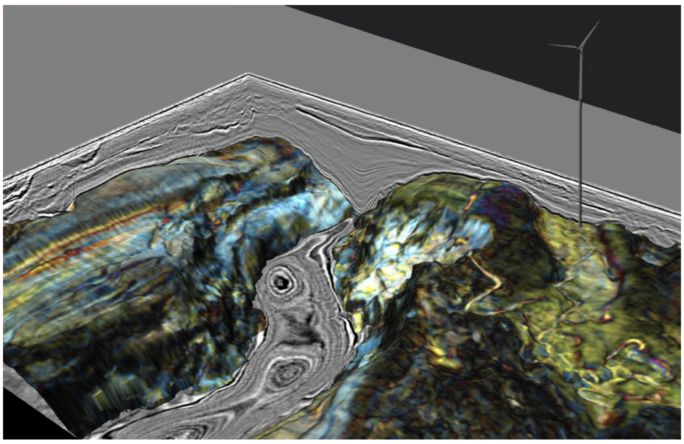
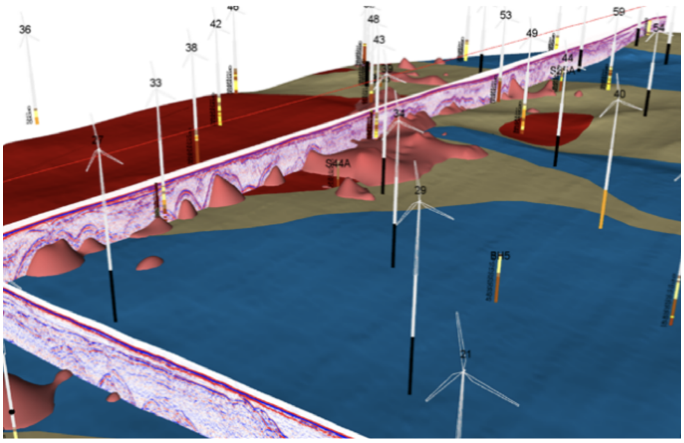
Society for Underwater Technology

OFFSHORE SITE INVESTIGATION AND GEOTECHNICS COMMITTEE

GUIDANCE NOTES FOR THE PLANNING AND EXECUTION OF GEOPHYSICAL AND GEOTECHNICAL GROUND INVESTIGATIONS FOR OFFSHORE RENEWABLE ENERGY DEVELOPMENTS

Revised September 2022





Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments

ISBN 0 906940 59 1

First published in 2022 by
The Society for Underwater Technology
HQS Wellington, Victoria Embankment, London WC2R 2PN

SUT
Society for
Underwater
Technology

GUIDANCE NOTES FOR THE PLANNING AND EXECUTION OF GEOPHYSICAL AND GEOTECHNICAL GROUND INVESTIGATIONS FOR OFFSHORE RENEWABLE ENERGY DEVELOPMENTS

These Guidance Notes were prepared by:

Editor:
Mick Cook (MCL)

Technical Sub-committee:
Andy Barwise (RWE)
Nigel Carey (Vysus Group)
Tim Carrington (Fugro)
Justin Dix (MarineSpace/Southampton University)
Giorgio Giuliani (COWI)
Ray Hobbs (Consultant)
Leo James (RPS)
Alastair Muir Wood (Wood Thilsted)
Mark Lawrence (RES)
Dafydd Lloyd Jones (MarineSpace)
Neil Morgan (Lloyds Register)
Richard Orren (Inosys)
Julian Osborne (Ocean Infinity)
Miguel Pacheco Andrade (Ørsted)
David Rushton (East Point Geo/AqualisBraemar)
Alex Searle (Ternan Energy)
Alex Smith (Ørsted)
Phil Wilson (Ocean Infinity)

ACKNOWLEDGEMENTS

These Guidance Notes are dedicated to the life of our colleague Leo James who contributed enormously to these notes and sadly passed away all too prematurely during their preparation.

In Loving Memory

Leonora 'Leo' Ruth James

5th September 1968 - 21st May 2020

"Lover of Life, Lover of Rocks"

A tribute from her friend and colleague, Karen Dalton

Leo was a hugely talented, very well respected and supremely dedicated and passionate geoscientist who knew from an early age exactly what she wanted to do with her life, and she achieved that through a degree in Soil Science and then a PhD at UCNW, Bangor. Leo moved to Aberdeen and worked for Fugro, notably 'cracking' the Caspian and the complex geohazards which she loved. Leo then joined Hydrosearch/RPS Group working offshore as a QC geophysicist, and then became a leading specialist in offshore wind, working with all the experts in the industry, from Statoil, Innogy, BGS, NGI among others, alongside various university research groups. She had huge energy and drive and thrived on problem solving, and there were never enough hours in the day for everything she needed to do.

Leo worked tirelessly on everything she was involved in, whether that was offshore as a QC in Yemen where we sent her into a really difficult situation and she saved a project from failing, to the data integration and technical support on the huge Dogger Bank windfarm projects. The latter will see just one of her many lasting legacies, where she worked for a number of years alongside other industry and academic experts, and developed new and innovative methods of acquisition and interpretation for offshore wind projects. She was an amazing thinker and loved all debate and discussion, no matter what the topic or complexity!

Much more than that, Leo was my friend for 30 years, and I couldn't have asked for a more fierce and loyal friend. She'll be greatly missed by everyone who knew her.

Table of Contents

Figures

Tables

Appendices

1 INTRODUCTION

Since the first publication of these Guidance Notes, in 2014, there has been a significant increase in the scale and number of offshore renewable energy projects. While projects in northwest Europe have led the way, renewable energy projects are now being proposed and progressed in many parts of the world, including significant projects in North America, Asia and Australia. Wind turbines (and thus their foundations) have been getting larger (Figure 1). This continued turbine development has led to a further refinement and fit for purpose design methods, and Site Investigation (SI) methodologies have also had to be adjusted accordingly. Proposals for floating offshore wind projects are also being advanced. Varying designs of wave and tidal turbines have been developed, with many test and full scale devices deployed. Complex areas of seafloor, previously considered unfeasible for development, are now built upon, and cable routes are now extending in excess of 150 km offshore and cross a wide range of seafloor materials.

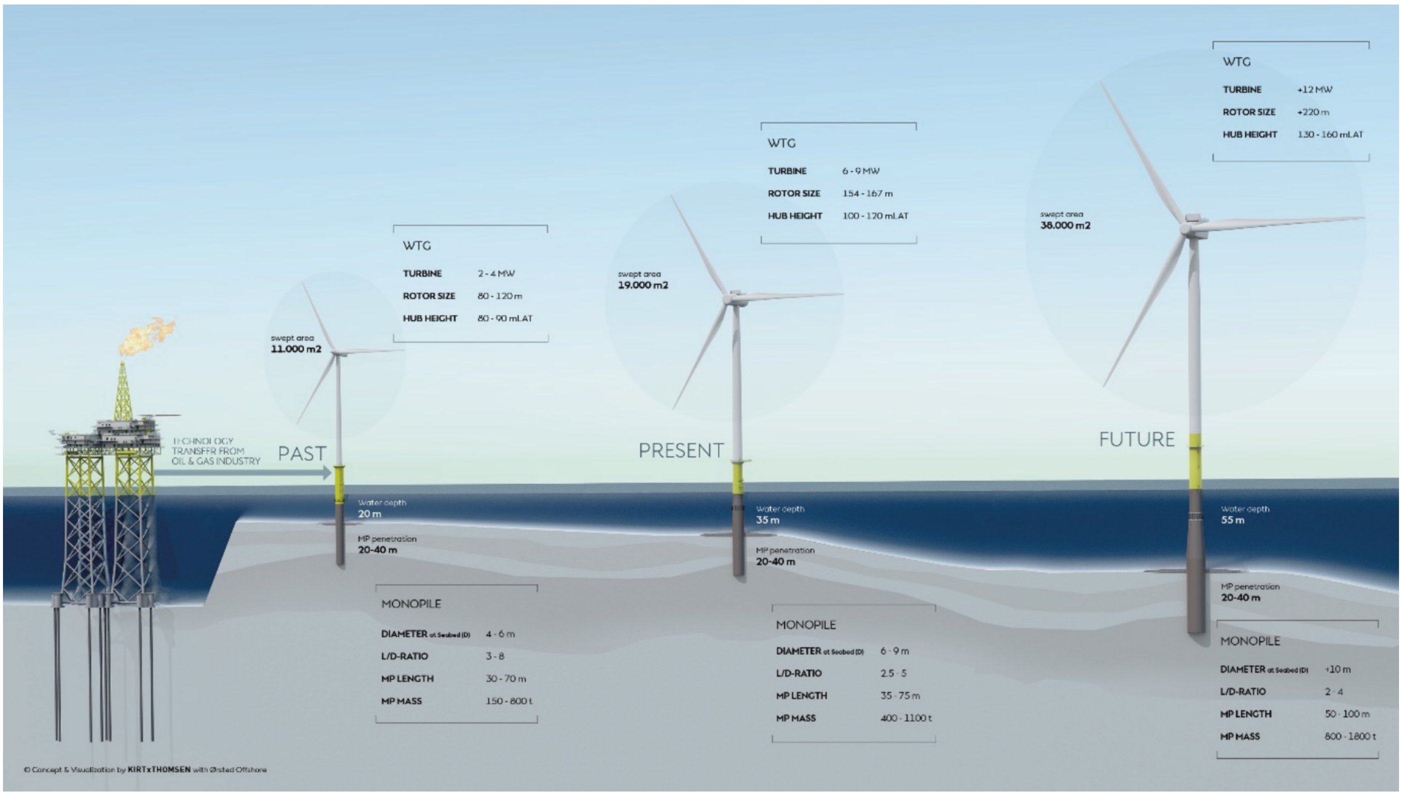


Figure 1: The increasing size of wind turbines

Some of the more significant risks that the developers of such projects face are the hazards and uncertainties that ground conditions present to project development, design, construction and operation. The constant pressure on prices (with many offshore wind farms now "subsidy free") means that pre-financial close expenditure is tightly controlled. Existing projects have experienced examples of early pile refusal/buckling and early decommissioning due to scour etc.; the need for integrated ground modelling, intelligent site investigation, and early understanding of ground conditions has never been greater.

The primary sources of information that are used to minimise and mitigate the risks posed by ground conditions and geohazards are complementary geophysical (remote sensing) and geotechnical (intrusive) methods. These Guidance Notes provide advice for the planning and execution of such investigations (hereafter termed ground investigations or site investigations) to developers, stakeholders, consultants and contractors involved in such projects. It is intended that the advice given will enable developers to formulate suitable strategies to mitigate the ground condition risks through the appropriate use of ground investigation methods, undertaken by suitably competent personnel, working together in integrated, multi-disciplinary teams.

These Guidance Notes have, therefore, been fully revised and updated from the 2014 publication. They have been separated into two parts:

- **Part 1 – Planning** – this section presents a strategy that developers are recommended to follow in the planning of ground investigations, including defining the aims and objectives of the investigation, and guidance on the selection of appropriately skilled and competent personnel for each stage of a project. It is aimed at practitioners without detailed experience of geophysical and geotechnical investigations.

- **Part 2 – Execution** – this section presents key aspects that should be considered when performing such geophysical and geotechnical ground investigations, including guidance on tools and techniques, positioning, data integration, analysis, interpretation and reporting, and a forward look towards novel technologies, techniques and methods which may provide alternatives in the near future. It is aimed at readers actively involved in the day-to-day management and application of site investigations, and should be used as an aide-mémoire for those that execute them.

The Guidance Notes are designed to be generic in nature, and to be applicable to a wide range of offshore renewable schemes, worldwide. Although, they are neither intended to be a standard nor a specification, they are technically robust and represent the state of the industry at the time of writing. Whilst the techniques and processes referred to are common and widely used in the marine environment, each project will have its own specific requirements.

Offshore site investigation is a specialist subject area and developers are, therefore, advised to engage specialist help to ensure that investigations are successfully achieved in a timely manner. Further, it is advised that the end-users of the investigation (e.g. foundation designers or installers, cable route developers or installers, etc.) should be engaged at an early stage in the process and consulted throughout the project. It should be noted that, in certain jurisdictions, complementary environmental surveys may be required for consenting purposes. Such requirements should be considered together with the engineering requirements, to optimise survey vessel utilisation.

This document contains a Glossary and, in **Appendix 1**, a list of references, standards, codes and guidelines pertaining to various aspects of offshore ground investigation. **Appendix 2** covers geohazards, their investigation and their likely impact on a development, while **Appendix 3** covers geotechnical testing methods.

PART 1 - PLANNING

2 MANAGING GEOLOGICAL AND GEOTECHNICAL RISK

When the developer of an offshore renewable project first assesses the feasibility of the project, one of the greatest uncertainties in the predicted cost – and therefore the project viability - will be the ground conditions. Ground-related issues can severely impact costs, design, schedules, construction methodologies, health and safety, and can also cause additional environmental issues. In the history of construction projects worldwide, there are numerous examples where unforeseen ground conditions have led to significant increases in overall project costs and indeed, in some cases, ultimately constructability.

Clayton (2001) summarises very concisely why ground-related risks to projects are so high, by highlighting a number of points including the following:

- The properties and distribution of the ground at a potential development site are predetermined and, therefore (unlike other materials used in construction), largely outside the developer's control.
- Soils and rocks are created by many processes, out of a wide variety of materials. Because the deposition is irregular, ground conditions can be highly variable, both geographically and with depth. This is in sharp contrast to other construction materials.
- Ground conditions will affect different methods of construction in numerous and different ways.
- Construction in the ground is normally performed early in a project, and problems at this stage will delay and affect the later stages of construction.

To control these variables, and to ensure that they do not adversely impact a project, it is recommended that developers create and maintain a project-specific geological and geotechnical risk register as soon as practicable. This will contain all identified and potential geological or geotechnical hazards, and provide a structure for managing the risks associated with these hazards as the project progresses.

Geotechnical risk management is an iterative process, that comprises the collection, collation and interpretation of potential and actual geological and geotechnical hazards, in order that the risk of these hazards to the project can be identified and properly quantified (Figure 2). This is a continuous process, which is maintained throughout the life cycle of a project, in order to manage the ground risks until the residual risks are considered to be acceptable. In general, the level of risk is inversely proportional to the level of knowledge and, ideally, the risk assigned to any development will decrease with increased knowledge of the area, prior to the design being finalised. The aggregation and assimilation of all site investigation data collected during this process is commonly referred to as the ground model (Section 3).

The rate of change of environmental, geological or anthropological aspects should also be considered when assessing the temporal validity of data, and thus determining the appropriate frequency of any re-survey required over the lifetime of the development and operation of the project. This helps to ensure that the cost benefit of surveys is optimised. For further detail refer to Section 3.3.1.

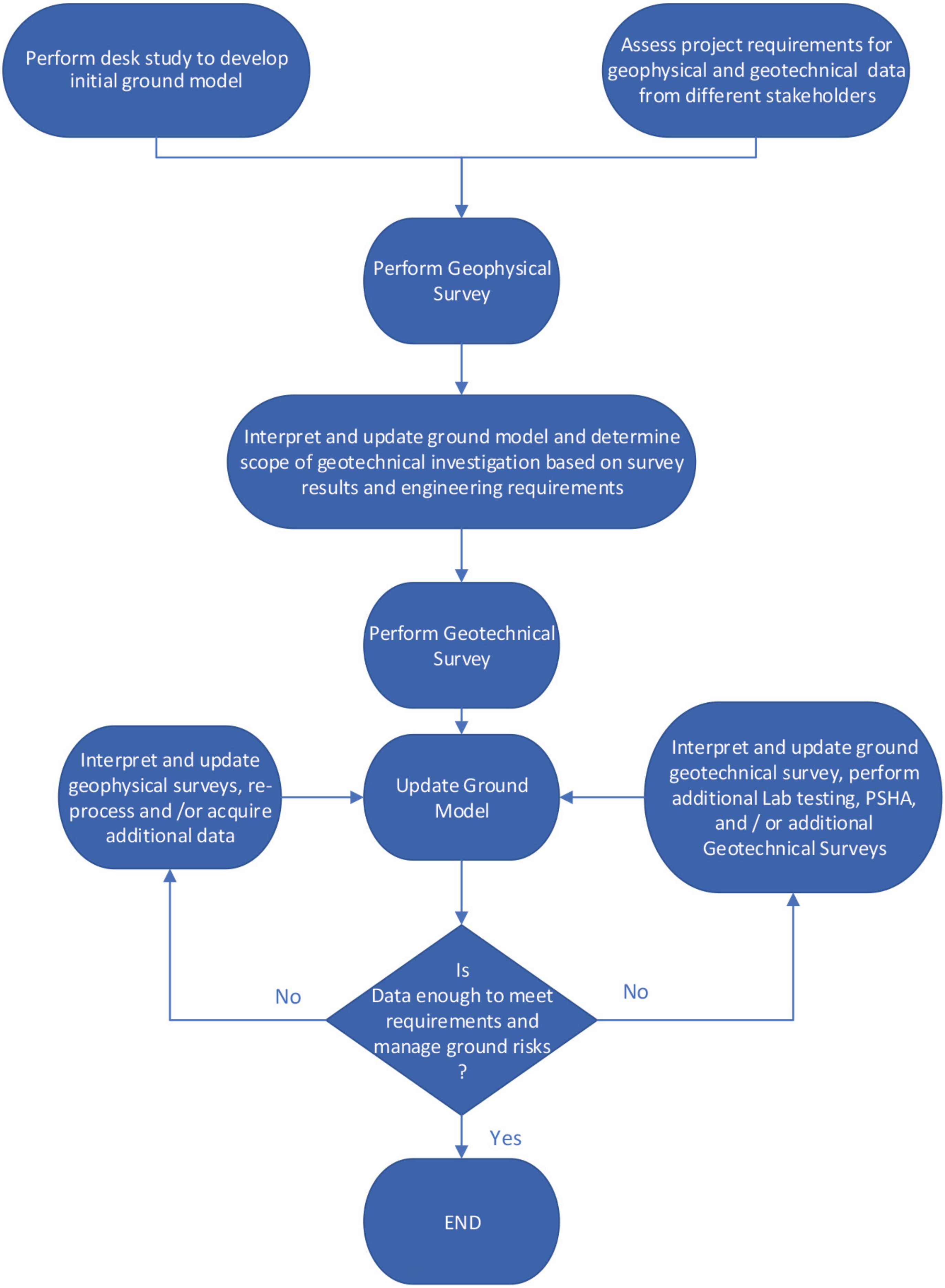


Figure 2 : A typical process for understanding ground risk

3 THE GROUND MODEL

3.1 What is a Ground Model?

A ground model is a database of available information, such as the structural geology, geomorphology, sedimentology, stratigraphy, geotechnical properties and geohazards of a site (a geohazard is a geological state, feature or process that presents a risk to humans, property or the environment - see Section 7.1 for further details). Creation of a ground model is an industry standard approach to collating all available site information. This resource is used to identify all relevant unknowns and project hazards, to direct investigations, and to inform the foundation design and selection of installation methods for a field development.

Creation of the ground model is not a linear process developed from a single data study, investigation or analysis, but from a continuous and iterative cycle of collecting new information, interpreting these data, updating the model, identifying the remaining unknowns and planning any subsequent investigations. The ground model remains live throughout the project, from initial inception through to decommissioning. The form of a ground model varies, and is influenced by the attitude of a developer to risk and by the complexity of the site and project. It will typically consist of three parts:

- Written reports that detail the phases of development of the ground model.
- A database, most often stored spatially, e.g. in a geographic information system (GIS) database and/or ground model software, of all the information collated (including raw and interpreted data) in an internationally recognised format (Section 10).
- A hazard register (Section 3.3.1.1).

The ground model will inform all phases of the project – development, design, construction, operation and decommissioning.

With all but the smallest and simplest ground models, it is considered standard practice to present the information as a 3D or 4D interactive model that can be used by geoscientists, engineers and other relevant stakeholders, alike.

3.2 Use of the Ground Model

Due to the iterative nature of the process of gaining an understanding of ground conditions, and in order to reduce the ground risks, a ground model will normally comprise several stages of evolution before these risks are considered to be acceptable. The ground model is useful for a project developer throughout its evolution, provided that the uncertainties of the model are recognised at every stage. Each modification to the ground model needs to be verified and subject to version control.

When attempting to constrain development parameters, or identify buildable and non-buildable areas, it is sensible to adopt a design envelope of parameters, such as the Rochdale Envelope (The Planning Inspectorate, 2018), the size of which will capture the uncertainty that normally exists during consenting phases of the project (e.g. uncertainty in the ground model or size of turbine to be constructed).

The 'Rochdale Envelope' approach, as applicable to the Environmental Impact Assessment (EIA) process, is employed when there is some uncertainty at the time of submission of an application, regarding some details of the whole project (e.g., in the context of an offshore renewables project, the precise dimensions of foundation structures, or the exact route of an export cable).

Consideration should always be given as to whether or not the model is fit-for-purpose for the application to which it is being applied.

3.3 Typical Stages in the Development of a Ground Model

There is no model or site investigation type that will suit every development as these will depend on the ground conditions encountered, the type of structure being proposed, the design method to be adopted, the installation methods, the developer's attitude to risk, the speed of development being proposed and the stage of the development. Budgetary constraints related to at-risk pre-consent spend, often govern the extent and type of any ground investigations. Thus, the needs of the ground model must be defined in advance, with an understanding of the explicit aims and objectives for each phase of the project considered against engineering requirements. Figure 3 shows typical stages for a large offshore wind development.

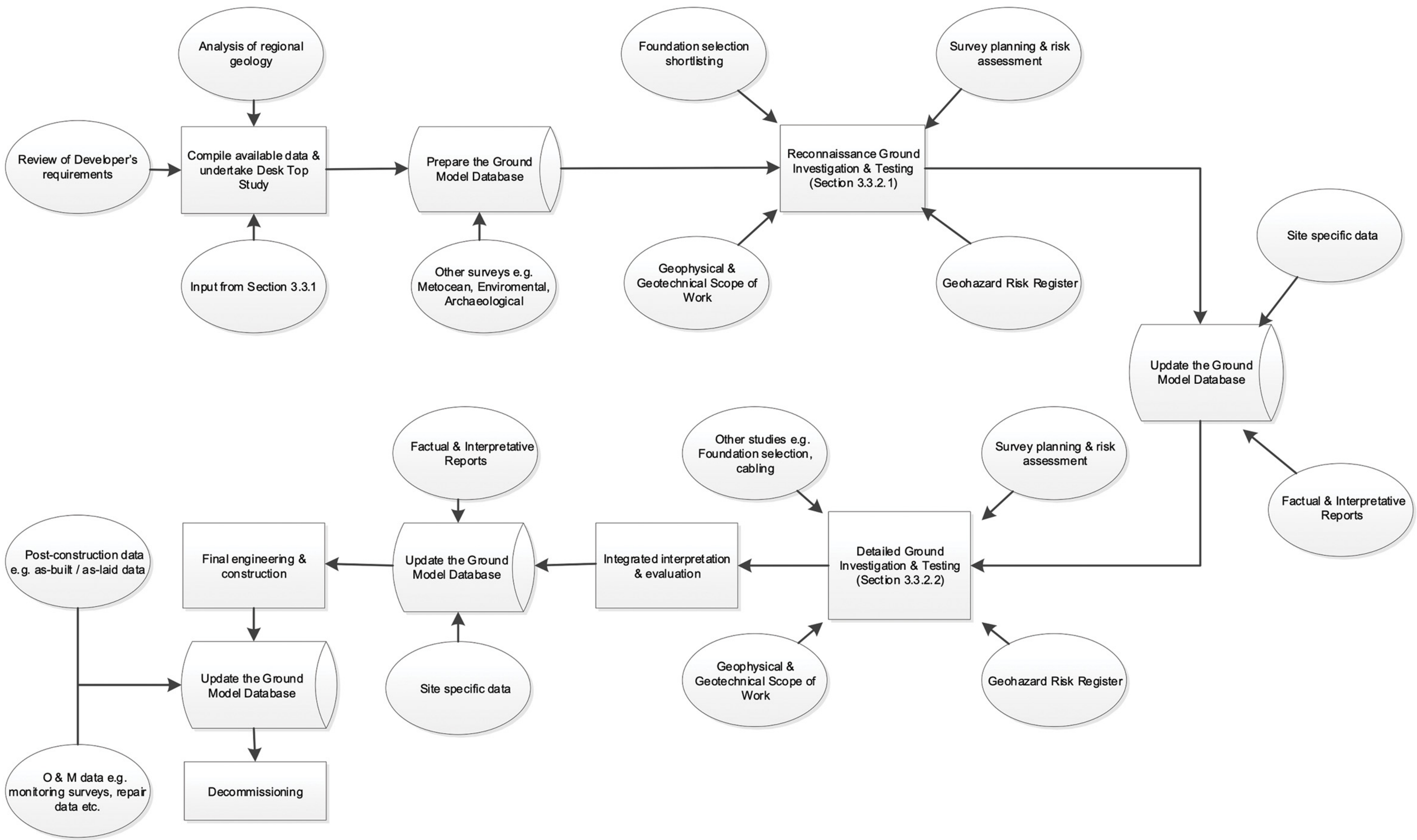


Figure 3 : Example ground investigation process for an offshore development

3.3.1 Desk-top Study

The first stage of determining the ground conditions and geological hazards that may be present on a site should always be a desk-top study – or review – of existing data, to ensure that the investigation is planned appropriately and efficiently, and that maximum use is made of existing knowledge of the area. Items to be addressed in the desk-top study should include, but not necessarily be limited to:

- Definition of the area to be developed (including export cable route corridors if known).
- Geodetic datum and projection to be used.
- Vertical (tidal) datum to be used.
- Project requirements.
- Licensing and consenting requirements pertinent to the area to be surveyed.
- Conceptual foundation selection studies.
- Assessment of shallow geological and ground conditions from all available sources (published and unpublished).
- Existing geophysical and geotechnical data for the site.
- Existing earthquake data for the site.
- Existing site investigation data and geohazard reports for other nearby sites.
- Environmental issues (marine mammals, seafloor ecology, etc.).
- Areas of interest for seafloor and sub-surface archaeology.
- Public domain data, e.g. winds, waves, tides, weather, climate (modelled and actual) etc.
- Nautical charts (historical and current) and other publicly available bathymetric data.
- Existing infrastructure (e.g. oil and gas structures, pipelines, cables, etc.) within or close to the investigation area, and installation records of the same, including the results of any scour monitoring.
- Existing or proposed activity in the investigation area (such as shipping, fishing or recreational use).
- Any other local experience or knowledge.

There is a wealth of public domain data (e.g. metocean, geological, nautical, etc.) published on the internet, national libraries, and in other sources, that may aid the desk-top study and the selection of optimum survey equipment or instrumentation and techniques.

Local regulatory and licensing requirements may include specific survey requirements for the proposed project, such as environmental surveys, or restrictions limiting the time of year that ground investigations can be undertaken.

When compiling and considering the use of data from various sources, sectors and vintages, particular attention needs to be given to the risk management of such data, and their validity. Specific issues include the use of data from older surveys, with their various limitations such as positioning inaccuracies that may be inherent, the mobility of environmental or geological features such as mobile bedforms, and the changes in technology utilised and the resolution achieved at the time of acquisition. Attention must be given to the geodetic parameters and conversion to the defined project parameters must be conducted with a high level of Quality Control (QC). These tasks must be conducted with appropriate care, to ensure that potential errors are not introduced or are not properly accounted for, leading to incorrect conclusions.

3.3.1.1 Hazard Register

A hazard register should include all hazards to safety, the programme and the environment, including known man-made hazards (such as unexploded ordnance (UXO), seafloor wrecks, seafloor infrastructure) and naturally occurring geohazards (such as boulders or gravel beds, soft sediment in-filled channels, bedrock, shallow gas, etc.). This should be a live document and updated throughout the project lifespan.

3.3.2 Data Collection

Data collection activities, or surveys, can be broadly classified into two types, based on when they are undertaken relative to the overall development schedule, as follows:

- Reconnaissance surveys.
- Engineering surveys.

Reconnaissance surveys are generally undertaken early in the overall development schedule, to support early stage planning (see Section 3.3.2.1), whereas Engineering surveys are generally undertaken later in the overall development schedule, and are more targeted to specific foundation locations, for example (see Section 3.3.2.2). These temporal classifications may be further subdivided to recognise specific phases of a development, e.g. consenting, pre- and post-construction, etc.

In addition to this primary temporal classification, surveys are also often further divided based on other aspects which include:

- Survey technique e.g. geotechnical, geophysical (seismic, bathymetric, LiDAR, …) etc.
- Geographic location e.g. marine/land, cable corridor, nearshore, landfall, etc.
- Purpose e.g. potential UXO (pUXO), environmental, topographic, drilling hazard, operations and maintenance, etc.

These classes and sub-classes of survey are referred to throughout this document.

3.3.2.1 Reconnaissance Surveys (Investigations for Site Characterisation)

Depending on the risk mitigation necessary, and on the scale and size of the proposed development, the desk top study will typically be followed by a reconnaissance survey or surveys, using geophysical and/or geotechnical methods (Sections 7 and 8). Assuming that appropriate data are available, a well-developed desk-top study can optimise the design of the reconnaissance survey. Indeed, for smaller developments, it may be feasible to proceed directly to the detailed engineering surveys as described in Section 3.3.2.2 without the need for reconnaissance surveys. Geophysical investigations should precede geotechnical investigations, and the results of the geophysical investigation should normally be used to optimise the location and quantity of geotechnical investigation locations.

Reconnaissance surveys are performed to:

- Provide an updated understanding of the bathymetry, shallow geology and ground conditions of the area to be developed, and to fill any data or knowledge gaps identified in the desk top study, to facilitate preliminary design and installation of a project.
- Identify possible hazards from man-made, natural and geological features which may constrain or influence the design, installation and operation of a project, or its environmental impact.
- Enable appropriate processes and operational practices to be put in place to mitigate any risks identified.
- Prove the feasibility of a project and give the developer confidence to continue investment in the project.

They also enable the most appropriate method of subsequent investigation to be determined. A developer must be prepared to undertake additional reconnaissance investigations, if the planned ones do not provide sufficient understanding of the key risks. In jurisdictions where information is required to obtain consent for a project, such consent requirements may be taken into consideration when planning the reconnaissance surveys.

On completion of the acquisition, processing and interpretation of the reconnaissance survey data, the ground model will be updated to reflect the new project information. The ground model will then be reviewed, along with the hazard register, and the scope of the detailed investigation can be defined, based on remaining uncertainty or on confirmation of preferred project layout and foundation solution, cable routing, substation location, etc.

3.3.2.2 Engineering Surveys (Site Investigations for Detailed Design and Construction)

The reconnaissance surveys will, normally, be followed by investigations for detailed design and construction. These subsequent investigations will be more targeted than the reconnaissance surveys, as they will involve investigation at more (if not all) turbine or other renewable energy structure positions, and may include additional geophysical data collection, and more complex laboratory testing of geotechnical samples to investigate the cyclic (including, in some cases, earthquake) behaviour of the seafloor materials. Therefore, these investigations should, ideally, take place once the developer has decided on the preferred infrastructure layout, cable route(s) and foundation type. Ideally, these should also be completed prior to the start of the detailed design process.

The engineering surveys are considered the last significant site investigations before detailed design and construction. It can therefore be extremely beneficial to iterate the ground model in (semi) real time, as the site investigation progresses, with regular feedback to the project team responsible for its scope. The scope can then evolve to better inform the project, within the given budget and schedule constraints.

Detailed cable route investigations may also be undertaken at this stage, to inform optimized route selection, anticipated burial requirements and installation methodology, thus enabling commencement of cable manufacture and installation procurement. As with the reconnaissance surveys, on completion of the interpretation of the new data sets, the ground model will be updated and reviewed.

3.4 Continuing Development and Use of the Ground Model

Whilst the ground model will initially be developed in support of the design of the project, it should be considered an evolving model that continually develops and maintains relevance throughout the life of the project, to help address appropriate issues that may arise, by the updating of existing data and by the addition of new datasets. Further survey data, such as those acquired during construction, routine operations and maintenance (O&M) surveys, or surveys conducted as part of local licence conditions, should be included in the ground model.

The frequency of post-construction surveys will, initially, be determined by design assumptions, licensing and consenting obligations, and by the device manufacturers. In areas where the developer, asset owner or operator can prove little to no change in the condition of the asset over time, the frequency may be justifiably reduced. A well maintained and current ground model will provide confidence to the various parties that the risks are well understood and being well managed. Continued iteration of the ground model throughout the life span of the project is considered best practice. For more specific information refer to Section 8.9).

4 COMPETENT PERSONNEL

The planning, acquisition, testing, processing, analysis, interpretation and reporting of data from site investigations require a combination of specific knowledge and competence in the relevant key subjects, namely:

- Geotechnical engineering.
- Engineering geophysics.
- Engineering geology.
- Hydrography.
- Navigation and positioning.
- GIS and geospatial data management.

These disciplines are distinct and not interchangeable. They involve specialist knowledge, experience and competence, based on university undergraduate and, often, post-graduate education, followed by professional experience, and it is unlikely that any individuals will be qualified and experienced in more than one or two of the required discipline areas.

Other specialist personnel with specific knowledge and skills may also be required for part of the work, such as for archaeology, UXO, environmental or metocean. Involvement of such specialists is encouraged in all aspects of planning and delivery of the survey.

In order that the key objectives of a ground investigation are met, it is imperative that appropriately skilled and experienced personnel are used for each stage of the work throughout the entire project. It is also necessary for the disciplines to be available to work together, concurrently, in an integrated multi-disciplined team, to optimise the understanding and application of the information gathered.

Key factors include:

- The ground investigations should be managed by a competent senior specialist or, preferably, by a team of appropriate senior specialists, working for or on behalf of the developer. Such personnel should have relevant qualifications and significant, demonstrable, experience. For successful completion of the investigation, the developer's offshore representatives should also have similar qualifications and experience.
- Different investigations require different sizes of survey teams. However, common to all investigations, and a significant aspect of contractor selection, should be the identification and appointment of an experienced core team to undertake the work. This should include party chief, senior engineer, senior surveyor, geophysicist and/or geotechnical engineer, and the drilling or downhole tool operators (for geotechnical surveys). For small-scale investigations, it may be that the party chief role is undertaken by one of the key engineering, survey, geophysical or geotechnical personnel.
- The contractor survey and site investigation teams should include leaders (e.g. party chief) with significant and demonstrable experience of similar work types to those being executed.
- It is important that all data processing, storage, testing, analysis, interpretation and reporting be overseen by experienced site investigation specialists (of the appropriate disciplines) to ensure that each constituent part of the final survey results is adequately checked, and that there is optimal integration of all data. GIS and geospatial data management skills/personnel are important to enable optimisation of such integration, and to maximise the value of this information through the future stages of the project.
- It is recommended that environmental specialists be integrated into the team at an early stage of the investigation. Early knowledge of environmental conditions can optimise survey design, to ensure that data collected are also appropriate for environmental assessment purposes (i.e., collect once, use multiple times). In addition, understanding of the environmental conditions can help guide decision making with regard to site selection or routing options, etc., to minimise environmental consenting challenges and licensing issues.

5 PLANNING AN OFFSHORE GROUND INVESTIGATION

5.1 Aims, Objectives and Evaluation

In order to manage offshore ground investigations effectively, it is important to have a full understanding of their purpose. All investigations must be planned with very clear aims and objectives. These should evolve from the risk management process and should be communicated clearly and directly to all those involved. It should be noted that the site investigations should attempt to take into account possible future changes due to the speed of technical development, such as increasing turbine sizes, throughout the project timescale.

Investigations may be designed to be multi-purpose. For example, the investigation for a development site may also be designed to cover part of a cable route, or a borehole for a potential substation position may be used to improve the general understanding of the ground conditions. However, each purpose will have specific requirements, and priorities must be defined to ensure cost benefits are optimised.

It is important that each stakeholder discusses its requirements at an early stage. This ensures that many of the data sets can be acquired in one pass and that the data acquired for environmental purposes can also be used for archaeology, scour, bathymetry and, where applicable, pUXO purposes.

When planning offshore ground investigations, it is important to consider the time required for planning and executing the works against the project development timeline. Adequate time must be allocated for effective scoping and specification of the investigation(s), procurement of the survey contactor, obtaining the necessary consents, undertaking the operations (including the impact of delays caused by weather downtime), and the processing, testing and reporting phase, which may take several months.

All investigations should be followed by a period of evaluation to confirm that the aims and objectives have been achieved, and to update the risk register in accordance with the survey results.

5.1.1 End-Users/Stakeholders

Planners of ground investigations must consider the wide range of end-users and stakeholders and the variety of purposes for which the data, reports and resulting ground model may be used. End-users and stakeholders may include:

- Developers.
- Foundation designers.
- Foundation installers.
- Site investigation contractors (hereafter termed contractors).
- Cable route developers and installers.
- Certifying authorities, warranty agencies or regulatory bodies.
- Insurers.
- Financiers or investors.
- Safety engineers.
- Geologists.
- Environmental scientists.
- Archaeologists.
- Oceanographers.
- Surveyors.
- Fisheries personnel.
- Mariners.
- Public organisations.

5.1.2 Influence of Design Codes and National Standards

Developers must make themselves aware of the requirements of national codes or standards and other country-specific regulatory provisions that may apply to the site investigations. The application of these codes and standards will, generally, not change the principles that are outlined in these Guidance Notes, but they may change the scope of the investigation, the nomenclature used, or the order in which activities are undertaken. Each project should be planned, conducted and reported in accordance with the project-specific requirements and also incorporate any local legislative obligations. It is recommended that developers compare legal or local requirements with these Guidance Notes and, where there are differences, apply the most appropriate guidance.

It is not practicable for this document to address the varying regulatory obligations that are in place in different jurisdictions around the world. However, to assist developers, a list of some of the relevant documents is included in Appendix 1.

5.2 Types of Investigation

These Guidance Notes cover a number of data requirements including water depths, seafloor topography, seafloor and sub-seafloor obstructions, seafloor soils, shallow geology, and ground conditions and geohazards. These are discussed below, in terms of their impact on different aspects or applications of an offshore renewable energy project, including field layout, foundation design, inter array and export power cabling, offshore substations, systems installation, and operations and maintenance. However, they do not cover detailed foundation design, nor detailed systems installation (e.g. foundations and cable lay). The planner of a ground investigation must consider the methodology that will be used for the design and type of foundation that will be constructed, as different design methods will require different parameters to be interpreted from the investigation results. Design engineers and installers should be consulted at an early stage in the process, and should be engaged throughout the ground investigation programme.

The two primary sources of data that are acquired during a site investigation are geophysical and geotechnical, and there are significant benefits to be gained in the understanding of the seafloor and underlying soil conditions through a well-integrated investigation using both techniques. The benefits and limitations of these techniques are summarised in Table 1. With the increasing size of sites, consideration should also be made to plan the site investigation to include corridors or partial areas of the site, in line with anticipated location of infrastructure.

Offshore wind is now expanding into earthquake prone areas and site investigations in these regions have to address probabilistic seismic hazard analyses (PSHA), site response analyses (including kinematic soil-structure interaction) and liquefaction analyses.

Acquisition of geophysical data primarily uses a range of acoustic-based instruments to characterise the seafloor, shallow soils and geology, and to identify any man-made and naturally occurring hazards that may adversely impact the offshore renewables project. Magnetic, electrical and optical-based systems are also available, and are applicable to various objectives.

Acquisition of geotechnical data primarily involves making an intrusive investigation of the seafloor. This generally involves the taking of samples of soil or rock, and *in situ* cone penetration tests (CPTU) in which an instrumented cone is pushed into the seafloor. Cone tests made with pore pressure measurement are referred to as piezocone tests, or as CPTU. CPTU measurements provide specific soil properties through both *in situ* and laboratory empirical correlations, that can be used for engineering design purposes when combined with sample test results. The geotechnical data are used, amongst other things, to "ground truth" the geophysical data and to build the ground model detailed in Section 3. Consideration should also be given to performing *in situ* measurement of soil stiffness and other dynamic properties – e.g. through use of seismic cone or P-S logging (Appendix 3).

Following the site investigations, geophysical processing and geotechnical testing (particularly more advanced testing) are often required at an onshore facility. This can add significant time to the programme, and so should be considered at an early stage. Opportunities for undertaking geophysical processing and geotechnical laboratory testing offshore, and provision for interim deliverables from onshore facilities, should be considered.

Table 1 : Characteristics of geophysical and geotechnical investigations

Benefits	Limitations
Geophysical Investigations	
Wide range of data acquired simultaneously from one vessel	Remote sensing tool that requires ground truthing
Large areal coverage in short time – efficiency	Dominantly qualitative results subject to interpretation
Continuity and/or correlation between geotechnical sample locations	Some systems are very weather- or noise-sensitive
Wide range of depth of sub-bottom investigation Geotechnical Investigations	Ground conditions can limit usefulness (e.g. biogenic gas blanking of underlying geology)
Geotechnical Investigations	
Range of systems for different soils and applications	Single data point - may need many locations to characterise the soils over the area of a development.
Quantitative results used for engineering design	Slower acquisition rates than for geophysics
Physical measurement of soil and rock properties through *in situ* and laboratory testing.	
Generally, less weather-sensitive than geophysics	

5.3 Scope of Investigation

Offshore renewable energy projects involve the installation of a variety of infrastructure types. The scope of geophysical and geotechnical investigations will differ between these applications.

The extent of the proposed ground investigation area should provide adequate coverage to achieve the aim of the investigation.

Prior to any discussion on the planning of an offshore renewables project, the co-ordinate reference system and the vertical (tidal) datum for all the work associated with the project should be established (Section 9). Significant cost, time and technical impacts can occur when surveys are undertaken using different geodetic data and/or vertical datums. This is specifically important at landfall, where datums change between offshore and land.

The following sections provide guidance on typical design issues that should be considered in advance of performing ground investigations. These are not exhaustive. Each site and development concept is likely to have a number of unique characteristics that need consideration.

5.3.1 Turbine and Substation Foundations

The following should be considered in the planning of turbine and substation foundations:

- Type(s) of structure or foundation under consideration (e.g. driven or drilled and grouted monopile, suction-installed caisson, gravity base structure (GBS), piled jacket, anchored floating structure, etc.).
- Likely planned extent of foundation footprint, penetration and mobilised stress depth, also considering jack-up emplacement for lifts and cable exclusion zones.
- Reliability, suitability, availability and installation constraints of foundation type for the given soil conditions (e.g. are there any specific test requirements for design assurance).
- Whether the foundations are limited by static or dynamic (cyclic strength and stiffness) loading considerations.
- Uniformity of design versus optimisation of foundations for each location.
- Susceptibility to seafloor mobility (scour, sand wave movement, etc.).
- Location, site specific or other factors identified by the foundation designer.
- Parameters required for seismic response analysis and liquefaction assessment.

It is recommended that close communication be maintained between all stakeholders to ensure data suitability.

5.3.2 Installation and Maintenance

Foundation and anchoring requirements for installation and maintenance vessels (including jack-up rigs) should also be considered. Reference, inter alia, should be made to RenewableUK (2013) guidelines and the 'InSafe' report (RPS, 2011).

5.3.3 Inter-Array Cables

Installation, and protection, of inter-array cables often carry a significant risk on a renewables development and warrant careful consideration, as a minimum, to the following aspects:

- Array cable layout.
- Bathymetry and seafloor gradients.
- Seafloor and sub-seafloor obstructions.
- Cable and pipeline crossings.
- Soil classification and engineering properties (e.g. particle size distribution, density, shear strength and thermal properties, as appropriate).
- Peat, gravel and shell content of the shallow soils.
- Seafloor mobility and the consequential effect of the structures on the seafloor.
- Burial protection specification – depth of lowering (DOL) from mean seafloor level, depth to top of cable (TOC), depth of cover (DOC) or backfill and trench cross-sectional profile.
- Potential exposed cabling over rocky seafloor, with anticipated protection from movement due to current or to human activity.
- Trenchability.
- Potential UXO, archaeology or environmental habitats.
- Geological substrata and their relationship with seafloor bedforms.
- Risk of liquefaction.

5.3.4 Export Cables

The design issues for export cables are similar to those for inter-array cables. However, the variation in water depth and soil type along an export cable route may be significantly greater. There may also be uncertainty about the route during the early stages of an offshore renewable energy project, and multi-cable systems will have specific corridor width requirements that will need accommodating. Particular attention should be paid to shallow water sections of the route, and to mobile seafloor areas and those where rock is expected to occur within the target trench depth. Specialist survey equipment may be required to accurately map features such as rock head.

Hazards associated with vessel anchoring and fishing gear interaction are the same as for inter array cables. However, the likelihood of such occurrences, and therefore the risk to the cable, is greater along an export route. This may result in a commensurate increase in the target protection specification. However, care should be taken to ensure that protection requirements (including by burial) are realistic, appropriate, achievable and commercially viable, given the limitations of equipment and installation techniques available.

5.3.5 Shore Crossings (Landfalls)

These Guidance Notes cover activities from the high water mark seaward, and do not include onshore cable installation or onshore substations, for which it is assumed that conventional onshore ground investigation practice will apply. However, the shore crossing survey, from the surf zone up to the high water mark, is typically combined with the nearshore or landfall marine survey for efficiency. Topographic (beach levelling) surveys using land survey techniques are the minimum such scope. These are usually combined with the marine survey, and terrestrial geophysical survey, using seismic reflection, refraction, and multichannel analysis of surface wave (MASW) or resistivity methods, which can be utilised for soil profiling.

Onshore geotechnical investigations would include the use of boreholes, CPTs and windowless samplers on suitable vehicles or rigs.

For geotechnical investigations, it is important to consider the protection implications for the proposed cables. In many instances, soil conditions, equipment limitations and environmental restrictions may necessitate the extension of onshore cable protection to a significant distance offshore. One notable example is the use of horizontal directional drilling (HDD) which can extend up to one kilometre or so offshore. Such drilling can be very sensitive to the soil or rock types encountered.

Careful planning of onshore and nearshore geotechnical investigations is essential, especially where the use of mobile jack-up rigs may be required. Care should be taken to ensure that boreholes are not placed on top of the proposed HDD trajectory or, if they are, then ensuring that they are backfilled appropriately. Other shore crossing techniques, including sheet piling and dredging or rock dumping, may also require specialist consultation.

Works within the nearshore area are some of the most complex and challenging of the project from an acquisition or variability perspective. This is a critical project interface and, whilst not explicitly covered in detail within these Guidance Notes, the investigation within the nearshore zone should receive an early and high focus within the project.

5.3.6 Data Collection Devices

Developers often require ground investigations to be performed very early in a project, in order to design data collection devices (e.g. wave buoys, met masts, etc.). Occasionally, developers attempt to advance such investigations to a detailed stage without having undertaken even a brief desk top study. This should be discouraged, as it may lead to ineffective management of geotechnical risk and to poor design. Generally, the investigation requirements for data collection devices are very similar to those for turbine and substation foundations, albeit on a smaller scale.

PART 2 - EXECUTION

6 GENERAL

6.1 Health, Safety and Environment

Health, safety and environmental (HS&E) issues should be given the highest priority when planning and executing ground investigations. A key element of this is the preparation of project-specific HS&E and emergency response plans. These should involve the joint resources of the developer, the contractor and any specific licensing authority, to ensure safe operations and minimal environmental impact, and to establish contingency planning for emergency situations. Consideration needs to be given to any local requirements and regulations, specifically in relation to geophysical, geotechnical and survey induced noise, in respect of disturbance to marine mammal and protected species.

All vessels or rigs to be used in the ground investigations should be subject to appropriate HS&E inspections prior to, and during, operations. Such inspections should incorporate review of all deployment, recovery and towing arrangements for the systems to be used, the operational processes to be employed and the HS&E management systems in place. These inspections should consider the actual proposed operations and may, therefore, need to exceed normal requirements of international maritime and local laws. All action items identified and highlighted as requiring rectification should be followed up and closed out expediently by the contractor.

All personnel deployed offshore should be required to have the appropriate offshore certification, namely:

- BOSIET (Basic Offshore Safety Induction and Emergency Training) for standard offshore surveying or;
- GWO (Global Wind Organisation) where applicable for installation/maintenance phases of the project (or as directed by company policy).

The maximum elapsed period between such vessel or rig HS&E inspections and the operations themselves is a subjective matter, and will be dependent on the specific circumstances pertaining to the vessel or rig and its operations. Inspections should be undertaken every time that significant changes are made to the vessel or rig use, or when major items of survey equipment are installed. It is considered unusual for a vessel not to be inspected at least once every twelve months.

A vessel safety guide for offshore renewable energy developers has been written by RenewableUK (2015). The guidance covers:

- Effective vessel selection and operation.
- Regulatory aspects of vessel selection, including certification.
- Suitability assessment when selecting a vessel.
- End of contract and project review.

6.2 Developer's Offshore Representation

To ensure that project specifications and objectives are met in the field, the developer's site investigation project manager should be supported by experienced developer's offshore representative(s) (DOR) on all vessels or rigs. Further, depending on the contractual agreement, it is common for the DOR to represent the developer regarding commercial aspects of the survey (including weather downtime, data acceptability and any contractual issues) and to confirm that operations are being conducted in accordance with HS&E requirements and standards established for the investigation. Consideration should be given to providing full 24 hours coverage offshore, where appropriate.

It is very important that the DOR has knowledge of:

- The developer's objectives.
- Survey objectives.
- Health and safety management.
- Offshore operations.

If there is any shortfall in these capabilities, the DOR will not be able to act in the developer's best interest offshore, resulting in an ineffective, uneconomical and/or unsafe campaign. The DOR should also have knowledge of the data acquisition techniques being employed, and the required quality of the data. Relying on onshore support for guidance can result in poor decisions being made overnight or at weekends, when this support may not be immediately available. The DOR is, typically, empowered to make operation-critical decisions 24 hours a day and 7 days a week, without reference to the developer.

It is also recommended that the onshore data processing, laboratory testing, analysis, interpretation and reporting of such data are similarly subject to continuous review by, or on behalf of, the developer during the post-acquisition phase of the project.

6.3 Contractor and Vessel/Rig Selection Considerations

When selecting a contractor and a vessel or rig to undertake ground investigations, factors to be considered include:

Contractor:

- The types of equipment being offered and its performance.
- Previous experience of the contractor and its personnel in the area of operations and the techniques and equipment offered.
- Good HS&E record and a demonstrable HS&E culture.
- Where the vessel or rig's marine crew and the survey and/or drilling crew are from different companies (as is common) then consideration should be given to the establishment of a "bridging document" between the parties, to ensure that the crews work effectively together as an integrated team.

Vessel/rig – general:

- Vessel or rig suitability to operate survey or drilling equipment to meet the objectives of the investigation.
- Vessel or rig suitability for efficient and safe operations in the area, during the proposed time frame of the investigation.
- Whether or not the vessel or rig proposed is owned by, or is on long-term charter to, the contractor and permanently mobilised with all survey/drilling equipment. Vessels of opportunity that are mobilised specifically for a ground investigation often require a period of 'shake-down' and are more likely to be affected by problems than contractor-owned or long-term charter vessels, or rigs with survey or drilling equipment permanently installed.
- Weather sensitivity of the vessel and its in-water equipment deployment and retrieval capabilities.
- Vessel or rig accreditation and audits for compliance with regulatory requirements.
- Legal status of the vessel and crew with regards to the jurisdiction where the project is located.

6.3.1 Geophysical Vessels

All vessels used in geophysical operations need to be proven to be acoustically quiet.

Where required, vessels used for geophysical investigations that can acquire both the single channel seismic and other shallow geophysical data (including ultra-high resolution (UHR) multi-channel seismic data) concurrently, in a single pass, are generally preferred over vessels that can only acquire the data in dual-pass mode. This assumes that data quality from all sensors is maintained, survey line programmes are suitable and such operations are practicable and safe.

In specific circumstances, the vessel should be capable of acquiring shallow geotechnical data to provide near real-time ground truthing of shallow geophysical data in the field.

Autonomous and remote vehicles such as Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs), and Remotely Operated Tow Vehicles (ROTVs) can be used as survey instrument platforms, especially for multibeam echo sounding (MBES) and side scan sonar instrumentation. These vehicles have battery power limitations for extended use but can be particularly useful where access for survey vessels is difficult.

6.3.2 Geotechnical Vessels/Rigs

All geotechnical investigations require a working platform from which to perform the investigation. In shallow water and in the nearshore environment, jack-ups can be used, but in deeper water, further offshore, a vessel is more likely to provide the most cost-effective option. Vessels can maintain station by use of either dynamic positioning (DP) – preferred - or an anchoring spread. For multiple location investigations, the DP vessel often provides a more efficient and productive solution, although in water depths of less than 20-25 m, they can be limited by drill-pipe flexibility and ”watch circle” constraints. An anchored vessel may require a larger area to be certified safe from UXO. Alternatives to vessels with drilling rigs are seafloor drilling units capable of remote operation from the ‘mother’ ship. In some situations, these may provide a technically advantageous solution.

Typically, the drilling spread on a drillship is mounted above a central moon pool and, on a jack-up, a moon pool is also often used. Cantilever drilling platforms can be used from vessels but are generally more weather sensitive.

Where seafloor cone penetrometer test units are the preferred *in situ* testing option, these can be deployed either through a moon pool or over the side or stern of the vessel. A seafloor CPT drive and deployment system can typically weigh in excess of 20 tonnes, and a safe deployment system is imperative. Where penetration below seafloor exceeds the water depth, additional CPT rods may have to be added during the test, in which case a safe working platform above the seafloor unit needs to be available, and the operation may become more weather sensitive. Coil rod systems are available, which eliminate the need for adding extra cone rods.

In areas where bedrock is encountered, and there is a requirement to sample this material in addition to the overlying deposits, secondary drilling systems are often necessary.

Operation of site investigation vessels can be hampered by strong currents and there may only be short tidal windows (e.g. half an hour) in which operations can be performed.

In areas with exposed bedrock, the anchoring of vessels can be difficult, and jack-up operations may require detailed knowledge of the localised bathymetry.

In some areas, prior to acquisition of geotechnical boreholes, both seafloor surveys (e.g. for pUXO, unlisted man made hazards, or in environmentally sensitive areas), and sub-seafloor surveys (e.g. for geohazards such as shallow gas) are required, either by the contractor or by regulatory requirements. These need to be scheduled sufficiently in advance.

6.4 Offshore Data Processing, Analysis and Interpretation

Consideration should be given to processing, analysis and interpretation of the geophysical and geotechnical data offshore, particularly in remote or geologically complex areas. Indeed, such a capability is imperative for large scale investigations, in order to enable development schedules to be met. Such offshore analyses will enable preliminary on-site assessment that may impact the proposed work scope. Further, this will speed up delivery of results and increase the flexibility of the ground investigation by allowing changes to the work scope, soil data acquisition methods and investigation area to be made, in response to variable or unexpected site conditions, or other changes in data requirements.

Where more than one vessel is used simultaneously on a ground investigation, it is essential that activities are well integrated and co-ordinated, to ensure compatibility between data sets and subsequent data interpretations.

It is important that all offshore data processing, analysis and interpretation is conveyed, in a well co-ordinated process, to those that subsequently continue such work onshore. This will ensure that all onshore effort is directed towards the final product, and that time and effort are not wasted, duplicating what has been done offshore, or by focussing on the wrong priorities. Ideally, the data processing, analysis and interpretation should be planned and managed as a single exercise, begun on board the survey vessel and completed (normally) onshore. The reporting project manager may be onshore, but he or she can still direct activities that are taking place offshore, to make sure the whole process is seamless and efficient. With the large area surveys required, and the enormous quantities of data involved in geophysical surveys, data management is the key to success.

Due consideration should also be given to the handling and preservation of geotechnical samples obtained during the investigation, and the transportation of these to a suitable geotechnical laboratory. Renewables projects typically require advanced geotechnical laboratory tests, hand in hand with *in situ* measurements, to determine the stiffness and cyclic properties of the seabed. These laboratory measurements require high quality, undisturbed, samples.

6.5 Developer/Contractor Liaison

When planning and conducting ground investigations, it is essential that effective communication between the developer, contractor and any developer’s representative(s) is maintained.

To ensure that the objectives of the ground investigations are met, early and continuous transfer of all relevant existing data and information pertaining to the investigation should be made to the appropriate parties.

Other related activities, such as oil and gas exploration seismic surveys or construction and installation activities, within or adjacent to the proposed investigation area, can severely impede access to the investigation area and adversely affect the quality of the data acquired. Hence, survey activities should be scheduled in coordination with both the developer's own and other party's ongoing and planned activities in and around the investigation area and, to facilitate this, early liaison is essential.

7 GEOPHYSICAL INVESTIGATION

7.1 General

There is a considerable amount of information available in the literature on the equipment and techniques used in offshore oil and gas projects for geophysical and geotechnical data acquisition, processing, testing and interpretation. The equipment and techniques used for offshore renewables projects are essentially the same. Hence, it is not intended in this document to duplicate this information and reference is, therefore, made to the guidelines listed in Appendix 1, particularly the IOGP (2015) Guidance Notes for the conduct of offshore drilling hazard site surveys and ISO 19901-8 on marine soil investigations.

Although much of the geophysical equipment and techniques used are similar to those employed in oil and gas projects, the surveys required for renewables projects have specific differences. It is these differences that need to be considered in the design and implementation of any geophysical survey, as discussed below:

- **Extent of area to be investigated** - renewables surveys typically cover large areas, covering hundreds of square kilometres. As a result, consideration needs to be given to the type of survey and coverage required, particularly with reference to the phase of the project, from initial or consent surveys through to detailed engineering surveys.
- **Depth of Investigation** - renewables surveys are focussed specifically on the depth required for the emplacement of the structure and the burial of cables. As such, the depth of investigation typically varies between 50 – 100 m, but requires a very high level of resolution across the entire site to allow for the engineering required. In some specific regions where earthquake seismicity may be present, this depth of investigation may need to be increased to determine bedrock level or the "stiff horizon" for the Probabilistic Seismic Hazard Analysis (PSHA).
- **Water depth variations** - renewables surveys, due to current technological constraints, are mainly concentrated in water depths of less than 100 m (although, with the onset of floating windfarms, this is likely to increase to 100-200 m). These relatively shallow water depths create a constraint on the swath widths of survey systems, which needs to be considered for planning line spacing and the choice of equipment deployed.
- **Stages of development** - renewables projects undergo a number of stages, requiring different geophysical surveys throughout the project lifecycle. Each phase has subtly different objectives, and the nature of the geophysical survey needs to change to meet these objectives – there cannot be a "one size fits all" approach to the surveys.

Due to the variable nature of the surveys, an experienced marine engineering geophysicist should be involved in preparing the survey scope and technical specifications. The extent of the geophysical investigation, and the choice of equipment, should take account of the stage that the development is at, and the purpose of the survey: reconnaissance; infill and cable route; pre-construction engineering; pUXO identification and characterisation; and post installation and maintenance. In addition to type, size and area of the development, the range of foundation options and cable types (and associated depths of interest) and the uniformity and type of seafloor and shallow soil conditions likely to be encountered, also inform the choice and mode of deployment of the instrumentation. The desk-top study (Section 3.3.1) provides essential information to assist this scoping work.

The geophysical investigation can provide relevant information on:

- Water depths.
- Seafloor features and obstructions.
- All geohazards (Appendix 2).
- Other hazards (e.g. pUXO, wrecks, debris, etc.).
- Environmental restrictions.
- Shallow soils and geology over the area, to a depth below which the underlying conditions will not influence the safety or performance of the structures being considered (both turbines and cables).
- Cable burial depth.
- Post-installation dynamics, both geological and environmental.

As with all marine surveys, a critical element, in addition to having the appropriate equipment on board the vessel to achieve the survey objectives, is the accuracy of positioning of both vessel and sensors. This includes dimensional control of the vessel (*i.e.*, where each individual piece of equipment is mounted) and subsea positioning (Section 9).

7.2 Project Phases and required Geophysical Surveys

As detailed in Section 7.1, there are a number of different phases of geophysical survey. Table 2 indicates the main aims of each survey and the geophysical sensors that may be required. In general terms, there is a direct correlation between sensor range and resolution. Therefore, it is typical for the early phases of the project to seek coverage with wider line spacing, whilst later phases focus on resolution with closer line spacing.

Table 2 : Geophysical surveys by phase

Phase	Primary aim	Data to be acquired	Geophysical sensors	Coverage/resolution
Reconnaissance survey	Validate desk top study or preliminary ground model (Section 3). Confirm water depths. Provide an overview of likely soils conditions to be encountered on the site and input into planning geotechnical surveys. Identify an area view of hazards. (e.g. boulder fields). Inform requirements for permitting, archaeology and ecology.	Water depths. Seafloor topography, features and obstructions. Shallow soils information.	MBES. Side scan sonar (wide range, low frequency/resolution- 100 kHz). Sub-bottom profiler – boomer/sparker/mini airgun – single or multi-channel – 2D or 3D. Magnetometer.	Project dependent – can be as low as individual corridors of data, or full coverage of the seafloor. Resolution required to identify main geohazards only. Does not require high enough resolution for engineering design.
Cable route (export route and inter-array) and in fill geophysical surveys	As above but covering cable corridors.	Water depths. Seafloor topography, features and obstructions. Shallow soils information.	MBES. Side scan sonar (dual frequency, low-medium frequency 100 400 kHz). Sub-bottom profiler – boomer/chirp/pinger/ parametric – single or multi-channel – 2D or 3D. Magnetometer.	100% coverage of cable route corridors for bathymetry and side scan sonar. Side scan range to be adequate to identify the minimum size of object detection needed for cable installation. Sub-bottom data to be of a high enough resolution to identify burial potential of the sediments.
Pre-construction engineering geophysical surveys	Provide detailed information on sub-bottom geology to allow for engineering design. Provide input into planning of detailed geotechnical survey.	Water depths. Seafloor topography, features and obstructions. Shallow geology to a depth to meet construction requirements.	MBES. Side scan sonar (dual frequency, medium - high resolution 300 600 kHz). Sub-bottom boomer/chirp/pinger/ parametric – single or multi-channel – 2D or 3D. Magnetometer/ gradiometer.	200% coverage of selected corridor widths for side scan sonar. 100% coverage for bathymetry. Line spacings to be selected to fit complexity of geology and aims of construction engineering.
pUXO detection survey (undertaken in conjunction with pre-construction survey, or stand-alone)	Provide data to allow ALARP (As Low as Reasonably Practicable) certificates to be issued for all locations and cable routes requiring seafloor intervention.	pUXO object detection.	Gradiometer/ magnetometer array. Side scan sonar (High - ultra -high frequency 400-900 kHz). MBES. 3D UHR chirp/pinger/ parametric.	100% coverage of an area around each planned turbine or geotechnical investigation location for bathymetry and side scan sonar. It is not always required to acquire additional data; existing data may be sufficient and should be considered first, prior to further acquisition.
Post installation and maintenance surveys	Confirm status of installed turbines and cables. Monitor variations in seafloor mobility .	Seafloor topography, features and obstructions. Cable detection, surface and depth of cover.	MBES. Side scan sonar. Camera or video. Cable tracker. 3D UHR chirp/pinger/ parametric.	100% coverage of installed equipment for all sensors.

7.3 Geophysical Equipment and its Application

Throughout the development of a renewables project, a number of different geophysical sensors need to be utilised over a number of different project phases. Figure 4 shows a schematic layout of equipment commonly used for offshore geophysical investigations. Precise configurations will depend on water depths and specific project objectives.

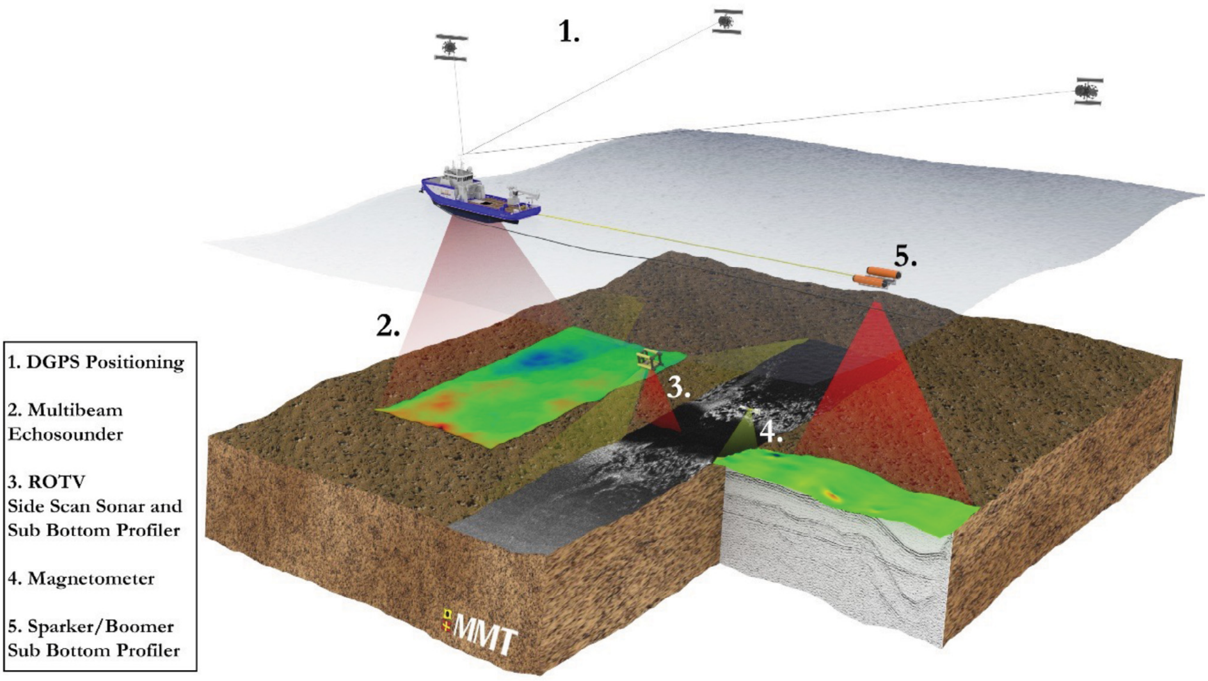


Figure 4 : Example geophysical survey equipment

For more detailed investigations (e.g. for pUXO and archaeological or environmental purposes) additional equipment may be required as indicated in Figure 5.

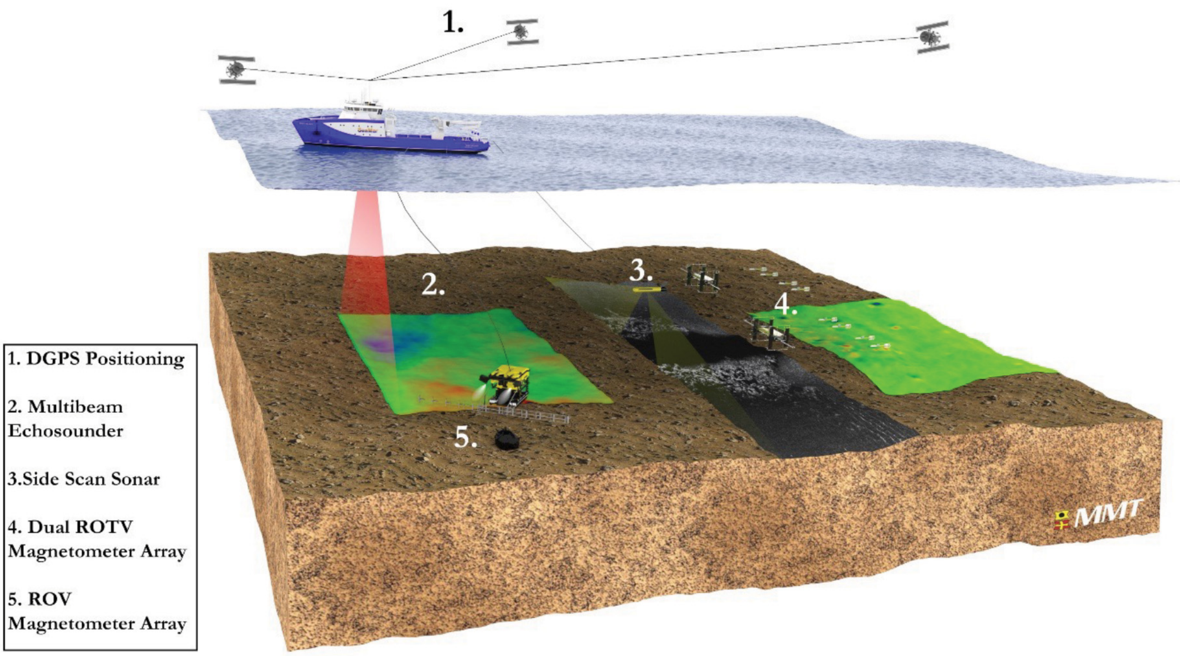


Figure 5 : Specialised geophysical equipment

7.3.1 Water Depth and Seafloor Topography

Bathymetry systems should be suitable for, and set up to accurately record, water depth data across the range of depths expected over the ground investigation area. The bathymetry system should be hull-mounted (or, increasingly, AUV- or ROV-mounted, especially for deeper water projects) and used in conjunction with suitable motion sensors to compensate for vessel or vehicle movement. Due to the large areas to be surveyed and the relatively shallow water depths, consideration should be given to wide swath systems (e.g. dual-head MBES). Water column sound velocities should be determined at the start and end of the survey, and at frequent intervals.

Statistical analyses of the MBES data should be undertaken and, coupled with repeated sampling of a single area (controlled patch test) throughout the survey period, be used to check the results for any gross measurement errors.

Survey line spacing should be selected to ensure more than 100% coverage by the MBES (except in the case of reconnaissance surveys where less than 100% may be acceptable).

Water depths should be corrected for vessel draft and tidal levels, and should be referenced to an appropriate project tidal survey datum (e.g. lowest astronomical tide (LAT) or mean sea level (MSL) etc.), as described in Section 9. Where MBES is used, the final processed digital terrain model (DTM) data cell size covering the entire investigation area (without gaps) should be optimised to provide appropriate results for all users of the data. The DTM should be output in an appropriate format, e.g. SO44 (IHO 2019), to enable further imaging and analysis of the data. In order to satisfy all users of the MBES data, it may be necessary to produce several DTMs using differing bin sizes. These can vary from 2 m for a regional approach, to 0.5 m for engineering surveys, and full density XYZ for point cloud representation in areas of specific interest.

It is likely that, as the project progresses, a number of different bathymetric surveys will be undertaken at different times. It is important that these datasets can be accurately compared, both to confirm water depths and also to identify any changes over time (e.g. due to seafloor mobility or scour evolution at turbines or along cable routes). Hopefully, acquisition metadata will allow a quantitative assessment of the positional uncertainties. However, practical semi-quantitative assessments can also be used. These can include comparisons of sections of seafloor (e.g. exposed bedrock outcrops) which typically exhibit no bed level change between surveys. For large area surveys at higher resolutions (typically more than 106 data points) the mean bed level difference between surveys tends to approximate to zero (except in areas of large sandbank migration). Time-lapse analysis can also be used to identify if bed level change is continuous or episodic, and how it relates to the hydrodynamic conditions, i.e., ambient tidal variation vs storm induced activity. A process level understanding can then, potentially, be fed into the design and the operation and maintenance phase of any project.

7.3.2 Seafloor Features and/or Seafloor Obstructions

For the identification of small (sub-metre) seafloor features and, in particular, obstructions (e.g. boulders or exposed pUXO) a dual channel, dual frequency, side scan sonar should be used to provide an acoustic image of the seafloor with suitable coverage across the entire investigation area, allowing sufficient overlap to obtain data at the nadir (the acoustically blank area directly under the side scan sonar fish). The dual frequencies should be selected to achieve appropriate seafloor coverage and resolution for all data users. Where MBES data are acquired (Section 7.3.1) it is recommended that backscatter data from seafloor returns be logged and processed for use in seafloor characterisation and integrated with SSS data. For detailed inspection of relevant sonar contacts, additional side scan sonar lines may be acquired using higher frequencies (as advised by a geophysicist) to provide enhanced feature resolution. Data should be recorded digitally to enable post-acquisition image processing to be performed, and to allow computer-aided analysis and subsequent mosaics to be made of the seafloor. Such mosaics should be output as geo-referenced, high resolution images, to be used as part of the revised ground model.

7.3.3 Shallow Soils/Geology

A suite of acoustic or seismic profilers should be employed to provide appropriate datasets for the various sub-bottom requirements of the ground investigation. The type of sub-bottom profiler to be used to investigate the shallow soils will be determined by a number of factors including:

- Depth of interest below seafloor.
- Nature of shallow soil or rock that are likely to be encountered.
- Desired resolution of the data that are to be used for mapping the shallow materials.

Hence, it is common to utilise a combination of sub-bottom acoustic profilers to image the various depths of interest for engineering. The zones of interest would typically include:

- Shallow sub-seafloor (0-5 m) for inter-array and export cable protection or burial depths.
- Intermediate sub-seafloor (5-10 m) for anchoring and small structure foundations.
- Deeper sub-seafloor: (10-100 m) for large structures (e.g., piled foundations).

Profiler seismic source systems that are available include:

- Pinger (2D single channel) – single frequency system within range 2-7 kHz; typical penetration 5-10 m (soil dependent: greater in finer soils); vertical resolution c. 0.3 m.
- Chirp (2D – single channel or multichannel, and 3D) – swept frequency systems with sweeps within frequency range 1-25 kHz; typical penetration 5-50 m (soil dependent: greater in finer soils); vertical resolution c. 0.1-0.2 m.
- Parametric source (2D – single channel, and 3D) – primary frequency range 10-130 kHz – secondary frequency 1-30 kHz; typical penetration 5-40 m (soil dependent: greater in finer soils); vertical resolution c. 0.1-0.2 m.
- Boomer (2D - single and multichannel) - frequency range 300 Hz-5 kHz; typical maximum penetration 20-50 m (soil dependent: greater in finer soils); vertical resolution c. 0.2-0.3 m.
- Sparker (2D - single and multichannel, and 3D) - frequency range 50 Hz-4 kHz; typical maximum penetration 75-100 m for single channel systems; up to 200 m for multi-channel systems; vertical resolution c. 0.5 m.
- Small airgun (multichannel) - frequency range 50 Hz-4 kHz; typical maximum penetration 75-150 m, vertical resolution c. 1.0 m.

For shallower investigations, data from the first five systems listed are normally recorded in single channel mode, although multi-channel systems and 3D systems are increasingly used. To obtain deeper information, data from the latter system are recorded in multi-channel ultra-high resolution (UHR) mode. Due to the distorting presence of multiple reflections (artefacts) in the data, the multi-channel technique, acquiring typically 12 to 48 channels of data at each shot, together with the associated data processing, is often necessary to image the deeper zones of sub-seafloor geology that are required for foundation assessments.

Data should be recorded digitally to allow subsequent signal processing to improve data quality, and for export to a computer work station for integrated interpretation and mapping of the shallow soils.

It is important to recognise that seismic data are recorded in the time domain, and seismic reflections that are used to image the seafloor and sub-bottom geology need to be converted to depths using derived seismic velocities. Ground models are likely to contain variable provinces, with different geological settings and processes encountered both vertically and laterally. Single seismic (p-wave) velocity models (commonly used in offshore site investigations) for depth conversion of seismic (time domain) data into depth data are, therefore, not appropriate over large and highly variable site investigation areas. In order that such changes across a site are accurately reflected, the velocity model used may be designed to take such variability into account. The model will typically take input from geotechnical stratification, and iteratively integrate this with the seismic velocity model to reach an appropriate correlation. P-wave velocity data can either be measured directly on cores, or empirically derived from other physical properties (e.g. bulk density, porosity and grain size) using standard published equations.

7.3.3.1 3D Sub-bottom Data

Over recent years, significant advancement has been made with the introduction of ultra-high resolution (UHR) seismic systems, enabling 3D visualisation of the shallow soils to be achieved. This methodology is of significant benefit in any areas where ground conditions are variable and interpolating between seismic lines is inadvisable. The technique involves towing multiple (typically 4-8) multi-channel streamers, at closely spaced intervals, coupled with a high resolution seismic source (e.g. a sparker or mini-airgun). In addition to significantly enhancing the spatial interpretation, the quality of the imagery is of a far higher accuracy and resolution than that which is typically seen on standard 2D profiles.

It should be noted that it is not always necessary to undertake 3D coverage over the entire site. 3D coverage may be restricted to smaller areas where it will be of most value, such as turbine locations and areas of potential geological complexity identified from reconnaissance surveys.

The exact configuration of the 3D UHR spread should be tailored to meet the survey objectives, both in terms of resolution required and depth of investigation. A typical configuration to achieve 0.5 m bin size and 50 m penetration is indicated by Table 3 and Figure 6.

Table 3 : Example 3D UHR configuration

Number of streamers	4
Streamer separation	4 m
Streamer length	50 m
Number of channels per streamer	Approx. 32
Streamer depth	0.3–1.0 m
Source type	2 x sparkers operated at 750 Joules
Shot Interval (flip-flop)	Approx. 0.8 m
Source depth	0.3 m

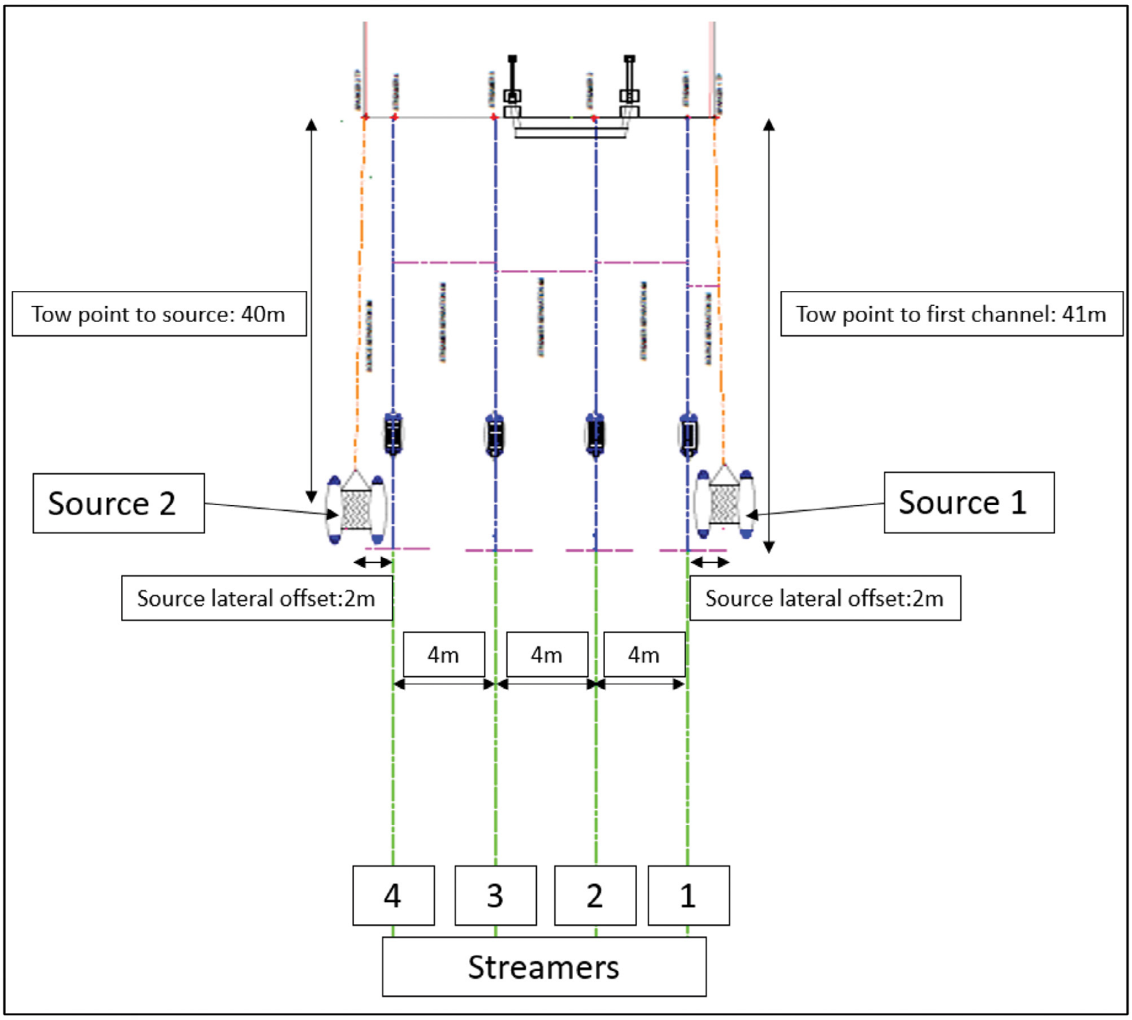


Figure 6 : Example 3D UHR towing configuration

Even higher resolution 3D and multi-channel systems, using chirp or parametric sources, are increasingly being used for pUXO object detection; boulder detection; archaeological site surveys; and to determine post installation depth of cable lay. Systems either operate in a fixed rigid frame, towed at the surface, and equivalent to the 3D UHR systems described above, or by an in-line synthetic aperture sonar approach, typically deployed from an ROV or AUV. Both approaches generate 3D volumes with bin sizes of c. 0.1 m and a vertical resolution of less than 0.05 m.

7.4 Unexploded Ordnance

Unexploded ordnance is a specific, high risk, seafloor or sub-seafloor obstruction. If the desk-top based UXO threat and risk assessment reveals that the offshore renewable energy site has a potential for UXO being present, then an appropriate phase of site investigation should be designed to detect them, to ensure the risk over the location is As Low As Reasonably Practicable (ALARP).

The majority of surveys where the UXO has a potential of being buried (dependent on water depth and sediment type) are conducted using magnetometers or gradiometers. These are used to measure total magnetic field strengths and to investigate ferrous objects lying on or very close to seafloor. Such systems can only detect pUXO items that have an associated ferrous metal casing or magnetic signature. Owing to the rapid reduction in magnetic field with increasing distance from a ferrous object, and consequently the limited range of practical detectability, the magnetometer sensor array should be towed close to the seafloor. This requirement precludes widely spaced survey lines, and renders it impractical to magnetically survey for pUXO over large investigation areas. Hence, such surveys should only be undertaken when:

- Energy structure layouts and cable routes are in an advanced stage of planning; and/or
- Geotechnical borehole or CPT locations or anchor spread layouts are known, in order to focus on limited areas of interest.

Single magnetometers, whilst able to detect buried ferrous material, are not able to delineate the position of the object in 3D space.

A magnetic gradiometer measures magnetic gradient in one dimension by taking the difference in readings between two or more independent magnetic sensors. Since the Earth's magnetic field is three dimensional, up to three independent gradient directions can be measured – vertical, horizontal (across-track) and longitudinal (along-track).

It is therefore recommended that, if the threat of UXO is considered significant from the desk-top risk assessment, then a gradiometer system be deployed in conjunction with additional geophysical sensors, which will significantly enhance the identification and analyses of any objects detected. A typical high resolution pUXO survey would therefore consist of:

- Hull mounted high frequency MBES.
- Towed high frequency side scan sonar with ultra-short baseline (USBL) positioning.
- Towed gradiometer/magnetometer array with USBL positioning.

Further techniques such as UHR acoustic 3D imaging and/or the use of ROVs equipped with cameras and other imaging tools, will be required to further characterise pUXO. It is recommended that specialist UXO personnel be used to assess any risk and to aid survey design, as appropriate. More detailed review of UXO risk management can be found in CIRIA (2015) Assessment and Management of Unexploded Ordnance (UXO) Risk in the Marine Environment..

7.5 Landfall Site Surveys

Land topographic surveys are undertaken using total survey stations or laser scanning. Subsurface profiling is undertaken using seismic reflection, refraction and Multi-channel Analysis of Surface Waves (MASW) techniques, with low power (e.g. sledgehammer, weight drop) sources and geophone arrays. In addition, the use of unmanned aerial vehicles (UAV) and Light Detection and Ranging (LiDAR) surveys can provide high resolution photographic imagery of the sites and shallow waters.

7.6 Key Outputs from Geophysical Survey

Numerous outputs are available from geophysical survey data, and these should be considered as carefully as the geophysical survey equipment used to acquire the data. Different data users require different products, or the same product in differing formats, or at stages of processing or interpretation. Clearly identifying the end-user's data needs, prior to commencing the acquisition phase of works, will enable the survey contractor to create the correct format files and datasets for the end-user requirements. A clear data management plan is required from the outset to ensure these aspects are properly covered.

In general, it takes as long or longer to interpret the datasets as it does to acquire them. Changing formats of data or cell sizes on binned data, or processing sequences of subsurface data, often leads to time-consuming, expensive, extensions to processing and reporting and is, in some cases, not possible.

8 GEOTECHNICAL INVESTIGATION

8.1 General

The geotechnical investigations should, ultimately, provide all the necessary soil and rock data to allow detailed design and installation for the project. These may include data for the founding of installation vessels (including jack-ups), for foundation design and installation, and for cable routing, burial and protection.

To add maximum value to the seafloor risk management process, the geotechnical investigation data should be integrated with the preliminary site assessment and the findings of the geophysical investigation. The aim of the surveys is to add to, and further develop, the ground model for the site, determine the vertical and lateral variation in seafloor conditions, and to provide the relevant geotechnical data for foundation design, for planning installation activities, and for operations and maintenance.

There is a considerable amount of information available in the literature on the equipment and techniques used in offshore oil and gas projects for geotechnical site investigation, geotechnical testing and interpretation. The equipment and techniques for offshore renewables projects are essentially the same. Hence, it is not intended to duplicate this information in this document, and reference is, therefore, made to the guidelines listed in Appendix 1, particularly the IOGP (2015) Guidance Notes for the conduct of offshore drilling hazard site surveys and ISO 19901-8 on marine soil investigations.

8.2 Geotechnical Vessel Selection

Vessel selection (Section 6.3) is critical to gaining high quality data in a timely and cost-effective manner. Depending upon the specific site environmental conditions (wind, wave, current) and water depth, fixed platforms (jack-up rigs) or anchored or dynamically positioned vessels can be used. For floating plant, the use of motion-compensated drilling equipment is recommended. Appropriately equipped vessels can also deploy seafloor drills, and shallow sampling or CPT equipment for applications such as cable route surveys.

The advantages and limitations of vessel or drill platform types are listed in Table 4.

Table 4 : Advantages and limitations of various vessel/drill platform types

Vessel Type	Advantages	Limitations
Jack-up	Provides stable platform. May offer simultaneous sampling/CPT option from two adjacent positions. Large jack-up rigs have deck space for additional laboratory capacity. Can operate in shallow water. Large jack-up rigs have accommodation units.	Risk of punch through and adverse leg penetration. Has limited water depth capability. In general, need additional vessels for moving and supply. Can only move when environmental conditions are within set limits. No accommodation on small jack-ups in shallow water, which can lead to crew change issues.
DP vessel with heave-compensated drill or seafloor CPT	Fast moving between locations and fast set-up. Heave compensation allows operations to proceed in marginal sea-state conditions.	In general, higher per diem cost than other options. Limited numbers of vessels in operation. Less suited to shallow water operations. Position-holding becomes difficult in high current areas.
Anchored vessel	Can offer more stability in high current areas. Minimum water depth for operations is typically less than for DP vessels.	Longer periods for anchoring and set-up. Increased weather sensitivity during anchor deployment and when on station, and susceptible to weather heading changes. Anchor type may need to be changed for some locations/require specialist anchors in areas of rock outcrops.
Seafloor drill	Reduced pipe handling Lower HS&E risk, with no personnel intervention when operating. Ability to operate in strong currents.	Assessment of samples delayed until the drilling unit or sample carousel has been recovered to deck. Limited downhole *in situ* testing options. Sampling and testing program may need to be pre-defined. Requires a DP vessel, with appropriate deck space and launch and recovery system, to deploy. Limited number of systems and experience in operation.

8.3 General Geotechnical Site Investigation

An experienced marine geotechnical engineer should be involved in preparing the survey scope and technical specifications. The extent of the geotechnical investigation, and the choice of investigation methods, should take account of the type, size and number of structures, the range of foundation options and the uniformity and type of seafloor and sub-seafloor conditions. The geotechnical investigation should provide relevant information to a depth below which the underlying conditions will not influence the safety or performance of the structures being considered, or of the installation vessels or rigs to be used. Depending on the homogeneity of the site geology and confidence in the ground model, this may not necessarily require information to the full foundation depth at every structure location. Conversely, in earthquake prone areas, information may be required to depths significantly below the foundation depth, to allow a detailed site response analysis to be undertaken.

For the detailed final pre-construction phase(s) of the geotechnical investigation, the number, depth and position of investigation locations should be a product of a rational engineering exercise, incorporating the developer's risk acceptance criteria, the robustness of the design, and the degree of geological homogeneity anticipated across the site.

Depending on the size of the complete development, the pre-construction geotechnical investigation may be divided into a number of discrete phases, if overall development of the renewable energy project is to be completed in stages. This may also apply if conditions show significant variation that warrants the consideration of more than one foundation type, or there are specific certifying authority or classification society requirements that are to be satisfied.

Due to the exploratory nature of the geotechnical ground investigation, it is probable that some modification to the scope of work will be required as data acquisition proceeds and results are reviewed. This is necessary to ensure that the objectives of the investigation are being achieved in the most cost-effective and optimised manner. Those specifying investigation services should bear this in mind. A geotechnical engineer familiar with foundation design should be present during the investigation, to represent the developer and ensure that the objectives of the investigation are fully met. Further, the geotechnical design engineer appointed for the detailed design of the foundations should approve the scope of work of the ground investigation, and should be available for the duration of the investigation to discuss any changes or challenges that arise.

8.4 Overall Approach to Investigation

The key steps to scoping a geotechnical site investigation are outlined in this section and should include, but may not be limited to:

1. Assess the geotechnical requirements for engineering application.
2. Assess the current uncertainty in the definition of geotechnical conditions at the relevant locations.
3. Undertake a gap analysis to determine the additional soils information required to ensure ground model quality is sufficient to define geotechnical conditions for engineering design (how much, to what depth, etc.). There are two main approaches:
   a. Based on a defined scope for each location, such as the benchmark requirements described in Section 8.8.
   b. Based on an optimised ground model approach that integrates soils information from the whole site to supplement location-specific data, as described in Section 8.9.
4. Assess the equipment required to obtain data to support engineering requirements.
5. Assess what the key outputs from the investigation should include.

8.5 Geotechnical Requirements for Engineering Application

The site investigation should be designed so that it provides sufficient geotechnical data for all of the engineering requirements within the development; or those engineering requirements determined to be within the scope. Examples of engineering activity are shown in Figure 7 and further engineering activities and associated requirements for geotechnical data are provided in Table 5. It is important the engineering requirements are understood at an early stage, to give input to the assessment of what equipment is required for the investigation and what the data coverage should be. In addition, for each engineering requirement, the tolerance to uncertainty should be assessed (further description of variability and uncertainty is given in Section 8.6). This will provide guidance on the level of precision that is required to define ground conditions and geotechnical parameters for design.

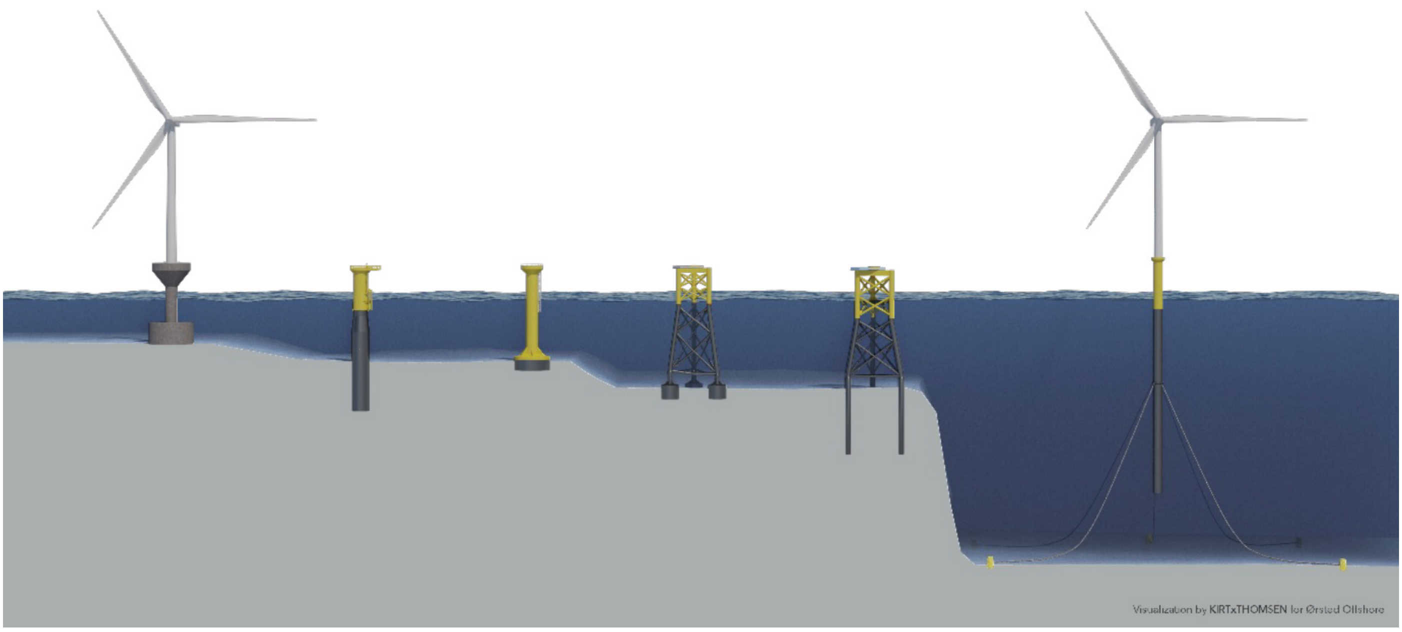


Figure 7: Structure and foundation types for offshore wind turbines.

(From left to right : Gravity based foundation, Monopile, Suction mono bucket, Suction bucket jacket, Piled jacket, Floating spar)

Table 5 : Examples of engineering activity within a windfarm and geotechnical engineering requirements.

Example of Engineering Activity	Geotechnical Engineering Requirements
Managing geohazards that may influence the development.	Description and index classification. Soil modulus and damping parameters. Permeability and consolidation parameters. Chemical composition. Seismic conditions, ground response and liquefaction. Scour.
Foundation design including monopiles, driven jacket piles, drilled and grouted piles, gravity bases, intermediate foundations (including suction installed caissons).	Foundation capacity. Foundation stiffness and damping. Settlement. Installation/driving/drilling.
Jack-ups used for installation or O&M.	Spudcan/spudpile penetration. Spudcan/spudpile retrieval. Spudcan/spudpile stiffness and damping.
Anchored or tethered foundations including anchor piles, suction piles, drag anchors, gravity base anchors and other anchor types such as plate anchors.	Anchor capacity. Anchor installation.
Cables.	Trenching (consider greater depth near shipping channels). Protection requirements. Landfalls/directional drilling. Stability. Thermal conductivity and permeability.
Note: The depth and extent of data should take into account the zone of influence of the engineering activity.	

8.6 Ground Model Quality and Risk

Uncertainty related to the ground model principally relates to the quality of the geophysical model and the number of existing ground-truth boreholes available to calibrate that model, at that particular time (refer to Sections 2 and 3). The inherent variability of ground conditions that occurs in terms of vertical depth, lateral variation and layer thickness, has a direct impact on the quality of the geophysical model. For simple soil conditions, a higher quality geophysical model might be achieved with less geotechnical ground truth data, than might be the case for more complicated soil conditions. The required quality of understanding from the ground model is also influenced by the ability of the engineering applications to tolerate variability or uncertainty.

Some examples of engineering-specific application, and shallow and deep variability are shown in Figure 8 and Figure 9 for simple and for more complex stratigraphies, respectively. Figure 8 indicates a simple site, with limited impact on jack-up operations, suction buckets, cables or shaft capacity of piles, and some impact on pile end bearing. Figure 9 provides a schematic illustration of a more complex site, with impact on scour depths for all foundation types, lower impact on pile foundations, and for other applications the variability could be significant – suction bucket installations may have variable installation, jack-ups legs may have varied penetration, and trencher performance for cables may vary. As well as soil layering, variability may manifest itself as variation of soil properties within the same unit across the site.

When considering variable soil conditions, the impact that these will have on engineering characteristics for each specific application and depth of interest should be assessed, taking into account appropriate uncertainties. As described in Section 8.5, it is important to understand the tolerance of a particular engineering application to uncertainty. Some examples of tolerance to uncertainty include:

- High tolerance to uncertainty might be a situation where there is uncertainty in defining whether a particular layer is dense sand or stiff clay; but that an understanding of pile driving behaviour shows that neither option would present a restriction based on the hammer size(s) likely to be available.

- Low tolerance to uncertainty might be a situation where it is not known if a particular layer is dense sand or stiff clay; however, a suction installed foundation might experience difficulties in installation within the stiff clay; but not the dense sand. In this case, it is important to resolve the uncertainty.

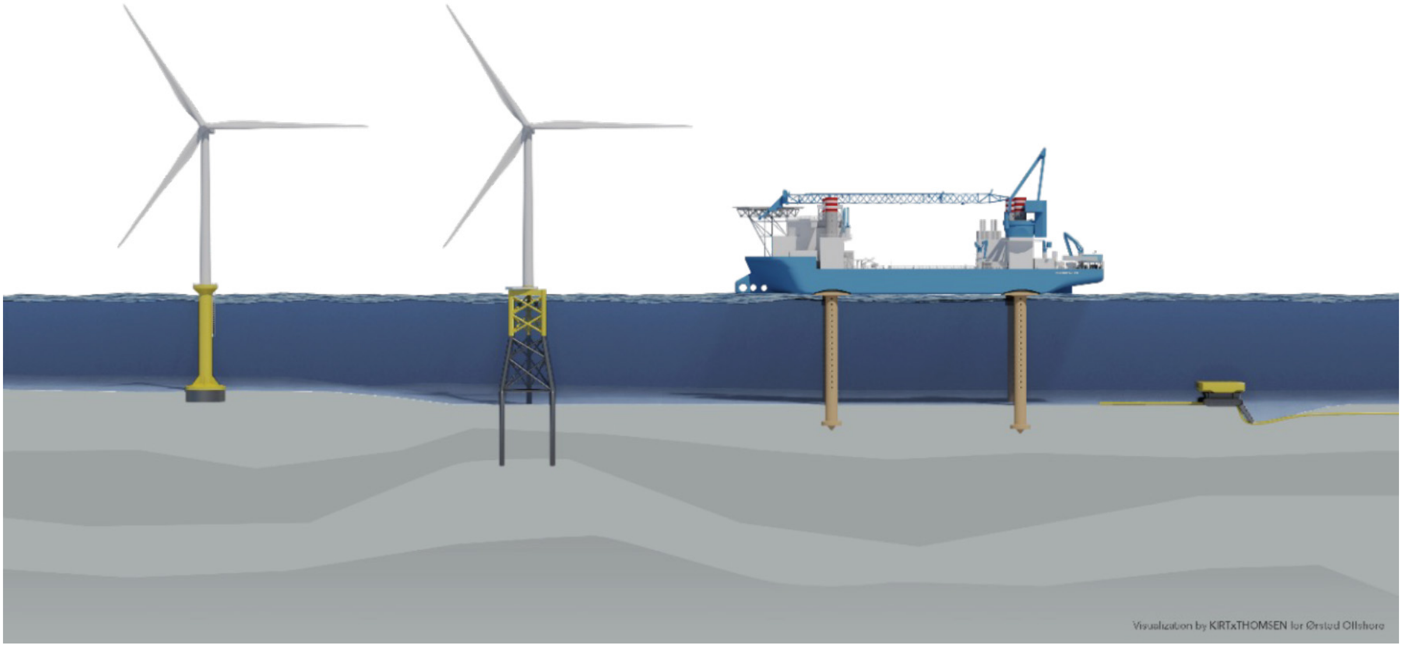


Figure 8: Simple site with some deeper variability.

Figure 9 : More complex site with shallow variability.

8.7 Type of Data Required and Equipment

Table 6 outlines the types of sample and *in situ* geotechnical data that can be obtained, with some suggested equipment and general comments on the data. Sufficient high quality sample data must be obtained in order to make a proper interpretation of *in situ* test data across the site and to select design parameters. A general minimum requirement for larger sites is that at least 10% of the boreholes across a site should be selected to obtain high quality samples.

Consideration should also be given to the acceptable level of sample disturbance. Depending on the design methodology and proposed laboratory tests, specific sample diameters, types of sampling, or drilling equipment, may be required. These may be stipulated by the design codes. Appendix 3 provides further guidance on these issues. In addition, it may be considered whether the use of wire-line geophysical logging, seismic cone penetrometer and pressure meter testing could enhance the quality of the survey data.

Positioning of geotechnical equipment should be undertaken using the techniques described in Section 9.

Table 6 : Types of sampling and *in situ* test data.

Data required	Suggested equipment	Comments
Shallow seafloor samples.	Vibrocorer, box corer, gravity corer, piston corer.	Seafloor samplers can be deployed from non-specialist vessels using an A-frame or by over-side crane deployment. Some operate from frames lowered to the seafloor. Others are dropped. They use gravity or vibration to penetrate the seafloor.
Continuous soil profile.	CPT using seafloor or downhole equipment. Seafloor CPT thrust capacity of 200 kN is recommended for deep push CPTs. For shallow penetration, 50 kN is generally acceptable along cable routes. In downhole mode, thrusts of 60 kN to 90 kN are typical.	Electrical cones measure the cone end resistance, sleeve friction and generated excess pore water pressure. They are pushed into the ground against a reaction force and the data are recorded at regular intervals to provide a near continuous profile.
Discontinuous sampling or CPT.	Drilling equipment combined with sampling tools and down hole CPT. 72 mm sample size is standard for soil sampling.	Drilling equipment can be mobilised on a vessel and operated with a heave compensation system, or from static jack-ups or using seafloor drilling units.
Continuous sampling in rock or very hard soils.	Rotary coring. Core size of at least 76 mm is recommended.	Wire-line coring equipment can be used with the main drill or by using a supplementary drilling system.
Downhole geophysical measurements.	Wire-line logging tools.	A range of wire-line tools are available to measure various geophysical parameters which can correlate with *in situ* and laboratory test data.
***In situ* stiffness of soils or rocks.**	Pressure meter/dilatometer/seismic cone.	Use of cavity expansion theory, or measurement of shear wave velocity to assess the stiffness of the soil at various strain ranges, can be used to compare *in situ* data with laboratory measurements.
Thermal Conductivity.	Laboratory based needle probe, heat-flow probe or T-CPT.	Laboratory-based samples can be tested with a needle probe. Heat-flow probes and T-CPTs measure the *in situ* thermal conductivity in shallow soil depths with an array of thermistors.
Permeability.	CPT dissipation test or laboratory based permeameter.	Permeability is important for understanding heat dissipation from cables.

8.8 Benchmark Requirements

Each project should be reviewed separately, and an appropriate sampling and testing programme determined by a competent geotechnical engineer. However, as a guide, a benchmark geotechnical survey work scope is suggested in Table 7. Note, guidance from an adopted code or certifying body, and advice from a competent geotechnical engineer, should be sought in developing the work scope.

The termination depth of the boreholes or tests should be sufficient to penetrate and obtain data beyond the zone of influence of the foundation structure within the soil.

Where soil conditions are likely to vary over the footprint, or where the location of a given structure is subject to uncertainty, more boreholes may be required. Further, more information may be required for large jacket and gravity base structures.

Vertical separation between geotechnical data should be minimised. Typically, gaps no greater than 0.25 m to 0.5 m should be considered. Regard should also be given to the quantity of sample required. If a significant amount of testing is to be performed, then more than one borehole on a single location may be necessary to obtain sufficient samples. Very large bulk surface samples may also be required to allow physical scour models to be constructed.

Where bedrock is present at the site, and the foundation may be affected by, or penetrate, the bedrock, specialist coring systems may be required to sample these strata. Tidal projects located in areas of high seafloor currents may be sited on bedrock, although pockets of sedimentary material infill may remain. Gravity base foundations, in particular, require detailed knowledge of the localised seafloor roughness, which can cause uneven contact. In addition, visual data can be collected using remotely operated vehicles (ROVs) to examine seafloor features and to establish the amount of marine growth present. Cable routing may be difficult on exposed rock and the natural structure of the rock may be required to provide cable protection. Where the bedrock is exposed nearby onshore, investigation of this can be used to supplement the offshore data.

Table 7 : Example geotechnical work scope for different foundation types and construction vessels.

Foundation Structure Type	Example Geotechnical Scope of Work
Monopile.	For a pile that does not rely on end bearing, a continuous CPT (from seafloor or down hole) to the anticipated depth of the pile plus 0.5 times the pile diameter. Adjacent to at least 10% of the CPTs, there should also be a selected high quality sample borehole to obtain sufficient samples for laboratory testing. The number of samples required will depend upon site variability. Stiffness measurements may also be important to design and downhole geophysical logging and *in situ* stiffness measurement may also be considered.
Monopile in rock, or combination of soil and rock.	For a pile that does not rely on end bearing, a combined borehole including soil sampling and rock coring to the anticipated depth of the pile plus 0.5 times the pile diameter. Additional CPT tests can be used to enhance data quality in soils and weak rocks. Downhole geophysical logging and *in situ* stiffness measurement may also be used.
Jackets and tripods.	Same as for monopile, except the depth of borehole beyond the expected pile penetration should account for mobilisation of end bearing. Additional CPTs may be necessary if significant lateral variability is anticipated across the foundation base.
Gravity base.	A sample borehole or deep continuous CPT borehole at the centre of the proposed structure to the skirt embedment depth, plus 1.5 times the base diameter or breadth. Further shallow CPTs or sample boreholes should be performed around the base if significant soil variability is expected. Sufficient high quality samples need to be obtained for laboratory testing. Downhole geophysical logging and *in situ* stiffness measurement may also be used.
Gravity base on rock.	Depending on the configuration of the foundation, it may be necessary to obtain rock samples in order to have an understanding of the bearing capacity and interface friction properties. The properties of any infill pockets may also need to be investigated.
Suction-installed foundations.	A sample borehole or continuous CPT borehole to a depth equivalent to the diameter of the suction can plus the embedment depth of the can, with emphasis on high quality sampling in the upper layers (to a minimum of 1.5 times the diameter). Further shallow CPTs or sample boreholes should be performed around the foundation, if significant soil variability is expected.
Jack-ups used for installation or O&M.	Further sub-surface investigation may be required where there is significant variability in soil conditions or where very hard or very soft soils are encountered, and/or the possibility of punch-through is predicted in the area where these will be located.
Anchored or tethered foundations.	A borehole with samples or CPT, or a seafloor CPT at each anchor location. The investigation depth is dependent upon the geology.

8.9 Ground Model Approach

A ground model approach can be an efficient approach to site characterisation, which makes use of soils information from the whole site to supplement location-specific data, reducing the overall data acquisition requirements (refer to Section 3). Laterally continuous geophysical data are used to define a stratigraphic model, identifying the presence and variations in elevation and thickness of units, which appear similar from geophysical interpretation. The geophysical model is calibrated through integration with laterally discrete geotechnical data to convert units, identified on geophysical data, into soil units with defined geotechnical design parameters.

The requirement for additional geotechnical site investigation data should be defined by considering what is needed to improve the ground model, such that it provides an appropriate level of confidence for the engineering design or application requirements for the stage of the development. For example, this may include the following targets:

- Units that are currently calibrated by relatively few geotechnical measurements.
- Units which show large variability based on existing geotechnical measurements.
- Units, or specific areas of units, which are poorly imaged with geophysical data and, hence, lateral interpolation has greater uncertainty.

The ground model approach is a balance between the quality of the ground model to provide input of sufficient confidence for design, and the ability of the design or application to tolerate uncertainty. In this sense, the geological and geotechnical risk is a function of the conditions within the site, degree of knowledge about those conditions, and the confidence with which a particular engineering application can be successfully achieved. It might be that the risk can be managed by collecting more data or, for example, by selecting a different foundation type or installation methodology.

Figure 10 outlines the principles of defining the amount of geotechnical data required, depending on the uncertainty in defining soil conditions and the ability of the design or engineering application to tolerate uncertainty. It is important to note that the ground model approach could lead to more site investigation data being collected for some sites or engineering applications, or areas within sites; and, conversely, less geotechnical data for other sites, or areas within sites.

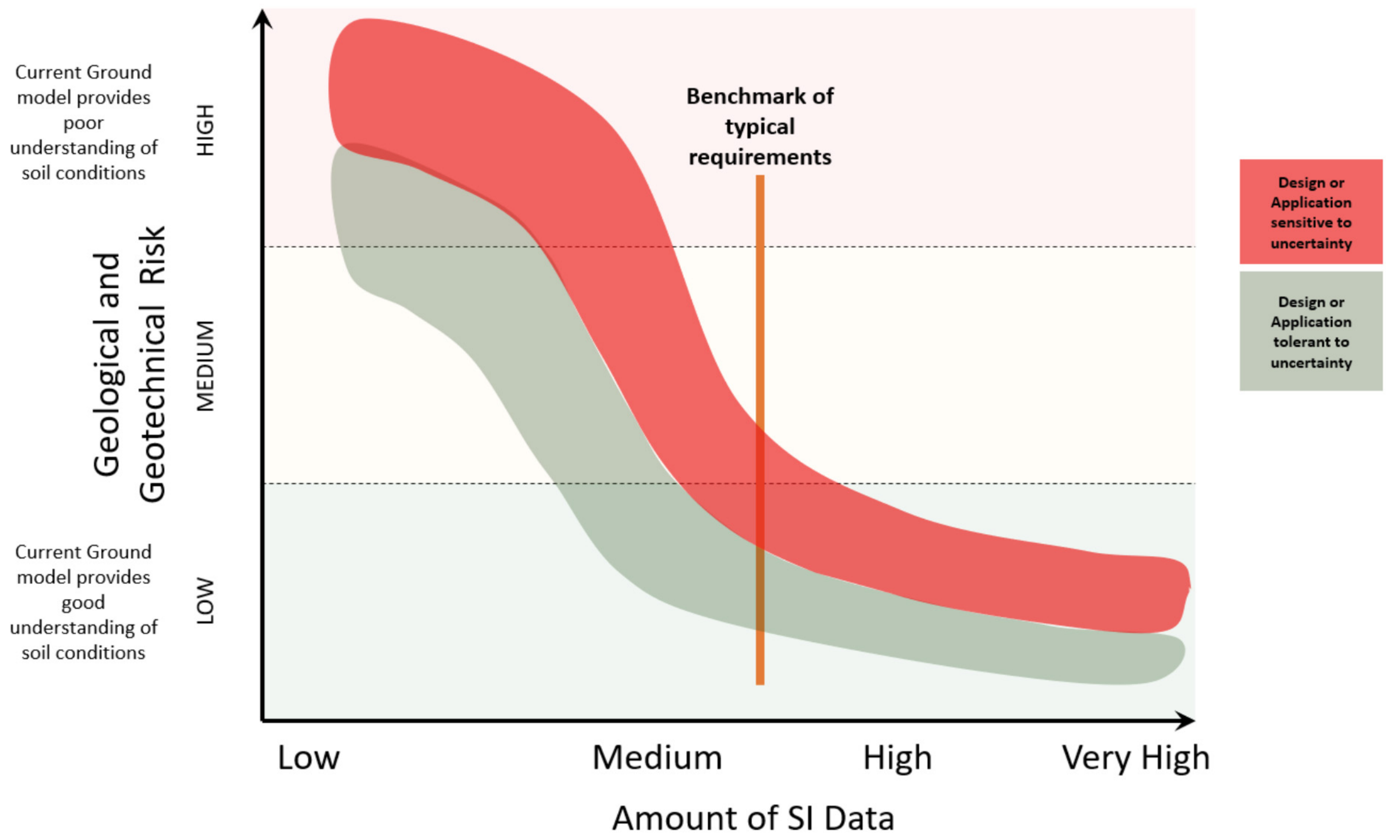


Figure 10: Schematic outline of an optimised approach to the amount of geotechnical site investigation data required compared to benchmark requirements in Table 7

8.10 Key Outputs from Geotechnical Investigation

In principle, the geotechnical investigation, and outputs from it, should be designed to meet the requirements of the development. Therefore, it is recommended to use the assessment of geotechnical requirements for engineering, as described in Section 8.5, to determine what should be reported from the geotechnical investigation and how it should be reported. Any laboratory test programme should be designed to provide the parameters required for design, to allow interpretation of *in situ* data, and to assist creation of the ground model.

9 POSITIONING

The need for accurate positioning throughout all phases of a project cannot be overlooked. Positioning of each vessel or jack up, and associated sensors and equipment, is an essential prerequisite to ensure that all subsequent surveys, investigations and structures are all confirmed to be accurately positioned and each must use the same pre-determined co-ordinate reference system. The required geodesy should be confirmed at an early stage in each project and it must be used across all phases of the development and construction until project completion. There should also be robust procedures in place to ensure that any discrepancies are quickly identified and rectified. These should involve Quality Assurance (QA) procedures to mitigate that, in the event of loss of power or signal, all offsets and other variables have not been altered or lost.

Horizontal positioning of the vessel or jack-up should be performed using two differential satellite systems. Any satellite navigation system with global coverage is termed a global navigation satellite system (GNSS). Currently, the United States' Global Positioning System (GPS) and Russia's GLONASS are fully operational systems. China's BeiDou Navigation Satellite System (BDS) and the European Union's Galileo are in the final stages of development. India, France and Japan are also in the process of developing regional navigation and augmentation systems.

Calibrated and checked primary and secondary differential global positioning systems (DGPS) should be used offshore during all phases of the works. Each system should be fully independent of the other. The independent secondary DGPS system should be operated continuously and in parallel with the primary system, in order to provide full real-time redundancy.

Bathymetric survey systems should be deployed with an appropriate motion reference unit and heading sensor to adjust data for the heave, pitch, roll and yaw of the survey vessel. Data acquired by the swath system should be recorded digitally. Bathymetric data should be tidally adjusted using tidal height correction data from real-time kinematic (RTK) or post-processing kinematic (PPK) global positioning system data, and reduced to a specified vertical datum using transformation models such as the Vertical Offshore Reference Frame (VORF) in UK and Irish waters (now with a global variant between International Terrestrial Reference Frame and LAT), BLAST for the North Sea, and VDATUM in the US.

A record should be kept of the position comparisons of the two DGPS systems, to serve as a quality assurance statement. The record of position comparisons should be included in the final report, with appropriate analytical comments.

GPS, or spinning mass, ring laser (RLG) or fibre optic gyrocompasses (FOG) should be installed and used to determine the real-time true heading of the vessel, enabling the computation of the vessel common reference point (CRP) and associated offsets points of key features such as the drilling derrick or vibrocore launch position. The accuracy and reliability of the heading observation is very important, particularly on larger vessels and where acoustic positioning of towfish or subsea vehicles is being undertaken using USBL systems (see below). Heading accuracy should be equal to, or better than, values traditionally considered acceptable and readily achievable using modern systems, and so should reflect the minimum specification.

The correct use of GNSS positioning and solutions is critical to the success of an offshore site investigation. It is recommended that they are installed, verified and operated in line with IOGP and IMCA (2011) Guidance Notes, which describe good practice applicable to both oil and gas and renewables sectors.

Where optimal vertical absolute accuracy is a requirement, or where bathymetry is to be reduced using a VORF (or suitable alternative model), RTK GPS positioning may be used. Traditionally, this assumes that the investigation area is within Very High Frequency (VHF) or Ultra High Frequency (UHF) radio transmitting range, of a fixed base station at a precisely known location and altitude. However, there is now an increasing number of satellite based correction services, with a near global range, whilst maintaining centimetric accuracy corrections in x, y and z. Alternatively, a dual frequency GPS receiver onboard the vessel must be used to acquire the raw observable code and carrier phase data, which may subsequently be post-processed to determine the rise and fall of the antenna, in the same way that an RTK system would observe and compute it in real time.

The surveyor should perform navigation system function and accuracy tests, along with offset check and verification, before sailing to the site. These should include alongside verifications, such as GNSS health check, primary and secondary GNSS comparison, gyrocompass alignment verification, navigation verification (comparing the RTK unit to any vessel nodes, to verify its own position), and vessel offset verification.

If towed sensors are being used, an alongside USBL beacon check should be performed. One of the beacons should be deployed to ensure that the USBL offsets, motion reference unit (MRU) orientation, and USBL depth sensors are correct, and that the system is correctly interfaced (see below).

A vessel dimensional control survey should also be performed, unless this has been recently completed and validated. This will determine whether there are any angular misalignments between the installed heading sensors and the vessel reference frame (VRF).

A positioning survey report should be included within the final operational report.

With all systems mobilised and proven to be fully operational alongside, certain calibrations and verifications are also required at sea, and when the vessel is manoeuvring. A primary and secondary GNSS system comparison, performed when the vessel is manoeuvring, will check that there are no latency or offset errors between the two systems.

Where towed sensors, such as side scan sonar or sub-bottom profiler, are being used, a high quality USBL underwater positioning system should be used. For optimum performance, the system needs to be appropriately installed, calibrated and operated. It is recommended that contractors adhere to the relevant guidelines described in IMCA (2017) (Guidance on vessel USBL systems for use in offshore survey, and positioning and DP operations).

The USBL system used should be interfaced with the following systems:

- Surface positioning system – differential GNSS (DGNSS). This should be fit for purpose and installed, operated and maintained in compliance with manufacturer and industry standards. Position updates are required at 1 Hz (one position update per second from the DGNSS to the USBL system). The physical offsets between the GNSS antennae, USBL transducer and vessel reference points should be accurately measured, to ensure that there are no errors introduced into the system.
- Heading reference system (HRS). An HRS typically consists of a gyrocompass, or uses dual GNSS antenna carrier phase observations.
- Motion reference unit (MRU).
- Sound velocity profiler (SVP) for the regular determination of sound velocity profiles in the water column.

The installation and commissioning of the USBL system on board the vessel should be documented in a comprehensive installation report covering:

- USBL system components – including topside software version, model of transducer or transceiver and model of transducer pole.
- Offsets between GNSS antennae and USBL transducers, including a definition of the local ship-based co-ordinate reference frame and description on the source and accuracy of the measured offsets.
- MRU configuration – including identification of primary and secondary sensors, internal MRU configuration and information on calibration and relative alignment of each sensor.
- HRS configuration – including identification of primary and secondary sensors, internal configuration (e.g. GNSS heading sensor, RLG or FOG settings) and information on calibration and relative alignment of each sensor.
- Transducer alignments – pitch, roll and heading alignments of the transducer.
- Calibration results – full details and analysis of the system initial calibration.
- Verification results – full details and analysis of the patch test (performed according to standard industry practice, with four lines run either side of a suitable target and two reciprocal lines on either side) and post-calibration verification.

The USBL system shall have been recently calibrated using a “boxing-in”, or similar alternative, of the seafloor transponder according to standard industry practice. A full calibration may not need to be performed prior to each survey, but data relating to the latest USBL calibration should be available on board for client review.

In shallow waters, less than 10 m, it may be impracticable to use a USBL system (although there are shallow water USBL systems available) in which case layback methods and position calculations may be considered. In some operations, e.g. positioning of a plough or a seafloor crawling vehicle, a pole mounted target that breaches the water surface may be used for observation by total station or laser system mounted on the vessel.

Vertical positioning is also very important, even though in industry it is generally not given the same attention as horizontal positioning. Unambiguous definition of the co-ordinate reference system and datum to which depths are related is essential for reliable interpretation.

For geotechnical investigations, the position should be that determined by beacons deployed on the seafloor frame (if used), rather than the surface position of the vessel moon pool.

In recent years, there has been increased use of unmanned vehicles in marine survey, including unmanned aerial vehicles (UAV), autonomous underwater vehicles (AUV), unmanned surface vehicles (USV), and ROVs. Positioning of these vehicles depends on the vehicle type but is usually a combination of inertial navigation system (INS) GNSS and, if underwater, long baseline (LBL) acoustic positioning.

10 DATA INTEGRATION, INTERPRETATION AND REPORTING

Data integration, interpretation and reporting should be undertaken using the combined skills of experienced and appropriately qualified marine geophysicists, geotechnical engineers, surveyors, engineering geologists and GIS specialists, working together to produce fully integrated technical reports which convey the results of the ground investigation effectively to the end-users listed in Section 5.1.1. Rigorous contractor QA/QC procedures are essential to ensuring the quality of the written and electronic reporting, and the survey contractor may be required to describe these procedures and demonstrate their effectiveness.

Detailed technical requirements are needed for the contractor to produce the correct report, which may include specification of the required interpretation and integration. A review of the required deliverables for end-users is integral to the reporting process. A data management and data tracking strategy is strongly recommended for this purpose.

Ground investigations for offshore renewables can be very large, incorporate a number of different phases and utilise several different contractors, and vessels or rigs, over a prolonged period of time. Therefore, it is essential to establish a co-ordinated, consistent and rigorous approach to data interpretation and subsequent integration from the early stages of the project and, preferably, at the planning phase (Section 5).

Further, due to the qualitative nature of much of the data obtained during a site investigation, it is important that the end-user be fully informed about the limitations of these data, when used to draw conclusions in the final report.

Data integration should occur at every appropriate opportunity, typically including the interpretation and reporting phase of an individual geophysical survey, where the contractor combines interpretation from each sensor into a rationalised set of deliverables, through to the culmination of multiple geophysical and geotechnical surveys integrated into a comprehensive ground model. Any additional or pre-existing data from general construction data, trenching data, pile records etc. should be utilised to assist in later stages of the project life cycle (e.g. life extension, inspection and management).

10.1 Reporting Deliverables

Report deliverables should be provided in both written form (pdf and paper) and as processed and interpreted digital sources (e.g. GIS-compatible, ground model software; compatible and basic spreadsheets; AGS format data (see Section 10.2.4), etc.). Integrated digital methods of compiling, presenting and delivering report information are recommended. In particular, GIS and web-based methods allow ease of retrieval for future reference, integration of results with other types of information, reporting to decision makers, and rapid archiving and retrieval.

Careful consideration should be given to the reporting requirements during the site investigations, as the duration of site works plus laboratory testing and final reporting can be well over six months. Interim reporting may allow some design activities to commence whilst the ground investigation progresses, provided the risks of using partial results are well managed.

Stakeholders for cable route surveys may require digital or paper alignment charts which describe the seafloor and sub-seafloor conditions along sections of the route, although accessing this information directly from a GIS deliverable is becoming more common. If alignment charts are required, they are time consuming to create and it is therefore advisable to define the scale and specifications for the charts early in the reporting phase. The integration of geotechnical data within these charts allows for convenient cross referencing between datasets.

10.2 Data Management

10.2.1 General

All data deliverables will be provided in digital form and careful regard should, therefore, be given to storage space, longevity and data accessibility. While some interpretations can be held as part of the ground model, consideration should be given to ongoing project data use, and any revisions and updates required over the life of the project, in order to ensure that data can be repackaged and sent out as part of supporting contracts.

Data management is, therefore, an essential role in the process of data acquisition and interpretation, for use in the design of all offshore renewables developments. Without proper data management, there is a significant risk that not all available data are used for characterisation of the ground conditions, that data are inaccurately represented (e.g. wrongly positioned), or the latest available information is not used (i.e. poor version control and use of superseded data). When properly planned and implemented, spatial data infrastructure (SDI) provides renewables developers with a means to manage, interrogate, integrate, and visualise project data that can be distributed to, or accessed by, a wide variety of users.

10.2.2 Data Management for Ground Investigation

Offshore renewables developments typically cover extremely large spatial extents. Site characterisation for foundation design of such developments requires geophysical and geotechnical datasets to match these large extents. As data acquisition technologies continue to improve, the data resolution that it is possible to acquire increases and, thus, the electronic storage size of acquired data continues to increase. Therefore, accurate and auditable data management is an essential consideration for offshore renewables developments.

Prior to commencing a ground investigation, it is important to understand the large data volumes which can be associated with offshore renewable energy projects, that often have an extensive seafloor footprint. Data can include the following:

- Raw survey data including positioning and motion, bathymetry, side scan sonar, magnetometer, single channel sub-bottom profiler, multi-channel sub-bottom profiler, CPT, geotechnical borehole, grab sample, shallow gravity core and seafloor camera or video footage, raw laboratory testing data, *etc*.
- Supporting survey data including water column sound velocity profiles, tidal reductions, seismic velocities, seismic processing sequences, values used to convert raw CPT data into geotechnical measurements, *etc*.
- Processed data including positioning, bathymetry, magnetometer, depth-corrected single channel sub-bottom profiler, processed multi-channel sub-bottom profiler, processed CPT, laboratory test geotechnical information and field reports, *etc*.
- Supplementary data that may need to be specified, as standard electronic data specifications may not include all information that is required.
- Derived data sets including side scan sonar mosaics, acoustic ground discrimination system (AGDS), geophysical and geotechnical factual and operations reports, *etc*.
- Deliverables including GIS files, geotechnical and geophysical interpretative reports, *etc*.

Careful consideration should be given early on in a project as to what level of electronic reporting is required. This should be agreed with the contractor and it is essential that during the planning stage of any project, appropriate thought be given as to how these data will be recorded and managed.

10.2.3 Data Interpretation

Primary interpretation of the datasets used to build a ground model for an offshore renewable development is currently routinely performed in separate software packages (e.g. seismic interpretation software such as IHS Kingdom, Petrel or DUG, and geotechnical database packages such as gINT), and the integration of these datasets requires the export of interpreted outputs into a common platform (e.g. a GIS data management system). In exporting these interpreted outputs, a disconnect is created between the primary datasets and the integrated ground model. It is important that this process is carefully managed through version control and metadata to avoid use of superseded data.

10.2.4 Data Structure and Data Models

Data models provide a prescriptive structure with which to manage data. The seafloor survey data model (SSDM), published by IOGP (2017), has been widely used in the oil and gas industry as a deliverable standard between developers and contractors, although it is less widely adopted for renewables projects. The AGS (2017) format is a very well-established data model for delivery of geotechnical data and is also used widely across the offshore renewables industries. No published single integrated data model currently exists to host all GIS ground model data and, therefore, consideration should be given to development of a combined data model to provide a fit-for-purpose basis for the data management requirements of the development. This should be developed early in the project, and issued to data acquisition contractors, so data are received in the required structure and format.

10.2.5 Data Delivery

The last decade has seen significant advances in the technology available for data management of spatial infrastructure projects, with developments in geospatial databases and 2D/3D/4D GIS interfaces for the visualisation and manipulation of these datasets. Improvements in web-GIS technology has made it possible to distribute data in a user-friendly map-based format, to a wide range of end-users who are not necessarily data management or GIS specialists. Web-based data management and delivery also provides a flexible way to control access to different user groups (*e.g.* cable route designers interested in shallow data across the full site and export route, and foundation designers interested in the 'infield' area to full foundation depth, etc.). Consideration should be given to the most appropriate data delivery interfaces to suit the requirements of the end-users throughout the development.

10.2.6 Standards and Metadata

Spatial data standards should be independent of particular software vendor applications. This allows renewable developers to use existing technology and software infrastructure and interchange data with the GIS teams in other organisations.

Spatial data standards broadly comprise guidelines for the expression of geospatial features and metadata. A metadata record is a stand-alone file, usually presented as an extensible mark-up language (XML) document, that provides information about the geospatial file; for example, but not limited to, title, abstract and co ordinate reference system.

Marine SDI data guidelines and metadata standards vary between international, regional and country-specific implementations. Also, marine data provisions have standards that vary between sectors, e.g. between oil and gas, and renewables.

Due to the increased uptake of GIS within renewable developers, many now have in-house teams that have specific requirements for geospatial deliverables, in terms of data model and metadata, that go beyond established standards. Therefore, in all cases, it is recommended that contractors and consultants should liaise with the developer with regard to specific policies for data standards.

In terms of data specification, the Open Geospatial Consortium (OGC, www.opengeospatial.org) is the globally recognised body responsible for specification of vendor-independent geospatial standards.

For metadata standards for geospatial data, there are several internationally recognised documents. Generally, best international practice follows ISO 19115:2014 (International Organisation for Standardization, 2014) which defines the scope of metadata while ISO/TS 19139-1:2019 (International Organisation for Standardization, 2019) defines the metadata record structure and format.

Generally, national geospatial standards either directly implement international standards (e.g. ISO) or regional standards, such as the European Union's INSPIRE Directive (Official Journal of the European Union, 2007).

It is recommended that developers and contractors should refer to the respective national standards and guidelines for geospatial data and metadata provision, as nation states may choose to implement country specific variants of international geospatial standards.

As an example of a national implementation, in the UK offshore renewable sector, developers are required to submit data to The Crown Estate that are in compliance with the Marine Environmental Data and Information Network (MEDIN) data guidelines and metadata standards. These cover a range of marine data types and have specific guidelines for site investigation and geophysical investigation. MEDIN-compliant geospatial data must follow the data standard guidelines and metadata standards (MEDIN, 2020), where the metadata schema is based on ISO19115:2003 (International Organisation for Standardization, 2003), includes all core INSPIRE metadata elements, and conforms to ISO19139:2007 (International Organisation for Standardization, 2007) for XML implementation.

10.3 Installation, Operation and Decommissioning Phases

A well-managed spatial database of all data acquired and interpreted for the evolution of a ground model for an offshore renewable project should be maintained, updated and developed for use during the installation and operation phases. The advantages of spatial data management go well beyond its use for ground model and foundation development, which is largely the focus of this document.

A GIS software interface may remain an appropriate way to capture, analyse and visualise data pertaining to the installation and operation of an offshore renewable development although, by the operational phase, the data management needs may be more appropriately served by other data management software, such as that used for building information modelling (BIM). However, regardless of the software platform, a well-managed spatial database of ground information is an important starting point for future phases of the offshore renewable energy development, although the data models and structure of the overall database may need to be re evaluated and adapted.

At the decommissioning phase, the existence of a database of historical information on the soils and foundation design, the installation records, and any operational and maintenance records of relevance is an extremely valuable resource. In addition to informing the design of the decommissioning approach, it may be appropriate to capture records of the decommissioning process itself within the data management structure for the site, for regulatory approval, and future reference about this then 'brownfield site'.

11 TOWARDS THE FUTURE

New technology, techniques and improvements are occurring all the time and, therefore, there may well be alternatives to the techniques described in these Guidance Notes. Experienced industry practitioners should be aware of these and be able to advise on their applicability. It is expected that contractors will make new techniques and equipment, that are available to the market, known to their potential clients. The following sections highlight some items that have been identified, at the time of writing, as potentially becoming available for use in industry, and also some areas that are currently problematic and may be better addressed in the future.

11.1 Fast Survey

Fast survey ROVs are specifically designed as dedicated survey sensor carriers, and offer an alternative to work-class ROV (WROV), AUV, and traditional survey techniques. As they are pure sensor carriers, they are designed to be much more hydrodynamic than WROVs, offering significantly higher survey speeds and delivering high resolution, high quality data whilst maintaining real-time data transfer and extended survey time, not currently possible with AUV. In addition to being equipped with a standard suite of geophysical survey sensors - MBES, SSS, sub-bottom profiler and magnetometer - fast ROVs are also equipped with laser bathymetry, cameras, video, and lighting capabilities enabling visual inspection to be undertaken at the same time as acoustic survey. This enables inspection of seafloor environments and obstructions, e.g. pUXO, in the same campaign as the site or route survey, thus potentially optimising the site appraisal process.

11.2 Seismic Inversion Techniques

The inversion of geotechnical properties from high resolution acoustic data has been a topic of discussion for several decades but, until recently, sufficiently successful inversion approaches have failed to materialise. The last five years have seen some significant breakthroughs in the inverse modelling of such data, through a combination of inverting acoustic properties such as impedance or attenuation (frequently expressed as the inverse seismic quality factor, Q) and the conversion of these through global empirical relationships, to physical properties such as porosity, bulk density and grain size. Critical to the recent success of these approaches has been the focus on establishing probabilistic uncertainty on these measurements (a product of the original acquisition, resolution and the applicability of the empirical relationships) through the use of generic algorithms. These approaches are being further extended by using artificial neural networks to perform multi-attribute regression between inverted acoustic properties and direct measurements of properties such as cone tip resistance from CPTs. This approach enables the extrapolation of geotechnical properties from the point information at each CPT location, via inter-connecting seismic sections. All of these approaches are starting to be used, but always in combination with conventional geotechnical measurements, to enhance the ground model. Finally, developments are being made in the use of full-waveform inversion to generate a detailed physical property model (p-wave velocity, density and Poisson's ratio) of the sub-surface, at decimetre scales.

11.3 Unmanned and Autonomous Vehicles

Unmanned and autonomous survey platforms, such as autonomous underwater vehicles (AUV), unmanned surface vehicles (USV), and unmanned aerial vehicles (UAV) are already used to perform specialist activities such as landfall and shallow water surveys and structure integrity inspections. Further developments in autonomous technology could bring significant improvements in operational efficiency, cost savings and reduced personnel exposure hours. It is anticipated that future developments will see autonomous vehicles being used for cable route surveys and for operations and maintenance activities, such as post-construction monitoring surveys and cable depth of burial surveys. Due to the payload limitations of the vehicles, it is not predicted that site-wide engineering surveys, such as those discussed in the Guidance Notes, which require complex sub-bottom profiling to 100 m, will be achievable. However, for sites where only surface and shallow sediment mapping is required, AUV surveys will become an option for developers to consider.

11.4 Photogrammetry

Photogrammetry techniques provide an opportunity to extract high resolution digital elevation data from high resolution photo-imagery, to create accurate, XYZ RGB 3D models of a range of targets exposed on the seafloor, or within the intertidal or sub-tidal zone. It can, naturally, only work in high visibility environments where photo-imagery can be obtained. The intensive nature of acquisition makes this most appropriate for imaging existing infrastructure and obstructions, e.g. exposed infrastructure, cable sections, UXO and archaeological sites (much of the recent development of underwater photogrammetry has been led by the archaeological community). Data are scaled and referenced to a local internal grid but can be placed in absolute space when cross-referenced against suitably acquired swath bathymetry. Traditionally, high cost software is required; but increasingly there are free software packages capable of generating the 3D images on a standard high performance desk top PC. In addition to standard GIS and 3D view products, the data can be used to generate virtual reality and 3D printed reconstructions.

11.5 Wireline Density Logging

Wireline gamma-gamma density logging is available but is not widely used. The gamma-gamma density probe is a wireline geophysical technique that can be used down hole, in an uncased borehole. The tool has a radioactive source and gamma ray detection. The attenuation of the gamma rays is directly related to the density of the surrounding soil and, therefore, the tool can provide a determination of the *in situ* soil density.

As the tool has to be run in an uncased section of borehole to be able to provide quantitative measurements of soil density, there is a risk of borehole collapse on top of the tool resulting in tool, and radioactive source, loss. It is the risk of the loss of the radioactive source that generally deters the use of this technique.

Similarly, the use of a wireline neutron density tool can determine the *in situ* voids in the ground and, hence, a measure of density, but this also suffers from the risk of the loss of the neutron radioactive source.

Magnetic resistivity tools are now available that can be used in the determination of the *in situ* porosity and, hence, density. These do not include a radioactive source.

11.6 Machine Learning

As has been demonstrated in the recent success of using artificial neural networks (ANN) for acoustic inversion of UHR data for geotechnical properties, machine learning techniques are starting to be applied to site investigation problems. Both onshore and offshore geotechnical investigations are beginning to use a range of machine learning techniques (e.g. in addition to ANN, decision trees (DT) and random forests (RF), k-nearest networks (k-NN), and support vector machines (SVM) are all being used) to undertake: soil classification; sediment thickness determination; automated object identification from side scan sonar, backscatter and video or photogrammetry data; and distinguishing true UXO from pUXO. Inevitably, the biggest strides over the next few decades will be in this data analytical space.

12 GLOSSARY

Word/Concept	Definition/Description
Acoustic ground discrimination system (AGDS)	Automated ground (seabed) classification system based on backscatter data from a single or multi beam echosounder. Usually requires site specific calibration.
ALARP	Term used in the regulation and management of safety-critical and safety-involved systems and stands for "As Low As Reasonably Practicable".
Airgun	A commonly used seismic source which injects a bubble of highly compressed air into the water to generate a pressure wave.
Anchor	Device to prevent or restrict vessel/structure movement.
Artificial neural networks (ANN)	Computing system comprising a network of computing 'units', able to perform tasks by considering examples; these examples effectively 'train' the system, such that it can look for similar features and patterns in new datasets.
Atterberg limits	Basic measure of the critical water contents of fine-grained soils (shrinkage limit, plastic limit and liquid limit)
Autonomous surface vehicle (ASV)	A self-propelled, automated, untethered vessel that is able to be programmed to travel along a predefined survey track, to collect data from various acoustic and other installed sensors.
Autonomous underwater vehicle (AUV)	A self-propelled, automated, untethered underwater vehicle that is able to be programmed to travel along a predefined survey track and/or at a predefined height above the seabed, to collect data from various acoustic and other sensors installed on it.
BAT probe	*In situ* gas-water saturation measurement.
Backfill	Material used to refill a trench after the product (e.g. cable) has been installed.
Bathymetry	The act of measurement of water depth. Often used to describe the variation of water depth across a site.
Beacon	Transmitter device deployed at locations of known co-ordinates and used for positioning of mobile receivers, mounted on appropriate vehicles. Typically acoustic or radio technology based.
Bedform	Sedimentary feature that develops at the interface of a fluid and a mobile bed, resulting in the movement of the bed material by the fluid flow. Examples include ripples and sand waves.
Bedrock	Relatively undisturbed rock, either present at the seabed surface or beneath soil. More or less solid, undisturbed rock either present at the surface or beneath soil.
Bin	A spatial subdivision of a 3D seismic or hydrographic or sonar survey, analogous to a pixel in photographic survey, the dimensions of which relate to the resolution achieved.
Boomer profiler	Type of acoustic sub-bottom profiler in which sound pulses are created by an electromagnetically-driven plate, and reflected signals are received via towed or integral hydrophones.
Borehole	Holes drilled into the seabed for the purposes of carrying out *in situ* geotechnical testing, or to collect samples for geotechnical laboratory testing and analysis.
Box corer	Shallow seabed sampling system designed to recover a cube of relatively undisturbed seabed sediment. Generally used for soft soil conditions.
Brownfield site	Any previously developed area that is not currently in use for its original purpose, and is available for re-use for another.
Cable tracking system	Electromagnetic geophysical method that utilises conductive coils that interact with metallic objects, or in some cases high-resolution acoustics systems, to locate shallow-buried items such as (e.g. cable, pipelines and pUXOs).
Cable percussion drilling	A drilling technique in which a hammer bit is lowered into an open hole or within temporary casing.
Cavity Expansion Theory	Theoretical framework to explain the behaviour of a cavity in soil as it undergoes expansion into the surrounding medium.
Chemosynthetic communities	Accumulations of benthic organisms that use chemosynthesis to convert inorganic molecules such as methane into energy.

Word/Concept	Definition/Description
Chirp profiler	Acoustic energy source used in sub-bottom profiling that emits a frequency modulated pulse over a specified range of frequencies; survey system utilising such techniques.
Common reference point (CRP)	Location on a vessel to which all horizontal (and often vertical) measurements are referenced.
Common depth point (CDP)	In multi-channel seismic surveys, the unique point on an individual reflecting horizon from which seismic reflection information is recorded in receiver channels at different offsets, from successive shots along a line.
Consolidation parameters	Geotechnical soil parameters used in compressibility analyses, typically defined by onshore laboratory testing of recovered seabed samples.
Core	Cylinder-shaped mass of material taken out of the earth (e.g. soil, rock) for study.
Corridor	Area covered by a geophysical route survey, within which a suitable route for the installation of a cable will be sought.
Cone penetration test (CPT)	*In situ* soil strength testing device that makes real time soil resistance measurements as it is pushed into the seabed by mechanical means.
CPT dissipation test	A CPT test which is paused by stopping the penetration to monitor the dissipation of pore pressure with time.
Damping	Restraining vibratory motion.
Data acquisition	The gathering of new survey or sampling data. Often used to discriminate data gathering from data processing or interpretation.
Depth of cover (DOC)	The height of soil or other backfill material measured directly above the top of cable. The depth of soil overlying a cable.
Depth of lowering (DOL)	The vertical distance between the top of a buried cable and undisturbed (mean) seabed level.
Deepwater gas probe (DGP)	*In situ* deep gas measurement device.
Diapir	Geologic structure resulting from the vertical intrusion of a relatively low-density mobile and ductile rock mass (salt, gypsum) into pre-existing denser rocks lying above.
Differential GNSS satellite positioning system	Satellite positioning system which utilises the difference in the real-time measured position of known reference points to adjust positioning data of a remote sensor or vehicle to improve position precision.
Direct simple shear test	Laboratory test for determining the shear strength of soil under horizontal shear loading. Can also be used to investigate the (interface) shear strength of soil–structure interfaces.
Down-hole tool	Pieces of equipment that are inserted in boreholes to measure *in situ* ground properties.
Dredging	The removal of seabed soils – e.g. to prepare the seabed for installation of foundations.
Drill-pipe	Hollow, thin walled piping fitted with special threaded ends used in drilling of a borehole.
Drilling spread	The entire suite of vessel's equipment and personnel involved in an offshore geotechnical drilling operation; may include tugs, etc., as well as the drilling vessel.
Driven pile	Pre-made piles installed into the ground by percussion, pressing or vibration.
Digital terrain model (DTM)	A topographic model of the earth or seabed that can be manipulated by computer programs. The data files contain the elevation data of the terrain in a digital format which relates to a rectangular grid.
Drumlins	Oval or elongated hill formed by movement of glacial ice sheets across rock debris or till, and aligned in the direction of ice flow.
Dynamic positioning (DP)	Automated system of multiple propellors/thrusters installed on a vessel to maintain position during operations without anchoring.
Electrical resistivity profiling	Non-destructive geophysical technique that measures how much the soil resists the flow of electricity, applied using a seabed-deployed cable. This parameter can then be correlated with various soil properties to provide semi-continuous profile data.
End bearing	In the context of pile foundations refers to the axial pile capacity component associated with the bearing capacity of the soil at the pile embedment depth.

Word/Concept	Definition/Description
Engineering geology	Application of geological knowledge to engineering problems to ensure that relevant geological aspects affecting design, operation and maintenance, etc., are recognised and accounted for.
Engineering geophysics	Application of geophysical methods to assess the structure and composition of the Earth surface and subsurface, define physical properties of the soil or rock layers, etc., relevant to engineering activities.
Environmental impact assessment (EIA)	Process of identifying and quantifying the biological, biophysical, social and other relevant environmental effects of a proposed project.
Fall cone test (FCT)	A laboratory test used to measure the liquid limit and undrained shear strength of soils other soil parameters by the penetration of a falling cone.
Flip-flop	In 3D seismic surveys, the alternate sequential firing of dual energy sources to enable the acquisition of multiple survey lines of CDPs in one sail line.
Flute	Elongate streamlined ridges of sediment that are produced beneath a glacier and which are aligned in the direction of ice flow.
Friction angle	Line fitting constant used in the model (usually Mohr Coulomb) used to define the drained shear strength of the soils.
Gas hydrate	Ice-like crystalline minerals that form when low molecular weight gas (such as methane, ethane, or carbon dioxide) combines with water and freezes into a solid under low temperature and moderate pressure conditions.
Geodetic datum	Geodetic datums define the size and shape of the Earth and the origin and orientation of the co-ordinate systems used to map the Earth. Position co-ordinates must be referenced to the geodetic datum to which they relate.
Geodetic parameters	Set of parameters required to define the geodetic reference system that uniquely defines the Earth's model used as the basis of a particular spatial co-ordinate system.
Geohazards	Geological state or feature which is or has the potential to be a hazard that poses a risk to one or more aspects of the proposed activity or development at a site.
Geological fault	Crack in the geological formations in the Earth's crust; the rocks separated by an active fault may move.
Geotechnical engineering	Application of engineering principles for the acquisition, interpretation and the use of the data related to the Earth's crust materials (soils and rock), for the solution of engineering problems and the design of engineering works.
Gyrocompass	Non-magnetic instrument used for navigation and orientation which is based on a fast spinning disc, and the rotation of the Earth, used to find geographical direction.
Geographic information system (GIS)	A system that captures, stores, analyses, manages, and presents data in map form, as linked to the co-ordinates of the data's origin.
Global navigation satellite system (GNSS)	Global positioning system based on a number of Earth orbiting satellites, e.g. GPS, Galileo, GLONASS, etc.
Grab corer	Shallow seabed sampling system consisting of a mechanically or hydraulically driven clamshell bucket, designed to recover a sample of the seabed sediment. Generally used for soft soil conditions.
Grab sample	Seabed samples acquired by mechanical or hydraulic grab methods.
Gradiometer	Instrument used to measure the gradient of a physical quantity; usually applied to a magnetic gradiometer, which utilises multiple sensors, to measure magnetic field gradient.
Gravity base structure	A concrete or ballasted steel structure, supported by a shallow foundation, that may or may not have skirts.
Gravity core	Sample acquired using a gravity corer.
Gravity corer	Seabed sampling device that penetrates the seabed using force exerted by its own weight, when accelerated by gravity.

Word/Concept	Definition/Description
Ground truthing	Information provided by direct observation, sampling or measurement.
Gully	Referring to submarine gullies, these are small-scale, confined seabed channels of the order of metres to tens of metres depth.
Heat-flow probe	An instrument probe used to measure thermal conductivity.
Heave	Referring to a vessel, heave is one of the motions a vessel experiences at sea, and corresponds to the linear vertical motion.
Heave compensation system	Techniques used to reduce the vertical motion influence of waves upon offshore vessels, equipment or instruments.
Horizontal directional drilling (HDD)	Trenchless method to install underground utilities (e.g. cables).
High resolution (HR) seismic	A type of multi-channel seismic survey ('high resolution', HR) that utilises frequency ranges of seismic energy of approx 50 Hz-500 Hz, that enables information to be gathered to a resolution of a few metres, to approx 500 m sub-surface, using airgun or sparker sources.
Hydrographical survey	The activity of measuring bathymetry, may also include the gathering of data concerning other physical features related to the height or movement of a body of water, such as tide or current.
***In situ* testing**	Soil parameter testing carried out using tools that penetrate into the undisturbed seabed in the field, as opposed to in the laboratory with recovered samples; e.g. a CPT.
***In situ* vane**	A vane shear test can directly measure peak and remoulded undrained shear strength of the soil. An *in situ* vane is typically pushed 0.5 m into the soil before being activated, and can be deployed from seabed or a borehole.
Index classification	Classification of the soil based on index properties (e.g. particle size distribution, consistency, *etc.*).
Inter-array cables	Cables within a specific development area (as opposed to export cables), typically between wind turbines or other renewable energy generating units and hub platforms.
Intermediate foundations	Comprise shallow foundations with skirts penetrating deeper into the seabed than the width of the foundation or shorter, more rigid, and larger diameter piles.
Jack-up	A type of mobile platform with a floating hull, capable of lowering its legs to the seabed to raise the platform above the surface of the sea.
Jacket	A Jacket structure is a welded tubular space frame consisting of vertical or battered legs, supported by a lateral bracing system.
Kinematic GNSS data correction	Technique used to increase the accuracy of differential GNSS signals by using more precise and additional correction data from a fixed base station, transmitted in real-time, to a moving receiver (Real-Time Kinematic, RTK); or may be used at the post processing stage (Post-Processing Kinematic, PPK).
Lab vane	A vane apparatus used in a laboratory to measure the undrained shear strength of soil.
Light detection and ranging (LiDAR)	LiDAR is a surveying method used to make high resolution maps, that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor.
Liquefaction	The process by which soil loses its strength due to an increase in pore pressure during single or repeated loading.
Lobes	A peninsula-like ice projection from a glacier, or a similar shaped form from a downslope movement of soil or rock debris.
Loess	Sediment accumulation formed by wind-blown silt.
Long baseline (LBL) acoustic positioning	Underwater positioning system that uses networks of acoustic beacons deployed on the seabed as reference points.
Lowest astronomical tide (LAT)	Lowest tide level which can be predicted from astronomical factors (solar and lunar effects, etc.). Ignores factors that are due to meteorological conditions.

Word/Concept	Definition/Description
Magnetometer	An instrument to measure magnetic field strengths in order to investigate ferrous objects lying on – or buried immediately beneath – the seafloor. Typically used to attempt to determine the position of cables, pipelines or abandoned wells that cannot be identified by acoustic means.
Manifold	Subsea structure that consists of an arrangement of piping or valves designed to control, distribute and typically monitor fluid flow.
Marine growth	Refers to species that attach to, or grow on, ships and marine infrastructure which may cause structure reliability and functionality issues.
Mean sea level	Average height of sea surface midway between high and low tide.
Metocean	Refers to the combined meteorological and oceanographic sciences and such measurements, or such conditions, as found at a certain marine location.
Met mast	Free standing tower equipped with meteorological instruments.
Moon pool	Feature in vessels such as survey vessels or drill ships, consisting of an opening in the floor or base of the hull, giving access to the water below, to allow the lowering of instruments or tools into the sea, whilst protected from external sea conditions.
Moraine	Any glacially formed accumulation of unconsolidated glacial debris.
Motion reference unit (MRU)	Device used to measure and monitor the roll, pitch, yaw and heave motion of a vessel or underwater vehicle.
Mudmat	Flat plate or grillage used as a gravity base foundation.
Multi-beam echo sounder (MBES)	Bathymetric measuring instrument employing multiple acoustic transmitting and receiving elements, arranged transversely across a transducer to provide data across a swath of seafloor, enabling the acquisition of bathymetric data over a corridor of width typically more than twice the water depth. Enables complete seafloor mapping at high spatial resolution.
Multichannel analysis of surface wave (MASW)	Geophysical method that consists of measuring the seismic surface waves generated from various types of seismic sources, via an array of surface-mounted geophones; and analyses the propagation velocities of those surface waves, and then finally deduces shear-wave velocity (Vs, an indicator of soil strength) variations below the surveyed area.
Multi-channel seismic data	Seismic survey data recorded simultaneously on multiple receiver channels, at varying distances from the seismic energy source, to enable data processing to improve data quality and signal to noise ratio, and derive seismic velocities. Used to investigate deeper geological zones than can be investigated using single channel profilers.
Multi-channel sub-bottom profile	Data interpreted from a multi-channel seismic survey.
Needle probe	Instrument used to measure the thermal conductivity of an undisturbed or remoulded soil sample.
Oedometer	An oedometer can be used to measure the settlement or expansion behaviour of soil.
Peat	Type of soil formed by the partial decomposition of vegetable matter.
Pinnacles	Rock pillars, usually of limestone.
Piezocone test	A cone penetration test which also records excess pore pressure on the cone tip or on the cone sleeve. A cone penetration test made with pore pressure measurement.
Piezoprobe	*In situ* pore pressure measurement.
Pile refusal	Where a pile cannot be completely driven to its target depth without further intervention, typically associated with reaching the maximum energy transfer for a given hammer system.
Piled jacket	Fixed typically steel framed structure with pile foundations.

Word/Concept	Definition/Description
Pinger	Acoustic source (or the complete system in which it is used) employed in single channel seismic profiling. Usually achieves sub seabed data down to a few metres.
Piston coring/piston sampling	Sampling device consisting of a long heavy tube that is plunged under self weight, into the seabed, to extract samples of soft sediment, and featuring a piston device in the tube to improve sample retention.
Pitch	The up/down rotation of a vessel or vehicle about its transverse (side-to-side or port-starboard) axis.
Pocket penetrometer	A hand-held penetrometer device for testing the unconfined compression strength of clays. Use is generally limited to providing quick estimates of soil strength off shore, and is usually supplemented by higher quality testing in the laboratory.
Pockmark	Crater in the seabed caused by gas and/or liquids erupting and streaming continuously, or episodically, through the seabed sediments.
Point load testing (PLT)	An index test performed in the laboratory on rock samples mounted between two pointed plates; pressure is applied until failure of the sample. The test results are usually correlated with uniaxial compressive strength.
Probabilistic seismic hazard analysis (PSHA)	Methods of assessing the probability of certain magnitude seismic (earthquake) events at a given location, over a given period, by analysis of historic data of the distribution of earthquakes across a relevant area around the location.
Pulse per second (PPS) signal	Number of electrical or acoustic signal bursts emitted per second, output by such as transducers, radio beacons, etc.
Pressuremeter/dilatometer	Instrument for *in situ* measurement of soil stiffness.
Punch-through analysis	Analysis performed on jack-up spudcan load capacity, to determine if rapid uncontrolled penetration of the spudcans may occur during installation or in-service, typically where relatively soft soils are present underneath a stiffer layer.
P-S logging	The measurement of compression (P-) wave velocities and formation shear (S-) wave velocities of surrounding rock and soil, at specific depths within uncased boreholes.
pUXO	Items identified in survey data that are potentially UXO objects (but as yet unconfirmed as such).
P-wave	Acoustic compression wave, used in reflection seismic, seismic cone and P-S logging techniques.
Reflection seismic techniques	Seabed and sub-seabed geophysical survey methods using the measurement of reflected seismic waves from soil/rock layers. The most common seismic technique, sensors are deployed in the water column, and can obtain data to many hundreds or thousands of metres subseabed.
Refraction seismic techniques	Sub-seabed geophysical survey methods using the measurement of refracted (shear, S-wave) seismic waves from soil/rock layers, typically to several metres sub-seabed. Operationally more complex than reflection, as requires sensors to be deployed on seabed; usually used to obtain data nearshore.
Resistivity techniques	Electrical survey method involving injection of current into the ground via a pair of electrodes, and then measurement of the resulting potential field by a corresponding pair of potential electrodes; resistivity correlates with porosity, permeability and other soil characteristics.
Ring shear test	Laboratory test performed with a torsional shear device to determine the residual shear strength of cohesive soils and interface friction.
Rochdale Envelope	A planning approach that allows a meaningful EIA to take place by defining a 'realistic worst case' scenario that decision makers can consider in determining the acceptability, or otherwise, of the environmental impacts of a project. As long as a project's technical and engineering parameters fall within the limits of the envelope, and the EIA process has considered the impacts of that envelope and provides robust and justifiable conclusions, then flexibility within those parameters is deemed to be permissible within the terms of any consent granted.
Rock dumping/rock placement	Installation of rock or gravel in the form of protective structures, typically around foundations or over cables, *etc*.

Word/Concept	Definition/Description
Rockhead	The surface of the bedrock beneath the soil cover.
Roll	The tilting rotation of a vessel or vehicle about its longitudinal axis.
Rotary coring	A technique for obtaining cores involving the use of a rotating bit; generally appropriate for cemented soils or rock formations, and can also be a good alternative in hard boulder clays, especially if recovery is more important than sample quality.
Remotely operated vehicle (ROV)	An underwater vehicle that is operated from a vessel, to which the ROV is tethered by a cable which provides power and data connections.
Sample disturbance	Changes to material properties of a soil sample, by disturbance, occurring during the process of sampling, transportation and testing.
Sensitivity	Soil sensitivity is defined as the ratio of peak to remoulded shear strength.
Shaft friction	Refers to the axial pile capacity component associated with the interface friction between the pile walls and the surrounding material.
Scour	The process by which the seabed soil is removed from around structures due to the action of currents and waves.
Slump	A form of mass wasting that occurs when a coherent mass of loosely consolidated materials, or a rock layer, moves a distance down a slope.
Spatial data infrastructure (SDI)	A means to manage, interrogate, integrate, and visualise project data, using its spatial component, that can be distributed to or accessed by a wide variety of users.
Seismic cone penetrometer	A penetrometer instrument that has one or more seismic receivers that detect shear wave energy emitted by a seismic source deployed at the seafloor.
Seismic processing	The computer-based treatment of digital seismic data (typically multichannel) to enhance the signals that relate to the geological interfaces being investigated, and to remove various artefacts and noise, to obtain the optimum image for interpretation.
Seismic velocity	The velocity of the seismic wave through a particular medium, water, soil or rock. Knowledge of the velocity is critical to optimising seismic processing.
Shallow gas	The presence of shallow biogenic or hydrocarbon-originated gas charged sediment. Any gas pocket encountered above the setting depth of the first pressure containment string, in a borehole.
Sheet pile	Sheet piles are sections of sheet materials with interlocking edges that are driven into the ground to provide earth retention and excavation support.
Shipping channel	Navigational pathway; authorised or regularly used route for shipping vessels.
Side scan sonar (SSS)	Instrument for the efficient mapping of seabed morphology and features, by the transmission and reception of fan-shaped acoustic beams from the sides of a towed or vessel mounted transducer, and measurement and display of the backscattered acoustic energy. Creates an oblique acoustic image of the seafloor.
Single channel seismic data	Recording seismic data with a single receiver, typically from a pinger, chirp, boomer or sparker source, used for sub-bottom profiling.
Single channel sub-bottom profile	Data gathered and presented to investigate sub-seabed geology along a survey line, using a single channel seismic system.
Single beam echo sounder (SBES)	Instrument for measuring water depth immediately below a survey vessel, will produce a single line profile of data, and requiring multiple closely spaced survey lines to achieve a bathymetric map.
Skirt or skirt embedment	Skirts are vertical plates below gravity base or mudmat structures, that penetrate into the seabed. Embedment is the penetration depth below seabed.
Soil profiling	Process of defining the different soil layers or strata along a line.

Word/Concept	Definition/Description
Sonar contacts	Features or objects on the seabed, as seen on side scan sonar data, that stand out from their surrounds (e.g. boulders, items of debris, wrecks, etc.).
Sparker	Seismic source produced by an electric spark discharge in water.
Spudcan	Inverted cones mounted at the base of a jack-up leg, which provide stability to lateral forces on the jack-up rig when installed on the seabed.
Stratigraphy	A branch of geology that studies rock layers and layering (stratification), primarily used in the study of sedimentary rocks and also soils.
Streamer	Buoyant cable containing hydrophones and associated electrical wires and sensors, that is towed through the water to receive reflected seismic signals, and then relay such data to the survey vessel or vehicle.
Suction caisson/suction pile/suction bucket/suction can	A cylindrical caisson foundation that is installed using a combination of self weight and suction. A pile/deep skirted foundation that is installed using suction pumps for assistance.
Swath width	Width of any surveyed area of the Earth's surface, from which data are collected by a moving survey instrument such as side scan sonar or MBES.
2D seismic	A seismic survey method that uses a set of parallel survey lines and a single source-receiver system to survey an area, such that sub seabed information needs to be interpolated between survey lines.
3D seismic	A seismic survey method that uses a set of very closely spaced parallel survey lines obtained by use of multi source/streamer arrays towed behind a survey vessel, achieving a spatially dense 3D seismic dataset, that can be processed into a 3-dimensional image of the sub-seabed of the entire surveyed area.
T-bar	*In situ* soil strength testing device that makes real time soil resistance measurements by continuous penetration of a cylindrical rod (T-bar penetrometer) positioned perpendicular to the lower end of a push rod. Other measurements can include resistance during retraction, cyclic penetration resistance and pore pressure.
Tethered foundations	Floating structures that are held in place by anchors or piles. Structures that are held in place by anchors.
Thermal conductivity	The property of a material to conduct heat, typically measured in watts per metre kelvin. Typically, is computed from the linear portion of the plot of temperature vs. the natural log (ln) of time.
Thermal CPT (T-CPT)	CPT instrument that includes temperature sensors capable of measuring the thermal conductivity properties of the soil during a CPT push.
Thermistor	Electrical resistor whose resistance is dependent on temperature.
Tidal lagoon	Power station that generates electricity from the natural rise and fall of the tides. Such installations enclose an area of seabed adjacent to a coastline with a high tidal range, behind a man-made structure (breakwater), which enables the directed flow of water during a tidal cycle to drive turbines and generate electricity.
Top of cable	Depth to the 12 o'clock position on a cable, usually measured relative to LAT.
Torvane	Hand-held vane shear device for rapid determination of the shear strength of cohesive soils.
Tow fish	Vehicle on which survey sensors are mounted, that is towed behind a survey vessel, using a tow cable that usually contains power and signal carrying elements.
Towed grapnel survey	Pre-installation activities utilising towed grapnel devices, to engage with and remove seabed obstructions.
Triaxial test	Laboratory soil test for determining the strength of the soil under controlled conditions of confinement. This test allows the determination of the full constitutive behaviour of the soil.

Word/Concept	Definition/Description
Tripod	A structure supported by three separate foundations.
Ultra high frequency (UHF)	Radio frequencies in the range between 300 MHz - 3 GHz.
Ultra high resolution (UHR) seismic	A type of multi-channel seismic survey that utilises frequency ranges of seismic energy of approx. 250 Hz-2500 Hz, that enables information to be gathered to sub-metre resolution, with penetration to approx. 100 m sub surface, using small airgun, boomer or sparker sources.
Ultra-short baseline (USBL) positioning	Method of underwater acoustic positioning consisting of a transceiver mounted on a pole under a vessel, and a transponder or responder on the seafloor, on a towfish or on an ROV/ AUV. Computer methods are used to calculate the target position from the ranges and bearing measured by the transceiver.
Unconfined or uniaxial compressive stress (UCS) test	Laboratory test for determining the maximum axial compressive stress of a soil or rock specimen at zero confining stress.
Unconsolidated undrained triaxial compressioncompression	Relatively quick measurement of undisturbed soil shear strength by triaxial testing.
Undrained shear strength	In the context of soil mechanics, resistance to shear failure of the soil without dissipation of the pore water pressure generated by the applied shear stresses.
Umbilical line	Connection lines used offshore between subsea equipment and platforms or floating units to enable the control from the surface.
Unexploded ordnance (UXO)	Explosive objects that did not explode when they were employed and still pose a risk of detonation.
Unmanned aerial vehicle (UAV)	Robotic aircraft controlled by an operator on the ground, that carries various sensors to obtain visual and other data across a site area.
Unmanned surface vessel (USV)	Robotic vessel controlled by a remote operator either onshore or onboard a support vessel, that carries various sensors to obtain acoustic, visual and other data across a site area. May also be referred to as an Uncrewed Surface Vessel.
Vertical (tidal) datum	Local vertical datum below which the tide will not normally fall (e.g. commonly used is Lowest Astronomical Tide - LAT). The vertical datum should be defined for a project.
Vessel draft	Vertical distance between the waterline and the bottom of the hull (keel) including the thickness of the hull.
Vessel reference frame	Origin and system of co-ordinates to define the heading, pitch and roll of a vessel.
Very high frequency (VHF)	Radio frequencies in the range of 30 to 300 MHz - 3 GHz.
Vibrocorer	Seabed continuous sampling device, typically up to 6 m long, that penetrates the seabed using force exerted by a vibrating motor mounted on top of a coring barrel.
Vertical offshore reference frames (VORF)	A set of high resolution surfaces which together define the vertical datum for hydrographic surveying and charting in the United Kingdom and Ireland, enabling GNSS data to be used to obtain high precision hydrographic survey data.
Water column sound velocity profile	The vertical distribution of acoustic velocity, measured using an instrument lowered or dropped from a survey vessel, to enable accurate conversion of signal travel time to depth when measuring bathymetry.
Wave buoy	Instrumented buoys able to measure a whole range of weather variables such as wave height, swell period and direction, may also include instruments for measuring wind speed and direction, etc.
Wire-line logging tools	Various geophysical tools lowered into a borehole to measure soil or rock properties.
Yaw	The turning rotation of a vessel about its vertical axis.

Appendix 1 Bibliography, references, codes, standards and guidance notes

NOTE: The following documents were believed to be the latest versions at the time of drafting these guidance notes. Their inclusion in this list does not imply endorsement.

American Bureau of Shipping (2014) Guide for building and classing bottom founded offshore wind turbine installations. Updated July 2014 (Chapter 5, Section 4.5)

American Bureau of Shipping (2014) Guide for building and classing floating offshore wind turbine installations. Updated July 2014 (Chapter 4, Section 13)

American Petroleum Institute (2014) Recommended Practice RP2A, Planning, designing and constructing fixed offshore platforms – Working Stress Design, 22nd Edition, November 2014

American Petroleum Institute (2014) Recommended Practice RP2GEO, Geotechnical and foundation design considerations, 1st Edition 2012 plus Addendum 1, October 2014

Association of Geotechnical and Geoenvironmental Specialists (2017) Electronic transfer of geotechnical and geoenvironmental data, AGS4 (Edition 4.0.4), Guidance document. Updated February 2017

British Standards Institution (2014) BS 8574, Code of practice for the management of geotechnical data for ground engineering projects, March 2014

Bundesamt für Seeschiffahrt und Hydrographie (2013) Standard - Investigation of the impacts of offshore wind turbines on the marine environment (StUK 4), October 2013

Bundesamt für Seeschiffahrt und Hydrographie (2014) Standard - Ground investigations, Minimum requirements for geotechnical surveys and investigations into offshore wind energy structures, offshore stations and power stations. Second update, February 2014

Bundesamt für Seeschiffahrt und Hydrographie (2015) Standard design - Minimum requirements concerning the constructive design of offshore structures within the Exclusive Economic Zone (EEZ). July 2015, corrected December 2015

Bureau of Ocean Energy Management (2013) Guidelines for submission of spatial data for Atlantic offshore renewable energy development site characterization surveys, United States Department of the Interior, Office of Renewable Energy Programs, February 2013

Bureau of Ocean Energy Management (2015) Guidelines for providing geophysical, geotechnical, and geohazard information pursuant to 30 CFR Part 585,United States Department of the Interior, Office of Renewable Energy Programs, July 2015

Bureau of Ocean Energy Management (2018) Draft guidance regarding the use of a project design envelope in a construction and operations plan, United States Department of the Interior, Office of Renewable Energy Programs, January 2018

Bureau Veritas (2012) Guide on offshore wind farm project certification (based on IEC 61400 Series), BV-WFPC 100, Version 1, December 2012

Carbon Trust (2015) Cable burial risk assessment methodology. Guidance for the preparation of cable burial depth of lowering specification, February 2015

Carbon Trust (2020) Guidance for the geophysical surveying for UXO and boulders supporting cable installation, Carbon Trust Offshore Wind Accelerator, April 2020.

Centre for Environment, Fisheries and Aquaculture Science (2012) Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Report ME 5403 – Module 15, May 2012

CIRIA (2015) Assessment and management of unexploded ordnance (UXO) risk in the marine environment. C754.

Clayton, C R (2001) Managing geotechnical risk - Improving productivity in UK building and construction, London: Institution of Civil Engineers and Thomas Telford Ltd

Comité Français de Mécanique des Sols et de Géotechnique (2019) Recommendations for planning and designing foundations of offshore wind turbines, Version 2.1, September 2019

Danish Energy Agency (2001) Recommendation for technical approval of offshore wind turbines, December 2001

Det Norske Veritas Germanisher Lloyd (2016a) Recommended Practice DNVGL-RP-0360 Subsea power cables in shallow water, March 2016 (Sections 3.3, 3.4)

Det Norske Veritas Germanisher Lloyd (2016b) Standard DNVGL-ST-0145 Offshore substations, April 2016 (Section 4.8.5)

Det Norske Veritas Germanisher Lloyd (2019a) Offshore standard DNVGL-OS-C101 Design of offshore steel structures, general - LRFD method, July 2019 (Section10.1.2)

Det Norske Veritas Germanisher Lloyd (2019b) Recommended Practice DNVGL-RP-C212 Offshore soil mechanics and geotechnical engineering, September 2019

Det Norske Veritas Germanisher Lloyd (2019c) Standard DNVGL-ST-0126 Support structures for wind turbines, July 2019 (Section 7.3)

European Subsea Cables Association (2018) ESCA Guideline No.14 Power cable installation guidelines, Issue 3, October 2018

European Committee for Standardisation (2013) EN1997-1:2004 Geotechnical design – Part 1: General rules, published 2004. Amendment 1, 2013

European Committee for Standardisation (2007) EN1997-2:2007 Geotechnical design – Part 2: Ground investigation and testing

Evans, T. G. (2011) A systematic approach to offshore engineering for multiple-project developments in geohazardous areas, Proc. 2nd Intl. Symposium on Frontiers in Offshore Geotechnics, Perth, Australia, November 2010, Editors: Gourvenec, S and White, D (pp 3-32)

Gribble, J. and Leather, S. for EMU Ltd (2007) Offshore geotechnical investigations and historic environment analysis: Guidance for the renewable energy sector. Commissioned by COWRIE Ltd. Project reference GEOARCH-09

Health and Safety Executive (2002) Site investigations, Offshore Technology Report 2001/012 (previously published as part of Offshore installations: Guidance on design, construction and certification,1990 plus amendments)

Health and Safety Executive (2004) Risk implications in site characterisation and analysis for offshore engineering and design, Research Report 286

International Association of Oil and Gas Producers and International Marine Contractors Association (2011) Guidelines for GNSS positioning in the oil and gas industry, Report No. 373-19, Version 1, June 2011

International Association of Oil and Gas Producers (2015) Conduct of offshore drilling hazard site surveys – Technical notes, Report No. 373-18-2, Version 1.0, October 2015

International Association of Oil and Gas Producers (2017a) Guideline for the delivery of the seabed survey data model, Report No. 462-02, Version 2.0, January 2017

International Association of Oil and Gas Producers (2017b) Guidelines for the conduct of offshore drilling hazard site surveys, Report No. 373-18-1, Version 2.0, October 2017

International Association of Oil and Gas Producers (2017c) Managing HSE in a geophysical survey, Report 432, Version 4.0, November 2017

International Association of Oil and Gas Producers (2017d) Risk management in geophysical operations, Report 432-02, Version 2.0, November 2017

International Cable Protection Committee/Society for Underwater Technology (2002) Recommendation - Minimum technical requirements for the acquisition and reporting of submarine cable route surveys

International Electrotechnical Commission (2019a) IEC 61400-3-1:2019 Wind energy generation systems - Part 3-1: Design requirements for fixed offshore wind turbines, Edition 1.0, April 2019

International Electrotechnical Commission (2019b) IEC TS 61400-3-2:2019 Wind energy generation systems - Part 3-2: Design requirements for floating offshore wind turbines, Edition 1.0, April 2019

International Electrotechnical Commission (2020) IEC 61400-6 FDIS Wind energy generation systems - Part 6: Tower and foundation design requirements (IN PREPARATION)

International Hydrographic Organisation (2019) IHO Standards for hydrographic surveys, Special Publication No. 44, 6th Edition draft 1.7.0, July 2019 (IN PREPARATION)

International Marine Contractors Association (2017) Guidance on vessel USBL systems for use in offshore survey, positioning and DP operations. Report S017, Rev. 1, March 2017

International Marine Contractors Association (IMCA) (2022) IMCA S 029 Guidelines for the Measurement of Depth of Burial

International Organisation for Standardization (2003) ISO 19115:2003 Geographic Information – Metadata, May 2003.

International Organisation for Standardization (2007) ISO/TS 19139:2007 Geographic Information – Metadata – XML schema implementation, April 2007.

International Organisation for Standardization (2013) ISO 19902:2007 Petroleum and natural gas industries – Fixed offshore structures, Edition 1, December 2007, plus Amendment 1 (2013) August 2013

International Organisation for Standardization (2014a) ISO 19115-1:2014 Geographic Information – Metadata, Part 1: Fundamentals, Edition 1, April 2014. (Note: BS EN version amended 2018)

International Organisation for Standardization (2014b) ISO 19901-8:2014 Petroleum and natural gas industries – Specific requirements for offshore structures – Part 8: Marine soil investigations, Edition 1, December 2014

International Organisation for Standardization (2016a) ISO 19905-1:2016 Petroleum and natural gas industries - Site-specific assessment of mobile offshore units, Part 1: Jack-ups, Edition 2, January 2016

International Organisation for Standardization (2016b) ISO 19901-4:2016 Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations, Edition 2, July 2016

International Organisation for Standardization (2017) ISO 19901-2:2017 Petroleum and natural gas industries – Specific requirements for offshore structures -- Part 2: Seismic design procedures and criteria, Edition 2, November 2017

International Organisation for Standardization (2019a) ISO/TS 19139-1:2019 Geographic information metadata – XML schema implementation, Edition 1, March 2019

International Organisation for Standardization (2019b) ISO 19905-4:DIS Petroleum and natural gas industries - Site-specific assessment of mobile offshore units, Part 4: Jack-ups: Emplacement and removal at a site (IN PREPARATION)

International Organisation for Standardization (2019c) ISO 19901-10:DIS Petroleum and natural gas industries – Specific requirements for offshore structures – Part 10: Marine geophysical site investigations

International Society for Soil Mechanics and Geotechnical Engineering (2005) Geotechnical and geophysical investigations for offshore and nearshore developments, TC1 report 220805, September 2005

Lloyd's Register (1989) Rules and regulations for the classification of fixed offshore installations, Part 3, Environmental and design considerations, December 1989 (Chapter 2, Section 2)

Lloyd's Register (2019) Guidance notes for offshore wind farm project certification, July 2019 (Chapter 3)

MEDIN (2020) Marine Environmental Data and Information Network, medin.org.uk, accessed 07/01/2020.

Official Journal of the European Union (2007) Directive 2007/2/EC of the European Parliament and of the Council Establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), inspire.ec.europa.eu, 14 March 2007.

Offshore Soil Investigation Forum (2000) Guidance notes on geotechnical investigations for subsea structures, Rev.02, August 2000. Maintained by SUT Offshore Site Investigation and Geotechnics committee

RenewableUK (2013) Guidelines for the selection and operation of jack-ups in the marine renewable energy industry. Issue 2. Prepared by London Offshore Consultants

RenewableUK (2014) Offshore wind and marine energy. Health and safety guidelines. Issue 2. Prepared by Sgurr Energy Ltd

RenewableUK (2015) Vessel safety guide. Guidance for offshore renewable energy developers. Report RUK15-009-3

Rochdale Envelope The Rochdale Envelope approach arises from cases in UK planning law, namely R. v Rochdale MBC ex parte Milne (No. 1), R. v Rochdale MBC ex parte Tew (1999) and R. v Rochdale MBC ex parte Milne (No. 2) (2000). These dealt with an application for a proposed business park.

RPS (2011) InSafeJIP. Improved guidelines for the prediction of geotechnical performance of spud can foundations during installation and removal of jack-up units, March 2011 (Chapters 2, 3)

Society for Underwater Technology (2004) Guidance notes on geotechnical investigations for marine pipelines. Original version prepared by the Offshore Site Investigation Forum. Updated by SUT Offshore Site Investigation and Geotechnics committee, September 2004

Society of Naval Architects and Marine Engineers (2016) Recommended practice for site-specific assessment of mobile jack-up units, Bulletin 5-5, Rev.3, January 2008 plus corrigenda April 2016 (Section 3)

The Planning Inspectorate (2018) Advice note nine: Using the Rochdale Envelope, Version 3, July 2018.

Wessex Archaeology Ltd (2007) Historic environment guidance for the offshore renewable energy sector, commissioned by COWRIE Ltd. Project Ref. ARCH-11-05

Wessex Archaeology Ltd (2010) Model clauses for archaeological written schemes of investigation, offshore renewables projects. Prepared for the Crown Estate, Report 73340.75, December 2010

Carbon Trust (2020) Guidance for geophysical surveying for UXO and boulders supporting cable installation, Offshore Wind Accelerator, April 2020

Sandia (2014) Offshore wind guidance document: Oceanology and sediment stability. Development of a conceptual site model. Version 1.June 2014

Appendix 2 Hazards, their investigation and their likely impact on an offshore renewables energy development

A geohazard is a geological state, feature or process that presents a risk to humans, property or the environment. They can be localised features or regionally extensive. Assessment of risk and subsequent mitigation and prevention is essential in location-specific geohazard assessment and requires an understanding of their causes and implications. However, it should be recognised that not all such geological features are a hazard to development. As a result, geohazards need to be considered with respect to the renewable energy development and its associated operations, rather than on a wider scale. For example, gas present in shallow soils may be considered a risk if present at the location of a borehole that is to be drilled but is not, generally, a risk to cable installation, or necessarily a risk to installation vessels. In considering key features that may have an impact on the development of an offshore renewable energy project, the export cable(s), associated installations and construction operations should be included. (Table A2. 1 and Table A2. 2 below provide additional information).

Table A2. 1: Key features of constraint, hazard or concern, to be assessed by means of site investigations.

Man made features, Anchorages	Natural seafloor features	Subseafloor geological features
Pipelines on seafloor or buried.	Seafloor topography and relief.	Sedimentary sequences.
Communications cables.	Seafloor sediments.	Stratigraphy.
Power and umbilical lines and cables.	Subaqueous dunes.	Buried infilled channels and other paleo-landscape features.
Export and intra-array cables.	Glacial features including iceberg. plough marks, flutes and moraines.	Hard grounds or cemented sands or buried land surfaces.
Wrecks, including ships aircraft and submarines.	Rock outcrops, pinnacles and boulders.	Gravel beds.
Wellheads and abandoned well locations.	Seafloor channels and scour	Boulder beds.
Unexploded ordnance and related debris, previously deployed or dumped.	Peat.	Rock head or igneous intrusion near seafloor.
Navigation or metocean buoys.	Gravel beds.	Peat.
Archaeological remains.	Hard grounds or cemented sands.	Erosion and truncation surfaces.
Miscellaneous debris.	Submerged forest or terrestrial paleo-landscape.	Shallow water flow zones or loose sands.
Sediment, waste, chemical, or other material dumping grounds.	Unstable or steep slopes.	Glacial features including drumlins, loess and moraines.
Jack-up rig footprints.	Gas vents and pockmarks.	Faults - tectonic or glaciogenic.
Rock dumps.	Collapse features.	Shallow gas charged intervals.
Scour protection material.	Fluid expulsion features.	Gas chimneys.
Marine aggregate extraction areas.	Chemosynthetic communities.	Salt or mud diapirs and diatremes.
Wind turbines, wave, tidal arrays.	Fault escarpments.	Buried slumps and mass transport complexes.
Manifolds and templates.	Reefs.	Gas hydrate zones and hydrated soils.
Oil and gas platforms: active, abandoned, or toppled.	Mud flows, gullies, mud volcanoes, lumps, lobes.	
Anchorages.	Slumps.	
	Diapiric structures.	
	Gas hydrate mounds.	

Note: The order of significance is likely to depend on the area of the world and the previous experiences of specific environments. Surveys are performed in order to identify what is present – other man made, or geological hazards may be present that are not included on this list. A risk and impact assessment is required to determine whether a hazard present is a risk to development.

Table A2. 2: Feature/hazard investigation methods and effect on renewable energy developments.

Feature of constraint or hazard of concern	**Effect of such features on:**		**Investigatory data requirements**	
	Structure or device foundations	**Export and array cables**	**Geophysical**	**Geotechnical**
Manmade features	Safety hazard; obstruction to structure or its installation, operation or longevity; soil strength changes; litigation hazard from third party damage; historic or sensitive feature with protection obligations. Location or distribution of such features can require device relocation or field re-design.	Safety hazard; obstruction to cable or its installation, protection by burial, operation or longevity; soil strength effects; litigation hazard from third party damage. Location or distribution of such features can require cable route relocation or layout re-design.	Location, identification and avoidance by means of side scan sonar, multibeam bathymetry, magnetometer and shallow sub-bottom profiler, drop- or ROV-deployed camera.	N/A.
Natural seafloor features	Obstruction or hazard to structure or its installation, operation or longevity; soil strength foundation changes; local marine current or wave climate effects; environmental feature with protection obligations. Location or distribution of such features can require device relocation or field re-design.	Obstruction or hazard to cable or its installation, protection, operation or longevity; local marine current or wave climate effects; environmental feature with protection obligations. Location or distribution of such features can require cable route relocation or layout re-design.	Location, identification and avoidance by means of side scan sonar, multibeam bathymetry, magnetometer and shallow sub-bottom profiler, drop- or ROV-deployed camera	Shallow geotechnical samplers – grab, box, etc. samplers, gravity corers, vibrocorers, shallow CPT systems
Subsurface geological features	Soil and rock characteristics are key factor in foundation type and size required for structure and safe installation, operation and longevity; lateral variations of subsurface features and units across site can affect variety of foundation types required or suitable. Such factors affect optimisation of device location or field design. Geohazard factors affect safe undertaking of geotechnical investigations using intrusive tools.	Soil and rock characteristics are key factor in cable installation for buried systems, their operation and longevity; lateral variations of subsurface features and units across site can affect variety of installation methods required or suitable. Such factors affect optimisation of array and cable location.	Single and multi-channel, 2D and 3D seismic reflection profiling systems. Resistivity and seismic refraction for landfall cable route investigations.	Geotechnical boreholes, CPT systems, gravity corers, vibrocorers.

Appendix 3 Geotechnical testing methods

Table A3. 1: Conventional testing methods.

Soil Parameters	***In Situ* Testing**					**Laboratory Testing on Samples**				
	Type of Tests	**Applicability: SAND**	**CLAY**	**C&C (D)**	**WEAK ROCK**	**Type of Tests**	**Applicability: SAND**	**CLAY**	**C&C (D)**	**WEAK ROCK**
Geological description		N/A	N/A	N/A	N/A	Geological Logging	3	4	4	4
Soil classification	CPT	5	5	3	2	Grain size (sieve)	5	3	4	1
						Water content	2	5	5	1
						Atterberg limits	N/A	5	5	1
						Angularity	5	N/A	N/A	N/A
						Mineralogy	5	1	2	2
Soil density	CPT	3 to 4	2	3	2	Unit weight and water content measurement	2	5	5	5
Soil strength (undrained shear strength)	CPT	N/A	3 to 4 (a)	3	2	Unconsolidated undrained (UU) triaxial compression	N/A	4	4	3
						Consolidated undrained triaxial direct simple shear	N/A	5	4	1
	In situ vane	N/A	4 to 5	2	1	Small T bar	N/A	5	3	1
						Fallcone, pocket penetrometer, torvane, lab vane	N/A	2	2	2
	T bar	N/A	5	3	1	Unconfined or uniaxial (UCS) testing	N/A	1	3	5
						Point load testing (PLT)	N/A	1	3	4
Friction angle (drained shear strength)	CPT	3 to 4	2	3	2	Consolidated triaxial compression, direct shear (shear box), direct simple shear	5 (b)	5	2	2
							4 (b)	1	2	2
Sensitivity	CPT	N/A	2	2	2	Fallcone, lab vane, triaxial	N/A	5	3	1
	In situ vane	N/A	3							
Consolidation characteristics and permeability	CPT (piezocone)	1	3 (c)	3	2	Oedometer	2 (b)	5	4	2

Table A3. 2: Special testing methods.

<table>
<tr><th rowspan="3">Soil Parameters</th><th colspan="5">In Situ Testing</th><th colspan="5">Laboratory Testing on Samples</th></tr>
<tr><th rowspan="2">Type of Tests</th><th colspan="4">Applicability</th><th rowspan="2">Type of Tests</th><th colspan="4">Applicability</th></tr>
<tr><th>SAND</th><th>CLAY</th><th>C&C (D)</th><th>WEAK ROCK</th><th>SAND</th><th>CLAY</th><th>C&C (D)</th><th>WEAK ROCK</th></tr>
<tr><td>Interpolation of soil layering in between borings/CPTs</td><td>Instrumented plough</td><td>2</td><td>2</td><td>2</td><td>2</td><td></td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="5">Soil density and stiffness</td><td>Electrical resistivity probe</td><td>2 to 3</td><td>1</td><td>1</td><td>1</td><td rowspan="5">Small strain effective stress triaxial testing
Bender element testing</td><td rowspan="5">3 to 4 (b)</td><td rowspan="5">5</td><td rowspan="5">4</td><td rowspan="5">4</td></tr>
<tr><td>Nuclear density probe</td><td>1 to 2</td><td>2 to 3</td><td>2 to 3</td><td>1</td></tr>
<tr><td>Pressuremeter /high pressure dilatometer</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>P-S logging</td><td>4</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>Seismic cone</td><td>3 to 4</td><td>3 to 4</td><td>2</td><td>2</td></tr>
<tr><td>Soil strength and deformation</td><td>Pipe model test /plate load test</td><td>3 to 4</td><td>3 to 4</td><td>3 to 4</td><td>3 to 4</td><td>Direct simple shear</td><td>4 (b)</td><td>4</td><td>3</td><td>1</td></tr>
<tr><td>Interface friction</td><td></td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>Ring shear</td><td>3 to 4</td><td>5</td><td>3 to 4</td><td>N/A</td></tr>
<tr><td rowspan="3">Cyclic behaviour</td><td rowspan="3">Seismic cone</td><td rowspan="3">3 to 4</td><td rowspan="3">3 to 4</td><td rowspan="3">4</td><td rowspan="3">4</td><td>Resonant column (small shear strain modulus)</td><td>4</td><td>4</td><td>4</td><td>1</td></tr>
<tr><td>Direct simple shear – static / cyclic</td><td>4 (a)</td><td>4</td><td>3</td><td>1</td></tr>
<tr><td>Cyclic consolidated triaxial</td><td>5 (b)</td><td>5</td><td>4</td><td>3</td></tr>
<tr><td rowspan="2">Permeability</td><td>CPT (piezocone) – dissipation tests, BAT probe</td><td>2</td><td>4</td><td>4</td><td>1</td><td rowspan="2">Special permeability tests</td><td rowspan="2">5 (b)</td><td rowspan="2">4</td><td rowspan="2">2</td><td rowspan="2">2</td></tr>
<tr><td>Piezoprobe</td><td>2</td><td>4</td><td>4</td><td>1</td></tr>
<tr><td>Thermal conductivity</td><td>Heat flow probe/TCPT</td><td>4</td><td>4 to 5</td><td>2</td><td>1</td><td>Transient method/steady state method</td><td>5 (b)</td><td>5</td><td>2</td><td>1</td></tr>
<tr><td rowspan="6">Corrosion or chemical effect potential</td><td rowspan="6">Electrical resistivity cone</td><td rowspan="6">4</td><td rowspan="6">4</td><td rowspan="6">3</td><td rowspan="6">3</td><td>Mineralogy and porosity</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>Electrical resistivity</td><td rowspan="5">4 (b)</td><td rowspan="5">4</td><td rowspan="5">4</td><td rowspan="5">3</td></tr>
<tr><td>Sulphate</td></tr>
<tr><td>Carbonate</td></tr>
<tr><td>Chloride testing</td></tr>
<tr><td>pH</td></tr>
<tr><td>Gas content</td><td>BAT/DGP (deep gas probe)</td><td>4</td><td>4</td><td>4</td><td>1</td><td>Geochemical</td><td>5</td><td>5</td><td>2</td><td>1</td></tr>
</table>

Table A3. 2: Special testing methods.

Type of Equipment*	Sample Quality				Recovery (relative to length of sample tube)			
	SAND (f)	CLAY	C&C (D)	WEAK ROCK	SAND	CLAY	C&C (D)	WEAK ROCK
Gravity corer/piston corer	2	3	3	1	1	3 to 4	3	1
Vibrocorer	2 to 3	2 to 3 (f)	2 to 3	2 to 3	3 to 4	2 to 3	3	1
Grab sampler	1 to 2	1	1	1	1 to 2	2	2	1
Box corer	1 to 2	5	3	1	2	5	3	1

* Note: These represent the main generic equipment types. Actual sample recovery is a function of soil strength and/or density

Table A3. 4: Downhole sampling equipment.

Type of Equipment*	Sample Quality				Recovery (relative to length of sample tube)			
	SAND (f)	CLAY	C&C (D)	WEAK ROCK	SAND	CLAY	C&C (D)	WEAK ROCK
Hydraulic piston sampler	3 to 4	5	3	1	3	5	3	3
Hydraulic push sampler	3 to 4	4 to 5	3	1	3	5	3	3
Cable percussive	3	2	2	1	4	4	3	2
Hammer sampler	2 to 3	2 to 3	2	1	3 to 4	3 to 4	3	2
Rotary coring (g)	1	2	5	5	1	3	5	5
Sonic coring	2 to 3	2	2	2 to 3	4	3 to 4	3	4

* Note: These represent the main generic equipment types. Actual sample recovery is a function of soil strength and/or density

Suitability Scale:

1: Poor or inappropriate
2: Acceptable for non-critical analyses
3: Moderately good
4: Good
5: Very good

Notes:

a) Good if calibrated against site specific laboratory tests.

b) If *in situ* density is known.

c) If dissipation tests are performed.

d) In the above tables, C&C is calcareous and carbonate and the material is assumed to be weathered. Intact C&C should be considered equivalent to a weak rock.

e) If *in situ* shear wave velocity and laboratory shear wave velocities for different densities are available.

f) Poor in soft clays (but can be improved if controlled self-weight penetration of barrel is achievable, i.e. no vibration used).

g) Normally only used in rock or very hard clay. Assumes good practice is followed.