

BS EN ISO 19901-8:2015



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Petroleum and natural gas industries — Specific requirements for offshore structures

Part 8: Marine soil investigations (ISO 19901-8:2014)

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National foreword

This British Standard is the UK implementation of EN ISO 19901-8:2015. It is identical to ISO 19901-8:2014.

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 secretary.

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Investigations des sols en mer (ISO 19901-8:2014)

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Offshore-Anlagen - Teil 8: Meeresbodenuntersuchungen
(ISO 19901-8:2014)

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Foreword

The text of ISO 19901-8:2014 has been prepared by Technical Committee ISO/TC 67 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 19901-8:2015 by Technical Committee CEN/TC 12 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” the secretariat of which is held by AFNOR.

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of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

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Endorsement notice

The text of ISO 19901-8:2014 has been approved by CEN as EN ISO 19901-8:2015 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, SC 7, *Offshore structures*.

ISO 19901 consists of the following parts, under the general title *Petroleum and natural gas industries — Specific requirements for offshore structures*:

- *Part 1: Metocean design and operating considerations*
- *Part 2: Seismic design procedures and criteria*
- *Part 3: Topsides structure*
- *Part 4: Geotechnical and foundation design considerations*
- *Part 5: Weight control during engineering and construction*
- *Part 6: Marine operations*
- *Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*
- *Part 8: Marine soil investigations*

Introduction

The series of International Standards applicable to offshore structures, ISO 19900 to ISO 19906, constitutes 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.

It is important to recognize that 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. The implications involved in modifications, therefore, need to be considered in relation to the overall reliability of all offshore structural systems.

This part of ISO 19901 is applicable for marine soil investigation, which is only one of many possible marine site investigations as illustrated in [Figure 1](#). The terminology used in [Figure 1](#) and other important terminology are defined and given in [Clause 3](#).

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 should be 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 parameters. An example report format is given in [Annex G, Table G.1](#), but for each project the final reporting structure can be adjusted by deleting inapplicable sections, or by adding new sections.

This part of ISO 19901 gives requirements, recommendations and guidelines for the planning and execution of marine soil investigations and is applicable from the planning phase to reporting of soil parameters. It is important to use documented methods when soil parameters are established, and to refer to these methods in the report.

In situ and laboratory testing methods included in this part of ISO 19901 are selected based on their importance in marine soil investigation practice, availability in commercial geotechnical laboratories and the existence of an accepted testing procedure.

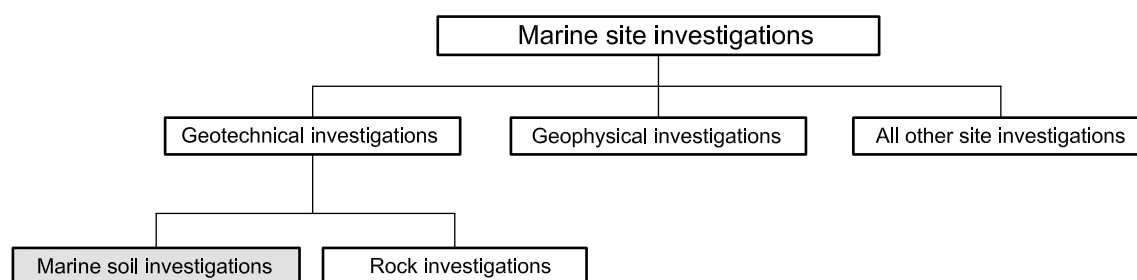


Figure 1 — Marine soil investigations shown as one of many types of marine site investigations

Seabed characterization can require several types of site investigations, for example marine soil investigations and geophysical investigations including geological and geohazard evaluations. For each project, the types of site investigations required are usually defined in project specifications. Also of importance for proper seabed characterization is consideration of required investigation equipment and its deployment mode(s) and methods, in order to acquire adequate quality soil data to the target depth.

This part of ISO 19901 is applicable for marine soil investigations at any water depth and to any depth below seafloor which can be reached with the tools used.

Use of this part of ISO 19901 is based on the assumptions that:

- adequate 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 parameters are collected, recorded and interpreted by qualified personnel;
- the project-specific scope of work for marine soil investigations is defined by one or more project specifications.

Seabed soils can vary widely, and experience gained at one location is not necessarily applicable at another. The scope of a soil investigation for one type of structure is not necessarily adequate for another. Extra caution is therefore necessary when dealing with unconventional soils or unconventional foundation concepts. Marine soil investigations include both offshore and nearshore soil investigations, which can provide very different challenges.

The detailed requirements for equipment and methods given in this part of ISO 19901 are only applicable if relevant for the scope of work defined in the project specifications.

This part of ISO 19901 is intended to provide flexibility in the choice of soil investigation techniques without hindering innovation.

The primary objectives of this part of ISO 19901 are to provide requirements and guidance for how the most important aspects of a marine soil investigation should be performed to obtain reliable soil parameters based on documented methods.

In this part of ISO 19901, in accordance with the latest edition of the ISO/IEC Directives, Part 2, the following verbal forms are used:

- ‘shall’ and ‘shall not’ are used to indicate requirements strictly to be followed in order to comply with the document and from which no deviation is permitted;
- ‘should’ and ‘should not’ are used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited;
- ‘may’ and ‘need not’ are used to indicate a course of action permissible within the limits of the document;
- ‘can’ and ‘cannot’ are used for statements of possibility and capability, whether material, physical or causal.

This part of ISO 19901 includes informative annexes. Informative annexes give additional information intended to assist the understanding or use of the document. They do not contain requirements, except that informative annexes may contain optional requirements (for example a test method that is optional can contain requirements), but there is no need to comply with these requirements to claim compliance with this part of ISO 19901.

The following International Standards are also relevant to offshore structures for the petroleum and natural gas industries:

- ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*
- ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*
- ISO 19903, *Petroleum and natural gas industries — Fixed concrete offshore structures*
- ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*
- ISO 19905-1, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 1: Jack-ups*

- ISO/TR 19905-2, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 2: Jack-ups commentary*
- ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*
- ISO 13623, *Pipeline transportation systems*
- ISO 13628-1, *Design and operation of subsea production systems — Part 1: General requirements and recommendations*

Petroleum and natural gas industries — Specific requirements for offshore structures —

Part 8: Marine soil investigations

1 Scope

This part of ISO 19901 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; and
- g) reporting.

Rock materials are only covered by this part of ISO 19901 to the extent that ordinary marine soil investigation tools can be used, e.g. for chalk, calcareous soils, cemented soils or similar soft rock.

Hard rock investigations are not covered by this part of ISO 19901; see [F.13](#) for further guidance.

Foundation design is not covered by this part of ISO 19901, but by ISO 19901-4 and the respective design standards for the specific types of offshore structures as listed in the Foreword and Introduction.

Planning, execution and interpretation of geophysical investigations are not covered by this part of ISO 19901. However, the results from geophysical investigations should, where appropriate, be used for planning, optimization and interpretation of marine soil investigations.

This part of ISO 19901 does not cover the planning and scope of geohazard assessment studies, only the corresponding marine soil investigations aspects thereof.

Soil investigations from ice in Arctic regions are not covered by this part of ISO 19901.

This part of ISO 19901 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 and nearshore structures, or geohazard assessment studies, for petroleum and natural gas industries.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22476-1:2012, *Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

accuracy

exactness of a measurement compared to the true value of the quantity being measured

3.2

application class

classification of equipment based on achievable level of accuracy or classification of soil samples which can be used to determine various soil properties

Note 1 to entry: Application classes have been developed to provide guidance on equipment selection centred on the accuracy required when using the results.

Note 2 to entry: The term 'application class' in this part of ISO 19901 is called 'quality class' in 3.4.1 of EN 1997-2:2007 where the term 'application class' is not used. For the definition of 'quality class', see [3.24](#).

3.3

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

3.4

characteristic value

value assigned to a basic variable associated with a prescribed probability of not being violated by unfavourable values during some reference period

Note 1 to entry: The characteristic value is the main representative value. In some design situations a variable can have two characteristic values, an upper and a lower value.

[SOURCE: ISO 19900:2013, definition 3.10]

3.5

characterization

description, evaluation and/or determination of the most typical characteristics based on all types of site investigations and other available data

3.6

client

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

3.7

contractor

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

3.8

derived value

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

3.9

design value

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

[SOURCE: ISO 19900:2013, definition [3.18](#)]

3.10

disturbed sample

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

3.11

drained condition

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

3.12

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.).

3.13

geohazard

geological state and process that can cause material and environmental damage as well as loss of life

3.14

geophysical investigation

marine site investigation of seafloor or seabed by the use of non-destructive methods requiring marine deployment of geophysical tools

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

3.15

ground truthing

process of using soil investigation data to characterize the various geological formations defined from geophysical investigations

3.16

in-pipe logging

logging in a section of the borehole or 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.

3.17

intact sample

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

3.18

marine site investigation

any type of investigation at an offshore or nearshore site

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

3.19

marine soil investigation

type of marine site investigation 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 evaluation

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

Note 2 to entry: The scope of work and extent of a marine soil investigation varies from one project to another, but usually includes one or more of the items listed in [Clause 1](#).

3.20

measured value

value that is measured in a test

3.21

nominal value

value assigned to a basic variable determined on a non-statistical basis, typically from acquired experience or physical conditions

3.22

open-hole logging

logging in a section of the borehole without, for example, casing or drill pipe, allowing a direct measurement of the soil properties outside the borehole wall to be made

3.23

project specification

scope of work for marine soil investigations assigned by the client to a contractor

3.24

quality class

classification of sample quality for low to medium OCR clays, where the sample quality is based on measured volume change from laboratory consolidation tests

Note 1 to entry: Exact definitions of the various sample quality classes are given in [10.5, Table 6](#).

Note 2 to entry: The definition of 'quality class' given in this part of ISO 19901 differs from the definition of 'quality class' given in 3.4.1 of EN 1997-2:2007. What is called 'quality class' in EN 1997-2:2007 is called 'application class' in this part of ISO 19901, see [3.2](#). The term 'application class' is not used in EN 1997-2:2007.

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 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

Note 1 to entry: For fine-grained soils, the specimen is prepared as a slurry (at or above the liquid limit) and then consolidated. For coarse-grained soils, it is either poured or pluviated in dry (dried) or wet conditions and compacted, or consolidated.

3.27

remoulded sample

remoulded specimen

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

3.28

remoulded shear strength

shear strength measured on a remoulded specimen

3.29

representative value

value assigned to a basic variable for verification of a limit state

[SOURCE: ISO 19900:2013, definition [3.38](#)]

3.30

residual shear strength

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

3.31

sample

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

3.32

seabed

materials below the seafloor

3.33

seafloor

interface between the sea and the seabed

3.34

settlement

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

3.35

site

defined investigation area

3.36

soil [geotechnical] parameter

measured, derived or representative soil [geotechnical] parameter

Note 1 to entry: The term 'geotechnical' includes both soil and rock.

3.37

specimen

part of a sample used for a laboratory test

3.38

strength index test

test that yields an indication of the shear strength

3.39

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.

3.40

uncertainty

reliability of the measurement results due to sources of systematic and random errors

3.41

undisturbed sample

sample in which no change of practical significance has occurred in the soil characteristics

3.42

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

3.43

undrained shear strength

maximum shear stress at yielding or at a specified maximum strain in an undrained condition

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

Note 2 to entry: Strain softening is also to be considered.

4 Symbols, units and abbreviated terms

4.1 Symbols

a	net area ratio of a cone penetrometer
c_v	coefficient of consolidation
C_s	swelling index (for consolidation tests)
h_{sf}	height of reference point above seafloor
f_s	sleeve friction
G	specific gravity of solid particles
G_{max}	initial (small strain) shear modulus
I_L	liquidity index
I_P	plasticity index
i	inclination
K_0	coefficient of earth pressure at rest ($= \sigma'_{h0} / \sigma'_{v0}$)
m_v	coefficient of compressibility
p_0'	<i>in situ</i> vertical effective stress ($= \sigma'_{v0}$)
q_c	cone resistance
q_t	cone resistance corrected for pore water pressure effects
s	vane blade thickness
$s_u = c_u$	undrained (undisturbed) 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_{ufv}	shear strength by field vane testing
$s_{ufv,rem}$	remoulded shear strength by field vane testing
$s_{ufv,res}$	residual shear strength by field vane testing
S_t	soil sensitivity
u_2	pore pressure measured through a filter location in the cylindrical cone part just above conical part
v_p	compression wave velocity
v_s	shear wave velocity
v_{vh}	vertically (v) propagated, horizontally (h) polarized shear wave velocity

ξ	material damping ratio
z	height above seafloor for drilling mode <i>in situ</i> probe zero reference readings
γ'	submerged unit weight of soil
ν	Poisson's ratio
σ	stress
σ'_{v0}	<i>in situ</i> vertical effective stress ($= p_0'$)
σ'_{h0}	<i>in situ</i> horizontal effective stress
σ'_p	preconsolidation stress
$\Delta\sigma'_v$	change in effective vertical stress
ϕ'	effective angle of internal friction

4.2 Units

Units to be used can vary somewhat from one clause to another based on historical use. For example, a CPT cone cross-sectional area should be given in units of square millimetres (mm²) as used today, and not in square metres (m²). If there are no special historical reasons for deviating from the units listed below, then the units to be used are:

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

BHA	bottom hole assembly
CCV	consolidated constant volume
CD	consolidated drained
CPT	cone penetration test
CPTU	electrical CPT with measurement of the pore pressures around the cone
CRS	controlled rate of strain
CT	computerized tomography
CU	consolidated undrained
DGPS	differential global positioning system
DS	direct shear

DSS	direct simple shear
ERP	emergency response plan
FVT	field vane test
GIS	geographical information system
GNSS	global navigation satellite system
HAZID	hazard identification
HAZOP	hazard and operability
HSE	health, safety and environment
HVAC	heating, ventilation and air conditioning
IL	incremental loading
JSA	job safety analysis
LAT	lowest astronomical tide
LBL	long baseline
MSCL	multi-sensor core logging
MSL	mean sea level
OCR	overconsolidation ratio
PEP	project execution plan
PPE	personal protective equipment
QA	quality assurance
QC	quality control
RFID	radio-frequency identification
ROP	rate of penetration
ROV	remotely operated vehicle
RS	ring shear
SCPT	seismic CPT
SH	shear wave
SHANSEP	stress history and normalized soil engineering parameters
SIMOPS	simultaneous operations
SOW	scope of work
SRB	sulfate-reducing bacteria
SWL	safe working load
TC	triaxial compression

TE	triaxial extension
TOC	total organic content
UCT	unconfined compression test
USBL	ultra-short baseline
UU	unconsolidated-undrained
VSP	vertical seismic profiling
WGS	world geographic system
YSR	yield stress ratio

5 Objectives, planning and requirements

5.1 Objectives

The objectives of marine site investigations are to make relevant and adequate soil 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 level of risks for the foundation and integrity of that structure.

NOTE 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 soils by acquisition, evaluation and presentation of geotechnical information derived from methods relying on tools penetrating into the seabed. Specific objectives of a marine soil investigation may be given in project specifications.

5.2 Planning

Marine site investigations commonly consist of the following activities, often performed in the sequence listed:

- a) 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.
- b) Shallow geophysical investigations.
- c) Marine soil investigations, which may comprise one or more phases to suit the design phases.
- d) Further integrated study combining the information gathered in the desk study, shallow geophysical investigation and marine soil investigation phases.

Shallow geophysical investigations typically comprise:

- bathymetry and seafloor topography, using echo-sounding or swath bathymetry;
- seafloor features and obstructions, using methods such as side-scan sonar imaging and magnetometry;
- seabed stratigraphy, using methods such as sub-bottom profiling, usually by means of high-resolution reflection seismic.

NOTE 1 Shallow geophysical investigations are not covered by this part of ISO 19901, but the use of the results is important for marine soil investigations.

NOTE 2 ISSMGE (2005) provides guidance on shallow geophysical investigations.

A 'limited-scope' marine soil investigation is commonly performed in conjunction with shallow geophysical investigations for the purpose of preliminary groundtruthing of the sub-bottom profiling data. The results of a shallow geophysical investigation, alone or in addition to a desk study, are generally not sufficient for detailed design of an offshore structure.

A shallow geophysical investigation typically covers a large extent of seabed, enabling the identification of localized, non-characteristic seabed features such as the following:

- Buried channel or ice gouge features.
- Erosion features.
- Slides or shallow mass transport deposits.
- Seabed expression of a fault.
- Gas, gas pockets or potential gas pockets.
- Specific seafloor features (e.g. pockmarks, concretions, chemo-synthetic communities and seafloor expulsion features, drill cuttings mounds).

A marine soil investigation can include 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 part of ISO 19901. The date by which appropriate geotechnical information is required 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 a marine soil investigation include project phases, requirements of the offshore structure and risk level.

NOTE 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.

Geotechnical design requirements for the offshore structure depend on several factors that can influence the planning of the scope and extent (spatial area and explored depth) of the marine soil investigation, in particular the following:

- design 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, etc;
- 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.

Depth coverage can range from a few metres below seafloor for a seabed pipeline to generally less than 100 m below seafloor. However, coverage to 100m to 200 m can apply for foundations of specific offshore structures and to possibly 200m to 400 m if necessary for characterizing geohazards such as shallow water flow sands.

The following factors are typically considered for planning marine soil investigations:

- the type of offshore structures to be designed and the way in which they will interact with the seabed;
- the needs for determination of the area geology and related geohazards;
- the results of desk studies, earlier geophysical and marine soil investigations;
- the prior knowledge of seabed conditions and local geological variability and geohazards including shallow gas;
- other considerations, such as local metocean conditions, existing facilities, location of site (e.g. remoteness, possible political instability, medical hazards), unexpected unexploded ordnance, and the possibility of contaminated ground;
- interaction of investigation equipment with seafloor, see [6.4](#) for more details;
- regulatory requirements.

Investigation of contaminated ground can require special equipment and procedures.

The variability of the seabed and soil conditions at the site is important for the scope of a marine soil investigation. Investigations are usually targeted at locations where variations in seabed and soil conditions are anticipated, if of significance to the development, as well as at locations more typical of the overall area of the site.

The choice of vessel, equipment and procedures typically includes the following considerations:

- Operational requirements, including:
 - project-specific HSE (for example, possibility of encountering shallow gas),
 - local metocean conditions,
 - equipment capability to reach target depth,
 - grouting or not of boreholes after they have been drilled as part of the marine soil investigations (for example, if the borehole is at the location of a structure it can be desirable to grout it up, whereas in areas with shallow gas it can be preferable to leave the borehole open).
- Quality requirements, including:
 - accuracy and resolution of control of depth below seafloor;
 - tolerance of actual investigation locations relative to target locations;
 - sampling (for example, whether sharp-edged thin wall piston sample tubes are desirable);
 - need for and testing activities suitable for the anticipated soil conditions;
 - borehole geophysical logging;
 - water depth;
 - seafloor slope or unevenness, in terms of deployment of equipment and effects on, for example, depth control.

The planning and the scope of work may be modified during the course of a marine soil investigation, upon review and evaluation of the results from the investigation as they become available.

5.3 Scope of work

5.3.1 Responsibility and development of scope of work

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 consider the possibility of an activity that cannot be completed as intended and should consider an appropriate course of action.

NOTE A project may have more than one project specification.

Regarding marine operations, project specifications shall define responsibility for clarifying site clearance issues and any required mitigation measures. Site 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, unexploded ordnance and contaminated ground;
- site permits, including sample export.

Where the client holds relevant information, this shall be made available to 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.

Where relevant, the project specifications should refer to methods described in this part of ISO 19901. Any references to methods should be accompanied by method-specific information as applicable. If method-specific information is not contained in the project specification, then the contractor's practice shall apply. The project specifications may refer to or describe alternative methods not covered by this part of ISO 19901.

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

- determination of the extent of logging, sampling and testing, consisting of:
 - type, number, location and depth of *in situ* testing locations (see [Clause 8](#)),
 - type, number, distribution, location and depth of sampling locations (see [Clause 9](#)),
 - type and number of offshore and onshore laboratory tests (see [Clause 10](#)),
- choice of appropriate vessel, equipment and techniques (see [Clauses 5 to 10](#));
- reporting, including presentation of the results of the marine soil investigation and any associated data interpretation (see [Clause 11](#)).

5.3.2 Default and project specified application classes/methods

The following clauses of this part of ISO 19901 give requirements and information on items that should be covered by project specifications, which include application classes that are considered to be appropriate in many cases. Application classes should be specified such that the objectives of the marine soil investigation can be met.

Default application classes and default methods that shall be used if not otherwise given in project specifications, are:

- depth accuracy; see [6.2.3](#); default is class Z4, except for samplers with no fixed seafloor reference where default class shall be Z5, see [9.5](#) and [B.1.2.3](#);

- *in situ* test accuracy for:
 - CPT/CPTU; see [8.3.3.1](#); default is class 3,
 - vane test; see [8.7.3](#); default is class 2.

When assessing the required accuracy, consideration should be given as to whether accuracy of the relation between two data points or the accuracy of each data point is required, and the level of variability of the quantity being specified. For example, when specifying depth accuracy, accuracy of the vertical distance between two points can be more important than the depth accuracy for each point. Knowledge of the thickness of a soil unit can be required to be known to a greater degree of accuracy than its absolute depth. In addition, it should be considered that the depth and thickness of a soil unit can vary across a site, and therefore determining its depth at a given location to a high degree of accuracy can be unnecessary if the variability of depth between locations is substantially greater or unknown.

If any requirements are not specified in the project specifications, or not given as default values in this part of ISO 19901, then the contractor's practice shall apply.

5.4 Health, safety and environmental (HSE) requirements for marine operations

The marine soil investigation should conform to local and/or regional regulatory requirements and project HSE requirements. Marine operations should be conducted in accordance with a project HSE plan. The project HSE plan can be part of a project execution plan, see [Annex A](#).

ISO 19901-6 should be considered for marine operations for a vessel used for marine soil investigations. The vessel shall have a Health, Safety and Environment Management system (HSEMS), and 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 Safety of Life at Sea (SOLAS) code, or equivalent codes. The vessel should also conform to the International Ship and Port Facility Security (ISPS) code, where applicable.

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

The safety and well-being of those involved in, and impacted by, the marine soil investigation shall be considered. Persons involved shall be familiar with safety procedures requisite for the safe completion of tasks in which they participate [Job Safety Analysis (JSA)] and general onboard safety. The operators of marine soil investigation equipment shall have proper training and experience in the use of the equipment. Relevant persons shall be aware of proper 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 or equivalent codes, including adequate maritime lifesaving equipment, and personal protective equipment (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 should 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, etc., 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.

It is essential to pay attention to the impact of marine soil investigation on HSE. Special 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 should be documented in a project-specific safety plan.

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

5.5 Other requirements

5.5.1 Operational requirements

The environmental conditions at the planned fieldwork site, such as water depth, seafloor slope, wave and current conditions, possibility of shallow gas/hydrates, shallow water flow and other drill hazards, and the proposed scope of the marine soil investigation shall be considered when selecting vessels and investigation tools. Responsibility for undertaking this shall be defined in the project specifications. The primary concern when considering the size and class of a vessel is the safety of the operations and personnel during the work.

Lifting, handling and deployment facilities (A-frames, booms, davits, cables, cradles, drilling equipment, winches, etc.) for the required logging, sampling and *in situ* testing equipment, supplies and other equipment shall be safe. 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 considered when determining the maximum anticipated load on a lifting element, as these additional loads 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.

Vessel positioning and equipment positioning requirements shall be defined in the project specifications. Further guidance is provided in [6.3](#).

5.5.2 Quality requirements

Experienced geotechnical practitioners shall be involved during the planning and preparation of the soil investigation scope and project specifications.

The client should have an appropriate project quality management system in place, with quality control to be exercised consistently and competently in all phases of investigation and evaluation. The contractor should operate a documented quality management system such as the ISO 9000- series of International Standards.

A project quality plan (QP) should be incorporated as part of a project execution plan (PEP) for the marine soil investigation (see [Annex A](#)). This 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 requirements for unconventional soils

The requirements and recommendations in this part of ISO 19901 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 global marine soil investigation practices. When performing a marine soil investigation in frontier areas, or areas known or suspected to contain unconventional soils, this may require special handling or treatment for soils such as:

- siliceous terrigenous soils (e.g. glacial tills, frozen soils);

- unconventional terrigenous soils (e.g. volcanic ash, silts, glauconitic soils, micaceous soils);
- non-terrigenous soils [e.g. carbonate soils (see Note below), calcareous soils, siliceous oozes].

The equipment, methods and procedures can also require tailoring to investigate characteristic 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 Carbonate deposits offer an example of how an investigation can need to 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. This is particularly the case for sands and silts that contain more than 15 % to 20 % carbonate material. Therefore, in planning a marine soil investigation, it is important to incorporate sufficient flexibility in the scope of work to switch between soil sampling, rock coring, 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.

General guidance on types of unconventional soils and soils with generic properties that have potential difficulties associated with them is given in [A.3](#).

6 Deployment of investigation equipment

6.1 Deployment modes

6.1.1 General

Marine soil investigation equipment can be deployed in a variety of ways. The elected deployment method can influence the quality and the depth to which data can be acquired. The client should ensure that the selected equipment is capable of providing suitably accurate and sufficient geotechnical data for the intended purpose.

6.1.2 Non-drilling mode

Non-drilling mode encompasses the practice by which geotechnical testing or sampling tools are initiated at the seafloor and penetrated in a single stroke to refusal depth or to a predetermined depth. 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 in a very soft seabed.

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. 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.

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 or *in situ* data. At the other end of the spectrum, non-heave-compensated winch-controlled tools such as gravity corers, Kullenberg piston corers and vibro corers can have a limited capacity to acquire high quality samples.

A common limitation of non-drilling mode equipment relates to their 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.

6.1.3 Drilling mode

6.1.3.1 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 either from the sea surface, (referred to as 'vessel drilling'), or alternatively using remotely controlled, seafloor-founded drill rigs (referred to as 'seafloor drilling').

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 electrical, 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](#).

6.1.3.2 Vessel drilling

Vessel drilling operations are undertaken from either:

- a) a spudded, anchored or dynamically positioned floating vessel, such as a drill ship, semi-submersible vessel, barge or similar craft, or
- b) 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. For many vessel drilling systems, the vertical stability of the drill string may be controlled or limited by means of

- a seafloor-founded template with a 'hard-tie system' heave compensator, see Zuidberg et al. (1986), or
- a heave compensator on the drilling vessel in conjunction with soil resistance that prevents 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 accuracy of borehole depth measurements, is provided in [B.1](#).

6.1.3.3 Seafloor drilling

Seafloor drilling systems are either landed on the seafloor and a catenary is formed with the control umbilical, or alternatively a constant tension winch is used to isolate the rig from vessel movements. All operations are then undertaken via remote control.

The stability of seafloor drilling systems is largely dependent on the capabilities of the footings used to support the rig. Sophisticated footings systems can incorporate the capacity to self-level the rig, and monitor the vertical height of the rig relative to the seafloor to enhance the accuracy of borehole depth measurements. Less sophisticated rigs can lack the capacity to land and stay reliably at the seafloor, leading to uncontrolled penetration on landing, an increased potential for tilting, and poor estimation of actual borehole depth.

The action of initially landing equipment on the seafloor can disturb the natural characteristics of the upper seabed. This issue is discussed further in [B.2](#).

6.2 Accuracy of vertical depth measurements

6.2.1 General

The accuracy of vertical depth measurements is a critical component of a marine soil investigation. Accurate measurement of vertical depth assists in ensuring, for example:

- that variations in seabed stratigraphy are accurately defined;
- that appropriate overburden and pore water pressure corrections are applied to *in situ* test data;
- that adjacent samples and *in situ* test data are able to be precisely correlated; and
- that appropriate confining stresses are specified during the course of subsequent laboratory test programmes.

6.2.2 Factors affecting the accuracy of vertical depth measurements

A data point can be defined at any particular depth below seafloor at which geotechnical data are acquired. The depth accuracy of a data point can vary depending on the mode by which equipment is deployed, the vertical stability of the equipment during the data acquisition phase, the accuracy to which vertical measurements are able to be made, and the accuracy to which a sample data point can be estimated within a sampling tool. For example, the achievable depth accuracy 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 accuracy 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 accuracy can additionally vary as a result of the performance of a sampling tool. For example, 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.

Further discussion on the factors affecting the accuracy of vertical depth measurements is provided in [B.1](#).

6.2.3 Specification of depth accuracy classes

The project specifications should include the class of depth accuracy to be achieved in a marine soil investigation based on the intended use of the geotechnical data, with due consideration of the capabilities of the equipment under consideration. Different degrees of depth accuracy may be specified for *in situ* testing and sampling operations.

Documentation demonstrating the depth accuracy that can be achieved with proposed investigation equipment should be provided by the contractor(s). For cases where depth accuracy is expected to vary with changes in water depth and/or borehole depth below the seafloor, the variation in accuracy class should be estimated for each intended investigation area.

Depth accuracy classes are presented in [Table 1](#). Information on the factors affecting depth accuracy for different equipment types, and key parameters for consideration in calculations, are included in [Annex B](#).

Table 1 — Depth accuracy classes for data point measurements relative to seafloor

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

If requirement to depth accuracy is not given in project specifications, a default value Z4 shall apply except for samplers with no fixed seafloor reference where default shall be Z5, see [9.5](#) and [B.1.2.3](#).

6.3 Positioning requirements

The requirements regarding vessel and equipment horizontal positioning accuracy shall be given in the project specifications (as noted also in [5.5.1](#)).

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 soil investigations, and the installation of facilities;
- known seafloor hazards, including installed facilities, natural seabed obstructions, excessive gradients, identified areas of shallow gas and other features, are avoided with confidence.

The geodetic system, positioning datum and other corrections to be applied to the data set shall be specified, and minimum acceptable calibration and integrity testing exercises shall be completed prior to the commencement of an investigation.

Specification of horizontal positioning tolerances can be influenced by:

- the type of facilities to be installed on the seafloor;
- the type, accuracy capabilities and levels of equipment redundancy of the positioning equipment;
- the proximity of existing facilities (including the estimated accuracy of their actual positions);
- the known seafloor topography: water depth, seafloor slopes, natural features.

For further guidance on horizontal positioning requirements, reference is made to IHO standards for Hydrographic Surveys (2008) and OGP-IMCA (2010).

6.4 Interaction of investigation equipment with the seafloor

Most sophisticated marine soil investigation equipment interacts with the upper seabed prior to commencement of data acquisition.

The action of landing equipment on the seafloor can disturb and apply elevated surcharge pressures to the upper seabed, which can be detrimental to data quality. The expected interaction of investigation equipment with the seafloor should be clarified prior to the commencement of a soil investigation.

Steep seafloor gradients can impede operation of investigation equipment. Detailed bathymetry information is normally required to confirm that the investigation equipment can be safely operated in such environments.

Further guidance related to disturbance of the seabed and operation of equipment on steep seafloor gradients is provided in [B.2.2](#) and [B.3](#), respectively.

7 Drilling and logging

7.1 General

Drilling operations can be undertaken either from the sea surface ('vessel drilling') or alternatively using remotely controlled, seafloor-founded drill rigs ('seafloor drilling'). The various modes of equipment deployment are defined within [Clause 6](#), which also describes the particular aspects that relate to rotary drilling and the subsequent logging of a borehole (if applicable).

In both drilling system deployment modes outlined above, 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 virgin material at the drill face. Excessive drilling fluid pressure can induce hydraulic fracture or erosion of virgin material. Excessive drilling fluid flow can soften or erode virgin material. Soil disturbance can often be assessed by inspection of the results from the sampling and *in situ* testing. The depth of soil disturbance below the drill face, and the magnitude of its effect, tend to be greater for softer soils.

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 is largely affected by the type of equipment used to deploy the drill string. Further information on this issue is provided in [Clause 6](#).

The efficient delivery of the drilling operation can be fundamental to the overall success of the marine soil investigation. [Clause 7](#) and [Annex C](#) describe the process for selection and adoption of the most appropriate drilling equipment and procedures for the work, based on project-specific requirements and drilling objectives.

7.2 Project-specific drilling requirements

The choice of drilling equipment suitable for a particular 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), i.e.
 - 1) borehole suitable for deployment of specific testing or sampling tools, and/or
 - 2) 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/buried infrastructure, seafloor topography, natural seafloor features;
- allowable uncertainty in borehole depth measurements (see [6.2](#));
- HSE considerations, e.g. manned interventions on the drill floor, environmental discharge regulations for drill cuttings, etc.;
- logistical considerations, e.g. project schedule, availability of equipment.

7.3 Drilling objectives and selection of drilling equipment and procedures

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

- to recover data of optimal quality, with minimal soil disturbance from drilling, where the soil investigation results will be used to determine geotechnical parameters 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, or pilot-hole drilling (for detection of shallow gas);
- to minimize the potential for a shallow gas incident. The rapid extraction of wireline tools from the seabed (swabbing effect) can induce a shallow gas 'kick'. It can also be necessary to perform a pilot-hole for the detection of shallow gas, thereby de-risking further drilling operations.

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

Further guidance on the selection of drilling equipment and procedures is given in [Annex C](#).

7.4 Drilling operations plan

A separate drilling operations plan (see [Annex C](#)) or the project execution plan for the soil investigation (see [Annex A](#)) should cover the proposed drilling operations and shall describe the predicted sequence of activities and contingencies, from initiation to completion of each geotechnical borehole, and include details of the required sampling/testing/logging programme.

The purpose of the drilling operations plan is twofold:

- a) during the pre-fieldwork phase, to provide assurance that:
 - all required information is in place,
 - the proposed solution is capable of meeting all of the project objectives,
 - due consideration has been paid to potential drilling hazards, and
 - contingency plans are in place in the event of foreseeable drilling-related problems;
- b) 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 soil investigation, on the tools and techniques to be employed, and on whether any new or modified equipment or procedures are required.

Some areas where marine soil investigations are carried out pose a possibility of encountering shallow gas, either natural or released from a nearby hydrocarbon extraction/processing infrastructure. Where the potential for a gas release exists, a shallow gas plan shall be in place. Part of this plan can include the drilling of a separate pilot hole prior to any geotechnical sampling or *in situ* testing.

Guidance for the content of the drilling operations plan and for the performance of shallow gas risk assessment is provided in [Annex C](#).

7.5 Recording of drilling parameters

During the process of borehole drilling the system operational and performance parameters shall be recorded either manually (usually by the driller) or by use of an electronic automated logging system.

When depth resolution of logged parameters better than about 1 m is required, use of automated logging is the preferred method.

Depending on project-specific requirements and upon the logging method adopted (manual or electronic), recorded parameters can include the following:

- Time (dd/mm/yyyy hh:minmin:ss).
- Penetration (m).
- Rate of penetration (ROP) (m/min).
- Drilling fluid pressure at the output of the pump (kPa).
- Drilling fluid circulation rate (input) (l/min).
- Drilling fluid recovery rate (l/min) (only for riser drilling with recirculation of drilling fluid).
- Drill head rotational torque (N·m).
- Drill head rotational speed (revolutions per min).
- Bit load (kN).

The accurate recording of drilling parameters can provide a valuable data set for use in interpolation/extrapolation of soil data and detection of layering. An example of such application for detection of hard layers in carbonate material is given in Becue et al. (1988).

7.6 Borehole geophysical logging

Depending upon project-specific requirements, geophysical wireline logging or logging while drilling can be employed. Typically, these methods provide enhanced geological and engineering detail over the logged borehole section.

A number of tools are available, some for in-pipe measurements and some for open-hole measurements [see Digby (2002) and ISO/TR 14685 for further information].

See [Annex C](#) for further guidance.

8 *In situ* testing

8.1 General

Results of *in situ* tests depend on how the tools or probes are deployed into the seabed, and whether the soil is disturbed prior to probe insertion. As noted in [Clause 6](#), tools can be deployed via two alternative methods:

- a) non-drilling mode, in which tool penetration is initiated at the seafloor and penetrated in a single stroke to refusal, or to a predetermined depth; or
- b) 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.

Management of metrological confirmation applicable should be in accordance with ISO 10012.

8.2 General requirements for the documentation of *in situ* tests

For each test, the following information shall (underlined) or can (not underlined) be recorded and reported in addition to the test results:

- a) site geographical details, including:
 - geographical location,
 - facility name,
 - borehole or test title,
 - coordinates, including site datum (e.g. WGS 84),
 - water depth [e.g. relative to lowest astronomical tide (LAT); mean sea level (MSL)].
- b) equipment details (as applicable):
 - equipment name,
 - deployment mode,
 - borehole progression method (drilling or non-drilling);
- c) test details (as applicable):
 - test type,
 - test/stroke number,
 - current borehole depth,
 - tool type (geometry/capacity),
 - unique equipment/tool number.

Reference shall be made to any deviations from the requirements of this part of ISO 19901 or the project specifications, where identified, including

- testing procedures,
- tool wear or damage,
- corrections made for depth below seafloor,
- actual test positions versus original target positions.

8.3 Cone penetration test (CPT/CPTU)

8.3.1 General

This Clause covers cone penetration tests performed with a friction cone (CPT) and with a piezocone (CPTU).

8.3.2 Equipment

The standard cone penetrometer is defined as having a nominal cross section, A_c , of 1 000 mm². The geometry of the standard cone penetrometer and allowable tolerances should be as given in ISO 22476-1:2012, 4.4.

Cone penetrometers with a diameter between 25 mm ($A_c = 500$ mm²) and 50 mm ($A_c = 2 000$ mm²) are permitted for special purposes, without the application of correction factors. The geometry and

tolerances given for the nominal 1 000 mm² cone penetrometer should be linearly scaled in proportion to the diameter.

The friction sleeve shall be placed just above the cone. The dimensions and tolerances for the friction sleeve should be as given in ISO 22476-1:2012, 4.5.

For measuring pore pressures, a filter location in the cylindrical part just above the conical part is recommended. Pore pressure measured at this location is denoted u_2 . Pore pressures may sometimes also be measured on the cone face (u_1) and/or just above the friction sleeve (u_3). The location of the filter(s), dimensions and tolerances should be as given in ISO 22476-1:2012, 4.6.1. The penetrometer tip and adjoining rod(s) should have the same diameter for at least 400 mm behind the tip for the 1 000 mm² cone penetrometer. For other size cones, this distance should be scaled linearly in proportion to the diameter.

NOTE Changing rod diameter at a distance of less than 400 mm (for standard 1 000 mm² cone penetrometers) can influence the measured cone resistance.

8.3.3 Test procedures

8.3.3.1 Selection of equipment and procedures

For cone penetration tests, the use of application classes as defined below should be adopted. Equipment and procedures to be used should be selected according to the required application class given in [Table 2](#). Application classes are defined as follows:

- a) **Application Class 1** is intended for very soft to soft soil deposits. Class 1 penetration tests are normally not achievable for mixed bedded soil profiles with weak to strong layers (although pre-drilling through these layers can overcome the problem). Tests can only be performed as CPTU.
- b) **Application Class 2** is intended for precise evaluation for mixed bedded soil profiles with weak to strong layers, in terms of profiling and material identification. Interpretation in terms of soil parameters is also possible, with restriction to indicative use for the soft or weak layers. The test type should be CPTU.
- c) **Application Class 3** is intended for evaluation of mixed bedded soil profiles with soft to stiff clays and loose to dense sands, in terms of profiling and material identification. Interpretation in terms of soil parameters is appropriate for very stiff to hard clay and for dense to very dense sand layers. For stiff clays or silts and loose sands, only an indicative qualitative interpretation can be undertaken using data acquired under this application class. The test type should be CPTU but in some cases CPT may be acceptable.

NOTE Mixed bedded soil profiles refer to soil conditions containing typically dense and stiff to hard soils, but possibly also including soft or weak layers.

If all possible sources of errors are added, the minimum accuracy of the recorded measurements for each application class should be better than the largest of the values given in [Table 2](#). The uncertainty analysis should include internal friction, errors in the data acquisition, eccentric loading, temperature effects (ambient and transient), pore pressure effects in gaps below and above the friction sleeve, and dimensional errors. The resolution of the measurements should be better than one-third of the required accuracy applicable to the application class given in [Table 2](#).

Seafloor CPT systems generally provide thrust perpendicular to the seafloor, with no opportunity for correcting the pushing force to vertical. In drilling mode, verticality of the downhole CPTU/CPT system depends on verticality of the drill string. A vertical pushing force is normally assumed for the calculation of the penetration depth.

NOTE The difference between accuracy and uncertainty is described in [Clause 3](#).

Table 2 — Accuracy of CPT/CPTU parameter values for application classes

Application class	Test type	Measured parameter	Allowable minimum accuracy ^a
1	CPTU	Cone resistance	35 kPa or 5 %
		Sleeve friction	5 kPa or 10 %
		Pore pressure	25 kPa or 5 %
2	CPT or CPTU	Cone resistance	100 kPa or 5 %
		Sleeve friction	15 kPa or 15 %
		Pore pressure ^b	50 kPa or 5 %
3	CPT or CPTU	Cone resistance	200 kPa or 5 %
		Sleeve friction	25 kPa or 15 %
		Pore pressure ^b	100 kPa or 5 %

^a The allowable minimum accuracy of the measured parameter is the larger value of the two quoted. The percentage values apply to the measured value and not to the measuring range.

^b Pore pressure can only be measured if CPTU is used.

If the project specification does not provide a required application class, Application Class 3 shall be the default.

The allowable minimum accuracies for cone resistance, sleeve friction and pore pressure shall apply relative to the seafloor.

The allowable minimum accuracy for penetration depth should be estimated in accordance with depth accuracy recommendations as provided in [Clause 6](#).

8.3.3.2 Preparation for testing

The thrust machine should act on the push rods so that the axis of the penetration force is as close to vertical as possible. The axis of the penetrometer shall correspond to the loading axis at the start of the penetration.

It is permissible to use the same filter for several tests, but the pore pressure response should be closely monitored for each test and the filter replaced when an unsatisfactory response is observed.

8.3.3.3 Pushing of cone penetrometer

The nominal rate of penetration should be (20 ± 5) mm/s.

The length of each stroke should be as long as possible, with due consideration for the mechanical and strength limitations of the equipment. Continuous penetration is preferred. The data recording frequency shall be at least 1 Hz.

For drilling mode and shallow non-drilling mode (<5 m), inclination measurements are not required.

8.3.3.4 Dissipation tests

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

8.3.3.5 Test completion

The penetration of the cone penetrometer shall be terminated when:

- the required depth below seafloor has been reached;
- the agreed maximum thrust or maximum capacity of the measuring system has been reached; or
- the cone inclination approaches or is beyond a limit 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. The fact that maximum thrust capacity is reached is also important information.

Potential damage to the equipment can also be a valid reason to prematurely terminate a test.

For quality control, zero-reference readings of cone resistance, sleeve friction and, if applicable, the pore pressure, shall be recorded before and after each test.

For seafloor-based drilling and non-drilling systems, reference readings can be made at the seafloor or a fixed distance above, with values corrected to seafloor where appropriate; see [Annex D](#) for further guidance on this topic. For downhole CPT/CPTU from a surface vessel, the zero reference shall be at deck level, and the reference readings at the bottom of the borehole shall also be recorded and compared to theoretically calculated values. Both non-drilling mode and drilling mode tests shall be reported for all measurements referenced to the seafloor.

Results of CPTU/CPTs carried out in drilling mode prior to 2014 may show q_c , f_s and u corrected relative to the bottom of the borehole rather than the seafloor.

NOTE 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.

8.3.3.6 Equipment checks and calibration

For each cone penetrometer, a calibration shall be made of the area ratios of the cone (a) and of the friction sleeve (b) in accordance with ISO 22476-1:2012, 7.2. These values are unique to each cone penetrometer and should be documented in the report(s) where results are given, as they are very important for data reduction. The (a) and (b) calibrations should be checked at least once a year, and preferably at the beginning of each offshore campaign.

It is recommended to use more than one calibrated cone on each project, preferably two in the first deep borehole.

8.3.4 Presentation of test results and reporting

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 shall also be given.

The following measured parameters shall be presented as functions of depth:

- cone resistance, q_c ;
- pore pressure, u_2 ;
- sleeve friction, f_s ;
- inclination, i , where applicable

NOTE 1 Inclination is defined as the angular deviation of the cone penetrometer from the vertical.

Derived parameters to be presented as functions of depth should include, but not necessarily be limited to:

- a) corrected cone resistance, $q_t = q_c + (1 - a) u_2$

where

a is the net area ratio = A_n/A_p ;

A_p is the projected area of the penetrometer in a plane normal to the shaft;

A_n is the area of the load cell or shaft on which pore pressure can act.

NOTE 2 The measured 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 f_t) is given in [Annex D](#).

b) friction ratio, $R_f = f_s/q_c$

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

where

σ_{v0} is the estimated total vertical 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 given.

NOTE 3 Additional parameters that can be plotted include: $q_{net} = q_t - \sigma_{v0}$, $Q_t = q_{net}/\sigma'_{v0}$ and $F_r = f_s/q_{net}$.

In general, the test results should be plotted with a depth scale of 1 scale unit = 1 m, but for shallower profiles, e.g. pipeline investigations, an enlarged scale can be used provided this is maintained across the acquired data set.

For the measured and derived CPTU parameters, the following scales are recommended for use where applicable:

- | | |
|--------------------------------|---------------------------------------|
| — cone resistance q_c, q_t | — 1 scale unit = 2 MPa or 0,5 MPa; |
| — sleeve friction, f_s : | — 1 scale unit = 0,05 MPa; |
| — pore pressure, u : | — 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. |

Different scales for cone resistance, sleeve friction and pore pressure can be used if the values in the profile fall outside a reasonable range.

NOTE 4 It can also be very beneficial to present two sets of plots in one profile. This is especially so 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 in the investigation report.

The measured and derived CPTU data shall be reported in digital (i.e. numerical) form in addition to being presented in the field report.

It is recommended that reference readings are recorded and documented in accordance with the procedure outlined in [Annex D](#).

8.4 Pore pressure dissipation test (PPDT)

8.4.1 General

This subclause covers pore pressure dissipation tests (PPDT) performed with a piezocone penetrometer.

The project specifications shall include

- a) type of test according to [Table 3](#),
- b) test depth,
- c) test duration in terms of termination criteria.

The accuracy of measurement is that for the corresponding application class of the piezocone penetration test (see [8.3](#)), unless agreed otherwise.

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

NOTE 2 Termination criteria can include: an agreed maximum test duration of for example 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; that the change in pore pressure over a given time interval is below a certain value, for example 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 3 — Test types

Test type	Description	Test duration
PPDT1	Pore pressure dissipation for estimation of <i>in situ</i> equilibrium pore pressure	Typically ≥ 90 % dissipation of the pore pressure immediately before the penetration interruption, relative to the estimated <i>in situ</i> equilibrium pore pressure
PPDT2	Pore pressure dissipation for estimation of coefficient of (radial) consolidation in fine grained, low permeability soil	Typically ≥ 50 % dissipation of the pore pressure immediately before the penetration interruption, relative to the estimated <i>in situ</i> equilibrium pore pressure
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 acceptable, for example a piezoprobe or a ball penetrometer equipped with a pressure sensor.

8.4.3 Test procedure

The test procedure is as follows:

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

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

Influence of the tidal variation should be considered, especially in shallow water.

8.4.4 Presentation of results

The following information shall be presented:

- results from the CPT/CPTU data acquisition according to [8.3](#), where applicable;
- test type according to [Table 3](#);
- test depth for the 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 presented versus time and log time, where $U = (u_2 - u_0)/(u_{2i} - u_0)$.

NOTE Guidance on interpretation of pore pressure dissipation test results is given by Lunne et al.(1997); see also Orange et al. (2005).

8.5 Ball and T-bar penetration tests

8.5.1 General

The ball and T-bar are particularly suitable for characterizing very soft to soft clays and clayey silts with an undrained shear strength < 50 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 is best suited for non-drilling mode.

The ball and T-bar shown in [Figure 2](#) are of a size suitable for mounting directly on standard CPT rods. The load cell(s) within the cone penetrometers may then be used to measure the soil resistance mobilized on the ball (T-bar) penetrometer.

8.5.2 Equipment

8.5.2.1 Ball penetrometer

The ball, see example in [Figure 2](#), is a steel sphere attached to a push rod, which is pushed into the soil using CPT/CPTU type deployment systems. The standard ball shall have a projected area of 2500 mm² (corresponding to a diameter of 56,4 mm) to 10 000 mm² (corresponding to a diameter of 113 mm). The diameter of the push rod shall be such that the minimum ratio of the projected area of the ball to the cross-sectional area of the push rod is 7:1, and with no increase in diameter of the connecting push rod for a distance of 10 times the diameter of the rod.

The ball should be manufactured to a surface roughness, R_a , of $0,4 \mu\text{m} \pm 0,25 \mu\text{m}$.

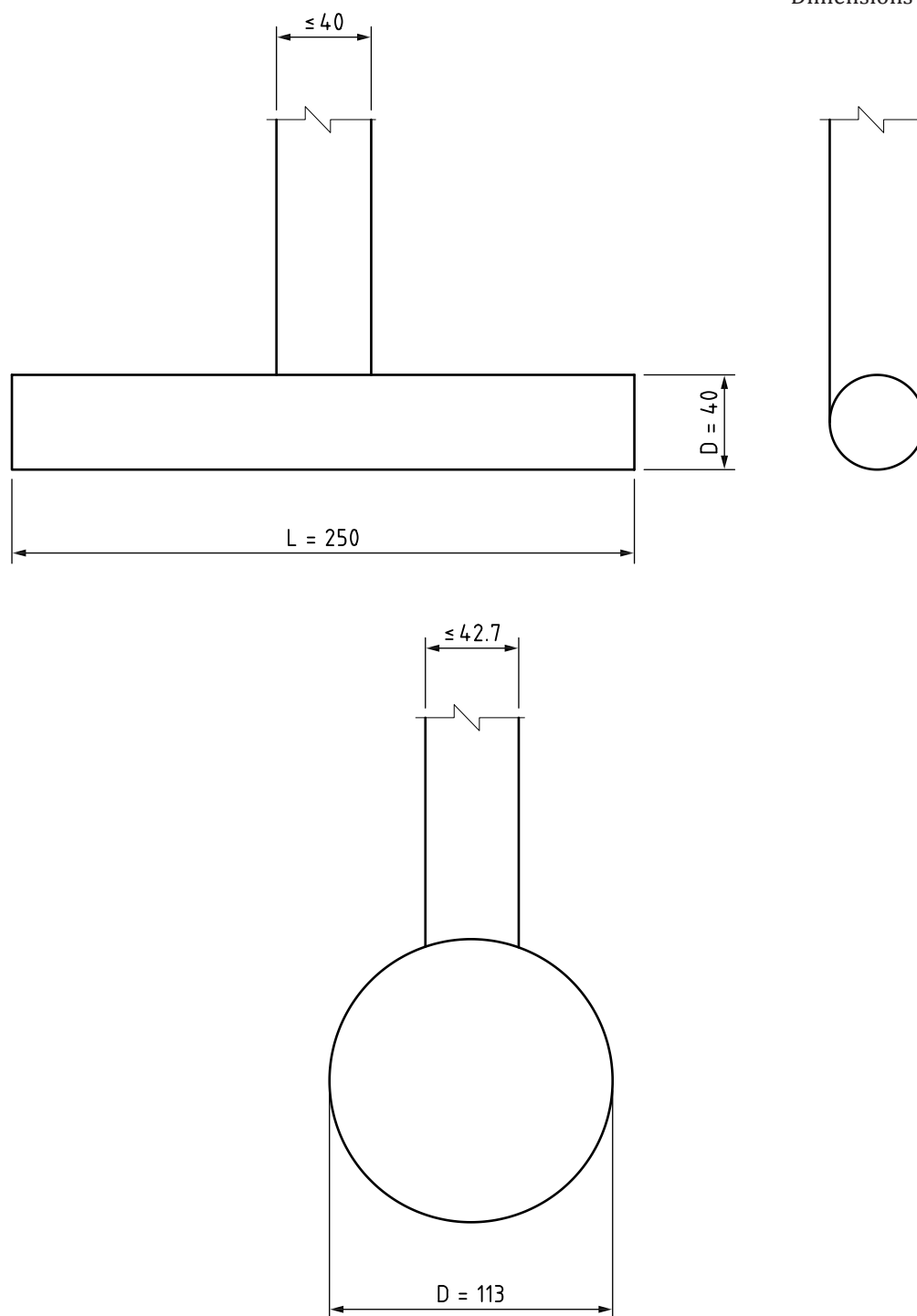
The load sensor for ball resistance shall be positioned within the ball or immediately above the ball. The load sensor shall be compensated for possible eccentricity of axial forces. The ball penetrometer shall be fitted with an inclination sensor; but this is not required where the target penetration is less than 5 m. The inclination sensor shall normally have a measuring range of at least $\pm 15^\circ$ relative to the vertical axis. Requirements for the thrust machine, the push rods and the measuring system for penetration are as given in [8.3](#).

8.5.2.2 T-bar penetrometer

The T-bar is a cylinder, or short bar, attached to a push rod, which is pushed into the soil in non-drilling mode using CPT/CPTU-type deployment systems, see [Figure 2](#). The standard T-bar used in offshore practice has a nominal diameter of 40 mm and a length of 250 mm (projected area of 10 000 mm², see example in [Figure 2](#)), although smaller devices may be used. The T-bar should satisfy similar requirements as above for the ball, in terms of the 7:1 ratio of the projected area of the T-bar to the cross-sectional area of the connecting push rod, and the minimum length of any push rod of reduced diameter. In addition, it should have a minimum length-to-diameter ratio of 5, and a diameter that is no smaller than that of the connecting push rod.

The T-bar should be manufactured to a surface roughness, R_a , of $0,4 \mu\text{m} \pm 0,25 \mu\text{m}$.

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 2 — Dimensions of 10 000 mm² ball and T-bar

8.5.3 Test procedures

8.5.3.1 General

The following procedures shall be followed:

- the ball (T-bar) resistance shall be measured during penetration;
- the rate of penetration shall be nominally (20 ± 5) mm/s;
- for tests with penetration deeper than 5 m, the inclination of the rod attached to the ball (T-bar) shall be measured;
- readings from all sensors shall be recorded at least once per second (i.e. for every 20 mm of penetration).

The ball (T-bar) resistance should be measured during retraction at a nominal rate of (20 ± 5) mm/s, if specified in the project specifications.

Cyclic testing can be included to obtain a measure of the remoulded shear strength.

If cyclic ball (T-bar) tests are carried out, these shall be done on ball (T-bar) penetration and comprise cycles of minimum up and down distances of at least 0,15 m (0,20 m) or three times the diameter of the ball (T-bar), whichever is greater, at a nominal rate of 20 mm/s. Ten full cycles should be carried out, unless no further degradation in ball (T-bar) penetration resistance is evident over three or more cycles.

In some cases, important information can be obtained by carrying out tests at rates of penetration outside those given above. If such tests are carried out, results shall clearly be marked with a note that a non-standard penetration/extraction rate has been used.

The thrust machine should push the instrument such that the axis of the pushing force is as close to vertical as possible. The axis of the penetrometer shall correspond to the loading axis at the start of penetration.

Consideration of the proximity of the ball (T-bar) to the seafloor during cycling should be given, so as to minimize water entrainment which could affect results.

8.5.3.2 Accuracy requirements

Taking into account all possible sources of error and using the complete field measurement system, the allowable minimum accuracy of test measurements shall be better than the largest of the following values:

- for penetration resistance: 5 % of the measured value or 20 kPa, whichever is larger;
- for inclination: 2° (if applicable).

The allowable minimum accuracy for resistance shall apply relative to seafloor.

The allowable minimum accuracy for penetration depth should be estimated in accordance with depth accuracy recommendations as provided in [Clause 6](#).

The resolution of the measured results shall be better than one-third of the required minimum accuracy.

Equipment checks and calibration for the ball (T-bar) penetrometer shall be the same as for the CPT/CPTU, see [8.3.3.6](#).

8.5.4 Presentation of test results and reporting

The reporting shall conform to [8.2](#). In addition, the area ratio, a , of the ball (T-bar) shall be listed. The measured results shall be presented in digital (i.e. numerical) form, consisting of the following:

- depth below seafloor, expressed in metres;

- ball (T-bar) resistance, q_m , during penetration and extraction, expressed in MPa or kPa;
- inclination (if measured), expressed in degrees.

In addition, the net ball (T-bar) resistance should be given according to the following simplified formula [see Randolph (2004)]:

$$q_{\text{ball}}(q_{\text{T-bar}}) = q_m - [\sigma_{v0} + u_0(1 - a)](A_s/A_p)$$

where

$q_{\text{ball}}(q_{\text{T-bar}})$	is the net penetration resistance for the ball (T-bar);
q_m	is the measured penetration resistance;
u_0	is the applicable hydrostatic water pressure at the mid-height of the ball (T-bar);
σ_{v0}	is the <i>in situ</i> total vertical stress;
A_p	is the projected area of the penetrometer in a plane normal to the shaft;
a	is the net area ratio = A_n/A_s , where
A_n	is the area of the load cell or shaft where pore pressure can act,
A_s	is the cross-sectional area of the connecting shaft.

For the reporting of cyclic tests, the net remoulded ball (T-bar) penetration resistance denoted as:

$$q_{\text{ball,rem}}(q_{\text{T-bar,rem}})$$

should be determined as the average penetration and extraction resistance over the last cycle.

If full degradation has not occurred, the average net remoulded ball (T-bar) penetration resistance from q_{ball} or $q_{\text{T-bar}}$ should not be reported.

It is recommended that reference readings be documented following the procedure outlined in [Annex D](#).

For all test types, the measured ball (T-bar) resistance shall be corrected relative to seafloor.

In general, test results should be plotted with a depth scale of 10 mm = 1 m, but for shorter profiles, e.g. for pipeline investigations, an enlarged scale can be used.

The zero reference for ball (T-bar) tests shall be the seafloor for non-drilling mode operation (see [Clause 6](#)). For vessel-based drilling mode and downhole testing, the zero reference shall be the deck level, but the reference readings at the bottom of the borehole shall also be recorded and compared to theoretically calculated values. Both non-drilling and drilling mode tests shall be reported for all measurements with reference to seafloor. For ball (T-bar) tests deployed in seafloor drilling mode and non-drilling mode, the zero reference shall be at seafloor, or a fixed distance above seafloor.

The scale for presenting the measured ball (T-bar) resistance during penetration and retraction shall be selected to suit the soil conditions.

The results of cyclic ball (T-bar) tests should be included in the main plot as well as in an enlarged plot in order to illustrate the results in adequate detail.

8.6 Seismic cone penetration test (SCPT/SCPTU)

8.6.1 General

The seismic cone penetrometer, in addition to the standard CPT/CPTU sensors (see 8.3), has one or more seismic receivers that detect shear wave (SH) energy generated by a specific source deployed at the seafloor that is integral to the system. A suitable seismic source and a seismic cone penetrometer allow the execution of a downhole seismic test, which provides shear wave velocity, typically SH propagating vertically. For the CPTU parameters, the guidance and requirements in 8.3 are valid.

A single seismic test event may be agreed, for example for earthquake studies requiring an approximate average SH velocity for depth range from the seafloor to 80 m depth.

The following subclauses give guidance and requirements for the seismic part of the SCPT/SCPTU, which basically follow the requirements and reference information presented in ASTM D7400.

8.6.2 Equipment

The geometry and dimensions of the seismic cone penetrometer should be in accordance with the requirements outlined in 8.3.2, with the exception that the diameter of the cone penetrometer at the location of the seismic receiver(s) should be greater than that of the sections immediately below the instrumentation package, in order to promote good coupling between the receiver(s) and the surrounding soil. Typical receivers include uni- or multi-axial geophones or accelerometers, located either at effectively one point, or at two points in the same tool (dual-element seismic cone penetrometer with receivers separated by a fixed distance).

The seismic source can be installed on the seafloor frame used for the cone penetration test or at a different position on the seafloor. In both cases, the horizontal distance between the seismic source and the axis of the seismic cone penetrometer should be determined accurately.

A horizontal hammer can be used as a seismic SH source, the important issue being that a clear SH with high repeatability signal is produced that can be readily identified by the seismic receiver(s).

NOTE 1 ASTM D7400 offers various recommendations about frequency for seismic receivers.

NOTE 2 Improved quality of measurement of interval SH velocity, v_s , can be achieved by using a dual-element seismic cone penetrometer.

8.6.3 Test procedures

The project specifications shall include:

- a) the type of seismic cone penetrometer, single element or dual element;
- b) the test depth or vertical test spacing;
- c) termination criteria.

NOTE 1 Shear wave velocity cannot reliably be measured in the upper 2 m to 5 m below seafloor, depending on the system characteristics and site conditions.

Termination criteria may include an agreed maximum test depth or a minimum signal-to-noise ratio combined with a maximum number of signal stacking events. Achievable test depth depends on factors such as deployed system characteristics, interaction of the seismic source with the upper seabed, soil conditions at depth and interference from nearby objects. Termination criteria for the CPTU (see 8.3.3.5) can also be taken into account.

The test procedure consists of activating the seismic source and receiving the generated signals at the seismic receivers. This is usually done during an interruption in cone penetration. However, some systems allow continuous operation of the seismic source and receivers during cone penetration. If cone penetration is interrupted, then multiple activation of the seismic source at a single depth can improve

data quality, particularly when deploying a seismic source that generates shear waves in two opposite horizontal directions or when applying the 'stacking method' [see e.g. Peuchen et al. (2002) and Nguyen et al. (2013)].

A triggering signal shall be generated at the time the seismic source is activated, i.e. at the start of propagation of shear waves. The triggering signal and the measurements from the seismic receivers in the seismic cone penetrometer shall be recorded as discrete time histories.

A recommended minimum sampling interval is 0,025 ms.

The accuracy requirement for average shear wave velocity shall be $\pm 10\%$ for a straight-line slant distance from source to receiver and assumed zero depth uncertainty.

NOTE 2 A single test with a dual-element seismic cone penetrometer provides three velocities, one average velocity from source to upper seismic receiver, one average velocity from source to lower seismic receiver and an average velocity for the zone between the two receivers. The accuracy for the average velocity for the zone between the two receivers is largely unaffected by depth uncertainty and travel path. Other shear wave velocities have lower accuracies, which can be calculated from an estimate of the uncertainties in travel path distance, either from source to receiver or from the relative distance between two test depths in a single profile. A single test with a single-element seismic cone penetrometer provides one velocity only. Two tests with a single-element seismic cone penetrometer in a single profile provide the opportunity for determination of three velocities, one from source to upper test depth, one from source to lower test depth and a differential velocity for the zone between the two test depths. Three or more tests provide additional opportunities for separating zones of interest.

8.6.4 Presentation of results

In addition to the requirements for presentation of the standard CPT/CPTU results given in [8.3.4](#), the following shall be presented:

- type and description of the seismic source and the seismic receiver(s);
- difference in depths between the seismic source and the position(s) of the seismic receiver(s);
- the horizontal distance between the seismic source and the axis of the seismic cone penetrometer;
- average, or interval, shear wave velocity, v_s , for the depth interval(s) over which it has been measured, including:
 - the depth uncertainty according to [Clause 6](#),
 - limitations of the methodology used,
- assumed travel path for the seismic waves.

NOTE A travel path is not always a straight line for materials with an abrupt change in density or elasticity, and in such cases Snell's law of refraction can be used. With small offset distances relative to depth below seafloor, e.g. 2 m offset and 10 m depth below seafloor, this becomes less important.

8.7 Field vane test (FVT)

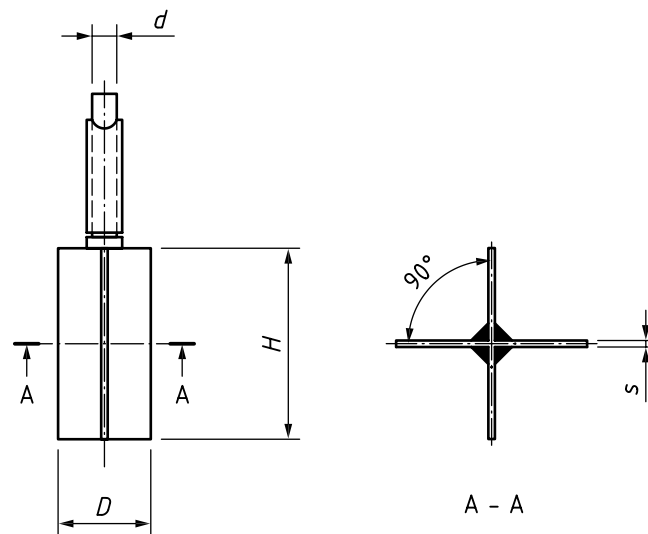
8.7.1 General

Field vane tests (FVT) are undertaken to measure the shear strength, residual shear strength and remoulded shear strength of clays with undrained shear strengths normally less than 100 kPa. However, the vane test can be used in clays with undrained shear strengths of up to 200 kPa.

8.7.2 Equipment

Vane blades should be rectangular. The ends of a vane blade may be flat or tapered as shown in [Figure 3](#) and [Figure 4](#). Vane blades should have a height (H) to diameter (D) ratio equal to 2 (see [Figure 3](#)). Maximum vane dimensions $H \times D$ of 200 mm $\times$ 100 mm are commonly used in soft soils with undrained

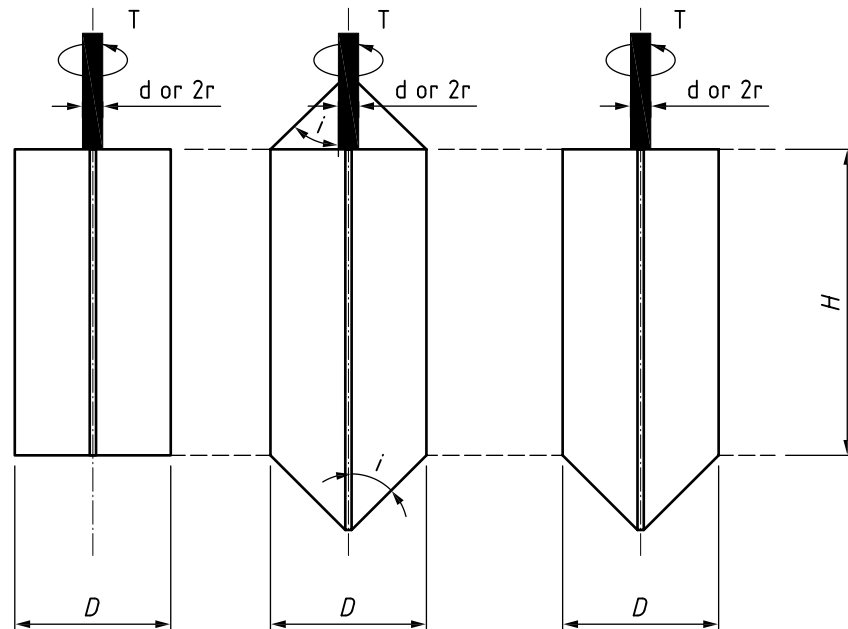
shear strengths less than 25 kPa and deployment in non-drilling mode. Minimum vane dimensions of 80 mm × 40 mm are commonly used in clays with undrained shear strengths up to 200 kPa.



Key

H	height of vane	s	blade thickness
D	diameter of vane	d	diameter of rod
A-A	cross section of vane		

Figure 3 — Example of design of rectangular vane



Key

T	torque	i	angle of tapered vane
H	height of vane	d	diameter of rod (= 2r)
D	diameter of vane		

Figure 4 — Examples of tapered vanes (from ASTM D2573)

The blade thickness, s , should be $0,8 \text{ mm} \leq s \leq 3,0 \text{ mm}$.

In very soft and sensitive clays, the blade thickness should not exceed 2,0 mm in order to limit the disturbance caused during vane insertion.

The diameter of the vane shaft, d , as well as possible welding seams in the centre of the vane, should be small enough to minimize soil disturbance.

The diameter of the vane shaft should be no greater than 16 mm in soft sensitive soils, with $s_{ufv} < 12,5$ kPa. However, the vane shaft shall be of such rigidity that it does not twist significantly under full load conditions. In clays with undrained shear strength higher than 100 kPa, the diameter of the vane shaft may exceed 20 mm.

The data acquisition system shall be such that the overall accuracy outlined in [8.7.3](#) is maintained.

The resolution of the measurement system shall be better than one-third of the required accuracy applicable to the application class given in Table 4.

8.7.3 Test procedures

Equipment and procedures to be used should be selected according to the required application class as shown in Table 4.

Application classes for FVT are defined as follows:

- Application Class 1: for special purposes (for example to measure soil stiffness and/or if requiring high accuracy in extremely soft soils);
- Application Class 2: for an accurate value of undrained shear strength of soft to very soft soils;
- Application Class 3: for stiffer soils.

The accuracy analyses shall include sources of friction other than those caused by the blade together with data acquisition, calibration and dimensional errors.

NOTE Achievable accuracy is a function of the dimensions of the vane used in the test. The use of larger vanes will result in higher accuracy, but a smaller measurement range.