



BSI Standards Publication

Oil and gas industries including lower carbon energy — Offshore structures

Part 8: Marine soil investigations

National foreword

This British Standard is the UK implementation of EN ISO 19901-8:2023. It is identical to ISO 19901-8:2023. It supersedes BS EN ISO 19901-8:2015, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/525/12, Design of offshore structures.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Published by BSI Standards Limited 2023

ISBN 978 0 539 18485 3

ICS 75.180.10

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2023.

Amendments/corrigenda issued since publication

Date	Text affected
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English Version

Oil and gas industries including lower carbon energy -
Offshore structures - Part 8: Marine soil investigations
(ISO 19901-8:2023)

Industries du pétrole et du gaz y compris les énergies à
faible teneur en carbone - Structures en mer - Partie 8:
Investigations des sols en mer (ISO 19901-8:2023)

Öl- und Gasindustrie einschließlich kohlenstoffarmer
Energieträger - Offshore-Anlagen - Teil 8:
Meeresbodenuntersuchungen (ISO 19901-8:2023)

This European Standard was approved by CEN on 15 September 2023.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

This document (EN ISO 19901-8:2023) has been prepared by Technical Committee ISO/TC 67 "Oil and gas industries including lower carbon energy" in collaboration with Technical Committee CEN/TC 12 "Oil and gas industries including lower carbon energy" the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2024, and conflicting national standards shall be withdrawn at the latest by March 2024.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN ISO 19901-8:2015.

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Endorsement notice

The text of ISO 19901-8:2023 has been approved by CEN as EN ISO 19901-8:2023 without any modification.

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 7, *Offshore structures*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 19901-8:2014), which has been technically revised.

The main changes are as follows:

- application classes for in situ testing tools are removed and replaced by an assessment of documented calibration results and uncertainty analyses;
- new procedures for calibration and verification of cone penetrometers are introduced with reference to the latest edition of ISO 22476-1.
- references to project specifications for technical details have been reduced where possible and roles and responsibilities have been further clarified.
- title and scope change adopted as per Technical Management Board Resolution 53/2022.

A list of all parts in the ISO 19901 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The International Standards on offshore structures prepared by TC 67/SC 7 (ISO 19900, the ISO 19901 series, ISO 19902, ISO 19903, ISO 19904, ISO 19905 series and ISO 19906) constitute a common basis covering those aspects that address design requirements and assessments of all offshore structures used by the petroleum and natural gas industries worldwide. Through their application, the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the nature or combination of the materials used. Application specific requirements for different energy industries are referencing relevant overarching standards. For example, for the offshore wind industry the IEC standards IEC 61400-1 and IEC 61400-3-1 outline the normative design requirements (e.g. return periods) for offshore turbine support structures.

Structural integrity is a concept comprising models for describing actions, structural analyses, design rules, safety elements, workmanship, quality control procedures and national requirements, all of which are mutually dependent. The modification of one aspect of design in isolation can disturb the balance of reliability inherent in the overall concept of structural integrity (see ISO 19900). The implications involved in modifications, therefore, should be considered in relation to the overall reliability of all offshore structural systems.

A marine soil investigation is only one of many possible marine site investigations as illustrated in [Figure 1](#). The scope of a marine soil investigation, such as field programme, equipment to be used, laboratory testing programme, soil parameters to be established and reporting, is usually defined in project specifications based on important factors, such as type of structures involved, type of soil conditions expected, regional or site-specific investigation, preliminary or final soil investigations. The reporting can comprise anything from field data only to reporting of soil parameter values.

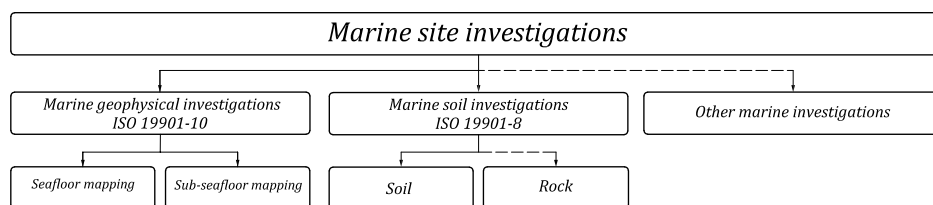


Figure 1 — Marine soil investigations shown as one of many types of marine site investigations.

Use of this document is based on the following assumptions:

- communication takes place between geophysical and geotechnical specialists for defining the scope of the marine soil investigation based on the results of a geophysical investigation (see ISO 19901-10);
- communication takes place between geotechnical personnel involved in marine soil investigations and the personnel responsible for foundation design, for construction and for installation of the offshore structures;
- soil data are collected, documented and interpreted by trained personnel;
- the project-specific scope of work for marine soil investigations is defined by one or more project specifications.

The detailed requirements for equipment and methods given in this document are only applicable if relevant for the scope of work defined in the project specifications.

This document is intended to provide flexibility in the choice of marine soil investigation techniques without hindering innovation.

In this document, the following verbal forms are used:

- “shall” indicates a requirement;

- “should” indicates a recommendation;
- “can” indicates a possibility or a capability;
- “may” indicates a permission.

Information marked as “NOTE” is intended to assist the understanding or use of the document. “Notes to entry” used in [Clause 3](#) provide additional information that supplements the terminological data and can contain requirements relating to the use of a term.

[Annex A](#) gives additional information intended to assist the understanding or use of this document. The clause numbers in [Annex A](#) correspond to the normative main text to facilitate easy cross-referencing. [Annex B](#) covers conduct of laboratory tests as part of marine soil investigations.

Oil and gas industries including lower carbon energy — Offshore structures —

Part 8: Marine soil investigations

1 Scope

This document specifies requirements and provides recommendations and guidelines for marine soil investigations regarding:

- a) objectives, planning and execution of marine soil investigations;
- b) deployment of investigation equipment;
- c) drilling and logging;
- d) in situ testing;
- e) sampling;
- f) laboratory testing;
- g) reporting.

Although this document focuses on investigations of soil, it also provides guidance, with less detail, for investigations of chalk, calcareous soils, cemented soils and weak rock.

Foundation design is not covered by this document.

NOTE 1 ISO 19901-4 and the respective design standards covering foundation design for the specific types of offshore structures to meet the requirements of application specific standards are given on the ISO website.

The results from marine geophysical investigations are, when available and where appropriate, used for planning, optimization and interpretation of marine soil investigations.

This document neither covers the planning, execution and interpretation of marine geophysical investigations nor the planning and scope of geohazard assessment studies, only the corresponding marine soil investigations aspects thereof.

NOTE 2 ISO 19901-10 covers the planning, execution and interpretation of marine geophysical investigations.

This document specifies requirements and provides guidance for obtaining measured values and derived values. This document excludes requirements for determination of design values and representative values. Limited guidance is provided in [11.3](#) related to data interpretation.

This document is intended for clients, soil investigation contractors, designers, installation contractors, geotechnical laboratories and public and regulatory authorities concerned with marine soil investigations for any type of offshore structures, or geohazard assessment studies.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14688-2, *Geotechnical investigation and testing — Identification and classification of soil — Part 2: Principles for a classification*

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

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 22476-1, *Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14688-1, ISO 14688-2, ISO 14689 and the following apply:

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

accuracy

closeness of agreement between a measured quantity value and a true quantity value of a measurand

[SOURCE: ISO/IEC Guide 99:2007, 2.13]

3.2

borehole geophysical logging

measurement of physical properties of a borehole and/or the surrounding soil, obtained by one or more logging probes deployed in the borehole

3.3

client

party or person with overall responsibility for the marine soil investigation, including preparation of project specifications

3.4

coordinate reference system

coordinate system that is related to an object by a datum

Note 1 to entry: Geodetic and vertical datums are referred to as reference frames.

3.5

contractor

party or person responsible for an assigned scope of work described in project specifications

3.6

derived value

value of a geotechnical parameter obtained from test results by theory, correlation or empiricism

3.7**design value**

value derived from the representative value for use in the design verification

[SOURCE: ISO 19900:2019, 3.14]

3.8**disturbed sample**

sample whose soil structure, water content and/or constituents have changed as a result of sampling and handling

3.9**drained condition**

condition whereby the applied stresses and stress changes are supported entirely by the soil skeleton and do not cause a change in pore pressure

3.10**drilling mud****drilling fluid**

fluid pumped down a rotary drilled borehole to facilitate the drilling process

Note 1 to entry: The hardware associated with handling drilling fluids is commonly prefixed 'mud' (e.g. mud tank, mud pump, mud valve). Drilling parameters associated with drilling fluids are similarly prefixed (mud pressure, mud flow, etc.).

3.11**geohazard**

geological condition that has the potential to have adverse effects on persons, operations, offshore structures or the environment

3.12**ground model**

2- or 3-dimensional representation of the seafloor (bathymetry) and, where applicable, the sub-seafloor conditions, at a given time, that is specific to the offshore structure(s) considered

3.13**ground truthing**

integration of seafloor or sub-seafloor geophysical data with data acquired by marine soil investigation and other data

3.14**in-pipe logging**

borehole geophysical logging ([3.2](#)) in a section of the borehole with drill pipe between the tool and the borehole wall

Note 1 to entry: The number of parameters that can be usefully measured in these circumstances is restricted.

3.15**inclination**

the angular deviation of the cone penetrometer from the vertical.

3.16**intact sample**

sample that was collected with intention to preserve its in situ characteristics

3.17**integrated geoscience study**

combination of geophysical data, a model for geological processes and geotechnical data for development of a *ground model* ([3.12](#))

3.18

marine geophysical investigation

type of marine site investigation of seafloor or sub-seafloor that uses non-destructive methods requiring marine deployment of geophysical tools

Note 1 to entry: See [Figure 1](#).

3.19

marine site investigation

type of investigation at an offshore or nearshore site

EXAMPLE Marine soil investigation, marine geophysical investigation, marine biological investigation, metocean investigation. See [Figure 1](#).

3.20

marine soil investigation

type of *marine site investigation* ([3.19](#)) whose primary objective is to obtain reliable and representative soil data for characterization of the seabed soil conditions to facilitate the design of offshore structures and/or for *geohazard* ([3.11](#)) evaluation

Note 1 to entry: See [Figure 1](#) and ISO 19901-10.

3.21

measured value

value that is measured in a test

3.22

nominal value

value assigned to a variable specified or determined on a non-statistical basis, typically acquired experience or physical conditions, or as published in a recognized code or standard

3.23

open-hole logging

borehole geophysical logging ([3.2](#)) in a section of the borehole without, for example, casing or drill pipe between the tool and the borehole wall

3.24

project specification

scope of work for *marine soil investigations* ([3.20](#)) assigned by the *client* ([3.3](#)) to a *contractor* ([3.5](#))

3.25

rat hole

additional depth drilled at the end of the borehole (beyond the last zone of interest) to ensure that the zone of interest for *borehole geophysical logging* ([3.2](#)) can be fully evaluated

Note 1 to entry: The rat hole allows tools at the top of the logging string to reach and measure the deepest zone of interest.

3.26

reconstituted specimen

laboratory specimen prepared by mixing a soil sample to specified state using a specified procedure

3.27

remoulded sample

remoulded specimen

laboratory specimen that is thoroughly reworked mechanically at a constant water content

3.28

remoulded shear strength

shear strength of remoulded soil

3.29**representative value**

value assigned to a basic variable for verification of a limit state in a design/assessment situation

[SOURCE: ISO 19900:2019, 3.40]

3.30**residual shear strength**

shear strength at large strains where shear stress versus strain levels off to a constant value

3.31**sample**

portion of soil or rock recovered from the seabed by sampling techniques

3.32**sample quality**

classification of soil *samples* ([3.31](#)) and specimens based on qualitative or quantitative techniques for assessment of the degree of inevitable disturbance induced by the sampling, transportation, handling and storage processes

Note 1 to entry: Sample quality criteria for low to medium OCR clays, where the sample quality is based on measured volume change from laboratory consolidation tests, are given in [Table 9](#).

3.33**seabed**

materials below the seafloor

Note 1 to entry: Sub-seafloor can also be used as an equivalent term (See ISO 19901-10).

3.34**seafloor**

interface between the sea and the *seabed* ([3.33](#))

3.35**settlement**

elastic or permanent downward movement of a structure as a result of its own weight and other actions

3.36**site**

defined investigation area, including vertical extent.

3.37**soil parameter**

soil property that can be quantified by a descriptor or a value

Note 1 to entry: Cone resistance and undrained shear strength are examples of soil parameters; low strength and very dense are examples of descriptors; nominal value, measured value and derived value are examples of types of values that can be determined for a soil parameter.

3.38**specimen**

part of a *sample* ([3.31](#)) used for a laboratory test

3.39**strength index test**

test that yields an indication of the shear strength

3.40
swelling

expansion due to reduction of effective stress, resulting from either reduction of total stress or absorption of (in general) water at constant total stress

Note 1 to entry: Swelling includes the reverse of both compression and consolidation.

Note 2 to entry: Exsolution of dissolved gas due to stress relief during sampling can cause significant swelling in samples.

3.41
taper angle

rate, in degrees, at which the outside diameter of the sampler cutting shoe reduces

3.42
uncertainty

non-negative parameter that characterizes the dispersion of the quantity values that are being attributed to a measurand

[SOURCE: ISO/IEC Guide 99:2007, 2.26]

3.43
undisturbed sample

sample ([3.31](#)) in which no change of practical significance has occurred in the soil characteristics

3.44
undrained condition

condition whereby the applied stresses and stress changes are supported by both the soil skeleton and the pore fluid and do not cause a change in volume

3.45
undrained shear strength

maximum shear stress at yielding or at a specified maximum strain in an *undrained condition* ([3.43](#))

Note 1 to entry: Yielding is the condition of a material in which a large plastic strain occurs at little or no stress increase.

4 Symbols, units and abbreviated terms

4.1 Symbols

A	projected area of the miniature cone, T-bar or ball penetrometer
A_c	nominal cross-sectional area of a cone penetrometer
A_n	area of the load cell or shaft on which pore pressure can act
A_p	projected area of the penetrometer in a plane normal to the shaft
A_s	surface area of the friction sleeve
A_{sb}	cross-sectional area of the bottom of the friction sleeve
A_{sp}	cross-sectional area of the ball or T-bar penetrometer connecting shaft
A_{st}	cross sectional area of the top of the friction sleeve
a	net area ratio of a cone penetrometer, ball or T-bar penetrometer
B	Skempton's pore pressure parameter

B_q	pore pressure ratio
b	net area ratio of the friction sleeve
C_A	area ratio of sampling tube
C_i	inside clearance ratio
C_c	compression index
c_v	coefficient of consolidation
c'	effective stress cohesion intercept
d_w	water depth
D	diameter of miniature penetrometer
D_i	inner diameter of sampling tube
D_o	outer diameter of sampling tube
D_1	diameter of miniature penetrometer in earlier test, for calculation of edge-to-edge test spacing
D_2	diameter of miniature penetrometer in later test, for calculation of edge-to-edge test spacing
e	void ratio
$e_{\min}$	minimum void ratio
$e_{\max}$	maximum void ratio
e_0	initial void ratio
F	measured axial force on the ball or T-bar relative to zero at seafloor
f_s	sleeve friction
F_r	friction ratio ($= f_s/q_{\text{net}}$)
F_{thrust}	applied thrust to push rod
G	shear modulus
$G_{\max}$	initial (small strain) shear modulus
G_s	specific gravity of solid particles
g	acceleration due to gravity ($= 9,81 \text{ m/s}^2$),
H	specimen height
h_e	height of the cylindrical extension
h_s	height of drill pipe above main deck level
h_d	height of main deck level above the sea level
h_{sf}	height of reference point above seafloor
i	inclination of the cone penetrometer

I_L	liquidity index
I_P	plasticity index
K_0	coefficient of earth pressure at rest ($= \sigma'_{h0} / \sigma'_{v0}$)
L	length of T-bar
L_{string}	length of drill string or push rods deployed downhole, in relation to a fixed datum point located either at the seafloor (seafloor-founded systems) or at the drill floor (vessel-drilling systems)
n	number of measurements or observations
p'_f	mean effective stress at s_u
p_0'	in situ vertical effective stress ($= \sigma'_{v0}$)
Q	force in the direction of miniature ball or T-bar penetration
Q_t	normalized cone resistance
q_{ball}	net ball resistance
$q_{\text{ball,rem}}$	net remoulded ball resistance
q_c	cone resistance
q_{ci}	cone resistance immediately before the penetration interruption in a PPDT
$q_{c;\text{max}}$	is the maximum value of cone resistance measured during the penetration phase of the test
q_m	ball or T-bar resistance
q_{MCPT}	penetration/extraction resistance of miniature cone penetrometer
q_{MTPT}	penetration/extraction resistance of miniature T-bar penetrometer
q_{MBPT}	penetration/extraction resistance of miniature ball penetrometer
q_t	cone resistance corrected for pore water pressure effects
q_{net}	net cone resistance ($= q_t - \sigma'_{v0}$)
$q_{\text{T-bar}}$	net penetration resistance for a T-bar penetrometer
$q_{\text{T-bar,rem}}$	net remoulded penetration resistance for a T-bar penetrometer
Ra	surface roughness of a cone penetrometer
R_{cla}	centre-line average roughness of soil-steel interface
R_i	individual roughness value of soil-steel interface
R_f	friction ratio ($= f_s / q_c$)
S_t	soil sensitivity
$s_u = c_u$	undrained (intact) shear strength of soil
s_{uC}	static triaxial compression undrained shear strength
s_{uD}	static DSS undrained shear strength

s_{uE}	static triaxial extension undrained shear strength
s_{ur}	remoulded undrained strength
t	time
T_0	temperature of the fluid in thermostat bath 2 at 0 °C
T_{30}	temperature of the fluid in thermostat bath 1 at 30 °C
T_a	temperature recorded by a temperature sensor in the cone penetrometer
t_{100}	time to end of primary consolidation at the final consolidation step
U	normalized excess pore pressure
U_c	expanded measurement uncertainty for calibration of cone resistance (denoted as U_{cqC}) and sleeve friction (denoted as U_{cfs})
U_{class}	measurement uncertainty for the determination of cone penetrometer class
$U_{fs:class}$	measurement uncertainty for sleeve friction for the determination of cone penetrometer class
U_{inc}	expanded measurement uncertainty for cone penetrometer inclination
$U_{qc:class}$	measurement uncertainty for cone resistance for the determination of cone penetrometer class
U_u	expanded measurement uncertainty for pore pressure
$U_{u:class}$	measurement uncertainty for pore pressure for the determination of cone penetrometer class
u_{tr}	Standard measurement uncertainty for repeatability of trigger latency
u_0	estimated or measured in situ equilibrium pore pressure relative to seafloor
u_1	pore pressure measured through a filter location on the cone face (location1)
u_2	pore pressure measured through a filter location in the cylindrical extension of the cone(-location2)
u_{2i}	pore pressure immediately before the penetration interruption in a PPDT
u_3	pore pressure measured through a filter location just above the friction sleeve (location 3)
V	total volume of the specimen
V_0	initial volume of specimen
v_p	compression wave velocity
v_s	shear wave velocity
v_{vh}	vertically (v) propagated, horizontally (h) polarized shear wave velocity
v_{1max}	rate of axial displacement of the loading press
w	water (moisture) content
w_L	Liquid limit
w_P	Plastic limit

Z	height above seafloor for drilling mode in situ probe zero reference readings
z	depth below seafloor
δ_{ultimate}	ultimate interface friction angle
ε_a	axial strain
ε_{af}	expected axial strain at failure
ε_{vol}	volumetric strain
γ	unit weight
γ'	submerged unit weight of soil
γ_s	unit weight of solid particles
γ_w	unit weight of distilled water at +4 °C
ρ	bulk (dry or wet) density of soil
ρ_{max}	maximum index dry density
ρ_{min}	minimum index dry density
ρ_s	particle density of soil grains
ν	Poisson's ratio
ξ	material damping ratio
σ	stress
σ_c	uni-axial compressive strength
σ_v	vertical total stress
σ_h	horizontal total stress
σ'_v	vertical effective stress
σ'_h	horizontal effective stress
σ_{v0}	in situ vertical total stress relative to seafloor
σ'_{v0}	in situ vertical effective stress ($= p_0'$)
σ'_{h0}	in situ horizontal effective stress
σ'_p	preconsolidation stress
τ_f	shear stress at failure
ϕ'	effective friction angle
Δa_{fs}	ambient temperature stability for sleeve friction
Δa_{fsc}	ambient temperature stability for corrected sleeve friction
Δa_{qc}	ambient temperature stability for cone resistance

Δa_{qcc}	ambient temperature stability for corrected cone resistance
Δa_u	ambient temperature stability for pore pressure
Δa_{uc}	ambient temperature stability for corrected pore pressure
Δb_{fs}	bending influence on sleeve friction
Δb_{qc}	bending influence on cone resistance
Δb_u	bending influence on pore pressure
Δe_0	change in void ratio during reconsolidation
Δf_{gfs}	variation in apparent sleeve friction during verification for temperature influence
Δf_{gfsc}	variation in temperature corrected apparent sleeve friction during verification for temperature influence
Δf_{gqc}	variation in apparent cone resistance during verification for temperature influence
Δf_{gqcc}	variation in temperature corrected apparent cone resistance during verification for temperature influence
Δh_{sr}	vertical spacing between the SCPT seismic receivers
Δt_{fs}	transient temperature stability for sleeve friction
Δt_{fsc}	transient temperature stability for corrected sleeve friction
Δt_{qc}	transient temperature stability for cone resistance
Δt_{qcc}	transient temperature stability for corrected cone resistance
Δt_u	transient temperature stability for pore pressure
Δt_{uc}	transient temperature stability for corrected pore pressure
ΔV	change in specimen volume (with reduction in volume being a positive numerical value)
ΔV_{ms}	change in volume of the pore pressure measurement system due to pore pressure change
$\Delta \sigma'_v$	change in effective vertical stress

4.2 Units

If there are no special historical reasons for deviating from the units listed below, then the International System of units (SI) should be applied:

force	kN
moment	kN·m
density	kg/m ³
unit weight	kN/m ³
stress, pressure, strength and stiffness	kPa
coefficient of permeability	m/s

coefficient of consolidation m^2/s

4.3 Abbreviated terms

ASV	autonomous Surface Vehicles
BHA	bottom hole assembly
CAU	consolidated anisotropic undrained
CCV	consolidated constant volume
CD	consolidated drained
CIU	consolidated isotropic undrained
CPT	cone penetration test
CPTU	cone penetration test with pore pressure measurement
CRS	controlled rate of strain
CT	computed tomography
CU	consolidated undrained
DNV	Det Norske Veritas
DS	direct shear
DSS	direct simple shear
ERP	emergency response plan
FVT	field vane test
GNSS	global navigation satellite system
HAZID	hazard identification
HAZOP	hazard and operability
HR	high resolution
HSE	health, safety and environment
HSEMS	health, safety and environment management system
HVAC	heating, ventilation and air conditioning
ID	identification
IEC	International Electrotechnical Commission
IL	incremental loading
ISM	International Safety Management
ISO	International Organization for Standardization
ISPS	international ship and port facility security

ISRM	International Society for Rock Mechanics
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
JSA	job safety analysis
LAT	lowest astronomical tide
MARPOL	international convention for the prevention of pollution from ships
MBPT	miniature ball penetration test
MCPT	miniature cone penetration test
MSCL	multi-sensor core logging
MSL	mean sea level
MTPT	miniature T-bar penetration test
NPR	needle penetration resistance
OC	over-consolidated
OCR	over-consolidation ratio
PEP	project execution plan
PPE	personal protective equipment
PPDT	pore pressure dissipation test
QA	quality assurance
QC	quality control
QP	quality plan
RFID	Radio-frequency identification
ROP	rate of penetration
ROV	remotely operated vehicle
RS	ring shear
SCPT	seismic cone penetration test
SEM	scanning electron microscopy
SHANSEP	stress history and normalized soil engineering parameters
SIMOPS	simultaneous operations
SOLAS	safety of life at sea
SPT	standard penetration test
SUT	Society for Underwater Technology
TBT	technical barriers to trade

TOC	total organic content
UCT	unconfined compression test
UHR	ultra-high resolution
UUHR	ultra-ultra-high resolution
UU	unconsolidated-undrained
UXO	unexploded ordnance
VSP	vertical seismic profiling
WGS	world geodetic system
WTO	World Trade Organization
YSR	yield stress ratio

5 Objectives, planning and requirements

5.1 Objectives

The objectives of marine site investigations are to make data available at the various project phases. In particular, the acquired data are usually required to enable assessment of the site suitability with respect to the offshore structure and the risk tolerance and exposure level determined for an offshore structure. The planning and determination of tools and techniques shall be done after the objectives of a marine site investigation have been determined.

NOTE 1 ISO 19900 outlines general requirements for offshore structures.

NOTE 2 IEC 61400-1 and IEC 61400-3-1 outline design requirements for offshore wind turbines.

NOTE 3 ISO 31000 provides guidance on risk management principles.

The general objectives of a marine soil investigation are to establish the characteristics and mechanical properties of the seabed by acquisition, evaluation and presentation of geotechnical information derived from methods relying on tools penetrating into the seabed.

5.2 Planning

5.2.1 Sequence of activities

Marine site investigations commonly consist of the following activities, often performed in the sequence listed below and illustrated in [Figure 2](#):

- desk study, including the evaluation of information available in the public domain, available geophysical data, and the results of any previous marine soil investigations in the area;
- marine geophysical investigations (guidance provided in ISO 19901-10);
- marine soil investigations, which can comprise one or more phases to suit the project needs;
- further integrated geoscience study combining the information gathered in the desk study, marine geophysical investigation and marine soil investigation phases.

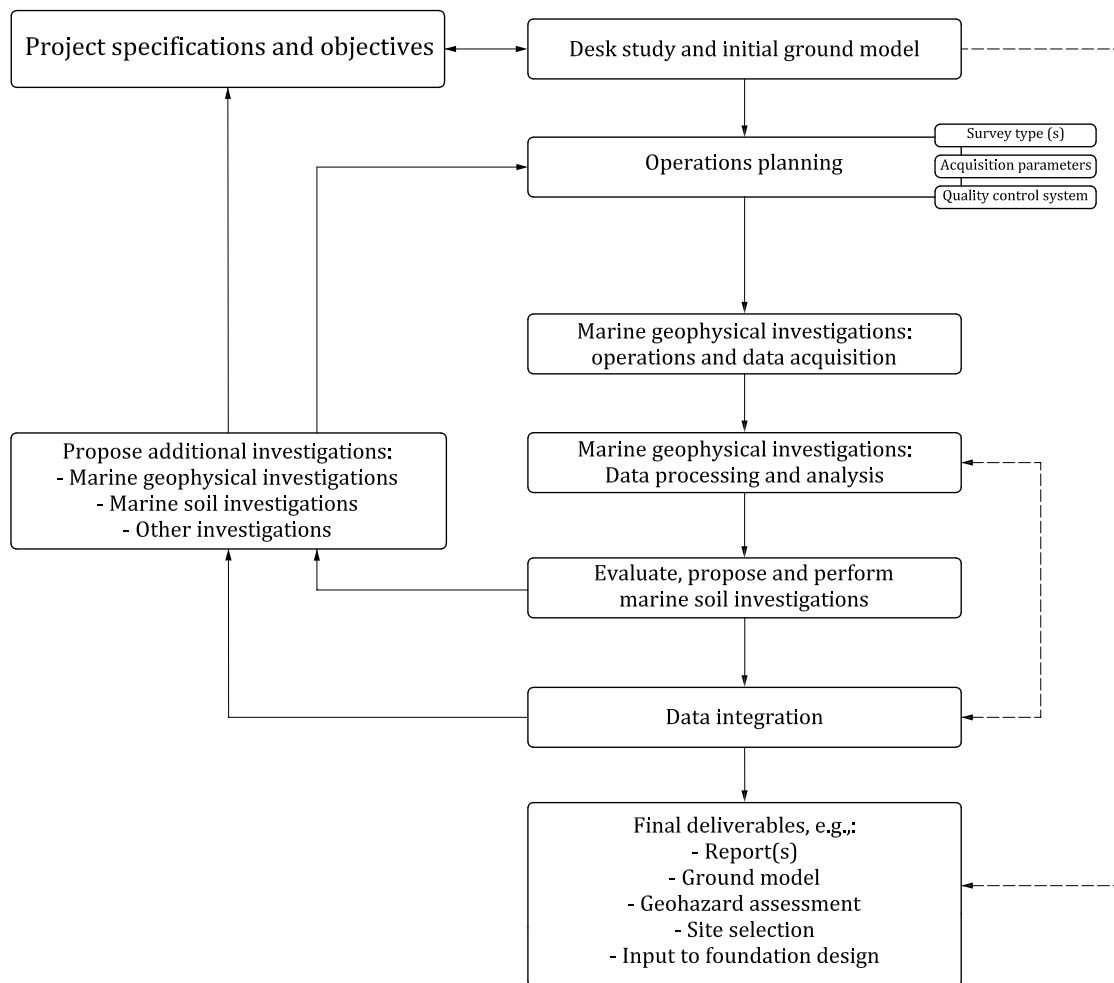


Figure 2 — Typical sequence of activities in marine site investigations

Marine geophysical investigations can comprise:

- bathymetry and seafloor topography, using a multi-beam echosounder;
- seafloor features and obstructions, using methods such as side scan sonar imaging and magnetometer surveys;
- seabed stratigraphy, using methods such as sub-bottom profiling and ultra-high-resolution seismic reflection.

A marine geophysical investigation can cover a large extent of seabed, enabling the identification of localized seabed features, such as the following:

- buried channel, or ice gouge features;
- erosion features;
- slides or shallow mass transport deposits;
- gas, gas pockets or potential gas pockets;
- specific seafloor features (e.g. pockmarks, boulders, concretions, chemo-synthetic communities and seafloor expulsion features, drill cuttings mounds);
- manmade hazards, such as unexploded ordnance (UXO).

A phased approach can be taken to a marine soil investigation. The extent of each phase shall be determined based on the marine site investigation objectives. A 'limited-scope' marine soil investigation is commonly performed in conjunction with marine geophysical investigations for the purpose of preliminary ground truthing. The results of a marine geophysical investigation, alone or in addition to a desk study, are generally not sufficient for detailed design of an offshore structure.

A marine soil investigation can include downhole geophysical logging, in situ testing and sampling operations, with field and onshore laboratory testing performed on any recovered samples, evaluation of geotechnical data and results and reporting. Specific guidance is given on selection of appropriate equipment and procedures in subsequent clauses of this document. The date by which appropriate geotechnical information is required for a given project phase determines when a marine soil investigation should be done. Having the marine soil investigation on the critical path can adversely impact subsequent activities, particularly in case of unexpected findings that require additional work.

Considerations for planning marine site investigations include project phases, requirements of the offshore structure and risk level.

NOTE 1 Examples of project phases are site selection, conceptual design, preliminary design, detailed design, re-certification and decommissioning. Risk level is commonly expressed by probability of failure and consequences of failure. Design codes commonly rely on implicit or explicit risk levels.

NOTE 2 Guidelines concerning the planning and scoping of site investigations for multi-facility sites like offshore wind farms can be found in SUT OSIG (2022)^[98].

Geotechnical design requirements for offshore structures shall be established in accordance with ISO 19900 or relevant application specific standards. The geotechnical design requirements depend on several factors that can influence the planning of the scope and extent (spatial area and explored depth) of the marine site investigations, in particular the following:

- project phase, ranging from concept selection to decommissioning;
- type of offshore structure and foundation solutions;
- types and magnitudes of actions (loadings);
- related design situations, such as bearing capacity, stability, settlements/displacements, soil-structure interaction, installation/removal aspects;
- criticality of design situations and the possible need for optimization of design and related geotechnical parameter values;
- methods to be adopted for solving/analysing the various design situations;
- geohazards.

5.2.2 Integrated geoscience studies

It is recommended to perform an integrated geoscience study to facilitate field development, planning and the design of offshore structures.

The principles of a ground model and an integrated geoscience study are given in ISO 19901-10. A multi-disciplinary team with close cooperation of geologists, geophysicists, geotechnical specialists and facility designers, involving both the marine site investigation contractor(s) and the site owner/operator, is essential for an integrated study.

The integrated study starts with an initial ground model based on the desk study. The initial ground model can be updated by a marine geophysical investigation, which is used to interpret general stratigraphy and define the scope of the marine soil investigation. Such an integrated approach allows for a comprehensive definition of an enhanced ground model and identification of potential geohazards in the zone of influence, which is typically the top 100 m to 200 m of soil below the seafloor, but can be 500 m or more in basins with deep soil profiles.

Experienced geotechnical and geophysical practitioners shall be involved in the data integration and development of a ground model. The integration of multiple data sets should consider the following:

- a) good communication and interaction in the multi-disciplinary team conducting an integrated study are essential, so that the practical limitations and uncertainties related to each set of marine geophysical and marine soil investigation data or methods are properly understood;
- b) the generation of soil parameter values using marine geophysical investigation data is a fairly novel and challenging exercise with inherent uncertainties that should be assessed consistently by integrated teams including geologists, geophysicists, geotechnical specialists and data science specialists.

5.3 Scope of work and development of project specifications

The scope of work and extent of a marine soil investigation shall be given in the project specifications, including any planning activities to be undertaken by the contractor.

The project specifications should state the objectives of the marine soil investigation.

The project specifications should, if relevant, include foundation details of the offshore structures and the selected design approaches.

The project specifications shall assign who is responsible for particular activities (i.e. client or contractor) and shall define the particular activities and corresponding methods to be adopted. Where relevant, the project specifications should refer to methods described in this document. The project specifications can refer to or describe alternative methods not covered by this document. Any references to alternative methods should be accompanied by method-specific information as applicable.

The order of precedence for application of requirements for the execution of work shall be:

- 1) the project specifications;
- 2) requirements of this document for the given scope of work;
- 3) contractor's normal practice.

NOTE 1 Requirements set by regional, national, and local regulations and standards can be different from those given in this document.

NOTE 2 A project can have more than one project specification.

NOTE 3 The project specifications can be updated during the course of a project when the client and contractor agree to deviate from the original project specifications.

Regarding marine operations, project specifications shall define responsibility for clarifying site clearance issues and any required mitigation measures. Site access or clearance issues typically include:

- navigation requirements such as minimum stand-off distance from existing facilities;
- water depth, seafloor slope and unevenness;
- possibility of encountering shallow gas, UXO and contaminated ground;
- site permits, including protected habitat and sample export.

Where the client holds site access or clearance related information, this shall be made available to the contractor.

The project specifications shall, where applicable, include requirements for:

- a) vessel positioning and equipment positioning methods and uncertainties, including the geodetic reference definition parameters and the requirements for reporting these;

- b) determination of the extent of borehole geophysical logging, sampling and testing, consisting of the following:
 - 1) type, number, location and depth of borehole geophysical logging (see [Clause 7](#));
 - 2) type, number, location and depth of in situ testing locations (see [Clause 8](#));
 - 3) type, number, distribution, location and depth of sampling locations (see [Clause 9](#));
 - 4) type and number of offshore and onshore laboratory tests (see [Clause 10](#));
 - 5) allowable data gaps and any re-testing;
- c) sample storage and transportation conditions, both offshore and onshore, including any long-term storage and storage period;
- d) choice of appropriate vessel, equipment and techniques (see [Clauses 5 to 10](#));
- e) reporting, including presentation of the results of the marine soil investigation, development of a ground model and any associated data interpretation (see [Clause 11](#)).

In situ testing data should be reported after the execution of each test, and, where practicable, prior to execution of subsequent tests, for verification purposes. Preliminary results should be reviewed in order to implement any changes to the programme of marine soil investigation before the end of the fieldwork.

Laboratory testing shall be performed in accordance with the project specifications. If not defined in the project specifications, an applicable method in an international standard or technical specification shall be followed. In the absence of an applicable method in an International Standard or Technical Specification, alternative methods, such as those defined in national standards can be followed. Any requirement for an offshore laboratory and offshore laboratory testing shall be included in the project specifications.

It may not be possible to define an item in the project specifications at the outset of a marine soil investigation, such as the consolidation stresses to be used in laboratory tests. In this case, the project specifications should define who is responsible for the activity and the approach to be taken.

5.4 Health, safety and environmental requirements for marine operations

5.4.1 General

The marine soil investigation shall conform to the project HSE requirements given in the project specifications. Marine operations shall be conducted in accordance with a project HSE plan. The project HSE plan shall be prepared before start of the project-specific marine operations and can be part of a PEP. [Annex A](#) provides guidance about the HSE plan. A risk assessment for the execution of the marine soil investigation shall be undertaken, and particular requirements/items should be included in the project specification.

5.4.2 Investigation vessel

This subclause applies to seagoing investigation vessels with national registration and an onboard crew. The requirements of this section should also be considered for small boats, jack-up platforms and ASVs, where applicable.

The vessel shall have an HSEMS. The HSEMS should conform to the requirements of the international management codes for safe operation of ships (ISM code) and for pollution prevention (MARPOL code), and with the SOLAS code, or equivalent codes. The vessel should also conform to the ISPS code, where applicable. Guidance on the documentation requirements for the vessel can be found in ISO 19901-6:2009, Table 1 for cargo vessels.

The vessel shall be crewed with a sufficient number of qualified, trained and experienced personnel to perform required marine soil investigation operations, including the operation, maintenance and repair of safety critical equipment.

The safety and well-being of those involved in, and impacted by, the marine soil investigation shall be considered. Personnel involved shall be familiar with safety procedures requisite for the safe completion of tasks in which they participate and general onboard safety, including appropriate offshore survival procedures. The operators of marine soil investigation equipment shall have training and experience in the use of the equipment. Relevant personnel shall be aware of reporting requirements for HSE incidents. HSE incidents or accidents shall be reported.

The investigation vessel shall have appropriate safety equipment to conform to SOLAS codes, including adequate maritime lifesaving equipment, and shall have PPE (e.g. hard hats, safety glasses, flotation work vests, safety lines) as required by individual JSAs and vessel HSEMS, and shall have onboard personnel familiar with and trained in its use.

Special care shall be exercised for 'specially-mobilized' vessels, as opposed to purpose-built vessels, for marine soil investigation, to ensure all temporarily-mobilized equipment is safely installed and operated, and that interfaces between permanent vessel crew, who can be unfamiliar with marine soil investigation operations, and temporary crew members (e.g. positioning crew, client representative(s) and any other specialist crew members) are properly managed.

Marine soil investigation equipment shall not be used before it is safely installed. Lifting equipment, such as cranes, booms, hoists, spreader bars, slings, shall be suitable for the proposed use, checked, inspected or certified, and appropriately tagged or marked. During the marine soil investigation, the vessel should be subject to ongoing safety monitoring.

When operations become unsafe for any reason, such as excessive vessel motion, work shall cease and equipment shall be secured.

5.4.3 Hazardous substances and acoustic noise

Substances, such as drilling mud, laboratory chemicals and radioactive sources, can require special care during handling and storage. The presence and special handling and storage requirements of any hazardous material on board the vessel shall be documented, such as in the project HSE plan.

The project HSE plan should consider the potential impact of in-water investigation equipment on the marine environment (e.g. loss of hydraulic fluid, acoustic noise).

5.4.4 Shallow gas

Shallow gas poses a significant hazard to marine operations. Release of shallow gas from the seabed into the sea and atmosphere also has an environmental impact.

A shallow gas hazard assessment shall be undertaken to identify the likelihood of encountering gas during a marine soil investigation for the specific locations, depths below seafloor and planned activities. The shallow gas hazard assessment should typically consider the following:

- a) distance to production infrastructure and historic well-drilling activity;
- b) desk study information, including regional geology, possible presence of gas hydrates and relevant offset well information;
- c) marine geophysical investigation data, considering type, quality, resolution, depth of penetration below seafloor, and timing of the data acquisition;

NOTE 1 There are several examples where a shallow gas release took place during a marine soil investigation while it was not identified by a site-specific marine geophysical investigation. Reasons can include the presence of dissolved gas in pore water and the occurrence of thin gas bearing layers. Use of geophysical data alone can result in the inevitable level of uncertainty related to the identification of a shallow gas hazard.

- d) potential for changes since marine geophysical investigation (e.g. due to well-drilling activity);
- e) potential depth, pressure and volume of shallow gas;

NOTE 2 In most cases, no reliable information will be available on potential pressure, volume and formation flow rate of shallow gas.

- f) possible sources of shallow gas and likely gas characteristics (composition, toxicity, flammability, density).

A risk assessment shall be undertaken considering the potential consequences of gas release and the mitigating measures available, and documented in the HSE plan.

5.5 Other requirements

5.5.1 Operational requirements

The proposed scope of the marine soil investigation shall be considered when selecting vessels and investigation tools along with the environmental conditions at the planned fieldwork site, such as:

- water depth;
- seafloor slope;
- wind, wave and current conditions;
- possibility of shallow gas/hydrates, shallow water flow and other drilling hazards.

Lifting, handling and deployment facilities (e.g. A-frames, booms, davits, cables, cradles, drilling equipment, winches) for the required logging, sampling and in situ testing equipment, supplies and other equipment shall be suitable for the purposes required and shall be inspected or certified for such use where appropriate. An appropriate inspection regime shall be in place. Dynamic effects from vessel motion and the additional frictional and suction forces imposed on a piece of investigation equipment (e.g. seafloor frame, corer, CPTU) shall be included when determining the maximum anticipated loading on a lifting element, as this additional loading can be significant.

Equipment used during the marine soil investigation should have documentation consisting of operational and maintenance procedures. Where two or more pieces of equipment have a critical interface, those interfaces shall be evaluated to ensure proper operation.

Daily field activities shall be documented during the field operations.

5.5.2 Quality requirements

Geotechnical specialists shall be involved during the planning and preparation of the marine soil investigation project specifications.

The client should have a project quality management system in place, with quality assurance exercised consistently and competently in all phases of investigation and evaluation. The contractor should operate a documented quality management system, such as ISO 9001 or ISO 29001.

A project QP should be incorporated as part of a PEP for the marine soil investigation (see [Annex A](#)). The QP should detail the organizational responsibilities, activities, and an index of referenced and applicable procedures to complete the scope of the marine soil investigation.

Quality system audits against the quality management system should be performed. The client and contractor should address and resolve audit reports, recommendations and/or corrective actions within the responsibility of the client and contractor respectively.

5.5.3 Specific considerations for unconventional soils

The requirements and recommendations in this document have been developed primarily for use in conventional soils, i.e. siliceous sands and clays of terrigenous origins which have relatively well understood generic properties, and for which there are well established marine soil investigation practices. When performing a marine soil investigation in frontier areas, or areas known or suspected to contain unconventional soils, this can require special handling or treatment for soils. The equipment, methods and procedures can also require tailoring to investigate properties that can pose particular difficulties for geohazard assessments and engineering. Examples of soils with specific generic properties that can need special attention are listed in [Table A.3](#).

NOTE 1 Calcareous deposits offer an example of how an investigation can be adapted to suit soil type: such soils can be variably cemented and range from lightly cemented with sometimes significant void spaces to extremely well cemented. Therefore, in planning a marine soil investigation, it is important to incorporate sufficient flexibility in the scope of work to switch between soil push sampling, rotary core drilling, and in situ testing techniques as appropriate. In these soils, a carefully developed field and laboratory testing programme can be warranted. ISO 19901-4 provides relevant guidance.

NOTE 2 Relevant properties of frozen soils, permafrost and other geotechnical considerations in arctic environments are discussed in ISO 19906 and ISO 35106.

6 Deployment of investigation equipment

6.1 Non-drilling mode deployment

Non-drilling mode encompasses the practice by which geotechnical testing or sampling tools are initiated at the seafloor, or at the elevation where the equipment is stable, and penetrated to refusal depth or to a predetermined depth outside of a rotary drilled borehole. Tool penetrations generally vary from 0,5 m to greater than 25 m below seafloor, depending on the tool that is deployed and the geology that is encountered. Penetrations in excess of 40 m are possible using specialist equipment.

A vast array of geotechnical testing and sampling equipment is deployed using this technique. The more sophisticated of these tools are landed on the seafloor prior to the commencement of the seabed penetration, i.e. fixed seafloor reference. The simplest of these tools are simply lowered until they encounter the seafloor, allowed to penetrate to refusal under their own weight, then extracted and recovered to the vessel deck, i.e. no fixed seafloor reference.

The quality of data acquired can vary with the level of sophistication of the tools. Sophisticated seafloor-founded, non-drilling mode rigs can acquire high quality samples and/or in situ data. At the other end of the spectrum, non-heave-compensated winch-controlled tools, such as gravity core, Kullenberg piston core and vibrocore samplers, can have a limited capacity to acquire good quality samples.

A common limitation of non-drilling mode equipment relates to the inability to achieve a target penetration depth when a seabed layer is intercepted whose strength exceeds the penetration capability of the tool.

Notwithstanding the above, non-drilling mode tools are widely used for acquiring seabed geotechnical data in favourable geological conditions, due to their generally high level of availability, comparatively lower cost, and their capacity to be deployed from a wide range of vessels.

6.2 Drilling mode deployment

6.2.1 General

In drilling mode, logging, sampling and in situ test tools are deployed into the seabed, initially commencing from the seafloor and thereafter from the bottom of a borehole that is progressed via rotary drilling.

Drilling mode operations can be undertaken from the sea surface (referred to as ‘vessel drilling’), from seafloor-founded drill rigs (referred to as ‘seafloor drilling’) and combinations thereof.

Geotechnical tools are deployed to the bottom of the borehole using a variety of techniques, including wireline, free fall, or via advancement and recovery of the drill string itself. Once located at the bottom of the borehole, the geotechnical tool is penetrated via hydraulic or mechanical means until the maximum stroke length, the borehole target depth, or the mechanical capacity of the system is achieved.

At the completion of a testing or sampling interval, the tool is either recovered to the surface through the drill string (vessel drilling), or temporarily stored on the rig (seafloor drilling). The borehole is then progressed to the next testing or sampling depth.

Further provisions related to rotary drilling techniques are provided in [Clause 7](#).

6.2.2 Vessel drilling

Vessel drilling operations are undertaken from either:

- a spudded, anchored or dynamically positioned floating vessel, such as a drill ship, semi-submersible vessel, barge or similar craft, or
- a stable non-floating platform, such as a jack-up or permanent seabed structure.

Vessel drilling systems are influenced by movements associated with surface environmental conditions and subsea currents. For many vessel drilling systems, the vertical stability of the drill string can be controlled or limited by means of

- a seafloor-founded template with a ‘hard-tie system’ heave compensator (see Zuidberg et al. (1986) [\[173\]](#)), or
- a heave compensator on the drilling vessel in conjunction with soil resistance that reduces movement of the drill string.

Less sophisticated vessel drilling systems are uncompensated against vessel heave. Further discussion of the effects of vessel heave on drill string stability, and the uncertainty of vertical depth measurements, is provided in [A.6.3](#).

6.2.3 Seafloor drilling

Seafloor drilling systems are landed on the seafloor and all operations are undertaken via remote control with the rig being isolated from the vessel movements and environmental conditions at the sea surface.

The stability of seafloor drilling systems is largely dependent on the capabilities of the footings used to support the rig. Sophisticated footing systems can incorporate the capacity to land on steep slopes, self-level the rig, and monitor the vertical height of the rig relative to the seafloor to enhance the certainty of vertical depth measurements.

6.3 Uncertainty of vertical depth measurements

6.3.1 General

Appropriate measurement of vertical depth assists in ensuring that:

- the vertical positions of data points can be referenced to a vertical datum such as seafloor, LAT or MSL;
- variations in seabed stratigraphy, including seafloor, are adequately defined;
- appropriate overburden and pore water pressure corrections are applied to in situ test data;

- adjacent samples and in situ test data can be precisely correlated;
- appropriate confining stresses are specified during subsequent laboratory test programmes.

6.3.2 Factors affecting the uncertainty of vertical depth measurements

A data point can be defined at any depth below seafloor at which geotechnical data are acquired. The depth uncertainty of a data point can vary depending on:

- water depth;
- soil conditions near seafloor;
- metocean conditions at the time of investigation;
- selected investigation tools;
- the mode by which equipment is deployed;
- the vertical stability of the equipment during the data acquisition phase;
- the uncertainties of the measurement system;
- the uncertainties of estimation of a sample data point within a sampling tool.

The achievable depth uncertainty class when using a vessel-mounted drilling system can depend on the prevailing environmental conditions at the sea surface, the associated vessel motions, the water depth, the capability of a vessel's heave-compensation system, and whether the drill string can be stabilized at the seafloor during downhole data acquisition. In contrast, the depth uncertainty class achieved with a seafloor-founded system can depend on the capabilities of the monitoring system used to estimate the position and levelness of the rig relative to the seafloor, and the length of the drill string or push rods deployed downhole.

Data point depth uncertainty can additionally vary as a result of the performance of a sampling tool.

NOTE The allocation of sample loss within a sampling run is often solely based on engineering judgement. This can introduce additional uncertainty as to the actual depth from which the sample originated.

6.3.3 Depth uncertainty classes

The project specifications should specify the depth uncertainty class, as defined in [Table 1](#), to be achieved in a marine soil investigation based on the intended use of the geotechnical data, with due consideration to the investigation scope, the capabilities of the equipment under consideration and procedures. Multiple depth uncertainty classes can be specified, for example differentiating between data points acquired by in situ testing and sampling operations. The depth uncertainty for a sample data point depends on the uncertainty of the sample position within a sampling tool, i.e. allocation of any sample loss/extension within a sampling run. Guidance is provided in [9.5](#) and [Annex A](#).

If no depth uncertainty classes are given in the project specifications, a default value Z2 shall apply to data points acquired by borehole geophysical logging and in situ testing. A default depth uncertainty class Z3 shall apply for data points acquired by sampling, except for samplers with no fixed seafloor reference, where a default depth uncertainty class Z5 shall apply (see [9.4](#) and [A.6.3.3](#)).

Table 1 — Depth uncertainty classes for data points relative to seafloor

Depth uncertainty class	Maximum data point depth uncertainty m
Z1	0,1
Z2	0,5
Z3	1,0
Z4	2,0
Z5	>2,0

The depth uncertainty according to [Table 1](#) shall be estimated as combined standard uncertainty in accordance with ISO/IEC Guide 99. Demonstration of the depth uncertainty that can be achieved with proposed investigation equipment shall be documented by the contractor. For cases where depth uncertainty is expected to vary with changes in water depth and/or depth of data point below the seafloor, the variation in depth uncertainty class should be estimated for each intended investigation area. The achieved depth uncertainty class or depth uncertainty classes shall be reported. The reporting on depth uncertainty class shall include the method and numerical values used for estimation of data point uncertainty. The vertical datum should be seafloor as found immediately before the marine operations at the target location.

6.4 Horizontal positioning

The accuracy to which boreholes and/or equipment are located on the seafloor is an important aspect of a geotechnical data set, because it is imperative that:

- current investigation locations are aligned with previous and future marine soil investigations, and the installation of offshore structures;
- known seafloor hazards, including installed offshore structures, natural seabed obstructions, excessive gradients, identified areas of shallow gas, UXO and other features, are avoided with confidence.

The coordinate reference system and corrections to be applied to the data set shall be included in the project specifications.

Specification of horizontal positioning tolerances can be influenced by:

- the type of offshore structures to be installed on the seafloor;
- the type, levels of equipment redundancy and uncertainties of the positioning measuring system;
- the proximity of existing offshore structures, including the estimated uncertainty of their reported positions;
- the known seafloor topography: water depth, seafloor slopes, natural features.

Further guidance on horizontal positioning requirements is provided in ISO 19901-10.

6.5 Interaction of investigation equipment with the upper seabed

The action of landing and operation of equipment on the seafloor can disturb the upper seabed from the applied surcharge pressures or lead to the seafloor template penetrating into the upper seabed. This can be detrimental to data quality, particularly for very soft seabed. Where appropriate, consideration should be given to deployment of specific investigation equipment for acquisition of high-quality data for the upper seabed (e.g. equipment with no fixed seafloor reference, equipment with low bearing pressure, and sophisticated seafloor drills with large, extended footings). Detailed bathymetry information is normally required to confirm that the investigation equipment can be safely operated in order to optimize landing speed and upper soil disturbance during landing.

Reporting shall include an assessment of the interaction of the deployed investigation equipment with the upper seabed, and whether this can have adversely affected the acquired data, including any elevation changes of the investigation equipment and any correction applied to the acquired data. Further guidance is provided in [A.6.5.1](#).

7 Drilling and logging

7.1 General

Drilling operations can be undertaken by various modes of equipment deployment defined within [Clause 6](#).

The delivery of the drilling operation can be fundamental to the overall success of the marine soil investigation.

A borehole is advanced by the combined action of a rotating cutting surface (the drill bit) on material at the bottom of the hole and the flow of drilling fluids that flushes drill cuttings in suspension from the bottom of the hole up the enclosing annulus between the drill pipe and borehole wall (or casing inner wall).

Some soil disturbance ahead of the drill bit is inevitable and can have a measurable effect on data quality. Excessive, or varying, weight on the drill bit tends to increase soil disturbance as the bit impacts undisturbed material at the drill face; rotation speed and torque can also influence sample quality. Excessive drilling fluid pressure can induce hydraulic fracture or erosion of undisturbed material, and excessive drilling fluid flow can soften or erode undisturbed material. Soil disturbance can often be assessed by inspection of the results from the sampling and in situ testing and operational methods can be adjusted as required. For heave compensated drilling the depth of soil disturbance below the drill face, and the magnitude of its effect, tend to be greater for softer soils as many systems require a reaction force provided by the soil to compensate against. For marine drilling operations, the vertical stability of the drill string during borehole advancement is critical to the recovery of high-quality geotechnical data. Fluctuations in applied bit weight, and associated displacements, during sampling and in situ testing operations can be detrimental to data quality. Drill string stability and out-of-straightness is largely affected by the type of equipment used to deploy the drill string. Further information on this issue is provided in [Clause 6](#).

7.2 Project-specific drilling requirements

The choice of drilling equipment suitable for a particular marine soil investigation is generally dictated by a number of key project-specific drilling requirements, which can consist of the following:

- expected soil conditions and possible drilling hazards, such as shallow gas, flowing sands, swelling clays, hydraulic fracture potential;
- required borehole depth and purpose of geotechnical borehole(s):
 - borehole suitable for deployment of specific testing or sampling tools, and/or
 - performance of a pilot hole or borehole to acquire drilling parameters (i.e. destructive drilling);
- site environment and seafloor characteristics (e.g. water depth, expected weather and sea conditions (current, tide, extremes of temperature), proximity of surface, submerged, seafloor or buried infrastructure, seafloor topography, natural seafloor features);
- required depth uncertainty class (see [6.3](#));
- HSE considerations (e.g. personnel interventions on the drill floor, environmental discharge regulations for drill cuttings and/or mud type);
- Logistical considerations (e.g. project schedule, availability of equipment).

7.3 Drilling objectives and selection of drilling equipment and procedures

Drilling objectives of a marine soil investigation are typically one or more of the following:

- to recover data of sufficient quality, whilst minimising soil disturbance from drilling, where the marine soil investigation results will be used to determine geotechnical parameter values for design purposes;
- to maximize the continuity of data recovered within a borehole (at the possible expense of reduced data quality), for example for geological investigations for which key horizons can be very thin and therefore require a data record as continuous as possible;
- to maximize the speed of drilling, at the expense of data quality and/or continuity, in the interests of providing as much spatial or depth coverage of a site as possible within a given time or budget constraint, for example for hard-layer detection;

The selection of drilling equipment and procedures shall be based on the drilling objectives given in the project specifications, with due consideration to the range of expected soil conditions and drilling hazards that can be encountered. For sampling by rotary core drilling, the drilling system and the associated sampling techniques can conform to the requirements of ISO 22475-1 (mainly for onshore and nearshore soil investigations).

Further guidance on the selection of drilling equipment and procedures is provided in [A.7.3](#).

7.4 Drilling operations plan

A drilling operations plan should be in place before start of drilling activities on site. The purpose of the drilling operations plan is twofold:

- 1) during the pre-fieldwork phase, to provide assurance that:
 - required information is documented as detailed below;
 - the proposed solution is capable of meeting the objectives of drilling and logging;
 - consideration has been paid to potential drilling hazards (see [7.2](#));
 - contingency plans are in place in the event of foreseeable drilling-related problems;
- 2) during the fieldwork phase, to control the execution of the drilling and borehole works.

The level of detail required depends on the complexity of the marine soil investigation, on the tools and techniques to be employed, and on whether any new or modified equipment or procedures are required.

The plan should not hinder the continuous assessment of data quality and if necessary, the adjustment in operational procedures if required during the completion of the work. For the range of possible soil conditions, the drilling operations plan shall document the following components, where applicable:

- a) drilling equipment and operational details (see [A.7](#));
- b) borehole construction plan, describing the sequence of borehole construction (with drill string details and drill bit selection), identification of possible drilling problems, borehole abandonment procedures and grouting procedures, and contingencies or remediation options (e.g. in the event of stuck string or tool lost in the borehole);
- c) mud plan, with the drilling fluid solution adopted and criteria for change of fluids considering potential for adverse chemical reaction (see [A.7](#));
- d) requirements for documentation and reporting of drilling parameters;
- e) schedule for borehole geophysical logging, in situ testing and sampling;

- f) shallow gas plan if potential for a shallow gas release exists (see [5.4.4](#));
- g) grouting plan, with the grouting fluid/additives selected, grouting procedures and requirements for grout testing (i.e. grout cube crush tests and acceptance criteria).

7.5 Recording of drilling parameters

During the process of borehole drilling, the system operational and performance parameters shall be documented. Recording can be done manually (usually by the driller) or by using an automated logging system. When depth resolution of logged parameters better than 0,5 m is required, use of automated logging is the preferred method.

The recorded parameters and information shall include the following:

- a) geographical location and borehole name;
- b) water depth (e.g. relative to LAT or MSL);
- c) type of drilling fluid and properties;
- d) type of drill bit and bottom hole assembly;
- e) Date and time (dd/mm/yyyy hh:min);
- f) penetration (depth to bottom of borehole) (m);
- g) ROP (m/min);
- h) time to drill each interval (min);
- i) duration and reason for any stoppage (min);
- j) drilling fluid pressure at the output of the pump (kPa), where available;
- k) drilling fluid rate (input) (l/min), where available;
- l) drilling fluid recovery rate (l/min), only for riser drilling with recirculation of drilling fluid, and where available;
- m) drill head rotational torque (N·m), where available;
- n) drill head rotational speed (revolutions per min), where available;
- o) weight on bit (kN), where available.

The recording of drilling parameters can provide a valuable data set for use in interpolation/extrapolation of soil data and detection of layering.

NOTE An example of such application for detection of hard layers in carbonate material is given in Becue et al. (1988)^[102].

7.6 Borehole geophysical logging

7.6.1 General

Borehole geophysical logging provides enhanced geological and engineering detail over the logged borehole section. Further guidance is provided in [A.7.6](#).

The project specifications should specify the following, where applicable:

- a) required measurement types and corresponding logging tools;

- b) applicability of logging tool for expected setting, including metocean conditions, depth below seafloor and soil conditions;
- c) deployment method (e.g. wireline, open- or cased-borehole logging);
- d) minimum number of measurements per logged depth section;
- e) required sequence, direction and speed of lifting (or lowering) of the tool for logging;
- f) uncertainty of depth below seafloor;
- g) required correlations between measurements and geotechnical parameters;
- h) number of tools or length of logging section per run;
- i) whether a heave-compensated logging line is required;
- j) length of rat hole to be drilled.

7.6.2 Reporting of results

Reporting of borehole geophysical logging results shall include, where applicable:

- a) geographical location and borehole name;
- b) coordinates, including coordinate reference system;
- c) water depth (e.g. relative to LAT or MSL);
- d) measurement results and derived values of geotechnical parameters;
- e) characteristics of the borehole geophysical logging system, including deployment method;
- f) details of borehole conditions in accordance with [Clause 7](#);
- g) statement on corrections applied to the data;
- h) details of the processing performed on the data;
- i) distinction on open-hole logging or in-pipe logging;
- j) sequence, direction and rate of travel of the logging probes in the borehole;
- k) achieved depth uncertainty class according to [6.3.3](#);
- l) definitions, formulae, assumptions, and limitations of derived values of geotechnical parameters.

8 In situ testing

8.1 General

In situ tools can be deployed via two alternative methods:

- 1) non-drilling mode, in which tool penetration is initiated at the seafloor and penetrated to refusal, or to a predetermined depth; or
- 2) drilling mode, where the tool is lowered down a predrilled borehole and in situ testing is initiated at the bottom of the borehole.

The recommendations and requirements given in [Clause 6](#) should be taken into account when planning and performing in situ tests. For tests undertaken in drilling mode, [Clause 7](#) should also be consulted.

Calibration of in situ probe sensors shall be performed in a calibration laboratory that meets the requirements of ISO/IEC 17025. The calibration laboratory should be accredited for the calibration and verification activities required for in situ tools.

In situ tools and probes shall be manufactured using corrosion resistant material applicable to marine conditions.

8.2 General requirements for the reporting of in situ tests

For each test, the following information shall be reported in addition to the test results:

- a) site geographical details, including:
 - geographical location;
 - borehole or test title;
 - coordinates, including coordinate reference system given in the project specifications (e.g. WGS 84);
 - water depth (e.g. relative to LAT or MSL);
- b) equipment details (as applicable):
 - deployment mode;
 - cone penetrometer class according to [Table 2](#);
 - measuring intervals for calibration of the sensors for test measurements;
- c) test details (as applicable):
 - test type;
 - time and date;
 - test/stroke number;
 - current borehole depth;
 - tool type (geometry/capacity);
 - unique equipment/tool number;
 - applied thrust to push rod (F_{thrust} in kN) during penetration into the seabed;
 - summary of procedures for verification of applied thrust and for verification of achieved penetration;
 - stop criteria/reason for termination;
 - test category in accordance with [Table 4](#).

In addition, the following information should be documented:

- d) additional site geographical details, including facility name;
- e) additional equipment details (as applicable):
 - equipment name;
 - type of penetration system;
 - borehole progression method;

Any deviations from the test requirements (e.g. testing procedures, tool wear and tool damage) shall be identified and reported.

8.3 Cone penetration test

8.3.1 General

This subclause covers cone penetration tests performed with a CPT and with a CPTU.

8.3.2 Equipment

A standard cone penetrometer is defined as having a nominal cross-sectional area, A_c , of 1 000 mm². Cone penetrometers with diameter between 25 mm ($A_c = 500$ mm²) and 50 mm ($A_c = 2 000$ mm²) may be used for special purposes without the application of correction factors. Cone penetrometers with diameter less than 25 mm or diameter exceeding 50 mm may be used for special purposes, and for such cone penetrometers, suitable correction factors shall be applied, and the values of the correction factors shall be reported.

The geometry, surface roughness and surface hardness of a cone penetrometer shall comply with ISO 22476-1, subject to the following clarifications and amendments:

- 1) For cone penetrometers with a diameter other than a nominal diameter of 35,7 mm, the dimensional tolerances given for standard $A_c = 1 000$ mm² cone penetrometer should be linearly scaled in proportion to the diameter;
- 2) The surface area of the friction sleeve, A_s , may differ from 15 000 mm² for cone penetrometers with a diameter other than a nominal diameter of 35,7 mm. The nominal ratio of length to diameter of the friction sleeve should be between 3 and 5 (preferably 3,75);
- 3) For measurement of u_2 , the filter element shall be in the cylindrical part of the cone. The cylindrical part of the cone excludes the gap between the cone and the friction sleeve;
- 4) For measurement of u_2 , the diameter of the filter at the start of the test shall be equal to the diameter of the cylindrical part of the cone, applying dimensional tolerance limits in accordance with ISO 22476-1;
- 5) The diameter of the filter element may differ from the diameter of the friction sleeve.

NOTE 1 The amendments and clarifications above are based on ISO 22476-1.

For pore pressure measurements, the filter element location in the cylindrical extension part of the cone is recommended. Pore pressure measured at this location is denoted u_2 (Location 2). Pore pressures can also be measured on the cone face (u_1) (Location 1) and/or just above the friction sleeve (u_3) (Location 3).

NOTE 2 Pore pressure measurement at Location 1 (u_1) can show lower susceptibility to loss of saturation upon penetration in dense dilating sands, compared to measurements at Location 2 (u_2).

A cone penetrometer designed solely for the measurement of cone resistance may be used, if the following conditions are met:

- a) geometry and surface roughness of the cone penetrometer comply with ISO 22476-1, where applicable;
- b) downhole deployment in drilling mode; and
- c) ground conditions are such that cone resistance values exceeding 120 MPa can be expected.

NOTE 3 The permission for a cone penetrometer with a limited number of sensors allows the use of more robust cone penetrometers. The primary benefit would be increased CPT coverage in hard ground, i.e. an increase in safe deployment limits.

The cone penetrometer and adjoining rod(s) should have the same diameter for at least 400 mm behind the tip for standard $A_c = 1\,000\text{ mm}^2$ cone penetrometers. For other size cones, this distance should be linearly scaled in proportion to the diameter.

NOTE 4 Changing rod diameter at a distance of less than 400 mm (for standard $A_c = 1\,000\text{ mm}^2$ cone penetrometers) can influence the directional stability of the system and possibly the cone resistance.

8.3.3 Test procedures

8.3.3.1 Selection of equipment and procedures

Equipment and procedures to be used should be selected considering the expected ground conditions and the project specifications.

Cone penetration test results shall be classified considering the cone penetrometer uncertainty characteristics and diagnostic checks of the sensors during the field work, using:

- a) cone penetrometer class described in [8.3.3.3](#);
- b) test category described in [8.3.4](#).

[A.8](#) provides guidance for selection of cone penetrometer class and provides an indication of test categories that can be achieved.

8.3.3.2 Calibration and verification requirements

Cone penetrometers shall be calibrated for the following measurands, where applicable:

- a) cone resistance;
- b) sleeve friction;
- c) pore pressure;
- d) area ratios of the cone (*a*) and of the friction sleeve (*b*);
- e) inclination.

Calibration shall include determination of dimensions of the cone, friction sleeve and, where applicable, filter element and gaps. Cone penetrometers shall be verified for temperature influence and for bending influence.

Calibration and verification of cone penetrometers shall be in according to ISO 22476-1, subject to the following clarifications and amendments:

- 1) The calibration interval shall be limited to the following, whichever is earlier:
 - twelve months after first use of a cone penetrometer for a cone penetration test, and
 - up to the date and time when one or of the sensors is overloaded or showing signs of malfunction.
 The period prior to first use shall not exceed 12 months;
- 2) The statement of conformity with at least one of the cone penetrometer classes shall be according to requirements for the cone penetrometer classes given in [8.3.3.3](#) of this document;
- 3) The uncertainty contributions for calibration of the pore pressure sensor may exclude uncertainty of the dimensions of the cone penetrometer;
- 4) If the pressure vessel for calibration of the pore pressure sensor is filled with gas, then the temperature in the pressure vessel shall be recorded and presented as described for a pressure vessel filled with fluid;

- 5) For determination of cone and friction sleeve dimensions, the expanded measurement uncertainty for the measuring device for dimensional measurement shall be determined for a coverage factor of $k = 2$;
- 6) The maximum value of expanded measurement uncertainty for cone penetrometer inclination shall be used for conformity assessment according to [8.3.3.3](#) of this document;
- 7) For verification of a cone penetrometer for temperature influence, the apparent temperature T_a refers to the temperature recorded by a temperature sensor in the cone penetrometer that is used for determination of Δa_{qcc} , Δa_{fsc} , Δa_{uc} , Δt_{qcc} , Δt_{fsc} or Δt_{uc} . The temperatures T_0 and T_{30} refer to the temperatures of the fluid in respectively thermostat bath 2 at 0 °C and thermostat bath 1 at 30 °C;
- 8) For verification of a cone penetrometer for temperature influence, the position requirements (e.g. fluid level) for the cone penetrometer in thermostat bath 1 shall be as described for thermostat bath 2;
- 9) For verification of a cone penetrometer for temperature influence, test records and test report may be split, similar to the test records and calibration report for the pore pressure sensor;
- 10) For verification of a cone penetrometer for temperature influence, the test report shall include, where applicable, variation in cone resistance (Δf_{gqc} and Δf_{gqc}) and variation in sleeve friction (Δf_{gfs} and Δf_{gfs}) determined as defined by ISO 22476-1;
- 11) For verification of a cone penetrometer for bending influence, clamping of the cone penetrometer shall not be done with the loading device. The loading device shall be independent from the frame for clamping;
- 12) For cone penetrometer classes 1 and 2 according to [8.3.3.3](#) of this document, the verification of a cone penetrometer for temperature influence and for bending influence may be limited to reporting the results for 20 or more tests on cone penetrometers of the same design, the same type and made according to the same manufacturing and assembly process. The verification results for these penetrometers shall all meet the decision rules for respectively temperature influence and bending influence defined in [Table 2](#) of this document.

NOTE The amendments and clarifications above are based on ISO 22476-1.

Test records, calibration reports and test reports for calibration and verification shall include:

- i. description and identification of the cone penetrometer;
- ii. identification of the calibration laboratory (or calibration laboratories);
- iii. description of the calibration laboratory environment during calibration, average temperature and range of variation;
- iv. identification and uncertainty characteristics of reference instruments used for calibration and verification;
- v. details of any adjustment or repair made prior to calibration;
- vi. date of calibration, measuring intervals for calibration and calibration results;
- vii. analysis of the uncertainty of the calibration for each of the penetrometer sensors;
- viii. statement of conformity to cone penetrometer class according to [Table 2](#);
- ix. statement identifying how the measurements are metrologically traceable.

8.3.3.3 Cone penetrometer class conformity assessment

Cone penetrometers shall be classified following the scheme presented in [Table 2](#). Required values of the parameters of [Table 2](#) ($U_{qc:class}$, $U_{fs:class}$, $U_{u:class}$, Δa_{qc} , Δa_{fs} , Δa_u , Δt_{qc} , Δt_{fs} , Δt_u , Δa_{qcc} , Δa_{fsc} , Δa_{uc} , Δt_{qcc} , Δt_{fsc} , Δt_{uc} , Δb_{qc} , Δb_{fs} and Δb_u) shall be calculated in accordance with [8.3.3.2](#), where applicable.

For the fulfilment of cone penetrometer classes 1+ and 1, the cone penetrometer shall have cone resistance, sleeve friction and pore pressure sensors. The cone penetrometer shall meet all the requirements for each of the sensors for a given cone penetrometer class to be achieved.

Conformity to a cone penetrometer class shall be determined after each calibration of the cone penetrometer.

Table 2 — Classification of cone penetrometers under laboratory conditions

Cone penetrometer class	Measurand	Allowable maximum measurement uncertainty ^a	Ambient temperature stability ^c	Transient temperature stability ^c	Bending influence ^c
		$U_{qc:class}$ $U_{fs:class}$ $U_{u:class}$	Δa_{qc} or Δa_{qcc} Δa_{fs} , or Δa_{fsc} Δa_u or Δa_{uc}	Δt_{qc} or Δt_{qcc} Δt_{fs} or Δt_{fsc} Δt or Δt_{uc}	Δb_{qc} Δb_{fs} Δb_u
1+	Cone resistance	35 kPa or 1 %	1 kPa/°C	5 kPa/°C	0,3 kPa/N
	Sleeve friction	5 kPa or 1 %	0,1 kPa/°C	0,5 kPa/°C	0,1 kPa/N
	Pore pressure	25 kPa or 0,5 %	0,1 kPa/°C	0,5 kPa/°C	0,05 kPa/N
1	Cone resistance	35 kPa or 1 %	2 kPa/°C	10 kPa/°C	0,3 kPa/N
	Sleeve friction	5 kPa or 1 %	0,1 kPa/°C	0,5 kPa/°C	0,1 kPa/N
	Pore pressure	25 kPa or 0,5 %	0,1 kPa/°C	0,5 kPa/°C	0,05 kPa/N
2	Cone resistance	100 kPa or 2 %	10 kPa/°C	50 kPa/°C	1 kPa/N
	Sleeve friction	15 kPa or 2 %	0,5 kPa/°C	2,5 kPa/°C	0,5 kPa/N
	Pore pressure ^b	50 kPa or 1 %	1 kPa/°C	2,5 kPa/°C	0,1 kPa/N
^a The allowable maximum measurement uncertainty is the larger value of the two quoted. The relative uncertainty applies to the measured value and not the measuring range.					
^b Pore pressure requirements apply only to CPTU.					
^c The values of ambient temperature stability, transient temperature stability and bending influence represent the maximum allowable for each cone penetrometer class.					

Conformity to a cone penetrometer class shall apply when all the following requirements are met, where applicable:

- each of the parameters given in [Table 2](#) meets the requirements of [Table 2](#) for each of the measurands for a given cone penetrometer class;
- resolution and output stability, as defined in [8.3.4](#), are better than one-third of the allowable maximum measurement uncertainty values of [Table 2](#), for a given cone penetrometer class;
- each of the expanded measurement uncertainty values for cone penetrometer inclination is better than 1 degree, for any of the cone penetrometer classes.

The determination of cone penetrometer class includes a smaller set of uncertainty contributions ([Table 3](#)), $U_{qc:cal}$, $U_{fs:cal}$ and $U_{u:cal}$ as defined in ISO 22476-1, than those required for expanded measurement uncertainty for the calibration, U_{qc} , U_{fs} and U_u as defined in ISO 22476-1. A cone penetrometer can thus conform to a cone penetrometer class, where uncertainties presented in a calibration test report are higher than values of [Table 2](#).

A cone penetrometer can conform to more than one cone penetrometer class for the case of multiple intervals for calibration.

For cone penetrometers that rely on real-time or post-processing correction for temperature influence on CPT results, the corrected values of ambient temperature stability (Δa_{qcc} , Δa_{fsc} and Δa_{uc}) and the corrected values of transient temperature stability (Δt_{qcc} , Δt_{fsc} , Δt_{uc}), as defined in ISO 22476-1, can be used for the assessment of cone penetrometer class in addition to the assessment without applying corrections. The equations applied for correction shall be reported.

Table 3 — Uncertainty contributions for cone penetrometer measurands

Uncertainty contribution ^a	Measurand		
	Cone resistance	Sleeve friction	Pore water pressure
Reproducibility	√	√	
Repeatability	√	√	√
Resolution	√	√	√
Zero drift	√	√	√
Interpolation	√	√	√
Reversibility	√	√	√
Apparent load transfer	√	√	
^a Definitions and formulae for the calculation of uncertainty contributions listed are presented in ISO 22476-1.			

8.3.4 Procedures for testing offshore

A filter element can be used for several tests if the pore pressure response is closely monitored for each test and the filter element is replaced when an unsatisfactory response is observed.

Reference readings and values of output stability for cone resistance, sleeve friction and pore pressure, where applicable shall be reported before and after the penetration phase of the test. For reference readings, the output of cone resistance, sleeve friction and, if applicable, the pore pressure of the cone penetrometer shall be continuously recorded for a period of one minute at a frequency of at least 1 Hz before and after the penetration phase of the test under conditions of no soil pressure and under similar temperature and ambient pressure conditions. For each of these periods, reference readings for cone resistance, sleeve friction and pore pressure shall be calculated as the mean of the recorded output values. Output stability is defined as the subtraction of minimum output value from maximum output value, for each period of 1 min.

NOTE 1 Temperature changes in the cone penetrometer can cause significant sensor drifts, so it is important to ensure similar temperatures for the cone penetrometer while taking reference readings before and after the test.

NOTE 2 Soil can adhere to the cone penetrometer or get trapped in the gaps below and above the friction sleeve, which can influence the reference readings. The cone penetrometer can be cleaned or rinsed before taking reference readings.

For seafloor-based drilling and non-drilling systems, reference readings can be made at deck level, at the seafloor or a short, fixed distance above. For CPT/CPTU during vessel drilling operations, the reference readings shall be at deck level. The output of cone resistance, sleeve friction and, if applicable, the pore pressure of the cone penetrometer at the bottom of the borehole should be compared to theoretically calculated values.

For quality control and early diagnosis of malfunction, additional checks of output stability can be taken at seafloor level for seafloor CPT/CPTU and at the bottom of the borehole for drilling mode (down-hole mode) CPT/CPTU. The penetration phase shall not commence until the observed output drift is less than 3 kPa per minute for cone resistance, less than 0,15 kPa per minute for sleeve friction, and less than 0,5 kPa per minute for pore pressure. Output drift is defined as the difference between the output at the start and end of a one minute period. Output drift can be calculated by applying a moving average to sensor output.

The rate of penetration derived from the depth sensor shall be (20 ± 5) mm/s. In rock and soils such as cemented soils, dense sands and gravels, penetration rates less than (20 ± 5) mm/s may be required.

to prevent damage to the cone penetrometers and push rods or to achieve larger depths. The rate of penetration may be less than (20 ± 5) mm/s immediately before and immediately after a penetration interruption, including specific stationary testing (e.g. PPD, SCPT), start and end of penetration and add-on of a push rod. These variations on the rate of penetration shall be reported.

The length of each stroke should be as long as possible, with due consideration for project specifications as well as the mechanical and strength limitations of the equipment.

The data recording frequency shall be at least 1 Hz (i.e. one recording every 20 mm of penetration).

Inclination of the cone penetrometer shall be measured. Inclination measurements may be omitted for CPT/CPTUs in drilling mode and in shallow non-drilling mode (<5 m penetration below seafloor).

Guidance and recommendations related to the CPTU pore pressure dissipation tests are provided in [8.4](#).

The penetration of the cone penetrometer shall be terminated when one of the following conditions are met:

- the required depth below seafloor has been reached;
- the maximum thrust or maximum capacity of the measuring system defined by the project specifications has been reached; or
- inclination of the cone penetrometer approaches or is beyond a limiting value given in the project specifications.

For CPT/CPTUs in drilling mode, reaching maximum thrust capacity at one depth should not prevent subsequent strokes being performed. Reaching maximum thrust capacity is also important information.

Potential damage to the equipment may be a valid reason to terminate a test.

NOTE 4 The achievable penetration length or penetration depth depends on the soil conditions, the allowable penetration force, the allowable forces on the push rods and push rod connectors, the use of a friction reducer and/or push rod casing and the measuring range of the cone penetrometer.

For each test, the differences observed in reference readings and the larger value of output stability obtained before and after the penetration phase of the test shall be used to determine the test category according to [Table 4](#). Tests shall meet all the requirements for each of the measurands for a given test category to be accomplished, where applicable.

NOTE 5 The project specifications can include criteria for avoiding repeating of tests that do not meet the requirements of [Table 4](#). [Annex A](#) includes guidance.

Table 4 — Test categories of CPT/CPTU

Test category	Application	Measurand	Difference of reference readings	Output stability
A	Characterisations of seabed with $q_{c;\max} < 2 \text{ MPa}$	Cone resistance	$\leq 35 \text{ kPa}$	$\leq 11 \text{ kPa}$
		Sleeve friction	$\leq 15 \text{ kPa}$	$\leq 1,5 \text{ kPa}$
		Pore pressure	$\leq 25 \text{ kPa}$	$\leq 8 \text{ kPa}$
B	Characterisations of seabed with $2 \text{ MPa} < q_{c;\max} < 60 \text{ MPa}$	Cone resistance	$\leq 100 \text{ kPa}$	$\leq 33 \text{ kPa}$
		Sleeve friction	$\leq 25 \text{ kPa}$	$\leq 5 \text{ kPa}$
		Pore pressure	$\leq 50 \text{ kPa}$	$\leq 16 \text{ kPa}$
$q_{c;\max}$ is the maximum value of cone resistance measured during the penetration phase of the test. The difference of reference readings is according to 8.3.4 . The larger value of output stability according to 8.3.4 applies.				

Table 4 (continued)

Test category	Application	Measurand	Difference of reference readings	Output stability
C	Characterisations of seabed with $q_{c,max} > 60 \text{ MPa}$	Cone resistance	$\leq 200 \text{ kPa}$	$\leq 66 \text{ kPa}$
		Sleeve friction	$\leq 50 \text{ kPa}$	$\leq 8 \text{ kPa}$
		Pore pressure	$\leq 100 \text{ kPa}$	$\leq 33 \text{ kPa}$
$q_{c,max}$ is the maximum value of cone resistance measured during the penetration phase of the test. The difference of reference readings is according to 8.3.4 . The larger value of output stability according to 8.3.4 applies.				

8.3.5 Presentation of test results

The reporting of results from CPT/CPTUs shall conform to 8.2. The net area ratio, a , of the cone penetrometer and the end areas of the friction sleeve, determined according to ISO 22476-1, shall be reported for each penetrometer used during the marine soil investigation. Calibration reports, cone penetrometer class, reference readings, output stability, and test category shall be reported. Test category shall be reported for each test, where test category is defined as the combination of IDs of Table 2 and Table 4.

NOTE 1 Examples of possible test categories are 1+B, 1A and 2B.

Measured values of the following parameters shall be reported as functions of depth, with seafloor as zero reference for the parameter values, where applicable:

- cone resistance, q_c ;
- pore pressure, $u_2(u_1, u_3)$;
- sleeve friction, f_s ;
- inclination of the cone penetrometer, i ;
- applied thrust to push rod, F_{thrust} ;

Depth should be derived from penetration length and inclination, i , of the cone penetrometer, where values of i are available.

Any corrections applied to the measured data shall be reported. Measured values shall be reported in digital (i.e. numerical) format without the application of corrections performed manually, by electronic means or by microprocessors.

Derived values of the following parameters, reported as functions of depth, should include:

- a) corrected cone resistance, $q_t = q_c + (1-a)u_2$, where a is the net area ratio of the cone determined according to 8.3.3.2;
- b) friction ratio, $R_f = f_s/q_c$;

NOTE 2 Sleeve friction is influenced by surrounding water pressure. Since it is not standard practice to measure the pore pressure u_3 above the friction sleeve, the uncorrected sleeve friction f_s is commonly used. A possible correction method for the friction sleeve (to get corrected sleeve friction f_c) is given in Annex A.

- c) pore pressure ratio, $B_q = (u_2 - u_0) / (q_t - \sigma_{v0})$,

where:

σ_{v0} is the (estimated) in situ vertical total stress relative to seafloor;

u_0 is the (estimated or measured) in situ equilibrium pore pressure relative to seafloor.

The basis for computation of the σ_{v0} and u_0 profiles shall be reported, where applicable.

NOTE 3 Derived values of additional parameters that can be reported include: net cone resistance, $q_{\text{net}} = q_t - \sigma_{v0}$; normalised cone resistance, $Q_t = q_{\text{net}}/\sigma'_{v0}$; and normalised friction ratio, $F_r = f_s/q_{\text{net}}$.

The following scales should be used for graphical presentation, where applicable:

- depth, 1 scale unit = 1 m;
- cone resistance q_c , (q_t , q_{net}), 1 scale unit = 2 MPa or 0,5 MPa;
- sleeve friction, f_s , 1 scale unit = 0,05 MPa;
- pore pressure, u_2 (u_1 , u_3), 1 scale unit = 0,2 MPa or 0,02 MPa;
- friction ratio, R_f , 1 scale unit = 2 %;
- pore pressure ratio, B_q , 1 scale unit = 0,5 units;
- applied thrust to push rod, F_{thrust} , 1 scale unit = 20 kN.

NOTE 4 It can be beneficial to present parameter values at multiple scales when soil parameters values show large vertical variations. For instance, if there are layers of dense sand and clay in the same profile. If the results in clay are to be used for interpretation in terms of soil parameters, it is particularly important to use an enlarged scale in the presentation of test results. It is also important that consistent scale(s) are used.

CPT/CPTU measured values, values for F_{thrust} and, where applicable, derived values shall be reported in digital (i.e. numerical) form.

8.4 Pore pressure dissipation test

8.4.1 General

This subclause covers PPDT performed as part of a cone penetration test CPTU according to [8.3](#).

The project specifications shall include:

- a) type of test according to [Table 5](#);
- b) test depth;
- c) test duration in terms of termination criteria.

NOTE 1 Increasing test duration can improve the uncertainty of interpretation of test results, particularly for test types PPDT1 and PPDT2.

NOTE 2 Termination criteria can include: a predetermined maximum test duration, (e.g. five hours); a certain percentage of the dissipation of the pore pressure immediately before the penetration interruption, relative to the estimated in situ equilibrium pore pressure; or the change in pore pressure over a given time interval is below a certain value (e.g. 3 kPa per 10 min). Termination criteria can also consider gas in the soil preventing reliable pore pressure measurement, soil heterogeneity or absence of significant penetration pore pressure for interpretation of the test results.

Table 5 — Pore pressure dissipation test types

Test type	Description	Test duration
PPDT1	Pore pressure dissipation for estimation of in situ equilibrium pore pressure	Typically, ≥ 80 % dissipation of the pore pressure immediately before the penetration interruption, relative to the estimated in situ equilibrium pore pressure u_0
PPDT2	Pore pressure dissipation for estimation of coefficient of (radial) consolidation in fine, low permeability soil	Typically, ≥ 50 % dissipation of the pore pressure immediately before the penetration interruption, relative to the estimated in situ equilibrium pore pressure u_0
PPDT3	Pore pressure dissipation for qualitative indication of soil permeability	Typically, < 600 s
PPDT4	Pore pressure dissipation to distinguish between drained, undrained and partially drained soil behaviour during cone penetration	Typically, < 60 s

8.4.2 Equipment

Equipment for a pore pressure dissipation test should consist of a piezocone penetrometer and ancillary equipment in accordance with [8.3](#).

Other probe types may be used, for example a piezoprobe or a ball penetrometer equipped with a pressure sensor, provided the information listed in [8.7.1](#) is given.

8.4.3 Test procedure

The test procedure shall be as follows:

- interruption of the push-in penetration of the penetrometer at the required test depth for pore pressure dissipation;
- recording of pore pressure, cone resistance and sleeve friction versus time until the predetermined termination criterion;
- resumption of penetration, if applicable.

Data recording should be at 1 Hz or higher during the initial 60 s and can be halved every log (time) cycle thereafter.

8.4.4 Presentation of results

The following information shall be reported:

- results from the CPTU data acquisition according to [8.3](#), where applicable;
- test type according to [Table 5](#);
- test depth for the filter position of the piezocone penetrometer;
- filter position of the piezocone penetrometer;
- method of fixing the position of the piezocone penetrometer during the dissipation phase;
- pore pressure, u_2 , and cone resistance, q_c , versus time and log time, including the values of pore pressure (u_{2i}) and cone resistance (q_{ci}) immediately before the penetration interruption.

Normalized excess pore pressure, U , can additionally be reported versus time and log time, where $U = (u_2 - u_0)/(u_{2i} - u_0)$.

NOTE The position of the filter has a significant influence on the excess pore pressure generated during penetration.

In line with 8.3.2, a filter element location in the cylindrical part just above the cylindrical extension of the cone is recommended. A filter element at location 1 may be used, in which case test results shall be presented for u_1 and u_{1i} , instead of u_2 and u_{2i} .

8.5 Ball and T-bar penetration tests

8.5.1 General

Ball and T-bar penetrometers are intended for deriving intact and remoulded shear strength of very soft to firm clays and clayey silts with a ball (T-bar) resistance $q_m < 500$ kPa.

There are many similarities between ball and T-bar penetrometers. In practice, the ball can be used in both non-drilling and drilling modes, while the T-bar should be use in non-drilling mode only.

The ball and T-bar penetrometers shown in Figure 3 are of a size suitable for mounting directly on standard CPT push rods.

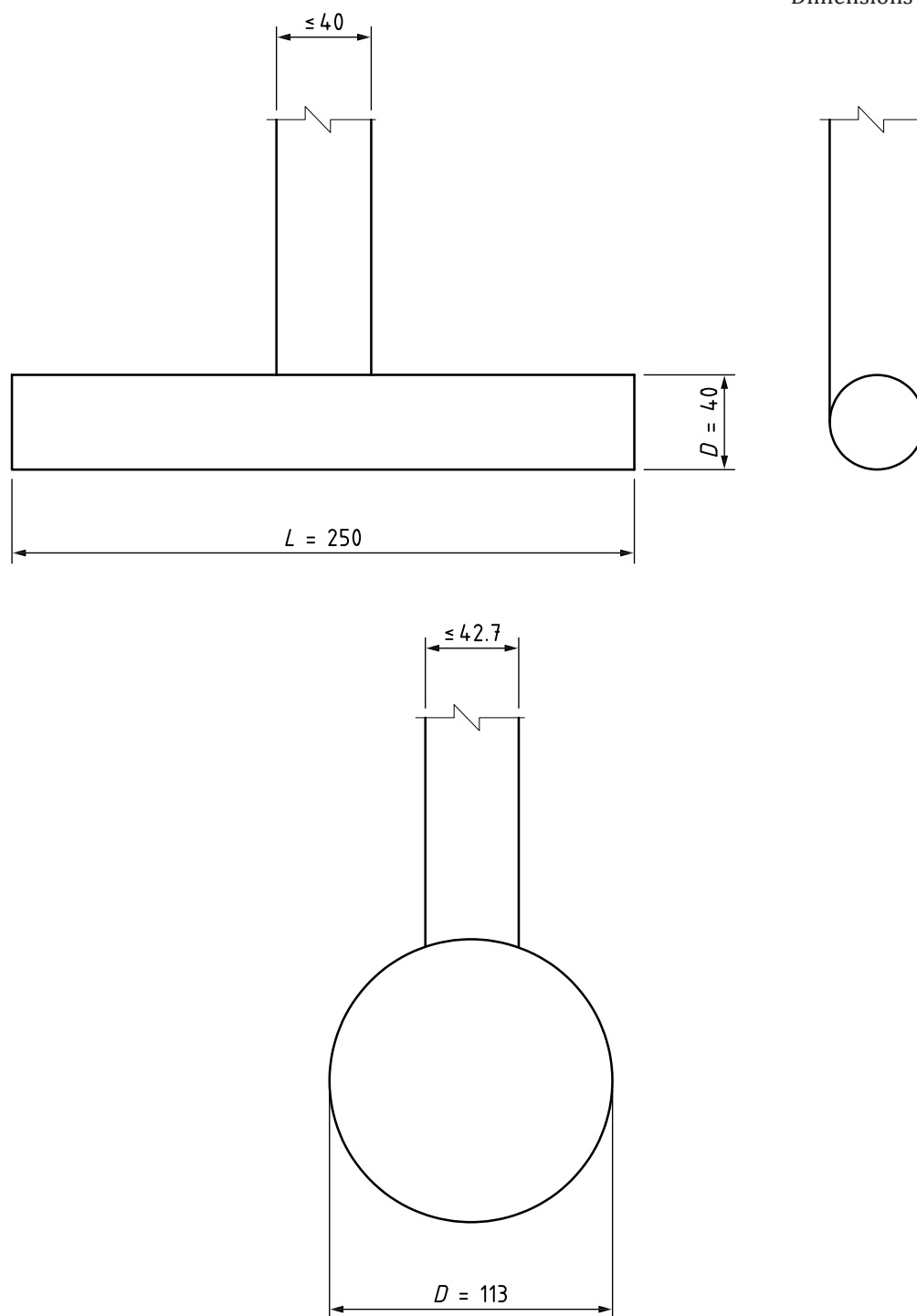
The load sensor for ball (T-bar) resistance shall be positioned within the ball (T-bar) or immediately above the ball (T-bar). The load sensor shall be compensated for possible eccentricity of soil resistance mobilized on the ball (T-bar) penetrometer. For a T-bar penetrometer, the load sensor should also be compensated for a possible torsional component of soil resistance acting on the penetrometer.

NOTE The load cell(s) within a cone penetrometer (without the cone) can be used to measure the soil resistance mobilized on the ball (T-bar) penetrometer.

The ball (T-bar) penetrometer shall be fitted with an inclination sensor with a measuring range of at least $\pm 15^\circ$ relative to the vertical axis. The inclination sensor may be omitted for tests in shallow non-drilling mode (< 5 m penetration below seafloor).

Requirements for the thrust machine, the push rods and the measuring system for penetration should be as given in 8.3.

Dimensions in millimetres



Key

L length of T-bar

D diameter of T-bar or ball

NOTE Upper part of figure shows T-bar. Lower part of figure shows ball.

Figure 3 — Dimensions of 10 000 mm² ball and T-bar