International Association of Oil & Gas Producers

REPORT
373-18-2

OCTOBER
2015

Conduct of offshore drilling hazard Site Surveys – Technical Notes

Acknowledgements

DHSS Task Force of the IOGP Geomatics Committee

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Conduct of offshore drilling hazard Site Surveys – Technical Notes

Revision history

VERSION	DATE	AMENDMENTS
1.0	October 2015	First release

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1. Introduction

This report, published by The International Association of Oil & Gas Producers (IOGP), is a companion to Report 373-18-1, *IOGP Guidelines for the Conduct of Offshore Drilling Hazard Site Surveys* (hereafter The Guidelines). The Guidelines address the conduct of geophysical and hydrographic drilling hazard site surveys (hereafter referred to as Site Surveys) of proposed offshore well locations and the use of exploration 3D seismic data to enhance, or to replace, acquisition of a Site Survey.

Report 373-18-2, *Conduct of offshore drilling hazard Site Surveys – Technical Notes* (hereafter *The Technical Notes*) provides more detailed guidance, supporting technical information and background theory on the various equipment, planning, acquisition, processing and interpretation techniques used in a Site Survey project that are outlined in *The Guidelines*.

The Guidelines and *The Technical Notes* replace the former UKOOA Guidelines for the conduct of Mobile Drilling Rig Site Surveys, Version 1.2, previously published under the auspices of the former UK Offshore Operators Association (UKOOA), now Oil & Gas UK.

The Technical Notes comprise four sections:

1. Introduction
2. Survey planning
3. Survey equipment
4. Data integration, interpretation and reporting.

The main sections are supplemented by a comprehensive glossary available at the back of the report.

The Technical Notes may be used as a technical reference to gain more detailed knowledge about specific Site Survey techniques, processes or equipment. However, it is important to note that if the reader is unfamiliar with, or seeks guidance on, the conduct of Site Surveys, *The Technical Notes* should be read in conjunction with *The Guidelines*. A number of items that are already covered in detail in *The Guidelines* are not further detailed in *The Technical Notes*.

The techniques, processes and equipment described in this report can also be applied to other types of seabed surveys, such as pipeline or cable routes, etc. Whilst this report does not set out to directly address the planning and delivery of such projects, it is recognized that similar techniques, processes and equipment will be applicable to such projects.

1.1. Health, safety, security, and environment

When planning and conducting Site Surveys health, safety, security, and environment (HSSE) issues should be given the highest priority.

A key element of this is the preparation of project specific HSE and emergency response plans. These should utilize the joint resources of the operator and the contractor to ensure safe operations and minimal environmental impact and to establish contingency planning for emergency situations.

It is recommended the operator follows IOGP guidance in Report 432, *Managing HSE in a Geophysical Contract* (December 2009) in managing HSE issues in delivery of survey operations.

Vessel HSE inspections should be undertaken in advance of or during mobilization activities and should follow the IMCA Common Marine Inspection Document (CMID) rationale.

Vessel HSE inspections should be undertaken prior to and again, if necessary, during operations, as appropriate. These inspections should include review of:

- the mounting and deployment of over-the-side and through hull systems
- ergonomic and safety implications of equipment deck layout and deployment arrangements
- operational processes, and
- HSE management systems

in addition to the inspection of statutory items required of the vessel.

Any action items identified by these inspections should be followed up and closed out well in advance of the vessel leaving port at the start of the project.

The maximum required period between HSE inspections is subjective. However, a maximum interval between such inspections of twelve months has become accepted industry practice.

1.2. Competent personnel

The planning, acquisition, processing, interpretation, and reporting of a properly conducted Site Survey for an offshore drilling location requires a combination of specific geophysical, geological, survey, and other skills. In order that the key objectives of a Site Survey are met, it is imperative that appropriately skilled and experienced specialist personnel are used throughout the entire project.

1.2.1. Site Survey contractor personnel

In order to ensure that a Site Survey is conducted satisfactorily, it is essential that the core of the contractor's Site Survey team are experienced in such surveys. It is important that this survey team includes an appropriately skilled and experienced core of: Party Manager, Chief Engineer, Senior Surveyor, and Senior Geophysicist.

Additionally, it is important that all data processing, interpretation and reporting are overseen by experienced Site Survey specialists to ensure that each constituent part of the delivered results is combined to produce a Site Survey dataset and report that have been adequately checked and integrated.

1.2.2. Operator personnel

The Site Survey project should be managed for the operator by a competent Site Survey specialist.

To ensure that project specifications and objectives are met, the operator's Site Survey project manager should be supported by experienced offshore Quality Control (QC) supervisors acting as the operator's representatives on the survey vessel. These personnel should be responsible for oversight of contractor HSE management, the data acquisition, provide independent quality control of the geophysical and positioning data, and of the onboard processing and interpretation of these data.

It is recommended that the onshore data processing, interpretation, and reporting is subject to similar careful QC during the reporting phase of the project by either the project manager or other independent QC staff.

1.3. Operator/contractor liaison

When planning and conducting Site Surveys, effective communications between the operator, the contractor and any QC personnel are critical.

To ensure that the objectives of the Site Survey are met, the early transfer of all relevant existing data and information pertaining to the proposed Site Survey to the relevant parties is important. Where available, the following and any other relevant data and information should be exchanged:

- drilling objectives and constraints
- previously acquired Site Survey results
- geotechnical data
- known geo-hazard information gleaned from previous work undertaken by the operator
- drilling rig foundation and/or anchoring information/experience from previous operations
- top-hole well log data from offset wells
- exploration seismic data
- previous top-hole drilling experience including details of any problems encountered
- location of any existing infrastructure.

2. Survey planning

2.1. Site survey objectives

Site Surveys are performed to minimize the risk of harm to personnel and equipment, and to protect the natural environment. The objective of any Site Survey is to identify all possible constraints and hazards including man-made, natural and geological features which may affect the operational or environmental integrity of a proposed drilling operation, and to allow appropriate operational practices to be put in place to mitigate any risks identified. In addition, the proposed Site Survey study area should be of adequate coverage to plan any potential relief well locations, and to provide sufficient data to fully assess potential top-hole drilling hazards at these locations. It should be noted that if a well control incident (an uncontrolled underground or surface flow) has taken place on the prospect, field or in an immediately adjacent area since acquisition of the Site Survey, any existing seabed and subsurface data shall be considered invalid. In such a case a new survey is always required.

The interplay of the physical environment with the intended drilling operations has a fundamental impact on the scope and objectives of a Site Survey.

These objectives are usually addressed in one integrated Site Survey using a fit-for-purpose survey platform and a range of specialist equipment and survey techniques and processes. The rationale behind the Site Survey requirements is discussed in *The Guidelines* (IOGP Report 373-18-1). The following text expands on the survey planning phase of the Site Survey and cross-references relevant sections within *The Guidelines*.

2.2. Initial planning – desk study

All Site Surveys should commence with a desk study – or review – of existing data (section 4 of *The Guidelines*). In its simplest form, this should comprise a review of available relevant data. The aim of this study is to ensure that existing data are assessed and the information that is gleaned is used to ensure that a Site Survey is planned appropriately and efficiently and that maximum use is made of available data and existing knowledge of the Site Survey area.

There is a wealth of Public Domain data published on the internet and from other sources that may aid in the delivery of the desk study and in the selection of optimum survey equipment/instrumentation and techniques; data availability will vary with the geographic location. Items to be addressed in this desk study should include but not be limited to:

- relevant academic references
- definition of the area to be covered by the Site Survey
- exploration and production licence requirements pertinent to drilling and survey operations
- history of geo-hazard problems in the area or with offset wells
- existing 2D and 3D exploration seismic data
- nearby existing Site Survey data and reports

- public domain data, e.g. metocean and JEBCO bathymetry
- nautical charts
- public databases: wrecks, communications cables, etc.
- other activities in survey area to include: submitted permits and plans, conflicting operations (seismic operations, construction activity, etc.)

The area to be covered by the Site Survey desk study should be defined considering the location tolerance for the proposed drilling location. If there is any possibility of a change of surface and/or TD locations prior to drilling, the extent of the survey area needs to include all possible alternative locations. The survey area should also be sufficiently large to cover any potential stand-off locations for use by the rig as it approaches location, and the surface location of any relief-well locations under consideration. (Please refer to 2.1 above concerning data validity in case of a well control incident.)

Exploration and production licence requirements may include specific survey requirements for the proposed well location, such as requirements for any environmental surveys (2.4.2 below) or restrictions limiting the time of year that Site Surveys can be undertaken.

A review of drilling (and other) reports for nearby offset wells should be used to identify drilling hazards and/or operational difficulties previously experienced in the area and that may need to be assessed in the proposed Site Survey; for example, shallow gas, lost circulation, poor rig foundation and other restrictions to rig emplacement and to the drilling of the top-hole section.

Existing 2D and 3D exploration seismic data covering the planned survey area should be reviewed. These may indicate geo-hazards that need specific attention when planning the Site Survey. The review can also be used to determine optimum survey line direction and line spacing (5.5.3 of *The Guidelines*). The review may also help to determine the areal extent for the planned Site Survey coverage both to ensure that areas with potential drilling hazards are adequately covered and to define extended survey lines to enable interpretation of the Site Survey high resolution (HR) seismic data within a regional geological context.

The review should be used to determine if, for deep water well locations, existing exploration 3D seismic data is adequate to negate/minimize the need for acquisition of additional HR seismic Site Survey data (5.6 and Figure 2 of *The Guidelines*).

Review of nearby existing Site Survey data and related reports should be conducted to identify drilling hazards previously mapped in the area and any operational survey problems that may be expected. It may also help to determine optimum selection of survey equipment/instrumentation and techniques, and specific contractor expertise.

Existing Site Survey data may also cover part (or all of) the proposed Site Survey area. When evaluating if existing data can be used for a new well location assessment or if new data needs to be acquired, the data types and the activities in the survey area need to be considered (Table 2 of *The Guidelines*). In deciding on the validity and value of pre-existing data, however, the operator must ensure they are meeting local regulatory requirements or those of the rig insurance underwriter.

A review of up-to-date nautical charts or public domain bathymetric databases should provide an indication of water depth, seabed topography, and existing infrastructure and other features such as seabed wrecks, telephone/power cables and pipelines, which may influence the survey design and equipment selection, as well as the location of the proposed well.

The presence of shipping lanes and other areas where operations may be constrained can also limit survey activities.

The range of water depths across the survey area will dictate the selection of geophysical survey equipment/instrumentation and the required capability of subsea positioning equipment.

Other ongoing exploration and production related activities such as seismic surveys or construction/installation activities within or adjacent to the proposed survey area can severely impede access to the survey area and adversely affect the quality of the data acquired. Survey activities should be scheduled in coordination with both the operator's own, and other operators', ongoing and planned activities in, and around, the survey area.

2.3. Contractor and vessel selection

When selecting a contractor and a survey vessel to undertake the Site Survey, the following factors should be considered:

- evaluation of the contractor HSE management systems
- results of recent HSE inspections of tendered vessel(s)
- appropriate accommodation for the required survey crew and operator quality supervisor personnel
- vessel availability to complete the survey work within the required time frame relative to the planned well spud date
- vessel suitability for safe and efficient operations in the proposed survey area.
    - Vessels that can acquire both the single channel and other shallow geophysical data and the HR multi-channel seismic data concurrently in a single pass are generally preferred, over vessels that can only acquire the data in dual pass mode, and that have adequate space for handling of all equipment, including soil sampling equipment (corer, etc.)
- suitability of the contractor proposed survey equipment to meet the objectives of the survey
- maximum length of time between port calls, especially in remote settings
- previous experience of the contractor in the area of operations, and the techniques and equipment required
- vessel accreditation for compliance with regulatory requirements
- whether, or not, the vessel is owned by, or is on long term charter to, the contractor and permanently mobilized with all survey equipment
    - Ad hoc vessels that are mobilized specifically for a Site Survey will usually require a significant period of 'shake-down' and are more likely to be affected by equipment problems than contractor-owned, or long term charter vessels, where the majority of the survey equipment is permanently installed

Here the vessel's operator and survey contractor are different companies (as is common) then a bridging document (for operational and HSE management systems) shall be in place between the marine and survey sides to ensure that both the vessel's crew and the survey crew work safely and effectively together as an integrated team.

More detailed information on survey platforms (including survey vessels) and survey equipment and specifications is given in section 3 below.

2.4. Other data requirements

2.4.1. Metocean data

The acquisition of metocean data is outside the scope of *The Technical Notes*. Acquisition, processing, interpretation and reporting of metocean data should be the responsibility of a metocean specialist employed by the operator. However, the following should be considered when planning a Site Survey.

For efficient survey planning, metocean data for the survey area 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 that are commercially available for many offshore oil provinces. Knowledge and understanding of these data may influence survey timing, survey line orientation and survey specifications.

It is not common practice to acquire metocean data specifically for Site Survey purposes. However, metocean data may need to be acquired for the well/drilling planning process. There may be cost benefits in acquiring such data or deploying/retrieving metocean instrumentation during the Site Survey.

2.4.2. Environmental data

The acquisition of seabed samples, seabed photography and other data for environmental purposes is outside the scope of *The Technical Notes*. Acquisition, analysis, interpretation and reporting of environmental data should be the responsibility of a specialist marine environmental scientist. However, the following should be considered when planning a Site Survey.

Some exploration and production licence conditions will specify that environmental assessment needs to be made before any drilling can take place, this may include identification of habitats like herring spawning grounds, chemosynthetic communities, sabellaria, corals, etc. and it may be necessary to acquire environmental data. There may be cost benefits in acquiring such data during the Site Survey. If this is the case, this must be considered in vessel selection and mobilization of an appropriate spread of sampling equipment.

2.5. Offshore data processing and interpretation

Consideration should be given to preliminary processing and interpretation (at least in part) of the survey data offshore; particularly in remote or geologically complex areas.

This will allow preliminary on-site assessment of any drilling hazards that may require a move of the proposed surface location of the well. It may also reduce and/or preclude the need for time consuming 'data drops'. This work should speed delivery of final results and increase the flexibility of the survey by identifying required changes to the work scope to be made in response to variable or unexpected site conditions, or other changes in survey requirements, prior to the vessel leaving the survey area.

2.6. Integration of results into well design and final operational planning

The processing, interpretation and reporting of the Site Survey data are covered in section 4 of *The Technical Notes*. However, an important aspect of survey planning is the final integration of the results of the Site Survey into the final approval of the well location, the well design, and the planning of the drilling operations.

This procedure should be an interactive and iterative process involving the operator's Site Survey specialist and the end-users of the Site Survey results (e.g. drilling engineer, operations geologist and tow master).

It is the responsibility of the Site Survey specialist, or project manager, to convey the nature and scale of any drilling hazards identified at the site that may impact drilling operations directly to the end users of the information, e.g. the drilling operations team. The survey results should be presented in a consistent manner that is readily understandable to the non-specialist and that requires no specialist geophysical or geological knowledge by the end-user. It is essential that the Site Survey specialist works closely with the end-users to ensure that they have a full appreciation of any drilling hazards that may impact the drilling operations.

3. Survey equipment

3.1. Survey platform

The choice of survey vessel and acquisition platform used for deployment of survey equipment will generally be determined by the water depths, equipment to be deployed and environmental conditions anticipated over the Site Survey area.

3.1.1. Survey vessel

- For a transition zone survey (defined as the zone between 10 m water depth and the shore), a shallow-draft inshore vessel (maybe landing craft type) is recommended.
- In open waters, where water depths are greater than 10 m, a conventional survey vessel is required.

3.1.2. Acquisition platform/equipment deployment

- For a transition zone survey equipment may be over-the-side mounted, shallow towed or deployed on a shallow water (mini) Autonomous Underwater Vehicle (AUV). Shallow water AUVs are a developing technology and both AUV power and payload capacity are factors to be assessed when considering such a platform's appropriateness for transition zone operations.
- For a shallow water survey (defined typically as on the continental shelf and in water depths between 10 m and 500 m), survey equipment and HR multi-channel seismic equipment should preferably be towed from the survey vessel and, where appropriate, be hull-mounted.
- For a survey in water depths >500 m it is recommended that the seabed survey equipment is deployed on a deep-water AUV, or, on a Remotely Operated Vehicle (ROV). Generally, the AUV is preferred to the ROV as it allows a faster and more flexible execution of the survey. HR multi-channel seismic equipment would be towed from the survey vessel.

3.1.3. Survey vessel

The survey vessel should satisfy all regulatory and statutory requirements and conventions. For work in tropical climates, the vessel should be appropriately air-conditioned to provide an efficient working environment. For work in cold climates and high latitudes, the vessel should be appropriately ice-classed.

The vessel should be of adequate size to carry and allow safe launch and recovery of all towed and other survey equipment and to navigate safely in the weather conditions and sea states expected during transit to/from, and throughout operations in the survey area.

The vessel should provide a stable and acoustically quiet platform for the survey operations. The vessel should also possess good manoeuvrability and be capable of operating at a constant and low survey speed of around 4 knots (2 m/s). Such slow speeds are necessary to achieve appropriate shot intervals during 2D HR multi-channel seismic data acquisition. Vessel transit speed to/from and between sites should preferably exceed 10 knots.

In general, the vessel's officers should be experienced in survey line keeping and survey operations. Should the survey vessel be required to work in close proximity to offshore structures and/or installations, the operator's requirements may be for a DP class vessel. In such cases the vessel's officers shall be both appropriately certified for DP operations and experienced in the type of operations planned.

3.1.4. Equipment deployment

3.1.4.1. <10 m water depth

For operational and safety reasons, manned shallow draft vessel surveys should be confined to daylight working only. Data may be acquired using single or dual pass operations with data being downloaded daily to the shore base.

In the case of shallow water AUV based surveys, deployment may be directly from the shore or from a moored host survey vessel. In such cases data download and processing can be undertaken offline ashore or on the host vessel.

Due to vessel sizes in a transition zone environment it may well not be possible to deploy an HR multi-channel seismic spread from the same vessel which may necessitate a dual pass, or dual vessel, operation.

3.1.4.2. 10 – 500 m water depth

Where over-the-side mounted equipment is used, particular attention should be paid to the installation arrangement to ensure its robustness at survey and transit speeds. Preference is for over-the-side mounts that can be pulled out of water to protect them during transit.

Seabed survey and HR multi-channel seismic data may be acquired by single or dual pass, dependent on the total complexity of the suite of data to be recorded.

3.1.4.3. >500 m water depth

Deep water seabed and shallow geophysical surveys should preferably be conducted from a vessel through the deployment of an appropriate AUV that can operate in the required water depths at site. Where appropriate, support vessel requirements should match those stated for shallow water survey vessels.

Deep water surveys may also require acquisition of multi-channel seismic data. Such data will necessarily require a survey vessel to be deployed for such data acquisition. While such equipment should be carried aboard the same vessel with the AUV, the data are normally acquired in a separate pass from the AUV survey or from a different vessel altogether.

Should deep water seabed and shallow geophysical survey data need to be acquired using deep-towed equipment, a second 'tracking' vessel may be required to position the towfish. Such a vessel should be positioned and be able to track and position the towfish using surface and acoustic positioning systems as described in 3.2 below.

3.1.4.4. Operational considerations

Survey equipment and sensors should be subject to in port and in field calibrations and verifications as appropriate (detailed in the individual equipment 3.2 – 3.8, below) and particular attention should be paid to the following operational considerations:

- The effective range and accuracy of acoustic positioning of subsea sensors depends on the signal to noise ratio of the acoustic signal between the vessel mounted transducer and the acoustic transponder on e.g. the towfish. Acoustic noise from e.g. the survey vessels propeller or weather induced sea surface noise will adversely affect range and accuracy.
- The optimal configuration of hull-mounted and over-the-side mounted sensors in order to ensure that data resolution and accuracy meet project objectives.
- The planned acquisition survey line plan to assess the ability of the acquisition spread to handle the anticipated seabed slopes, ocean currents and other operational/acquisition constraints that may be encountered.
- The actual performance of sensor deployments (including winch speeds) for towed sensors, planned offsets and depths (length of deployment cables) and estimates of deployment times at required water depths.

3.1.5. AUV operations

AUV selection will be determined by the water depths in the Site Survey area and by the following:

- vehicle endurance and deck turn-around times
- the possibility, and ease, of beach deployment for transition zone operations
- required payload to satisfy the survey requirements
- availability of suitable 'master' vessel for the operation to include:
    - safety and suitability of the launch and recovery system from the vessel in question
    - means of capture for surfacing AUVs, putting people over the side of the vessel or use of small boats is to be avoided in open sea settings wherever possible
    - planned manning for deck operations, data acquisition quality control and processing
    - associated weather/sea state constraints.

In general, the AUV payload should comprise positioning equipment, collision avoidance sonar(s), multi-frequency side scan sonar, multi-beam echo sounder (MBES) and single channel seismic sub-bottom profiler, still camera and, or, video. Due to their size, some shallow water AUVs may not be capable of carrying such a complete payload.

Where possible, data should be acquired in a single pass and on a 24 hours a day operational basis.

The AUV should be positioned by integrated acoustic and inertial positioning systems (3.2 below).

In deep water, the AUV should be capable of communicating real-time positions and data packages to the host survey vessel to allow real-time monitoring of survey progress and quality control of the acquired data.

Final processed survey equipment positions should be determined on the survey vessel within 12 hours of AUV recovery.

For deep water AUV operations, a system should be provided for real-time monitoring of AUV operational status and of survey data quality (e.g. via an acoustic data link). This should include:

- monitoring of AUV attitude, battery status and other relevant indicators to provide sufficient control for effective operations
- capability to acoustically transmit updates to the survey plan e.g. extra lines down to the AUV, or recall the AUV e.g. due to changes in weather for safe recovery
- transmission of sub-sets of data to the host vessel to verify data logging and quality of data being acquired.

3.1.6. ROV operations

It is not common to use ROVs as a platform for Site Survey data acquisition. More commonly, ROVs are used for visual inspection of the seabed at the time a drilling rig arrives at the proposed drilling location.

If an ROV is considered as a platform for acquiring Site Survey data, it is important to consider the impact of acoustic noise generated by the ROV on the data quality. Such noise can often preclude the use of hydrographic and geophysical survey equipment or make the data unacceptable for use.

Should an ROV be considered for use for Site Survey data acquisition, then the following is recommended:

- The survey vessel should be minimum DP1 Class (preferably DP2 for deep water survey operations).
- The ROV deployment system should allow safe and fast deployment and recovery to/from the required water depth. A cage and tether management system is recommended for deep water operations.
- The ROV should be of sufficient size to carry the survey equipment payload and to provide a stable and acoustically quiet platform for data acquisition, have sufficient power to ensure a constant and adequate survey speed in the expected current conditions and be rated for the maximum water depth in the survey area.
- The umbilical of the ROV must have enough spare capacity to allow sensor integration and operation.

3.2. Positioning

The absolute positions of the survey equipment and sensors must be determined and recorded at all times during a Site Survey. Positioning of the individual sensors will typically be achieved using a combination of surface and subsea positioning systems.

A survey vessel's surface position should be continuously determined by two or more high accuracy augmented Global Navigation Satellite Systems (GNSS) as defined in 5.5.1 of *The Guidelines* and operated in accordance with IOGP 373-19, *The Guidelines for GNSS positioning in the Oil and Gas Industry* (June 2011), downloadable from http://www.iogp.org/Our-library.

The antennae positions observed by these systems should be used to calculate the position of a common reference point (typically the centre of gravity of the survey vessel) by the fixed offset between them and the observed vessel heading. Vessel mounted survey sensors should be positioned similarly using their fixed offsets from the common reference point and the observed vessel heading.

In water depths of greater than 25 m, or where laybacks to the towed survey sensors exceed 50 m, or where sensors are mounted on a ROV, positioning relative to the survey vessel should be by means of a suitable subsea acoustic positioning system, typically an Ultra Short Baseline (USBL) acoustic positioning system.

An AUV should be positioned using an integrated subsea positioning system comprising acoustic positioning, inertial (dead reckoning) navigation system and an acoustic doppler velocity log.

3.2.1. Positioning accuracy requirements

For Site Surveys, the positioning accuracy requirements are primarily determined by:

- the ability to repeat positions with high relative accuracy. This may be the position of a previous seismic or Site Survey or the positions of existing wells, geotechnical boreholes or seabed features (e.g. a wreck)
- the ability to map the position, size and extent of seabed or sub-surface drilling 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 position, line keeping, all sensor positions and the seismic shot point interval.

This typically requires that the vessel, survey equipment and sensors are positioned to the highest practically achievable accuracy.

3.2.2. Surface positioning

Positioning of the survey vessel should be based on augmented GNSS.

The correct use of GNSS positioning is critical to the success of a Site Survey. It is recommended that the GNSS are operated in line with the *Guidelines for GNSS positioning in the oil & gas Industry* issued jointly by IOGP and IMCA. These describe good practice for the use of GNSS in offshore survey and related activities for the oil and gas industry. *The Guidelines* include the recommended statistics and measurement criteria for assessing the quality of GNSS position fixes and for ensuring reliable positioning.

The basic principles of GNSS positioning (error sources, augmentation techniques etc.) are outside the scope of *The Technical Notes*. For in depth descriptions, the reader is referred to the above GNSS Guidelines and to text books covering the subject.

The GNSS observations used to determine the survey vessel position are affected by a number of error sources. The resulting observational errors vary in magnitude from a few millimetres to tens of metres. GNSS augmentation techniques have been developed to eliminate or reduce most of the errors and are broadly divided into relative and absolute categories. In the context of Site Surveys, the most commonly used GNSS augmentation techniques are Differentially Corrected GNSS (DGNSS) and Clock and

Orbit Corrected GNSS (also referred to as SDGNSS or Precise Point Positioning (PPP)). Augmentation signals are typically provided by commercial service providers. It should be noted that different services will yield different positioning accuracies, but both the techniques mentioned above can yield sub-metre positioning accuracy.

3.2.2.1. Considerations for the use of satellite positioning

A number of issues concerning selection, installation and operation of GNSS need to be considered prior to commencing a Site Survey; particularly if the survey equipment is mobilized on a vessel of convenience. The same considerations apply for the many permanently mobilized Site Survey vessels. However, positioning and survey system installation and tests will typically have been carried out when systems were first installed. During project mobilization, documentation of positioning equipment tests, antennae offsets etc., should be checked for validity and accuracy.

The following should be considered:

Geographic operating region

At high latitudes, choice of GNSS may be limited. Working in polar regions presents difficulties due to geomagnetic disturbances which are intensified during periods of increased solar activity. Work areas near the geomagnetic equator could, in periods of increased solar activity, be affected by increased ionospheric disturbance. This may adversely affect both GNSS and augmentation signals.

Level of redundancy

It is recommended that at least two fully independent surface positioning systems are used and that they are selected and configured for redundancy of hardware (including spares), redundancy of augmentation signal delivery links and redundancy of positioning methods.

Level of support

The available level of service and technical support should be considered when selecting a positioning system. Commercial service providers typically offer a dedicated support network, service engineers and system performance monitoring.

Geodetic issues

In most circumstances, the coordinates output from the GNSS need to be transformed to the local geodetic Coordinate Reference System (CRS). It is imperative that the correct coordinate transformation parameters are applied and that the accuracy of these is known.

Once the satellite positioning systems have been installed and configured it should be checked that:

- the satellite positioning systems are operating correctly and to specification
- offsets between GNSS antennae, common reference point and survey equipment and sensors are measured accurately and applied correctly. The offset measurements should be verified annually and before starting a new project. Documentation of original offset measurements and annual and follow-on verifications should be readily available for reference

- coordinate transformation parameters are applied correctly. The coordinate transformation parameters and the transformation computation should be verified before starting a new project. The operator should provide the contractor with a set of test coordinates for transformation to allow a check to be undertaken that the transformation parameters are being applied correctly prior to the start of the survey.

Offsets and transformation parameters should be validated by in-port and in-field verifications against independent control points and by in-field verification against installations/structures with known coordinates during vessel mobilization.

3.2.3. Subsea positioning

Except in shallow water depths of less than 25 m (where it may be impractical or where layback to the towed equipment is less than 50 m), it is recommended that the position of towed sensors is determined by a vessel mounted acoustic positioning system, e.g. an Ultra Short Baseline System (USBL). Other types of acoustic positioning systems exist but they are not considered in *The Technical Notes*.

3.2.3.1. USBL measurement principles and error sources

The USBL positioning technique is based on transmission of an acoustic signal from a vessel mounted transducer (deployed on a retrievable pole through the hull, via a gate valve, or on an over-the-side mount), to a transponder or responder mounted on the towfish, AUV or ROV carrying the survey sensor. USBL systems may also be used to position seabed sampling equipment. The system will include a surface control unit that calculates the position of the transponder or responder relative to the vessel mounted transducer. The absolute position of the sub-surface equipment is then calculated from the relative position determined by USBL and the vessel's absolute position and heading.

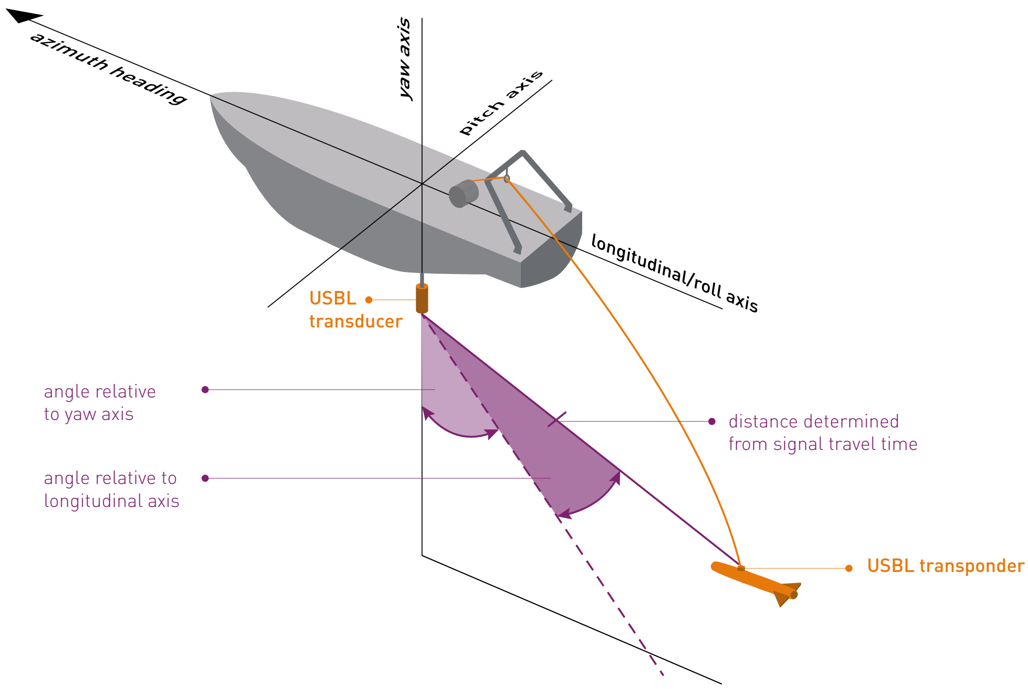


Figure 1: Illustration of USBL Positioning

The relative position of the transponder/responder is calculated from the slant range and vertical angles between the transducer and the transponder/responder (see Figure 1). The slant range is determined by measuring the acoustic signal travel time. The vertical angles are determined by measuring differences in signal phase and arrival time across the transducer head.

In order to determine the slant range from the signal travel time, the velocity of sound in the water column between the transducer and the transponder must be known accurately (3.3 below).

In order to determine the absolute position of the transponder/responder, the absolute position and orientation of the transducer must be known accurately. The position is determined from the vessel's surface position (3.2.2 above), the azimuth is determined by gyro compasses and/or GNSS based heading reference systems (3.2.4 below) and the vertical orientation by a Vertical Reference Unit (VRU) that measures the pitch and roll of the vessel (and of the USBL transducer) relative to the direction of gravity.

The achievable subsea positioning accuracy using USBL is a function of the accuracy of the individual measurements of travel time, horizontal and vertical angles and of any biases caused by misalignment between the axes of the reference frames of the vessel, transducer head, VRU and gyro compass or by bias in the applied velocity of sound. The measurement accuracy is dictated by the system design and is typically available from the manufacturer's technical specifications. The biases should be determined by calibration of the system and corrected for during position calculations. The positioning accuracy is also affected by the signal to noise ratio and sea state. In acoustically noisy environments and in adverse weather conditions the accuracy will decrease. Also, some USBL systems are most accurate immediately below the transducer and have a directional component to the accuracy.

3.2.3.2. Considerations for the Use of USBL Positioning

A number of issues concerning installation and operation of USBL systems need to be considered prior to commencing a Site Survey:

Required positioning accuracy

The subsea positioning accuracy should be commensurate with the positioning tolerances required to meet the survey objectives. When properly calibrated, USBL systems typically provide a relative positioning accuracy of better that 1% of slant range, which is the expectation stated in *The Guidelines* (5.5.1). When water depths exceed 750 m, the slant ranges for towed systems typically may exceed 1,500 m. At these ranges, the absolute accuracy of conventional USBL systems fall to unacceptable levels and many systems can become unreliable. It is recommended that seabed survey sensors and equipment are deployed on an AUV in water depths greater than 750 metres (3.1.1 above). Alternatively, towed sensors in deep water may need to be positioned by a second vessel carrying the USBL system and following the survey vessel to track, and observe, the towfish position (3.1.3 above). This, however, now is not a commonly used practice.

Level of redundancy

It is important to note that there will rarely be any redundancy of USBL systems on a survey vessel. It is, therefore, important that adequate spares are carried.

Calibration

The USBL system must be carefully calibrated as described below (3.2.3.3).

Quality control

As the USBL observations have no redundancy, it is imperative that system performance is validated in the field and that the data quality is monitored in real time during data acquisition to ensure that the system is performing within specifications and that observations are not adversely affected by acoustic noise and/or uncorrected biases.

3.2.3.3. USBL calibration

When the USBL transducer is installed, its alignment relative to the reference frame of the survey vessel must be determined by conventional land survey methods[1]. For through hull mounted systems, this is carried out when the system is first installed on the vessel, and then only repeated if the installation is changed. The location of the USBL transducer relative to the vessel reference system may be entered into an Erasable Programmable Read Only Memory (EPROM) in the USBL surface control unit or as a parameter in the online integrated positioning system. Documentation should be retained on the vessel and should be available for checking during subsequent survey mobilizations.

Prior to the USBL calibration, the alignment of the vessel heading reference system should be checked (3.2.4 below). Further, the velocity of sound in the water column at the calibration site should be observed (3.3 below).

The USBL calibration should take place at water depths similar to those expected in the survey area. Several methods exist, all involving deployment of an acoustic transponder, typically on a degradable weight with a floatation collar, and an acoustic release for easy recovery. The following method is recommended.

The vessel should be stationed sequentially over the transponder and at the four cardinal points at a distance of approximately 1.5 × water depth from the transponder, whilst maintaining a constant heading. Data is continuously recorded from the surface and USBL positioning systems and the vessel heading reference system. In water depths exceeding 750 m, it is recommended that the process is repeated on the reciprocal vessel heading. The recorded data is then processed to determine any biases of the: slant range (scale), horizontal, and vertical angle measurements. Such biases are corrected for in real time by applying corrections to the observations from the gyro compass/GNSS heading sensor and VRU.

Prior to commencing data acquisition for a Site Survey, it is recommended that the correct calibration and system performance is validated by an in-field verification of the USBL system. This is done by the 'box-in' of a prominent seabed feature with known coordinates using side scan sonar. Alternatively, it can be performed by observing on reciprocal vessel headings the position of an acoustic transponder on a point on the seabed with known coordinates e.g. a well head. Another method is to observe any prominent seabed feature using side scan sonar run on lines acquired on reciprocal headings and comparing the two positions. Agreement between known and observed coordinates should be within the specified accuracy of the USBL system.

[1] The vessel reference frame is defined as a 3 dimensional Cartesian coordinate system whose origin coincides with the centre of gravity of the vessel. The X-axis is aligned with the longitudinal centre line of the vessel, positive forward, and the Y-axis perpendicular to the X-axis, or across the vessel, positive to port. The Z-axis is perpendicular to both X- and Y-axes i.e., vertical, with positive upwards.

3.2.4. Vessel heading

In order to determine the position of individual survey equipment and sensors from the observed GNSS antennae position, the offsets and heading from the antennae to the sensors must be known. The vessel heading is measured by a gyro compass and/or a GNSS based heading reference system. It is recommended that two independent heading sensors are used.

3.2.4.1. Gyro compass

For technical details and functionality of gyro compasses, reference should be made to available text book material.

For Site Surveys, it is recommended that 'survey grade' gyro compasses are used. These have a higher accuracy than vessel navigation gyro compasses. The dynamic accuracy of survey gyro compasses is typically better than 0.5 – 0.7°; this varies with the secant of latitude. It is important to note that when using gyro compasses for heading reference purposes, the inherent latency will cause the accuracy of the heading observations to decrease immediately after sharp vessel turns; for example the turns between survey lines. For offset points on the vessel, the effect on positioning accuracy will typically be insignificant, but for laybacks of 200 m and more to towed sensors, the heading accuracy will have a significant effect on the cross track positioning accuracy of the towed sensors.

3.2.4.2. 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 accuracy is typically better than 0.2° (1σ).

The main advantage of GNSS based systems over gyro compasses, is that the dynamic accuracy is equal to the static accuracy and that observations are not affected by the movements/turning of the survey vessel.

For work in water depths exceeding 300 m, it is recommended that a GNSS based system is used as the primary heading reference.

3.2.4.3. Alignment

During mobilization of a survey vessel for a Site Survey, the alignment of the gyro compasses and/or the GNSS heading reference systems relative to the centre line of the vessel (the X-axis of the vessel reference frame) must be determined.

This is typically performed 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 should be conducted on reciprocal vessel headings to ensure that any inaccuracy in the set out of the centre line of the vessel is eliminated and does not adversely affect the results of the alignment check. 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.

3.2.5. Inertial navigation system

The position of an AUV and the survey equipment and sensors mounted on it, is determined by an integrated solution of surface and subsea positioning systems combined with an Inertial Navigation System (INS) and an acoustic doppler velocity log.

Inertial navigation systems use 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 without the need for an external reference. From an initial known starting position, an AUV can thus calculate its own position and velocity based on dead reckoning by integrating the observations from the motion sensors.

The INS needs to be initialized with input of position and velocity from another source; typically a GNSS receiver while on the surface. Once initialized, the system needs no external input or references to operate.

However, as the INS motion sensors are subject to drift, the systems need to receive external correction, or be re-initialized, at regular intervals to ensure that the positioning accuracy remains within required accuracies.

The typical external reference for an AUV is GNSS on the surface. While the AUV is submerged, however, it may receive external corrections from a ship based USBL tracking system or a seabed based [sparse] LBL acoustic system. In addition, most survey AUVs are fitted with an acoustic doppler velocity log that accurately measures the speed over the ground. All these inputs are included into the integrated position calculation routine.

3.2.6. Source/receiver positioning and depth control for HR multi-channel seismic acquisition

Accurate and reliable positioning and depth control of seismic sources and streamers used for HR multi-channel seismic data acquisition is critical to ensure appropriate system performance, that data meets the Site Survey requirements, and that the data can be processed and interpreted to identify all potential drilling hazards.

3.2.6.1. Positioning

In shallow or shelf waters, due to the relatively short offsets (typically in the order of a few tens of metres, the near trace offset generally being less than: water depth / 2) from the vessel to the source and between the source and the near trace of the streamer, the source and receiver positions are normally determined from layback and course made good measurements. The layback is determined by tape measuring the length of source/streamer tow bridles/lead in section. This should be done to an accuracy of better than 1 m. The course made good is calculated from the vessel antenna position.

The streamer feather should be continuously monitored. It is recommended that the feather angle should not exceed 7°. For 2D HR multi-channel seismic using seismic streamers up to 600 m in length, this may be done using the survey vessel radar and a radar reflector on the steamer tail buoy. For longer streamers it is recommended that an active tail buoy, fitted with a GNSS receiver, is used.

For 3D HR multi-channel seismic acquisition active positioning of the source, streamer head, and tail buoys are needed, together with streamer compasses, in order to ensure that all receivers can be accurately positioned, that the data coverage and quality of the binning can be monitored during data acquisition, and that data can be processed to the highest accuracy.

3.2.6.2. Depth

Accurate control of towing depth of both source and streamer is important as it impacts the free surface ghost notch on the frequency bandwidth of the outgoing signals (source depth) and recorded signals (streamer depth). Towed too deep and higher frequency data content will be lost. Towed too shallow and the systems will be more weather dependent.

Streamer depth should be controlled and monitored by conventional streamer depth controllers ('birds') and calibrated depth sensors. It is recommended that these are fitted at interleaved intervals of 100 m over the active length of the streamer, providing an effective spacing of 50 m.

The source depth is controlled by the length of the chains which connect the source to its flotation buoy(s). This should be measured to an accuracy of better than 0.1 m.

3.2.7. Position data processing

The positions of the vessel(s) and all survey sensors, whether mounted on the vessel or deployed in the sea, should be calculated and displayed in real time for navigation and QC purposes. Summaries of line keeping and positioning quality parameters should be available for each survey line to ensure that the survey positioning specification requirements are met and to identify any lines that are out of tolerance.

On completion of a survey line or at other regular intervals, positioning data should be post-processed to remove any spurious data and excessive measurement noise that may affect observations and the calculation of accurate and reliable positions of survey equipment end sensors. This typically includes filtering and smoothing. It is important that such processing is fully documented and that copies of the raw unprocessed data are kept for reference.

3.2.8. Position data deliverables

Raw and processed source and, if applicable, receiver position data should be delivered with the final Site Survey report in an agreed electronic data exchange format. It is recommended to use the IOGP P2/11 and P1/11 formats for exchange of raw and processed seismic position data respectively. These common industry data exchange formats are maintained by the IOGP and although the formats are primarily intended for exchange of raw and processed seismic source and receiver positions they also enable exchange of data from survey equipment and sensors. (IOGP Reports: 483-1, 483-1u, 483-2, 483-6 and 483-6G can be downloaded from http://www.iogp.org/Our-library.

It should be noted that the former UKOOA seismic position data exchange formats P2/94 and P1/90 that the IOGP formats have replaced are still being used by some survey contractors and that their data acquisition and processing software may not yet support the newer IOGP formats. The former UKOOA formats only support the exchange of seismic position data, they do no not allow exchange of data from survey equipment and sensors.

3.3. Sound velocity in seawater

For the correct performance of acoustic positioning systems (3.2.3 above) echo sounders (3.4 below) the velocity of sound in seawater must be known through the entire water column.

This should be observed either by a direct reading sound velocity probe or by a Conductivity Temperature and Depth (CTD) probe. The sound velocity probe will give the velocity as a direct readout whereas the data observed by a CTD probe is used to calculate the sound velocity from empirical formulae. Several formulae exist for different water depths and conditions and yield different accuracies; the most commonly used is the so-called UNESCO, or Chen and Millero, equation.

The sound velocity should be measured at regular intervals (typically every 1 – 5 m) down through the water column. The probe is typically deployed on a wire from a winch and systems log values automatically as they are lowered through the water column. Resultant values are then entered directly into the USBL surface and/or echo sounder control units.

Profiles should be measured and updated at regular intervals, and should always be repeated after any weather enforced breaks in survey activities. For large survey areas profiles may have to be measured at different locations to obtain representative values across the whole survey area.

The velocity probe should be calibrated annually and documented with a calibration certificate. As sound velocity measurements are critical to both USBL positioning and echo sounding it is recommended that redundancy is ensured by carrying at least two calibrated probes.

Individual sound velocity profiles as observed by velocity or CTD probes may not represent the sound velocity sufficiently accurate over a larger survey area to meet project requirements. Velocimeters may be deployed to make continuous direct velocity measurements at the transducer head in real time during the survey. This is especially common for AUV mounted systems.

3.4. Echo sounders

The seabed bathymetry of a Site Survey area should be observed by multi and single beam echo sounders. Selecting the appropriate echo sounding equipment and operating parameters, for the environmental conditions, and the objectives of the Site Survey should be carefully considered during survey planning.

3.4.1. Basic principles

The basic echo sounding technique to measure water depth is based on transmission of a timed acoustic signal or pulse from a transmitting transducer typically mounted on the survey vessel through, or on, the hull, or an 'over-the-side' mounting.

It is not recommended to mount any echo sounding system on a towed survey vehicle even if it is integrated with a high resolution motion reference system.

The signal is reflected by the seabed and received by a receiving transducer (usually the same transducer is used for transmitting and receiving). The observed two-way signal travel time is used to calculate the distance between the transducer and the seabed, known as the 'sounding'. For the resulting output depth value to be accurate the signal propagation velocity, or the velocity of sound in water, must be known accurately (3.3).

Echo sounder transducers typically operate in the frequency range 10 kHz to 700 kHz. Range increases and resolution decreases with decreasing frequency.

The overall accuracy of the final processed echo sounder dataset is a function of:

- the absolute accuracy of the raw observation
- the accuracy of the corrections applied to the soundings to compensate for systematic biases that affect the data
- the positional accuracy of the echo sounder transducer
- correct application of post processing techniques.

Echo sounding accuracy is primarily dictated by the resolution and beam width of the transducer, which defines an insonified area on the seabed, or 'footprint', from where energy is reflected. It is generally desirable to minimize this area by use of as narrow a system beam width as possible in order to maximize resolution and thereby the accuracy of the soundings. Resolution is described further in 3.4.3 below.

In order to determine the absolute water depth from echo sounder measurements, the draught of the transducer (depth below sea surface) and the velocity of sound in the water column must be accurately determined. Echo sounder measurements also need to be corrected for the effects of vessel heave (vertical vessel movement), heading, pitch and roll, as well as for changes in tidal level to reference the individual soundings to a common vertical datum e.g. Mean Sea Level (MSL) or Lowest Astronomical Tide (LAT).

There are two main types of survey echo sounder used in Site Surveys: Single Beam Echo Sounders (SBES) and Multi-Beam Echo Sounders (MBES), also referred to as swathe bathymetry systems.

With single beam echo sounders water depth is measured along the track of the survey vessel. Data density along line will be very high but to obtain high data density across an area, multiple, closely spaced, survey lines will be required.

Multi-beam echo sounders transmit a single acoustic signal with a very narrow beam width along track but with a very wide beam width across track. The reflected signal is received by an array of receivers. Using beam forming signal processing techniques, a large number of acoustic receive beams are formed that are of narrow width both along *and* across track. For each received beam the signal travel time is converted into a range to a defined small area of seabed. By measuring the heading and attitude of the MBES transducer accurately, geometrical corrections can be applied to convert the slant ranges into water depths, and to determine the position of these depths on the seabed. For each survey line, therefore, the MBES covers a wide swathe of the seabed with a high sounding density both along and across track. Dense areal coverage can be achieved with far fewer survey lines than using SBES systems.

Interferometric MBES systems sample the reflected signal hundreds, or even thousands of times, for each transmission. For each sample the phase difference of the reflected signal arriving at two (or more) receivers is measured and used to compute the angle of arrival of the return signal. The signal travel time is then measured, converted into a range, and corrections are applied to convert the arrival angles and ranges to determine the position of the resultant soundings across the seabed.

For Site Surveys MBES should be used, especially when dense echo sounder coverage of the seabed is required, e.g. to investigate complex seabed morphologies.

Many MBES systems also allow the recording of backscatter data, which is the intensity of the acoustic energy reflected from the seabed. As the intensity is a function of the physical properties of the seabed from the point of reflection (acoustic impedance, roughness and volume variability in the layer of sediment impacted by the acoustic signal), the backscatter data can be used to characterize the seabed and to assist in seabed classification. Capability is now available to invert backscatter data to remove angular dependence of the backscatter values and produce maps of acoustic impedance, which enables direct classification of seabed sediments.

A few of the current generation of MBES systems also allow the recording of backscatter data from the water column. This information has been used for fish-finding sonars for some time, but potential application from MBES data now include monitoring of sediment plumes, the detection of gas seeps and monitoring of oceanographic features such as thermoclines.

While use of the backscatter data for seabed sediments classification and for observations of events in the water column are emerging techniques, their use are becoming more common in Site Surveys.

3.4.2. System characteristics

A wide variety of SBES and MBES systems are available, many of which are suitable for Site Surveys. Systems are characterized by operating frequency and beam width, system choice will depend upon water depth, seabed conditions, required data density (in-line and cross-line) and the objectives of the survey.

Water depth will influence the selection of the survey platform required to deploy the echo-sounding system, acquisition of high resolution high density data in deep water will require the echo sounder to be deployed on an AUV (or ROV) close to the seabed whereas in shallow water the echo sounder will be mounted on the survey vessel close to the sea surface.

Water depth range	<25 m	25 to 150 m	150 to 750 m	>750 m
Recommended frequency	120 – 710 kHz	38 – 200 kHz	12 – 38 kHz	12 kHz
Typical beam width (3db points)	10° (120 kHz) 2.8° (710 kHz)	9° (38 kHz) 7° (200 kHz)	9° (38 kHz) 20° (12 kHz)	20°
Pulse length	User selected	0.3 – 1.3 ms	>4 ms	0.3 – 1.3 ms
Max sounding rate	20 Hz	20 Hz	20 Hz	20 Hz

Information is based upon manufacturer's data.

Table 1: **Basic characteristics of single beam echo sounders commonly used for Site Surveys**

Water depth range	<25 m	25 to 150 m	150 to 750 m	>750 m
Recommended frequency	300 – 500 kHz	100 – 500 kHz	10 – 100 kHz	30 kHz
Recommended maximum angular coverage	160° (12 × water depth)	150° (8 × water depth)	132° (5 × water depth)	132° (5 × water depth)
Number of beams	Up to 250	Up to 250	Up to 100	Up to 250
Max sounding rate	40 Hz	40 Hz	10 Hz	10 Hz
Information is based upon manufacturer's data.				

Table 2: **Basic characteristics of multi-beam echo sounders commonly used for Site Surveys**

Both Tables 1 and 2, above, refer to the 'deployment' altitude relative to seabed rather than absolute water depth. For example, AUV or ROV borne echo-sounding systems in greater than 750 m water depth will not use 12 or 30 kHz systems but high resolution systems operating at 200 kHz or higher.

3.4.3. Resolution

Resolution of echo sounding systems is controlled by the transducer frequency, the beam width, the pulse repetition rate, the signature and length of the acoustic signal, the water depth, and vessel speed over ground.

The choice of transducer frequency is typically dictated by the required range. For deep water locations low frequency transducers will be needed in order to obtain the required range. These systems will have a lower resolution than high frequency transducers used in shallow water.

For MBES systems, the incident angle also affects the size of the footprint, the outer beams will have larger footprints and lower resolution across track than the centre beams.

Data for transducer beam widths are quoted by manufacturers but should be treated with caution, since the criteria for which they are measured may not be provided. The beam width is usually defined by the –3 dB points of the acoustic signal, which is the insonified area at a particular distance from the transducer within which the energy level of the signal (as opposed to the power output) is about 70% of the maximum. Figure 2 shows the diameter of the insonified area in metres for various beam widths and distances between transducer and seabed or water depths. For example, using a hull mounted echo sounder with a beam width of 2 degrees in a water depth of 100 m, the detected water depth will be the shallowest point within an area of 3.5 m diameter.

SBES transducers typically transmit beam widths of between 8 and 20 degrees whilst the individual receive beams of MBES transducers typically are between 0.5 and 2 degrees.

The along track density of echo soundings is determined by the pulse repetition rate. This in turn depends upon the transducer operating frequency, the water depth and, in the case of MBES systems, the opening angle, or the cross track angle within which the beams are defined. In shallow water settings more soundings can be recorded per unit distance of survey line than in deep water, as there is sufficient time between successive pulses for the seabed return to be received. Table 3 shows the along track sampling interval in m for various ranges and pulse repetition rates, assuming a vessel speed of 4 knots (2 m/s).

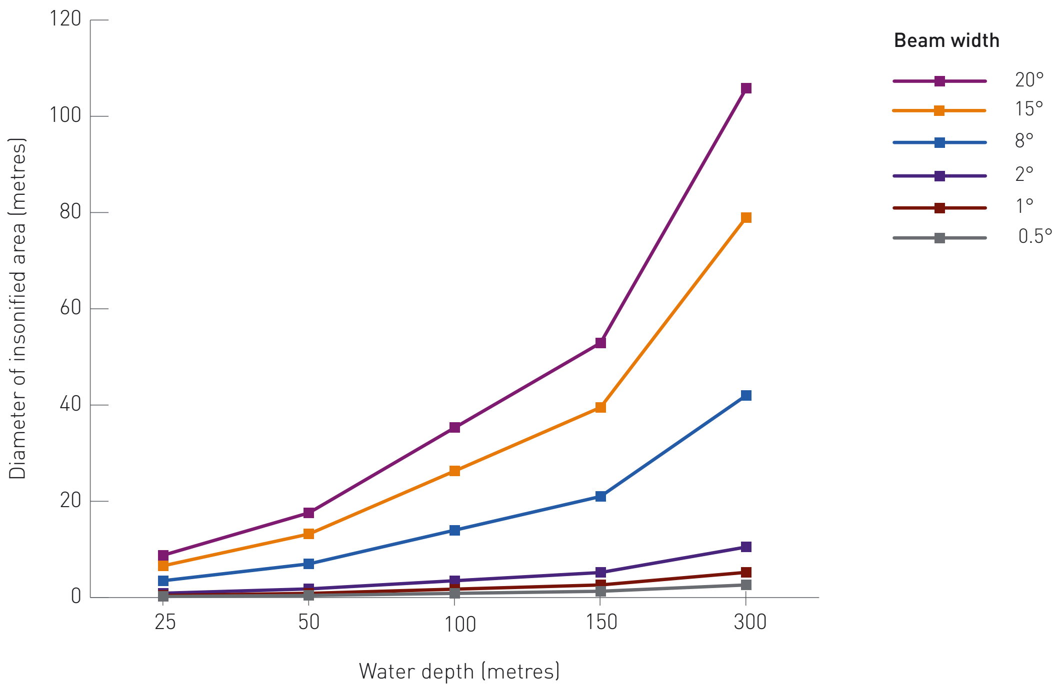


Figure 2: **Area insonified by different echo sounder transducer beam widths at different distances between transducer and seabed**

Water depth	Repetition rate	Along track sampling interval
75 m	10 Hz	0.2 m
150 m	5 Hz	0.4 m
300 m	2.5 Hz	0.8 m
1500 m	0.5 Hz	4.0 m

Table 3: **Along track echo sounder sampling interval for various ranges and pulse repetition rates for a vessel speed of 4 knots (approx. 2 m/s).**

Some MBES systems transmit multiple pulses that have overlapping travel times in the water column, thereby effectively decreasing the sampling interval beyond the limits shown in Table 3. The systems do this using a technique known as 'pitch steering' of the transmission pulses that takes the vessel motion into account and allows adjacent swaths to be recorded sequentially.

Resolution will also be affected by the characteristics of the transmitted pulse. A short sharp pulse will enable higher resolution than a longer less constrained pulse.

Footprint and repetition rate will limit the size and detectability of seabed features that can be mapped by echo sounders. This should be carefully considered when specifying and selecting a system for any particular application.

3.4.4. Range

The maximum range at which an echo sounder can operate is controlled by the frequency of operation, signal level, and signal to noise ratio. High level low frequency signals are required for deep water operations where hull mounted transducers are being used. Range may be restricted with vessels that are acoustically noisy and in marginal weather, due to aeration under the hull, as these factors may significantly reduce the signal-to-noise ratio.

Range	SBES frequency	MBES frequency
<25 m	210 kHz	250 – 400 kHz
25 – 150 m	210 and 38 kHz	150 – 300 kHz
150 – 750 m	38 and 12 kHz	80 – 200 kHz
>750 m	12 kHz	30 – 100 kHz

Table 4: Typical ranges of echo sounders as a function of transducer frequency.

The transducer frequency needs to be selected to ensure a range larger than the maximum water depth that is to be recorded. Many MBES systems employ transducers with selectable frequencies to allow the optimization of operating frequency with varying water depths.

3.4.5. Heave, attitude and position

Echo sounder data will be affected by the vertical movement (heave) and the attitude (pitch and roll) of the transducer. In order to correct or compensate the soundings for these effects, a high accuracy Motion Reference Unit (MRU) needs to be used.

In order to use the soundings for mapping their horizontal position must be known accurately. The position of the echo sounder transducer must be determined, typically by knowing its accurate position relative to the vessel common reference point (3.2 above), and the attitude data must be applied to compensate and correct the soundings for vessel movement.

For MBES systems, the heading (azimuth) of the transducer must also be accurately established using gyro compasses and, or, a GNSS based heading reference system (3.2.4 above).

3.4.6. System calibration

3.4.6.1. Sound velocity

The velocity of sound through the water column should be measured at representative locations across the survey area (3.3 above). Velocity should be measured prior to the start of any calibrations or system verifications and thereafter at regular intervals over the duration of the survey – in particular after any breaks in survey operations, e.g. after a period of weather standby.

Velocity values should be entered into the echo sounder control unit. Some echo sounders will only accept a mean water column velocity, while others will accept an entire velocity profile, and will be able to compensate for errors in the soundings caused by the velocity variation through the water column. Flat array transducers require real-time sound velocity measurements at the transducer face for use in the beam forming process.

3.4.6.2. SBES calibration

Calibration of SBES system should be undertaken for index error, transducer draught and the velocity of sound through the water column.

Index error is the term used for any systematic delays within the transducer elements and the receiver electronics.

Index error and transducer draught should be determined by a 'Bar Check' where a bar is lowered to a known, measured, distance beneath the echo sounder transducer, although this is often impractical on larger vessels.

Transducer draught must be known as accurately as possible at all times. The vertical distance between reference marks at the vessel's waterline and the transducer should be measured in dry dock during system installation. The draught of the transducer can then be calculated by taking into account the observed draught of the vessel; this will vary depending on how the vessel is loaded, density of surrounding seawater, and the vessel's speed through the water. Changes in the vessel's draught during a survey should be monitored by measuring any change in the height of reference marks above the sea surface.

3.4.6.3. MBES calibration

Transducer draught should be established in the same way as single beam echo sounders (described above).

It is critical that the position of the MRU relative to the transducer and the vessel's common reference position is known accurately. For large vessels the MRU should be located as close to the centre of gravity of the vessel as possible. For smaller vessels it may be of great benefit if the MRU is located close to the MBES transducer - preferably directly above it, especially if the MBES is mounted on an over-side mount.

The installation of MBES and MRU systems is a specialist subject and it is recommended that experienced advice is obtained in all cases, for both permanent and temporary installations.

MBES systems require a full system calibration prior to use. Calibration routines are designed to check for transducer draught, velocity of sound, any misalignment or offset between the axes of the reference systems of the heading sensors, the MRU, and the echo sounder transducer, and to determine any latency in the data recording system. This is done by acquiring a series of recordings over a flat and sloping sea bed, or over a flat seabed with a prominent seabed feature that is easy to distinguish.

For a detailed description the MBES calibration see IMCA S 003 Rev. 2, *Guidelines for The Use of Multibeam Echosounders for Offshore Surveys* (International Marine Contractors Association, 2015).

3.4.7. Data recording

Systems should be set to record data at the optimum sampling frequency for the water depth and survey vessel speed for the water depth in which the survey is being performed and to meet required along-line sounding density (3.4.3 above).

Environmental factors and acoustic noise levels from the survey platform (e.g. vessel and ROV) may cause a degree of noise in logged soundings. The level of noise will tend to vary with sea condition, vessel heading, vessel speed, transducer mounting (e.g. hull and over side pole), marine life and, possibly, interference from other acoustic survey sensors – any overlap in operating spectra of different survey sensors must be carefully considered during the planning phase.

Observation of 'water-fall' quality control displays, either paper or on screen, are useful in observing potential interference or progressive degradation in recorded data quality in, for example, marginal weather conditions.

All multibeam echo sounder data are recorded digitally.

Single beam echo sounder data should also always be recorded digitally with motion compensation applied to the recorded values. Although rare, data may be recorded on paper as well for quality control purposes, or as a back-up in case of digital logging failure.

Multibeam echo sounders produce very large datasets, and it is recommended that these data are backed up in real or near real time to prevent loss of data and thereby operational time.

The main dataset is the seabed return from which the water depth is calculated during processing; if required, e.g. for seabed classification purposes and enabled by the system, backscatter data (3.4.1 above) should also be recorded.

Raw uncorrected echo sounder data and the observed pitch, roll and heave data should also be recorded so that on line corrections can be analysed and if necessary re-applied in post processing. All data required in determining the position of the echo sounder transducer and to correct the echo sounder data for transducer draught, sound velocity in the water column and tidal level should also be recorded.

3.4.8. Quality control

During data acquisition the quality control of echo sounder data should be carried out in a systematic way to ensure that the equipment operates within specifications, and that the data meets the project specific requirements (e.g. coverage and density).

An online quality control system must be able to:

- function with the MBES and its peripheral systems
- perform residual bias tests and other software calibration routines
- provide real-time output sufficient to successfully maintain the system and ensure that specifications are met
- log data with suitable flags to allow the use and review of this data during offline processing
- provide an online display of coverage and data density.

Data acquisition should be planned with adequate cross lines to allow verification that calibration values are being applied correctly.

For MBES surveys it is recommended to always operate a single beam echo sounder concurrently for QC purposes. A minimum overlap of 100% between the swathe coverage from adjacent MBES lines is recommended to ensure complete data coverage and to allow the editing of the data from the outer beams that may be degraded by the longer signal travel distance, the larger propagation angle and the low angle of reflection.

For MBES surveys special care should be given to ensuring that calibration values and vessel, or platform, motion corrections are applied correctly, and that the data do not contain residual errors from biases that have not been fully corrected. A check should also be made that the logging frequency of the MRU is appropriately matched to the vessel motion, e.g. high frequency for small vessels.

3.4.9. Data processing and presentation

3.4.9.1. Tidal reduction

The required accuracy of the bathymetry data will dictate the type, or source, of tidal level data used to reduce the soundings to the required vertical datum.

During planning the required accuracy of the tidal level data should be considered and a suitable source selected: observed, predicted or modelled. For engineering surveys and other surveys where accurate water depths values are required, use of observed tidal level is recommended over predicted values.

There are a number of possible sources for observed tidal level data, for example a tide gauge installed on a production platform, or a seabed tide gauge deployed in the survey area over the duration of the survey. The most accurate tidal level data can be obtained from tide gauges that have been tied to a vertical datum through observations over a longer period of time.

Observed tidal level data can also be obtained in real time using GNSS techniques. It is a technique of increasing maturity and application on Site Surveys is becoming more common.

In many survey applications, it is common practice to use predicted tidal levels based on tide tables and co-tidal charts. However, if there are concerns of the inadequacy of such data, either because they have been previously shown to be inaccurate, or do not meet the needs of the survey, then observed tidal levels should be used.

It is also common practice to use tidal level data derived from tidal models based on satellite altimetry.

Prior to the start of the survey care should be taken to specify the required vertical datum to which soundings are to be reduced (e.g. LAT and MSL) and the means by which reduction is to be achieved.

3.4.9.2. SBES

For SBES data the conversion of travel time to water depth, and the application of vessel motion data is performed online in real-time. Post-processing is primarily concerned with merging positional data so that the recorded water depths are correctly positioned, and reduction of soundings to the required output vertical datum.

3.4.9.3. MBES

The post-processing of MBES data is more complex, although most systems will provide a basic preliminary processed dataset in real-time for QC purposes.

The signal travel times for each beam, combined with the starting angle, are used in conjunction with the water velocity to ray-trace the path of each beam from the transducer to the seafloor. Vessel motion data and tide and draught corrections are then applied to give an accurately positioned water depth for each beam.

A typical MBES data processing flow will be as follows:

- process positioning data to determine absolute position of echo sounder transducer
- refraction correction (ray-tracing)
- merge MBES data with processed positioning data and vessel motion data
- apply tide and draught corrections
- remove MBES spurious data and outliers
- process backscatter
- output final deliverables.

The processed MBES data will be a set of closely spaced but arbitrarily distributed individual water depth points or soundings. To enable improved visualization and presentation, and to enable integration with other products of the survey, data is typically binned or gridded and output in a regular square grid to produce a Digital Terrain Model (DTM) or Digital Elevation Model (DEM).

Gridding and binning techniques and QC are beyond the scope of this report. However, the required output DTM grid cell size and, hence, the spatial resolution of the final dataset should be considered during survey planning with due attention to the choice of acquisition system and parameters. The choice of DTM cell size should meet both the survey objectives and honour the source data, and it will depend on the size of the footprint of each beam and on the positioning accuracy. The quality of a high resolution dataset can be wasted if the output DTM cell size is too coarse – decimating the possible resolution and losing seafloor detail. Conversely, if the output cell size is too fine relative to the resolution of the acquired dataset it may result in noise in the output DTM (due to an inadequate number of beam hits per bin) or an incorrect presentation of seafloor morphology.

3.4.9.4. Deliverables

Raw and processed echo sounder data, as well as motion and heading data, should be delivered in agreed formats. There is no accepted industry standard but the IOGP P11-formats may be used; alternatively suitable ASCII formats may be agreed.

Processed MBES data should be delivered in ASCII XYZ format as well as a gridded DTM. A number of dedicated DTM file formats exist and the DTM may also be delivered in raster format. The choice of format may depend on the GIS and other geoscience applications to be used in subsequent data analysis.

Contour and image products should be presented as bathymetry charts within the final report and in GIS format, e.g. in compliance with the IOGP SSDM GIS data model for seabed survey data.

3.5. Side scan sonar

3.5.1. Basic principles

Side scan sonar provides an oblique acoustic image of the seafloor. By repeated insonification of adjacent swaths of seabed, and recording the amplitude of the back-scattered return signals as a function of time (range), an image of the seabed is developed.

Interpretation of these data allow mapping of seabed features such as (dependent on the resolution), but not limited to, surface geology and processes, geomorphology, natural and man-made obstructions and debris considered to be significant to the emplacement of a mobile drilling rig and the planned drilling operations.

The basic operating principle of side scan sonar is to transmit high frequency sound pulses from transducers mounted either side of a towfish or other suitable vehicle, such as an ROV or AUV. The transmitted pulses are composed of horizontally narrow, but vertically broad, beams at a slightly depressed angle relative to sea level. The narrow beam width is required for achieving a sharp image of the seabed and rejecting noise from extraneous sources. The distance travelled from the transducers to the seabed is termed the 'slant range' and should not be confused with the true horizontal distance from the nadir of the side scan sonar to the insonified target area.

The returned signal strength is dependent on the hardness and roughness of the reflecting surface and its proximity to the perpendicular, relative to the propagating source. The harder, or more perpendicular, the reflecting surface is relative to the incoming beam, the stronger the return.

Side scan sonars are available as analogue and digital systems. However, digital systems are preferred for Site Survey purposes because of improved data quality, increased swathe width and, in many cases, increased survey speed capability. Digital systems also allow for more advanced signal processing and data mapping capabilities.

3.5.1.1. Analogue side scan sonar systems

These systems record raw data at a typical dynamic range of ~130 dB, which is then sampled at 8-bit to view on a VDU or as hard copy records. Much of the information held within the returned signal is lost in this data visualization process.

3.5.1.2. Digital side scan sonar systems

These systems record raw data in 24-bit (~144 dB), which allows greater flexibility in data processing and presentation. Digital systems are recommended because of the improved along track resolution at greater survey speeds, through the use of multiple focused beams.

It is recommended that all side scan sonar data be recorded digitally in order allow signal processing, to produce side scan sonar mosaics and to perform on-screen interpretation. The digital data may be supplemented by hard copy records in some situations, such as for emergency back-up or quality control purposes.

3.5.2. Operational considerations

The quality of side scan sonar data depends on a number of factors, but the main survey parameters required to achieve reliable quality are:

- Survey speed should be constant.
- Side scan sonar frequency for obstruction identification should be no less than 100 kHz using narrow beam transducers. Sound frequencies used in side scan sonar usually range from nominally 100 to 500 kHz. Higher frequencies yield better resolution but less range.
- Dual frequency systems allow for the frequency to be switched as and when required or for two frequencies to be recorded simultaneously.
- Side scan sonar range for obstruction identification should not exceed 200 m for standard nominal 100 kHz systems. The maximum range selected for nominal 500 kHz systems should not exceed 100 m. More resolution can be achieved by a reduction in range but this may require a reduction in survey line separation to ensure full side scan sonar coverage.
- Side scan sonar height above seabed is recommended to be between 10 and 15% of the selected range. It should not be less than 5% or greater than 20%.
- Deployment. Side scan sonars can be deployed/mounted on multiple platforms (e.g. hull-mounted, towed, ROTV, ROV and AUV mounted).

Side scan sonars are characterized by their frequency of operation, horizontal and vertical beam widths, pulse lengths and pulse repetition rates. These factors will control the resolution and range of the side scan sonar system and are discussed in more detail in the following sections.

3.5.3. Resolution

Resolution of a side scan sonar system is primarily controlled by pulse length, pulse repetition rate, sound velocity in sea water and beam width. Also of great importance is the side scan sonar height above seabed and the selected operating range. Positioning of the side scan sonar is also critically important to ensure that the data is accurately positioned and that features interpreted from the side scan sonar data can be mapped in their correct positions on the seabed.

When recording side scan sonar data on hard copy records, the resolution limitations of the display media are usually greater than those of the side scan sonar system and the theoretical resolution values discussed below are academic. However, the ability to record side scan sonar data in a digital format allows for full recorded resolution to be preserved within the data and can be further enhanced in post-processing to fully optimize the imagery.

Side scan sonar fish movements will degrade the theoretical resolution. It is therefore essential that the side scan sonar sensors are deployed on a streamlined and stable platform designed to minimize the adverse effects on the data of survey platform heave, yaw, pitch and roll. This is one of the advantages of AUV and ROTV deployed sonar systems in that motion effects are lessened compared to e.g. towfish deployment.

Resolution can be sub divided into transverse (cross track) and axial (along track) resolution.

3.5.3.1. Transverse (cross track) resolution

Transverse resolution primarily depends on pulse length. Due to the way in which the data is displayed (amplitude modulated) transverse resolution is unlikely to be better than the pulse length of the system. This equates to resolution of features on the record which are separated by one half of the pulse length, due to the two way travel time of the signal. Based on these physical factors, the theoretical resolutions detailed in Table 5 should be achievable:

Pulse length	Transverse resolution
0.2 ms	15.0 cm
0.1 ms	7.5 cm
0.02 ms	1.5 cm
0.01 ms	0.75 cm

Table 5: Transverse resolution versus pulse length

It should be noted that due to slant range distortion (which causes compression as a function of the towfish altitude) of the side scan sonar image, the above range resolutions will only be 'correct' at extreme side scan sonar ranges, where the angle of incidence is close to horizontal.

3.5.3.2. Axial (along track) resolution

The axial or along track resolution is controlled by the horizontal beam width, the pulse repetition rate and the speed over the ground of the transducer. Beam width along track is dependent on the side scan sonar transducer design and will generally widen with increasing distance from the towfish. Beam width will dictate better resolution at short ranges than at longer ranges.

Repetition rate will depend upon the range required since there must be sufficient time between pulses to record the required seabed returns. Along track sampling interval is dependent on the repetition rate and over the speed of the ground of the transducer. Speed of the survey platform is therefore important as a control for axial resolution; the greater the speed over the ground, the lower the resolution.

The horizontal beam width, when combined with the repetition rate, may result in under-sampling at close ranges (narrow beam widths) and the possibility of missing small seabed features (e.g. small boulders). At far ranges, the resolution degrades due to the size of the area from which reflections are received but data will not be under-sampled. In general, axial (along track) beam width is the limiting factor. This only loses its importance at either very short ranges and/or with very narrow beam width systems.

3.5.4. Detectability

Object or feature detectability cannot be easily defined as it is reliant on several variables including (but not limited to):

- object size
- object angle of incidence to the side scan sonar
- object composition

- side scan sonar operating frequency
- repetition rate
- environmental conditions
- survey platform stability.

When using narrow beam width systems at short ranges, very small standalone objects (e.g. 20 cm wide by 10 cm high) should theoretically be detectable. However, to recognise a significant feature, it must be large enough to provide returns from several side scan sonar pulses. A linear object orientated perpendicular to the side scan sonar fish track will be less easy to detect than one orientated parallel to the side scan sonar fish track.

Small features falling within the acoustic shadow of larger features would only be detected on an adjacent survey line.

Objects located directly below the side scan sonar towfish may not be clearly resolved in a slant-range corrected display due to a combination of restricted sampling and smoothed height correction. In survey design, therefore, line spacing and operating range of the sonar must be selected to allow imaging of the 'nadir' zone from adjacent lines to ensure that any objects lying within this zone are detected and mapped.

3.5.5. Range

The range of side scan sonar systems is controlled by signal level, signal to noise ratios, operational carrier frequency and repetition rate.

Lower frequency signals are required for longer range operations but these will reduce resolution due to increased pulse length and beam width and reduced repetition rates.

In some circumstances, especially in shallow water settings, surface returns, thermoclines and haloclines may limit effective range due to internal reflections caused by such phenomena.

3.5.6. Quality control

Side scan sonar data quality should be closely monitored throughout a survey to ensure that fit for purpose data is delivered for offline processing and interpretation. This monitoring must include all of the survey acquisition systems on which side scan sonar data quality is reliant, such as surface and sub-surface positioning systems.

Acceptance trials are recommended prior to the start of survey operations. These may include transducer 'rub tests', known structure 'box-ins' and comparison with complementary datasets (e.g. MBES). The objective of these trials is to ensure correct operation of the side scan sonar hardware and accurate data positioning.

Side scan sonar data may be affected by many variables that can have a detrimental effect on data quality. Careful selection of the side scan sonar system, a thorough understanding of operational parameters and survey area conditions can, however, reduce or eliminate the negative impact of many of these variables.

Typical factors that may affect data quality are listed below:

- acoustic cross talk
- electrical cross talk (analogue systems only)
- towfish or AUV/ROV height above seabed
- towfish or AUV/ROV stability and, or, yaw
- interference caused by water column density contrasts (e.g. thermoclines and haloclines)
- sea surface reflections (e.g. surface clutter)
- interference from fish and cetaceans
- interference from other acoustic survey sensors
- recording and logging (e.g. under sampling or reduced bit recording)
- limited bandwidth
- limited dynamic range (hard copy records only)
- poor data coverage through inappropriate choice of line spacing/operating range
- poor towfish or AUV/ROV positioning.

It is also worth noting that certain seabed soil types are not conducive to inducing a strong reflective response. Very soft, saturated clays can yield little or apparently no side scan sonar response and, therefore, careful online observations of side scan sonar response are required to differentiate between total loss of signal due to equipment failure/loss and the effects of very soft seabed soils.

During AUV surveys, the side scan sonar's altitude is typically automatically maintained at a set height above seabed. Unless the survey is specifically run for side scan sonar purposes, this can mean that Side scan sonar altitude can be up to 40 m above the seabed, which is normally considered too high for effective side scan sonar imaging. At this height, the slant range is increased, the ability to take measurements of an object's height is compromised and the size of the nadir zone is increased. The impact of this compromise should be assessed during the survey design stage and taken into account during data processing and interpretation.

3.5.7. Equipment

The choice of side scan sonar system is dictated by the survey's resolution requirement and the selected range, which should be at least equivalent to the maximum survey line separation.

A wide variety of side scan sonar systems are available, many of which are suitable for Site Surveys. However, the preference is use of a digital side scan sonar system because of the improved along track resolution, at greater survey speeds, through the use of multiple focused beams and the improved suitability for advanced offline processing, imaging and interpretation.

To detect obstructions on the seabed and to delineate seabed features, dual channel side scan sonar with a nominal operational frequency of 100 kHz or higher should be used. These systems provide transverse resolution of features to 20 cm in good environmental conditions. If there are particular requirements for identification of very small seabed features or objects, then a very resolute system should be used, operating at nominally 500 kHz. These systems allow resolution of events to 10 cm or less in optimal environmental conditions.

The selected survey line spacing should be less than the side scan sonar range in order to achieve in excess of 100% overlap of side scan sonar coverage. Transducer beam widths and depression angles should be selected for optimum resolution and data coverage in the survey area.

If practical, it is advisable to 'box-in' any significant seabed objects using a 500 kHz system for enhanced resolution and for optimum target interpretation and positioning.

Nominal system characteristics for side scan sonar systems commonly used for Site Surveys are provided in Table 6 below:

Nominal frequency	Pulse length	Horizontal beam width (3 dB points)	Vertical beam width (3 dB points)	Source level (ref 1 µbar at 1 m)	Likely achievable range per channel	Approximate minimum detectable object size (width × height)
90 – 120 kHz	0.1 ms	1 – 1.5°	40 – 55°	128 dB	200 m	1 × 0.5 m
400 – 500 kHz	0.01 – 0.02 ms	0.2 – 0.5°	40 – 50°	116 – 122 dB	75 m	0.2 × 0.1 m

Table 6: Nominal system characteristics for side scan sonar systems

Synthetic aperture sonar (SAS) is a form of side scan sonar in which sophisticated post-processing of the data is used in ways closely analogous to synthetic aperture radar. Although not commonly used for Site Surveys, this is considered to be an emerging technology that increases and provides a uniform across track resolution, thereby preserving resolution across the record. SAS combines a number of adjacent acoustic pulses to form an image with much higher resolution than conventional side scan sonars. The principle of SAS is to move the transducer along a line and illuminate the same spot on the sea floor with several pulses. This produces a synthetic array equal to the distance travelled. By coherent reorganization of the data from the return signal received, a synthetic aperture image is produced with improved along-track resolution. When these systems first appeared the data required significant post-processing. However current systems deliver processed results in real-time which make them more practicable and encourages their uptake.

3.5.8. Data processing and display

All side scan sonar data should be recorded digitally with event marks and event annotation (e.g. time, date, towfish position and heading (if available) written into the data headers). The purpose of recording the data digitally is to allow full digital post processing, such as signal conditioning and mosaicking, and workstation interpretation of the data to be performed.

Hard copy records may be produced for archiving or back-up purposes in case, for some reason, digitally recorded data are corrupted or lost. Such data should be recorded on electrosensitive or thermal paper which has a dynamic range in the order of 24 dB. For various reasons, older carbon sandwich or wet paper graphic recorder systems should not be used. The important characteristics for side scan sonar data display are repetition rate, sweep speed and rate of paper advance. Recorders should permit display of the side scan sonar data at a scale which allows the resolution of the data to be exploited without excessive scale distortion or loss of information.

3.5.8.1. Data processing

The objectives of side scan sonar data processing are amplitude manipulation and, if required, scale distortion removal to produce an evenly balanced (cross and along track), slant range and speed corrected, geo-referenced image. The processing is usually carried out on line however; the benefit of recording data digitally is that the sonar data can be manipulated post acquisition, to focus on areas of particular interest or to correct for initial recording parameters where they were sub-optimal, or to create side scan sonar mosaics.

In general, the processing sequence should comprise:

- slant range correction
- towfish heading correction (if available)
- beam forming of individual scans in the cross line direction to correct and allow for:
    - side lobe amplitude effects
    - range amplitude decay
- balancing of along track amplitude variations
- plotting of the true recorded position and direction of each scan for coverage check
- geo-referencing
- sonar mosaic compilation.

Many of these processes are performed within the recording unit on line in real-time. However, any processing that requires the final post processed positioning data to be applied (e.g. towfish heading correction and mosaicing) are performed offline.

Slant range correction is required to compensate for slant range compression in the near-range areas. Slant range correction re-maps the side scan sonar image from its apparent position to its 'true' position and is computed from the elapsed two-way travel time, and side scan sonar fish height.

Amplitude manipulation is usually achieved by Time Varied Gain (TVG) amplification which may be operator selectable or automatic. Such an approach may not be adequate to appropriately compensate for side lobe effects which may require careful offline design of a gain recovery function.

Whilst the across track scale of a side scan sonar record is determined by the range setting, the along track scale will be determined by the towfish speed. Since these two factors are independent, the record will suffer from scale distortion. Every side scan sonar pulse transmission is recorded with a position, a time and a tow fish heading. Scale distortion removal re-positions every pulse geospatially to produce a record that is scaled equally in the along track and across track directions. Scale distortion removal does not enhance data quality but assists in the speed of data interpretation and provides the ability to mosaic data sets.

Scale distortion removal does not enhance data quality but assists in the speed of data interpretation and provides the ability to mosaic data sets, if required. In some areas (e.g. rippled seabed) scale distortion removal may degrade the data.

Mosaics are produced by combining adjacent side scan sonar swathes to produce a continuous geo-referenced acoustic image of the surveyed area. Consideration should be given to optimising features observed while producing mosaics, rather than maximizing productivity. It may appear more aesthetically pleasing to superimpose adjacent lines to cover the nadir but this may not enhance the observed features.

Similarly, simply plotting lines into a mosaic in the order they were acquired may well not generate the best, or most meaningful, mosaic display. Particular attention should also be paid to any TVG applied to ensure that features are not 'smoothed out' at the expense of achieving a uniform data appearance. It is advised to avoid hard writing TVG changes to the raw digital files as sudden alterations of gain can affect the quality of the final mosaic.

In developing the sonar mosaic, an interactive session with the end user is recommended, so that the final order of line superimposition can be agreed to optimize the final image for feature classification during the interpretation stage. It can also be beneficial to deliver mosaic files of individual lines so that the end user can manipulate the data, interchanging overlapping lines to focus on particular features.

3.5.9. Deliverables

The processed data set from a side scan sonar survey will allow an experienced interpreter to determine the nature and distribution of seabed sediments, to identify natural geomorphological elements and to detect man-made and other seabed features. The primary deliverable from such an interpretation is a seabed features map and a list of interpreted sonar targets with dimensions, positions and possible feature identification; these data should be accompanied by estimates of their accuracy and validity.

It is recommended that all side scan sonar data is presented in a format suitable for the end user's requirements. There are numerous industry data formats available for recording side-scan-sonar data. While XTF is a commonly used recording format, careful consideration should be given in project planning to ensure that the format specified for use on a project is compatible with software, data exchange and data archiving requirements.

Individual line files should be delivered with the processed positioning data merged, and/or sensor position data provided as a separate file, in an agreed data exchange format. The IOGP P1/11 format is the industry standard for seismic position data exchange, it also enables the exchange of survey sensor position data. However, some contractors' processing software may not yet support this format.

The side scan sonar mosaic should be delivered as a high resolution geo-referenced raster file (such as GeoTIFF) at a resolution suitable for the purpose of the project. This should be at a sufficient resolution to identify the majority of features of interest. For example, mapping of seabed morphology and mapping of seabed debris would have different output resolution requirements. For large surveys, it may be necessary to deliver a suite of tiled mosaics and the GeoTIFF file format may be unsuitable due to the generally large file size that the format generates. In this case, the use of graphic file compression routines and compressed file formats, such as ecw, may significantly reduce the graphic file size without significant degradation of resolution.

In summary, the side scan sonar data package should comprise:

- digital side scan sonar XTF (or similar) files for all lines (raw and gain adjusted files)
- sensor position data in an agreed data exchange format (such as IOGP P1/11)
- side scan sonar sensor position track chart (required for position QC and data coverage checks)
- survey line log and QC log (required for identifying any changes to on line settings and data quality issues that may affect processing)

- geo-referenced side scan sonar mosaic in GeoTIFF or other agreed file format
- individual geo-referenced line mosaic in GeoTIFF or other agreed format (optional).

On occasion, an automated seafloor classification may be required and there are numerous systems available that provide this; although the level of success varies greatly and is greatly influenced by the level of manual calibration. Many systems rely on image classification, although others utilize proprietary algorithms to analyse the backscatter response. In any case, it is essential that the seafloor classification be calibrated with *in situ*, ground-truth data.

Data retention is very much specific to the project needs and in some degree to the expected time validity of the data (*The Guidelines*, 5.4). Data validity will depend on the survey's geographical location and the level of operational activities in the Site Survey area.

3.6. Seismic profiling systems

3.6.1. General objectives of seismic profiling data acquisition

The objectives of seismic profiling data acquisition are to provide a 2D or 3D sub-seabed image of the shallow soils and top-hole geology. The choice of systems (seismic sources, receivers and recorders) used in offshore Site Surveys is dependent upon a number of factors and on the specific objectives of the survey.

Shallow survey objectives include investigaton of the seabed anchoring and foundation conditons, the subsequent stability of the proposed drilling unit, and the installation of the drilling conductor. Such investigations range from seabed to ~80–100 m below seabed. These data should always be recorded digitally and are normally acquired using single, or a combination of single and multi-channel seismic recording systems.

Single channel seismic data are recorded using very high frequency sources such as pingers/chirp, electro-mechanical devices (e.g. boomers) and electrical spark generators (sparkers) – 3.6.4. Corresponding receivers include integrated transducers or external/separate hydrophones. The sources can be hull mounted or surface, shallow or deep towed. These data acquisition techniques are often referred to as single channel sub-bottom profiling or simply sub-bottom profiling.

Deeper survey objectives include identification of top-hole drilling hazards (e.g. shallow gas) and other features which may adversely impact: the drilling of the top-hole section, choice of casing setting depths and cementing practices. Due to the increased depth of investigation, a different suite of seismic tools is used to those described above. For these deeper investigations, a 2D multi-channel seismic spread (using similar techniques to those used for exploration purposes, but designed to emit, and record, a higher and broader band of frequencies to provide higher resolution imagery) should be used. Source descriptions are provided in 3.6.4.1. Such methods are termed 2D high resolution (HR) multi-channel seismic or ultra high resolution (UHR) depending on the frequency content and resolution required from the data. Preferably, these data should be acquired in 3D or pseudo-3D mode (3.6.1.1 and 3.6.6.4 below). However, this is currently rarely done due to the additional cost and limited availability of such systems for acquiring and processing such 3D data. However acquisition of high resolution data in 3D mode is recommended wherever possible.

Profiling technique	Single/multi-channel	Definitions[a]
Sub-bottom profiling	Single channel	Single channel seismic (including use of pingers/chirp, boomers and sparkers) to investigate the shallow soils/ geology down to ~80–100 m below seabed.
HR seismic	Multi-channel	Multi-channel seismic to investigate top-hole drilling hazards using the following example data acquisition parameters: source ~4 × 40 cu in airguns towed at ~2–3 m sub-sea, 48 or 96 channel streamer (group interval 6.25–12.5 m) towed at ~2–3 m sub-sea.
UHR seismic	Multi-channel	Multi-channel seismic to investigate shallow soils foundations and upper top-hole drilling hazards using the following example data acquisition parameters: source –single 10 cu in airgun towed at ~1–1.5 m sub-sea, 48 or 96 channel streamer (group interval 6.25 m) towed at ~1.5 m sub-sea.

[a]All numbers are typical examples that will vary dependant on soils types and water depths.

Table 7: Definitions of conventional seismic profiling techniques

Single channel, or sub-bottom, profiler systems (e.g. pinger, chirp, boomer and sparker) data are frequently acquired in a single survey line pass mode simultaneously with echo sounding and side scan sonar. Similarly multi-channel seismic data have, traditionally, been acquired independently in a second pass of the survey lines. However, if the systems configurations are controlled appropriately, it is possible and quite common to acquire both single and multi-channel data together in a single survey line pass.

3.6.1.1. High resolution 3D seismic

The vast majority of high resolution multi-channel seismic data is collected as 2D surveys using one source and one seismic streamer in lines spaced at anything between 25 m and 500 m apart and with limited source and streamer positioning. However, it is possible to apply the principles of exploration 3D seismic acquisition to high resolution acquisition for Site Surveys using multiple streamers and active source and streamer positioning systems. In practice, these surveys have normally been carried out in areas of especially complex subsurface geology: where geo-hazards are expected to directly impact on drilling and field development plans and, therefore, improved understanding of conditions is required.

In its simplest form, a 3D seismic volume may be created from closely spaced 2D lines by 'pseudo 3D' seismic processing (see below), this requires active tail buoy for streamer positioning. If true high resolution 3D coverage is required over a substantial area such as a field development, then there are advantages in towing multiple streamers and/or sources to improve the efficiency of acquisition. Sources and streamers need to be positioned with high accuracy using active tail buoys, source positioning and streamer compasses as on a conventional exploration 3D seismic survey. Such arrays, however, need to be carefully designed to prevent directional effects being present in the final data due to excessive cross-line offsets, or inadequate cross-line sampling due to excessive streamer spacing.

3D volumes of single channel seismic data may also be developed using closely spaced, and binned, profiler data acquired with hull mounted or surface towed arrays or accurately positioned systems deployed on AUVs or ROVs. Such volumes may be advantageous in analysis of complex foundation issues such as placement of suction caissons.

3.6.2. Significant issues relating to marine seismic profiling

The fundamentals of seismic reflection theory are well publicised in text books and journals. Should the reader require further information, reference should be made to specialist text books on the subject. However, the most significant issues relating to marine seismic profiling, and the major parameters impacting the choice of the profiling systems, with regards to the final survey objectives, are provided below.

3.6.2.1. Sub-bottom penetration

Sub-bottom penetration achieved from seismic profiling results, in part, from a combination of the seismic source amplitude/power output and the frequency bandwidth of the seismic wavelet produced. Other factors such as the absorption characteristics of the geological strata being investigated are also significant.

Low frequencies are required for greater penetration, but this generally requires the use of high power sources which may not have suitable high frequency bandwidths for high resolution data acquisition. A careful compromise is required, therefore, between the opposing requirements for penetration and resolution. Parameter choice will be dependent on the Site Survey objectives and geological and environmental (e.g. water depth and currents) conditions expected.

3.6.2.2. Vertical resolution

Seismic reflections are generated by impedance contrasts at the interfaces of geological units. The magnitude of the reflection is related to this impedance contrast and also to other factors such as the bandwidth, the shape of the seismic wavelet, and/or the interference of other closely spaced thin geological layers or beds.

Vertical resolution is commonly defined as the minimum bed thickness between two discrete interfaces that seismic data is able to define as being separate. If two geological interfaces are too closely spaced, the reflected signals from both interfaces will give rise to interference patterns in the resulting seismic wavelet. Whenever the separation (in reality, two-way travel time) is too small, a complex, composite, wavelet is generated. Destructive interference will tend to attenuate the overall signal reflected, whereas constructive interference will tend to enhance it.

These considerations give rise to two distinct criteria to predict vertical resolution:

- *First criterion*: valid in the case of destructive interference – the peak to peak amplitude of the two reflections is maximum at the vertical resolution (tuning criteria)
- *Second criterion*: valid in case of constructive interference: the two peaks related to the reflection on the top and the bottom of the layer must be distinguishable.

It is thus widely accepted that vertical resolution is roughly equal to λ/4 (Rayleigh criterion), where λ is the wavelength of the dominant reflected signal detected at the target depth. If V_{int} denotes the interval velocity of a thin layer of thickness Δz, and F_{dom} the dominant frequency of the signal, the related resolution is thus given by:

$$\text{vertical resolution} = \frac{V_{int}}{4F_{dom}}$$

This equation provides a good understanding of the theoretical minimum separation and allows graphs relating interval velocity, dominant frequency and the vertical resolution to be drawn (for which the minimal signal frequency was fixed to 20 Hz and F_{dom} to $(F_{min} + F_{max})/2$).

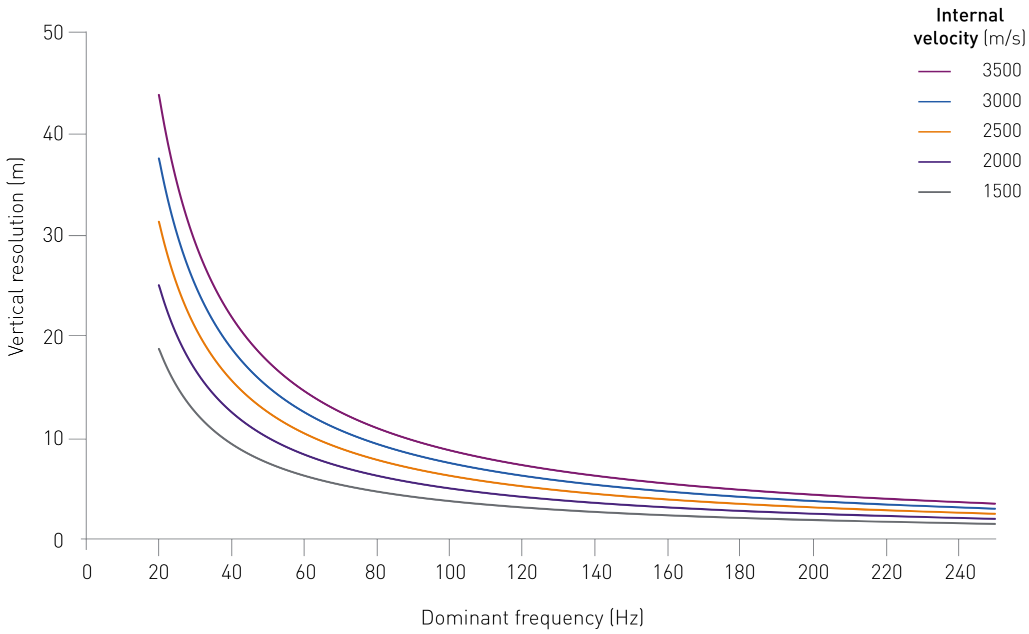


Figure 3: Vertical resolution versus dominant frequency

If the seismic wavelet consisted of a single frequency, the optimum resolution would be one quarter of the wavelength (λ /4) but in a noisy acoustic environment, resolution of half the wavelength (λ /2) may be more realistic. However, a seismic wavelet does not consist of a single frequency, but a range of frequencies (the bandwidth), with a particular fundamental frequency. Resolution is therefore determined by a combination of bandwidth and fundamental frequency.

Anything that affects the seismic wavelet in terms of amplitude or frequency content affects the vertical resolution. The major factors are listed below:

1. characteristics of the transmitted seismic signal (e.g. power spectrum, signal directivity, repeatability)
2. water column losses (spherical spreading)
3. reflection/refraction losses at seismic interfaces (seabed and sub-seabed)

4. absorption (frictional losses during propagation which are frequency dependent) and scattering
5. acquisition/recording parameters and equipment limitations.
6. seismic data processing.
7. geological dip.

Items 1, 5 and 6 are controllable and must be carefully selected during the survey planning phase. Item 2 can be controlled to some extent by utilizing deep tow systems, where appropriate. Items 3, 4 and 7 are not controllable and depend completely upon the geology of the survey area. Table 8 shows the variation of vertical resolution with frequency, based solely on fundamental frequency and assuming the λ/4 criteria referred to above. It is a simplistic model but it illustrates the degradation of resolution that occurs with decreasing frequency. This is important, as higher frequencies are preferentially lost as the signals propagate through the sub seabed strata and, consequently, resolution decreases with increasing sub seabed depth.

Fundamental Frequency	Seismic Velocity 1500 m/s	Seismic Velocity 2000 m/s
	Vertical Resolution	
5000 Hz	0.08 m	0.10 m
1000 Hz	0.38 m	0.50 m
500 Hz	0.75 m	1.00 m
250 Hz	1.50 m	2.00 m
100 Hz	3.75 m	5.00 m
75 Hz	5.00 m	6.67 m
50 Hz	7.50 m	10.00 m
25 Hz	15.00 m	20.00 m

The seismic velocities are examples used to illustrate the principle.
The actual seismic velocity will vary vertically and laterally

Table 8: Vertical resolution versus fundamental frequencies and seismic velocities (λ/4 criteria)

3.6.2.3. Layer detectability

Resolution is defined as the ability to separate two very closely spaced seismic reflectors. However, layers thinner than the 'resolvable thickness' will still generate a seismic response and can thus be 'detected'.

Detectability is particularly influenced by signal to noise ratio of the data. Very thin layers can be detected on low noise level data. However, as a rule of thumb, detectability on seismic data is a factor of four smaller than the theoretical resolution.

If a bed is detectable, it does not necessarily imply that it can also be interpreted. The interpretability depends upon resolution, detectability and geological complexity. In rapidly varying geology, a change in seismic response cannot be uniquely related to the reflection properties of a single bed.

3.6.2.4. Lateral resolution

Seismic imaging limitations also exist in the horizontal domain and lateral resolution determines the smallest areal extent of a feature which can be detected.

In most cases, lateral resolution is determined by the spatial width of the seismic wavelet and some events (of limited lateral extent) may not be detected by the seismic imaging process. Acoustic propagation from source to receiver involves propagation of a spherical wave-front, not a single ray path. The signal reaching a seismic receiver comes not only from the primary reflection point being investigated but also from neighbouring reflection points that behave as secondary reflection points. This zone, located in the vicinity of the wave front (within λ/4), is referred to as the first Fresnel zone or more commonly just as the Fresnel zone, and any two reflection points within this area cannot be separated on the raw seismic data. The size of the Fresnel zone depends on the depth of the reflector, the signal bandwidth, the seismic velocity and the incidence angle. The lateral resolution (R_f) of raw seismic data can be derived for zero source-receiver offset reflections in a homogeneous medium using the equation:

$$R_f \approx \sqrt{\frac{\lambda d}{2}}$$

Where d is the reflector depth and λ the signal wavelength.

Figure 4 shows that the maximum achievable lateral resolution is λ/4.

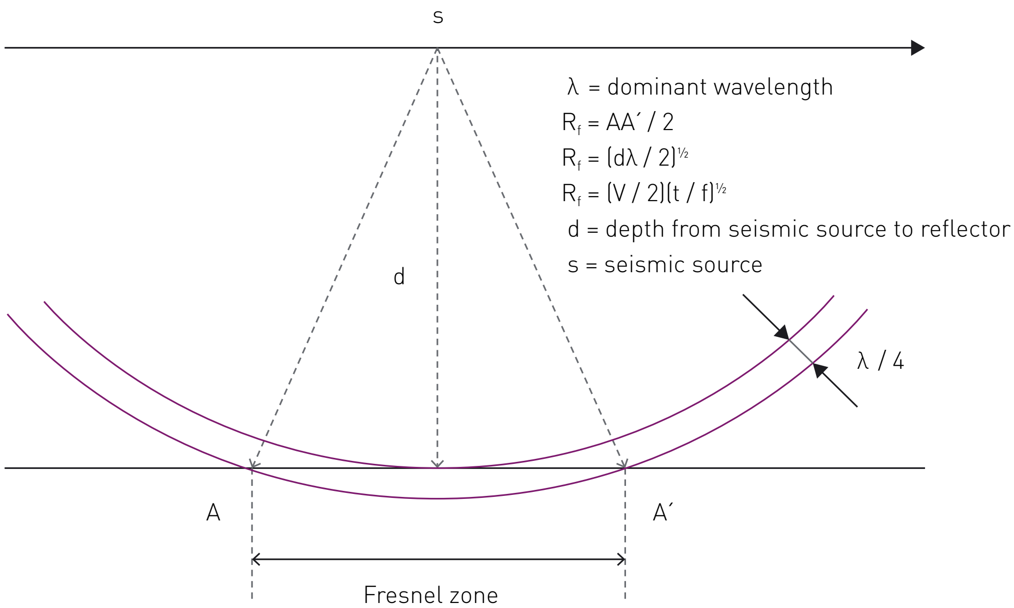


Figure 4: Fresnel zone and lateral resolution

The reflecting zone diameter is roughly half of the Fresnel zone diameter. The larger the area of the reflecting zone, the greater the 'smearing' of events with a corresponding reduction in lateral resolution. Therefore, the ideal signal for lateral resolution is a high frequency signal, producing a narrow reflecting zone. Unfortunately, such signals will not penetrate very far into the seabed.

This explains why, in the case of single channel seismic acquisition, it is preferable to tow the source/receiver close to the seabed and why, in deep water, or over a rugged seafloor, or complex shallow overburden, either deep-towed or AUV-mounted equipment is recommended for single channel profiling.

Lateral resolution is controlled by the following eight major factors:

1. characteristics of transmitted seismic signal
2. single channel hydrophone array length and/or multi-channel streamer group interval
3. seismic wave propagation
4. survey line spacing
5. streamer feathering angle
6. seismic data processing
7. geological dip
8. migrated, or unmigrated, nature of the data for multi-channel data.

Items 1, 2, 4, 5, 6 and 8 are controllable and must be carefully selected to meet the survey objectives. Items 3 and 7 are out of our control and are determined by geophysics and the geology of the survey area. However, with careful selection of line spacing and orientation, the effects can be minimized.

During survey planning it is essential to ensure that the survey line spacing is appropriate, such that the area between lines is imaged by the reflecting zone of the available frequencies; particularly the fundamental frequency. This may mean that in deeper water a degraded 2D line spacing, relative to what one might choose in shallow waters, is entirely appropriate.

Table 9 shows the diameter of reflecting areas (Fresnel zones) for a range of sub source depths and frequencies.

Depth Below Source (m)	**Frequency**								
	25 Hz	**50 Hz**	**75 Hz**	**100 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**5000 Hz**
50 m	39 m	27 m	22 m	19 m	12 m	9 m	6 m	4 m	3 m
100 m	55 m	39 m	32 m	27 m	17 m	12 m	9 m	6 m	
200 m	79 m	56 m	45 m	39 m	25 m	18 m	12 m		
300 m	98 m	69 m	57 m	49 m	31 m	22 m			
400 m	115 m	81 m	66 m	57 m	36 m	26 m			
500 m	130 m	92 m	75 m	65 m	41 m				
750 m	164 m	116 m	95 m	82 m	52 m				
1000 m	195 m	138 m	113 m	97 m					
1250 m	224 m	158 m	129 m	112 m					
1500 m	251 m	177 m	145 m						
2000 m	297 m	210 m							

Table 9: **Theoretical diameter of Fresnel zone (in metres) versus frequencies and depths below source (seismic velocity ~1750 m/s) for un-migrated seismic data**

The Fresnel zone criteria indicate the size of the reflection area, but not the minimum areal extent of a feature that is detectable. To recognize an event within the Fresnel zone it must make a significant contribution to the returns from the zone, to such an extent that it is recognizable as variations in signal amplitude when compared to returns from adjacent traces. Lateral detectability, therefore, depends on the reflection contrast between the event and the adjacent or background reflectors.

In the case of high resolution multi-channel data the size of the Fresnel zone can be collapsed by application of migration in data processing.

$$FZ = \lambda / 4$$

Therefore to maximize the achievable lateral resolution of a multi-channel dataset data should always be migrated in processing.

3.6.3. Noise

3.6.3.1. Noise and signal to noise ratio

Seismic data are never recorded in a noise-free environment and such data are, therefore, always a combination of desired seismic signal and unwanted noise. As a general definition, any recorded energy which interferes with the desired seismic signal can be considered to be noise.

Noise can be considered to fall into two categories: random, such as wave noise, and coherent, such as seismic interference.

The diversity and magnitude of noise types often makes separation of signal and noise a challenging process. However, efficient noise attenuation and/or removal are important components of high quality imaging. Some of the primary sources of seismic noise include:

- hydrostatic pressure variation
- swell/wave effects
- vessel tugging effects on streamer
- vessel propeller cavitation
- seismic interference
- electrical (pick-up, cross-talk, etc.).

Figure 5 highlights the impact of noise on the recoverable bandwidth of recorded data and Figure 6 shows the spectrum computed at the target level for a UHR seismic line. Assuming that the noise level on the seismic section is approximately –15 dB, then the maximum recoverable frequency in this case would be around 350 Hz.

The actual seismic fold coverage at target level on the seismic line used in Figure 6 is equal to 48. Fold contribution to the signal to noise ratio is commonly regarded to be proportional to the square root of the fold. Therefore in choosing the acquisition parameters required, fold of cover must be considered.

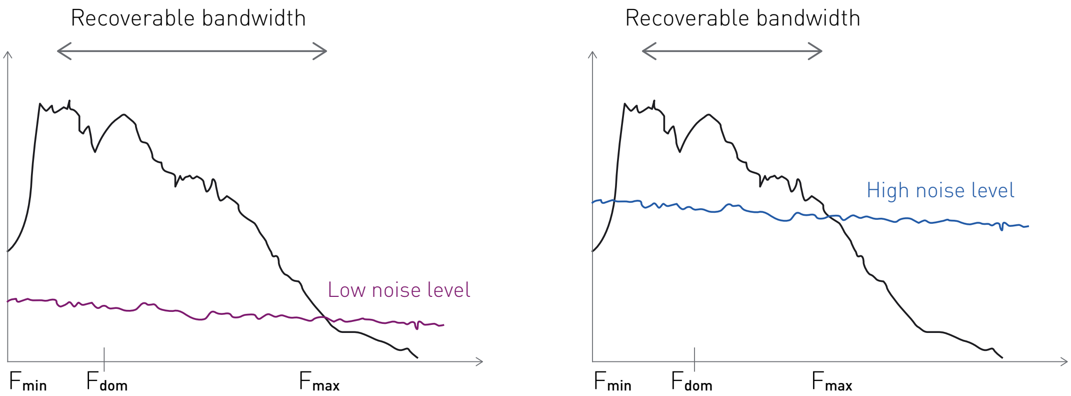


Figure 5: **Influence of noise level on recoverable signal bandwidth**

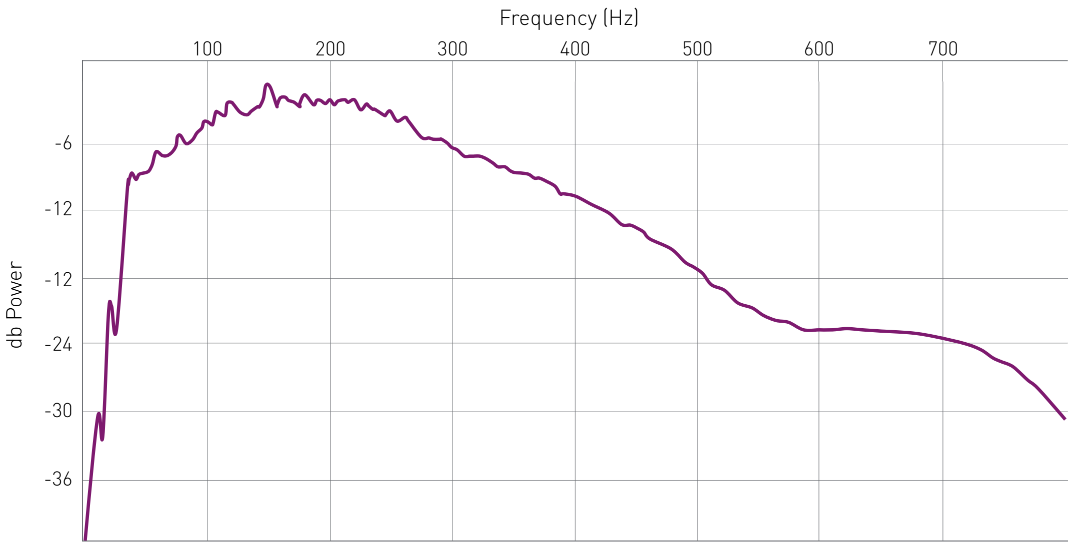


Figure 6: **UHR Seismic: typical target level frequency spectrum**

3.6.3.2. Hydrostatic pressure variation

Hydrostatic pressure variations relate directly to the height of the water column above the seismic streamer. Such variations are caused by ocean swell and by streamer buckling. However, the frequency content of hydrostatic pressure variations is limited to 0 – 2 Hz and this frequency band does not contain a lot of useful seismic data for Site Surveys. This type of noise can therefore be removed by application of an appropriate low-cut filter in the field or in post processing.

3.6.3.3. Swell and wave effects

Sea swell and wave effects can induce high amplitude noise with typical frequencies from 2 – 20 Hz. Such noise usually affects a number of adjacent seismic channels on a multi-channel shot record and can be observed in single channel seismic data by characteristic vertical stripes across the record.

There are two different mechanisms that create such noise.

In fluid-filled streamers, swell-induced streamer motions can induce transverse waves, known as bulge waves. These can generate high-amplitude noise up to ~10 Hz. Solid streamers are not affected by such noise which is an advantage of such systems.

Flow induced by ocean currents surrounding seismic streamers can create strong alternating pressure fluctuations along the streamer which manifests itself as high-amplitude swell-noise.

Swell noise can be removed by careful use of time variable low-cut frequency filtering. Great care should be taken in choosing the low-cut filters to ensure significant parts of useful seismic data are not removed. For most Site Survey applications, removal of swell and wave effect noise is not a significant issue, unless weather conditions are extreme in which case acquisition should be curtailed.

3.6.3.4. Vessel tugging effects

Vessel tugging noise is caused by sudden movements of the vessel, or tail-buoy, due to the impact of waves. In addition to tugging, induced vibrations of the streamer may also affect some seismic channels. Such noise is generally observed on the near trace sections of the streamer for Site Surveys and is characterized by relatively large amplitudes in a narrow frequency band between 3 and 12 Hz. To minimize the effect stretch sections should be used in the streamer at the front and rear end to reduce tug energy being transmitted through to the active sections. This can be difficult in shallow water settings where the source to near channel offset has to be short.

This noise can be removed by choice of an acquisition low-cut filter or by processing similar to that used for swell noise attenuation.

3.6.3.5. Vessel propeller cavitation

As a propeller moves through a fluid, low pressure areas are formed as the fluid accelerates around and moves past the propeller blades. If these low pressure areas reach vapour pressure, the fluid vaporizes and forms small bubbles. The collapse of these bubbles causes strong local 'shock-waves' (cavitation) thereby creating noise on the seismic data.

Cavitation normally occurs when a propeller operates outside its design window or has been damaged in some way. Because cavitation noise originates from the vessel propeller, the noise follows almost the same move-out curve as the seismic response of a sound source located ahead of the receiver array. Cavitation noise is generally broad band and intermittent. It is imperative therefore that a new vessel, being considered for a survey, should undergo noise trials ahead of mobilization to see if this may be an issue rendering the vessel unsuitable for survey work.

3.6.3.6. Seismic interference

Seismic interference can be generated by a variety of different sources including:

- drilling operations adjacent to the survey area
- piling or construction operations adjacent to the survey area
- large vessels transiting the survey area
- seismic energy transmitted from other seismic vessels or other seismic operations in the vicinity
- natural seismic events.

Such noise is generally broad-banded and can often exhibit large amplitudes when compared to sub-surface reflection data. There are different approaches for removing this type of noise using post-processing techniques that include f-x prediction and tau-P transformation.

3.6.3.7. Recording noise acceptability levels

It is generally accepted that the maximum acceptable average noise on a multi-channel seismic streamer should be as follows:

- average random, or background, noise: ⩽ 7 – 10 µbars
- random noise bursts: ⩽ 18 – 20 µbars
- coherent noise from ahead of the survey vessel: ⩽10 µbars
- coherent noise from behind the survey vessel: ⩽20 µbars
- coherent noise abeam the survey vessel: ⩽5 µbars.

As a general guide, acceptable coherent noise should not exceed the following levels, for time differences between the front and rear of the streamer, ahead and astern of the vessel, as set out in the following Table 10. These time differences relate to an active length of 1200 m and may be adjusted in proportion for streamers of different lengths.

Noise (µb)	Moveout	
	Ahead (ms)	Astern (ms)
5	0 – 450	0 – 25
10	450 – 475	25 – 50
15	475 – 500	50 – 75
20	500 – 525	75 – 100
25	525+	100+

Table 10: Acceptable coherent noise criteria

3.6.3.8. Cable noise

Before any seismic profiling is undertaken, seismic streamer (cable) noise tests should be undertaken.

A cable noise test is conducted with the cable towed at approximately the operational recording speed during a straight line run of approximately one and one half cable lengths. Such a test should be conducted with variable revolutions, or pitch, settings of the propeller (if there are concerns about the contribution of vessel noise) and during different sea states (if possible) in order to define the best acquisition configuration and the sea state limits to obtain reliable signal to noise ratios. Cable noise is generally quoted in microbars (RMS equivalent) and is defined as the noise at the amplifier input in microvolts (RMS equivalent) divided by the sensitivity of the detector group (when loaded with cable and amplifiers) in microvolts per microbar.

Background noise should generally be uniform across each streamer channel. Any persistent non-uniformity should be investigated.

3.6.4. Seismic profiling equipment

3.6.4.1. Seismic sources

Seismic sources can be divided into electrically generated sources (e.g. pinger, boomer and sparker) and pneumatically generated sources (e.g. airgun and water-gun).

Electrically generated sources are mainly used for single channel seismic. The frequencies of these electrical sources are generally in the range 200 Hz – 8 kHz, preferably adjustable and the recommended power output is a minimum of 5 kW (for pinger and chirp systems).

Pinger, or chirp systems, are best utilized in soft, fine grained, sediments where sub-seabed penetration of up to 50 m can be achieved under ideal conditions with a vertical resolution of 0.2 to 0.3 m.

Boomer and sparker sources are more suited to more consolidated and granular sediments where sub-seabed penetrations of up to 80 – 100 m can be achieved with a vertical resolution of 0.5 m close to the seabed and 1.5 m at greater depths.

With all very high frequency systems, sub-bottom penetration is largely dependent on the relative consolidation and particle size of the sub-seabed sediments. In general, the more consolidated the sediments, and the larger the particle size, the less the sub-bottom penetration that will be achieved.

Pinger

The pinger, sometimes referred to as 'penetration echo-sounder', is a transducer that is designed to generate an acoustic output signal at a given frequency in response to an electrical input, where piezo-electric devices (crystalline materials) transform the electric energy to acoustic energy. An applied electric field results in a mechanical stress in the piezo-electric components proportional to the electric field strength. The sense of the stress reverses from compression to tension (and vice versa), with a reversal of the electric field polarity. Cavitation occurs when contracting the piezo-electric element, the pressure in water decreases to a level where water vaporizes producing a bubble. For Site Survey purposes, pinger frequencies are generally in the range of 2 to 7 kHz. The disadvantage with the pinger is that the bandwidth of the emitted signal tends to be poor (e.g. 3.5 KHz) with a poor, 'ringing' pulse shape. Therefore while the stated frequency of the source is higher than a boomer pulse the resolution is lower.

Chirp

A chirp source is a variation of the pinger transducer principle, as it transmits a computer generated frequency modulated (FM) pulse that sweeps over a defined, or chosen, frequency range (200 Hz to 30 kHz) depending on the transducer configuration. For Site Survey purposes, chirp frequencies are in the range of 2 to 8 kHz. The energy of the transmitted FM pulse can be varied within a range of 1 to 500 joules by adjusting the power amplifier level and/or by selecting the pulse length. Varying the amplitude and frequency of the emitted pulse in a predetermined pattern is called 'chirping' and can provide advantages over conventional pingers in terms of resolution, due to the emitted signal bandwidth, and penetration in certain sediment types.

It should be noted that for both pinger and chirp sources, the source device (transducer) is also the receiving device (transponder). No additional receiver (streamer) is required.

Parametric sources

Parametric profiling sources use the non-linear interaction in the water column of two high intensity acoustic beams transmitted at high frequencies, to produce the desired lower profiling frequency that is reflected and recorded. The resulting signal has a high relative bandwidth, narrow beam profile, and no side lobes, which offer a number of theoretical advantages in resolution and penetration.

The system's transducer size is also significantly reduced, relative to other conventional sub-bottom profilers that operate at the same beam width and similar frequencies, enabling these systems to be fitted to small vessels.

Parametric sources may be either hull mounted or fitted into towed systems.

Boomer

Boomers consist of two electro-mechanical plates that are forced apart suddenly by a heavy surge of electrical current through a coil embedded within one of the two plates. The electrical current generates eddy currents in the opposing plate resulting in a sudden repulsion thereby generating an acoustic wave in the water. The return of the two plates to their original position is damped by rubber to prevent cavitation behind the initial output pressure wave.

The typical input energy is several hundred Joules, with frequencies ranging from ~200 Hz to about 10 kHz. For Site Survey purposes, frequencies are in the range of 300 Hz to 3 kHz. The broad frequency output of greater than 3 octaves results in a very resolute pulse.

Sparker

Sparkers utilize the discharge of the stored electrical charge of a capacitor bank to create a spark between two electrodes located in sea-water. The heat generated by the discharge vaporizes the water creating a steam bubble. The collapse of the bubble results in a pressure peak. However the creation of the original bubble can result in further oscillation to the detriment of the outlet pulse. Various approaches have therefore been used to try and minimize this effect by varying the number of spark-tips to minimize bubble size and sharpen the pulse.

In general, small sparkers, as used for Site Surveys, operate at several hundred Joules input energy, producing a seismic pulse in the frequency range of 20 to 4000 Hz.

Larger sparkers operating at energy input levels of 1 – 12 kilojoules were popular sources for multi-channel high resolution acquisition in the early days of the industry. However these suffered from problems with poor pulse shape and lack of stability of the output pulse and are no longer recommended for use.

Airgun

Pneumatically generated sources are mainly used for multi-channel seismic acquisition. The most commonly used source for HR seismic is an array of several airguns (generally 2 to 6) deployed in a closely arranged cluster or clusters. With such a configuration, particular attention must be paid to the synchronization of individual firing times of the individual guns. This should be in the range of ±0.1 millisecond.

The principle of an airgun is an explosive release of a high pressure volume of air in the water. Traditionally, airguns include two chambers – a control chamber and a firing chamber – divided by a moving shuttle with a hole in the shaft. At the instant the gun is fired, a valve is opened to inject high pressure air that moves a shuttle, or sleeve at high velocity allowing the sudden release of a stored volume of 2000 psi air. This releases an oscillating air bubble into the water column similar to those produced by explosive sources.

A typical high resolution (HR) seismic airgun source used for Site Surveys has the following characteristics:

- total volume minimum ~160 cu.in
- firing interval 6.25 – 12.5 m
- type of source: Sleeve-gun cluster(s) or GI gun
- operating air pressure 2000 psi
- total number of guns 1 to 6
- depth of guns 2 – 3 m.

With such source characteristics, the resulting frequency range is expected to be between 20 and 220 Hz and, dependent on the geological character of the area being surveyed, this should deliver imagery over the whole top-hole section (~1000 m below mud line).

An important parameter when using an airgun source is the shot interval. This is the minimum time between successive firing that the system will record. The shot interval is determined by system performance and the chosen record length. With 'fast' source firing, record length will need to be chosen carefully. Typical shot intervals for Site Surveys are 6.25 m or 12.5 m. For record lengths of 2.0 seconds or more it may not be possible to use a 6.25 m shot interval due to a combination of the cycle rate of the seismic source and recorder and the vessel's minimum survey speed.

A summary of the characteristics of the various seismic sources is provided in Table 11.

Source	Receiver	Frequency range	Potential sub-bottom penetration
Pinger	Single	2000 – 7000 Hz	Up to 50 m *
Chirp	Single	2000 – 14000 Hz	Up to 50 m *
Parametric source	Single	2000 – 22000 Hz	Up to 50 m *
Boomer	Single	300 – 3000 Hz	Up to 100 m *
Sparker	Single	50 – 4000 Hz	Up to 100 m *
Single 10 cu. in. airgun	Single	20 – 500 Hz	Up to 500 m *
Single 10 cu. in. airgun	Multi-channel	20 – 500 Hz	Up to 1000 m
4 × 40 cu.in. airgun cluster	Multi-channel	20 – 220 Hz	Up to 2000 m

* In soft sediments and dependent on water depth.

Table 11: Summary of seismic source frequencies and sub-bottom penetrations

3.6.4.2. Seismic receivers

It will be apparent from the preceding sections that in order to achieve the multiple objectives of a Site Survey, a range of equipment and seismic profiling systems will need to be deployed to acquire the required data. Profiling systems fall into two primary categories: those employing single channel receivers and those employing multi-channel streamers.

The receiver for pinger/chirp systems is an integral part of the seismic source (transceiver) whereas all other systems employ a separate hydrophone system for receiving the seismic signals.

Hydrophones may be single element receivers but are more commonly arranged as an array consisting of multiple elements. The advantages of a hydrophone array are an improvement in the signal to noise ratio, improved response to reflected signals from the target area below the receiver array, a reduction of ambient noise, and a reduction of coherent noise arriving along the line of the array.

Hydrophone arrays have a pattern and spacing response which is related to the number of elements and the overall array length. The pattern response controls the directionality of the receiver. Directionality is greater for higher frequencies than for lower frequencies. The longer the hydrophone array, the more directional the characteristics of the receiver are. It is the directionality of the array which results in the reduction in ambient and coherent noise. However, if array lengths are not chosen with care they will also reduce signal levels due to this directionality. With increasing offset, signal suppression will become more of a problem; particularly at higher frequencies. Emergence angle (i.e. the angle of incidence of reflected data arriving at the receiver) is therefore very important. This has particular implications for choice of near trace offset, particularly in shallow water settings.

If high frequency data are required, therefore, source to receiver offsets should be small and array lengths short.

When using a hydrophone array, consideration should also be given to spacing of the individual hydrophones. These should be equally spaced to uniformly sample the incoming seismic wave-front and their spacing should satisfy Nyquist sampling criteria.

Single channel receiver

The single channel receiver/streamer is in fact usually made up of several hydrophones spaced sufficiently close to be considered as a single element. The element spacing is usually less than one metre. Therefore, for acceptable emergence angles, data up to 10 kHz may be recorded (assuming the seismic source can generate these high frequencies, and that there are primary reflectors present that respond at these frequencies).

Single channel hydrophone/streamer characteristics are generally as follows:

- Number of hydrophones: 8 – 20
- Length of array: up to 10 m
- Typical bandwidth: 100 up to 10,000 Hz.

Multi-channel receivers

Digital and analogue multi-channel receivers/streamer arrays in common Site Survey usage have group lengths of 6.25 m, 12.5 m. Group lengths of 25 m are sometimes used in Site Surveys but are non-optimal for recording higher frequencies and should, therefore, not be used.

Typical characteristics of such streamers are listed below:

- Bandwidth: 5 – 1000 Hz
- Groups: 48 to 120
- Group length: 6.25 or 12.5 m
- Length: 600 to 1500 m active length
- Depth controllers/indicators: Every 100 m (preferably interleaved)
- Preferably equal spacing of hydrophone elements throughout the streamer.

It should be noted that a 600 m streamer may not provide adequate move-out for imaging deeper geological objectives (>1000 m sub-seabed). For good seismic velocity control at these levels, longer streamers should be considered. A rule of thumb is that the streamer length should be equal or equivalent in length to the total depth of study below seabed.

Multi-channel (and to a lesser extent single channel) streamers may be affected by external factors that can impair the quality of the seismic data being received. These factors include streamer feathering, signal stretch and tow depth ghosts and are described below.

Streamer feathering

Excessive streamer feathering (i.e. lateral deviation of the streamer tail from the survey line track) will degrade lateral resolution of the seismic data when the data are CMP stacked. Streamer feather effectively increases the size of the area from which reflections are received. In extreme cases of feathering, reflecting areas may not even overlap at higher frequencies.

This is illustrated in Table 12, which shows the spread of CMP positions for various feather angles, source-receiver offsets and sub sea surface depths. As long source-receiver offsets will be muted in post-processing at shallow depths, shorter offsets have been used with the shallower depths.

Horizon Depth Below Source-Receiver CMP	Source Receiver Offset (assuming 10% stretch mute)	Feather angles		
		1°	7°	10°
		CMP Spread (m)		
50 m	50 m	0.4 m	3.1 m	4.4 m
100 m	90 m	0.8 m	5.5 m	7.9 m
200 m	180 m	1.6 m	11.0 m	15.9 m
300 m	250 m	2.2 m	15.3 m	22.0 m
400 m	320 m	2.8 m	19.6 m	28.2 m
500 m	380 m	3.3 m	23.3 m	33.5 m
750 m	570 m	5.0 m	35.0 m	50.3 m
1000 m	750 m	6.6 m	46.0 m	66.1 m
1250 m	930 m	8.1 m	57.1 m	82.0 m
1500 m	1120 m	9.8 m	68.8 m	98.7 m
2000 m	1250 m	10.9 m	76.8 m	110.2 m

Table 12: **CMP spread (in m) for 1°, 7° and 10° feather angles (assuming a 50 m stretch mute offset and a 1200 m streamer)**

For optimum lateral resolution, zero streamer feathering is required. In practice, this is very difficult to achieve due to operational constraints and the maximum recommended feather angle is 7 degrees. As shown in Table 12, for a 570 m source receiver offset, this may produce a spread of CMP positions in the order of 35 m at deeper objective levels.

Excessive feathering, where there is cross-line geological formation dip, will also introduce seismic stacking velocity errors. Excessive feathering will degrade lateral detectability, since the size of the reflection area will increase.

Signal stretch

Although only relevant to multi channel seismic data, which is subsequently CMP stacked, signal stretch must be considered when designing survey acquisition parameters as it determines the acceptable source to hydrophone offsets that should be employed. Signal stretch will degrade vertical resolution in the shallow section unless 'over stretched' data are subsequently muted in post-processing of the data. Impact of signal stretch will be particularly severe in the shallow section where near-trace offsets are too long (see below).

If multi-fold coverage is required in the shallow section, short source-receiver offsets are necessary. Unfortunately, the longer offsets are useful for seabed multiple suppression.

An acceptable angle of incidence of reflected data arriving at the streamer of up to 20 degrees is often quoted in the literature. This 20 degree criterion is advised for several reasons including signal stretch, avoidance of total internal reflection, avoidance of refracted events, and permitting a simple relationship between reflection coefficient and impedance.

Near-trace offset choice

The choice of source to near channel, or trace, offset is important for preservation of higher frequencies.

In shallow water if the near trace offset is too long, higher frequencies will be phased out across an individual receiver group as arriving energy on the near hydrophone in the group is out of phase with arrivals on the furthest receiver in the group.

A general rule of thumb for high resolution multi-channel acquisition is that the near trace offset should be no greater than half the water depth in the survey area. However for ultra-high resolution acquisition the sensitivities are even greater in shallow water and extreme care should be taken in choice of a short near trace offset.

Tow depth ghosts

The depth below sea surface at which both seismic sources and receivers are towed is critical due to the presence of (unwanted) secondary signals reflected from the sea surface (ghosts). Destructive interference of primary and secondary signals will generate frequency notches in the recorded frequency spectrum which are dependent on the tow depth employed for source and streamer. If these notches occur within the bandwidth of the desired signal, the usable bandwidth will be reduced and vertical resolution of the data will be degraded.

The source and receiver should be towed at a depth equivalent to one quarter of the wavelength of the desired frequency.

Table 13 shows the frequency of the first free surface ghost notch frequency for different tow depths used in Site Surveys.

Tow Depth (m)	Notch Frequency (Hz)
1	750
2	375
3	250
4	188

Table 13: First free-surface notch frequency vs. tow depth based on 1500 m/s water velocity

3.6.4.3. Seismic recorders

Single channel recorders

Single channel seismic data have traditionally been recorded in analogue form on paper records or magnetic tape but is now commonly recorded in digital form on computer hard drives. These seismic data are typically processed online. Data should be recorded raw (with no signal processing applied) and signal enhanced (with online processing parameters applied) in SEG-Y standard format. This will allow subsequent re-processing, if required, and loading data onto interpretation workstations.

Recordings should include raw data, trigger and event mark and source position data on separate channels. Final trace coordinate information should be written into trace headers after final position data processing.

Great care should be taken to conform to the SEG-Y format header convention for ease of subsequent work station loading and recovery from archive.

Multi-channel recorders

The purpose of these systems is to convert analogue signals into digital form for analogue streamers, or to record digital signals for digital streamers. These data are then recorded onto suitable mass storage media. The standard recording format for raw multi-channel seismic data is SEG-D.

Older systems that record data in SEG-B or SEG-C format should no longer be used.

To ensure the systems are operating to specification, comprehensive system tests are required to be performed on a daily and monthly basis.

Important characteristics of multi-channel seismic recording are discussed below.

Digital sampling

The sampling interval of the system should allow preservation of the frequency bandwidth required to achieve the data resolution required. When applying Nyquist sampling criteria, the sampling interval must, therefore, be less than half of the shortest wavelength of the frequency to be sampled and, thus, preserved. For example, to sample 1000 Hz, a sample interval of 0.5 ms is required, whereas to sample 250 Hz a 2 ms sample interval will suffice. In practice the signal phase is adversely affected at ~70 percent of the Nyquist frequency and the impact of this is explained more fully below.

Anti-alias filter

Any signal with a frequency greater than the Nyquist frequency will 'alias' back into the signal spectrum. A high-cut filter is required, therefore, to reduce the amplitude of these frequencies. Traditionally, the filters are selected to start at half the Nyquist frequency. The slope of the filter is chosen to conform with the source and hydrophone characteristics and is steep (~72 dB per octave) so that there is high attenuation of noise (and any other signal) at the Nyquist frequency.

However, to preserve the bandwidth of the data normally required for Site Surveys, without the requirement for increased sampling intervals, the filter should start at around three quarters of the Nyquist frequency. This may allow a small amount of aliasing, but will preserve higher frequencies. Therefore, when recording data at a 1 millisecond sampling interval (Nyquist frequency of 500 Hz) a high-cut filter of 375 Hz should be selected.

Low-cut filters

Low-cut filters are used to attenuate low frequency noise. Such noise, however, is best attenuated at the seismic processing stage. The low-cut filter should therefore be designed such that it does not significantly impact the bandwidth of the source. A low-cut filter in the order of 8–12 Hz is recommended for the sources typically used for Site Surveys. Care should be taken to ensure the low-cut filter is designed to exclude noise which may overdrive any analogue-digital signal converter. If this happens, the dynamic range available for the seismic data may be substantially reduced.

In some cases it may be desirable to record field data with the low-cut filter out. While this may have some benefits, it makes estimation of acceptable acquisition noise levels very difficult to assess, and is therefore not recommended unless an onboard processing system is present to undertake offline low-cut filter trials.

Dynamic range

The dynamic range of a digital seismic recorder is a critical parameter and the minimum expected standard is 24 bit recording which has a dynamic range of 115–120 dB. Careful selection of filter and amplifier gain settings, as well as seismic source and hydrophone selection and geometry, are required to ensure that the dynamic range in the signal does not exceed the recorder performance.

3.6.5. Quality control (QC)

Seismic profiling has a wide variety of inputs and variables. To ensure good results the seismic profiling set-up, equipment performance and data acquired, should be subjected to comprehensive and rigorous QC in the field by the contractor undertaking the work and this should be supervised by a competent Site Survey specialist representing the operator.

As a minimum, the following lists can be used as a guide for ensuring that the data are acquired in the field in accordance with the technical specifications, and are appropriate to meet the requirements of the Site Survey. The following items should be addressed:

Pre-survey (mobilization)

- seismic recorder instrument tests
- source/streamer layback measurements
- source signature tests
- source timing/synchronization tests
- source tow depth checks
- source cycle rate tests
- source-streamer offset checks (arrival time vs. direct measurement)
- streamer depth control tests
- streamer section integrity tests (tap tests, polarity check, channel order, etc.)
- streamer section noise tests at required survey vessel speed
- source and tail buoy positioning system verification (if applicable).

Data acquisition

During the period of data acquisition, comprehensive QC should be performed on the seismic data that is acquired to ensure adherence to survey specifications, including:

- daily/monthly seismic recorder instrument tests
- source/streamer configuration checks
- streamer active channel checks (dead, noisy, low, erratic channels)
- streamer depth control for each line recorded
- streamer noise for each line recorded (directly before and after line)
- post-plot line positioning with respect to the pre-planned survey line positions
- on-line cross-course acceptability of source and streamer positions
- full-fold data coverage checks
- streamer feather
- source signature (operating pressure, timing, array tuning, pulse shape, etc.)

- source misfires
- lost shots, gained shots, recording errors, etc.
- total shots vs. line length (i.e. mean shot point interval criteria)
- seismic data integrity checks
- QC of preliminary stacks of seismic data processed onboard the vessel.

Care should be taken to observe data quality control displays on-line to check data quality and consistency. These should be read-after-write displays to verify data that are being recorded are readable. Otherwise recommended displays include: near trace play out, (camera) shot records, and oscilloscope or computer displays showing incoming energy levels for all channels over the duration of the file. Such displays will help identify, for example: dead channels, increasing noise levels, onset of seismic interference, time break issues, etc.

Generally, if the seismic profiling data acquired in the field can be interpreted to such an extent as to meet the objectives of the Site Survey, then the data may be presumed to be fit-for-purpose.

All QC information compiled before and during acquisition should accompany the data to the seismic data processing facility to assist the data processor during processing of the seismic data to final processed state.

3.6.6. Seismic data processing

3.6.6.1. Single channel data processing

Processing of single channel seismic data includes amplitude manipulation, improvement of signal to noise ratio, removal of wave or tow depth effects and suppression of multiples. Processing of single channel seismic data is usually carried out on line in real time as the data is acquired. Recording of raw, unprocessed data permits replay with different processing parameters and is therefore recommended.

The main processing steps are as follows:

Amplitude manipulation

Data require compensation for attenuation of signals due to geometric spreading, absorption and transmission losses. Application of a Time Varied Gain (TVG) amplification is the usual method used for this and can be very useful for seismic data enhancement.

Systems are available which scale the data by means of a sliding gate Automatic Gain Control (AGC) these however remove the relative amplitude characteristics of the data and are therefore not recommended.

Band pass filters

To achieve optimum resolution data require: good signal to noise ratio, a broad bandwidth and a high fundamental frequency. When selecting filters, these factors should be considered.

Band-pass filter parameters should be chosen to retain as broad a frequency range of the desired events as possible, whilst removing unwanted noise of other frequencies. If the final filter bandwidth is less than three octaves then the data will lose resolution and begin to 'ring' in appearance.

With increased sub seabed depths (increased two-way travel time), low frequencies begin to predominate and signal to noise ratios will decrease. Different filter settings may therefore be required with increasing travel time. For optimum data quality, a time variant band pass filter should be used.

Swell filters

Swell filters may be used to remove the vertical motion caused by wave action or swell; a correction commonly referred to as static correction. Although swell filters permit an increase in the operational weather window, they should be used with care since signal to noise ratios will also degrade with poor weather. As such filters utilize signal comparison from adjacent traces, they may also remove real variations in seabed topography (e.g. sand ripples) thereby distorting the data sub seabed.

Heave/depth compensation

Heave/depth compensation systems are used in conjunction with profiling systems that are towed below the sea surface to remove differential statics caused by wave action, swell or towfish depth adjustments. The vertical corrections that are made are based on accelerometer or pressure transducer measurements which make such heave/depth compensation preferable to the use of swell filters.

For AUV or ROV carried systems, the depth below the sea surface and height of the source above the seabed should be directly compensated for from the combined use of in-built depth and altimeter sensors. The output profile should therefore accurately represent the true seabed depth profile.

Trace summation

Summing and averaging a number of adjacent traces may be used to improve signal to noise ratios. However, degradation, or smearing of lateral resolution will occur, therefore careful limits on the number of traces to include, and the weights to be used, in the use of such a process should be applied.

Deconvolution

Deconvolution is a process that removes unwanted repeatable events from the seismic data such as reverberations or multiples. Wavelet deconvolution, correctly applied, will optimize the vertical resolution of the data by removing source wavelet contamination. In particular deconvolution should be considered in areas of shallow water, where multiple reflections occur within the sub seabed depth of interest.

Output

Data should be recorded digitally to allow full offline processing to be applied and their loading to an interpretation workstation. Final processed data should be output in SEG-Y format.

Care should be taken to ensure that the output data are tied to the defined vertical datum (e.g. MSL). This may require static adjustment of individual records to recover the true seafloor profile and, or, adjust for delays in the start time of recording, or the depth at which the profiler has been deployed relative to the sea surface. Any delays or static corrections applied to the output records should be fully documented and recorded in trace headers in a consistent location to allow their application, or removal, in subsequent reprocessing or data loading.

3.6.6.2. Multi-channel seismic data processing

Multi-channel 2D and 3D seismic processing sequences for Site Surveys are similar to those used for exploration seismic. However, parameters to be used are significantly different as the objectives of the surveys are not the same. To maintain the desired high frequency content of the raw data, true amplitudes should be preserved at all stages of the processing sequence. As a result, all processing steps should be subjected to rigorous QC.

This section briefly describes the typical processing steps that are conventionally used to process HR multi-channel seismic for Site Survey purposes. It should be borne in mind that, as a general guide for processing HR multi-channel seismic data, the data processor should only apply processes that significantly enhance data quality. When in doubt, the data processor should err on the side of minimal processing rather than applying too much processing of the data. The processing steps provided below are discussed in the order in which they are normally applied. If rigorous testing shows that any particular step is not required, it can simply be omitted without affecting the order in which the remaining steps are applied. A similar processing sequence is applied for both 2D and 3D seismic data.

Designature

Although the majority of well maintained modern seismic sources provide repeatable minimum phase signatures, application of designature may benefit the data. A designature operator which converts the outgoing (far field) source signature to its minimum phase equivalent should be applied. The frequency spectrum should be left unaltered. The operator should be designed using the far field source signature recorded in the field on an auxiliary channel of the seismic recorder or, if not available, a library signature of the source used. Correct application of the process should improve the vertical resolution by the compression of the pulse. In addition, subsequent deconvolution should be more effective as these processes assume data to be minimum phase.

Gain recovery/amplitude manipulation

Corrections for spherical spreading and absorption losses have to be applied to the data. The preservation of relative amplitude relationships must therefore be constantly addressed throughout processing.

Demultiple techniques

There are a number of different techniques available to remove multiple noise in seismic data. Some of these techniques will be proprietary to specific data processing centres. Their application will depend on the characteristics of the field dataset, the objectives of the survey and the water depths over the survey area. The commonly used options that should be tested include pre-stack deconvolution in the time domain, deconvolution in the Tau-P domain, Surface Related Multiple Elimination (SRME) and Radon demultiple. The primary factor for determining which technique to use is water depth. For example, Radon demultiple works better on seismic data acquired in deeper water where a greater differentiation in move-out is observed. SRME is most effective in shallower water areas. Deconvolution is least effective in deeper waters where the record length is less than 5 to 10 times the water depth in two way travel time.

Pre-Stack Time Migration (PSTM)

PSTM is increasingly being applied to Site Survey datasets where the geology exhibits significant faulting, such as over a diapir, or where there are conflicting geological dips, where fault definition may be enhanced and there is a complex velocity variation. The benefits of PSTM include enhanced velocity analysis, improved AVO analysis, increased spatial resolution and, therefore, better tying of datasets in areas of steeply dipping geology.

With modern computing power, there is no longer any significant impact to processing turnaround on applying PSTM and its use is recommended.

Velocity analysis

Accurate and spatially frequent velocity analysis is critical to the successful processing of Site Survey data. The interval at which velocity analyses are spaced is important. Theoretically, this could imply that velocity analysis spacing should be as close as 50 m. In practice, however, a compromise of 250 m spacing between velocity analysis points is recommended, although it is good practice to increase the frequency in areas of rapidly changing geology.

Continuous, automatic, event following velocity analyses available within workstation based processing software are capable of high quality velocity picking, but still require some user guidance and careful QC of results.

An initial velocity field should be derived before application of multiple removal, e.g. SRME, and PSTM (if applied) with the final velocity field being derived after these processes have been finalized.

Deconvolution Before Stack (DBS)

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

Normal Move-Out (NMO) corrections

NMO corrections are applied using the final velocity field defined from velocity analysis. The velocity field that is applied should have been defined on data after multiple removal and, if applied, PSTM. Resulting gathers should be carefully quality controlled to ensure that velocity corrections have been properly applied.

Mute

Application of an appropriate outer trace mute is an essential and critical step in the processing of Site Survey data in order to preserve vertical resolution whilst enabling effective noise reduction in the CMP stack process.

Common Mid Point (CMP) stack

The CMP stack is the most significant process in the data processing sequence for improving the signal to noise ratio in a data set. Signal-to-noise ratio is improved by a factor equivalent to the square-root of fold by stack. Therefore a 24 fold section will improve signal-to-noise ratio by a factor of close to five through stack, while for a 48 fold section it will be close to a factor of seven.

A number of different algorithms are available. Critical to the maximum benefit of stack is that NMO velocity corrections have been applied accurately and that an effective mute has been applied to remove any stretch effects.

Deconvolution After Stack (DAS)

Predictive DAS is normally performed to remove remaining seabed and other multiple contamination effects. The process can also be applied to improve vertical resolution by compressing the signal wavelet. Deconvolution is a process which works on the assumption that the signal wavelet in the data is minimum phase. It should, therefore, be applied prior to zero phase conversion of the data.

Post-Stack Time Migration

While preference is for the application of PSTM (see above), it is important that if PSTM is not applied that all data at least have Post-Stack Time Migration applied to them to improve their interpretability. Migration, correctly applied, improves lateral resolution in the data set either by collapsing diffractions to their zero offset origin, or collapsing the Fresnel zones.

Care should be taken over the type of migration algorithm that is selected, FK, or Stolt, migration is computationally fast but cannot handle laterally varying velocity fields. Kirchhoff-based algorithms can handle steep geological dips but not laterally varying velocities. Finite-difference approaches can handle laterally varying velocity fields but can be dip limited. FX or omega-X, frequency domain migration solutions, allow imaging of steeper dips. Lower angle algorithms, however, can be applied incrementally to image up to very steep dips (80 degrees).

Therefore, in choosing an algorithm for application the geological setting, lateral velocity variation, and the dip limit of the algorithm being considered must be known to check its applicability to the data set being processed.

If data have PSTM applied then Post-Stack time migration is not required.

Post stack coherent noise attenuation (FK dip filter)

The dip filter process is designed to remove any remaining unwanted coherent noise trains from the seismic section. However, it should be noted that the process applies a cross trace filter which can adversely affect the lateral resolution of the data.

Zero phase conversion

The zero phase signal wavelet has the shortest duration and largest amplitude for a given amplitude spectrum. Site Survey data therefore benefits from zero phase conversion for the following reasons:

- the zero phase wavelet increases the ability to distinguish an event against background noise and enhances resolution

- 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 amplitude maps of key interfaces to be built automatically.

For Site Survey data, it is normal practice to extract a wavelet from the seabed event in order to design a zero phasing operator to be applied to the data set. The operator applied should be a phase only operator. Care should be taken to check that in applying the zero-phasing operator a gross static shift of the data is not introduced.

Time Variant Filter (TVF)

TVF attenuates any unwanted frequencies (random noise) down the section and therefore improves the signal to noise ratio.

Resolution requirements must therefore be considered when choosing frequency 'cut offs' to ensure at least a three octave bandwidth is preserved. If signal and noise energy of the same frequency is present, the design of the TVF may be a compromise.

TVF is a zero phase process and should therefore be applied after zero phase conversion of the data.

3.6.6.3. Seismic attributes and amplitude versus angle/amplitude versus offset (AVA/AVO) processing

In addition to imaging the geometry of the sub-surface geology, seismic analysis techniques can be used to aid assessment and characterization of lithologies and fluid charge within the sub-surface. These seismic attribute methods, originally developed for the characterization of hydrocarbon reservoirs, can also be used with appropriate multi-channel seismic Site Survey data, in particular to enhance shallow gas hazard detection (4.5.3) in assisting discrimination of hydrocarbon vs. lithological effects.

Seismic attributes are characteristics attributed to each seismic trace in a seismic data set. They may be surface attributes, related to a particular horizon or event pick, or can be seismic volume based. The simplest attributes are time and amplitude. However, many other attributes can be calculated. For shallow gas assessment for Site Surveys, the following trace attributes are generally used:

- amplitude
- energy (power spectrum)
- instantaneous phase
- instantaneous frequency.

AVA/AVO

The amplitude of a seismic event depends, in part, on the incidence angle of the recorded reflection. Such analyses are performed pre-stack and are used to provide information on the lithological and fluid content properties of the geological layers being imaged. There is a direct relation between reflection angle and offset. The Amplitude Versus Angle (AVA) is, therefore, first measured on the seismic data as a variation in amplitude with the offset, and is more commonly referred to as Amplitude Versus Offset (AVO). This is where the advantage of PSTM becomes apparent. The AVO information is directly accessible on the image gather of a pre-stack migration by common offset. AVO parameters (e.g. sub-stacks and /or R_o*G) should be computed across a constant angular aperture for the whole survey; R_o being the amplitude at offset zero and G the gradient of the AVO. The constant angular aperture should be determined such that it can be computed across the survey according to the available acquisition geometry and for a specified time interval.

Particular caution should be taken during AVO processing for shallow gas determination of the following issues:

- No AGC should be applied to the data. Geometric spreading compensation should be applied. Pattern effects can be removed deterministically.
- Spiking deconvolution should be avoided.
- Multiple elimination by use of FK methods should be avoided due to potential amplitude effects within the Fast Fourier Transform (FFT).
- Multiple attenuation by Tau-P processes, where scaling is applied prior to filtering, should be reversed after filtering. Mild and well tapered filters should be selected, allowing for uncertainties in primary velocities.
- During NMO, a 30 degree stretch mute should be considered as a limit, as stretching the wavelet in time is equivalent to compressing it in frequency in order to keep the wavelet shape the same at all offsets.
- Gathers should be displayed with angles overlaid on a number of AVO anomalies.

Prior to determining the processing parameters (and the final processing sequence) tests should be performed for noise removal, multiple attenuation and filtering.

The results of an AVO processing approach are preserved amplitude sections, AVO displays (output volumes of nears, mids and fars, R_o, G and R_o*G). Final AVO and stacked data should be supplied in SEG-Y format in order to be loaded for detailed analysis on an interpretation workstation alongside the final migrated full offset volume.

3.6.6.4. Pseudo 3D seismic processing

Closely spaced (25 – 50 m) 2D HR multi-channel seismic lines can be successfully processed into a fully migrated 3D volume with minimal extra positional control to standard operations. This is advantageous to the improvement of imaging capability but also presents a number of advantages to the interpreter when being able to interpret the data as a 3D volume on a seismic data interpretation workstation.

Software for 3D interpretation tends to be more sophisticated, offering: the ability to work with time slices and random lines, advanced auto-tracking algorithms for efficient speed picking, loop-tying and the ability to interpret data directly within a 3D volume.

The success of the processing to a 3D volume will depend on the line spacing of the original 2D data set, which for high resolution Site Survey data should be no greater than 50 m, and the structural complexity in the cross line direction.

If such an approach is being considered GNSS tail-buoy positioning is required to support modelling of the streamer shape and individual receiver positions. Beyond this GNSS-based source positioning should be considered and compasses in/along the streamers. However if such effort is considered to be a requirement it is recommended that full 3D data acquisition is pursued with multiple streamers, sources and in-sea positioning systems to maximize field efficiency and accuracy of the results.

Interpolation of traces can be achieved in the cross-line direction to narrow the cross-line line/trace sampling, however the success of this will be limited by the severity of cross line structuring and the signal-to-noise of the field data.

3.6.6.5. Enhancement of exploration 3D seismic data

In certain circumstances, exploration 3D seismic data can be a useful analytical tool to conduct drilling hazard site assessments (*The Guidelines*, 5.6). Such data sets provide a 3D view of the seabed and subsurface conditions and, due to their wider areal extent, can provide a more 'regional' assessment of drilling hazards through an understanding of the regional geological setting, than conventional Site Surveys that are typically of limited aerial coverage.

However, even with an appropriate reprocessing sequence applied, the resolution of such 3D exploration datasets will rarely attain the vertical resolution of a dedicated 2D HR multi-channel seismic Site Survey data set. Hence, the use exploration of 3D data sets must be evaluated and validated jointly by Site Survey and seismic processing specialists, on a case by case basis, to determine if such data possesses the appropriate vertical resolution/event detectability required for drilling geo-hazard evaluation.

It should be noted that exploration 3D seismic data are rarely appropriate for identifying hazardous surface zones (slides, etc.) at the scale required for a drilling site assessment or assessing shallow soils with respect to their integrity for structures (e.g. jack-up rig foundations, mooring of floating drilling units, and in guiding setting of drilling conductor pipe).

Production of shallow hazard dedicated seismic volumes by enhancement of conventional exploration seismic raw data through specialized processing flows is straightforward, cost effective and is recommended. This may be as simple as application of spectral broadening and de-ghosting of the volume, or a more rigorous 'near offset trace' reprocessing to produce a standalone volume for site investigation use.

If enhancement of the 3D seismic data is required, then production of a short (near) trace offset volume is a good and established method for such enhancement. Data processing is performed on the near offset traces of the seismic data set. Commonly, shallow hazard volume processing sequences start from field data and incorporate the following items in the processing sequence:

- preservation of amplitude integrity
- careful selection of equidistant source to near trace groups on each streamer for optimum resolution, even amplitude response and signal to noise ratio
- improvement of vertical resolution by signal spectrum whitening and de-ghosting.
- maximizing spatial resolution through interpolation (in the cross or in-line direction)
- attenuation of acquisition related footprints in time and amplitude in the shallow data window
- in shallow water, water bottom attenuation of the multiples on near offset traces.

The processing workflow should balance the need to enhance resolution, improve signal to noise ratio, minimize multiple contamination, time and spatial sampling.

For each project the following issues should be addressed:

- input data set selection
- critical acquisition survey parameters
- time and spatial sampling needed for meaningful hazard detection (maximum 2 ms sampling in the time domain)
- need for and type of demultiple processes needed on short offsets
- amplitude and time de-striping processes in line with shallow Site Survey objectives
- potential increase of signal to noise ratio in order to enhance event detection.

Different processing scenarios should be considered depending on the objectives of the Site Survey and the original exploration 3D parameters of the data set.

3.6.7. Deliverables

Both raw, or field, and processed seismic data should be delivered digitally on a suitable mass storage media in the current version of the SEG industry standard seismic data recording and exchange formats for archiving and for loading to seismic interpretation workstations.

Both single and multi-channel seismic data files are typically large and require high capacity storage media. The most commonly used mass storage media for delivery of seismic data are hard disk drives and high density tape cartridges. A number of different tape cartridge types and associated data formats exist that are typically proprietary to the manufacturer of the tape drive. The choice of media (e.g. tape cartridge) and format is typically dictated by the operator's choice of computer hardware and software used for seismic data loading and for on line and archive data storage.

Unprocessed raw multi-channel seismic field data should be delivered in SEG-D format and single channel sub-bottom profiler data in SEG-Y format.

Final processed seismic data (multi-channel and single channel) and any specified interim processed data (e.g. PSTM CMP gathers) should be delivered in SEG-Y format. Data is normally provided as a set of single line files of relative amplitude final processed sections. Some operators may specify an additional set of equalized sections but this is not strictly necessary since equalization can usually be carried out by the interpretation workstation software.

The SEG-Y file headers should include line name, shot number range, trace coordinates and coordinate reference system, sample interval and record length. For 3D datasets, the bin grid geometry, origin and alignment must also be provided. Preferred information includes details of data acquisition and processing. Data location in the trace headers should precisely follow SEG published standards.

Additionally, seismic velocity information is normally provided in the form of ASCII files containing all the velocity analyses from the complete Site Survey data set. These will then be available for time to depth conversion either at individual well locations and other points of interest, or to produce velocity grids for depth conversion of horizon maps but can also be an important interpretation tool.

Other information such as CMP gathers, shot records and partial stacks may also be provided from the seismic processing as SEG-Y files.

3.6.7.1. Seismic interpretation workstation requirements

Some seismic interpretation workstations require pre scaling of amplitudes prior to the data being loaded. This is most easily performed during seismic processing prior to output of the SEG-Y formatted processed seismic data.

Processed multi-channel data should be provided and loaded to the workstation at 32bit resolution to preserve highest possible dynamic range and provide maximum possible amplitude resolution in interpretation.

Some workstation applications have difficulty reading single channel seismic data in SEG-Y format (e.g. due to irregular shot point interval of profiler data). These issues can usually be overcome but may require customization of software, very careful definition of trace header values to assist in data loading, and/or adaption of data loading procedures (see 3.6.6.1 above).

3.7. Magnetometers

3.7.1. Introduction

Objects lying on the seabed or buried in the top few metres of sediment beneath the seabed can present a significant hazard to offshore drilling operations.

Pipelines, cables, Unexploded Ordnance (UXO), boulders, wrecks and other debris need to be identified and their positions accurately mapped such that these risks can be mitigated.

Acoustic instruments such as echo sounders (3.4 above) and side scan sonars (3.5 above) provide data that enable the identification and detailed mapping of such features and objects that lie on, or are exposed at, the seabed. These acoustic instruments do not, however, penetrate seabed sediments significantly and cannot, therefore, detect buried objects. Single channel seismic profiling techniques (3.6 above) are useful for identifying some buried objects. However, as detection relies on many variables such as target size, equipment towing geometry, seismic pulse shape, pulse frequency and repetition rate, results can be unreliable and detection intermittent.

Towed marine magnetometers (and gradiometers) provide a means of detecting ferromagnetic infrastructure and objects (typically iron or steel) both exposed at the seabed and, importantly, those buried in the top few metres of sediment which are invisible to acoustic and seismic techniques.

3.7.2. Basic principles

3.7.2.1. Magnetometers

The majority of magnetometers currently available for Site Surveys are of two different types: proton magnetometers and caesium magnetometers. Both of these instruments measure total magnetic field intensity. The former utilize the precession of protons (hydrogen nuclei) in a hydrocarbon fluid (commonly kerosene) for the measurement of total field intensity.

Proton magnetometers typically have a resolution of one nanotesla (nT) or better.

Caesium magnetometers typically have a greater resolution than proton magnetometers. Caesium magnetometers utilize caesium metal in the form of a vapour within a chamber. This vapour is illuminated by a laser light source and a photocell captures the light once it has passed through the vapour cell, thereby allowing the measurement of total magnetic field intensity.

Whichever method is used, the magnetometer sensor is housed in a ruggedized marine pressure housing or towfish (sometimes referred to as a bottle) at the end of an electrically and mechanically suitable tow cable. This should allow the magnetometer to be towed by a vessel at an appropriate distance away from the survey vessel (to minimize magnetic interference from the vessel) and sufficiently close to seabed to detect metal objects/infrastructure (3.7.4 below).

3.7.2.2. Gradiometers

Magnetic data can be adversely impacted by short-term time variations in the earth's magnetic field causing spurious magnetic anomalies that can be misinterpreted on magnetic records. These spurious readings can be greatly reduced by the use of a marine gradiometer in which two or more conventional magnetometers are utilized in a horizontally or vertically separated configuration, thus allowing measurement of the magnetic gradient between the individual magnetometers rather than the earth's total magnetic field.

The use of a gradiometer provides greater accuracy in measuring the depth of an object (in the case of vertically mounted sensors) or its horizontal distance from the gradiometer (in the case of horizontally mounted sensors).

A gradiometer that utilizes several magnetometers mounted in both the horizontal and vertical planes can provide accurate positioning of objects in a three dimensional sense, assuming that the gradiometer position is precisely known through subsea acoustic positioning.

3.7.3. Applications

3.7.3.1. Detectability

In considering the use of a magnetometer or gradiometer in a marine debris or object/infrastructure search, it must first be ascertained whether or not the target of the search is truly magnetic and of sufficient mass to be detected.

Typical items that may be detected include pipelines, steel telephone cables, electric current carrying conductors (power cables), steel hulled shipwrecks, drilling wellheads and casing (including those cut off below seabed), anchors, anchor chains, UXO, iron and steel debris and other iron or steel containing man-made items.

In some cases, ancient ship wreck sites may also be detected as some ballast stone and kiln fired clay items are slightly ferromagnetic.

In general, magnetic anomalies in ferromagnetic materials can be divided into two classes: induced magnetism and permanent magnetization. Induced magnetism is a combination of the earth's magnetic field, the magnetic susceptibility of the object and the shape and orientation of the object relative to the earth's magnetic field. The combination of these factors leads the object to behave like a magnet and it is this magnetic field that may be detected by a magnetometer.

Permanent magnetization is a property related to the object alone (and not to the earth's magnetic field or the object's shape or orientation within that field). In most cases, the permanent magnetization of an object is greater than the induced magnetism and is, therefore, the predominant magnetic property used in detecting the object. In practice, however, it is a combination of both induced and permanent magnetism that leads to the detection of a magnetic 'anomaly' which is observed with a magnetometer. Example magnetic anomalies of common objects are given in Table 14 below.

Object	Typical maximum anomaly			
	Near distance		Far distance	
	Distance from object	Anomaly strength	Distance from object	Anomaly strength
Ship (1000 tons)	30 m	300 – 2000 nT	300 m	0.3 - 2.0 nT
Anchor (20 tons)	15 m	200 – 650 nT	30 m	25 – 80 nT
12″ pipeline	8 m	50 – 200 nT	15 m	12 – 50 nT
6″ pipeline	3 m	100 – 400 nT	15 m	4 – 16 nT
Well casing & wellhead	15 m	200 – 500 nT	150 m	2 – 5 nT

Table 14: **Magnitude of magnetic anomalies of example objects found on the seabed.**

In general, marine sediments will not affect a magnetic anomaly and, therefore, the detectability of a ferromagnetic object. Igneous or volcanic rock (either *in situ*, or redistributed as glacial erratics, or erosion surface cobble/boulder beds) may, however, introduce large magnetic anomalies that could disguise relatively smaller anomalies from the objects of a search. If the rocks are buried beneath a layer of sediment their magnetic anomalies will be broader, allowing the superimposed shorter wavelength anomaly of a ferrous object to be differentiated.

The ability to estimate the amplitude and probable appearance or signature of a magnetic anomaly can be useful during the planning stages of a Site Survey to determine grid size, line spacing and sensor towing requirements and search feasibility. Understanding the signature of an object can be important in recognising the target anomaly, in estimating its location and distance/depth from the sensor, and defining the potential value or success of a survey in, for example, attempting to find an abandoned telecommunications cable. Given the approximate weight, size and distance of an object from the sensor it is possible to estimate the amplitude of the magnetic anomaly. A detailed description of this calculation is beyond the scope of *The Technical Notes*.

3.7.3.2. Anomaly signature

The shape of a magnetic anomaly is important in distinguishing an object of interest from background magnetic signal and 'noise' and in estimating the object's depth, or distance, from the sensor.

The anomaly may be asymmetrical about the object with the actual position of the object generally corresponding to the point on the anomaly with the greatest rate of change of the anomaly with respect to distance. An object's magnetic anomaly will appear proportionally broader with depth or distance from the sensor, a characteristic that can be useful in determining the burial depth of an object - assuming that the sensor's position and height above the seabed is accurately known.

The use of a gradiometer, however, will allow the depth of an object to be calculated more accurately.

3.7.4. Towing configuration

The configuration of the towing system utilized for a magnetometer survey is important for ensuring that high quality data is acquired during a Site Survey. The cable tow length, sensor height above seabed, position of the sensor and speed of tow are some of the more important operational considerations.

It is most important that the magnetometer is towed as close to the seabed as possible since a discrete object's magnetic anomaly is proportional to the cube of the distance between the sensor and the object.

The magnetometer also needs to be sufficiently far away from the towing vessel to eliminate noise in the data brought about by the magnetic effects induced by the vessel. As a rule of thumb, the magnetometer should be towed a distance equivalent to at least five times the vessel's length.

This rule of thumb can be reduced if using a gradiometer (which is affected less by the noise introduced by the towing vessel) or a vessel with a hull made from a material other than steel (e.g. aluminium).

Accurate positioning of the sensor using an acoustic positioning system (3.2.3 above) is essential to ensure that magnetic anomalies can be mapped accurately. However, care should be taken to locate the USBL transponder far enough away from the sensor to avoid magnetic interference. Positioning the sensor by the application of a measured fixed layback from the towing vessel may be the only practical option in very shallow water.

3.7.5. Data processing

Magnetometer data can be processed, interpreted and in some cases modelled, thereby providing greater confidence in, and accuracy of, the interpreted results.

In the case of gradiometer data, processing and gridding of data to produce a mathematical 'surface' of relative magnetic differences is very useful in identifying and positioning buried ferromagnetic objects and features, particularly if these data are overlaid, or integrated with, other complementary data sources such as side scan sonar (3.5 above). It is recommended using a GIS to facilitate data integration and maximising the data value.

3.7.6. Quality control

Unless there are known metallic objects within the area being surveyed, it can be difficult to ascertain how well a magnetometer is performing. Often, if signals of only a few nT are recorded, these may be due to background noise.

If there is doubt over the equipment performance then good practice is to survey a line over a known feature such as a wellhead or pipeline, if practical. Two lines should be run in opposite directions over an identified anomaly to ensure the positioning of the system is accurate. Such a test should be part of the mobilization acceptance trials, especially if the magnetometer data are seen, pre-job, as critical to hazard identification and mitigation.

3.7.7. Deliverables

The normal digital output from a magnetometer or gradiometer system is in the form of an ASCII line file. As a minimum, this file should record sensor position and magnetic intensity (nT). Other data such as sensor depth and/or height above seabed are also useful and should be included in the ASCII file, if possible, this may require offline processing prior to production of the final ASCII file.

Following data processing and interpretation using a suitable software package, the final deliverable will normally be a map.

There are no accepted industry standards for the recording and exchange of raw and processed magnetic data. However, it is recommended that these data are delivered by the contractor in an agreed electronic format (e.g. ASCII files).

3.8. Seabed sampling

3.8.1. Introduction

Seabed soil sampling and *in situ* geotechnical soil testing equipment in the upper few metres of sediment below the seabed should be undertaken to ground-truth geophysical data or interpretations. Techniques described here are essentially geological and geotechnical. There is a wealth of literature and guidance on the subject; in particular *Guidance notes on Geotechnical Investigations for Subsea Structures*, Revision 02, 2000, by the Offshore Soil Investigation Forum (OSIF), and ISO 19901-8: 2014, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 8: Marine soil investigations*.

Seabed soil sampling and *in situ* testing carried out to ground-truth the geophysical data can be used to ascertain the nature and geotechnical properties of soils. However, the configuration of the equipment that is typically used will only penetrate the top few metres of sediment below the seabed and data are, therefore, only suitable for shallow soil characterization e.g. for anchoring or pipeline construction. Sampling techniques for deeper soil information (e.g. for assessment of jack-up rig foundations) are outside the scope of *The Technical Notes*.

A preliminary study of the survey area (section 2 above) should have been carried out to determine which equipment will need to be used for the expected soil conditions and to satisfy the needs of the project. Special consideration should be given to deep water surveys and areas of high seabed slope angles, as some sampling and *in situ* testing equipment will have operational constraints in these conditions.

It is normal practice to select the number and positions of sampling and testing stations after interpretation of the shallow geophysical data acquired over the area to ensure that representative soil samples are acquired. Sample stations should be chosen prior to a site-survey but should always be revisited and checked for their absolute validity on the basis of any Site Survey geophysical data acquired.

3.8.1.1. Equipment

Equipment can be divided into seabed sampling equipment (of which there are several different types) and *in situ* testing equipment (of which only cone penetration testing (CPT) is considered here).

Sampling is used for soil type identification and description and sub-samples may be extracted for geotechnical and/or environmental laboratory testing. *In situ* testing provides more accurate soil stratification and empirical determination of some soil parameters. There are advantages in using both techniques at the same positions and integrating the results accordingly.

The following methods of acquiring seabed samples are described:

- grab samplers
- box cores (particularly for environmental surveys)
- gravity and piston corers
- vibrocorers.

3.8.1.2. Grab samplers

There are many different types of grab sampler and all are designed to retrieve a small surface soil sample from the seabed. Grab samplers are often used for environmental sampling where benthic information is required, but are also suitable for ground-truthing of geophysical survey data where standard coring techniques do not recover an adequate soil sample.

Soil samples are often disturbed and are not generally suitable for obtaining geotechnical information. Grab samplers are relatively light and easy to deploy but are not recommended for use in deep water.

It should be noted that, in some cases, the soil sample will not be truly representative of the surficial soils, either because the sampler has penetrated into soft sediments or because fine sediment has been lost through the jaws of the sampler during retrieval.

3.8.1.3. Box and multi-corers

These systems are used when recovery of an undisturbed sample of the sea sediment interface is critical without the loss of any material during recovery.

Multi-corer systems are hydraulically damped systems that slowly push up to twelve short core sleeves into the seabed after the frame on which they are deployed settles on the seabed. On recovery the multiple samples can be sent for individual analysis: geotechnical, geochemical, chemical, biological or sedimentological knowing that they were acquired from the same location and they are undisturbed. Such systems are very useful for environmental surveys.

Box corer systems push a large box into the seabed and seal it for recovery. The dimensions of the box vary but can be in excess of 0.25 m^2. Again the advantage is that the sea-sediment interface is recovered intact. The side of the box can be removed upon recovery to allow the section of sediment recovered to be recorded and described. Sample tubes can be pushed into the soil to be sent for laboratory analyses. While generally of better quality than a piston core (3.8.1.4 below) soil sample for the sea-sediment interface these samples are not of as high a quality as the multi-corer samples as the water above the sediment interface is not preserved.

Both multi and box corers only recover sediments to less than 1 m in depth.

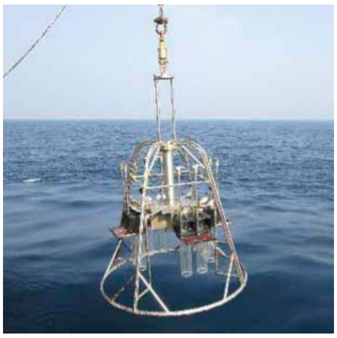


Figure 7: (Left) **Spring loaded grab system in its deployment frame (source: Northeast Coastal & Barrier Network)**

Figure 8: (Centre) **Hydraulically damped multi-core system, the empty sample tubes are visible.**

Figure 9: (Right) **Box core, this model has a transparent side allowing description of the sediment section on recovery.**

3.8.1.4. Gravity and piston corers

Gravity corers provide a rapid means of obtaining a continuous soil sample in a wide range of water depths. They consist of a heavy weight (which may be adjustable) attached to a core barrel (up to 8 m long) fitted with a steel cutting shoe. The core barrel contains an inner PVC liner that has a typical diameter of 80 – 90 mm which retains the soil sample. Thinner core barrels and liners are sometimes used to assist penetration. A spring steel core catcher ('tulip') is fitted inside the cutting shoe to assist soil sample retention. Water is allowed to pass through the liner and out through a one-way valve fitted at the top of the corer.

Gravity corers are either deployed by a free fall winch (which is typically released after the corer is lowered to about 10 m above the seabed) or by use of a Kullenberg trigger device (Figure 10). This is a simple release mechanism activated by a weight attached to a trigger arm. When the weight lands on the seabed, the corer is released and free-falls into the seabed from a set height (usually 5 – 10 m). This is determined by the length of the trigger weight line. Fixed winches are used to deploy and recover this equipment.

A piston corer is a gravity corer fitted with a piston that is drawn up the core barrel as the corer penetrates the seabed. As the corer is withdrawn, the piston remains in contact with the top of the soil sample creating a vacuum which assists sample retention and recovery. When operated correctly, a piston corer will be capable of collecting better quality soil samples of greater length than a simple gravity corer particularly in a soft sediment setting. However, piston corers can be difficult to operate, and safe, successful operation requires some knowledge of the ground conditions and experience with the equipment and handling systems.

Gravity and piston cores are best suited for use in soft to firm clays and silts.

The aluminium or steel spring tulip or core catcher is fitted behind the core cutting shoe to assist sample retention. Care should be taken in selection of a suitable strength tulip to ensure the soil sample is not disturbed or lost on recovery. If the fingers of the catcher are too strong and the sediments too soft the catcher will not open in response to the sediment and either: no soil sample will be recovered, or the sediments will be badly disturbed. If, however, the fingers are too weak they may not close upon recovery of the corer allowing sediment to be lost during recovery.

Figure 10: (Left) **Piston corer with Kullenberg type release awaiting deployment.**
Figure 11: (Right) **Vibrocorer, the vibration unit (yellow) is visible at the top of the barrel.**

3.8.1.5. Vibrocorer

A vibrocorer consists of a heavy vibrating motor supported within a steel frame that vibrates a core barrel into the seabed. A tripod cylinder-configuration is the most commonly used vibrocorer although there are variations on this which usually show variations in sample diameter, vibrating motor power and frame configuration. Vibrocorer s can weigh up to 10 tonnes in air and recover soil samples of around 80-90 mm in diameter and up to 6 m in length.

The core barrel contains an inner PVC liner which retains the sample. A tulip is again fitted behind the cutting shoe inside the barrel to assist in sample retention, along with a piston placed inside the liner.

Operation of a vibrocorer requires the survey vessel to be stationary whilst the equipment is on the seabed. The core barrel is vibrated into the seabed normally for between 5 and 10 minutes depending on the soil type. This time may be reduced in loose sandy soils. The rate of penetration into the seabed is normally transmitted to the surface via the system umbilical and monitored in real time. This information is very valuable when interpreting results and to ensure minimum soil sample disturbance during acquisition.

Vibrocorers are recommended for use in hard clays and granular sediments such as sands and gravels, where gravity and piston corers are often not successful or suffer from limited penetration. Sample disturbance can be high especially in soft clays (where they should not be used) and sands and whilst laboratory testing may be undertaken, this is normally limited to basic geotechnical properties.

Sample disturbance during vibrocoring may give the following misleading information:

- Rodding and plugging may lead to softer sediment layers being completely missed by the corer.
- Soft or very loose surface soils may be pushed away from the sample tube due to the stiff nature of the tulip.
- Samples may be compacted giving a reduced apparent thickness.
- Strength of soft clays may be reduced by the vibration of the soil.
- Horizontal banding of layers may be distorted.
- Suction caused by retraction of the corer may drag soil down the tube and distort layering.

Vibrocorers, therefore, should only be used where gravity coring has been proven to fail to reach required, or critical, sample recovery depths.

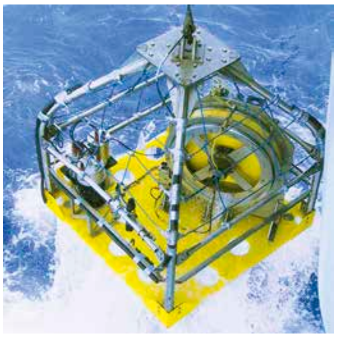
3.8.1.6. Cone penetration testing (CPT)

The CPT is the most widely used *in situ* test for obtaining geotechnical soil information. CPTs work on the principle of an instrumented cone on the end of a series of rods (or alternatively a coiled rod) being pushed into the ground at a constant rate. Sensors mounted in the cone conventionally measure the following:

- cone end resistance
- local side friction
- pore pressure.

These data may be combined to provide an empirical determination of soil type, strength and other geotechnical parameters. Used in conjunction with soil samples, a skilled interpreter of CPT data can define the information needed for stratigraphic delineation of soils and derivation of geotechnical soil properties for pipeline or shallow foundation design.

CPT frames are lowered to the seabed from a survey vessel crane, 'A' frame, or through a moon pool. Tests are usually carried out at a penetration rate of 2 cm per second. Communication with the surface is usually in real-time using either an umbilical or acoustic modem connected to a surface display unit. The operator is thus able to monitor progress of the test.



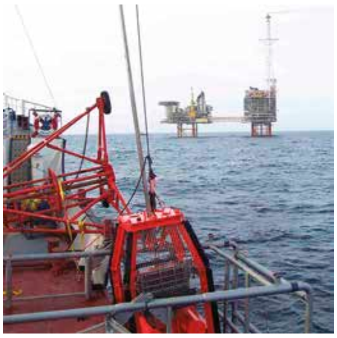


Figure 12: (Left) **Mini-CPT with coiled rod system.**
Figure 13: (Right) **CPT with straight rod, vibrocorer stored horizontally in background.**

The CPT units can vary in thrust capacity, rod handling systems and cone size as follows:

- For systems deployed from survey vessels, the thrust capacity typically ranges from 1 tonne up to 10 tonnes; the greater thrust requiring increased weight to provide the necessary reaction force. The size and handling capability of the vessel will dictate the maximum weight of CPT that can be used. Stiff and dense soils and/or deeper penetration require more thrust than softer, less dense soils.
- There are two main types of rod handling system; the straight rod configuration where the required length of rod is either pre-loaded onto the CPT rig before it is launched or added to during testing, and the coiled rod system, which can carry up to 20 m of rod on a cylindrical drum.
- The standard CPT cone size is 10 cm^2. However, other cone sizes also in use are 2 cm^2, 5 cm^2 and 15 cm^2.

CPT systems with thrust capacities up to 30 tonnes, with a correspondingly greater penetration capacity, are generally deployed from specialist geotechnical vessels.

3.8.1.7. Other seabed sampling techniques

There are more specialized seabed sampling systems for specific applications. These are outside the scope of *The Technical Notes* but are mentioned briefly here for completeness:

- Rock Corer – primarily used where rock outcrops at the surface or for very stiff to hard sediments.
- Jumbo Piston Corer – this is the same as a standard piston corer but with a much longer core barrel – up to 30 m. Best suited for soft sediments in deep water settings.
- Deep Water Sampler – generally used for deep penetration, high quality samples in very soft clays.

CPT equipment can also include specialized cones and penetration devices for specific purposes, these include:

- full flow penetrometers for soft soils
- dissipation tests to assess soil drainage parameters
- gas or chemical detection systems.

3.8.2. Equipment deployment

The operation of seabed sampling and CPT equipment from survey vessels involves handling heavy equipment in a hazardous environment. The challenges are especially great when working in deep water.

In order to ensure safe and efficient operation, specialists should be involved in the selection of: vessel, safe deck layout, configuration of winches, handling and deployment systems and the generation of working procedures.

An acoustic transponder should be attached to the sampling or testing equipment to enable it to be accurately positioned by a subsea acoustic positioning system (3.2.3 above). On some systems, such as a vibrocorer, placement of two transponders, at the top and base of the frame, will assist verification that the system is upright on landing and throughout the test.

3.8.3. Data processing

3.8.3.1. Soil samples

Soil sample handling, description and testing should follow recognized industry standards.

Aboard the vessel, soil samples should be cut into suitable lengths (normally one metre). Every effort should be made to avoid disturbing the soil samples at all stages of acquisition, extraction from the core barrel, cutting, storage and transport. It is essential that all soil sample pieces be labelled correctly with date, time, station number, sequence number, position etc. and that the top and bottom of each length are easily recognized.

All soil samples should be described in accordance with the relevant international standards. It is recommended that simple strength tests (torvane or shear vane and pocket penetrometer) are carried out on cohesive soil samples at each end of the soil sample sections on recovery. All soil samples should be sealed to prevent moisture loss and should be stored vertically in a robust storage container. Information concerning the samples should be recorded on field sample logs in digital format.

3.8.3.2. *In situ* tests

It is recommended that data is reported in the form of a summary table and CPT sample log. For details of information required to be reported for each test, reference should be made to the relevant international standards. As a minimum the following data should be recorded:

- site area and location identification
- test number
- date of test
- cone serial number
- cone geometry and dimensions with position and dimensions of filter stone
- calibration factors used
- zero readings of all sensors before and after each test, at seabed and surface
- total thrust during test
- observed wear or damage on the tip or sleeve
- penetration rate
- any irregularities during testing
- cone area ratio
- water depth.

The three parameters of cone end resistance, local side friction and pore pressure should be plotted against depth of penetration corrected for cone inclination. Other common graphical parameters to be included are:

- shear strength for clays and relative density for sands
- friction ratio
- pore pressure ratio
- interpreted soil description and legend.

Some CPT software packages also include an automatic interpretation of the soil using recognized soil behaviour models. These are useful as a first pass assessment; particularly if a geotechnical engineer is not present or the soils are not known. However, they should not be relied upon for final interpretation. This should be carried out by a qualified and experienced geotechnical engineer taking into account all available soil data and the final results of any geotechnical soils tests.

3.8.4. Deliverables

All sample positions should be plotted and labelled on the geophysical maps and longitudinal profiles in the Site Survey report (section 4 below). Laboratory results should be presented in an agreed standard text format. The description, classification and results of any laboratory testing of the soil samples should be integrated into the geophysical Site Survey report.

All CPT data should be supplied as an electronic data file in an agreed format for further use in engineering design models. The information from the CPTs, including the final interpretation of soil type and strength, should be integrated into the geophysical Site Survey report.

It is recommended that soil and CPT profiles results are superimposed on both the geophysical profile upon which the sample/CPT location was placed and on the interpreted depth profile of the same geophysical profile to verify the nature of the units penetrated.

3.8.5. Quality control

It is essential that strict quality control is applied to all aspects of seabed sampling and testing. Tried and tested procedures should be applied, and overseen by qualified and experienced professionals. The different aspects of the operation to be considered should include the following:

- selection of sampling/testing equipment
- selection and configuration of winches, equipment handling, and deployment systems
- definition of safe operational procedures
- selection of sample stations – this should be completed by experienced geoscientists following review of all available data including shallow geophysical data collected during the survey programme
- operating parameters, including core barrel size, drop height for gravity/piston cores and vibration time for vibrocores
- calibration of CPT cones
- calibration of soil strength test equipment
- quality of the soils samples and CPT data
- handling and storage of recovered soil samples
- specification of geotechnical laboratory testing programme
- conduct of soil sample analysis and laboratory testing
- interpretation of CPT data
- integration of results with geophysical data and other existing data and reports.

4. Data integration, interpretation and reporting

4.1. General

The end result of a Site Survey is a report that comprises an interpretation of the specifically acquired and processed Site Survey data (hydrographic, geophysical and geotechnical) that has been integrated fully with all relevant existing data for the area of interest.

The report should describe and assess the seabed topography and relief and geological conditions, from seabed to a depth of at least 200 m below the preferred setting depth of the first pressure containment string, or a depth of around 1000 m below seabed, whichever is greater, to help plan safe and efficient rig emplacement and drilling operations, and to assist in identifying potentially sensitive seabed environments.

The following lists data that may be available and should be included in the site assessment:

- existing survey reports and, if available, the datasets on which they are based
- desk studies and the work carried out during pre-survey planning
- all records acquired from the sensors used during the Site Survey, including single and multi-beam echo sounders, side scan sonar, sub-bottom profiler, multi-channel seismic and magnetometer data
- seabed soil samples, CPT data and geotechnical reports
- the results of environmental surveys, including seabed photographs soil samples and analyses
- exploration seismic data, logs from offset wells and previous operational drilling experiences
- cultural and infrastructure information.

It is important that the datasets listed above are considered together with data from the Site Survey in a fully integrated manner. Specific conclusions may be drawn during the course of interpretation of an individual dataset (e.g. the presence of seabed obstructions from side scan sonar data), but the final interpretation should only be made after a fully integrated study of all available data is completed.

In this context, the use of GIS is of great benefit and constitutes a key tool for integration and visualization of processed data and interpretive results. In addition to enabling fast and easy access to all the data, and to easing the process of integrating and comparing different components of data, a properly configured GIS can also provide specialist applications to assist data analysis. Any existing GIS data that may have been prepared during a pre-survey desk study will contain useful information about the survey area and should be integrated with newly acquired data.

Detailed integrated interpretation and report preparation is normally carried out onshore after the Site Survey data acquisition is complete and the data is fully processed. However, preliminary data processing and interpretation should always be carried out on-board the survey vessel as part of the quality control process during data acquisition, to ensure that the quality of the acquired data meets the requirements, and the objectives, of the Site Survey. This preliminary interpretation immediately increases knowledge of the conditions in the area and may assist modification of the original survey programme in the field to allow for any re-location of the proposed well location that may be required.

4.2. Ground-truthing of geophysical data

Geophysical data acquisition is a remote sensing technique and ground-truthing of geophysical data should, wherever possible, be a fundamental part of the interpretation process.

Interpretation of seabed conditions is normally aided by the collection of seabed samples collected during the Site Survey. However, soil samples from environmental surveys and/or samples from geotechnical surveys are equally useful. Seabed photographs, often taken during environmental surveys, also aid such interpretation.

When interpreting shallow sub-seabed soil conditions, drilled geotechnical boreholes and cone penetration test data acquired by a geotechnical drilling vessel for drilling rig foundation assessment or engineering purposes provide the most useful ground-truth information, defining both the soil type and the geotechnical parameters to several tens of m sub-seabed with good vertical resolution. In areas where there is good lateral geological continuity, this information can provide significant value through extrapolation along carefully planned seismic tie-lines.

When interpreting deeper geological conditions, a similar approach can be taken using top-hole offset well data; normally provided in the form of interpreted composite logs and raw geophysical logs.

In areas where no ground-truthing is available, alternative sources of information such as previous reports, published maps, academic research and previous rig installation and drilling operations experience, should be used.

4.3. Seismic data loading

The seismic interpreter should be presented with relative amplitude 2D and/or 3D HR seismic data loaded to the seismic data interpretation workstation. Seismic positioning data should always be included within the seismic trace headers in accordance with the SEG-Y format requirements. When the data is loaded, the correct location of the seismic data should be checked. For 2D datasets, this should include checking that the seabed and other key horizons correspond vertically at cross-line intersections. For 3D datasets, the volume alignment, inline and cross-line spacing should be checked against an independent reference. It is recommended that a geodetic specialist checks the relative and absolute positioning accuracy of the data and that the correct coordinate reference system is being used. Where possible, offset well information should be used to check for consistency with the seismic data.

4.4. Bathymetry and seabed topography/features

All relevant data sets should be used to map bathymetry, seabed topography, sediment distribution and seabed features.

MBES data is processed to produce a Digital Terrain Model (DTM), seabed contour maps, seabed gradient maps and other 3D images of the seabed. Most MBES systems also record backscatter and signal intensity data from which classification of the seabed sediments may be derived. MBES data may be an effective supplement to side scan sonar data and can provide valuable additional information on seabed features. However, the height of the MBES transducers above the seabed is a significant constraint to interpreting seabed features and the results should be used accordingly. Hull-mounted echo sounder/MBES data in deep shelf and upper slope settings may be more accurately positioned than towed fish side scan sonar data and this attribute can be used to improve the accuracy of the mapped positions of interpreted seabed features.

Side scan sonar data should be processed into a seabed mosaic (3.5.8 above) before detailed interpretation takes place. These data should always be interpreted in conjunction with single or multi-beam echo sounder data since the two datasets are complementary. The echo sounder provides measurements of water depths whilst the MBES backscatter and side scan sonar data provides information about seabed texture, composition, features and topography.

The objectives of the bathymetry and seabed topography/features interpretation include:

- mapping of water depths and seabed gradients
- identification, location and height measurement of man-made objects and obstructions on the seabed (e.g. wrecks, wellheads, debris, pipelines and cables)
- identification, location and height measurement of natural objects and obstructions on the seabed (e.g. boulders, outcropping rocks, reefs and bed forms.)
- identification of seabed composition and the distribution of sediment types
- identification of surface geo-hazards (e.g. pockmarks, hardgrounds, fluid escape zones, slump zones and mud volcanoes).

If a magnetometer or gradiometer dataset has been recorded, its interpretation should be integrated with the results of the side scan sonar interpretation. Interpretation software should be used that can either display the single line magnetometer trace superimposed on the mosaic or, where there is sufficient density of data, a gridded and contoured magnetometer plot should be superimposed on the mosaic.

In deep water, the seabed 'pick' from exploration 3D seismic data (preferably a near-trace reprocessed, or enhanced, volume) can be used to visualize and evaluate water depth and seabed conditions.

Water depths over the whole survey area should be illustrated by contoured and/or posted depth maps referenced to the appropriate local vertical datum (e.g. MSL or LAT). Seabed gradients, irregularities, bed forms, reefs and other such features can be usefully illustrated using shaded relief maps and illuminated digital elevation models. Water depths should be described, particularly in the areas, or locations, of interest, and specific attention should be drawn to water depths which are significantly different from those charted in previous surveys.

All man-made and natural seabed features within the survey area (e.g. wrecks, boulders, cables and moorings) should be described in the text and clearly and unambiguously mapped. This information should be derived from both survey data and any other sources (e.g. as-built construction/installation data and nautical charts). If sonar mosaics are reproduced on the final maps, interpreted features should be clearly indicated and annotated. A list of all relevant identified seabed objects or obstructions should be made together with their description, location and range and bearing from the proposed well location(s).

Seabed features (e.g. pockmarks and hardgrounds) should be mapped to show their true extent rather than use of a simple icon to mark their centre point.

4.5. Sub-seabed assessment

4.5.1. General

All seismic profiling data, including single channel and multi-channel 2D and 3D seismic data, should be interpreted. These should form the basis of an integrated interpretation of the sub-seabed overburden tied together using any other relevant data. Interpretation, mapping and assessment of the seismic data should be carried out over the entire top-hole section, or to the total depth of interest defined by the operator.

Data interpretation should identify any prominent marker horizons (geophysical interfaces) in order to establish an overview of the geological conditions and to reference with the results of the pre-survey desk study (section 2) that should be undertaken during survey planning. This should be followed by a detailed characterization of the seafloor topography and recent sedimentary processes with the objective of developing a single, coherent model of shallow geological conditions at the site. Regional geological information should be incorporated to further enhance the study. Of particular value, is information on the stratigraphic sequence, deposition rate models and seismic time-depth conversion.

In describing the overburden reference should be made to published seismo-stratigraphic nomenclature for the area being studied, and cross-referenced to geological chronology (e.g. period, epoch, age, group, formation etc.). Relevant references used in achieving this should be properly referenced in the text.

Seismic character should be used to interpret data; particularly if there is no direct ground-truthing of geological sequences available. In certain circumstances, it may be possible to use seismic data to differentiate seismic facies, for example, to discriminate between sand sequences and clay sequences, and between soft clays and hard clays. However, the constraints of such predictions should be fully understood by the interpreter and made absolutely clear to the end-user of the results.

Geotechnical characteristics such as shear strength, friction angle and relative density cannot be derived directly from geophysical data. As a result, discussion of the soil conditions relevant to engineering activities such as anchoring, conductor driving or jack-up rig emplacement, should be limited to a general discussion about the expected soil types and their variability.

The presentation of the results should include:

- Isopach maps of horizons interpreted to represent significant changes in sediment type, compaction or other variations that produce a seismic response and are directly relevant to rig installation and top-hole drilling. If in doubt the interpreter should discuss the appropriate horizons to be mapped with the Operator.
- Geological features or drilling hazard maps showing anything that could impact the installation or operation of the drilling rig. Features commonly shown include gas seeps, shallow gas, shallow water flow intervals, faulting, buried channels, hard grounds, mud lumps and flows, boulder beds, steep slopes, reefs. (See Appendix 1, Hazard Impact Tables in *The Guidelines*.)

- Geological cross-sections along the primary lines intersecting at the proposed drilling location(s), representative seismic survey lines going through or close to existing, alternate and planned relief well locations and other locations of interest (e.g. planned jack-up rig leg locations). Vertical scales should be defined in accordance with the objectives of the survey and cross-sections should clearly show the main lithological units.
- Tie-lines to key offset wells should be included wherever possible and reference directly to drilling experiences at those wells (e.g. flows, kicks, fluid losses and tight zones). Such information should be provided to the interpreter by the operator.

All interpretation products should show the locations of soil sampling stations such as grab samples, gravity and vibrocores, geotechnical boreholes, CPTs and previously drilled wells that have been used to ground-truth the seismic data.

All interpretation products should be accompanied by the estimated accuracy of the relevant parameters and results, e.g. positions, dimensions/sizes, areal extent, depths and distances.

4.5.2. Shallow drilling hazards

The relevant data to be used for shallow drilling hazard (geo-hazards) interpretation are single and multi-channel seismic data which have the relative amplitudes preserved. These data are usually 2D HR or 3D HR seismic acquired during the Site Survey. However, it may be possible to use data derived from exploration 3D seismic surveys (4.5.5 below). Other exploration 3D seismic data sets such as near, mid and far angle and velocity volumes may provide additional information for detection of geo-hazards.

The full capabilities of the seismic interpretation workstation should be used in data analyses, including enhanced display options and attribute analyses of both interpreted horizons and selected geological intervals.

The geo-hazard assessment should focus on the identification of conditions at the seabed and within the top-hole section that could adversely impact drilling operations. All identified geo-hazards should be recorded with a detailed description of their nature, areal extent, depth below a defined vertical datum and distance from the proposed drilling location(s).

Seismic attribute displays are of great value for the analyses of significant intervals of the seismic data. In this respect, interpretation workstations provide a number of options, including, but not limited to:

- Instantaneous amplitude or amplitude envelope: amplitude is presented irrespective of phase, and the total amplitude within the signal wavelet envelope is displayed. This type of display is particularly useful for identifying amplitude anomalies.
- Instantaneous phase: sometimes described as a continuity plot, it is an amplitude independent estimate of the trace. Instantaneous phase is useful because it often enhances weak events not evident on conventional seismic displays. This is particularly helpful in the definition of geological discontinuities, pinch-outs, angularities and events with different dip which interfere with each other. As a result, these displays are also useful in identifying tuning effects and phase reversals. Similar results to instantaneous phase can be achieved by applying a very short gate AGC (e.g. 12 ms) to the data.

- Instantaneous and weighted average frequency: This is a sample by sample measure of the frequency in the trace and is equivalent to the time derivative of the trace. Instantaneous frequency is useful for identifying low frequency shadow zones that may occur below a gas accumulation resulting from high frequency signal attenuation. However, the usefulness of such a display is dependent on the choice of frequency bandwidth of the palette for colour representation of the frequency data and the signal to noise ratio in the data.

The hazard impact tables contained in Appendix 1 of *The Guidelines* list a number of geo-hazards that may impact the installation of different types of rig and the drilling of a well. These notes do not contain a detailed discussion of how each one of these geo-hazards may be identified and analysed from seismic data. However, one geo-hazard, shallow gas, is especially significant having caused numerous industry blowouts and multiple fatalities, and its detection is a primary reason for conducting Site Surveys. This is especially critical in shelf settings and for bottom founded rigs (e.g. jack-ups) that cannot move away if a blowout occurs. Consequently, the interpretation of shallow gas is described in more detail below.

4.5.3. Identification of shallow gas in seismic site survey data

Seismic criteria for detecting shallow gas should be systematically investigated and assessed. These criteria include the following:

- a thorough understanding of the top-hole geology (and in some circumstances deeper geology) including the stratigraphic sequence and the depositional history.
- high amplitude reflectors or 'bright spots'
- phase reversal – carefully compared with the seabed wavelet and the stated phase and polarity of the processed dataset
- edge diffractions
- velocity effects (e.g. apparent sagging of seismic reflectors underlying gas filled layers)
- energy absorption
- attenuation of high frequencies
- gas migration indicators
- amplitude versus offset and amplitude versus angle (AVO/AVA) effects on un-stacked data
- dim spots
- flat spots.

Some of the above criteria are stronger indicators of shallow gas than others. For example, amplitude changes can be caused by lithological variations or by thin bed tuning as well as shallow gas. On the other hand, 'velocity sag' provides a very strong indication of shallow gas in the overlying sediments. Shallow gas interpretation from seismic data involves the accumulation of evidence by an experienced interpreter. However, in general terms, the more positive shallow gas indicators that are present at an event, the greater the likelihood that shallow gas may be present.

AVO/AVA analysis differs from other indicators referred to above because it can provide a more definitive prediction of shallow gas. In some circumstances, over the range of seismic reflection angles typically observed on 2D HR multi-channel seismic data, the top of a gas-charged sand layer will show an increase in amplitude as the source to receiver offset increases. Water-charged sand will, however, show a very small decrease.

The technique may, therefore, assist in distinguishing amplitude anomalies caused by shallow gas from anomalies resulting from other features. However, to be effective, the seismic acquisition geometry must meet certain strict criteria; processing, which can be complex (3.6.6.3 above), requires significant attention. A good understanding of both acquisition and processing is required by the interpreter to gain the maximum benefit from the possible use of AVO/AVA in shallow gas interpretation.

Since a small proportion of gas in sediment (approximately 5 – 12%) will cause a high amplitude reflection of similar magnitude to that caused by a large proportion of gas (e.g. 30%), it is difficult to directly quantify gas content from the seismic response. Shallow gas identification from seismic data alone should be limited to assessing the likelihood of gas being present or not being present. The results of a Site Survey cannot be used to accurately estimate the quantity or pressure of gas in place. However where a significant gas column height is interpreted this should be clearly stated due to the partial pressure effect that may be caused by the gas. Similarly, wherever possible, the results of the Site Survey should be compared to, and integrated with the shallow pore pressure prediction for the well (e.g. does the onset of overpressure fit with the statements from the Site Survey).

The interpretation should result in drilling hazard maps that clearly indicate the lateral extent and depth to shallow gas features (and other geo-hazards) below the applied absolute vertical datum (e.g. MSL) and below the seabed. The distance and/or horizontal location relative to the proposed drilling location (s) should also be indicated. For each feature assessed, the likelihood of gas being present should be clearly indicated together with the uncertainties attached to the stated depths, extent and distances. Seismic cross-sections along each tie-line passing through, or close to, the proposed drilling location(s) and any offset wells should be interpreted and included in the report.

It is recommended that shallow gas features/anomalies be classified with an assessment of the likelihood of gas being present in accordance with a clearly defined and consistent classification system. An example of such a system is provided in Table 15.

Shallow gas potential	Definition
High	The majority of shallow gas indicators are evident in the data, the horizon may tie to gas in an offset well, and there is no viable explanation for the anomaly other than shallow gas.
Low	A small number of shallow gas indicators are evident but there is an element of interpretive doubt about the anomaly being shallow gas. Shallow gas cannot be ruled out.
Negligible	There is no evidence of any shallow gas indicators or the anomaly is clearly interpreted to be the result of other factors (e.g. tuning). Therefore gas is not interpreted to be present.

Table 15: Potential for shallow gas presence – example classification system

4.5.4. Depth conversion

To derive maximum value from the interpretation and reporting process, depths to key geological horizons and geo-hazards should be presented in terms of depth below vertical datum, e.g. sea level and/or seabed. It is essential to establish a two-way time to depth conversion that is reliable at the well location(s) to be drilled and over the area of interest.

Often, the only source of time to depth information is stacking velocities or interval velocities derived during HR multi-channel seismic data processing. It is recommended that a single conversion function is used from a velocity analysis derived close to the proposed well location(s). However, this should be compared with other nearby analyses to check for gross errors. If time-depth pairs from an offset well are available, these should also be compared with the processing derived velocities and, depending on the proximity to the proposed well location(s) and lateral geological variation, these should be incorporated in the actual function used. The operator should also supply any velocity function that they would prefer to be used to allow the Site Survey results to be tied to any internal overburden mapping that is being undertaken. The validity of any function provided should always be checked for gross accuracy in the shallow overburden against time/velocity pairs derived from the HR multi-channel seismic data processing at, or close to, location.

A cross-check should also be made of the seabed depth value derived from bathymetry data versus calculated depth from the seabed pick on the HR multi-channel seismic data to check for presence of any gross time shifts or statics.

Used correctly and with the appropriate levels of quality control, time to depth conversion based on processing velocities is normally accurate to better than 5% of the depth. Thus, the absolute accuracy will reduce with increased depth. It is important to recognise that there are other uncertainties (other than the time to depth conversion) that affect the accuracy of interpreted depths to horizons and geo-hazards. These include acquisition parameters such as source and receiver depths, system timing errors and tidal statics. All these factors must be reliably assessed and accounted for during data processing and interpretation. Additionally, the relationship between a seismic horizon and a geological interface may not be simple and straightforward and this can add to the uncertainty of the results.

4.5.5. Standalone use of exploration 3D seismic

For deep water wells, drilling hazard assessment may be based solely on exploration 3D seismic data providing that the data meets the minimum criteria as described in *The Guidelines* (5.6.2).

Reprocessing and enhancement, either through production of a near trace or short offset volume, or by simple spectral whitening of the original volume, can deliver significant improvements in resolution and data quality.

It is recommended that as large an area as possible is loaded to the workstation for interpretation and a seabed map is created in order to gain a better understanding of the regional context, even if the subsequent sub-surface interpretation focuses on a smaller sub-set of data (3.6.6.5 above).

Whilst exploration 3D seismic can provide general bathymetric and good quality sub-seabed information, it is not suitable for the detection of objects and obstructions on the seabed. To detect such objects and obstructions it is necessary to carry out a seabed survey using side scan sonar. Therefore when anchored drilling rigs are used, or in areas with known or suspected seabed hazards such as munitions dumping grounds areas, a seabed clearance survey should always be acquired.

4.5.6. Site Survey reports

The Site Survey report should be concise and relevant to the survey objectives. The content and format of the report should be planned to meet the required objectives of the Site Survey and should take account of those who will use the report.

There may be a number of different users, including drilling engineers, well site geologists, geotechnical engineers, exploration geoscientists, rig tow masters and marine operations specialists. It is the responsibility of the report writer to ensure that the essential conclusions are readily understandable to those who do not have a specialist understanding of geological or geophysical terminology.

Producing separate results and operations report volumes rather than one large combined report may be more practical and more convenient for users who are interested in just one of these aspects of the survey.

The results volume should contain all interpretive maps, cross-sections, data examples and figures together with the description of geological conditions, drilling hazards identified and conclusions. The results should be accompanied by their estimated accuracy.

The report should clearly indicate water depths at specific locations of interest reduced to a defined vertical datum such as MSL or LAT. In situations where water depths have been determined solely from exploration 3D data, the depth conversion methodology and limitations should be detailed.

A prognosis of lithology throughout the top-hole section should be included. A series of maps, cross-sections and figures is required to illustrate the results of the survey. These should be designed to convey the information in the most accessible and informative way to the end user.

Attention should be given to paper sizes, and scales.

Data examples should be included both to show the data quality and to illustrate key features, including examples of any geo-hazards in the vicinity of the proposed well(s). Data examples should be clearly cross-referenced in the text and their location clearly marked on any relevant interpretive charts.

All drawings should clearly show horizontal and vertical scales and maps should include a detailed description of the geodetic and projected coordinate reference systems used.

A full legend should be provided for all charts defining all symbology used on the chart and the origins of data used to produce the interpretation shown.

As a minimum, the following should be included in the Site Survey report:

- bathymetry map
- seabed features map
- isopach maps of significant shallow soils units
- depth converted interpreted soils profiles of representative survey lines for bottom-founded rigs
- interpreted geo-seismic profiles of the primary seismic lines that pass through, or close to, the proposed drilling location(s), alternate/relief well locations and offset wells/geotechnical boreholes

- geo-hazards summary map
- annotated data examples illustrating geo-hazards and other significant features.

The following additional maps may also be included:

- regional bathymetry map (possibly from Exploration 3D seismic or published DTM)
- regional seabed gradient map
- regional shaded relief map
- depth converted horizon structure maps of key seismic horizons
- amplitude maps of key seismic horizons
- selected hazard maps, time slices (3D seismic data only) or volume attribute map(s) to illustrate shallow gas zones or other significant hazards.

Recommended map scales are as follows:

- Site Survey maps for anchored rigs: 1:10,000
- Site Survey maps for bottom founded rigs: 1:5,000
- Regional maps: 1:25,000 (or appropriate to the size of the area being considered).

It is recommended that at the front of the report a summary is provided in order to present the essential findings and conclusions of the survey in a brief and easily accessible form.

A separate summary should be prepared for each individual proposed well location, clearly referring to the name/nomenclature for the location provided by the operator, and any alternate (relief) well location. It should be laid out as a series of short statements and informative tables (rather than sections of text) and should contain limited geological terminology (e.g. clay, sand, shale). It should be constructed as a précis of the main results section of the report and not merely repeat sections of the main text.

A top-hole prognosis figure should also be included that illustrates the predicted geological sequence at the proposed well location (and alternate well locations) together with any geo-hazards, or significant features identified during the study, in an easily understandable graphic form; in particular any interpreted shallow gas features including an assessment of the likelihood of gas being present. The figure should also provide predicted depths to key seismic horizons based on the best available time to depth conversion.

The operations volume should contain a description of the equipment and techniques employed in the survey including:

- survey operations including sequence of events
- survey equipment
- equipment calibrations
- data reduction and processing
- data quality and accuracies
- lessons learnt: system applicability, etc. for application in future surveys in the area.

Reports may be delivered both in hard copy and in a standard electronic format such as PDF. Hard copies of reports are required as the maps will typically be presented in A0 format that does not lend itself to being viewed and used on screen in electronic format. There are, however, a number of ways in which report information can be compiled and presented using GIS techniques to improve accessibility and understanding.

IOGP have published a Seabed Survey Data Model (SSDM) to define an industry standard GIS data model for seabed surveys. This model should be used as a deliverable standard between operators and survey contractors, as well as a data model for managing seabed survey data within operator companies.

The SSDM documentation and supporting guideline and material can be downloaded from http://www.iogp.org/Geomatics.

5. Glossary

Term	Definition
"A" frame	A-shaped frame capable of being extended over the side of a ship to deploy sampling equipment.
2D multi-channel high resolution seismic	Seismic reflection data designed to image the shallow section and detect drilling hazards such as shallow gas.
3D migrated volume	The end product of a fully processed 3D seismic survey.
Acoustic impedance	Seismic velocity multiplied by density.
Acoustic noise	Any unwanted acoustic signal.
Acoustic propagation	Transmission of acoustic or seismic energy.
Acoustic release	Device for securing equipment to the seabed which may be released when required by transmitting a coded acoustic signal.
Acoustic seabed imagery	Images derived from acoustic reflection data processed to illustrate seabed: topography, features, and changes in texture.
Acoustic shadow	Area of a side scan sonar record on which there is no seabed return. Usually caused by an object on the seabed.
Acquisition artefacts	Noise on seismic data that is a function of the data acquisition process rather than geology.
AGC	Automatic Gain Control. Automatic variation of the amplification or attenuation of an amplifier to compensate for variations in signal strength.
Air gun	A commonly used seismic source which injects a bubble of highly compressed air into the water.
Alias filter	A filter used before sampling to remove undesired frequencies that would not be reproduced by the sampling process. See Nyquist frequency.
Ambient noise	Background seismic energy not derived from explosion of the seismic source.
Analogue signal	A continuous signal in which the small fluctuations of a time varying property, such as voltage or frequency, are meaningful. Differs from a digital signal which is discrete.
Analogue streamer	Marine cable incorporating pressure hydrophones providing an output of analogue signals.
Anchor radius of a semi-submersible rig	The radius of the smallest circle that includes all the seabed anchor positions for a semi-submersible rig.
Archaeological remains	Objects that are of historical interest. These may be man-made, for example shipwrecks, or human or animal remains of any age.
Auto-tracking	The process by which seismic horizons are automatically tracked in a seismic dataset by an interactive seismic interpretation system.
AUV	Autonomous underwater vehicle. A self propelled, untethered underwater vehicle that is able to be programmed to swim along a predefined survey track to collect data from sensors installed on it.
Auxiliary channel	Channel on a recording system designated for recording information ancillary to the seismic survey rather than seismic data. For example source performance data.

AVA	Amplitude Versus Angle (or amplitude variation with offset). Variation in seismic reflection amplitude with changes in the reflection angle.
AVO	Amplitude versus offset. Commonly used term for AVA, since reflection angle increases with the horizontal offset between source and receiver.
Backscatter	The amplitude of the acoustic echo sounder energy reflected by the seabed that may be processed into maps that provide information about seabed features and texture.
Band pass filter	Attenuates frequencies in a seismic signal below and above specified values, allowing only those that fall between the two to pass with little attenuation.
Bandwidth	The range of frequencies in a seismic signal between the two half power points, i.e., the frequencies at which the power drops to half the peak power (3 dB).
Bathymetry	Water depth.
Bedform	Depositional feature on the seabed formed by movement of the bed material caused by the current.
Benthic samples	Seabed samples recovered by grabs, or corers, that are normally taken for environmental investigations.
Boomer	Marine seismic energy source that operates by the rapid movement of a restricted metal plate.
Bottom founded rig	Mobile drilling rig such as a jack-up rig or a drilling barge that relies on a seabed foundation for stability during drilling.
Boulder beds	Accumulations of boulder sized material, greater than 10cm across, buried in sediments. Typically found in the base of buried channels or within glacial sediments.
Box corer	Seabed sampling system designed to recover a cube of seabed sediment. Generally used for soft seabed sediments.
Box-in survey	Seabed survey lines run on four sides of a feature for the purposes of detailed investigation and/or precise positioning.
Bright spot	Discrete high amplitude reflector often indicating the presence of hydrocarbon bearing sediment.
Buried infilled channels	Ancient eroded channels that have subsequently been infilled and buried by sediment.
Buried slumps	Ancient submarine landslides that have been buried by sediment.
Cable noise	Unwanted seismic energy generated by a seismic cable and its passage through the water.
Cavitation	Low pressure region in a liquid into which there may be implosive collapse that generates a shock wave. This may occur at the edges of ship's propeller blades or following a seismic explosion.
Central reference position	Datum point of a survey ship to which all survey systems are referenced in three dimensions.
Characterization	The process of conveying information about the previously unknown by classification according to type. In the context of Site Survey this may apply to the geological conditions under investigation.
Chemosynthetic communities	Discrete life forms normally in the vicinity of the seabed that exist only because of specific, localized chemical conditions.
Chirp system	Energy source used in sub-bottom profiling that emits a computer generated frequency modulated pulse over a specified range of frequencies.

Clock and orbit corrected GPS	Corrections applied to the clock and orbit ephemerides data that has been uploaded to each GPS satellite. Corrections are broadcast at 1 Hz to the NASA GDGPS system.
CMP common mid-point	Position in the sub-surface producing reflections from a range of different source to receiver offsets.
CMP gather	Side by side display of the traces for a particular CMP corrected after correction for normal moveout and statics and ready for stacking.
Coherent noise	Unwanted seismic energy in which there is a well-defined phase relationship between waveforms. This often makes removal much easier than incoherent or random noise.
Cohesive	The behaviour of soil, such as clay, in which the material exhibits strength without any confining pressures (sediment such as clay has an inherent strength called cohesion, also more correctly termed undrained shear strength).
Communications cables	Cables on or beneath the seabed laid either between continents and islands or to offshore installations.
Conductor pipe	Large diameter pile that is set into the ground to provide the initial stable foundation for a borehole or oil / gas well.
Cone end resistance	Resistance force measured by the tip of a CPT system and used to determine soil type and strength in conjunction with other cone measurements, such as sleeve friction and pore water pressure.
Constructive interference	The superposition of two or more waveforms such that the resultant waveform is of greater amplitude.
Coordinate transformation parameters	Set of mathematical parameters necessary to convert position coordinates based on one spheroid to those based on another.
Co-tidal chart	A chart that has two sets of curves connecting points having equal tidal ranges and points having simultaneous high and low waters.
Course made good	Direction a ship is moving over the ground. May differ from the ships heading when there is a cross current.
CPT	Cone penetration test. *In situ* soil strength testing device that makes real time measurements as it is pushed into the seabed by mechanical means.
Cross talk	Interference caused by the unintentional pickup by one channel of information or noise on another.
Crossline direction	Azimuth bearing of subordinate lines in a marine survey.
CTD	Conductivity, temperature and depth meter. Device for making real time measurements of conductivity and temperature against depth over the full water column to derive the speed of sound in water to calibrate e.g. echo sounder and USBL observations.
Data drop	Port call during a marine survey carried out for the sole intention of landing survey data.
Deconvolution	A filtering process that undoes the effect of another filter. There are many applications in seismic data processing but one example is removing the filtering effect of the earth.
Demultiple	A seismic processing application that attenuates multiple energy.
Deposition rate	The rate at which sediments were deposited, often measured in centimetres per thousand years.
Designature	Filtering process to compensate for the non-minimum phase characteristics of a seismic source.

Desk study	Exercise to derive as much information as possible about the site conditions in an area from existing data and public domain information.
Destructive interference	The superposition of two or more waveforms such that the resultant waveform is of lower amplitude.
DGNSS	Differentially corrected GNSS. See DGPS.
DGPS	Differentially corrected GPS. A method of improving GPS solution for position in plan and height by applying corrections to satellite ranges. Corrections are calculated between observed and calculated ranges at reference station(s) of known position.
Diapiric structures	Positive geological structures formed by the deformation of plastic material, for example salt or clays. They can be associated with hydrocarbon accumulations and may also have a surface expression that in the marine case would result in a bathymetric high.
Diatreme	A volcanic, or injective, feature piercing sedimentary strata.
Digital streamer	Marine cable incorporating pressure hydrophones providing an output of digital signals.
Dim spot	Discrete low amplitude zone on a seismic horizon caused by destructive interference but may be related to shallow gas.
Directionality	Property of seismic source and receiver arrays that gives preference to transmitted or received energy from a particular direction.
Doppler log	Instrument to measure a vessel's speed over the ground by measuring the frequency shift of acoustic pulses reflected from the seabed.
Drift	Gradual and unintentional change in the reference value to which measurements are made, for example in gyro or an inertial navigation system.
Drilling hazard	See geo-hazard, applied in the context of drilling.
DTM	Digital Terrain Model. Digital representation of a mapped surface usually defined by xyz values for defined cells.
Dynamic range	Ratio of the largest recoverable signal to the smallest recoverable signal.
Dynamically positioned (DP) rig	Mobile drilling rig that relies on thrusters automatically controlled by a dynamic positioning system for stability during drilling.
Emergency response plan	Document produced in advance of a survey that ensures that the correct action is taken in the event of an emergency.
Engineering activity	Any construction or maintenance activity that could result in changes to facilities at the seabed, deformation of the seabed, or dropping of debris items.
Environmental impact	The affect that a project has on the environment – may be positive or negative.
Environmental surveys	Information collected for environmental purposes. Examples are to establish baseline conditions and for monitoring purposes.
EPROM	Erasable programmable read only memory. Type of memory chip that retains its data when its power supply is cut off. Used for providing programmable information that is subject to routine upgrades.
Equalized	Description given to one or more seismic trace in which the gain levels have been adjusted so that the amplitudes are comparable.
Erosion and truncation surface	Geological interface that marks the lower limit of erosion and on which deposition has subsequently taken place. Erosion and truncation surfaces therefore mark unconformities in the sequence of geological deposition.

Exploration 3D seismic data	3D seismic reflection data collected for the purpose of exploring for oil and gas rather than studying geo-hazards and the shallow section.
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 straight line. In practice this is difficult to achieve and a mid-field source Signature is more common.
Fault escarpments	Bathymetric ridges on the seabed aligned with underlying geological faults.
Feather angle	Angle between a seismic streamer and course made good caused by a cross current.
First pressure containment string	The first casing to be installed in a well that will enable the pressure inside the well to be controlled.
Flat spot	Distinctive reflector produced by the gas/water contact sometimes seen at the base of a gas pocket. The flat or saucer shaped form is caused by a lowering of the seismic velocity by the gas.
Fluid expulsion features	Seabed depressions such as pockmarks believed to have been caused by the expulsion of pore water or gas.
Fold of cover	The number of seismic traces, each recorded at a different source to receiver offset, that are combined together in multi-channel seismic reflection profiling.
Foundational depth	The maximum depth below seabed of interest for foundation design and installation.
Frequency notch	Single narrow band of frequencies missing from a signal.
Frequency spectrum	Graphical display of frequency versus power that illustrates that frequency content of a wavelet or signal. Produced by a Fourier transform.
Fresnel zone	Circular area on a reflecting interface from which all reflections contribute to the recorded signal. Is dependent on the period of the wave and determines lateral resolution.
Friction ratio	Ratio of sleeve friction to cone tip resistance measured by a CPT and used for identifying soil type.
Gas Bearing Sand	Buried sand body in which pore space contains gas.
Gas chimney	A zone within the sub-seabed section where the vertical migration of gas is taking place. This is often characterized by energy scattering and absorption on seismic reflection data and a lack of coherent reflectors.
Gas hydrate mounds	Accumulations or build ups of gas hydrate at seabed normally over a seabed seep in deep water or at high latitudes.
Gas hydrate zones	Parts of the sub-seabed section where gas hydrate is present.
Gas vents	See Fluid expulsion features.
Geo-hazard	Geological condition that has the potential to cause harm to man or damage to property.
Geo-hazard register	Geo-hazards identified within a particular study area, listed with other information such as their potential impact on the proposed development and recommendations for further investigation.
Geological interface	Common surface between two different geological units.
Geological model	Computerized representation of subsurface geology.
Geomagnetic disturbance	Temporary changes in the earth's magnetic field caused by interplanetary influences.
Geometric spreading	See spherical divergence.

Geophysicist	A specialist in the physics of the earth. In the context of Site Surveys the geophysicist is the senior scientist in the survey team, with responsibility for the qc of acquired data and the presentation of results.
Geo-referenced Tiff file	File format for storing images with a defined location on a map projection or coordinate system.
Geotechnical boreholes	Boreholes drilled into the seabed for the purposes of carrying out *in situ* geotechnical testing, or to collect samples for geotechnical testing and analysis.
Geotechnical engineering	The branch of civil engineering concerned with the engineering behaviour of earth materials.
GIS	Geographic Information System. A system that captures, stores, analyzes, manages, and presents data that are directly linked to the coordinates of the data's origin.
Global Nnavigation Ssatellite Ssystems (GNSS)	Generic term for satellite based navigation systems like GPS, Glonass and others that provide autonomous global positioning of GNSS receivers.
GPS	See GNSS.
Grab	Seabed sampling device.
Gradiometers	A system which measures the magnetic gradient using two or more closely spaced magnetometers.
Gravity corer	Seabed sampling device that penetrates the seabed using force exerted by its own weight of momentum.
Grid geometry	Definition of a 2D spatial grid that enables it to be correctly positioned within a map projection or coordinate system from a corner point.
Ground truthing	Calibration of geological interfaces interpreted from seismic data using samples.
Gun array	Two or more seismic source guns deployed and fired to produce a seismic pulse that has certain characteristics.
Gyro compass	Non magnetic compass based on a fast spinning disc and the rotation of the earth that automatically finds geographical direction.
Habitat	An ecological or environmental area inhabited by a particular animal or plant species.
Halocline	Typically horizontal layer in a water body in which the salinity varies greatly over a relatively short vertical distance. Can affect the performance of sonars and echo sounders.
Hardgrounds	Hard material, such as cemented sediment, coral or rock, at seabed.
Heave compensation	Counteracting the effect of vertical motion on an echo sounder or profiling system by applying corrections derived from a motion sensor.
High cut filter	Filter that transmits frequencies below a given cut-off frequency and attenuates others. Same as a Low-pass filter.
High resolution seismic	See 2D multi-channel high resolution seismic.
Horizon map	Map based on the reflector associated with the surface separating two different geological layers where it can be traced over a large area.
HR 3D survey	3D seismic reflection survey designed to image the shallow section in great detail by recording high frequencies.
HR multi-channel Seismic	See 2D multi-channel high resolution seismic.
Hydrophone	Seismic detector sensitive to variations in pressure.

Hydrophone array	Group of hydrophones connected to a single recording channel.
Hydrophone streamer	Marine cable incorporating pressure hydrophones designed for continuous towing through water.
Hydrostatic pressure	Pressure exerted by a fluid at equilibrium through the force of gravity.
IMCA	International Marine Contractors Association. Trade association for offshore, marine and underwater engineering companies.
Incidence angle	Angle that a raypath makes with the perpendicular to an interface.
Inertial navigation system	A navigation aid that uses motion sensors and rotation sensors to continuously calculate position, orientation and velocity by dead reckoning.
Inline direction	Azimuth bearing of primary lines in a marine survey.
***In situ* testing**	Soil parameter testing carried out in the ground as opposed to in a laboratory on recovered samples. For example a CPT.
Instantaneous frequency	Seismic attribute that classifies seismic events within each trace based on their frequency content.
Instantaneous phase	Seismic attribute that classifies seismic events within each trace based on their phase.
Interference	A phenomenon in which two waves superpose to form a resultant wave of greater or lower amplitude. See constructive interference and destructive interference.
Interpretation workstation	Computer workstation for viewing and interpreting 2D and 3D seismic and related datasets and generating maps.
Interval velocity	Seismic velocity measured over a depth interval.
Isopach	Contour that denotes points of equal thickness of a rock type.
Jack-up rig footprint	Depression left on the seabed after a jack-up rig leg has been withdrawn.
Latency	Time delay between taking a measurement, for example with an echo sounder, and recording the position.
Lateral resolution	Ability to distinguish between two features in the lateral direction. See Fresnel zone.
Layback to towed equipment	Horizontal distance from the survey vessel to a towed sensor.
Line keeping	Accuracy at which a survey ship maintains position on a survey line.
Lithology	General characteristics of sediments and sedimentary rocks.
Sleeve friction	Resistance measured along the side of a cone penetrometer.
Local vertical datum	A vertical datum that has been chosen for a project where a standard datum such as LAT may not be appropriate; for example on a platform or jack-up rig superstructure.
Lost circulation	Condition while drilling a borehole or oil / gas well when fluid is lost into the formation rather than circulated to the surface.
Low cut filter	Filter that transmits frequencies above a given cut-off frequency and attenuates others. Same as a High-pass filter.
Magnetic anomaly	Local change in the earth's magnetic field caused by the presence of a ferromagnetic object.
Magnetic gradient	Change in magnetic field strength with distance.
Magnetic intensity	Strength of magnetic field.

Magnetic susceptibility	Measure of the degree to which a substance may be magnetized
Magnetometer	An instrument used to measure the strength and/or direction of the magnetic field in the vicinity of the instrument.
Manifolds and templates	Examples of facilities placed on the seabed for the purposes of drilling and/or production.
Marine crew	Those responsible for operating a survey ship as opposed to those responsible for operating survey equipment.
Marker horizon	Seismic reflector that maintains its characteristics over an extensive area so that it may be used as an interpretation reference.
Mass transport complexes	MTCs, see Slump.
Maximum offset	The maximum horizontal source to receiver offset in a multi-channel seismic survey.
Mega-ripples	Current ripples normally present on a sandy seabed having a wavelength of greater than 0.5 metres.
Metocean data	Generalized term for meteorological and oceanographic data.
Migration	Plotting of dipping reflectors in their true spatial positions rather than directly beneath the point midway between shot and receiver.
Minimum offset	The minimum horizontal source to receiver offset in a multi-channel seismic survey.
Minimum phase output	The output of a seismic source where the energy is front-end loaded in the first energy peak of the pulse and is not followed by a larger peak.
Monotrace seismic	Seismic data recorded using a single channel. Normally high frequency data of limited penetration that requires a minimum amount of post processing.
Moonpool	An opening in the deck and hull of a ship or platform that gives access to the water below and through which equipment may be deployed.
Mosaic	Compilation of side scan sonar records to form a geo-referenced seabed map.
Motion sensor	An instrument for measuring horizontal and vertical motion. and attitude of for example a survey vessel. The information is needed to correct, e.g. multi or single beam echo sounder data and USBL data for vessel motion.
Mud volcano	Formations created by geo-excreted liquids and gases. See Diatreme.
Mudflow	See Slumping.
Mudline	Seabed. Term often used when the seabed is composed of particularly soft, water saturated sediment.
Multi-beam echo sounder	See Swathe Bathymetry System.
Multi-channel, digital signal processing	The process by which field recordings from multi-channel seismic reflection surveys are enhanced and converted to interpretable sections or volumes.
Multiple energy	Noise on seismic records caused by reverberations between strong reflecting interfaces, such as the seabed and the sea surface.
Multitrace	Seismic data recorded using two or more channels that require post processing to produce an enhanced display.
Mute	Removal of certain components of certain seismic traces prior to CMP stacking.
Nadir zone	The seabed vertically below side scan sonar transducers where the acoustic energy strikes the seabed at close to 90 degrees. Since no acoustic shadows are produced, object detection is impared.
Nautical charts	Charts produced for the purpose of navigation.

Near offset volume	A processed 3D seismic dataset that uses only traces recorded by the receivers positioned closest to the seismic source with most vertical incidence angle. The data will contain the highest frequencies and thus the best vertical resolution, but will be affected by noise especially in the deeper part of the section.
Noise	Any unwanted signal.
Nyquist frequency	Frequency associated with sampling that is equal to half the sampling frequency.
Ocean bottom cable	Seismic recording cable placed on the seabed with four component receivers that will have the capability to record S-waves as well as P-waves.
Octave	The separation of two frequencies, one of which is double that of the other.
Offset	Horizontal distance from the shot to the centre of the first hydrophone group.
Offset well	Existing well from which information is available to tie back to and assist with making predictions about conditions at a proposed well location.
Offshore drilling unit	Facility from which offshore wells are drilled. For example a mobile drilling unit.
Online integrated positioning system	Computer system providing the information to steer a survey vessel along a predetermined line, and simultaneously logging the positions of survey sensors at regular intervals.
Operator	Company having responsibility for drilling an offshore well.
Over-pressure zone	Sub-seabed layer having a pressure above normal hydrostatic pressure.
Parametric source	Source for seismic profiling that uses the non-linearity of water to generate a difference frequency from two high frequencies. Has advantages of broad bandwidth and narrow beam width.
Partial stack	CMP stack comprising a limited number of input traces, for example near, mid or far offset stacks.
Party Manager	Commonly used term for the person in charge of a survey team.
Penetration	The greatest depth from which seismic reflectors can be picked with reasonable certainty.
Permanent magnetization	Magnetic property of an object alone, and in most cases the predominant magnetic property that enables detection by a magnetometer.
Phase reversal	A change of 180 degrees in the phase angle.
Pinger	High power transducer used in monotrace seismic profiling.
Pinning up activity for a jack-up rig	Procedure by which jack-up rig legs are initially lowered to contact with the seabed to secure the rig to the seabed and make it resistant to lateral movement.
Piston corer	Seabed sampling device best suited to soft sediments where a piston helps draw sediment into the core barrel.
Pitch error	Error in multibeam echo sounder surveying caused by incorrect application of vessel pitch.
Pitch steering	Ability of some multibeam echo sounder systems to use pitch data to actively direct transmission pulses and increase the frequency of soundings.
Platform based rig	Drilling rig mounted on a fixed platform.
Pockmarks	Shallow seabed depressions thought to be caused by the release of pore fluids.
Pore pressure	Pressure of groundwater that fills the spaces between soil and rock particles, also known as geopressure.
Pore pressure ratio	Ratio of pore water pressure created by CPT to cone tip resistance and used for identifying soil type.

PPP	Precise point positioning. GPS data processing technique that combines results from a single receiver with location and time information from satellites and clocks.
Project engineer	The oOperator's pProject eEngineer responsible for overall well or development planning and interface to the Site Survey project manager.
Project manager	Can refer to either or both of: the Operator staff member responsible for planning and delivery of the Site Survey, and the Contractor Representative responsible for actioning the Operator's plans.
Protection frames	Structure placed over a seabed installation normally to protect it from trawl nets or dropped objects.
Random noise	Energy that does not exhibit correlation between two or more receivers.
Record length	The length of time that seismic signals are recorded following the firing of a seismic source.
Recording system	Instrument for recording seismic signals.
Reefs	Sedimentary features, built by the interaction of organisms and their environment, that have synoptic relief and whose biotic composition differs from that found on and beneath the surrounding sea floor, for example a coral reef.
Reference hydrophone	Calibrated hydrophone used to measure the energy level of a seismic source.
Reflecting zone	Central area of a Fresnel zone that produces the most significant higher amplitude returns, thus determining lateral resolution.
Reflection coefficient	A value between –1 and +1 that describes the amplitude of a reflected wave relative to an incident wave.
Relative amplitude	Term given to a processed seismic section that retains amplitude information so it may be used as a property of seismic horizons during interpretation.
Relative density	Ratio of the density of a substance to the density of a given reference material. Specific gravity is the relative density with respect to water.
Relief well	Well designed to provide intervention in the event of incurring a well control incident at depth.
Repetition rate	Firing frequency of an acoustic or a seismic source.
Resolution	The minimum distance between two features that may be separated.
Responder	Same as transponder (see below). An electronic acoustic device that produces an acoustic response when it receives a trigger signal through an umbilical between e.g. a vessel and towed equipment.
Rock corer	Tool for sampling rock.
Rock dump	Mound of rock or gravel placed on the seafloor for example to stabilize a pipeline or submarine cable.
Roll error	Error in multibeam echo sounder surveying caused by incorrect application of vessel roll.
ROV	Remote operated vehicle
ROTV	Remote operated towed vehicle
S/N	Signal to noise ratio. Energy of desired events divided by all remaining energy (noise) at that time.
Salt or mud diapirs	See Diapiric structures and Diatremes.
Sample decimation	Resampling of digital seismic data at a longer interval than originally used.
Sample interval	Time interval between successive samples in a digital seismic record.

Sand ripples	Seabed undulations produced by water movement.
Sandwave	Mobile submarine sand dune created by currents. Typically up to 10 metres high but occasionally higher.
Seabed acoustic array	A number of acoustic transponders strategically placed on the seabed to position either surface vessels, for example drilling rigs, or sub-sea installations.
Seabed characterization	Classification of seabed topography and sediments through investigation.
Seabed clearance data	Dataset that enables objects and obstructions on the seabed to be located and identified.
Seabed feature	Any discontinuity in the seabed whether natural or man made.
Seabed morphology	The natural shape and form of the seabed.
Seabed return	Energy reflected from the seabed on an acoustic or a seismic record.
Seafloor classification	Use of discrete physical properties within an acoustic dataset to classify the seabed in respect of physical, geological chemical or biological properties.
Sedimentary processes	The geological processes that create sedimentary rocks.
Sedimentary sequence	Succession of sediments that makes up the geological sequence.
SEGD format	Society of exploration geophysicists standard format commonly used to record multi-channel field seismic data.
SEGY format	Society of exploration geophysicists standard format commonly used to exchange seismic data.
Seismic attributes	Any quantity derived from seismic data such as time, amplitude, frequency output as a subset to aid interpretation.
Seismic Data Processing	Applying geometrical corrections and signal processing techniques to improve the signal to noise ratio and facilitate interpretation.
Seismic gathers	See CMP gathers.
Seismic horizon	Surface separating two different rock layers that reflects seismic energy and is traceable over a large area.
Seismic response	The effect that seismic energy has on a geological feature.
Seismic source	Source of controlled seismic energy that is used in reflection and refraction seismic surveys.
Seismic streamer	Receiving system for marine seismic surveys that is towed behind a survey vessel. Usually consists of a large number of hydrophones arranged in groups and may extend to several km in length.
Semi-regional	Area of study extending beyond a single well to include several wells, prospects or developments.
Senior surveyor	A specialist in position fixing, geodesy and hydrography. In the context of Site Surveys the senior surveyor is responsible for the correct operation of all position fixing equipment and ensuring that all data collected is correctly positioned.
Shaded relief	A flat map on which relief is illustrated by simulated shadows.
Shallow gas blowout	Uncontrolled egress of shallow gas from a well.
Shallow section	The geological section above the setting depth of the first pressure containment string in a well.
Shallow water flow zone	Overpressured geological interval from which pore water flows into a well causing difficulties in well control and effective cementing of casing.

Shear strength	Primary term used in soil mechanics to describe the undrained, or cohesive, strength of a soil, normally clay or silt.
Shipping lanes	Regularly used route for ocean going vessels. May be enforced in areas of high shipping activity.
Short offset volume	3D seismic dataset containing only those traces recorded with short source to receiver offsets. Commonly used for shallow section geo-hazard studies and may have further resolution enhancements.
Shot number	Unique sequential number given to each shot in a seismic line.
Shot point interval	Horizontal distance between successive shot points.
Side scan sonar	Instrument for scanning the seabed to either side of a survey line using acoustic pulses. Can detect objects on the seabed, and variations in seabed topography and seabed sediment type.
Signal stretch	The application of NMO correction to a seismic reflection trace that has the effect of lowering its frequency and thus the resolution of any detectable horizons. This will be most apparent for long offset traces.
Single channel seismic	See monotrace.
Single, beam hydrographic echo sounder	Instrument for measuring water depth immediately below a survey vessel.
Slant range	Distance from a side scan sonar towfish to the seabed.
Slant range correction	Geometrical correction applied to the slant range to obtain the horizontal distance from the survey track to a feature on the seabed.
Slump	Movement of a sediment mass under the influence of gravity. An example is the outflow of sediment from a seabed expulsion feature such as a mud volcano. Also known as gravity transport.
Source signature	Output wavelet, or waveshape, of a particular seismic source from which frequency, output power and phase may be determined.
Sparker	Seismic source produced by an electric discharge in water.
Spatial resolution	The lateral size of a feature that can be detected by the seismic method. Usually defined as the radius of the Fresnel zone at a particular depth. On migrated data the Fresnel zone radius is related to approximately one quarter of the signal wavelength.
Spherical divergence	Decrease in wave strength with distance as a result of geometric spreading of a spherical wave travelling through a body.
Spud can	Base of a jack-up rig leg.
Stacking	Process of making a composite record by mixing seismic traces from different records. Most common application is CMP stacking.
Stacking velocity	Velocity calculated from normal moveout measurements.
Stand-off location	Area of seabed that has been surveyed and established as a safe place for a rig to be placed while waiting to move onto an intended drilling location.
Statics	Corrections applied to seismic data to eliminate the effects of variations in elevation.
Stratigraphy	A branch of geology that studies rock layers and layering (stratification) primarily used in the study of sedimentary rocks.
Streamer bird	Depth control device fitted to a seismic streamer.
Streamer sensitivity	Ability of a seismic streamer to detect incoming signals. Normally specified in volts per bar.

Stretch	See signal stretch
Stretch mute	Mute designed to remove the low frequencies introduced into seismic traces when they are corrected for NMO.
Sub-bottom profiler	Seismic reflection instrument for investigating the upper few tens of metres of the sub-seabed with as high a vertical resolution as possible.
Subsea isolation valves	Valves on submarine pipelines that automatically cut off the flow in the event of an emergency. They are often placed within a few hundred metres of a platform.
Subsurface data	Geophysical and geotechnical data for investigating sub-seabed geology.
Survey crew	Those responsible for operating survey equipment on a survey ship as opposed to those responsible for operating the ship.
Survey platform	Vehicle on which survey sensors are mounted. Examples are a towfish, AUV, ROV or the survey ship itself.
Swathe bathymetry system	Instrument for measuring water depths within a defined swathe either side of a survey vessel track.
Swell filter	Device for removing vertical motion from an echo sounder trace or seismic profile by smoothing undulations. Differs from a heave compensator in that it does not apply empirical corrections from a motion sensor.
Tail buoy	Buoy fitted to the end of a seismic streamer.
Tapered filter	Filter in which the cut off is spread over a range of frequencies rather than being abrupt.
TD location	Touch Down location. Point at which for example and anchor cable touches down onto the seabed. Also used during pipeline laying and for the pinning of jack-up legs.
Thermocline	Thin but distinct layer in a water body in which temperature changes more rapidly with depth than it does in the layers above and below.
Thin bed tuning	Term given to the interference between closely spaced reflectors on a seismic section.
Tidal level data	Information provided by a tide gauge.
Tidal model	Mathematical model describing water levels during a tidal cycle at a particular location.
Tide gauge	Instrument for recording water level.
Time frequency filtering	A type of filter used in seismic processing for multiple often referred to as Tau-p domain filtering
Time migration	See Migration.
Time slice	Horizontal section through a 3D seismic volume that displays information at the same two way reflection time.
Time-depth pair	Time and depth values calculated from velocity measurements made in a well.
TMS tether management system	System for operating an ROV that attaches it to the main lifting system.
Top-hole prognosis	Summary of top-hole conditions predicted from a Site Survey.
Top-hole section	The shallow geological section above the setting depth of the first pressure containment string in a well.
Topography	The study of Earth's surface shape and features.
Towfish	Vehicle on which survey sensors are mounted that is towed behind a survey vessel.

Tow-depth ghost	Energy that travels upwards from a source or streamer, is reflected from the sea surface and joins the down travelling wave.
Towed sensors	Survey sensors mounted on a towfish and towed behind a survey vessel.
Trace decimation	Reducing the number of seismic traces in a seismic record in order to reduce its volume.
Trace header	Identification information and parameters which precedes data in a recorded seismic file.
Trace Summation	Adding together of similar seismic traces to enhance events and reduce noise.
Track plot	Visual display of a survey line or track.
Transducer	Any device that converts one form of energy to another. A hydrophone is thus a transducer, but in acoustic surveying the term is normally applied to devices that produce acoustic pulses from electrical energy.
Transducer draught	Depth of a transducer below the surface – a critical parameter in all forms of echo sounding.
Transponder	An electronic acoustic device that produces an acoustic response when it receives an acoustic signal from e.g. a vessel mounted transducer or another transponder.
TVF	Time variant filter. Filter that applies different characteristics at different points on a seismic trace.
TVG	Time varied gain. Non uniform gain function applied to a seismic trace with the intention of producing similar amplitudes throughout.
Two way travel time	Time taken for a seismic wave to travel from source to reflector and back to the receiver.
Ultra high resolution seismic	Multi-trace seismic recoded using a digital sampling interval of less than 1 ms (normally 0.5 or 0.25 ms) and recording higher frequencies than HR seismic.
Unscaled	A processed seismic section in which the magnitude of reflection amplitudes is preserved in a meaningful way, and may be used, for example, in the identification of shallow gas.
Unstable slopes	Submarine slopes that have the potential to fail.
USBL	Ultra short baseline system. A subsea acoustic positioning system used to determine the position of towed or deployed sensors in the water column. A transponder or responder is mounted on the sensor to be positioned and interrogated from a transducer of known position.
UUV	Untethered Underwater Vehicle. See AUV.
Velocity analysis	Process of calculating velocity from measurements of normal moveout.
Velocity model	The assignment of different seismic velocities to certain discrete geological or reflection time intervals.
Velocity probe	Instrument for making real time measurements of the speed of sound in water to calibrate echo sounder readings.
Velocity profile	Plot of seismic velocity with depth.
Velocity sag	Localized lowering of seismic velocity because of the presence of gas in overlying sediments.
Velocity volume	3-dimensional grid of seismic velocities.
Vertical datum	Reference level for elevation measurements.

Vessel mounted acoustic positioning system	A subsea acoustic positioning system that is permanently installed on a vessel. This system can either determine the relative position of acoustic transponders or responders mounted on other equipment (e.g. towfish) or absolute positions within a network of seabed acoustic transponders.
Vessel transducer	A transducer, to transmit and receive acoustic signals, that is either permanently installed in the hull of a vessel or deployed from the vessel for the acquisition of different data types; water depth (echo sounder), shallow geophysical data (sub bottom profiler), range and bearing to towed equipment (acoustic positioning system).
Vibrocorer	Seabed sampling device that penetrates the seabed using the oscillating force exerted by a out-of-balance motor mounted on top of a coring barrel. Used for stiff clays and sands. Generally obtains disturbed samples.
Water bottom multiple	Seismic energy that has been reflected from the water bottom (or seabed), the sea surface and the water bottom a second time. It produces an apparent reflector corresponding to exactly twice the water bottom reflection time.
Wavefront	The surface over which the phase of a travelling wave disturbance is the same.
Wavelet	A seismic pulse usually consisting of one and a half to two cycles.
Wellhead	A general term used to describe the pressure containing component at the surface of an oil or gas well that provides the interface for drilling and production equipment.
Whitening	To adjust the amplitudes of all frequency components within a certain band pass to the same level.
Windowed attribute extractions	Analysis of the reflection amplitudes or other seismic attributes over a specific reflection time window carried out using an interactive seismic interpretation system.
XTF	Extended Triton format. Commonly used digital format for storing and interchange of echo sounder and side scan sonar data.
Yaw	Vertical axis of motion for a ship or vessel. Parallel to the other axes of pitch and roll. Yaw motion is the movement of the bow of the vessel from side to side.
Zero offset ray path	Vertical ray path. The seismic trace that assumes source and receiver are exactly coincident.
Zero phase	Filter for which the phase shift is zero for all frequencies. A zero phase wavelet has the energy concentrated at its centre.

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This report (373-18-2) provides detailed guidance, supporting technical information and background theory on the various equipment, planning, acquisition, processing and interpretation techniques used in a Site Survey project.

It is a companion to Report 373-18-1, *IOGP Guidelines for the Conduct of Offshore Drilling Hazard Site Surveys*.

The Guidelines and *The Technical Notes* replace the former UKOOA Guidelines for the conduct of Mobile Drilling Rig Site Surveys, Version 1.2, previously published under the auspices of the former UK Offshore Operators Association (UKOOA), now Oil & Gas UK.