H	L	L	H	H	H
		Ground source heat installations	C	C	H	H	H	L	H	H	M	H	H	H	L	L	L	H	H	L	L	M	H

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Ground information needed (FprEN 1997-2 clauses) H = High relevance M = Medium relevance L = Low relevance C= compulsory		5.2.1 Desk Study - history and past uses of site	5.2.2 Site Inspection - ground features and geomorphology	5.2.3 Disposition and nature of geotechnical units	5.2.4 Groundwater conditions	5.2.4 Geohydraulic properties	5.2.5 Geotechnical monitoring	6 Description and classification of ground	7.1 and 7.2 Physical properties	7.3 Chemical properties	8 Strength properties	9 Stiffness properties	10 Cyclic response and seismic properties	11 Groundwater and geohydraulic properties	12 Geothermal properties	Presence of voids (natural or man-made)	Properties of material for reuse	Contaminated ground	Aggressive ground
Appropriate methods of investigation (see 5.3) H = High, M = Medium, L = Low applicability " " = not applicable	Mapping and remote sensing	H	H	M	H	L		M						L		H		M	M
	Probing		M	H	M	L	L	H	L	M	H	H	M	M	L	H	L	M	L
	Boreholes		L	H	H	H	M	H	H	M	M	M	L	H	M	M	M	H	M
	Test pits		M	H	H	M	L	H	H	M	M	L	L	H	L	L	H	H	H
	Geophysical tests		H	H	M	L	L	M	H	L	H	H	H	M	M	H	L	L	L
	Field testing		M	H	H	H	H	M	H	H	H	H	H	H	H	L	M	L	M
	Sampling and laboratory testing. <-		M	H		H	H	H	H	H	H	H	H	H	H		H	H	H
	Description and classification of ground	H	H	H			H	H	H	M	H	M	M	M	M	H	M	H	H
	Groundwater conditions	H	H		H	H	H			M			M	H	H	M		H	H
	Geohydraulic testing				H	H	H						M	H	H	H		H	H
	Geothermal testing														H				
	Monitoring						H								H	M		M	
	Large scale tests of prototypes								H		H	H	M	M			H		
	Back analysis of structures				H				H		H	H	H	M			M		
	Back analysis of slopes				H				H		H	H		H			M		

B.4 Applicability of field investigation and laboratory tests

- (1) Specification of the scope of a ground investigation should consider the applicability of field investigation techniques covered by Clause 5 when planning field investigations, as indicated in 5.4.

NOTE 1 An indication of the applicability of field investigation and laboratory tests covered is given in Table B.2 through Table B.4.

NOTE 2 The confidence levels that appear in this Annex refer only to the confidence derived from the intrinsic characteristics of the tests.

NOTE Guidance on test standards are given in Clause 7 to 12, and B.5

Table B.2 — Simplified overview of the applicability of field investigation tests covered by Clause 5

	Field investigation tests																									
Property	BDP Borehole Dynamic penetration test	BJT Borehole Jack Test	BST Borehole Shear test	CPT/CPTU Cone penetration test	DMT Flat Marchetti dilatometer test	DPT Dynamic Penetration test	Electrical density method	FDP Full displacement pressuremeter	FDT Flexible Dilatometer test	FVT Field Vane Test	ISRM-Flat Jack	ISRM – Geophysical Methods	ISRM – Hydraulic Fracturing	ISRM – Overcoring in borehole	ISRM – Total pressure Cells	Loose bulk density and voids	MPM Ménard Pressuremeter	Nuclear methods	PBP Pre-bored pressuremeter	PLT Plate Loading Test	Sand replacement method	SBP Self-boring pressuremeter	SCPT/SDMT/SPBP Seismic tests	SPT Standard penetration Test	Total Pressure Cells	WST Weight Sounding test
7.1.2 Bulk mass density						C2	FCR 2-3									C2		FCR 2 - 3			C2					
7.1.3 Water content																		FC2								
7.1.6 Density Index	C2			C2		C1											C2							C1		C1
7.1.7 Horizontal stress,					FC3			FC 1-2			R3						FC2		FCR 2-3			FC3			FC3	
7.1.7 Hor stress state / orientation													R2-3													
7.1.7 insitu stress state (stress tensor)														R3												
8.2 (Undrained) strength			CR2	FC3	FC3	C2		FC3		F3							FC3		FCR 3			FC3		C2		
9.1 Oedometer modulus				FC2					FC3								FC3							FC1		

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	Field investigation tests																									
Property	BDP Borehole Dynamic penetration test	BJT Borehole Jack Test	BST Borehole Shear test	CPT/CPTU Cone penetration test	DMT Flat Marchetti dilatometer test	DPT Dynamic Penetration test	Electrical density method	FDP Full displacement pressuremeter	FDT Flexible Dilatometer test	FVT Field Vane Test	ISRM-Flat Jack	ISRM – Geophysical Methods	ISRM – Hydraulic Fracturing	ISRM – Overcoring in borehole	ISRM – Total pressure Cells	Loose bulk density and voids	MPM Ménard Pressuremeter	Nuclear methods	PBP Pre-bored pressuremeter	PLT Plate Loading Test	Sand replacement method	SBP Self-boring pressuremeter	SCPT/SDMT/SPBP Seismic tests	SPT Standard penetration Test	Total Pressure Cells	WST Weight Sounding test
9.1 E-Modulus		R2		FC1	FC3	FC1		FC3	FC3								FC3		FC3	C2		FC3		FC1		
9.1. Shear Modulus				FC2				FC3				R3					FC3		FC3			FC3	FCR3	FC1		
9.2 Horizontal consolidation c_h				F2-3	F2-3				F2-3													F3				
10.4 Shear wave velocity				FC1	FC1			FC1									FC1		FCR1			FC1	FC3	FC1		
— F = Fine Soils, C = Coarse Soils, R = Rock, 1 = Low Confidence/Applicability, 2 = Medium Confidence/Applicability, 3 = High Confidence/Applicability																										

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Table B.3 — Simplified overview of the applicability of laboratory tests covered by Clauses 7 to 10 – part 1

	Laboratory Tests																											
Property	Atterberg - Casagrande	Atterberg - Fall cone	Atterberg - Tread Method	CBR-test	Chemical tests tables 7.8 and 7.9	Crumb test	Double Hydrometer test	Drying in ventilated oven	Hole erosion test	Immersion in water	ISRM – Water content	Jet erosion test	Laser diffraction	Linear measurement	Immersion in fluid	Mercury Intrusion porosity	Methylene blue test	Oven drying at 105 ^o	Pinhole test	Part. Size distribution after compaction	Pactor compactionr	Sedimentation method	Shrinkage Limit	Sieve method	Vibrating Hammer/Table	Water absorption Coefficient by capillary	Water method	X-ray gravitational
7.1.2 Mass bulk density											R2-3			FC3												FC3		
7.1.3 Water content								FC3			R3							FC3										
7.1.4 Macropores porosity																FCR 3											FCR 2-3	
7.2.1 Grain size distribution													FC2									F2-3		C3				FC2
7.2.2 Plastic Limit			F2																									
7.2.2 Liquid Limit	F2	F3																										
7.2.2 Methylene blue value																	F3											
7.2.2 Shrinkage Limit																							F2-3					
7.2.8 Stability										R3																		
7.2.8 Dispersibility						F1	F2												F2									
7.2.8 Critical stress and erosion coefficient									F3			F2																
7.2.9 Ref density and water content																					CF3				CF3			

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	Laboratory Tests																			
Property	Atterberg - Casagrande	Atterberg - Fall cone	Atterberg - Tread Method	CBR-test	Chemical tests tables 7.8 and 7.9	Crumb test	Double Hydrometer test	Drying in ventilated oven	Hole erosion test	Immersion in water	ISRM – Water content	Jet erosion test	Laser diffraction	Linear measurement	Immersion in fluid	Mercury Intrusion porosity	Methylene blue test	Oven drying at 105°	Pinhole test	Part. Size distribution after compaction
7.2.9 CBR				FC 2-3																
7.2.9 Fragmentability and degradability (aggregates)																			C3	
7.3 Chemical properties* ¹					FCR3															
F = Fine Soils, C = Coarse Soils, R = Rock, 1 = Low Applicability, 2 = Medium Applicability, 3 = High Applicability																				
*1 Mineralogy, Carbonate content, Organic content, Sulphate/Sulphide, Acidity and Alkalinity, Chloride, Others																				

Table B.4 — Simplified overview of the applicability of laboratory tests covered by Clauses 7 to 10 – part 2

	Laboratory Tests																								
Property	Atterberg - Casagrande	Atterberg - Fall cone	Atterberg - Tread Method	BE – Bender Element test	P-Wave	CDSS - Cyclic Direct Simple Shear	CTS-Cyclic Torsional Shear	CTX – Cyclic Triaxial Test	Direct shear test	DSS – Direct Simple shear	ISRM- creep characteristics of Rock Methods	ISRM – Huder Amberg method	ISRM - TX – Consolidated triaxial compression test-	ISRM – UCT-Unconfined Compression test	IST – Interface Shear Test	OED CRS Oedometer – CRS	OED – IL Oedometer – incremental	Point Load test	RC – Resonant Column Test	Ring shear test	Schmidt Hammer test	Swelling tests - Other methods – see Table 9.6	TX – Consolidated triaxial compression test	UCT -Unconfined Compression test	UUTX -Unconsolidated Undrained triaxial test
7.1.7 At rest coefficient K0																F3	F3						FC2-3		
7.1.7 Pre-consolidation, OCR																F3	F3								
8.2 Soil Strength	F1	F1	F1						FC2	FC3										FC3			FC3	F2	F2
8.3 Rock Strength													R3	R3				R2			R2				
9.1 Oedometer Modulus																F3	F3								
9.1 Modulus of elasticity					FCR2			FC3					R3	R3	R2								FC3	F3	
9.1 Shear modulus				FC1				FC3		FC3					R3				FC3				FC3		
9.2 Compression, Consolidation and Creep Properties	F1	F1									R3					F3	F3						F3		
9.2.4 Swelling properties												R2-3				F3	F3					F2-3			
10.3 Secant shear modulus and damping ratio curves						FC3	FCR2	FC1											FC3						

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B.5 National standard for investigation and laboratory tests

- (1) In the absence of published EN and ISO standards for field investigation and laboratory testing, national standards may be applied.

NOTE Guidance on available national standards for state, physical and chemical properties is given in Table B.5, for strength properties in Table B.6, for stiffness properties in Table B.7, for compressibility, consolidation and swelling in Table B.8, for response to cyclic and dynamic actions in Table B.9, for shear and compressional wave velocities in Table B.10 and for geothermal properties in Table B.11, unless the National Annex give different references.

Table B.5 — List of national test standards for state, physical and chemical properties

Property	Method	Standard	MQC	Comments on suitability and interpretation
Table 7.1 Field and laboratory test to determine state properties				
Bulk mass density (ρ)	Nuclear gauge	NF P94-061-1 ASTM D6938 - 23	-	Presence of nuclear source as a hazard
	Electrical density method	ASTM D7698-21	-	-
Water density	Water density	ASTM D1429-13	-	
Water content (w)	Water content	ISRM Suggested Methods	2	For rock
Density index	Minimum/maximum density	JIS A 1224:2009		Sand
Porosity	Mercury intrusion porosimetry for soil	ASTM D4404		
	Porosity of rock by saturation and caliper	ISRM Suggested Methods	-	Determination of porosity and density of rock
	Porosity of rock by saturation and buoyancy	ISRM Suggested Methods	-	Determination of porosity and density of rock
Table 7.2 Field and laboratory test to determine in-situ stress parameters				
In-situ stress state component	Flat jack	ISRM suggested method	-	Measured stress component in a rock mass surface
In-situ stress state: minimum/maximum horizontal stresses and orientation/components of the stress tensor	Hydraulic fracturing in a borehole/ hydraulic tests on pre-existing joints	ISRM suggested methods	-	Vertical axis often considered as one principal direction and vertical stress magnitude equals the weight of the overburden
In-situ stress state in rock mass: independent components of the stress tensor	Over coring in a borehole	ISRM suggested methods	-	Elastic parameters of the rock required
Pre-consolidation pressures (σ'_p), over-consolidation ratio (OCR)	Constant rate of strain oedometer test	ASTM D4186/D4186M-20E1	1	-

Property	Method	Standard	MQC	Comments on suitability and interpretation
Table 7.4 Laboratory tests to determine consistency limits				
Shrinkage limit (ws)	Volumetric or linear method	NF P94-060.1 NF P94-060.2 DIN 18122-2 ASTM D427	2	For fine soils
Table 7.5 Laboratory tests to determine rock physical properties				
Weathering and alteration		ISRM suggested method	-	-
Abrasivity		ISRM suggested method NF P94-430-1,2 ASTM D7625-22	-	-
Table 7.6 Field and laboratory tests to determine stability, dispersibility and erodibility properties				
Dispersibility	Double Hydrometer Test	BS 1377-5 ASTM D4221-18	4	Compares the dispersion of clay particles in plain water without mechanical stirring with that obtained using a dispersant solution and mechanical stirring Qualitative evaluation
	Crumb Test	BS 1377-5 ASTM D6572-	2	Stability of soil aggregates subjected to the action of water Qualitative evaluation
	Pinhole test	BS 1377-5 ASTM D4647/D4647M	2	Need to consider specifying different compaction conditions for specimens Avoid drying of the specimen before testing Qualitative evaluation of internal erosion
Critical stress and erosion coefficient	Jet erosion test	ASTM D5852-00	2	In-situ or laboratory on small surface Representativeness External erosion
Table 7.7 Laboratory tests to determine compaction properties				
Fragmentability and degradability	Evolution of particle size distribution after dynamic compaction or humidification drying of soil	NF P94-066 NF P94-067	4	for aggregates
Table 7.8 Laboratory tests to determine chemical properties of ground				
n.a.				
Table 7.9 Laboratory tests to determine chemical properties of groundwater				
Carbonate content	-	ASTM D4373	-	-

Table B.6 — List of national test standards for strength properties

Property	Method	Standard	MQC	Comments on suitability and interpretation
Table 8.1 Direct determination of soil strength properties				
Peak effective cohesion and friction (c'_p, φ'_p)	Direct simple shear	ASTM 6528-17 SS 27127	1	See 8.2.1 (4) to (10)
Angle of friction critical state (φ'_{cs})	Direct simple shear	ASTM 6528-17	1-4	See 8.2.1 (4) to (9)
Peak undrained cohesion ($c_{u,p}$)	Laboratory vane	ASTM D4648	1	
	Direct simple shear	ASTM 6528-17 SS 27127	1	
Remoulded undrained cohesion $c_{u,rm}$	Laboratory vane	ASTM D4648	1	
Table 8.3 Determination of rock material strength properties				
Compressive strength (σ_{ci})	Unconfined compression test (UCT)	ISRM Suggested Methods	-	See 8.3.1 (2) See ISRM (2007a)
	Triaxial test (TX)	ISRM Suggested Methods	-	See 8.3.1 (2) See ISRM (2007b)
	Point load test	ISRM Suggested Methods	-	See 8.3.1 (2)
	Schmidt hammer test	ISRM Suggested Methods	-	See 8.3.1 (2)
Parameter (m_i)	Triaxial test (TX)	ISRM Suggested Methods	-	See 8.3.1 (2) See ISRM (2007b)
Tensile strength (σ_t)	Direct tensile tests	ISRM Suggested Methods	-	See 8.3.1 (2) See ISRM (2007b)
	Point load test	ISRM Suggested Methods	-	See 8.3.1 (2)
Flexural strength (σ_f)	3 and 4-point bend tests for flexural strength	ASTM C880-98	-	See 8.3.1 (2)
Table 8.4 Determination of strength properties for rock discontinuities				
Peak shear strength along discontinuity ($c'_{dis,p}, \varphi'_{dis,p}$)	Direct shear of rock discontinuities	ISRM Suggested Methods	-	See 8.1.5 Only derived for a certain range at a particular value of normal stress
	Triaxial test of rock discontinuities (TX)	ISRM Suggested Methods	-	Only derived for a certain range at a particular value of normal stress
Joint Roughness Coefficient (JRC)	Direct shear of rock discontinuities	ISRM Suggested Methods	-	See 8.1.5.2
	Tilt or pull test of discontinuities	ISRM Suggested Methods	-	See 8.1.5.2
Joint-wall Compressive Strength (JCS)	Schmidt Hammer test	ISRM Suggested Methods		See 8.1.5.2
Residual shear strength along discontinuities ($\varphi_{dis,r}$)	Tilt or pull test of discontinuities and Schmidt Hammer test	ISRM Suggested Methods	-	See 8.1.5.2

Table B.7 — List of national test standards for stiffness

Property	Test	Standard	Comments on suitability and interpretation
Table 9.1 Direct determination of ground stiffness properties from field investigation			
E_{rm}	Rigid Plate Loading	ASTM D4394-17	-
E_{PLT}	Flexible plate loading method	ASTM D4394-17	-
E_{rm}	Radial jacking test	ISRM suggested methods	-
E_{rm}	Large flat jack tests	ISRM suggested methods	-
-	Drill hole deformation gauges	ISRM suggested methods	Full curve-
Table 9.2 Direct determination of ground stiffness properties from laboratory tests			
G_0	Resonant column tests	ASTM D4015-21	Several/full curve
G, G_{cyc}	Consolidated Undrained Direct Simple Shear Testing	ASTM 6528-17	Several/full curve
G, E	Triaxial tests for rock specimens (with global or local strain measurement)	ISRM suggested methods	-
G, E	Direct shear test for discontinuities (for normal and tangential stiffness)	ISRM suggested methods	-
G_{cyc}, E_{cyc}	Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus (CTxT)	ASTM D3999-91	Several/full curve
$G_{0,RC}$	Modulus and Damping of Soils by Fixed-Base Resonant Column Devices (RC)	ASTM D4015-21	Several/full curve
E_{OED}	Constant Rate of strain test (CRS)	ASTM D4186/D4186M-20E1 SS 27126	Full curve
E_{OED}	Modulus of oedometer	NF P94-261	Correlation
G, G_{sec}	Consolidated Undrained Direct Simple Shear Testing (DSS)	ASTM 6528-17	Several/full curve
E	Unconfined compression test (UCT)	ISRM suggested methods	Several
K_s, K_n	Discontinuity shear test	ISRM suggested methods	-
G, G_{sec}	Consolidated Undrained Direct Simple Shear Testing (DSS)	ASTM 6528-17	Several/full curve
G, E	Unconfined Compression Test (for rocks)	ISRM suggested methods	-

Table B.8 — List of national test standards for compressibility, consolidation and swelling

Property	Method	Standard	MQC	Comments on suitability and interpretation
Table 9.4 Direct determination of compression and consolidation properties				
Compression index (C_c)	Constant rate of strain	ASTM D4186 /D4186M-20E1 SS 27126	1	1-dimensional value
Recompression index (C_r)	Constant rate of strain	ASTM D4186 /D4186M-20E1 SS 27126	1	Single value
Pre-consolidation pressure (σ'_p)	Constant rate of strain	ASTM D4186 /D4186M-20E1 SS 27126	1	1-dimensional value
Coefficient of vertical consolidation (c_v)	Constant rate of strain (CRS)	ASTM D4186 /D4186M-20E1 SS 27126	1	At any set of readings
Table 9.6 Direct determination of swelling properties from laboratory tests				
Swelling pressure (σ_g)	One specimen with axial surcharge Huder Amberg method	ISRM suggested methods	n/a	σ'_{vo} deduced from the Ground Model should be provided
	under zero volume change	NF P94-090 UNE 103602 ASTM D4546	1	Specific to stress path
	Several specimens with axial surcharge	NF P94-091	-	-
Swelling amplitude (ε_g)	Free swelling	NF P94-090 UNE 103602	1	Specific to stress path
Swelling coefficient (C_g)	Several specimens with axial surcharge; one-Dimensional Swell or Settlement Potential	NF P94-091 DIN 18135-K BS 1377-5 BS 1377-6 ASTM D2435 and D4546	1	Pressures should be specified
	Huder Amberg method	ISRM suggested methods		
Swelling index (C_{sw})	Constant rate of strain test	ASTM D4186/D4186M-20E1 SS 27126		-

Table B.9 — List of national test standards for response to cyclic and dynamic actions

Table 10.1 Laboratory tests for measuring response to cyclic and dynamic actions						
Test	Cyclic torsional shear	Cyclic direct simple shear	Cyclic triaxial	Resonant column	Bender elements	Cyclic triaxial for rock
Standard	JGS0543	ASTM D8296-19	ASTM D3999 ASTM D5311	ASTM D4015-07	ASTM D8295-19	JGS 2561 JGS 2562

Table B.10 — List of national test standards for determine shear and compressional wave velocities

Parameter	Test	Standard
Table 10.2 Geophysical tests to determine shear and compressional wave velocities		
Shear wave velocity (v_s)	Cross-Hole Test	ASTM D4428/D4428M-14
	Down-Hole Test	ASTM D7400-19
	P-S suspension logging test	-
	Seismic Refraction	ASTM D5777-18
	Seismic Cone Penetration Test	-
	Seismic Flat Dilatometer Test	-
	Surface Wave Methods	-
Compressional wave velocity (v_p)	Cross-Hole Test	ASTM D4428/D4428M-14
	Down-Hole Test	ASTM D7400-19
	P-S suspension logging test	-
	Seismic Refraction	ASTM D5777-18
	Seismic Reflection	ASTM D7128-18

Table B.11 — List of national test standards for determine geothermal properties

Property	Method	Standard	Comments on suitability and interpretation
Table 12.1 Direct determination of geothermal properties			
Thermal conductivity	Multi-probe method	ASTM D5334	Transient field and lab. method
	Single-probe method (needle-probe)	ASTM D5334	Transient field and lab. method
	Divided-bar method	ASTM D5334	Stationary laboratory method
	Transient plane source (TPS)	ASTM D5334	Transient laboratory method
Thermal diffusivity	Multi-probe method	ASTM D4612	Transient field and lab. method
	Single-probe method (needle-probe)	ASTM D4612	Transient field and lab. method
	Transient plane source (TPS)	ASTM D4612	Transient laboratory method

Annex C (informative)

Desk study and site inspection

C.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 5.2 regarding the desk study and site inspection.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this informative annex, it can be used.

C.2 Scope and field of application

- (1) This Informative Annex covers desk studies and site inspection.

C.3 Desk study

- (1) The desk study should comprise factual information supplemented by interpretation to summarize surface, geological, geo-environmental and geotechnical aspects of the site in the formulation of the ground model.
- (2) The successive stages of assessment and investigation should identify potential geotechnical, environmental and health and safety issues that are likely to affect the site, its investigation and its development.
- (3) Sources of information to be consulted should include, when available:
- site details:
 - location (address, coordinates);
 - boundaries;
 - land ownership;
 - present and proposed land use;
 - future structure;
 - site protection and environmental status;
 - topographic maps and site surveys including drainage courses;
 - presence of services and utilities (above and below ground);
 - seismic maps;
 - remotely sensed images; and

- details of site accesses, and other relevant information.
- site history:
 - historical maps, photographs, remotely sensed images;
 - maps and documentary evidence of past site usage;
 - identification of changes in topography and unstable ground;
 - presence of watercourses and potential for flooding;
 - archaeological potential;
 - the presence of and protective designation;
 - historical assets;
 - unexploded ordnance;
 - man-made structures including foundations, infrastructure and mine workings; and
 - potential for anthropogenic contamination or naturally occurring harmful substances given current/past uses of the site and other relevant information.
- site geology:
 - geological, engineering geological, geomorphological, soil and hydrogeological maps and memoirs;
 - reports and other documents including digital data;
 - borehole logs and well records;
 - past ground investigations in the vicinity,
 - past environmental investigations;
 - seismicity; and
 - information on natural voids and anthropogenic cavities.
- previous experience:
 - previous experience in the area;
 - performance of other constructions in the area;
 - properties of similar ground from the site or elsewhere.
- database of geotechnical and geological information:
 - historical maps;
 - archive material of previously constructed structure in the zone of influence; and

- stress fields in use for rock masses (world stress map)

(4) Interpretation of the desk study should include:

- ground-related site constraints;
 - cataloguing of the identified site-specific factors that might affect the ground investigation and development proposals;
- ground-related hazards;
 - list the identified ground hazards (both site- and project-specific) and identify and prioritize proposals for further investigation and subsequent mitigation;
 - ground hazards can be topographic, geological, hydrogeological or man-made;
 - evaluation of the seismicity of the site according to EN 1998 (all parts);
 - assessment of the information for reliability and completeness in terms of identifying possible hazards;
 - possible unexploded ordnance;
 - list of potentially seismic active faults.
- extent of zone-of-influence.

(5) Recommendations for ground investigation should be made and include the following:

- recommendations for the scope of the ground investigation required;
- specific site/project-specific issues identified which require particular investigation; and
- sources of construction materials including water supplies.

C.4 Site inspection

(1) The following information should be collated in preparation for carrying out the site inspection:

- site maps and plans, district maps or charts, geological maps, and remotely sensed data;
- permission to gain access from both owner and occupier;
- listing of items of evidence which are lacking or where local verification is needed on a particular matter;
- information about the local area including excavations, exposures, structures of relevant interest, underground structures; and
- health and safety risk assessment including natural and anthropogenic hazards.

(2) The site inspection should be carried out after factual information about the site and its environs has been compiled (in the desk study) in order to collect additional information on the geology and

hydrogeology, relevant geotechnical conditions, potential construction and access and environmental constraints for ground investigation.

(3) Items to inspect during the site inspection should include:

- geotechnical, geological, and geomorphological conditions;
- indications of ground water;
- ground stability or instability;
- vegetation and changes in vegetation;
- current and former drainage systems;
- openings to underground structures, tunnels or mines;
- indications of excavation and their backfilling;
- the presence of harmful or toxic material in any form;
- the presence and location of previous structures;
- the presence of any designated historical asset or monument;
- any indication of contamination or the presence of potentially harmful soil gases;
- ecological conditions (including protected flora and fauna);
- access routes and storage areas for investigation and construction;
- sources of construction materials including water supply for construction; and
- availability of utilities (water, gas, telecommunications) for investigation and construction.

(4) The site inspection should include activities and observations as follows:

- traverse the whole area, preferably on foot;
- set out the proposed location of work on plans;
- inspect and record details and integrity of existing structures;
- check access, including the probable effects of investigation plant and construction traffic and heavy construction loads on existing roads, bridges and services;
- check and note water levels, direction and rate of flow in rivers, streams and canals, and also flood levels and tidal and other fluctuations, where relevant;
- observe and record:
 - adjacent property and the likelihood of its being affected by proposed works and any activities that might have led to contamination of the site under investigation;

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- mine or quarry workings, old workings, old structures, and any other features that might be relevant;
- any obvious immediate hazards to public health and safety (including to trespassers) or the environment;
- any areas of discoloured soil, polluted water, distressed vegetation or significant odours;
- any evidence of gas production or underground combustion;
- tree types and locations if site underlain by fine soils;
- obstructions; and
- differences and omissions on plans and maps.

NOTE 1 Obstructions can include transmission lines, ancient monuments, trees subject to preservation orders, manhole covers, gas and water pipes, electricity cables and sewers.

NOTE 2 Differences and omissions can include boundaries, buildings, roads and transmission lines.

- observe the ground morphology and associated features to provide information on the geomorphology of the site and surrounding area, including:
 - type and variability of surface conditions;
 - comparison of surface topography with previous maps to check for presence of fill, erosion or cuttings;
 - in mining areas steps in surface, mining subsidence, compression and tensile damage in brickwork, buildings and roads structures out of plumb;
 - mounds and hummocks in more or less flat country which frequently indicate former glacial conditions;
 - mounds and hummocks or depressions which can also indicate historical mining;
 - broken and terraced ground on hill slopes, small steps and inclined tree trunks;
 - crater-like holes in chalk or limestone country;
 - low-lying flat areas in hill country, sites of former lakes and the presence of soft silty soils and peat;
 - details of ground conditions in exposures in quarries, cuttings and escarpments, on-site and nearby;
 - ground water level or surface water levels, positions of wells and springs, any signs of artesian flow;
 - record the vegetation in relation to the soil type and to the wetness of the soil, unusual green patches, or varieties indicating wet ground conditions; and

- study embankments, buildings and other structures in the vicinity having a settlement history, in particular, looking for cracks in walls, subsiding floors, and other structural defects.

(5) The inspection should be enhanced by suitably referenced photographs.

(6) Inspection of the site for ground investigation purposes should include:

- the location and conditions of access to working sites;
- obstructions such as overhead or underground pipes and cables, boundary fences and trenches, trees and other vegetation clearance requirements;
- environmental conditions;
- areas for depot, offices, sample storage, field laboratories;
- ownership of working sites;
- suitable water supply where applicable and record location and estimated flow;
- suitable means of disposing of solids and liquid arising from the investigation;
- particulars of lodgings and local labour;
- particulars of local telephone including mobile phone reception, employment, transport and other services;
- surface conditions at each exploratory location and the particular reinstatement requirements;
- details of post investigation access to instrumentation and any requirements to protect the instrument; and
- mapping of visible geotechnical and geological features.

NOTE 1 Reinstatement requirements include e.g. breaking out pavement and replacement.

NOTE 2 Requirements to protect instruments e.g. fencing.

(7) Rock mass quality, rock mass outcrops, zones of degradation, and discontinuities should be determined during site inspections.

Annex D (informative)

Information to be obtained from ground investigation

D.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 5 for information to be obtained from ground investigation.

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 the information to be obtained from ground investigation.

D.3 Information to be obtained from ground investigation

- (1) The information obtained from the ground investigation should enable assessment of the following aspects for execution:
- the suitability of the site with respect to the proposed execution and the level of acceptable risks;
 - the level and type of uncertainty of the ground investigation results with respect to the proposed execution and the level of acceptable risks;
 - the deformation of the ground caused by the structure or resulting from execution, its spatial distribution and behaviour over time;
 - the safety with respect to limit states, including subsidence, ground heave, uplift, slippage of soil and rock masses, and buckling of piles; and
 - the loads transmitted to the structure from the ground and the extent to which they depend on its design and execution, including:
 - foundation construction methods;
 - sequence of construction works;
 - effects of the structure and its use within the zone of influence;
 - need for and types of ground improvement;
 - any additional structural measures required;
 - potential for seismic ground motion amplification and soil liquefaction;
 - possible densification under dynamic and seismic loads;
 - effects of construction work on the surroundings;

- type and extent of ground contamination on, and in the vicinity of, the site;
 - effectiveness of measures taken to contain or remedy contamination;
 - health and safety risks from natural and anthropogenic hazards; and
 - identification of potentially seismic faults.
- (2) The information obtained from investigation for materials to be used in execution should include assessment of the following:
- suitability for the intended use;
 - extent of deposits;
 - whether it is possible to extract and process the materials, and whether and how unsuitable material can be separated and disposed of;
 - prospective methods to improve the ground;
 - workability of the ground during execution and possible changes in their properties during transport, placement and further treatment;
 - effects of construction traffic and heavy loads on the ground; and
 - prospective methods of dewatering and/or excavation, effects of precipitation, resistance to weathering, and susceptibility to shrinkage, swelling and disintegration.
- (3) Information obtained from investigations of rock mass conditions should be sufficient to determine the following:
- presence of weakness zones, weathered zones, and discontinuities;
 - geometrical properties of any weakness zones, weathered zones or discontinuities;
 - physical properties of any weakness zones, weathered zones or discontinuities;
 - the level of the bedrock, rockhead or transition zone between soil and rock;
 - the in-situ stress conditions;
 - quality, strength, and stiffness properties of the rock mass; and
 - groundwater according (4).
- (4) Information obtained from investigations of groundwater conditions should be sufficient to determine the following:
- depth, thickness, extent and permeability of water-bearing geotechnical units in the ground, and joint systems in the rock mass;
 - elevation of the groundwater surface or piezometric surface of aquifers and their variation over time and actual groundwater levels including possible extreme levels and their periods of recurrence;

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- groundwater pressure distribution; and
- chemical composition and temperature of groundwater.

(5) The information obtained should be sufficient to assess the following:

- scope for and nature of groundwater-lowering work;
- possible harmful effects of the groundwater on excavations or on slopes;
- any measures necessary to protect the structure;
- data to enable the design of soakaways and other infiltration devices;
- effects of groundwater;
- to absorb water injected during construction work;
- whether it is possible to use local groundwater, given its chemical constitution, for construction purposes after lowering, desiccation, impounding etc. on the surroundings; and
- the water storage capacity of the ground.

NOTE 1 Harmful effects of groundwater include e.g. risk of hydraulic failure, excessive seepage pressure, erosion or dissolution.

NOTE 2 Measures to protect the structure include e.g. waterproofing, drainage and measures against aggressive water.

Annex E (informative)

Methods for determining density index and strength properties

E.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 7 for evaluating the density index of soil and to Clause 8 for evaluating the strength properties of soils and rock.

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:

- density index;
- peak effective angle of friction;
- peak undrained cohesion; and
- Geological Strength Index.

NOTE The Formulae in this Annex are provided as examples.

E.3 Density index

- (1) Density index may be determined from the results of field tests using the expressions in Table E.1.

Table E.1 — Correlations to determine density index from results of field tests

Field Test	Standard	Example of correlation	Coefficients
CPT	EN ISO 22476-1	$I_D = \frac{1}{C_2} \cdot \ln \left[\frac{q_c}{C_0 \cdot (\sigma'_m)^{C_1}} \right]$	q_c is measured cone resistance σ'_m is mean effective stress
DPT	EN ISO 22476-2	$I_D = C_1 + C_2 \cdot \log(N)$	N is number of blows to drive the penetrometer over a defined distance
SPT	EN ISO 22476-3	$I_D = \left(\frac{(N_1)_{60}}{C_1} \right)^{0,5}$	$(N_1)_{60}$ is normalized number of blows to drive the penetrometer over a defined distance
PMT	EN ISO 22476-4	$I_D = C_1 (p_{LM})^{C_2}$	p_{LM} is pressuremeter limit pressure of the ground
WST	EN ISO 22476-10	$I_D = C_2 + \left(\frac{N_{WST1}}{C_1} \right)^{0,5}$	N_{WST1} is the number of half rotations per 1 m penetration
BDP	EN ISO 22476-14	$I_D = C_1 + C_2 \cdot \log(N)$	N is number of blows to drive the penetrometer over a defined distance
^a C_0, C_1, C_2 are soil constants that depend on the particular test.			

where

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C_0, C_1 and C_2 are soil constants that depend on the particular test and site specific

q_c is the measured cone resistance in kPa

as per EN ISO 22476-1

σ'_m is the mean effective stress in kPa

N of blows to drive the penetrometer over a defined distance

for DPT as per EN ISO 22476-2

for BDP as per EN ISO 22476-14

p_{LM} is the pressuremeter limit pressure of the ground

as per EN ISO 22476-4

N_{WST1} is the number of half rotations per 1-m penetration

NOTE The data supporting relationships in Table E.1 derive from Baldi et al (1986) for CPT.

E.4 Peak effective angle of friction**E.4.1 From CPT results**

- (1) Provided the conditions given in (2) are satisfied, the angle of peak effective friction (φ'_p in degrees) may be determined from the results of cone penetration tests (CPTs) using:

$$\varphi'_p = \min \left\{ 11 \log_{10} \left(\frac{q_t}{\sqrt{\sigma'_{v0}/p_a}} \right) + 17,6^\circ; 45^\circ \right\} \quad (E.1)$$

where

q_t is the corrected cone resistance as per EN ISO 22476-1 [MPa];

σ'_{v0} is the vertical effective stress at the measurement location;

p_a is atmospheric pressure (approximately 100 kPa).

- (2) Formula (E.1) should only be used if the:

- fine content of the soil is less than 20 %;
- soil D50 is less than 40 mm;
- soil mineralogy is consistent mostly of quartz; and
- vertical effective stress σ'_{v0} is less than 1 MPa.

NOTE 1 The standard error associated with Formula (E.1) is 3,2°.

NOTE 2 The data supporting this relationship derive from triaxial compression tests by Ching et al. 2017.

E.4.2 From SPT results

- (1) Provided the conditions given in (2) are satisfied, the angle of peak effective friction (φ'_p in degrees) may be determined from the results of standard penetration tests (SPTs) using:

$$\varphi'_p = \min \left\{ 22,3^\circ + 3,5 \sqrt{N_{60}/\sqrt{\sigma'_{v0}/p_a}}, 45^\circ \right\} \quad (E.2)$$

where

N_{60} is the energy-normalized SPT blow count as per EN ISO 22476-3;

σ'_{v0} is the vertical effective stress at the measurement location;

p_a is atmospheric pressure.

(2) Formula (E.2) should only be used if the:

- soil is classified as sand according to EN ISO 14688-2;
- fines content of the sand is below 15 %; and
- sand mineralogy comprises mostly quartz.

NOTE 1 The standard error associated with Formula (E.2) is 2,3°.

NOTE 2 The data supporting this relationship derive from triaxial compression tests by Hatanaka and Uchida (1996).

E.4.3 From DMT results

(1) Provided the conditions given in (2) are satisfied, the angle of peak effective friction (φ'_p in degrees) may be determined from the results of dynamic penetration tests (DMTs) using:

$$\varphi'_p = \min \{28^\circ + 14,6 \log_{10} K_D - 2,1(\log_{10} K_D); 45^\circ\} \quad (\text{E.3})$$

where

K_D is the DMT horizontal stress index as per EN ISO 22476-11.

(2) Formula (E.3) should only be used if the soil is classified as sand according to EN ISO 14688-2.

NOTE Formula (E.3) is believed to give conservative estimates of φ'_p .

E.4.4 From density index

(1) In the absence of data indicating otherwise, the angle of peak effective friction (φ'_p in degrees) of coarse soil may be determined from measurements of density index using:

$$\varphi'_p = \varphi'_{cs} + m(I_D[Q - \ln p'] - 1) \quad (\text{E.4})$$

where

φ'_{cs} is the critical state angle of friction;

m is a coefficient that depends on the relevant shear mode to failure ($m = 5$ in plane strain and $m = 3$ in triaxial compression);

I_D is the density index of the coarse soil (see 7.1.6);

Q is a coefficient that depends on the crushability of the material;

p' is the mean principal effective stress at failure [kPa].

NOTE 1 For quartz and feldspar grains, $Q = 10$. For carbonate grains, $Q = 7$.

NOTE 2 The critical state angle of friction can be evaluated by testing or inferred from particle size, particle shape, and nature.

NOTE 3 The data supporting this relationship is given by Bolton (1986).

E.5 Peak shear stress in total stress analyses

E.5.1 From plasticity and pre-consolidation pressure

- (1) Provided the conditions given in (2) are satisfied, the peak undrained cohesion ($c_{u,p}$) of a clay may be determined from its plasticity index and pre-consolidation pressure using:

$$c_{u,p} = (0,11 + 0,0037 \times I_p) \sigma'_p \quad (\text{E.5})$$

where

σ'_p pre-consolidation pressure;

I_p is the plasticity index of the clay.

- (2) Formula (E.5) should only be used if the:

- soil is classified as clay according to EN ISO 14688-2;
- soil is not silt-dominated or formed by diatomite; and
- clay organic matter content is below 2 %.

NOTE 1 The bias in the measurement/prediction ratio for Formula (E.5) is 0,97, with a coefficient of variation of 0,35.

NOTE 2 The data supporting this relationship derive from field vane measurements by D'Ignazio, et al. (2016).

E.5.2 From CPT results

- (1) Provided the conditions given in (2) are satisfied, the peak undrained cohesion of a clay ($c_{u,p}$) may be determined from the results of cone penetration tests (CPTs) using:

$$c_{u,p} = \frac{q_n}{N_{kt}} = \frac{q_n}{10,5 - 4,6 \log_e \left(\frac{\Delta u_2}{q_n} + 0,1 \right)} \quad (\text{E.6})$$

where

q_n is the net cone tip resistance measured as per EN ISO 22476-1;

N_{kt} is a cone factor;

Δu_2 is the excess pore water pressure measured at the gap between cone tip and friction sleeve as per EN ISO 22476-1.

- (2) Formula (E.6) should only be used if the:

- soil is classified as clay according to EN ISO 14688-2;
- clay is saturated when the CPT is performed;
- clay is of low sensitivity according to EN ISO 14688-2; and
- clay has $OCR < 2,5$.

NOTE 1 The bias in the measurement/prediction ratio for Formula (E.6) is 1,09, with a standard deviation of 0,28.

NOTE 2 The data supporting this relationship derive from triaxial compressions tests on samples anisotropically consolidated to the in-situ stress state, as given by Mayne and Peuchen (2018).

E.5.3 From SPT results

- (1) Provided the conditions given in (2) are satisfied, the peak undrained cohesion of a clay ($c_{u,p}$) may be determined from the results of standard penetration tests (SPTs) using one of the following Formulas:

$$c_{u,p} = 7,57 \cdot N_{60} \quad (E.7)$$

$$c_{u,p} = f_1 \cdot N_{60} \quad (E.8)$$

where

N_{60} is the energy-normalized SPT blow count complying with EN ISO 22476-3.

f_1 is a factor that depends on the clay's plasticity index; and

N is the uncorrected SPT blow count

NOTE 1 The data supporting Formula (E.7) derive from unconsolidated undrained triaxial compression tests results, as given by Sivrikaya and Toğrol (2006).

NOTE 2 The factor f_1 in Formula (E.7) is typically between 5,5 and 6,0. See White et al. (2019).

- (2) Formula (E.7) should only be used if the:

- soil is classified as clay according to EN ISO 14688-2;
- clays of low sensitivity according to EN ISO 14688-2; and
- Atterberg limits are such that $20 \% < w_L < 110 \%$ and $14 \% < w_p < 44 \%$.

NOTE 1 The standard error associated with Formula (E.7) is 36 kPa.

E.5.4 From Ménard Pressuremeter Test results

- (1) The peak undrained cohesion (c_{up}) of a clay may be determined from the results of Ménard Pressuremeter Tests (MPMTs) using:

$$c_{u,p} = \frac{p_{LM} - p_1}{K_{PMT}} \quad (E.9)$$

where

p_{LM} is the pressuremeter limit pressure of the ground (EN ISO 22476-4);

p_1 is the corrected pressure at the origin of the pressuremeter modulus pressure range (see EN ISO 22476-4);

K_{PMT} is a calibration factor.

NOTE The value of K_{PMT} typically ranges from 2 to 20 (with higher values corresponding to stiffer soils), depending on the specific geological formations.

E.5.5 From FVT results

- (1) Provided the conditions given in (2) are satisfied, the peak undrained cohesion of a clay ($c_{u,p}$) may be determined from the results of field vane tests (FVTs) using:

$$c_{u,p} = m \cdot c_{fv} \quad (\text{E.10})$$

where

c_{fv} is the peak shear strength of soil, derived from the maximum torque measured by field vane test (see EN ISO 22476-9);

m is the correction factor based on plasticity and state of consolidation.

- (2) Formula (E.10) should only be used if the:

- soil is classified as clay according to EN ISO 14688-2;
- test is performed in saturated soil.

E.5.6 Flat Dilatometer test results

- (1) The peak undrained cohesion (c_{up}) of a clay may be determined from the results of flat dilatometer tests (DMT) using correlations in EN ISO 22476-11, annex A.

E.6 Geological Strength Index (GSI) Rock mass classification systems

- (1) A number of rock mass classification systems are in widespread use, and these may be used to determine rock mass strength.
- (2) The Geological Strength Index (GSI) for a rock mass may be obtained using charts that have been developed for this purpose.

NOTE Examples of charts are given in Marinos and Hoek (2000), and Marinos P., Marinos V., and Hoek E. (2007)

- (3) The value of GSI should be derived from the lithology, rock mass structure, interlocking, discontinuities, discontinuity sets, and discontinuity surface conditions.
- (4) An average value of GSI should be determined for each distinct rock mass unit to consider the spatial variability of the parameter.
- (5) Estimates of values of the Hoek-Brown strength parameters may be determined from GSI using:

$$m_b = m_i e^{\left(\frac{GSI-100}{28-14D}\right)} \quad (\text{E.11})$$

$$s = e^{\left(\frac{GSI-100}{9-3D}\right)} \quad (\text{E.12})$$

$$a = \frac{1}{2} + \frac{1}{6} e^{\left(\frac{-GSI}{15}\right)} - e^{\left(\frac{-100}{15}\right)} \quad (\text{E.13})$$

m_b , s , and a are as defined for Formula (8.4);

m_i is a non-dimensional material parameter for the intact rock;

GSI is the Geological Strength Index;

D is the disturbance factor of the rock mass ($0 < D < 1$).

Annex F (informative)

Methods for determining stiffness and consolidation properties of soils

F.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 9 for evaluating the stiffness and consolidation properties of soils.

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 Informative Annex covers:

- evaluation of sample disturbance;
- definitions of soil stiffness; and
- parameters for empirical models;

F.3 Evaluation of specimen disturbance of soils

- (1) Qualitative assessment of specimen quality may be made by visual inspection, amplified where appropriate using X-rays or computerised tomography (CT) scans as described in ISO 19901-8.
- (2) Petrographic examination of soil fabric may be used to assess the amount of disturbance in fine, fragile carbonate soils.
- (3) Quantitative assessment of specimen quality for intact, low to medium overconsolidation ratio clays may be made by measuring volume change at the estimated in-situ stress state during laboratory consolidation, using Table F.1.

NOTE This method is only applicable for non swelling minerals.

Table F.1 Evaluation of intact specimen quality for low to medium OCR clays

Quality	$\Delta e/e_0$		Specimen MQC
	OCR = 1 to 2	OCR = 2 to 4	
Very good	< 0,04	< 0,03	1 (small strain)
Good	0,04 to 0,07	0,03 to 0,05	1
Poor	0,07 to 0,14	0,05 to 0,10	2
Very poor	> 0,14	> 0,10	3 ^a

^a The specimen quality criteria are not valid for data for load step durations during which secondary compression are observed. For marine soil, a duration below 24 h is commonly used.

- (4) The normalized specimen quality parameter $\Delta e/e_0$ should be computed from Formula (F.1):

$$\Delta e/e_0 = \varepsilon_{\text{vol}} \cdot (1 + e_0)/e_0 \quad (\text{F.1})$$

where

Δe is the change in void ratio;

e_0 is the void ratio of the prepared specimen;

ε_{vol} is the volumetric strain ($= \Delta V/V_0$) from reconsolidation to $(\sigma'_{\text{v0}}, \sigma'_{\text{h0}})$;

σ'_{v0} is the in-situ vertical effective stress;

σ'_{h0} is the in-situ horizontal effective stress.

- (5) The values of $\Delta e/e_0$ and ε_{vol} should be computed and reported for laboratory consolidation tests conducted on intact clay soils, provided the best estimate in-situ effective stresses are given.

NOTE 1 Laboratory consolidation tests conducted on intact clay soils include incremental load oedometer, constant rate of strain and anisotropic consolidation phase of strength tests such as triaxial and direct simple shear.

NOTE 2 Minimum quality classes 4 and 5 correspond to specimens subject to a decrease in effective stress, a reduction in the inter-particle bonds, and a rearrangement of the soil particles. These classes are used for determination of physical and chemical properties according to EN ISO 22475 -1. Specimen quality class is different from sample quality class defined in 5.4.5 qualifying the a priori disturbance induced by the sampling technique.

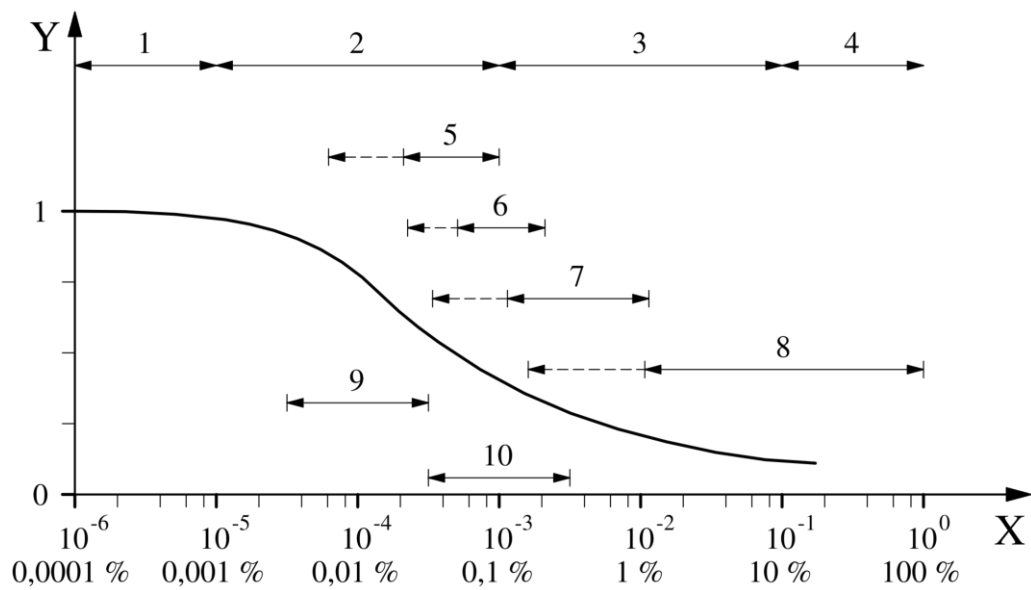
- (6) Disturbance of a soil specimen may be determined by comparison of values of the wave propagation velocities determined on lab specimens with respect to the material in its natural state at the site scale.

F.4 Definitions of soil stiffness

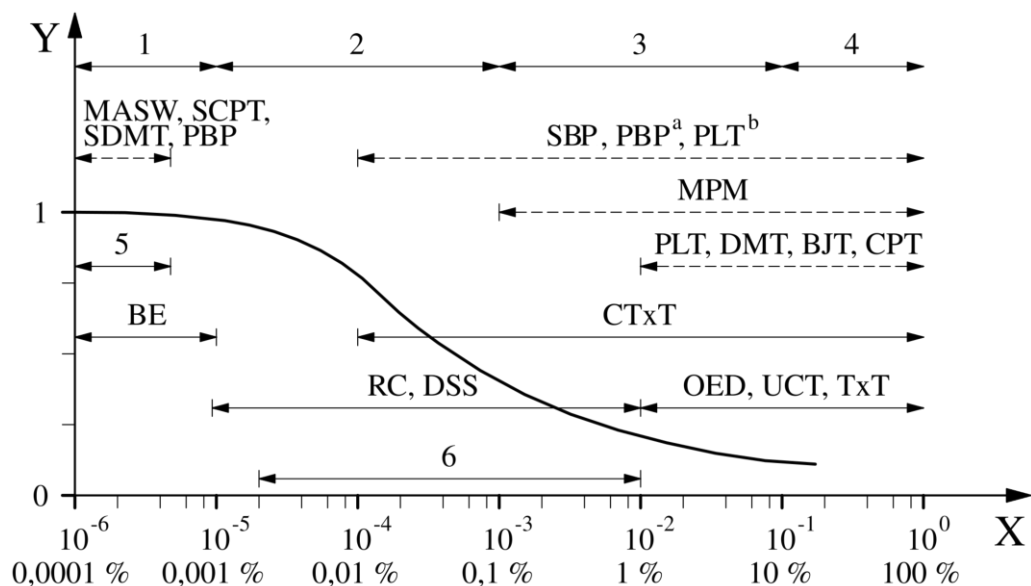
- (1) Values of the modulus of elasticity (G or E) should be determined at strain levels appropriate for the geotechnical structure.

NOTE 1 Strain levels appropriate for different geotechnical structures are shown in Figure F.1

NOTE 2 Figure F.2 shows the measuring ranges of laboratory and in-situ equipment. These ranges correspond to the strains generated in the vicinity of geotechnical structures during their construction and operation. The ranges are extended on the left to the maximum threshold, which can be reached during very careful tests where the remoulding of the soil is limited.

**Key**

X	strain	5	retaining walls
Y	secant modulus	6	shallow foundations
1	very small strain	7	tunnels
2	small strain	8	embankment on low strength soils
3	large strain	9	pile groups
4	very large strain	10	single piles
<->	typical range	<---	potential range

Figure F.1 — Typical strain ranges for common geotechnical structures**Key**

X	strain	5	P-wave
Y	secant modulus	6	gauges attached directly to the specimen
1	very small strain	a	PBP other than MPM

2	small strain	^b	with local measurement
3	large strain	<-->	laboratory tests
4	very large strain	<-->	field tests

Figure F.2 — Typical strain ranges for laboratory and field tests

- (2) The determination for the modulus of elasticity based on experimental curves should take into account its variation with strain.
- (3) The deformability characteristics of a homogeneous soil mass determined from tests should be representative of its average behaviour.

NOTE Determination of the parameters is a compromise between possibilities of the tests and a satisfactory representation of the behaviour of the structure and the ground. A suitable data acquisition frequency is needed to obtain experimental curves complying with the proposed rheological model within the potential range of parameter values.

- (4) The modulus of elasticity should be determined from an unloading path.
- (5) The load and deformation cycles applied during cyclic laboratory and field tests should be specified when planning the ground investigation.

F.5 Parameters for empirical models

- (1) The secant shear modulus of a soil (G_{sec}) may be estimated from:

$$\frac{G_{\text{sec}}}{G_0} = \left[1 + \left(\frac{\gamma - \gamma_e}{\gamma_{\text{ref}}} \right)^m \right]^{-1} \quad (\text{F.2})$$

where

- G_0 is the soil's very-small-strain shear modulus;
- γ is the shear strain in the soil;
- γ_e is the elastic threshold strain beyond which shear modulus falls below its maximum value;
- γ_{ref} is a reference value of engineering shear strain (at which $G_{\text{sec}}/G_0 = 0,5$); and
- m is a coefficient that depends on soil type.

NOTE A database supporting this relationship is given by Oztoprak and Bolton (2013).

- (2) Formula (F.2) may also be used to validate direct or indirect measurements of stiffness.
- (3) Values of the parameters for use with Formula (F.2) may be taken from Table F.2.
- (4) Values other than those given in Table F.2 may be used with Formula (F.2) provided the testing, reporting, and interpretation procedures comply with to the general prescriptions given in Clause 9.

Table F.2 — Values of parameters for use with Formula (F.2)

Soil type as per EN ISO 14688-1	Parameters			Reference
	$\gamma_{\text{ref}} \%$	m	$\gamma_e \%$	
Sand	0,02-0,1 (0,044) ^a	0,88	0,02% + 0,012 γ_{ref}	Oztoprak and Bolton (2013)
Clay and silt	0,0022 I_p ^b	0,736 ± 0,122 ^c	0 (assumed)	Vardanega and Bolton (2013)
^a mean value ^b I_p is the soils plasticity index ^c ± value indicate standard error				

(5) The very-small-strain shear modulus of a soil (G_0) may be determined from:

$$\frac{G_0}{p_{\text{ref}}} = \frac{k_1}{(1+e)^{k_2}} \left[\frac{p'}{p_{\text{ref}}} \right]^{k_3} \quad (\text{F.3})$$

where

- e is the void ratio;
- p' is the mean effective stress in the soil;
- p_{ref} is a reference pressure;
- k_1 , k_2 , and k_3 are coefficients that depend on soil type.

NOTE See Bolton et al. (2000) and Clayton et al. (2011) for further information.

- (6) Formula (F.3) may also be used to validate direct or indirect measurements of very-small strain stiffness.
- (7) Values of the parameters for use with Formula (F.3) may be taken from Clause 9.
- (8) Values other than those given in Table F.3 may be used with Formula (F.3) provided the testing, reporting, and interpretation procedures comply with Clause 9.

Table F.3 — Values of parameters for use with Formula (F.3)

Soil type as per EN ISO 14688-1	Parameters				Reference
	k_1	k_2	k_3	p_{ref} (kPa)	
Fine grained soil	2100	0	0,6-0,8	1	Viggiani and Atkinson (1995)
Sand ^a	370-5760	3	0,49-0,86	100	Oztoprak and Bolton (2013)
Clay and silt	20000 ± 5000	2,4	0,5	1	Vardanega and Bolton (2013)
^a Decreasing with strain.					

(9) The rock mass modulus (E_{rm}) may be estimated from empirical models, such as:

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$$\frac{E_{rm}}{E_i} = 0,02 + \frac{1-D/2}{1+e^{[(60+15 \cdot D-GSI)/11]}} \quad (F.4)$$

where

E_i is the modulus of elasticity intact rock;

GSI is the Geological Strength Index, with a value between 0 and 100;

D is the disturbance factor, with a value between 0 and 1.

NOTE See Hoek and Brown (2018) for further information.

Annex G (informative)

Indirect methods for determining cyclic, dynamic, and seismic properties of soils

G.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 10 for evaluating the mechanical response of soils and rocks to dynamic actions and parameters for seismic design.

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.

G.2 Scope and field of application

- (1) This Informative Annex covers:

- indirect methods for the evaluation of normalized secant shear modulus and damping ratio curves; and
- indirect methods for the evaluation of shear wave velocity (v_s).

G.3 Indirect methods for the evaluation of normalised secant shear moduli and damping ratio curves

G.3.1 Fine soils

- (1) The secant shear modulus G_{sec} of fine soils may be determined as a function of cyclic shear strain from Formulae (G.1) to (G.2):

$$\frac{G_{\text{sec}}}{G_0} = \left[1 + \left(\frac{\gamma_{\text{cyc}}}{\gamma_{\text{ref}}} \right)^\alpha \right]^{-1} \quad (\text{G.1})$$

$$\gamma_{\text{ref}}(\%) = (\phi_1 + \phi_2 \times I_p \times OCR^{\phi_3}) \times \left(\frac{\sigma'_0}{p_a} \right)^{\phi_4} \quad (\text{G.2})$$

where

G_0	is the very small-strain shear modulus of the soil;
γ_{cyc}	is the cyclic shear strain;
γ_{ref}	is a reference value of engineering shear strain (at which $G_{\text{sec}}/G_0 = 0,5$);
α	is a curvature coefficient, given in Table G.1 as ϕ_5 ;
I_p	is the plasticity index;
OCR	is the overconsolidation ratio;
σ'_0	is the mean effective stress;
$\phi_1, \phi_2, \phi_3, \phi_4$	are constants given in Table G.1.

NOTE (G.1) to (G.2) were originally proposed by Darendeli (2001).

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- (2) The shear damping ratio D of fine soils may be determined as a function of cyclic shear strain from Formulae (G.3) to (G.5):

$$D = D_0 + f(G(\gamma_{\text{cyc}})/G_0) \quad (\text{G.3})$$

$$D_0 = (\phi_6 + \phi_7 \times I_P \times OCR^{\phi_8}) \times \frac{\sigma'_0{}^{\phi_9}}{p_a} \times [1 + \phi_{10} \ln(f)] \quad (\text{G.4})$$

$$f\left(\frac{G_{\text{sec}}}{G_0}\right) = b \times D_M \times \left(\frac{G_{\text{sec}}}{G_0}\right)^{0,1} = b \times \left[c_1(D_{M,\alpha=1}) + c_2(D_{M,\alpha=1})^2 + c_3(D_{M,\alpha=1})^3 \right] \times \left(\frac{G_{\text{sec}}}{G_0}\right)^{0,1} \quad (\text{G.5})$$

where

b is given by $b = \phi_{11} + \phi_{12} \ln N$

D_0 is the small strain damping ratio;

$D_{M,\alpha=1}$ is given by

$$D_{M,\alpha=1} = \frac{100}{\pi} \left[4 \frac{\gamma_{\text{cyc}} - \gamma_{\text{ref}} \ln\left(\frac{\gamma_{\text{cyc}} + \gamma_r}{\gamma_r}\right)}{\frac{\gamma_{\text{cyc}}^2}{\gamma_{\text{cyc}} + \gamma_r}} - 2 \right]$$

c_1 is given by $c_1 = 0,2523 + 1,8618\alpha - 1,1143\alpha^2$

c_2 is given by $c_2 = -0,0095 - 0,0710\alpha + 0,0805\alpha^2$

c_3 is given by $c_3 = 0,0003 + 0,0002\alpha - 0,0005\alpha^2$

N is the number of cycles (default value 10)

I_P is the plasticity index;

OCR is the overconsolidation ratio;

σ'_0 is the mean effective stress;

p_a is the atmospheric pressure;

f is the frequency of the load in Hz (default value: 1 Hz);

$\phi_6, \phi_7, \phi_8, \phi_9, \phi_{10}$ are constants given in Table G.1.

NOTE Formulae (G.3) to (G.5) were originally proposed by Darendeli (2001).

Table G.1 Constants for the evaluation of normalised shear modulus and damping ratio of fine soils

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
ϕ_1	0,0352	ϕ_5	0,9190	ϕ_9	-0,2889	ϕ_{13}	-4,23
ϕ_2	0,0010	ϕ_6	0,8005	ϕ_{10}	0,2919	ϕ_{14}	3,62
ϕ_3	0,3246	ϕ_7	0,0129	ϕ_{11}	0,6329	ϕ_{15}	-5,00
ϕ_4	0,3483	ϕ_8	-0,1069	ϕ_{12}	-0,0057	ϕ_{16}	-0,25

- (3) The variability of the normalised shear modulus may be estimated assuming a normal distribution and a value of variance σ_{NG} given by Formula (G.6):

$$\sigma_{\text{NG}} = e^{\phi_{13}} + \sqrt{\frac{0,25}{e^{\phi_{14}}} - \frac{([G_{\text{sec}}/G_0]_{\text{mean}} - 0,5)^2}{e^{\phi_{14}}}} \quad (\text{G.6})$$

where

$[G_{\text{sec}}/G_0]_{\text{mean}}$ is given by Formula G.1; and

ϕ_{13}, ϕ_{14} are constants given in Table G.1.

NOTE Formula (G.6) was originally proposed by Darendeli (2001).

- (4) The variability of the shear damping ratio may be determined assuming a normal distribution and a value of the variance σ_D from:

$$\sigma_D = e^{\phi_{15}} + e^{\phi_{16}} \sqrt{D_m} \quad (\text{G.7})$$

where

D_m is given by Formulae G.3 to G.5;

ϕ_{15}, ϕ_{16} are constants given in Table G.1.

NOTE Formula (G.7) was originally proposed by Darendeli (2001).

G.3.2 Coarse soils

- (1) Provided the conditions given in (2) are satisfied, the secant shear modulus G_{sec} for coarse soils may be determined as a function of cyclic shear strain from Formulae (G.8) to (G.9):

$$\frac{G_{\text{sec}}}{G_0} = \left[1 + \left(\frac{\gamma_{\text{cyc}}}{\gamma_{\text{ref}}} \right)^\alpha \right]^{-1} \quad (\text{G.8})$$

$$\gamma_{\text{ref}}(\%) = 0.12 C_{U, \text{PSD}}^{-0.6} \times \left(\frac{\sigma'_0}{p_a} \right)^{0.5 C_u^{-0.15}} \quad (\text{G.9})$$

where

G_0 is the soil small-strain shear modulus;

γ_{cyc} is the cyclic shear strain;

γ_{ref} is a reference value of engineering shear strain (at which $G_{\text{sec}}/G_{\text{max}} = 0.5$);

α is the curvature coefficient given by $\alpha = 0.86 + 0.1 \log \left(\frac{\sigma'_0}{p_a} \right)$;

$C_{U, \text{PSD}}$ is the uniformity coefficient;

p_a is the atmospheric pressure;

σ'_0 is the mean effective stress;

NOTE Formulae (G.8) to (G.9) were originally proposed by Menq (2003).

- (2) The shear damping ratio D of coarse soils may be determined as a function of cyclic shear strain from Formula (G.10):

$$D = D_0 + b \times D_M \times \left(\frac{G_{\text{sec}}}{G_0} \right)^{0.1} = \left[0.55 C_{U, \text{PSD}}^{0.1} \times D_{50}^{-0.3} \times \left(\frac{\sigma'_0}{p_a} \right)^{-0.05} \right] + \left[b \times D_M \times \left(\frac{G_{\text{sec}}}{G_0} \right)^{0.1} \right] \quad (\text{G.10})$$

where

D_0 is the small strain damping;

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- $C_{U,PSD}$ is the coefficient of uniformity;
- D_{50} Is the median grain size
- p_a is the atmospheric pressure;
- σ'_0 is the mean effective stress;
- b is given by: $b = 0,6329 - 0,0057 \ln N$
- D_M is given by: $D_M = c_1(D_{M,\alpha=1}) + c_2(D_{M,\alpha=1})^2 + c_3(D_{M,\alpha=1})^3$
- $D_{M,\alpha=1}$ is given by: $D_{M,\alpha=1} = \frac{100}{\pi} \left[4 \frac{\gamma_{cyc} - \gamma_r \ln\left(\frac{\gamma_{cyc} + \gamma_{ref}}{\gamma_{ref}}\right)}{\frac{\gamma_{cyc}^2}{\gamma_{cyc} + \gamma_{ref}}} - 2 \right]$
- c_1 is given by: $c_1 = 0,2523 + 1,8618\alpha - 1,1143\alpha^2$
- c_2 is given by: $c_2 = -0,0095 - 0,0710\alpha + 0,0805\alpha^2$
- c_3 is given by: $c_3 = 0,0003 + 0,0002\alpha - 0,0005\alpha^2$
- N number of cycles (default value 10),

NOTE 1 The model is reliable for dry soils and shear strains ranging between 0,000 1 % and 0,6 %.

NOTE 2 Formula (G.10) was originally proposed by Menq (2003).

G.4 Indirect methods for the evaluation of shear wave velocity or very small strain shear modulus

G.4.1 From Standard Penetration Tests

- (1) The shear wave velocity v_s of sands may be determined from the results of Standard Penetration Tests using Formula (G.11):

$$v_s = k_{vs} N_{60}^{0.23} \sigma_v'^{0.25} \quad (G.11)$$

where

- k_{vs} is a constant equal to 27 for Holocene sands and 35 for Pleistocene sands;
- N_{60} is the blow counts of a standard penetration test for energy efficiency of 60 % [blows/30 cm];
- σ'_v is the vertical effective stress.

NOTE Formula (G.11) was originally proposed by Wair et al. (2012).

G.4.2 From Cone Penetration Tests

- (1) The shear wave velocity v_s of Pleistocene sands may be determined from the results of Cone Penetration Tests using Formula (G.12):

$$v_s = \sqrt{10^{(0,55I_c + 1,68)} \frac{q_t - \sigma'_v}{p_a}} \quad (G.12)$$

where

- I_c is the soil behaviour type index;

- p_a is the atmospheric pressure;
 q_t is the corrected cone resistance;
 σ'_v is the vertical effective stress.

NOTE Formula (G.12) was originally proposed by Robertson (2009).

G.4.3 From Flat Dilatometer Tests

- (1) The small-strain shear modulus G_0 may be determined from the results of Flat Dilatometer Tests using Formula (G.13):

$$G_0 = k_1 K_D^{-k_2} M_{DMT} \quad (G.13)$$

where

- M_{DMT} is the dilatometer modulus;
 K_D is the horizontal stress index;
 I_{DMT} is the dilatometer material index;
 k_1 is a constant equal to: 26,177 for $I_{DMT} < 0,6$; 15,686 for $0,6 \leq I_{DMT} < 1,8$; and 4,5613 for $0,8 \leq I_{DMT}$.
 k_2 is a constant equal to: 1,0066 for $I_{DMT} < 0,6$; 0,921 for $0,6 \leq I_{DMT} < 1,8$; and 0,7967 for $0,8 \leq I_{DMT}$.

NOTE Formula (G.13) was originally proposed by Monaco et al. (2009).

Annex H

(informative)

Spacing and number of investigation locations

H.1 Use of this Informative Annex

- (1) This Informative Annex provides supplementary guidance to Clause 5.4.3 for spacing and number of investigation locations.

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.

H.2 Scope and field of application

- (1) This Informative Annex covers spacing and number of investigation locations.

H.3 Spacing and number of investigation locations

- (1) The spacing of investigation location on plan should be no greater than X_{\max} .

NOTE Values of X_{\max} for structures in Geotechnical Category 2 are given in Table H.1 unless the National Annex gives different guidance.

- (2) The number of investigation location should be no less than N_{\min} .

NOTE Values of N_{\min} for structures in Geotechnical Category 2 are given in Table H.1 unless the National Annex gives different guidance.

Table H.1(NDP) — Maximum spacing and minimum number of investigation locations for structures in Geotechnical Category 2

Structures		Maximum spacing X_{\max}	Minimum number N_{\min}
Low-rise structures		30 m	3
High-rise structures	4-10 storeys	25 m	3- <u>4</u> ^b
	11-20 storeys	20 m	3- <u>5</u> ^b
	> 20 storeys	15 m	3- <u>6</u> ^b
Estate roads, parking areas and pavements		40 m	2
Silos and tanks		15 m	3
Bridges piers and abutments		1 per pier/base	
Power lines		1 per pylon	
Wind turbines		2 per turbine	
Retaining structures		150 m	- ^a
Slopes and cuttings	< 3 m high	100 m	- ^a
	≥ 3 m high	50 m	- ^a
Embankments and reinforced fill structures	< 3 m high	200 m	- ^a
	≥ 3 m high	100 m	- ^a
Excavations in urban areas > 5 m deep from ground surface		25 m	3
^a Where no spacing or number of locations is given, it is assessed on a project-specific basis.			
^b Underlined numbers are more appropriate for complex structures			

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.

EN196-2, *Method of testing cement - Chemical analyses of cement*

EN 932-3, *Tests for general properties of aggregates - Part 3: Procedure and terminology for simplified petrographic description*

EN 933-9, *Tests for geometrical properties of aggregates - Part 9: Assessment of fines - Methylene blue test*

EN 1097-3, *Tests for mechanical and physical properties of aggregates - Part 3: Determination of loose bulk density and voids*

EN 1097-5, *Tests for mechanical and physical properties of aggregates - Part 5: Determination of the water content by drying in a ventilated oven*

EN 1097-6, *Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption*

EN 1744-1, *Tests for chemical properties of aggregates - Part 1: chemical analysis*

EN 1744-5, *Tests for chemical properties of aggregates - Part 5: Determination of acid soluble chloride salts*

EN 1925, *Natural stone test methods - Determination of water absorption coefficient by capillarity*

EN 1936, *Natural stone test methods - Determination of real density and apparent density, and of total and open porosity*

EN 12407, *Natural stone test methods - Petrographic examination*

EN 12501-1, *Protection of metallic materials against corrosion - Corrosion likelihood in soil - Part 1: General*

EN 13286-2, *Unbound and hydraulically bound mixtures - Part 2: Test methods for laboratory reference density and water content - Proctor compaction*

EN 13286-4, *Unbound and hydraulically bound mixtures - Part 4: Test methods for laboratory reference density and water content - Vibrating hammer*

EN 13286-5, *Unbound and hydraulically bound mixtures - Part 5: Test methods for laboratory reference density and water content - Vibrating table*

EN 13286-47, *Unbound and hydraulically bound mixtures - Part 47: Test method for the determination of California bearing ratio, immediate bearing index and linear swelling*

- EN 13577, *Chemical attack on concrete - Determination of aggressive carbon dioxide content in water*
- EN 13925-1, *Non-destructive testing - X-ray diffraction from polycrystalline and amorphous materials - Part 1 - General principles*
- EN 14146, *Natural stone test methods - Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency)*
- EN 14579, *Natural stone test methods - Determination of sound speed propagation*
- EN 14580, *Natural stone test methods - Determination of static elastic modulus*
- EN 15935, *Soil, waste, treated biowaste and sludge - Determination of loss on ignition*
- EN 15936, *Soil, waste, treated biowaste and sludge. Determination of total organic carbon (TOC) by dry combustion*
- EN 16502, *Test method for the determination of the degree of soil acidity according to Baumann-Gully*
- EN 17542-3, *Earthworks - Geotechnical laboratory tests - Part 3: Methylene blue value VBS on soils and rocks*
- EN 27888, *Water quality. Determination of electrical conductivity. (ISO 7888:1985).*
- EN ISO 7980, *Water quality - Determination of calcium and magnesium - Atomic absorption spectrometric method (ISO 7980)*
- EN ISO 9963-1, *Water quality - Determination of alkalinity - Part 1: Determination of total and composite alkalinity (ISO 9963-1)*
- EN ISO 10304-1, *Water quality - Determination of dissolved anions by liquid chromatography of ions - Part 1: Determination of bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulfate (ISO 10304-1)*
- EN ISO 10390, *Soil, treated biowaste and sludge - Determination of pH (ISO 10390:2021)*
- EN ISO 10523, *Water quality - Determination of pH (ISO 10523)*
- EN ISO 10693, *Soil quality - Determination of carbonate content - Volumetric method (ISO 10693:1995)*
- EN ISO 14911, *Water quality - Determination of dissolved Li⁺, Na⁺, NH₄⁺, K⁺, Mn²⁺, Ca²⁺, Mg²⁺, Sr²⁺ and Ba²⁺ using ion chromatography - Method for water and waste water (ISO 14911)*
- EN 16907-2, *Earthworks - Part 2: Classification of materials*
- EN ISO 17628 (all parts), *Geotechnical investigation and testing - Geothermal testing - Determination of thermal conductivity of soil and rock using a borehole heat exchanger (ISO 17628)*
- EN ISO 17892 (all parts), *Geotechnical investigation and testing - Laboratory testing of soil (ISO 17892)*
- EN ISO 18674 (all parts), *Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation (ISO 18674)*
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References given in permissions (i.e. "may" clauses)

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