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

**Part 10:
Marine geophysical investigations**

*Industries du pétrole et du gaz naturel — Exigences spécifiques
relatives aux structures en mer —*

Partie 10: Enquêtes géophysiques marines



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

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*.

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

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

Introduction

The general objective of a marine site investigation is to provide information about the seafloor, the sub-seafloor and geological processes affecting both, geohazards, and human-made objects at or below the seafloor. Marine site investigations can encompass both marine soil investigations and marine geophysical investigations, as shown in [Figure 1](#). This document provides requirements for marine geophysical investigations to support oil and gas developments offshore, is complementary to ISO 19901-8 on marine soil investigations, and provides guidance on the integration of both types of investigations.

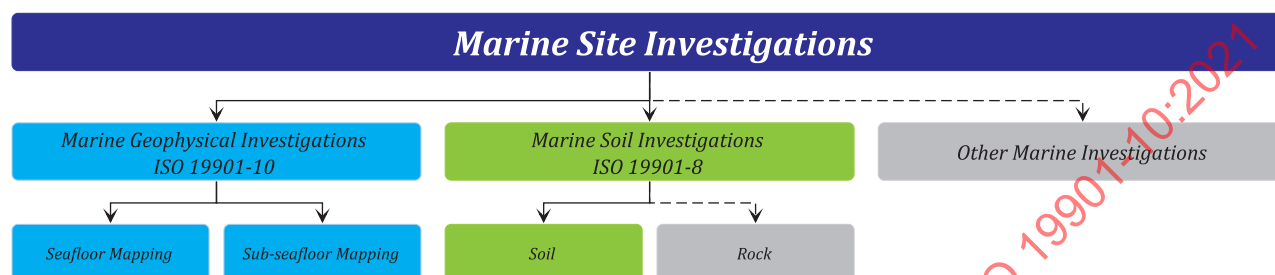


Figure 1 — Marine geophysical investigations as part of marine site investigations.

NOTE Subjects denoted in grey boxes in [Figure 1](#) are neither covered in ISO 19901-8 nor in this document. However, marine geophysical investigations can provide information about soils and rocks, whereas rocks are only covered by ISO 19910-8 to the extent that ordinary marine soil investigation tools can be used, e.g. for chalk.

Marine site investigations for a specific project can comprise both geophysical and geotechnical investigations, depending on project scale and complexity. It is common practice to conduct first a marine geophysical investigation, sometimes in combination with a limited marine soil investigation consisting of shallow soil sampling and/or in situ testing. A more extensive marine soil investigation is often conducted at a later stage. In some cases, a marine site investigation can consist solely of a stand-alone geophysical survey that has a specific and limited purpose. A marine site investigation can also consist solely of a stand-alone marine soil investigation, for which details on soil investigation equipment and procedures are provided in ISO 19901-8.

Particular objectives of a marine geophysical investigation should be addressed in project specifications, which should specify desired investigation depths, desired resolutions (horizontal and vertical), and whether the objective is to illuminate the seafloor and/or the sub-seafloor. Caution is necessary in the selection of the type of equipment to be used, and operational parameters for that equipment, in order to meet those desired depths, resolutions, and illumination targets, particularly because local site conditions can affect the abilities of certain equipment to meet those objectives. This document includes discussion of the selection and operation of appropriate geophysical equipment.

Marine geophysical investigations and marine soil investigations can be (and often are) carried out as separate exercises, the results of which can be integrated into a ground model. This document applies to critical stages in the development of a ground model, from the initial conception stage through successive stages of increased detail.

In this document, the following verbal forms are used:

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

[Annex A](#) provides additional information intended to assist the understanding or use of this document.

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

Part 10: Marine geophysical investigations

1 Scope

This document provides requirements and guidelines for marine geophysical investigations. It is applicable to operators/end users, contractors and public and regulatory authorities concerned with marine site investigations for offshore structures for petroleum and natural gas industries.

This document provides requirements, specifications, and guidance for:

- a) objectives, planning, and quality management;
- b) positioning;
- c) seafloor mapping, including instrumentation and acquisition parameters, acquisition methods, and deliverables;
- d) sub-seafloor mapping, including seismic instrumentation and acquisition parameters, and non-seismic-reflection methods;
- e) reporting;
- f) data integration, interpretation, and investigation of geohazards.

This document is applicable to investigation of the seafloor and the sub-seafloor, from shallow coastal waters to water depths of 3 000 m and more. It provides guidance for the integration of the results from marine soil investigations and marine geophysical investigations with other relevant datasets.

NOTE 1 The depth of interest for sub-seafloor mapping depends on the objectives of the investigation. For offshore construction, the depths of investigation are typically in the range 1 m below seafloor to 200 m below seafloor. Some methods for sub-seafloor mapping can also achieve much greater investigation depths, for example for assessing geohazards for hydrocarbon well drilling.

There is a fundamental difference between seafloor mapping and sub-seafloor mapping: seafloor signal resolution can be specified, while sub-seafloor signal resolution and penetration cannot. This document therefore contains requirements for the use of certain techniques for certain types of seafloor mapping and sub-seafloor mapping (similarly, requirements are given for certain aspects of data processing). If other techniques can be shown to obtain the same information, with the same or better resolution and accuracy, then those techniques may be used.

Mapping of pre-drilling well-site geohazards beneath the seafloor is part of the scope of this document.

NOTE 2 This implies depths of investigation that are typically 200 m below the first pressure-containment casing string or 1 000 m below the seafloor, whichever is greatest. Mapping of pre-drilling well-site geohazards is therefore the deepest type of investigation covered by this document.

In this document, positioning information relates only to the positioning of survey platforms, sources and receivers. The processes used to determine positions of seafloor and sub-seafloor data points are not covered in this document.

Guidance only is given in this document for the use of marine shear waves ([A.8.3.3](#)), marine surface waves ([A.8.3.4](#)), electrical resistivity imaging ([A.8.3.5](#)) and electromagnetic imaging ([A.8.3.6](#)).

2 Normative references

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

ISO 19901-8, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 8: Marine soil investigations*

3 Terms and definitions

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

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

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

3.1

abyssal water

water depths greater than 3 000 m

3.2

acoustic impedance

seismic velocity multiplied by density

Note 1 to entry: Compressional-wave impedance uses compressional-wave velocity, and shear-wave impedance uses shear-wave velocity.

3.3

acoustic noise

unwanted acoustic signal

3.4

active tail buoy

buoy fitted with a global navigation satellite system transponder attached to the end of a streamer

3.5

airgun

seismic source that injects a bubble of highly compressed air into the water

Note 1 to entry: Whereas single airguns can be used, it is common practise to deploy and fire several airguns in arrays to produce an acoustic pulse that has certain temporal and spatial characteristics.

3.6

aliasing

effect that causes signals to be misrepresented in recorded data as a result of undersampling

Note 1 to entry: Undersampling can be in time or spatial domain.

3.7

anisotropy

dependence of velocity on direction or upon angle of wave propagation

3.8

array

system of linked hydrophones or seismic sources arranged in a geometric pattern to increase sensitivity and/or directionality and/or in the case of a seismic source, the pulse characteristics

3.9**attenuation**

reduction in amplitude or energy

Note 1 to entry: Attenuation in seismic data is related in part to soil conditions.

3.10**attribute**

characteristic of a given object, structure or feature

Note 1 to entry: A seismic attribute is a quantity or property derived or extracted from seismic data that provides specific information contained within the data as an aid in interpretation.

3.11**backscatter**

amplitude of echo sounder energy reflected by the seafloor that can be processed into information about seafloor features and texture

3.12**bandwidth**

range of frequencies in an acoustic signal between the two half power points

Note 1 to entry: This corresponds with the frequencies at which the power drops to half the peak power (3 dB).

3.13**boomer**

seismic source that operates by the rapid movement of a restricted metal plate

3.14**chirp**

type of sub-bottom profiler that emits a frequency-modulated pulse of acoustic energy over a specified range of frequencies

3.15**common depth point****CDP**

common reflection point at depth on a reflector, or the halfway point when a wave travels from a source to a reflector to a receiver

Note 1 to entry: In the case of flat layers, the common depth point is vertically below the common mid-point.

3.16**common mid-point****CMP**

in multichannel seismic acquisition, the point on the surface halfway between the source and receiver that is shared by a number of source-receiver pairs

Note 1 to entry: CMP gather refers to the set of traces that have a common mid-point.

3.17**common reference point**

datum point on a vessel to which all positioning systems are referenced in three dimensions

3.18**cone penetration test****CPT****CPTU**

in situ soil strength testing device that makes direct measurements of cone resistance, sleeve friction and pore pressure response as it is pushed into the sub-seafloor

Note 1 to entry: See ISO 19901-8.

3.19

contractor

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

3.20

coordinate reference system

coordinate system that is related to an object by a datum

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

Note 2 to entry: For geodetic and vertical reference frames, the object will be the Earth. In planetary applications, geodetic and vertical reference frames can be applied to other celestial bodies.

[SOURCE: ISO 19111:2019, 3.1.9]

3.21

deconvolution

filtering process that undoes the effect of another filter

Note 1 to entry: There are many applications in seismic data processing. One example is removing the filtering effect of the sub-seafloor.

3.22

deep water

water depths between 750 and 1 800 m

3.23

demultiple

seismic processing application that attenuates multiple energy

3.24

signature

filtering process to compensate for the non-minimum phase characteristics of a seismic source

3.25

digital terrain model

DTM

digital representation of a mapped surface usually defined by xyz values for defined cells

3.26

dip move-out

DMO

difference in the arrival times or travel times of a reflected wave, measured by receivers at two different offset locations, that is produced from dipping reflectors

Note 1 to entry: Dip move-out can be compensated for in processing.

3.27

direct arrival

recorded seismic energy that has travelled directly from source to receiver and has neither been reflected nor refracted

3.28

doppler velocity log

DVL

instrument to measure the speed of a survey platform by measuring the frequency shift of acoustic pulses reflected from the seafloor

3.29

dynamic range

ratio of the largest recoverable signal to the smallest recoverable signal

3.30**exploration seismic data**

seismic data containing frequencies between 0 Hz and 100 Hz, typically acquired for the purpose of exploring for oil and gas rather than site investigation

Note 1 to entry: In this document, "exploration seismic data" also includes data acquired for the purposes of hydrocarbon reservoir management (assessment, development, and monitoring).

3.31**far-field source signature**

characteristic wave shape of a particular seismic source recorded at a remote distance, so that the wave front is close to a straight line

Note 1 to entry: In practice this is difficult to achieve, and a mid-field source signature is more common.

3.32**feather angle**

angle between the line connecting the near and far receivers of a streamer and course made good of the nearest receiver

Note 1 to entry: Differences are caused by a cross current.

3.33**feature**

item observed in seafloor mapping data or sub-seafloor mapping data that characterizes the site or renders it unique

Note 1 to entry: A featureless seafloor is completely smooth and flat, for example.

3.34**first break**

first recorded signal attributable to seismic-wave travel from a known source

3.35**first pressure containment string**

first casing installed in a well that will enable the pressure inside the well to be controlled

3.36**frequency spectrum**

function of power versus frequency that illustrates the frequency content of a wavelet or signal

Note 1 to entry: A frequency spectrum is produced by a Fourier transform.

3.37**Fresnel zone**

generally circular area on a reflecting interface from which all reflections contribute to the recorded signal

Note 1 to entry: The Fresnel zone is dependent on the period of the wave and determines lateral resolution.

3.38**geohazard**

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

3.39**geological model**

explanation of geological conditions

3.40

ghost

spurious seismic reflection that occurs when energy is reflected between sources and/or receivers and the sea surface

3.41

global navigation satellite system

GNSS

satellite based navigation system that provides autonomous global positioning of a receiving device

Note 1 to entry: Global positioning system (GPS), and global navigation satellite system (Glonass), Galileo and BeiDo are typical examples of global navigation satellite systems.

3.42

ground model

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

3.43

ground-truthing

integration of seafloor or sub-seafloor geophysical data with data acquired by marine soil investigation and other dataNote 1 to entry: See, for example, ISO 19901-8 for marine soil investigation data.

3.44

high-resolution seismic

HR seismic

seismic reflection method that acquires seismic data containing frequencies between 75 Hz and 300 Hz

3.45

horizon

seismic reflector associated with the surface separating two strata

3.46

hydrophone

sensor that detects variations in pressure

3.47

inertial navigation system

navigation aid that uses accelerometers and gyroscopes to continuously calculate position, orientation and velocity by dead reckoning without external input

3.48

interval velocity

seismic velocity measured over a depth interval

3.49

isochore

line drawn on a map through points of equal vertical thickness of a soil unit, bed, formation or group of these

3.50

isochron

line drawn on a map through points at which a characteristic reflection time or interval has the same value

3.51

isopach

line drawn on a map through points of equal stratigraphic thickness of a sub-seafloor stratum or a group of these

3.52

magnetic gradiometer

system which measures magnetic gradient using two or more closely spaced magnetometers

3.53

magnetometer

instrument used to measure the strength and/or direction of a magnetic field

3.54

marine geophysical investigation

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

3.55

marker horizon

seismic reflector that maintains its characteristics over an area or distance so that it can be used as an interpretation reference

3.56

metadata

metacontent

information describing the content and context of the data within the given file or format

3.57

migration

seismic data processing step in which seismic events are geometrically re-located to the true location at which the event occurs in the sub-seafloor rather than the location at which it was recorded at the surface

Note 1 to entry: A more accurate image of the sub-seafloor will be created by applying migration.

3.58

motion reference unit

MRU

instrument for measuring pitch, roll, yaw, surge, sway and heave

Note 1 to entry: The primary use is to provide observations needed to correctly determine the position of geophysical sensors and in the processing of the sensor data.

3.59

multiple energy

noise on seismic records caused by reverberations between strong reflecting interfaces, such as the seafloor and the sea surface

3.60

mute

removal of certain components of traces prior to common mid-point stacking

3.61

near-field signature

pulse shape measured within the near-field range of a seismic source, generally less than 1 wavelength

3.62

noise

unwanted signal

3.63

normal moveout

NMO

variation in reflection arrival time caused by variation in seismic source to receiver (offset) distance

3.64

offset

horizontal distance from the seismic source to the seismic receiver

3.65

offset well

existing well from which information is available to tie back to and assist with making predictions about conditions at another well location

3.66

penetration

greatest depth below seafloor from which geophysical signals (such as seismic reflections) can be recognized with reasonable certainty

3.67

pinger

transducer or array of transducers using piezo-electric effects used as seismic source in sub-bottom profiling profilers

3.68

pitch

up-and-down motion of the bow or stern of a survey platform about the horizontal axis that passes across it from port to starboard through its centre of gravity

3.69

positioning

process to derive a three-dimensional coordinate, which uniquely defines a location within the project coordinate reference system, that should include the time of the observations used to derive the coordinate

3.70

pre-stack depth migration

PSDM

migration applied to seismic data in depth domain, calculated from seismic data in time coordinates, and applied before the data is stacked

3.71

pre-stack time migration

PSTM

migration applied to seismic data in time domain before it is stacked

3.72

project specification

scope of work for marine site investigation assigned by the client to a contractor

3.73

P-wave

primary wave

elastic body wave in which the particle motion is in the direction of propagation

3.74

reflection

energy or wave from a seismic source which has been reflected or returned from an acoustic impedance contrast

3.75

refraction

change in the direction of travel of a wavefront, or the bending of a ray, as it passes from one medium to another, expressed mathematically by Snell's law

3.76**resolution**

distance between separate points or objects, such as sedimentary sequences in a seismic section, that can be distinguished

3.77**roll**

up-and-down motion of the sides of a survey platform about the horizontal axis that passes along it through the bow and stern, and through its centre of gravity

3.78**sample interval**

time interval between successive samples of a recorded signal

3.79**seafloor**

interface at the bottom of the water column between the sea and soil or rock

Note 1 to entry: Equivalent terms "water bottom" or "mudline" are commonly used in seismic acquisition and processing.

3.80**SEG-D****SEG-Y**

society of exploration geophysicists standard formats commonly used to record and/or exchange seismic data

3.81**seismic method**

use of sound waves to image the earth's subsurface

Note 1 to entry: This term should not be confused with the one used in ISO 19901-2, which defines seismic as being related to strong ground motions (earthquake-related). These ground motions are addressed during the design of structures, so that the structures are not vulnerable to the motions.

3.82**seismic data processing**

applying geometrical corrections and signal processing techniques to improve the signal to noise ratio and facilitate the interpretation of seismic data

3.83**seismic source**

source of controlled acoustic energy that is used in seismic reflection and seismic refraction marine geophysical investigation

3.84**shallow water**

water depths less than 25 m

3.85**shallow water flow**

flow of pore water into a hydrocarbon well from an overpressured formation causing difficulties in well control and effective cementing of casing

3.86**side scan sonar****SSS**

instrument for imaging the seafloor to either side of a survey track line using acoustic pulses

3.87

site

defined investigation space, including seafloor and sub-seafloor, that can also include the water column

3.88

soil province

3D unit in which soil or ground conditions demonstrate a particular characteristic or fall within a defined range

3.89

source signature

output wavelet, or waveshape, of a particular seismic source from which frequency, output power and phase can be determined

3.90

sparker

seismic source that operates by producing an electric discharge in water

3.91

spherical divergence

decrease in acoustic signal strength with distance as a result of geometric spreading of acoustic energy

3.92

stack

process of making a composite record by combining traces from different records

Note 1 to entry: Most common application is common mid-point stacking.

3.93

statics

corrections applied to seismic data to eliminate the effects of variations in elevation and near-seafloor velocities

3.94

streamer

set of seismic receivers contained in a linear, normally neutrally buoyant, cable that is deployed aft of a seismic acquisition vessel

Note 1 to entry: Streamers can contain hydrophones, accelerometers, and geophones.

3.95

streamer bird

depth control or heading measurement device fitted to a streamer

3.96

sub-bottom profiler

SBP

seismic reflection instrument for investigating the upper few tens of metres of the sub-seafloor with a high vertical resolution

3.97

sub-seafloor

soil or rock existing beneath the seafloor/base of the water column

Note 1 to entry: Referred to as "seabed" in ISO 19901-8. "Sub-seafloor" should not be confused with "seafloor". Other commonly used terms are subsurface, sub-bottom and shallow section.

3.98**survey platform**

vehicle on which survey sensors and/or sources for marine geophysical investigations are mounted

EXAMPLE Towfish, autonomous underwater vehicle, remotely operated underwater vehicle, hydrophone streamer and surface vessel.

3.99**survey track line**

line through coordinates of a sensor and/or sources used during seafloor mapping or sub-seafloor mapping

3.100**multi-beam echo sounder**

swathe bathymetry system

instrument for measuring water depths within a defined swathe either side of a survey track line

Note 1 to entry: Two technologies exist. Beam forming multi beam echo sounders and interferometric or phase differencing bathymetric systems.

3.101**shear wave****S-wave**

body wave in which the particle motion is perpendicular to the direction of propagation

3.102**tail buoy**

buoy fitted to the end of a streamer

3.103**time slice**

horizontal section through 3D seismic data that displays information at the same two-way reflection time

3.104**time-to-depth conversion**

application of the appropriate seismic velocity to a measured reflection time in order to derive distance through the earth or the water column

3.105**trace**

record of one seismic channel

3.106**trace header**

identification information and parameters that precede data in a file of recorded traces

3.107**transponder**

transducer that produces an acoustic response when it receives an acoustic signal from another transducer

Note 1 to entry: The other transducer can be mounted on a surface or subsea survey platform.

3.108**ultradeep water**

Note 1 to entry: water depths from 1 800 m to 3 000 m

3.109**ultra-high-resolution seismic****UHR seismic**

seismic reflection method that acquires seismic data containing frequencies between 250 Hz and 800 Hz

3.110

ultra-short baseline system

USBL

sub-sea acoustic positioning system used to determine the position of towed or deployed sensors in the water column

Note 1 to entry: A transponder or responder is mounted on the sensor to be positioned and interrogated from a transducer of known position.

3.111

ultra-ultra-high resolution seismic

UUHR seismic

seismic reflection method that acquires seismic data containing frequencies between 750 Hz and 2 000 Hz

3.112

velocity analysis

process of calculating acoustic velocity from measurements of normal moveout

3.113

velocity model

model of discrete geological units or reflection time intervals with different acoustic velocities

3.114

vertical datum

vertical reference frame

reference frame describing the relation of gravity-related heights or depths to the Earth

Note 1 to entry: In most cases, the vertical reference frame will be related to mean sea level. Vertical datums include sounding datums (used for hydrographic purposes), in which case the heights may be negative heights or depths.

Note 2 to entry: Ellipsoidal heights are related to a three-dimensional ellipsoidal coordinate system referenced to a geodetic reference frame.

[SOURCE: ISO 19111:2019, 3.1.72]

3.115

wavelet

seismic pulse usually consisting of one-and-a-half to two cycles

3.116

yaw

sideways movement of the bow and stern of a survey platform about the vertical axis that passes through the centre of gravity

4 Symbols and abbreviated terms

4.1 Symbols

R_p	ping rate
S_r	slant range
σ	standard deviation

4.2 Abbreviated terms

ASCII	American standard code for information interchange
AUV	autonomous underwater vehicle
AVO	amplitude versus offset
CIP	common image point
CRS	coordinate reference system
DBS	deconvolution before stack
DVL	doppler velocity log
EM	electromagnetic
FWI	full waveform immersion
GIS	geographical information system
GPS	global positioning system
HSE	health, safety and environment
INS	inertial navigation system
IOGP	International Association of Oil and Gas Producers
MBES	multi-beam echo sounder
MSL	mean sea level
psi	pounds per square inch
QC	quality control
QMS	quality management system
ROTV	remotely operated towed vehicle
ROV	remotely operated vehicle
SBES	single beam echo sounder
SEG	Society of Exploration Geophysics
SRME	surface-related multiple elimination
SSDM	seabed survey data model
SSS	side scan sonar
SV	sound velocity
TVF	time-variant filter
TWT	two-way travel time

UHR	ultra-high resolution
USBL	ultra-short baseline
UUHR	ultra-ultra-high resolution

5 Objectives, planning, and quality management

5.1 General

5.1.1 Objectives and project specifications

The general objective of a marine geophysical investigation is to provide information about the seafloor and sub-seafloor that is relevant to the design, placement, installation, operation, assessment/re-assessment, and decommissioning of offshore structures. This includes the assessment of geohazards over the lifetime of the development.

This document considers the upper portion of a hydrocarbon well as an offshore structure, and therefore covers the requirements for characterising ground conditions and identifying geohazards that can be encountered by the drilling operation and the installation, use and decommissioning of wells. The depth of interest for a marine geophysical investigation for a hydrocarbon well is typically (as appropriate)

- in the case of a targeted hydrocarbon reservoir shallower than 1 000 m below the seafloor, to a depth just above the reservoir, or
- for deeper reservoirs, at least 200 m below the preferred setting depth of the first pressure-containment casing string or 1 000 m below the seafloor, whatever is greater.

Marine geophysical investigations for pre-drilling well-sites focus on possible gas in the sub-seafloor overlying the reservoir that can pose a threat to the drilling operation. The investigations described here are not concerned with the reservoir that is targeted by the drilling operation.

Where relevant, project specifications should refer to methods described in this document. Any references to methods should be accompanied by method-specific information, as applicable. If method-specific information is contained neither in the project specification nor in this document, then contractor's practice applies. For some parts of a project specification, it can be necessary to provide preliminary specifications that require subsequent revision. An example is on-site revision of operational parameter values for data collection equipment, so that the actual site conditions can be taken into account and accommodated in order to achieve optimum performance.

With seafloor and sub-seafloor conditions having significant impacts on offshore structures, the following partial list of features can be of interest:

- human-made structure and debris, including existing infrastructure (e.g. platforms, cables, sub-sea infrastructure, etc.), archaeological features and unexploded ordnance;
- difficult soil conditions (e.g. very weak soils, boulders, permafrost);
- rugged or steep topography (e.g. escarpments, scarps, gullies);
- buried channels;
- seafloor or sub-seafloor instabilities or evidence thereof (e.g. mass transport deposits);
- faults;
- shallow gas, gas-charged pockets or fluid over-pressure zones;
- gas hydrates;

- fluid expulsion features (e.g. pockmarks);
- tectonic features;
- carbonate reefs or bedrock;
- erosional features and processes (e.g. current scours and scouring; ice gouges and gouging).

A well-designed marine geophysical investigation allows the detection and characterization of such features, both at and below the seafloor. It also allows the assessment of the spatial variability of sub-seafloor materials. These features are captured in a ground model.

A marine geophysical investigation can, in some cases, also provide information about

- a) environmentally or culturally sensitive areas,
- c) military areas,
- d) disposal areas, and
- e) other government-protected areas.

5.1.2 Georeferencing and GIS

Marine geophysical investigation data shall be georeferenced using a coordinate reference system (CRS). Full specifications of the CRS shall be delivered with the metadata; without this CRS reference the description of position is ambiguous. Results from marine geophysical investigations can, with advantage, be presented in a GIS-compatible format.

Additional guidance is given in [Clause 6](#) and in [A.5.1.2](#), which contains details of the IOGP's SSDM as one option for data presentation.

5.1.3 Ground model

A ground model is constructed from a database of any valid input data. It can take different forms and, in the strictest sense, can be of any complexity. For example, when based on bathymetric data, it can take the form of a terrain and geomorphological model; or when based on geological data, it can take the form of a geological model. A geological model can include structural, stratigraphic or lithological components typically interpreted from seismic reflection data verified by ground-truthing. If soil-type and soil-strength data are included (see ISO 19901-8), it can be a soil model or a geotechnical model.

A ground model allows conditions to be inferred at any location within the model boundaries and can be updated and refined as more targeted investigations are performed. Evolution of the ground model is a fundamental objective in the design and execution of a marine site investigation, as illustrated in [Figure 2](#). A ground model captures processes that influence the site in order to, where applicable,

- present an overview of seafloor and sub-seafloor processes, at regional and local scales,
- characterize the geological context of the site, in particular stratigraphic boundaries (horizons) that correlate with geotechnical data,
- present soil provinces and other information that estimate the spatial variability of soil types and terrain attributes,
- assess the potential for present and future natural and/or induced geological activity and human-made activity based on the evaluation of current conditions and inferred past geological events,
- allow selection of key targets for subsequent marine site investigations including soil investigations, and
- assess geohazards for risk management and mitigation purposes.

Integration of marine geophysical investigation data with geological and/or geotechnical data can be made with different levels of complexity:

- Geological and geotechnical information can be, in their simplest form, the background regional information or inferences made from earlier marine site investigations in nearby areas. In some cases, this can be sufficient to meet the project specifications and the requirements of ISO 19900 for adequate reliability.
- Pre-drilling well-site investigations for floating rigs are often based entirely on marine geophysical investigations, although these can be supplemented by other marine site investigation data to assist with the prediction of anchoring conditions.
- The integration of geophysical and geotechnical information enables development of a ground model which becomes the basis for
 - a) understanding the main geological, geomorphological and geotechnical conditions, features and processes that can affect (1) short term offshore activities such as well drilling, rig anchoring of floating units and jack-up operations, and (2) the reliability of more permanent infrastructure such as fixed or floating platforms, pipelines, risers and sub-sea structures, or
 - b) developing soil properties and parameter values for geotechnical design with advice from a geotechnical specialist (see ISO 19901-8 and ISO 19901-4).

The creation or update of a ground model can be a key outcome of a marine site investigation.

An initial ground model will be created at the desk study stage, and it can be incrementally improved with additional data and further interpretation. In some cases, such as a well-known site with existing structures where recent geophysical or geotechnical data are available, the initial ground model can prove to be adequate to satisfy the technical objectives without the need to collect additional information.

GIS can facilitate the integration of geoscience data with other datasets and help communication with end-users who might not be geospecialists.

5.2 Desk study

5.2.1 General

A desk study shall be performed and shall include the analysis of available data that are relevant for the project. A desk study is the starting point for every marine site investigation; its purpose is to investigate the site using existing data, and to address the need to acquire additional data.

A desk study can include output suitable for defining the scope and planning of seafloor mapping, sub-seafloor mapping and data integration, as applicable.

The following non-exhaustive list contains examples of data that can be included in the desk study:

- results (data and interpretation) of previous marine geophysical investigations in the area including exploration 2D and 3D seismic data;
- results (data and interpretation) of previous marine soil investigations;
- regional bathymetry, nautical and geological charts;
- research papers, publications and other public-domain data on geohazards, geology and spatial variability of the sub-seafloor;
- information about any known geohazards, for example, information from nearby hydrocarbon wells;
- drilling reports from hydrocarbon wells within the region;
- shipping lanes;

- information regarding seafloor debris, such as shipwrecks;
- known offshore structures, including pipelines, well heads, manifolds, power cables, etc.;
- metocean (wind, wave, current, climate) conditions;
- protected/restricted areas;
- exploration and production licence requirements;
- information on other activities in the area, including ongoing or planned exploration or project development and production-related activities (drilling, exploration seismic data acquisition).

The following should be covered by the desk study:

- a) assessment of existing data in terms of relevance, quality, age and spatial density to determine if they are usable and sufficient for an adequate understanding of site conditions;
- b) if relevant to the project (e.g. for geohazards reasons), assessment of recent events, either metocean or in the geological record;
- c) recommendation as to whether further marine geophysical and/or marine soil investigation data are required.

For investigations of very limited scope (in terms of geographic area or project specifications), repeat investigations in well understood areas, or for limited marine geophysical investigations performed for specific purposes, the desk study can be a relatively straightforward exercise that has an outcome of minimum complexity. For example, the desk study report can simply refer to nautical charts for planning of operations outside of designated shipping lanes or military testing zones.

5.2.2 Use of exploration 2D and 3D seismic data in a desk study

Exploration 2D and 3D seismic data are invaluable inputs to all but the most simple and straightforward site investigations including reconnaissance, engineering and detailed engineering. The data can allow early reviews of field-development plans and help identify areas where sub-seafloor mapping and marine soil investigation data can add value. Whenever they are available these data sets shall be included in the desk study.

Consideration should be given to the re-processing of exploration seismic data to enhance its quality in the depth range of interest.

5.2.3 Desk study for pre-drilling well-site investigations

The desk study for a pre-drilling well-site investigation shall consist of a review of relevant available site data and reports in the area of interest, including exploration 2D and 3D seismic data, covering all planned drilling locations (including potential relief-well locations). In frontier areas where there are no nearby existing wells, data and reports from wells linked to the area of interest by a seismic line should be included even if they are some distance away.

5.3 Scoping and planning

5.3.1 General

The process for marine site investigation typically comprises the following:

- determination of objectives
- desk study, including production of an initial ground model;
- scoping of marine site investigation;

- development of project specifications;
- operations planning;
- marine geophysical operations – seafloor mapping and sub-seafloor mapping;
- processing and analysis of marine geophysical investigation data and integration with desk study results for refinement of the ground model;
- marine soil (or other complementary) investigation(s) (see ISO 19901-8);
- analysis of marine soil investigation (or other complementary) data and integration with results of other investigations for refinement of the ground model;
- iteration, as required.

Project-specific data used to characterize the site and create the ground model(s) are usually acquired first from a marine geophysical investigation and then from a marine soil investigation. In some cases, seafloor mapping, sub-seafloor mapping, and marine soil investigation can be combined in a single campaign. The acquisition sequence is sometimes repeated or adjusted to fill knowledge gaps, investigate new challenges or to fit modifications in offshore structure layout.

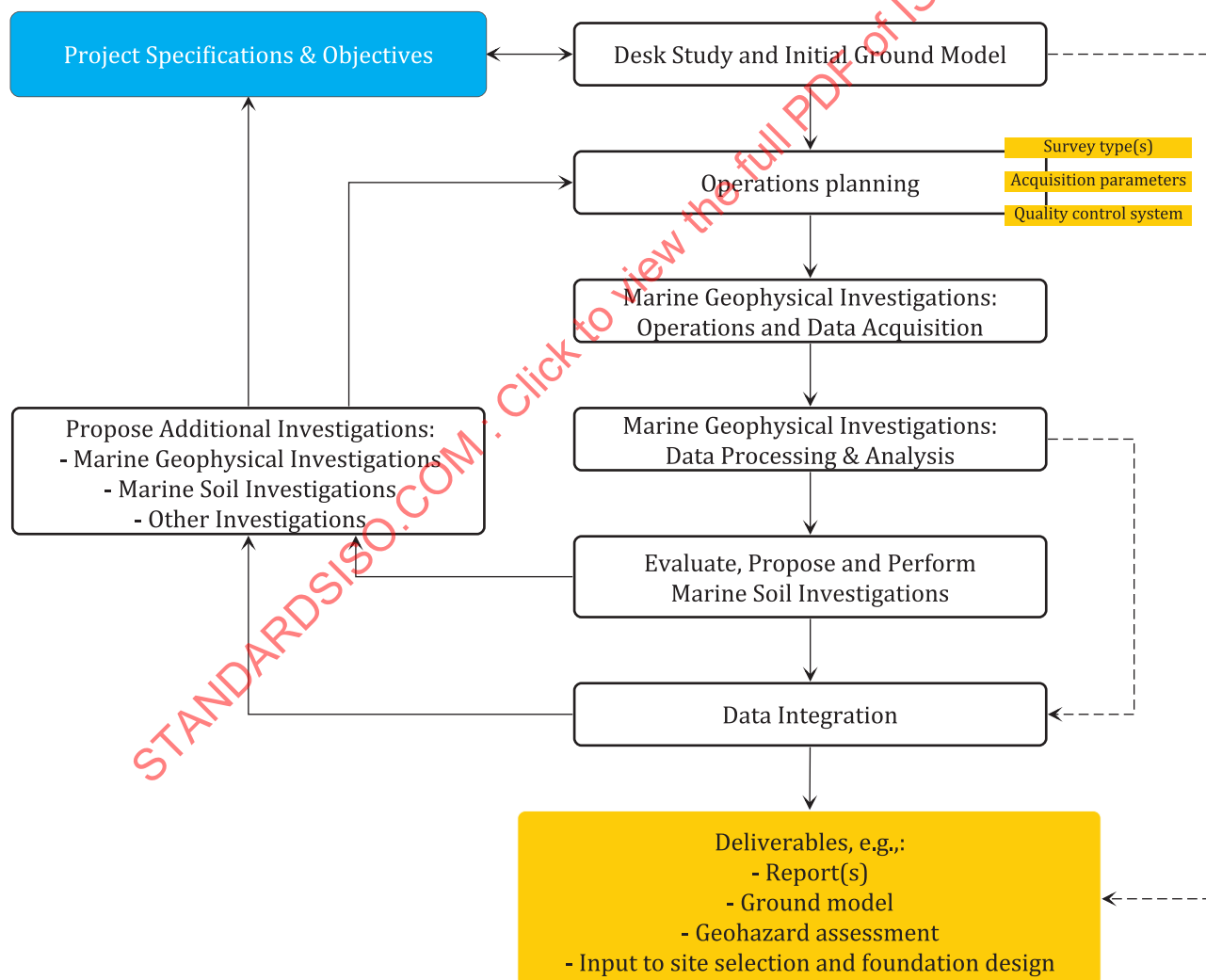


Figure 2 — Typical workflow for marine site investigation

5.3.2 Scoping of seafloor mapping and sub-seafloor mapping

5.3.2.1 General

Scoping of seafloor mapping and sub-seafloor mapping provides project specifications, including

- types of mapping that shall be performed for adequate understanding of the site conditions, with the relevant level of detail required (see survey types defined in [5.3.2.2](#) to [5.3.2.8](#)),
- specific specialist studies that shall be performed (for reasons such as slope stability, seepage, presence of carbonate soils),
- area that shall be covered, and
- specifications for sensors and sources.

Survey types are categorized as reconnaissance seafloor or sub-seafloor mapping, engineering seafloor or sub-seafloor mapping and detailed engineering seafloor or sub-seafloor mapping. Pre-drilling well-site investigation is included as a separate special category of seafloor and sub-seafloor mapping. This categorization considers required resolution of the data and is not necessarily related to life cycle phases of an offshore structure. For example, detailed engineering seafloor mapping can apply to the decommissioning phase of an offshore structure. Other survey types warranted to address specific or unusual concerns might not fit neatly into these categories, requiring an independent evaluation and definition of project specifications to meet the survey objectives.

For seafloor mapping, project specifications should specify required horizontal resolution in terms of DTM cell size. For sub-seafloor mapping, project specifications should specify required horizontal resolution in terms of spacing of survey track lines and shot point and receiver spacings.

For seismic methods, the vertical resolution achieved is partly determined by the temporal frequency bandwidth of the recorded pulse. This bandwidth will be strongly influenced by the bandwidth of the outgoing pulse and the characteristics of the sub-seafloor and can be much different from the bandwidth of the outgoing pulse. Therefore, vertical resolution of sub-seafloor mapping cannot be determined solely by the equipment used. Further guidance on this subject is given in [A.5.4.2](#).

Seafloor and sub-seafloor mapping source and receiver systems should be calibrated where applicable. A verification of the calibrations should be performed prior to the beginning of seafloor mapping, and not before the start of the last port call. The validity of the most recent calibrations should be verified, and further calibrations carried out as appropriate.

All geophysical equipment used during a survey whose calibrations cannot be verified prior to the beginning of field operations should have valid performance certificates provided by the manufacturer or a recognized third-party equipment testing service provider.

The specifications for sensors and seismic sources covered by this document shall apply at the time of calibration, prior to their use in mapping. If no calibration applies, then the specifications for sensors and seismic sources covered by this document shall apply at the time of verification, prior to their use.

5.3.2.2 Reconnaissance seafloor mapping

Reconnaissance seafloor mapping can provide an initial overview of an area, typically covers a large spatial extent and has lower resolution requirements than engineering seafloor mapping.

Reconnaissance seafloor mapping is often carried out with an MBES mounted in the hull of a surface vessel. ROVs, AUVs, tow-fish or other types of sensors can also be used as a survey platform.

Reconnaissance seafloor mapping can be performed as part of an initial marine site investigation of an area. The nature of the offshore structures to be installed at the site will typically determine the shape of the area of interest; a new pipeline will typically require mapping along a corridor, a new field development will require mapping within a defined region, etc.

5.3.2.3 Engineering seafloor mapping

Engineering seafloor mapping can be performed whenever there is a need for accurate HR data (e.g. conceptual engineering phase).

Engineering seafloor mapping can be performed with a combination of MBES (occasionally SBES) and SSS sensors. The choice of survey platform depends on factors such as water depth and sensor deployment restrictions. Some surveys in less than 100 m water depth can be carried out using hull-mounted sensors, whereas for deeper water an ROV, AUV, tow-fish or other types of sensors can be used to achieve the necessary data resolution.

Engineering seafloor mapping is commonly carried out simultaneously with engineering sub-seafloor mapping.

5.3.2.4 Detailed engineering seafloor mapping

Detailed engineering seafloor mapping can be performed prior to, and subsequent to, construction-related activities on the seafloor, and can be performed for the purposes of design engineering. The purposes of this type of mapping can also include

- providing baseline bathymetry (seafloor topography) for use during subsequent installation, maintenance or decommissioning operations,
- quantifying the amount of material to be excavated or placed,
- matching and verifying the baseline topography against designed intervention, and
- documenting that installation, maintenance or decommissioning operations are performed in accordance with requirements.

This type of mapping is commonly performed using an ROV equipped with an MBES or using an AUV equipped both with an MBES and SSS, and possibly other types of sensors, e.g. high frequency sonar, optic, laser.

5.3.2.5 Reconnaissance sub-seafloor mapping

Reconnaissance sub-seafloor mapping is typically performed over a large area, with the objective of collecting information about regional sub-seafloor characteristics and geology. The spacing of survey track lines will be relatively wide, to maximize the areal coverage relative to survey time.

This type of mapping is commonly performed using sub-bottom profiling and 2D or 3D HR or UHR seismic reflection.

5.3.2.6 Engineering sub-seafloor mapping

Engineering sub-seafloor mapping can provide spatial data at a scale that can

- provide input for scope and planning of marine soil investigations, and can include the assessment of gas hazard before drilling,
- provide geophysical data to correlate with geotechnical data,
- focus on particular locations where offshore structures are planned to be located, with a buffer zone to allow adjustment of structure positioning due to design issues or seafloor obstructions, or
- cover the general layout of offshore structures, sufficient to enable their more detailed positioning.

This type of sub-seafloor mapping is commonly performed using sub-bottom profiling and 2D or 3D HR or UHR seismic reflection.

In the case of marine geophysical investigations for pipeline and cable burial, the depth of investigation below the seafloor can be limited to 10 m or less.

5.3.2.7 Detailed engineering sub-seafloor mapping

Detailed engineering sub-seafloor mapping is the same as engineering sub-seafloor mapping, except for closer spacing of survey track lines to enable higher lateral resolution.

Detailed engineering sub-seafloor mapping for a planned offshore structure will typically be limited to the immediate planned area, with a buffer zone to allow adjustment of structure positioning due to design issues or seafloor obstructions. The width of the buffer will depend on the certainty of the location for the offshore structure, and the variability of seafloor and sub-seafloor conditions. Similar considerations will apply to detailed engineering sub-seafloor mapping for structure maintenance and decommissioning activities.

5.3.2.8 Pre-drilling well-site investigation seafloor and sub-seafloor mapping

A pre-drilling well-site investigation forms a special type of seafloor and sub-seafloor mapping. It aims to characterize the seafloor and sub-seafloor that can be encountered by the drilling operation to a specified depth, and to identify potential geohazards related to installing and securing the drilling unit, drilling, and removing and relocating the drilling unit. The depth of investigation should be, as appropriate,

- in the case of a targeted hydrocarbon reservoir shallower than 1 000 m, to a depth just above the reservoir, or
- in the case of deeper reservoirs, at least 200 metres below the intended setting depth of the first pressure-containment casing string or 1 000 m below the seafloor, whichever is greater.

This type of mapping is commonly performed using MBES, SSS, sub-bottom profiling and HR seismic reflection.

The sub-seafloor mapping information requirement for pre-drilling well site geohazard mapping depends on the type of rig and the water depth.

A bottom founded rig requires a secure foundation and is also vulnerable to shallow gas. This has the potential both to disrupt drilling activity and, if it escapes through the seafloor, to erode the foundations and compromise the stability of the rig. The marine geophysical investigation should therefore cover both the foundation zone within the expected penetration depth of the rig legs, and the depth range at which shallow gas might be a hazard to drilling. This is accepted to be 200 metres below the depth at which the first pressure containment string is installed. In terms of geophysical equipment selection this translates into the need for sub-bottom profiler and HR seismic reflection. Seabed mapping using multibeam echo sounder and side scan sonar will be required over the limited area in which the rig is in contact with the seafloor and in some circumstances to provide clearance for the approach route.

The foundation zone requirements for a floating, anchored rig are somewhat different and are limited to ensuring a secure foundation for the rig anchors and the well conductor. The marine geophysical investigation should include seabed mapping using multibeam echo sounder and side scan sonar and sub-seabed mapping using a sub-bottom profiler, over the area of the anchor pattern. Shallow gas and other geohazards that may impact on drilling will also need to be investigated. In water depths up to 750 metres, this will normally be accomplished by HR seismic reflection, but in deeper waters, this is often substituted by exploration 3D seismic, provided it is sufficiently resolute in the depth range of interest.

A drillship operating using dynamic positioning presents a different set of information requirements. Since there are no anchors, the only contact with the seabed is at the well itself, so there is no need for an extensive seafloor survey. Accurate measurement of the water depth at this point, together with an inspection by ROV immediately prior to spud, is normally sufficient. Shallow gas and other geohazards can impact on drilling activities and should be investigated by HR seismic reflection or suitable exploration 3D seismic as for all floating rigs.

As well as the important input to desk studies for pre-drilling well-site investigations described in 5.2.3, exploration 3D seismic can, in some circumstances, replace the collection of new HR seismic for pre-drilling well-site sub-seafloor mapping. This approach depends on water depth, the type of rig to be used and the characteristics of the 3D seismic data. The minimum exploration 3D seismic data acceptability criteria, which depends on the acquisition, processing or reprocessing parameters, are included in A.5.3.2.8.

The suitability of the 3D seismic data to replace the collection of new HR seismic should be evaluated on a case by case basis and is more likely to be the case for deep water wells because the CDP stack contains a higher proportion of near vertical traces in the shallow section than is the case in shallow water, thereby retaining high frequencies. Further, shallow gas is generally a less critical hazard to floating rigs operating in deep water, because there is a larger water column in which any escaping gas can disperse.

Since the resolution afforded by exploration 3D seismic data in the shallow section is lower than that afforded by sub-bottom profiling data,

- exploration 3D seismic data shall not be substituted for sub-bottom profiler data when the detailed identification and mapping of shallow geology and geohazards is needed in the top 100 m of the sub-seafloor, and
- exploration 3D seismic data shall not be substituted for a marine geophysical investigation when siting a bottom-founded drilling rig (see ISO 19905-1^[11]).

Regardless of the limitations, exploration 3D seismic data should always be reviewed when available within a pre-drilling well-site investigation even if only as a secondary source of information.

Since the resolution afforded by exploration 2D seismic data in the shallow section is lower than that afforded by HR seismic, the existence of exploration 2D seismic data at a location should not be used as a reason to avoid the collection of new HR seismic.

Further information is available in IOGP Report 373-18-1^[30].

5.4 Operations planning and data quality management

5.4.1 Quality plan

The project specifications should address the preparation of a quality plan (one aspect of operational planning) for seafloor mapping and sub-seafloor mapping. The quality plan should include the following:

- An assessment of potential risks to data quality, focusing on challenges related to the regional and local geology that are known to occur or suspected to occur in the area of the marine geophysical investigation.
- An assessment of metocean-related risks to data quality (caused by prevailing and likely wind speed, wind and/or wave direction, seawater currents and the anticipated sea states), focusing on situations that could reasonably be expected to pose difficulties for marine geophysical investigation.
- A procedure to ensure the correct operation of geophysical equipment.
- A system that specifies how to act in situations where data quality is degraded. This should address the use of other equipment if required to fulfil the project specifications, such as a more powerful seismic source or, conversely, a higher frequency seismic source.
- An up-to-date compilation of infrastructure within the area of interest, particularly all known infrastructure, not just those structures that are predicted to pose difficulties for the marine geophysical survey.
- A discussion of nearby marine geophysical investigations or other activities planned to be carried out concurrently with the marine geophysical investigation under discussion, and that can have implications for data quality.

Management of metrological confirmation should be in accordance with ISO 10012^[2].

The quality plan can address near real-time monitoring of data acquisition, for example by specialists onboard a surface vessel or remotely when adequate communication links are in place.

5.4.2 Effects of attenuation

It is important to note that because of attenuation effects, certain geological conditions can preclude sub-seafloor mapping from meeting its objectives, regardless of what methods are used. For example, shallow gas-charged layers in the sub-seafloor can make it impossible for seismic reflection methods to obtain the required resolution at a given depth below seafloor. The presence of even a small amount of gas (a few percent) in soil can drastically lower the P-wave impedance, and drastically increase attenuation of acoustic signal.

A quality management system can address measures for data acquisition operations that can help to improve results for locally difficult geological conditions.

The technical limits of the data should be explained in reports, so that end users understand what information the data can and cannot provide.

5.4.3 Data quality management

Quality management should utilize a checklist that provides for the following, where applicable:

- name of marine geophysical investigation on all documents, reports, charts, drawings, packages of deliverables and associated files;
- names of client and contractor;
- objectives of seafloor mapping and sub-seafloor mapping;
- equipment used and operating parameters;
- coordinate reference system and metadata;
- verifications and calibrations carried out on acquisition equipment;
- details of data processing performed;
- consistency of interpretation throughout the results report between report text and other deliverables;
- following manufacturers' instructions for use of relevant equipment.

6 Positioning

6.1 General

This clause covers horizontal and vertical positioning of deployed equipment (e.g. sensors, sources, receivers). The positioning of sub-seafloor data points, e.g. from seismic measurements, is the subject of a great deal of research in the petroleum exploration industry and is a subject beyond the scope of this text. See Reference [\[74\]](#) for a comprehensive introduction to the subject.

In order to determine the positions of individual vessel mounted deployed equipment from the observed GNSS antennae positions, the offsets and heading from the antennae are required.

During marine geophysical investigations, the coordinates of all vessel mounted, towed, AUV/ROV deployed and other sub-sea deployed sources and receivers shall be determined and recorded at intervals specified in the project specifications.

The project specifications should provide definitions and requirements for positioning. The positioning requirements can be determined by the following:

- The ability to repeat positions. This can be the position of a previous marine geophysical investigation or the positions of existing wells, marine soil investigation boreholes or seabed features (e.g. a wreck).
- The ability to map the position, size and extent of the seafloor and/or sub-seafloor hazards and obstructions at a scale, and with an accuracy, that ensures these can be safely mitigated or avoided.
- The ability to determine that the required data coverage and quality is being achieved during data acquisition by monitoring vessel or survey platform position, line keeping, all sensor positions and the seismic shot point interval.

The following industry guidelines relate to the installation, calibration, verification and operation of surface and sub-sea positioning systems:

- IOGP Report 373-19^[32];
- IOGP Report 373-18-2^[31];
- IMCA Report S-017 Rev.1^[26].

References are provided for other systems, e.g. determining streamer depth below sea level according to IOGP 373-18-2^[31].

A GNSS positioning system should be tested for performance by the guidelines given in IOGP Report 373-19^[32]. Positioning equipment (e.g. USBL, INS) should be calibrated and operated in accordance with manufacturers' instructions.

Positioning of towed or tethered survey sensors in water depths greater than 25 m should include a USBL system that is verified by the procedures outlined in IMCA Report S-017 Rev.1^[26], see 6.5.

When survey sources and receivers are deployed by an AUV, the positions of the equipment and sensors should be determined by an integrated solution of surface and sub-sea positioning systems combined with an INS and an acoustic DVL (see 6.6 and 6.7).

In addition to the verification techniques covered in IOGP Report 373-19^[32], Section 4.4.3, positioning can be confirmed by sailing over a seafloor target of known position, such as a wellhead, and observing it on an echo sounder (SBES or MBES).

6.2 Coordinate reference systems

6.2.1 Horizontal coordinate reference system

The coordinate reference systems should comprise a base geodetic CRS (datum) and a projected CRS.

Exploration and production related marine geophysical investigations are typically referenced to the local national or regional geodetic CRS, whereas the output from GNSS positioning systems are referenced to global coordinate reference systems. In such circumstances, the coordinates output from the surface positioning systems should be transformed to the project CRS. EPSG (European Petroleum Survey Group) codes are available at www.epsg.org and shall be provided.

6.2.2 Vertical coordinate reference system

In nearshore areas, the vertical ordinate should be tied to the relevant national vertical datum. In offshore survey areas, the vertical datum should be a sea level datum stipulated in the project specifications e.g. MSL or LAT. The depth from the stipulated vertical datum shall be reduced using either observed tidal data logged at a fixed reference station, by use of predicted tides, or by using sea level separation models referenced to the GNSS global CRS.

6.3 Surface positioning requirements

The marine geophysical survey vessel and if possible, towed surface equipment such as source and receiver buoys, should have their surface position continuously determined by augmented GNSS. Augmentation shall use any of, or combinations of, Differential (range domain), PPP (clock and orbit) or RTK (Real Time Kinematic) solutions.

To eliminate a single point of failure, the marine geophysical survey vessel should be equipped with a minimum of two fully independent surface positioning systems. The systems should use different GNSS receivers, antennae, control network, augmentation strategy and correction signal delivery systems. It is not normally practical to have multiple GNSS receivers installed on towed equipment. The specification for augmented GNSS should be according to [Table 1](#).

Table 1 — Recommended specification for augmented GNSS

Description	Value
Measurement error of horizontal position of GNSS antennae relative to geodetic CRS	<0,1 m (2 σ)
Measurement error of height of GNSS antennae relative to the reference ellipsoid	<0,2 m (2 σ)

6.4 Vessel heading

6.4.1 General

The vessel heading is a fundamental parameter for the positioning of survey tracks and is required for the computation of the position of towed and tethered survey equipment using sub-sea acoustic positioning.

The vessel heading should be measured by a gyro compass and/or a GNSS based heading reference system. Two independent heading systems should be used. For high-resolution mapping, a GNSS based system should be used as the primary heading reference. However, in some conditions gyro systems can be more stable than GNSS (see [A.6.4](#)).

The specification for heading systems should be according to [Table 2](#).

Table 2 — Specification for heading systems

Description	Value
Heading measurement error gyrocompass	<0,2° secant latitude (1 σ)
Heading measurement error GNSS-aided	<0,05° (1 σ)

For laybacks of 200 m and more to towed survey platforms, the heading measurement error will have a significant adverse effect on the cross-track positioning accuracy of the towed equipment. For a survey platform towed at more than 300 m below sea level, a GNSS based system should be used as the primary heading reference.

Additional guidance is provided in [A.6.4](#).

6.4.2 Gyro compass

For marine geophysical investigations, 'survey grade' gyro compasses should be used.

The inherent latency of gyro compasses will cause the accuracy of the heading observations to decrease immediately after sharp turns of the survey vessel, e.g. after line turns.

6.4.3 GNSS based heading reference

GNSS based heading reference systems determine heading from concurrent GNSS observations by two GNSS antennae mounted at the ends of a known fixed baseline. The dynamic measurement error is approximately equal to the static measurement error and observations are not affected by the movements/turning of the survey vessel.

6.4.4 Alignment

The alignment of the gyro compasses and/or the GNSS heading reference systems relative to the centre line of the vessel should be determined by observing the vessel heading by conventional land survey methods from control points or a known baseline on the quayside, while simultaneously recording the heading observed by the heading reference systems. The alignment check can be conducted on reciprocal vessel headings to reduce uncertainties in the set out of the centre line of the vessel.

After turning the vessel, a gyro compass will need adequate time to settle in line with manufacturer's recommendations before the alignment check is repeated.

Additional guidance is provided in [A.6.4](#).

6.5 Sub-sea positioning — Ultra-short baseline system

USBL is an acoustic sub-sea positioning system that determines the position of a transponder or responder mounted on the towed and other sub-sea deployed equipment, relative to a vessel mounted transducer. The absolute position of the sub-sea survey platform is calculated from the relative position determined by USBL, the vessel's absolute position and the vessel heading. The pitch and roll of the USBL transducer is determined by means of a MRU.

USBL positioning is not normally applied to the positioning of surface towed streamers that can use an independent GNSS system fitted to the tail buoy.

Prior to USBL use, the alignment of the heading reference system and the MRU relative to the reference frame of the survey vessel should be verified (see [6.4.4](#)) and the velocity of sound in seawater should be observed at the verification site and entered into the USBL control system (see [7.2.2](#)). This should be re-observed periodically. The time period between observations should take account of the likelihood of temporal change in the profile. Areas of upwelling and river influx will require more frequent reobservation than mid ocean locations.

Prior to commencing data acquisition, the calibration and system performance should be validated by a verification of the USBL system at the site by "box-in". This can be done using SSS to image a prominent seabed feature or by observing the position of an acoustic transponder on the seabed during survey track lines run on reciprocal headings, or by observing a point on the seafloor with known coordinates, e.g. a wellhead.

The sound speed profile in the water column at the worksite should be observed (see [7.2.3](#)).

The specification for USBL transducer should be according to [Table 3](#).

Table 3 — Specification for USBL transducer

Description	Value
Angular measurement error	<0,25° (1 σ)
Range measurement error	<0,5 % of slant range (1 σ)

Except in water depths of less than 25 m (where it can be impractical or where layback to the towed equipment is less than 50 m), the positions of towed sources, receivers and survey sensors should be determined by a vessel mounted tracking USBL.

The sub-sea positioning accuracy should be commensurate with the positioning tolerances required to meet the survey objectives. The USBL positioning accuracy depends on the slant range between the surface vessel and the towed equipment.

If properly calibrated, USBL systems typically provide a relative positioning measurement error of better than 1 % of slant range. When water depths exceed 750 m, the slant range for a towed or tethered survey platform positioned near seafloor might exceed 1 500 m. At these ranges, the absolute measurement error of conventional USBL systems can increase to unacceptable levels and many systems can become unreliable. In water depths greater than 750 m, survey sensors and equipment should be deployed on an AUV.

6.6 Inertial navigation system

An INS uses motion sensors in the form of accelerometers and rotation sensors to calculate the position, orientation and velocity of the moving object in which they are installed. From an initial known starting position, an AUV, ROV or fast ROV hybrid can thus calculate its own position and velocity based on dead reckoning by integrating the observations from the motion sensors.

The INS should be initialized with input of position and velocity from another source. As the INS motion sensors are subject to drift, the positioning errors should be monitored against limits in the project specifications. The INS should receive external corrections, or be re-initialized, prior to the positioning measurement error falling outside requirements.

The typical external reference for an AUV, ROV or fast ROV hybrid is GNSS on the surface. While the vehicle is submerged, it should receive external position references from a ship based USBL tracking system or a seafloor long baseline acoustic positioning system (which is not covered in this document).

The specification for INS sensors should be according to [Table 4](#).

Table 4 — Specification for INS sensors

Description	Value
Heading measurement error	<0,05° secant latitude (1 σ)
Pitch and roll measurement error	<0,025° (1 σ)
Heave measurement error	<0,05 m (1 σ)

Additional guidance is given in [A.6.6](#).

6.7 Auxiliary sensor: doppler velocity log

When survey sources and receivers are deployed by AUV, ROV or fast ROV hybrid, the INS-based positioning (see [6.6](#)) should be aided by an acoustic DVL.

The specification for DVL should be according to [Table 5](#).

Table 5 — Specification for DVL

Description	Value
Operating altitude	0,5 m – 90 m above seafloor
Data update rate	Minimum 4 Hz
Velocity measurement error	<1 % of velocity (long term)

6.8 Auxiliary sensor: altimeter

A survey platform consisting of AUV, ROV, or ROTV shall be equipped with an altimeter (a single beam echo sounder) whose offsets to other sensors are known. The altimeter operation should be according to the manufacturers' recommendations. Specification for an altimeter should be according [Table 6](#).

Table 6 — Specification for altimeter

Description	Value
Measurement error	$\leq (0,01 \text{ m} + 0,1 \% \text{ of measuring distance } (2 \sigma))$
Resolution	$\leq 0,03 \text{ m}$ for 500 kHz $\leq 0,075 \text{ m}$ for 200 kHz
Beam width	$< 5^\circ$ (at 3 dB point)
Frequency	Minimum 200 kHz
Data update rate	$\geq 1 \text{ Hz}$
Range	200 kHz systems: 2,5 m to 100 m 500 kHz systems: 1,0 m (minimum) – 50 m

6.9 Auxiliary sensor: pressure-depth sensor

A survey platform consisting of AUV, ROV, or ROTV shall be equipped with a pressure-depth sensor. The operation of the pressure-depth sensor should be according to manufacturers' instructions.

Guidance regarding values for the pressure sensor of the pressure-depth sensor is given in [Table 7](#). These values are based in part on manufacturers' claims and refer to laboratory bench calibrations.

Table 7 — Guidance for the pressure sensor of the pressure-depth sensor

Description	Value
Depth rating	Appropriate for the working depth of the project
Measurement error	$\leq 0,01 \% \text{ of full-scale range } (2 \sigma)$
Resolution	$\leq 0,001 \% \text{ of full-scale range}$
Output rate	Minimum 2 Hz

The density profile of the water column above the pressure-depth sensor shall be calculated from measured values of conductivity, temperature and pressure through the water column by means of the UNESCO formulae^[22]. This does not apply when the operating depth is less than 25 m.

The surface value of gravitational acceleration at a specified position is given by the international gravity reference formula^[63]. For greater accuracy, a further calculation can be made to find the corresponding gravitational acceleration value at a specified depth below sea level.

Pressure data shall be processed together with data for atmospheric pressure variation at the time and for the location of the pressure data.

If necessary, a low pass filter can be applied to the data to reduce any effects of swell in the data.

7 Seafloor mapping

7.1 General

[Table 8](#) shows geophysical methods that are normative, recommended or that can be used for each seafloor mapping type.

It is important to consider that [Table 8](#) stipulates certain methods because of the information obtained from these methods. If a different method can be shown to obtain the same information, with the same or better resolution and accuracy, then that method may substitute the one stipulated in [Table 8](#). For example, in extremely shallow water such as the nearshore surf zone it is possible that SBES provides the same resolution and accuracy as MBES, and the swathe width of MBES does not significantly improve bottom coverage over that of SBES. Reasons of convenience (such as equipment availability or

difficulties related to equipment importation / exportation), however, do not qualify as valid technical arguments for the substitution.

Table 8 — Geophysical methods required per seafloor mapping type^a

Seafloor mapping type	MBES	SBES	SSS	Magnetometer, magnetic gradiometer ^d
Reconnaissance seafloor mapping	XXX	X	XX	X
Engineering seafloor mapping	XXX	X	XXX	X
Detailed engineering seafloor mapping	XXX	X	XXX	XX
Pre-drilling well-site investigation				
— ≤25 m, shallow water depth	X	XX	XXX	X
— 25 m ≤ 750 m	XXX ^b	XX ^b	XXX ^b	X
— >750 m, deep, ultradeep and abyssal water depth (anchored rigs)	XXX ^c	XX ^c	XX ^c	
— >750 m, deep, ultradeep and abyssal water depth (DP rigs)	X ^c	X ^c	X ^c	
^a XXX indicates a normative method, which shall be performed; XX indicates a recommended method, which should be performed; and X indicates an additional method, which can provide useful data. ^b Anchored or bottom-founded rigs only. ^c Anchored or DP rigs only. ^d Requirements for use of magnetometer and magnetic gradiometer can be found in 8.3.2 .				

The sensors used for the geophysical methods listed in [Table 8](#) shall be used in combination with compatible and appropriately integrated positioning systems as addressed in [Clause 6](#).

Prior to the beginning of seafloor mapping and not before the start of the last port call, the validity of the most recent calibrations should be verified where applicable. New calibrations should be performed if previous ones cannot be validated.

7.2 Instrumentation and acquisition parameters

7.2.1 Multi-beam echo sounder

7.2.1.1 General

Multi-beam echosounders can be mounted either mounted on a sub-sea vehicle (see [7.2.1.2](#)) or on a surface vessel (see [7.2.1.3](#)).

MBES data should be acquired using a recording setup that also acquires backscatter data. The system should have sufficient dynamic range that backscatter data can be recorded unclipped.

Additional guidance is given in [A.7.2.1](#).

7.2.1.2 Sub-sea vehicle-mounted MBES

Subclause [7.2.1.2](#) applies to MBES deployed from a sub-sea vehicle, i.e. a survey platform consisting of AUV, ROV, ROTV or tow-fish.

The survey platform shall be equipped with an altimeter, a pressure-depth sensor, and a sound velocity sensor. The spatial relationship between these sensors shall be measured using dimensional control techniques. Roll-, pitch-, heave - and yaw data shall be collected and applied to the echo sounder data.

MBES seafloor mapping requirements shall be according to [Table 9](#).

Table 9 — Specification for sub-sea MBES

Description	Value
Sounding pattern	Equidistant and/or equiangular
Number of soundings per ping	≥240 (per head)
Beam width	≤1,0° transmit, ×2,0° receive
Swathe width	≥120°
SV measurement at MBES transducer ^a	Yes
Ping rate R_p , Hz, which depends on S_r (two-way slant range, m)	$0,4 \alpha < R_p < \alpha$, where $\alpha = 1\,500 \text{ m/s} / S_r$
^a See 7.2.3.	

The MBES system checks shall include timing, pitch, roll and yaw, for example by a 'patch test', i.e. a test of MBES system hardware that determines angular misalignments and timing differences by collecting and processing data from a pre-defined area of the seafloor.

7.2.1.3 Vessel-mounted MBES

7.2.1.3 applies to MBES deployed from a survey platform consisting of a surface vessel.

Roll-, pitch-, yaw, and heave data shall be collected and applied to the MBES data.

Measurements shall be corrected for the depth of the sensor below sea level.

MBES seafloor mapping requirements shall be according to Table 9 for a water depth less than 30 m.

For a water depth beyond 30 m, MBES seafloor mapping requirements shall be according to Tables 10 or 11, as appropriate.

Table 10 — Specification for vessel-mounted MBES, water depth ≤1 500 m

Description	Value
Sounding pattern	Equidistant and equiangular
Number of soundings per ping	≥400
Beam width	≤1,0° transmit, ×2,0° receive
Swathe width	User selectable: up to 140°
SV measurement at MBES transducer	Yes

Table 11 — Specification for vessel-mounted MBES, water depth 1 500 m to 6 000 m

Description	Value
Sounding pattern	Equidistant and equiangular
Number of soundings per ping	≥400
Beam width	≤2,0° × 2,0°
Swathe width	User selectable: up to 140°
SV measurement at MBES transducer	Yes

MBES data should be corrected for tidal variations, either from measurements or using predictions.

The MBES system checks shall include timing, pitch, roll and yaw, for example by a 'patch test', i.e. a test of MBES system hardware that determines angular misalignments and timing differences by collecting and processing data from a pre-defined area of the seafloor.

7.2.2 Side scan sonar

SSS images are typically used for seafloor classification (in terms of physical, geological, chemical, or biological properties) or to identify objects on the seafloor. The requirements for SSS seafloor mapping shall be according to [Table 12](#).

Table 12 — Specification for SSS

Description	Value
Operating frequency	In the range 30 kHz to 900 kHz
Recording type	Highest fidelity available, no less than 16 bit
Range at 30 kHz	≤1 000 m
Range at 100 kHz	≤250 m
Range at 500 kHz	≤100 m
Range at 900 kHz	≤50 m
Elevation of sonar head above seafloor	5 % - 20 % of range

For simultaneous dual frequency acquisition specifications for the higher frequency should be used.

The project specifications should provide the required range and operating frequency.

Additional guidance is given in [A.7.2.2](#).

7.2.3 Auxiliary sensor: velocity of sound in seawater

Sound velocity (SV) shall be measured both at the MBES head and through the water column from MBES head to seafloor. A measurement sensor shall be mounted at the MBES head to give a direct input to the MBES system at the head depth. When sub-sea vehicles are used, the full water column SV profile shall be measured for USBL positioning of the sub-sea vehicles.

CTD measurements allow a value for SV in seawater and a value for seawater density to be calculated. Alternatively, the SV in seawater can be measured directly using an SV probe. The requirements for CTD and SV sensors should be according to [Table 13](#).

Water column observations shall be taken:

- shortly before commencing operations, and
- as soon as practicable after operations are completed.

Water column SV observations should also be taken during operations. The frequency of the observations should be evaluated during the planning phase and determined by the expected variability in the water column. If necessary, this can be refined during seafloor mapping.

In areas known to have large variations in SV through the water column in a short-term spatial and temporal sense e.g. for areas near a fresh water source or oceanic upwelling. Procedures shall be established for monitoring the effect of the SV changes in real time and determining the frequency required of SV water column measurements. In some cases, a series of pre-operational observations can be conducted to determine if the site has spatial variation.

Table 13 — Specification for CTD and SV sensors

Description	Value
CTD sensors	
Electrical conductivity measurement error	better than $\pm 0,1$ mS/m
Temperature measurement error	$\leq 0,1$ °C
Pressure measurement error	$\leq 0,01$ % of full scale
SV sensor	
SV measurement error	$\leq 0,05$ m/s

The United Nations Educational, Scientific and Cultural Organisation (UNESCO) formulae^[22] for the calculation of the physical properties of seawater can be used:

- salinity: practical salinity scale 1978 (PSS 78);
- density: international equation of state of seawater 1980 (EOS 80);
- sound velocity: Reference [44].

7.3 Data acquisition methods

7.3.1 General

Survey track lines should have sufficient run-in to enable motion sensors to stabilize prior to the commencement of data acquisition.

If the survey platform consists of a surface vessel, the draft of the vessel and atmospheric pressure should be recorded continuously during the mapping operation.

For MBES surveys, the DTM cell size (for bathymetry and backscatter data) and the number of hits within each cell shall be defined in the project specifications. Side scan sonar seafloor coverage is specified in the following sections according to survey type. Guidance on side scan sonar coverage is given in [Figure A.2](#). The parameters below shall be defined in the project specifications where applicable, shall be consistent with MBES cell parameters (size and hits) and side scan sonar coverage, and shall be consistent with values in [Tables 10](#) to [12](#) as applicable:

- corridor width(s);
- spacing of survey track lines;
- overlap between MBES coverage on adjacent lines;
- off-track tolerance for survey track lines;
- SSS range on each channel.

7.3.2 Reconnaissance seafloor mapping

MBES DTM cell sizes values that should be used are:

- 2 m in case of water depth < 100 m;
- 6 m in case of water depth ≥ 100 m and < 300 m;
- 30 m in case of water depth ≥ 300 m and $< 1\,500$ m.

Side scan sonar seafloor coverage shall be a minimum of 100 %.

7.3.3 Engineering seafloor mapping

For guidance, recommended values for deep water MBES DTM cell sizes are 2 m to 3 m.

Side scan sonar seafloor coverage shall be a minimum of 200 %.

Engineering seafloor mapping surveys in water shallower than 250 m can be carried out with an MBES either mounted on a surface vessel or on a sub-sea vehicle (AUV, ROV, ROTV).

Engineering seafloor mapping surveys in water deeper than 250 m should be carried out with an MBES mounted on a sub-sea vehicle (AUV, ROV, ROTV).

The area for seafloor mapping shall be stipulated by the project specifications. The minimum corridor width for linear pre-lay seafloor mapping surveys in water deeper than 100 m should be 200 m.

7.3.4 Detailed engineering seafloor mapping

For MBES surveys, the maximum DTM cell size shall be 0,5 m × 0,5 m.

Side scan sonar seafloor coverage shall be a minimum of 300 %.

For linear structures, the MBES survey corridor width either side of the route centre-line shall be a minimum of 10 m. In areas with irregular or high-gradient seafloor (e.g. in area with ploughing), additional survey track lines can be required to improve MBES coverage of the survey corridor.

7.4 Seafloor mapping deliverables

[Table 14](#) lists seafloor mapping deliverables that should be supplied, as applicable. The formats of the deliverables shall be included in the project specifications and conform with [Table 14](#).

Table 14 — Recommended seafloor mapping deliverables and format specifications

Deliverable	Data format	Media
Motion and heading data applied to MBES data	None specified	Permanent archive media such as high capacity tape, DVD or hard drive
DTMs produced from processed MBES data (e.g. bathymetry, backscatter)	Compressed ASCII XYZ	
Side Scan Sonar data	Either native data in XTF format or raster files in PNG, JPG, or TIFF format (in this case the data should be georeferenced with the information either embedded into the raster file or delivered as separate files).	
CTD and SV data	ASCII XYZ	
Tidal reduction data including vertical datum, method of reduction of soundings, predicted or observed tidal curve	Text, spreadsheet or PDF file	
Point, linear, or polygon seafloor features interpreted from SSS or MBES data with appropriate metadata and attributes	GIS-compatible format	
Restricted areas including safety zones, anchoring and fishing prohibited areas, anchoring zones, dumping grounds, environmental protection areas and military areas presented as polygon features	GIS-compatible format	
Geo-referenced side scan sonar mosaic	GeoTIFF or other agreed file format	
Track lines of either survey platform(s) or sensors supplied as line features	IOGP P1/11 ^[33]	
Observers logs and navigation logs including all operational parameter values, numbering of survey track lines and data storage reference	Text, spreadsheet or PDF file	

8 Sub-seafloor mapping

8.1 General

8.1.1 Resolution and signal penetration

Marine geophysical investigation methods allow for site characterization of lateral and vertical physical property variations of the seafloor and sub-seafloor. Sub-seafloor mapping systems covered by this clause comprise three main components:

- the source (seismic, acoustic, electromagnetic), which generates controlled energy;
- the receivers (hydrophones, geophones, electrodes, coils), which convert the transmitted energy into electrical signals;
- the medium (water column, seafloor and sub-seafloor), through which the energy is transmitted.

For seismic reflection, resolution is a measure of minimum spatial or temporal separation between two reflection events that can be distinguished and resolved separately. Two types of resolution are basically considered:

- vertical resolution controlled by wave velocity and dominant frequency;

- lateral resolution controlled by the Fresnel zone (for unmigrated seismic data), a generally circular area on a reflector whose size depends on the depth to the reflector, the velocity above the reflector and the dominant frequency of the signal at that depth.

Data processing techniques, such as deconvolution, which improves vertical resolution, and migration, which improves lateral resolution, can be applied.

The sub-seafloor acts as a low-pass filter for seismic energy passing through it. This causes a lowering of frequency content with time on seismic records. Thus, shallow reflections will normally have higher dominant frequencies than deep reflections. In addition, there is an energy loss (attenuation) by seismic waves as they propagate through the subsurface that decreases seismic amplitudes. As seismic resolution is a function of the dominant frequency and as this dominant frequency is a function of the medium (geology), it is not possible to specify ahead of the acquisition a given seismic resolution. Hence, depending on the project objectives, seismic acquisition parameters (source/receivers characteristics) can be specified (HR, UHR, UUHR), but expected resolution can only be proposed.

If the project specifications include data from a well or a geotechnical borehole to tie to the seismic data, the well tie can be used to assess vertical resolution. Resolution can be determined either by noting the distance between two resolved layers from a well tie, or by using the quarter-wavelength criterion from a reflection. When using the quarter-wavelength criterion, the local interval velocity can be used to convert from time to depth.

8.1.2 Equipment selection for sub-seafloor mapping methods

The choice of equipment to be used for sub-seafloor mapping surveys shall be stated in the project specifications and based on the desk study.

[Table 15](#) includes normative methods which shall be performed. [Table 15](#) also includes methods that should be performed and methods that can be performed.

Table 15 — Seismic methods for sub-seafloor mapping types^a

Sub-seafloor mapping type	HR	UHR/UUHR	SBP
Reconnaissance sub-seafloor mapping	XX	X	XXX
Engineering sub-seafloor mapping	X	XX	XXX
Detailed-engineering sub-seafloor mapping	X	XX	XXX
Pre-drilling well-site investigation			
For bottom-founded or anchored rigs ^b	XXX ^c	X	XXX
For dynamically positioned rigs ^d	X ^c		X
^a XXX indicates a normative method, which shall be performed; XX indicates a recommended method, which should be performed; and X indicates an additional method, which can provide useful data. ^b For bottom-founded or anchored rigs HR and SBP are normative methods to provide sub-seafloor mapping to address shallow gas and other drilling hazards. ^c For anchored or dynamically positioned rigs in deep water, in some circumstances, HR seismic may be replaced by suitable existing exploration 3D seismic data (see 5.3.2.8). ^d Seismic methods to be used for pre-drilling well site investigation for dynamically positioned rigs should be assessed on an individual basis depending on the water depth, the drilling programme and knowledge of local conditions.			

If, at the desk study stage, there is reason to suspect that the use of P-wave methods might be of limited value, methods other than P-wave seismic reflection (refraction, shear-waves, magnetics, and electromagnetics) should be addressed in the study.

8.1.3 Assessment of data quality

Data quality can be affected by a number of factors, including the following:

- choice of equipment;

- deployment of equipment;
- equipment settings;
- equipment performance;
- electrical noise, whether generated internally within the equipment or externally;
- acoustic noise;
- weather and sea state;
- seafloor and sub-seafloor conditions.

The assessment of data quality and the judgement of data in meeting the requirements of the project specifications requires a thorough understanding of the above factors and should be supervised by an experienced specialist. It is seldom the case that all the above are optimal and careful judgments are often necessary.

The final assessment of data quality should be made by completing an integrated review of all the seafloor mapping and sub-seafloor mapping datasets collected in the marine geophysical investigation. Cross checks should be made between the different data types to see that conspicuous features such as seafloor pipelines or shallow marker horizons are imaged in the correct way and that positioning discrepancies are appropriately addressed.

8.1.4 Deliverables

The primary end-products of sub-seafloor mapping should comprise the processed, interpretation-ready datasets. In the case of seismic reflection data, this will normally be a seismic image of the sub-seafloor that can be interpreted. The project specifications can define additional deliverables, such as the following:

- Isochrons of horizons that are geologically or geotechnically significant in terms of the objectives of the sub-seafloor mapping. If these are not known, then marker horizons can be selected.
- Isopachs of horizons that are geologically or geotechnically significant in terms of the objectives of the sub-seafloor mapping. If these are not known, then marker horizons can be selected. The method of time-to-depth conversion shall be stated.
- Amplitude maps (illustrating the variation in seismic reflection amplitude of a picked horizon or a vertical zone of the seafloor or sub-seafloor).

8.2 Acquisition equipment and parameters for seismic data

8.2.1 Equipment performance

Prior to the beginning of seafloor mapping, the validity of the most recent equipment calibrations should be verified, and further calibrations carried out as appropriate. On long-duration projects this verification should be repeated no earlier than just before the start of the last port call.

Seismic sources should be tested for power output, acoustic pulse shape, and acoustic pulse repeatability. Source signature can be determined by

- direct far or medium field measurement, recorded without interference from the seafloor, using a reference hydrophone with valid calibration certificate, or
- industry-recognized source-modelling software using source mechanical and pneumatic characteristics or recorded near-field signatures.

Acoustic pulse repeatability can be assessed by surveying a particular line twice and comparing results, or by direct comparison of near-field hydrophone signatures.

Receivers/hydrophones should be tested for bandwidth by the recording of an acoustic pulse test (impulse response). Hydrophones and streamer sections and their sensitivities should be checked either by built-in system checks, or by comparing the responses to those of a reference hydrophone at a known distance.

The recording system should be subjected to the manufacturer's test routines. Tests can include the following checks (this does not apply to single channel profiling systems):

- harmonic distortion (distortion characterized by the generation of harmonics of input frequencies);
- equivalent input noise;
- instantaneous system dynamic range;
- gain accuracy;
- common mode rejection (the ability of a differential amplifier to reject acoustic signals that appear simultaneously and in-phase on both amplifier inputs);
- cross-feed.

8.2.2 Acquisition and processing parameters

Parameters for seismic reflection acquisition and processing methods (HR, UHR, UUHR and SBP) should be according to [Table 16](#), regardless of the type of sub-seafloor mapping.

Signal penetration below the seafloor shall be assessed. Signal resolution should be assessed at two depths: at seafloor and at the desired target depth or at the maximum assessed signal penetration depth, whichever is less. This assessment should be done before and after data processing.

The method of time-to-depth conversion, if applied, shall also be stated.

Table 16 — Recommended parameters for seismic reflection methods

	HR	UHR	UUHR	SBP
Range for dominant source frequency	75 Hz to 300 Hz	250 Hz to 800 Hz	750 Hz to 2 000 Hz	1 000 Hz to 15 000 Hz
Expected vertical resolution range (approximate) ^a	1 m to 7 m	0,5 m to 2 m	0,2 m to 1 m	<0,5 m
Acquisition				
Line spacing	based on project specification			
Source				
Number of source clusters	1	1	1	1
^a Describes desired resolution only. Values are calculated assuming the quarter-wavelength criterion, using 1 500 m/s for the higher frequency, and 2 000 m/s for the lower frequency. Refer to 8.1.1 and A.5.4.2 for more information on resolution and attenuation.				
^b Length of time that seismic signals is recorded following the triggering of a seismic source.				
^c The non-user-settable manufacturers' hardware filters should be recorded during acquisition and processing.				
^d Deconvolution of a trace to compensate for the seismic source not being minimum phase.				
^e Use of information from the earlier part of a trace to predict and deconvolve the latter part of that trace. Widely used in multiple suppression.				
^f Half the data-sampling frequency.				
^g Slant streamers are an example of innovation in seismic recording and require a unique approach to acquisition and processing. The streamer depth specifications given will necessarily not apply in this case.				
^h At a high cut of 80 % Nyquist @370 dB/Octave and a low cut of -3 dB @ 6 dB/Octave.				
ⁱ Tow depths for seismic source and streamer can be increased if accompanied by deghosting during processing.				

Table 16 (continued)

	HR	UHR	UUHR	SBP
Firing or energy release interval	based on project specifications			
Recommended source type(s)	airgun cluster array (sleeve gun, airgun, GI gun)	airgun cluster or single airgun (sleeve gun, airgun, GI gun)	single mini-gun, multi-tip spark-er, boomer, or equivalent	Multi-tip spark-er, boomer, mini air-gun, pinger, chirp, parametric, or suitable single channel source for target of interest
Source characteristic (for recommended source)	typically 80-160 cubic inch (cu.in.) source volume	typically 10-80 cu.in. source volume	typically 5-10 cu.in. source volume for airgun	single spark-er array or transducer, or a focussed array
Operating pressure (for airguns, when used)	2 000 psi	2 000 psi	2 000 psi	n/a
Tow-depth below sea surface of source when deployed at sea surface ⁱ	2 m to 3 m	1 m to 1,5 m	<1,5 m	0 m to 0,5 m
Streamer / Receivers				
Active length	≥600 m	typically 75 m to 300 m	typically 75 m, but may be zero offset, single-channel	typically zero-offset, single-channel system
Number of receiver groups / channels	≥48	≥24	typically 24	1
Group interval	3,125 m to 12,5 m	typically 3,125 m or 6,25 m	≤3,125 m	n/a
Bandwidth	1 Hz to 1 000 Hz	50 Hz to 1 500 Hz	200 Hz to 4 000 Hz	500 Hz to 20 000 Hz
Nearest offset	≤½ water depth	≤½ water depth	typically zero, but ≤½ water depth	0
Streamer depth ^{g, i}	<3 m	<2 m	<1,5 m	0
Maximum streamer noise	20 microbars ^h sustained	20 microbars ^h sustained	20 microbars ^h sustained	n/a
Dead traces at start of survey track line	<3	<2	<2	n/a
Number of birds	1 per active section	As required, generally 1 per active section	As required	n/a
^a Describes desired resolution only. Values are calculated assuming the quarter-wavelength criterion, using 1 500 m/s for the higher frequency, and 2 000 m/s for the lower frequency. Refer to 8.1.1 and A.5.4.2 for more information on resolution and attenuation. ^b Length of time that seismic signals is recorded following the triggering of a seismic source. ^c The non-user-settable manufacturers' hardware filters should be recorded during acquisition and processing. ^d Deconvolution of a trace to compensate for the seismic source not being minimum phase. ^e Use of information from the earlier part of a trace to predict and deconvolve the latter part of that trace. Widely used in multiple suppression. ^f Half the data-sampling frequency. ^g Slant streamers are an example of innovation in seismic recording and require a unique approach to acquisition and processing. The streamer depth specifications given will necessarily not apply in this case. ^h At a high cut of 80 % Nyquist @370 dB/Octave and a low cut of -3 dB @ 6 dB/Octave. ⁱ Tow depths for seismic source and streamer can be increased if accompanied by deghosting during processing.				

Table 16 (continued)

	HR	UHR	UUHR	SBP
Recommended feather angle	<7 degrees	<7 degrees	<7 degrees	n/a
Tail buoy	yes, tracked	optional	optional	n/a
Recording unit				
Sampling interval	1,0 ms	<1,0 ms, typically 0,5 ms or 0,25 ms	typically <0,125 ms	<0,062 5 ms
Recording format	SEG-D / SEG-Y	SEG-D / SEG-Y	SEG-D / SEG-Y	
Record length ^b	based on project specifications			
Low cut filter ^c	Low cut filter – no user-set filter	Low cut filter – no user-set filter	Low cut filter – no user-set filter	Low cut filter – no user-set filter
High cut filter	0,8 Nyquist ^f	0,8 Nyquist ^f	0,8 Nyquist ^f	out
Data processing				
Resampling to 2 ms	no	no	no	no
Spherical divergence	yes	yes	optional	optional
Spatial filtering (FK, Tau-P, etc.) (in shot domain)	optional, depending on data	optional, depending on data	optional, depending on data	no
Spatial filtering (FK, Tau-P, etc.) (in receiver domain)	optional, depending on data	optional, depending on data	optional, depending on data	no
Signature deconvolution ^d	optional, where signature is provided	optional, where signature is provided	optional	optional
Deghost	optional	optional	optional	optional
Predictive deconvolution ^e (DBS)	optional, depending on data	optional, depending on data	optional, depending on data	no
CDP gather	yes	yes	yes, when multi-channel	no
Velocity analysis	yes, typically at 500 m intervals	yes, typically at <500 m intervals	yes, when multi-channel	no
Multiple elimination	optional, depending on data	optional, depending on data	optional, depending on data	no
PSTM	optional, depending on data	optional, depending on data	not normally applied	no
PSTM velocity analysis	yes, when applied, typically at 200 ms intervals	yes, when applied, typically at 200 ms intervals	n/a	no
NMO corrections and mute	yes	yes	yes, when multi-channel	no
^a Describes desired resolution only. Values are calculated assuming the quarter-wavelength criterion, using 1 500 m/s for the higher frequency, and 2 000 m/s for the lower frequency. Refer to 8.1.1 and A.5.4.2 for more information on resolution and attenuation. ^b Length of time that seismic signals is recorded following the triggering of a seismic source. ^c The non-user-settable manufacturers' hardware filters should be recorded during acquisition and processing. ^d Deconvolution of a trace to compensate for the seismic source not being minimum phase. ^e Use of information from the earlier part of a trace to predict and deconvolve the latter part of that trace. Widely used in multiple suppression. ^f Half the data-sampling frequency. ^g Slant streamers are an example of innovation in seismic recording and require a unique approach to acquisition and processing. The streamer depth specifications given will necessarily not apply in this case. ^h At a high cut of 80 % Nyquist @370 dB/Octave and a low cut of -3 dB @ 6 dB/Octave. ⁱ Tow depths for seismic source and streamer can be increased if accompanied by deghosting during processing.				

Table 16 (continued)

	HR	UHR	UUHR	SBP
AVO processing and displays	optional, depending on data	n/a	n/a	no
Stack	yes	yes	yes, when multi-channel	no
Predictive deconvolution (DAS)	optional, depending on data	optional, depending on data	optional, depending on data	no
Time migration	optional, depending on data	optional, depending on data	optional, depending on data	no
Time variant filter	yes	yes	yes	no
Equalization	no	no	no	no
Displays	delivery of SEG-Y files	delivery of SEG-Y files	delivery of SEG-Y files	delivery of SEG-Y files
^a Describes desired resolution only. Values are calculated assuming the quarter-wavelength criterion, using 1 500 m/s for the higher frequency, and 2 000 m/s for the lower frequency. Refer to 8.1.1 and A.5.4.2 for more information on resolution and attenuation. ^b Length of time that seismic signals is recorded following the triggering of a seismic source. ^c The non-user-settable manufacturers' hardware filters should be recorded during acquisition and processing. ^d Deconvolution of a trace to compensate for the seismic source not being minimum phase. ^e Use of information from the earlier part of a trace to predict and deconvolve the latter part of that trace. Widely used in multiple suppression. ^f Half the data-sampling frequency. ^g Slant streamers are an example of innovation in seismic recording and require a unique approach to acquisition and processing. The streamer depth specifications given will necessarily not apply in this case. ^h At a high cut of 80 % Nyquist @370 dB/Octave and a low cut of -3 dB @ 6 dB/Octave. ⁱ Tow depths for seismic source and streamer can be increased if accompanied by deghosting during processing.				

8.2.3 High resolution seismic reflection

8.2.3.1 Checks of equipment performance

Project specifications should specify the frequency of equipment tests, which should be done at regular intervals during data acquisition. These should confirm the polarity and signal strength of each channel and can assess streamer balance and noise levels.

For HR 2D and 3D seismic reflection, the stability and tow depth of the streamer shall be continuously monitored by means of streamer birds fitted with depth indicators. The feather angle of the streamer should be continuously monitored by means of the active tail buoy or by integrating the compass readings from streamer birds.

Assessment of data quality

The following sources of information should be used for the assessment of HR seismic reflection data quality:

- observers log;
- navigation log including QC statistics;
- CDP position data;
- tail buoy position data;
- acquisition geometry;

- streamer noise records;
- seismic source monitor records;
- near-trace monitor display;
- seismic source performance data,
- streamer depth or feather angles.

In the first stage of quality assessment, the above information for each survey track line should be analysed for inconsistencies between the data sources and reconciled where practicable. The project specifications should provide criteria for this analysis, for example criteria for number of dead traces, streamer depth out of range and seismic source performance.

In the second stage of quality assessment, the seismic data should be loaded into a seismic processing system for analysis according to the following procedures:

- viewing of noise files for start- and end-of-line positions of a survey track line;
- spectral analysis of a minimum of every 50-shot records to verify frequency content, gun performance and geometry;
- production of a stack section to assess eventual processed data quality;
- production of selected stacked seismic sections as required to investigate certain conditions or sources of noise, for example near- or far-trace stacks.

Care should be taken that the gain recovery, mute and stacking velocities are appropriate.

8.2.3.2 Data processing

The following general principles apply to the processing of high-resolution seismic reflection data:

- a) The preservation of relative amplitude relationships should be constantly addressed throughout processing, because amplitude information is often more important than structural information in identifying geohazards.
- b) The high frequency content should be preserved throughout, because the focus of interpretation will normally be in the shallow part of the sub-seafloor, within the zone of engineering influence of the offshore structure. Temporal resampling should not reduce the usable bandwidth of the data.
- c) All processing steps should be tested and subjected to QC by a seismic processing specialist. It is often advantageous if the seismic interpreter is consulted during testing on the selection of processing parameters.
- d) As a general guide for processing HR seismic reflection data, the less that is done to the data the better, whilst reaching final processed dataset that preserves frequency content and images the sub-seabed.
- e) A similar processing sequence should apply for both 2D and 3D seismic reflection datasets. However, the 3D processing sequence may include additional steps to regularize the distribution of both data and offsets in the survey area, and to migrate the data in both X and Y directions.

Herein, a number of essential data processing steps are outlined. Additional processing methods can be applied by data processing specialists, if deemed necessary.

Gain recovery/Amplitude manipulation: Corrections for spherical divergence and absorption losses shall be applied to the seismic data.

Velocity analysis: Accurate and spatially frequent velocity analysis is critical to the successful processing of high-resolution seismic reflection data. Velocity analyses shall be made at intervals of no

greater than 500 m along each survey track line. In areas of rapidly changing geology and at points of interest, such as a future location of an offshore structure, this interval should be decreased to 50 m. Continuous, automatic, event-following velocity analyses are capable of producing high quality results and can be used, although the results should be carefully checked.

Mute: In order to preserve vertical resolution whilst enabling effective noise reduction in the CMP stack, a suitable outer trace mute is an essential and critical step. A suitable mute should be derived by producing a series of test stacks before application to the dataset.

NMO correction and CMP or CIP stack: The CMP/CIP stack is important in the data processing sequence for improving the signal-to-noise ratio in a data set. Most processing systems offer a choice of different algorithms. Careful testing should be completed before selecting an appropriate one for each particular dataset and application.

Designature: Many seismic sources provide repeatable minimum-phase signatures. In some cases, it can be beneficial to apply a designature operator that converts the outgoing (far-field) source signature to its minimum-phase equivalent. The frequency spectrum should be left unaltered. The designature operator should be designed using the far-field source signature that is modelled using the gun array specifications. Correct application of the process can improve the vertical resolution of the seismic data by the compression of the acoustic pulse. In addition, subsequent deconvolution can be more effective as deconvolution assumes data to be minimum-phase.

Deghost: The separation and attenuation of the ghost wave fronts relative to the primary wave front. Resolution can be greatly improved.

Demultiple techniques: The presence of multiples is a common source of noise in seismic reflection data and there are a number of techniques available that can remove them. Their application will depend on the characteristics of the seismic data, the objectives of the marine geophysical investigation and the water depth at the survey track lines. The following (common) options should be considered and tested: pre-stack deconvolution in time domain, deconvolution in Tau-P domain, SRME, and Radon demultiple. Water depth is the primary factor for determining which technique to use. For example, Radon demultiple can be effective for seismic data acquired in deep water where there is significant differentiation in move-out. SRME can be effective in shallow water.

DBS: This should be applied to further attenuate unwanted source signature effects, reverberations and multiples in the seismic data. An applied DBS should be offset-dependent.

PSTM: Migration, when correctly applied, can improve lateral resolution in the seismic data either by collapsing diffractions to the zero-offset origin, or by collapsing the Fresnel zones. It can be particularly beneficial when there are steeply dipping reflectors, channel flanks or faults. In horizontally-bedded sediments, post-stack time migration might not produce an improvement. A number of different migration algorithms should be tested.

Coherent noise attenuation: Coherent noise attenuation (FK, Tau-P etc.) may be applied either pre-stack or post stack as required.

Zero-phase conversion: The zero-phase signal wavelet has the shortest duration and largest amplitude for a given amplitude spectrum. HR seismic reflection data can benefit from zero-phase conversion for the following reasons:

- resolution of seismic data is enhanced;
- the ability to distinguish an event against background noise is enhanced;
- polarity reversals of seismic reflections are more easily observed;
- automatic event picking algorithms follow amplitude peaks more easily and with less error than zero crossings;
- peak reflector amplitudes can be directly extracted allowing automatically built amplitude maps.

It is common practice to extract a wavelet from the seafloor seismic horizon in order to design a zero-phasing operator to be applied to the seismic data.

TVF: For optimum resolution, the signal-to-noise ratio of the dataset should be maximised. TVF attenuates unwanted frequencies (noise) and improves signal-to-noise ratio. Resolution requirements should be considered when choosing frequency “cut offs”. If signal and noise energy of the same frequency are present, the design of the TVF can be a compromise. TVF is a zero-phase process and should be applied after zero-phase conversion.

Other processing steps: Testing and application of the following processing steps can produce benefits in some cases and can be considered (this list is not exhaustive):

- PSTM;
- PSDM;
- inner trace mute;
- DMO.

8.2.3.3 Deliverables

[Table 17](#) summarizes deliverables that should be provided.

Table 17 — Deliverables for HR seismic reflection

Deliverable	Data format	Media
Raw seismic data	SEG file (normally SEG-D)	Permanent archive media such as high capacity tape, hard drive
Observers log and navigation log including values for operational parameters, delays, numbering of survey track lines, data storage reference, numbering of seismic source activations, feather angle, streamer depths and seismic source depths	Text, spreadsheet or PDF file	
Positions of vessel from both primary and secondary positioning systems and position of tail buoy	IOP P1/11 and P2/11 ^a	
Annotated near-trace monitor records	PDF, TIFF or similar file	
Zero-offset processed seismic data	SEG-Y file	
Seismic source QC statistics for each survey track line	ASCII or spreadsheet	
Navigation QC statistics for each survey track line	ASCII or spreadsheet	
Description, analysis and results of testing of acquisition equipment for seismic data	Text file	
Seismic velocities used in data processing	ASCII file	
Final processed seismic data	SEG-Y files	
Interpreted horizons	Either XYZ or XYT file	
Contoured isopach or isochron map or other interpretive map	Graphics format or GIS format file	
Annotated example of seismic data profile		
Interpreted cross-sections		
^a Best efforts should be made to use the P1/11 and P2/11 for the processing flow; where not possible due to a limitation of a process this should be noted.		

8.2.4 Ultra-high-resolution seismic reflection

8.2.4.1 Checks of equipment performance

Project specifications should specify the frequency of equipment tests, which should be done at regular intervals during data acquisition. These should confirm the polarity and signal strength of each channel and can assess streamer balance and noise levels.

For UHR seismic reflection, the stability and tow depth of the streamer shall be maintained and continuously monitored. This can be by use of streamer birds fitted with depth indicators or by the use of passive means to avoid acoustic interference from active controllers. The feather angle of the streamer should also be monitored, if possible.

8.2.4.2 Assessment of data quality

Requirements for assessing data quality of UHR seismic reflection are the same as for HR seismic reflection described in [8.2.3.1](#), except that tail buoy position data might not be available.

8.2.4.3 Data processing

Requirements for data processing of UHR seismic reflection are the same as for HR seismic reflection described in [8.2.3.2](#), except that – beyond the essential steps – even less can be necessary, especially in deep water.

8.2.4.4 Deliverables

Deliverables for UHR seismic reflection should be identical to those for HR seismic reflection described in [Table 17](#).

8.2.5 Ultra-ultra-high resolution seismic reflection

8.2.5.1 Checks of equipment performance

Project specifications should specify the frequency of equipment tests, which should be done at regular intervals during data acquisition. These should confirm the polarity and signal strength of each channel and can assess streamer balance and noise levels.

For UUHR seismic reflection, the stability and tow depth of the streamer shall be maintained and continuously monitored. This may be by use of streamer birds fitted with depth indicators or by the use of passive means to avoid acoustic interference from active controllers. The feather angle of the streamer should also be monitored, if possible.

Assessment of data quality

Requirements for assessing data quality of UUHR seismic reflection are the same as for HR seismic reflection described in [8.2.3.2](#), except that tail buoy position data might not be available.

8.2.5.2 Data processing

Requirements for data processing of UUHR seismic reflection are the same as for HR seismic reflection described in [8.2.3.2](#), except that – beyond the essential steps – even less may be necessary, especially in deep water.

8.2.5.3 Deliverables

Deliverables for UUHR seismic reflection should be identical to those for HR seismic reflection described in [Table 17](#).

8.2.6 Sub-bottom profiling

8.2.6.1 Acquisition equipment

The project specifications should state the type or types of SBP to be deployed. Different types should be available.

For fine-grained soils, the source should be either a chirp-type, or an array-type, typically consisting of 3×3 or 4×4 transducers mounted in the hull of a surface vessel. The source can be deployed in combination with SSS from a single towfish or ROTV, as long as it conforms with the requirements for both side scan sonar and sub-bottom profiler.

The frequency of the seismic source for SBP profiling should be in the range of 1 kHz to 15 kHz, preferably adjustable depending on the project specifications. The maximum power output should be at least 5 kW.

Data shall be digitally recorded (DVD, portable hard disk, etc.) and automatically geo-referenced. Traces shall be recorded whole, i.e. unclipped; the entire waveform shall be sampled, without significant loss of bandwidth from the seismic source.

A boomer or sparker (or equivalent) can be deployed to record deeper sub-seafloor strata and features, as these sources typically produce signals that penetrate deeper than those from chirp sources. This can be relevant where there are coarse grained sediments (e.g. sand or gravel), hard or consolidated sediments or variable sediments not conducive to the use of a SBP.

For all SBPs, the position of the seismic source shall be written to SEG-Y trace headers for every trace.

8.2.6.2 Survey platform

The survey platform for the SBP should be selected depending on water depth, survey objectives, expected and discovered ground conditions and environmental conditions, as these will all directly affect performance. A surface vessel or a towfish towed close to the seafloor is commonly used to acquire sub-bottom profiler data. In some circumstances an SBP can be mounted on an AUV. These circumstances include deep water, engineering and detailed engineering surveys or sub-seabed conditions that are suited to investigation by systems that can be effectively mounted on an AUV such as a chirp profiler.

8.2.6.3 Data processing

Sub-bottom profiling data can be processed either in real time or separately as a post-acquisition exercise. In both cases, care should be taken to ensure that the frequency content is maintained. SBP seismic data of 1 kHz to 15 kHz typically require a minimum amount of data processing and often a time-based gain recovery function and a bandpass frequency filter are sufficient.

Other data processing steps, such as deconvolution and sequential trace stacking (combining adjacent traces in order to reduce noise, though at the expense of lateral resolution), can be applied in order to suppress certain types of noise or to condition the data for particular purposes. These should be used with caution and thoroughly tested before application to the entire seismic dataset.

8.2.6.4 Assessment of data quality

The primary measures of sub-bottom profiling data quality are vertical resolution and penetration of the seismic data, and positioning accuracy. Vertical resolution of the seismic data shall be assessed at the seafloor and at a desired depth below seafloor given in the project specifications.

Ground-truthing to assess vertical resolution shall be used if the project specifications provide a suitable control point such as a geotechnical log for this purpose (e.g. ISO 19901-8). Resolution shall be determined either by noting the distance between two resolved strata from the control point, or by

using the quarter-wavelength criterion from a reflection. When using the quarter-wavelength criterion, the local interval velocity shall be used to convert from time to depth.

8.2.6.5 Deliverables

Table 18 summarizes the deliverables that should be provided.

Table 18 — Deliverables for SBP

Deliverable	Data format	Media
Raw SBP data	SEG-Y / SEG-D	Permanent archive media such as high capacity tape, DVD or hard drive
Observers log and navigation log including all operational parameter values, delays, numbering of survey track lines, data storage reference, shot-point numbers, streamer depths and seismic source depths	Text, spreadsheet or PDF file	
Sensor position: each trace requires its own position data, in two formats	IOGP P1/11	
	SEG-Y trace headers	
Interpreted horizons	Either XYZ or XYT file	
Contoured isopach or isochron map or other interpretative map	Graphics format, spreadsheet, or GIS format file	
Annotated example of seismic data profile		

8.3 Non-seismic reflection methods

8.3.1 Seismic refraction

8.3.1.1 General

The seismic refraction method can provide data for interpretation of sub-seafloor strata and for estimates of P-wave velocities in these sub-seafloor strata.

Seismic refraction is carried out by flying a seismic source and seismic receivers (e.g. hydrophones, ocean bottom nodes) near to the seafloor or dragged along the seafloor, firing the seismic source at fixed intervals and deriving the arrival times of P-waves along the receiver (array). The seismic source can remain at one end of the receiver (array), fixing the acquisition geometry in an end-on setup.

The use of seismic sources at both ends (as well as within and off the ends) can be considered to improve resolving the ambiguity between P-wave velocity changes and changes in sub-seafloor strata thicknesses and dip. This ambiguity issue can also be addressed by the interpretation of suitable complementary seismic (reflection) data acquired along the same survey track line.

8.3.1.2 Acquisition equipment and parameters

Seismic refraction equipment should meet the following specifications:

- The selection of seismic source should consider the necessary energy to allow recording of first breaks to the end of the receiver (array);
- The shot interval should not be greater than half the streamer length;
- The selection of the number of receivers and the source-receiver offsets should consider recording of first breaks from (i) the direct arrival through the water (if the system is flown above the seafloor), (ii) the seafloor refraction, and (iii) refractions (if any) within the depth-range of interest indicated in the project specifications (seismic reflection data can indicate whether any potential refractors exist within this range);

- Sample interval should be no greater than 1/10 the dominant signal period from the seafloor refraction;
- Listen time should be sufficient to record first breaks to the end of the streamer;
- Traces shall be recorded whole, i.e. unclipped; the entire waveform shall be sampled, without significant loss of bandwidth from the seismic source.

8.3.1.3 Deliverables

[Table 19](#) summarizes the list of deliverables that should be provided.

Table 19 — Deliverables for seismic refraction

Deliverable	Data format	Media
Positioning data of shot point and receivers	IOGP P1/11 and P2/11	Permanent archive media such as high capacity tape, DVD or hard drive
Processed seismic data	SEG-Y	
Raw seismic data	SEG format	
First break arrival times	ASCII	
2D processed P-wave velocity/depth data	ASCII, GeoTIFF	
3D processed P-wave velocity/depth data	ASCII	

8.3.2 Magnetometer and magnetic gradiometer

8.3.2.1 General

Sub-seafloor mapping with a magnetometer or a magnetic gradiometer can be used to map the position of offshore structures, particularly pipelines and cables. These systems can also be used to identify hazards such as wrecks, although these are often identified from SSS data and occasionally from MBES data.

Altitude and sensor separation parameters should depend on the conclusions of the desktop study. Should a magnetic gradiometer be required, and flux-gate magnetometers are used they should be 3-axis sensors; other magnetometer types may vary.

8.3.2.2 Acquisition equipment and acquisition parameters

The sensor of the magnetometer shall be operated at its optimum resolution settings as dictated by the identification requirements of the survey.

8.3.2.3 Deliverables

[Table 20](#) summarizes deliverables that should be provided.

Table 20 — Deliverables for magnetometer and magnetic gradiometer

Deliverable	Data format	Media
Magnetic sensor data	ASCII text or spreadsheet	Permanent archive media such as high capacity tape, DVD or hard drive
Positioning data for magnetometer and gradiometer sensor	IOGP P1/11 and P2/11	
Where applicable, X, Y and Z coordinates of pipeline or other identified feature		

8.3.3 Marine shear waves

Guidance is given in [A.8.3.3](#).

8.3.4 Marine surface waves

Guidance is given in [A.8.3.4](#).

8.3.5 Electrical resistivity imaging

Guidance is given in [A.8.3.5](#).

8.3.6 Electromagnetic imaging

Guidance is given in [A.8.3.6](#).

9 Reporting of seafloor mapping and sub-seafloor mapping

9.1 General

Reports shall describe the operations for data acquisition ([9.2](#)), the equipment and operating parameters used ([9.2](#)), data processing ([9.3](#)), as well as a factual presentation of the results ([9.4](#)). Some degree of interpretation and integration can also be included if the project specifications require it. Information from the desk study can be included if helpful. Data acquisition operations, data processing and results can be covered in one report or in separate reports.

Daily progress reports should be made during data acquisition and circulated to the relevant stakeholders. These should contain, where applicable:

- a breakdown of the operational activities;
- progress details of seafloor mapping and sub-seafloor mapping;
- status of survey platform(s) and sensors;
- daily HSE report;
- details of data processing;
- preliminary findings or noteworthy discoveries.

9.2 Record of data acquisition operations

Data acquisition operations shall be described in sufficient detail for specialists to gain a thorough understanding of how the raw datasets have been obtained. The following is a list of subjects that can be included:

- project description, including names of client, contractor, and vessels;
- statement of objectives of the seafloor mapping and sub-seafloor mapping;
- description of the data acquisition techniques, including quality management;
- description of positioning equipment;
- dates of operations, including any concurrent data acquisition operations;
- data format description, or reference to standard formats;
- key parameter values for standard data formats (e.g. number of samples, sample rate, data type, endian);
- level of detail achieved: reconnaissance, engineering, detailed engineering, pre-drilling well site;
- verification of acoustic pulse quality (for seismic reflection methods);

- record of QC checks;
- assessment of limits (resolution, depth) of data;
- raw and processed seafloor mapping data and sub-seafloor mapping data;
- descriptions of equipment used for seafloor mapping and sub-seafloor mapping, including positioning equipment;
- equipment operating parameter values;
- summary of equipment performance and limitations (e.g. attenuation);
- geodetic and projection parameters;
- information about vertical datum used on charts and maps;
- details of all relevant equipment checks and verifications, including diagrams where appropriate;
- log of recording equipment used on each survey track line;
- locality map;
- vessel layout diagram showing offsets to sensors from the central reference point;
- map(s) of survey track lines;
- diary of events;
- description of full sequence for data processing, including parameter values selected for data processing.

9.3 Record of data processing

Data processing shall be described in sufficient detail for specialists to gain a thorough understanding of how the datasets presented for interpretation and analysis have been produced from raw field data. The following is a list of subjects that can be included:

- description of processing techniques applied to the datasets, including a rationale for tests carried out;
- description of the processing sequences used, including positioning data and including quality management;
- origin of the tidal corrections used (if applicable) and a description of how they have been applied to the data;
- an assessment of the data quality and resolution of the processed datasets.

Where applicable, a confidence factor on data quality can accompany the datasets which can be an uncertainty analysis, a possible error budget or an approximate estimate of positioning measurement error.

9.4 Results report

The results report shall include description of results as defined by the project specifications. It should cover in detail the findings of seafloor mapping and sub-seafloor mapping. It can also provide an interpretation of the data rather than just be a statement of facts.

Charts, feature maps, horizon maps and interpreted profiles should be included, if specified by the project specifications, to illustrate the interpreted results of the seafloor mapping and sub-seafloor mapping.

The project specifications can define the results report in a way that the acquired results of seafloor mapping and sub-seafloor mapping are consistent with other sources of information, which can include the following:

- data from previous seafloor mapping and sub-seafloor mapping;
- soil investigation data;
- top-hole well logs;
- exploration seismic data;
- data about existing offshore structures;
- public domain data.

10 Data integration, interpretation and investigation of geohazards

10.1 General

The data collected and processed in a marine geophysical investigation shall be interpreted and reported in accordance with the project specifications. This chapter describes how marine geophysical data can be integrated with other data. For other types of seafloor and sub-seafloor mapping a similar procedure can be followed.

Although there are great variations in project types and the complexity of the seafloor and sub seafloor, the techniques described here will be common to many marine site investigations, the differences being in the scope and level of detail involved.

Guidance on the integration of geophysical, geotechnical and other data is given in [A.10.7](#).

10.2 Horizons, isopachs and isochores

Horizons are interpreted by systematically picking a consistent phase of the wavelet. In the case of an appropriate grid of survey track lines, these picks can be spatially interpolated to produce maps displayed as contoured surfaces in the form of isopachs or isochores. Horizon maps should be created in the depth domain. Results can additionally be produced in the time domain.

The parameters and parameter values used to generate isopachs and isochores shall be described in the results report. Information reported typically includes

- distribution of the data points used,
- interpolation technique used and the parameters and parameter values applied,
- smoothing applied, and
- surface-subtraction and contour-generation parameters and parameter values.

10.3 Mapping stratigraphic units and defining geochronology

Interpretation of seismic data can provide maps of ground unit boundaries where significant contrasts in acoustic impedance occur. Ground-truthing, correlation with, for example, seabed samples or borehole samples, can enable these boundaries to be coupled to ground types and inform on the significance of the seismic horizon.

Where covered by the project specification, the following details of ground-truthing data shall be included in the results report:

- positioning data, including geodetic datum;

- offset distances and azimuths from relevant survey track lines;
- geotechnical logs or CPT profiles;
- ground characteristics;
- nature of correlation – continuous, discontinuous, etc.

Details of ground-truthing shall be described in the results report according to ISO 19901-8, where applicable. Any characteristics of ground (soil, rock, made-ground) that have been correlated to the seismic data should be noted in the results report.

The result can be illustrated by superimposing the ground-truth data on a vertical section of the actual sub-seafloor mapping data or an interpretation of the sub-seafloor mapping data. This then leads to the definition of stratigraphic soil units. The products will enable an understanding of shallow section geology and/or provide refinements to the ground model.

Geological and geochemical tests performed on samples acquired by marine soil investigation can be used to define geochronology and constrain the timing and frequency of past geological events. This information can aid the assessment of geohazard recurrence.

10.4 Time-to-depth conversion

Seismic reflection data are generally presented in terms of TWT from source and receiver. In the case of multi-channel seismic, this will be corrected during processing to the CMP. Interpreted horizon maps, vertical profiles and other ground model components are most usefully shown in terms of depth below a vertical datum which requires the conversion of two-way travel times to depth according to the following formula:

$$\text{Depth} = (\text{Velocity} \times \text{TWT}) / 2$$

Accurate time-to-depth conversion is often critical to the interpretation of seismic data and ground-truthing. Time-to-depth conversions should consider, in order of preference

- velocity derived from borehole geophysical logging in relevant ground strata at or close to the survey track line(s) of interest;
- correlation between seismic data and marine soil investigation data where there are measured depths to strata boundaries that are identified with a high level of confidence as seismic reflectors,
- other sources such as a vertical seismic profile, or
- velocities derived during seismic data processing.

If only velocities derived during seismic data processing are available, then time-to-depth conversion for a point of interest, such as a planned offshore structure, should be based on the closest velocity analysis. The chosen analysis should be checked against neighbouring analyses and the interpreted ground model.

Time-to-depth conversion of isopachs can be based on a single velocity function or a velocity grid derived from velocities derived from seismic data processing. In some circumstances, it can be valid to make adjustments to the grid based on information from marine soil investigation and hydrocarbon wells.

Details of time-to-depth conversion method(s) used shall be clearly described in the results report.

10.5 Borehole geophysical logging

Borehole geophysical logging is an invasive technique that can be performed in both soil and rock. It can provide an invaluable additional data set, and a variety of different parameters can be measured, recorded or inferred. Borehole geophysical logging is covered in detail in ISO 19901-8.

10.6 Investigation of geohazards

One of the most important objectives of marine geophysical investigations is to provide input for the identification, delineation, and analysis of geohazards. Guidance on use of geophysical data for geohazard analysis is given in [A.10.6](#).

10.7 Integrated studies

Regarding integrated studies for geotechnical engineering purposes, the following should be kept in mind:

- Good communication and interaction in the multi-disciplinary team conducting an integrated study are essential, so that the practical limitations, uncertainties and engineering implications related to each set of geophysical and geotechnical data or methods are properly understood;
- The derivation of quantitative soil properties using geophysical data is a challenging exercise with inherent uncertainties that should be assessed consistently by integrated teams including geologists, geophysicists and geotechnical specialists;

The geotechnical parameters derived from a ground model for designing the foundations of the planned structures shall be verified and validated by a geotechnical specialist.

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Annex A

(informative)

Additional information and guidance

This annex provides additional information intended to assist the understanding or use of this document. The subclauses in this annex have been numbered to correspond to the subclauses in this document to which they refer.

A.1 Scope

A marine site investigation should, where applicable, identify potential geohazards that can exist during the lifetime of the offshore structure. This aim should lead to, when planning a marine site investigation, an integrated and concerted set of data acquisition, processing and analysis requirements. The relevant disciplines should interact from the start of the planning, as the different specialists will recognize different types of geohazards. However, not all marine geophysical investigations need to be complex multidisciplinary efforts. For example, in areas or regions where conditions are predictable and well understood, a marine geophysical investigation can be considered as a screening exercise to check if unexpected, unusual or problematic conditions could apply to the offshore structure(s).

It is usual for several parties to be involved in a single marine geophysical investigation. Desk studies, for example, can be carried out by a client. Processing of acquired data is not always performed by a data acquisition contractor. Data interpretation and integration can be carried out by a client, a contractor, consultant, or a team of two or more of the above. In these cases, it is important that the team has a clear management structure and contains the appropriate technical skills.

Detailed engineering seafloor mapping and detailed engineering sub-seafloor mapping can relate to pipe/cable routes. Detailed engineering seafloor mapping can also relate to rock dumping and be connected with platform foundations in areas of high seafloor scour potential. These survey types can allow accurate calculation of rock quantities, required length of trenching or ploughing, or correct selection of trenching/ploughing tools.

Detailed engineering seafloor mapping and detailed engineering sub-seafloor mapping can document depth of product (or engineered structures) and depth of cover as well as the horizontal and vertical position of an existing pipeline. The data can also provide detailed information on the pipeline-seafloor interface and the seafloor in close vicinity to the pipeline. The data can also be interpreted to reveal the condition of the pipeline, focusing on any damage to the pipeline or conditions that can lead to damage in the future (e.g. free-spanning).

A.2 Normative references

No additional guidance is provided.

A.3 Terms and definitions

No additional guidance is provided.

A.4 Symbols and abbreviated terms

No additional guidance is provided.

A.5 Objectives, planning, and quality control

A.5.1 General

A.5.1.1 Objectives and project specifications

No additional guidance is provided.

A.5.1.2 Georeferencing and GIS

Consideration can be given to use of the seabed survey data model (SSDM) for data exchange. Note that 'seabed' in the SSDM refers to characteristics of both the seafloor and sub-seafloor.

The core of the SSDM is a geodatabase data model capturing

- a) seafloor features, seafloor/sub-seafloor geohazards and features interpreted from some types of marine geophysical investigation,
- b) positioning data, and
- c) database tables and inventory of records of seafloor mapping and sub-seafloor mapping and document management.

The SSDM excludes

- data model for marine soil investigation data,
- data model for deployed equipment/processed data which has vendor proprietary or industry de-facto format, e.g. SSS images and traces, and
- data model for underlying data processing system, e.g. multi-beam echo sounder raw data and processed data.

The SSDM stores complex and non-GIS data in their respective formats (e.g. XTF, GeoTIFF, SEG-D/SEG-Y, and text document). These data can be hyperlinked via GIS feature class attributes.

[Table A.1](#) outlines general GIS/spatial inputs into the SSDM.

Table A.1 — GIS/spatial inputs into SSDM

ID	Data type	Deliverable format	Equipment/ Data sources
1	Survey navigation tracks/Positioning data	SSDM (survey tracklines)	Survey tracklines ^a
2	Survey chart extents	SSDM (chart index)	Chart index based on charts generated
3	Survey extents/Project details	SSDM (survey key sheet)	
4	Survey equipment limits	SSDM	Equipment zones of use polygons
5	Seafloor features, ground types, geological features, geohazards	SSDM (seafloor features, sediments, isopach, geological features, acoustic anomaly, fault, paleo channel system)	SSS data, MBES data, sub-bottom profiles, HR seismic
6	SSS imagery	1. georeferenced raster database, GeoTIFF or JPEG2000 of image mosaic ^b (NO DATA = 0,0,0 or 255,255,255) 2. XTF	SSS data
7	MBES backscatter data	georeferenced raster database, GeoTIFF or JPEG2000 of image mosaic ^b (NO DATA = 0,0,0 or 255,255,255)	MBES data, SSS data
8	Offshore structures (e.g. pipeline or platform as-built deliverables)	SSDM (offshore structures)	SSS data, MBES data, ROV
9	Seismic section	SEG-Y	SBP data, HR 2D seismic or UHR seismic
10	Seismic horizon	1. SSDM (raster dataset or georeferenced terrain) 2. ASCII X, Y, Z (below seafloor) file of the horizon	SBP, HR 2D seismic or UHR seismic
11	Environmental information (e.g. water samples, ROV video locations, etc.)	1. SSDM 2. Movie file format (*.wmv or similar) 3. Images as TIFF, JPG or similar	ROV, water or soil sampling, gravimeter, magnetometer

^a This is required for all equipment for the survey e.g. MBES, SSS, SBP, etc. Shot points/fix positions should be embedded as “M” values within the survey tracklines feature class.

^b Compilation of SSS records to form a geo-referenced seafloor acoustic image.

A.5.1.3 Ground model

A ground model that integrates multiple forms of data and is set within a temporal and evolutionary framework of a defined area or volume of ground can provide a thorough spatial understanding and summary of the static and active conditions (geological processes) that have existed in the past, are present now, or can operate in the future. The ground model will typically be updated and refined during the course of an investigation as more data becomes available and can take the form of an engineering geological model upon which, for example, key decisions regarding geohazard risk, optimised data-acquisition programmes, layout plans, and foundation designs can be based.

During the desk study, the initial ground model is developed to initially define the geological conditions, sub-seafloor stratigraphy, and spatial soil variability throughout the project area. Upon completion of

the geophysical programme of seafloor and sub-seafloor mapping, the data are interpreted, and the model refined, so it can be used to plan the scope of the marine soil investigation. The ground model is valuable in terms of understanding the sub-seafloor conditions, selecting logging, sampling and in situ testing locations, and selecting geotechnical procedures most appropriate for the interpreted ground types (refer to the guidance provided in ISO 19901-8). The ground model also allows the identification of sites where the most uniform ground stratigraphies exist. In consultation with field developers, ground models can be used to select optimal locations for offshore structures to minimize uncertainty in soil conditions, and problematic anomalous areas can be avoided. All this information plays a critical role in establishing the final scope of a marine soil investigation.

An integrated geoscience study to develop a reliable ground model is best carried out by a team of geologists, geophysicists, geotechnical engineers, offshore structure facility designers, and other supporting geoscience professionals, who interact closely throughout the study. The interdisciplinary collaboration should begin at the start of the desk study phases at the planning stage and continues through all subsequent phases. Clear communication of all geological and geotechnical conditions and constraints is essential to confirm that the final locations of offshore structures and field architecture are placed at optimum sites. The geotechnical engineer, geologist and geophysicist will work closely together with offshore structure designers and facility planners in selecting the most appropriate foundation types for the soil conditions and geo-constraints defined in the ground model.

A.5.2 Desk study

A.5.2.1 General

The output of a desk study should include an initial ground model. The model can aid in defining the scope of the marine geophysical investigations and marine soil investigations, identifying:

- area to be studied;
- existing available data (public domain, in-house, etc.);
- existing current understanding of the site, including literature review;
- gaps in the current understanding of the site;
- requirements for additional data collection to fill gaps in the understanding of the site;
- level of detail and accuracy required for the desired investigations;
- international and national legislations and regulatory environments (e.g. corals, archaeology) as well as infrastructure;
- whether specific specialist studies are required in the area (such as slope stability, seepage, etc.).

A desk study for a larger-scale development typically includes an early assessment of the potential degree of risk posed by each geohazard for an offshore structure. This will aid the planning of a marine geophysical investigation. [Table A.2](#) (Reproduced from Reference [75] with permission) shows an example of various features, geological processes or conditions and typical geophysical data that can be used to assess the hazard, and ultimately the risk to infrastructure. The performance of a marine soil investigation is also recommended in most cases.

Table A.2 — Examples of geological processes or conditions which can constitute a hazard, and recommended relevant geophysical data

Features, geological process or condition (geo-hazard)	Recommended geophysical data
Slope gradient and irregular seafloor topography	MBES, (alternatively, Exploration 3D seismic data in deep water environments)
Fault displacement/ offsets	SSS, sub-bottom profiler, UUHR/UHR/HR 2D/3D seismic data
Slope instability	SSS, sub-bottom profiler, UUHR/UHR/HR 2D/3D seismic data
Debris/Turbidity flows	SSS and sub-bottom profiler, UUHR/UHR/HR 2D/3D seismic data
Spatial soil variability	SSS and sub-bottom profiler, UUHR/UHR/HR 2D/3D seismic data
Currents	MBES, SSS and sub-bottom profiler
Fluid/Gas expulsion Shallow water flow Gas hydrates	Exploration 3D seismic and UUHR/UHR/HR 2D/3D seismic data Converted wave seismics
Permafrost	MBES, SBP, UUHR/UHR/HR 2D/3D seismic data, refraction, electromagnetics
Diapirism (e.g. salt, mud)	MBES, SBP, UUHR/UHR/HR 2D/3D seismic data
Coral reefs	MBES, SSS, SBP, imagery

A.5.2.2 Use of exploration 2D and 3D seismic data in a desk study

No additional guidance is provided.

A.5.2.3 Desk study for pre-drilling well-site investigations

Marine site investigation reports and drilling reports for nearby offset wells can be used to identify pre-drilling well-site geohazards and/or operational difficulties experienced in the area, for example shallow gas, lost circulation, poor rig foundation or other rig emplacement problems, top-hole section drilling problems, and difficulties installing conductor pipes. Relevant geohazards and operational difficulties should be specifically addressed in planning of the marine site investigation. Existing data can also provide partial or complete coverage of the area around the planned wells. When evaluating whether existing data can be used for a new well location assessment or if new data need to be acquired, the data types, the age of the data, the type of rig and the well plan should be considered.

A pre-drilling desk study carried out over a large area at an early stage in the well planning process that provides early insight into geohazards can be a valuable source of information into exploration and appraisal drilling plans for the area.

If the project concerns a marine site investigation for drilling of the upper portion of a hydrocarbon well, the area to be covered should be defined considering the tolerance of the proposed drilling location. If there is any possibility of a change of surface and/or terminal depth locations prior to drilling, the investigation area should include these alternative locations. It can be beneficial for the investigation area to be sufficiently large to cover any potential stand-off locations and relief-well drilling locations, although in the event of a well control incident relief-well locations will require resurvey before they can be used.

A.5.3 Scoping and planning**A.5.3.1 General**

While this document treats the desk study separately from the project scoping, sometimes the project scoping will be treated as part of the deliverables of the desk study.

Although [Figure 2](#) shows many stages in a marine site investigation, an individual investigation does not need to include all these stages. For example, a client can require a relatively straightforward seafloor mapping as part of a much larger field development study. The contractor who carries out the seafloor mapping might be contracted only for the field data acquisition and can be provided with the desk study to aid survey planning. The seafloor mapping results can be incorporated into the initial ground model by others.

In the more complex situation of a major field development, most if not all of the stages shown in [Figure 2](#) are required.

A.5.3.2 Scoping of seafloor mapping and sub-seafloor mapping

A.5.3.2.1 General

No additional guidance is provided.

A.5.3.2.2 Reconnaissance seafloor mapping

No additional guidance is provided.

A.5.3.2.3 Engineering seafloor mapping

Engineering seafloor mapping is commonly carried out simultaneously with engineering sub-seafloor mapping.

A.5.3.2.4 Detailed engineering seafloor mapping

No additional guidance is provided.

A.5.3.2.5 Reconnaissance sub-seafloor mapping

No additional guidance is provided.

A.5.3.2.6 Engineering sub-seafloor mapping

No additional guidance is provided.

A.5.3.2.7 Detailed engineering sub-seafloor mapping

No additional guidance is provided.

A.5.3.2.8 Pre-drilling well-site investigation seafloor and sub-seafloor mapping

To replace new HR seismic acquisition with existing exploration 3D seismic data, the data should meet the following criteria:

- Frequency content: The dataset should preferably possess a useable frequency content up to, and beyond, 60 Hz to the full depth of interest below seafloor;
- Seafloor reflection: should be free of gaps and defined by a wavelet of stable shape and phase to allow auto-tracking of the seafloor event with minimum user intervention and guidance;
- Acquisition artefacts: such as cross-line statics and/or amplitude striping, though possibly identifiable in the sub-seafloor, should not detract from the overall interpretation of a picked event when mapped in time or amplitude. Similarly, time slices or windowed attribute extractions should be devoid of or show minimal acquisition artefacts that might otherwise be to the detriment of their interpretation;

- Merge points: between datasets of differing origin or vintage that cross a study area should be marked by minimal – and preferably no – time or phase shifts and amplitude changes across the joins that might otherwise be to the detriment of the interpretation;
- Bin sizes: processed bin sizes should preferably be less than 25m in both the inline and crossline direction;
- Sample interval: Processed output sample interval should preferably be 2 milliseconds and certainly no more than 4 milliseconds. This can be achieved by extracting a near offset subset from the original volume;
- Imaging: Attention to definition of an accurate velocity model in the sub-seafloor in processing should have allowed optimum structural and stratigraphic resolution to have been achieved in the migrated volume. The sub-seafloor should show minimal indication of under, or over, migration artefacts;
- Multiple energy: should either be unidentifiable or at a level that does not interfere with the analysis of the sub-seafloor;
- Data coverage: the available exploration seismic data coverage should fully meet the guidelines for data coverage set out above.

In water depths of less than 300 metres, the above criteria are generally not met because of the frequency content of the data and the long seismic recording offsets, but this can be decided on a case-by-case basis after review by geohazards and 3D seismic specialists.

Exploration 3D seismic data is not suitable for seafloor mapping for the detection and mapping of objects and obstructions on the seafloor, neither is it suitable for sub-seafloor mapping of shallow soils that affect, for example, anchoring. For this reason, special consideration will need to be given for anchored rigs in deep water where a side scan sonar survey and sub-bottom profiler survey, possibly acquired using an AUV, might be needed.

Exploration 3D data should be used at their optimum spatial, temporal, bit resolution and sampling interval. Data should be loaded to a workstation unscaled, at no less than 16- and preferably 32-bit data resolution.

Reprocessing of exploration 3D data, either through production of a near trace or short-offset subset, output of a high-resolution velocity model (e.g. using FWI or other techniques) or by application of other processing techniques (e.g. deghosting), can deliver significant improvements in resolution and data quality or interpretational information. Such approaches should be considered, especially if the original exploration 3D dataset fails to meet the minimum data acceptability criteria set out above.

Further information is available in IOGP report-373-18-1^[30].

A.5.4 Operations planning and data quality management

A.5.4.1 Quality plan

When selecting a vessel as an operational base or as a survey platform for seafloor mapping or sub-seafloor mapping, the following factors should be considered:

- Vessel suitability for efficient and safe operations in the proposed survey area. Vessels that can support acquisition of multiple methods of mapping concurrently in a single survey pass are generally preferred over vessels that can only support acquisition of the data in multiple-pass mode;
- Previous experience in the area of operations, and the techniques and equipment required;
- Vessel accreditation for compliance with regulatory requirements;
- Whether the vessel is owned or is on long-term charter to the contractor performing seafloor mapping or sub-seafloor mapping and permanently mobilised with all mapping equipment. Ad hoc

vessels that are mobilised specifically for a marine geophysical investigation will require a period of 'shake-down' and are more likely to be affected by technical problems than contractor-owned or long-term charter vessels with survey equipment permanently installed;

- If the vessel's operator and contractor performing seafloor mapping or sub-seafloor mapping are different companies, then consider the establishment of an operational management system ('bridging document') between the marine operational and marine geophysical investigation sides to ensure an integrated team.

Additional factors that can be useful to consider are

- deck handling equipment,
- freeboard for deployment/recovery of survey platform(s),
- vessel audit history,
- minimum/maximum speed possible and economical cruising speed, and
- vessel noise signature, if available, and
- requirement to work close to existing structures.

For efficient planning, metocean data for the site should be used, including prevailing and likely wind and surface current speeds and directions and the anticipated sea states. This information can be gleaned from pilot books, tide tables and public domain data sets or derived from metocean data models. Knowledge and understanding of these data can influence timing of seafloor mapping or sub-seafloor mapping, survey track line orientation and other project specifications.

It is not common practice to acquire metocean data specifically for marine site investigation purposes. However, metocean data might need to be acquired for the well drilling or planning process. There can be cost benefits in acquiring such data or deploying/retrieving metocean instrumentation during the marine geophysical investigation.

When planning and conducting a marine geophysical investigation, HSE issues should be considered. A key element of this is the preparation of project-specific HSE plans and ERPs. These can utilize the joint resources of the client and the contractor.

Vessel HSE inspections should be undertaken prior to and during operations, as appropriate. These inspections should include over-the-side systems, operational processes and HSE management systems, in addition to the required inspection of statutory items of the vessel. Any action items identified by these inspections should be followed up and closed out expediently. The maximum required period between these HSE inspections can be given in the project specifications. A common interval for such inspections is twelve months.

A QMS does not operate in isolation. A well-designed QMS will still fail, if it is implemented by non-specialist personnel who do not have the experience to recognize good practice, or who cannot distinguish good data from bad data.

For marine geophysical investigations, quality management will typically require expertise in the following:

- positioning;
- geophysical theory and practice relevant to the tools being used;
- instrumentation used on the project;
- data processing techniques;
- interpretation methods;
- team coordination;

— marine operations and logistics (non-geophysical).

The persons involved in marine geophysical investigations should be fully experienced in the quality management procedures required for the relevant activities.

A.5.4.2 Effects of attenuation

Sub-seafloor mapping is fundamentally different from seafloor mapping, because attenuation plays a significant role in sub-seafloor mapping but is not an issue in seafloor mapping.

For seismic reflection, attenuation is one of a variety of mechanisms that results in the dissipation of energy from the seismic source. Other mechanisms include spherical divergence (or other geometric spreading in the case of a focused beam), scattering, and internal reflection and transmission losses. Attenuation can be differentiated from the other mechanisms in that it is strongly frequency dependent; attenuation increases with increasing frequency. Attenuation dissipates energy by converting it to heat through frictional losses, either as a result of grain-to-grain motions, or as result of induced fluid flow within the sub-seafloor.

One result of the frequency-dependence of attenuation is that, for a given energy output, a trade-off exists between resolution and penetration; improved resolution is obtained by increasing dominant frequency content within the signal, but penetration decreases with increasing dominant frequency. This is true of almost every method of sub-seafloor mapping; improvement in resolution will be obtained at the expense of penetration, and vice-versa. Attenuation also varies with soil particle size distribution; generally, attenuation increases, and penetration decreases with increasing particle size.

The specification of methods for the acquisition of geophysical data for the description of shallow stratigraphy and deeper investigations should recognize that attenuation can play an important part in determining whether usable data are obtained. It is possible that some soils cannot be imaged to the required depth with the required resolution, particularly in case of coarse-grained soils (i.e., sand or gravel).

The decision tree in [Figure A.1](#) provides a framework that can be used to manage the effects of attenuation in sub-seafloor mapping

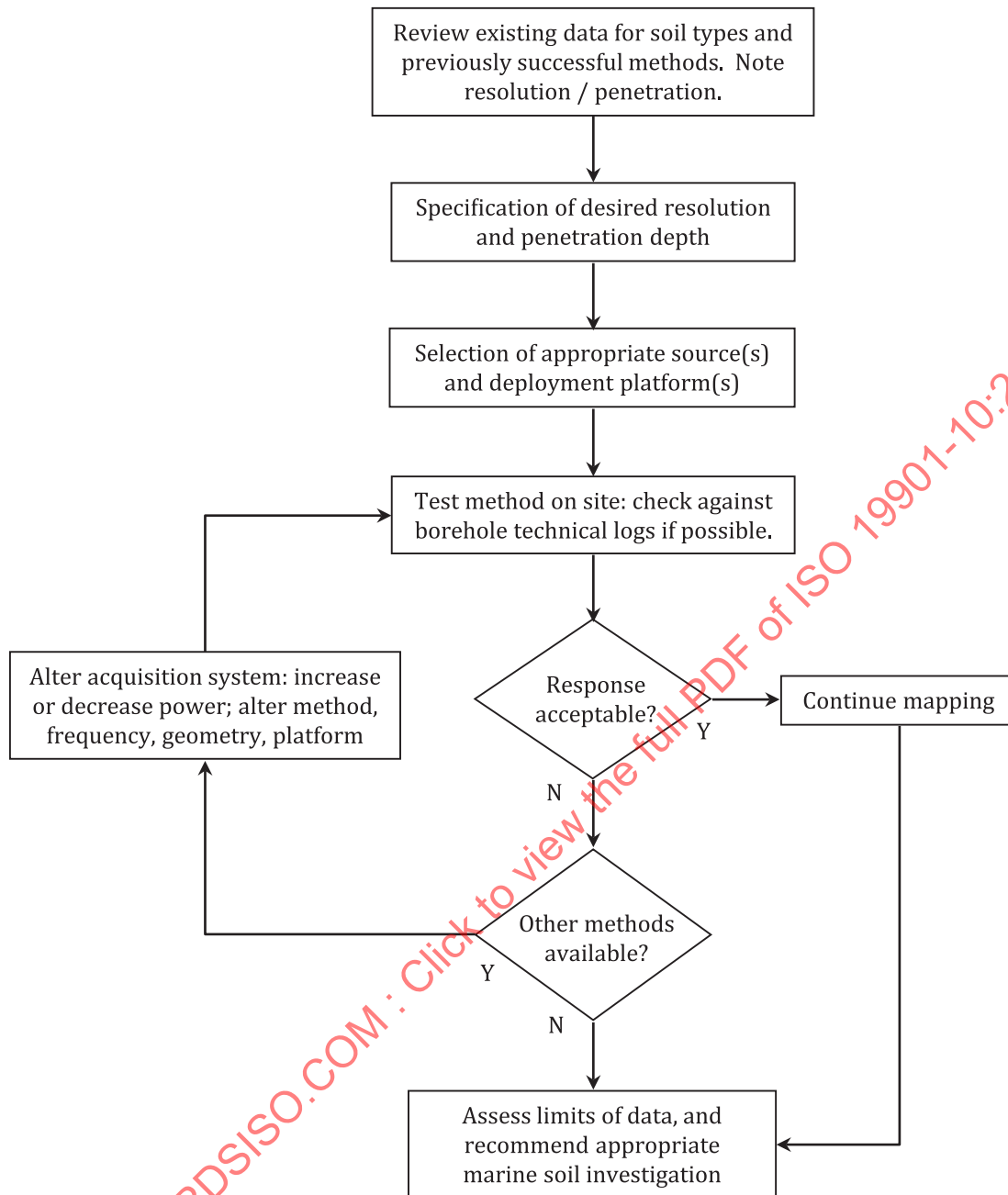


Figure A.1 — Decision tree for managing the effects of attenuation

A key point implied in [Figure A.1](#) is that for sub-seafloor mapping it is not possible to achieve a combination of resolution and penetration depth simply by stipulating it in a project specification. This is particularly important in areas where no nearby sub-seafloor mapping has been performed previously. In these areas, it is recommended to have multiple systems on-hand, in order to manage a range of sub-seafloor conditions and therefore a range of attenuation levels.

A.5.4.3 Data quality management

No additional guidance is provided.

A.6 Positioning

A.6.1 General

No additional guidance is provided.

A.6.2 Coordinate reference systems

No additional guidance is provided.

A.6.3 Surface positioning requirements

During mobilization of the marine geophysical survey vessel it should be checked that

- the GNSS positioning systems are operating correctly and to specification,
- offsets between GNSS antennae, common reference point and survey sources and receivers are measured accurately and applied correctly, and
- coordinate transformation parameters are applied correctly.

GNSS positioning systems, offsets and coordinate transformation parameters can be validated by in-port and in-field verifications against independent control points and by in-field verification against installations/ structures with known coordinates where these exist and can be used.

A.6.4 Vessel heading

For short baseline and unstable sea conditions, GNSS heading accuracy can be worse than gyrocompass for small (autonomous) surface vessel and for turbulent port conditions.

As an alternative to reciprocal vessel heading checks, vessel heading sensor alignment can be calibrated using dynamic methods that utilize fixed installation GNSS receivers on vessels

A.6.5 Sub-sea positioning — Ultra-short baseline system

The USBL positioning measurement error depends on the slant range between the transducer and the transponder/responder on the towed equipment; the water depth in the survey area therefore determines how accurately survey equipment towed near the seabed can be positioned. If properly calibrated, USBL systems typically provide a relative positioning measurement error of better than 0,3 % of slant range.

The absolute measurement error of conventional USBL systems will eventually increase to unacceptable levels as the water depth and hence slant range to the towed equipment increases. The following strategies can be employed to keep the absolute positioning of the towed equipment within the tolerances required:

- Using a responder where there is only a single through water path, the responder is triggered by a signal sent down the tow wire to sub-sea equipment;
- Aid the USBL by incorporating a depth sensor on the towed equipment, so that the USBL system only has to compute the plan position of the towed sensors;
- Using a depressor on the towed equipment to shorten the layback;
- Aid the USBL by incorporating an Inertial Measurement Unit on the towed equipment;
- Optimise the operating frequency of the USBL. The majority of USBL operate in the MF band but it is possible to utilize equipment in the LF band.

Very long tow lengths will affect operational efficiency and the use of AUV as the vehicle to carry the sensor suite should be considered. AUVs have the advantage of utilizing many of the aiding systems

mentioned and can be positioned close to the support vessel in plan thus minimising layback. The removal of a physical connection from the vessel to the AUV decouples the sensor suite from vessel motion.

A.6.6 Inertial navigation system

Positions from INSs can be improved by post-processing, using corrections obtained from a variety of verifications, such as comparisons of INS-observed positions of sub-sea equipment versus known positions.

A.6.7 Auxilliary sensor: doppler velocity log

No additional guidance is provided.

A.6.8 Auxilliary sensor: altimeter

No additional guidance is provided.

A.6.9 Auxilliary sensor: pressure-depth sensor

No additional guidance is provided.

A.7 Seafloor mapping

A.7.1 General

IOGP Report 373-18-2^[31] provides a comprehensive technical reference on survey techniques and equipment for a pre-drilling well-site geohazard investigation. This report covers the types of survey equipment recommended, including positioning equipment, echo sounders, SSS, seismic acquisition systems, magnetometers and equipment for marine soils investigations. It also covers survey planning and data integration, interpretation and reporting.

A.7.2 Instrumentation and acquisition parameters

A.7.2.1 Multi-beam echo sounder

MBES systems can vary according to the frequency bandwidths of their emitted pulses. Table A.3 provides guidance on appropriate bandwidths according to water depth.

Table A.3 — Suggested frequencies for MBES systems

Term	Depth range	Frequency range
Shallow water, vessel mounted, or vehicle mounted in deeper water – AUV, ROV or ROTV	<25 m	100 - 500 kHz
Standard, vessel mounted (neither shallow nor deep)	25 m to 750 m	50 – 200 kHz
Deep water, vessel mounted	750 m to 1 800 m	30 – 100 kHz
Ultradeep water, vessel mounted	1 800 m to 3 000 m	15 – 60 kHz
Abyssal, vessel mounted	>3 000 m	10 – 15 kHz

A.7.2.2 Side scan sonar

Figure A.2 provides an example of how to design a side scan sonar survey according to the required level of coverage.